WORKSHOP SERIES No 16

Sustainable Development for Traditional Inhabitants of the Torres Strait Region

Edited by

David Lawrence

and

Tim Cansfield-Smith

PROCEEDINGS OF THE TORRES STRAIT BASELINE STUDY CONFERENCE

Kewarra Beach, Cairns, Queensland
19 - 23 November 1990

ISSN 0156-5842
ISBN 0 642 12028 5
Published by GBRMPA September, 1991

Cover photograph: Robert Tapin from the Zeuber Erkup Murray Island Dance Group, Townsville

Drawings (pages 13, 23, 185, 333, 467, 503) by Lindsay Wilson. Reproduced with permission from *Thathilgaw Emeret Lu: A Handbook of Traditional Torres Strait Islands Material Culture* by Department of Education, Queensland.

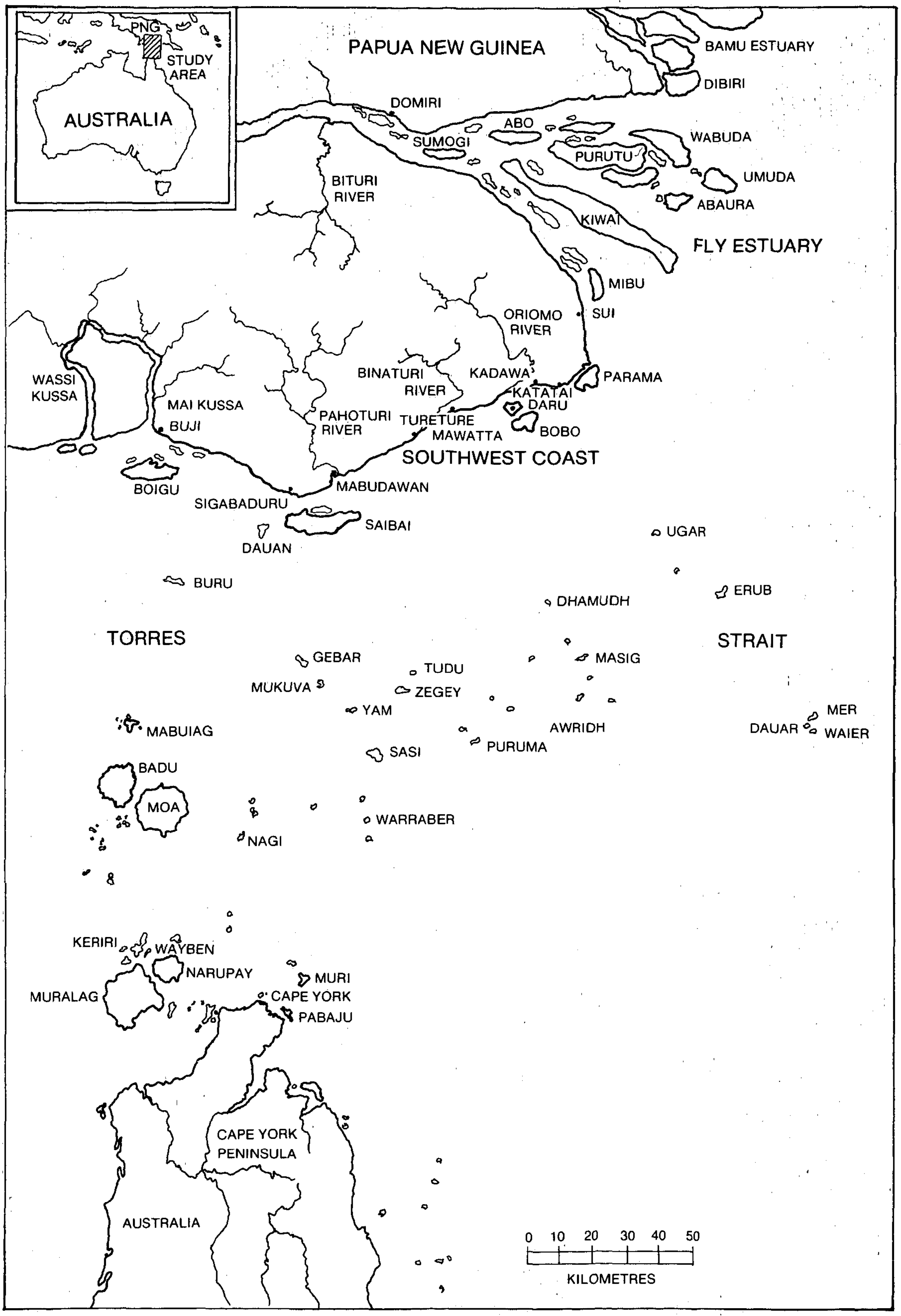
Great Barrier Reef Marine Park Authority
P.O. Box 1379
Townsville, Queensland 4810
Australia

Telephone: (077) 81 8811
Facsimile: (077) 72 6093

Published for the Great Barrier Reef Marine Park Authority by the Australian Government Publishing Service, Canberra

Printed for AGPS by Watson Ferguson and Co., Brisbane

Table of Contents



Map of the Torres Strait Region

Executive Summary

Torres Strait Baseline Study

In July 1989 the Prime Minister of Australia, the Rt. Hon. R.J.L. Hawke, MP, announced, as part of his statement on the environment, which was later published as *Our Country, Our Future,* that the Australian Government would fund a four year environmental study of the Torres Strait marine environment. This study, the Torres Strait Baseline Study, was instigated in response to concerns expressed by Torres Strait Islanders, commercial fishermen and scientists, about possible effects on the marine environment of the Torres Strait from mining operations in the Fly River catchment area of Papua New Guinea.

These concerns reflected those expressed at the Torres Strait Fisheries Seminar held in Port Moresby in February 1985. At the seminar the following statement was endorsed:

> Because the Fly River is the largest and most important freshwater input into the Torres Strait region, the participants of the Torres Strait Fisheries Seminar wish to express serious concern over the possible effects that dumping of Ok Tedi mining wastes in the Fly River may have, directly or indirectly, on Torres Strait fisheries.

At that seminar it was recommended that a scientific environmental monitoring programme be established as soon as possible to investigate the problems of possible contamination of the Torres Strait marine environment.

Since the establishment of the Torres Strait Baseline Study concern over potential environmental damage to the Torres Strait has increased. In addition to the mine at Ok Tedi in the Western Province there are now gold mining operations at Porgera in Enga Province, and the alluvial gold fields at Mt Kare, also in Enga Province are expected to commence production soon. Both these operations are near the headwaters of the Strickland River which feeds into the Fly River. Also, the development of the Lake Kutubu oil project which will have a marine oil loading terminal in the Gulf of Papua near Cape Blackwood has caused concerns among the Torres Strait Islanders as oil tankers are expected to pass through the Great North East Channel in the Torres Strait.

Funds for the Baseline Study were allocated for 1989/90 ($150 000), 1990/91 ($200 000), 1991/92 ($200 000) and for 1992/93 ($200 000) and the Great Barrier Reef Marine Park Authority in Townsville was charged with the management of the project. The Torres Strait Baseline Study commenced in May 1990 with the appointment of a Coordinator, and a part-time Scientific Adviser based in Townsville and an Assistant Coordinator based at Thursday Island.

The study will collect data which will determine whether there is evidence of contamination of the marine environment and aim to provide background information for options for managing and protecting the Torres Strait marine environment as required under Article 13 of the Torres Strait Treaty. The scientific programme is managed by the Great Barrier Reef Marine Park Authority, advised by the Torres Strait Baseline Study Advisory Committee which is comprised of representatives from the mining companies, Papua New Guinea Government officials, the Commonwealth Government and the Queensland state Government, scientists and academics as well as a representative from the Torres Strait Islander communities.

Torres Strait Baseline Study Conference

The first task presented to the Torres Strait Baseline Study managers was to organise a conference on the physical, biological and human environments of the Torres Strait region. The conference was designed to be a forum for the presentation of papers concerning research undertaken in the Torres Strait region and a means for the presentation, and discussion, of the proposed scientific programme of the Baseline Study. The conference on "Sustainable Development for Traditional Inhabitants of the Torres Strait Region" was held at the Kewarra Beach Resort, north of Cairns, Australia, between 19 and 23 November 1990. This publication contains the official proceedings of that conference.

The conference was unusual in that it brought together many different points of view, cultural outlooks and academic opinions. The success of the conference was, in many ways, determined by the level of interaction, both formal and informal, between so many different groups and individuals.

The objectives of the conference were: to bring together current information on the Torres Strait environment having regard for the impact of mining operations in the Fly River catchment area; to consider ways in which environmental protection and economic development of the region can be mutually compatible, rather than contrasting objectives; and, to consider ways in which the long-term economic and environmental well-being of the traditional inhabitants of the region can be sustained.

The Torres Strait is an area of considerable ecological, biological and cultural diversity. This diversity was shown in the wide range of papers presented by the participants at the conference. This diversity also makes a study of the Torres Strait marine environment not only interesting, but complex. In order to address the needs of the Islander and Papuan peoples, as well as scientists, academics, government officials and researchers present, the conference programme was divided into three parts: Physical Environment, Biological Environment and Human Environment.

Conference Programme

The conference was opened by Mr Graeme Kelleher, Chairman of the Great Barrier Reef Marine Park Authority who spoke on the importance of protecting the cultural and environmental heritage of the peoples of the Torres Strait region while recognising that development of the region must be sustainable, ecologically, socially and economically.

In reply Mr Getano Lui Jnr., Chairman of the Island Coordinating Council, and Chairman of the Yam Island Community Council, addressed the conference on the concerns of Torres Strait Islanders who, he stated, had not been accorded the rights and privileges available to all Australian peoples, and that many Islanders regarded themselves as a forgotten people. Mr Lui Jnr stressed that the Torres Strait Islanders are a separate, and a proud people, with a strong economic, cultural and spiritual attachment to the waters and the reefs of the Torres Strait region. Islanders, he stated, know that their life and livelihood depends on the quality of the marine environment. The people of the Torres Strait want genuine economic and political development, not welfare based development. The Torres Strait Treaty recognises the need for protecting the traditional way of life and livelihood of the traditional inhabitants. It is, he remarked, therefore crucial that all activities in the Torres Strait acknowledge the rights and customs of the Islanders. Australia has a duty to improve the well-being of the Islander people and needs to be more active in the protection of the Torres Strait Islanders' way of life.

In his reply to the address by Mr Kelleher, Mr Clement Hesaboda, the President of the Kiwai Local Government Council, acknowledged the genuine concerns of the coastal Kiwai people of the Daru region about the possible effects of mining pollution on the subsistence economy of the Papuan people. He stated that the local people could not understand the reasons for the decision to dump tailings directly into the Fly River system for the people could see for themselves the effects of pollution on the river system. Papua New Guinea, he stated, must also assume responsibility for the protection of the marine environment of the Torres Strait region.

The formal presentations at the conference and the publication of the proceedings follow the conference programme and are grouped into three main headings:

Physical Environment of the Torres Strait Region

Papers presented in the section on the Physical Environment covered a variety of topics including climate change and the impact of sea level rise, oil spill contingency planning in Papua New Guinea, metal distribution in sediments of the Fly River delta, sedimentation in the Fly delta and northern Torres Strait and water circulation in the Torres Strait. Other papers presented in this session included a detailed description on the environmental monitoring programmes being managed by both the Ok Tedi Mining Company and environmental staff at Porgera Joint Venture. As well, papers on the work being undertaken by the National Analytical Laboratory at Papua New Guinea University of Technology, Australian food standards for heavy metals and the transformation and fate of heavy metals in the marine environment were also presented.

Biological Environment of the Torres Strait Region

In the Biological Environment programme papers were presented on topics which included the status of dugong in Torres Strait, Queensland state Government research on commercial prawns, biological oceanographic measurements being undertaken in the Torres Strait and the Far Northern Great Barrier Reef and marine turtle resources in Torres Strait. The complexities of the biological environment were detailed in papers on Australia's fisheries research in the Torres Strait region, the artisanal turtle fishery in Daru, detrital movement from the Fly River system into the Gulf of Papua, management of the rock lobster fishery in the Torres Strait, and biological research being undertaken in the Fly River system by the Ok Tedi company. Queensland government policies for fisheries management in the Torres Strait as well as proposals to enhance the commercial rock lobster fishery, scientific research into trace elements in clams from the Torres Strait and the use of *Tridacna* as bio-indicators of trace metal pollution were also described.

Human Environment of the Torres Strait Region

Papers presented in the programme on the Human Environment included an examination of the importance of the marine environment to Torres Strait Islander culture in the western islands and in the eastern islands, the impact of large scale mining on the Wopkaimin landowners in the Ok Tedi region and the subsistence economy of the coastal Kiwai of the Daru region. Papers on the need for an information database of resource development activities, the results of a traditional fishing study of the Torres Strait, possibilities and limitation on indigenous economic development in the Torres Strait region, the effects of bureaucratic concentrations on Thursday Island and the growing internationalism of indigenous people were presented to the conference. The proceedings also include papers on the environment and human ecology in the middle Fly region, the political and environmental aspects of the Torres Strait Treaty, and the problems and future directions of the Maza Wildlife Management Area in the Western Province.

Concluding Remarks

On the final day of the conference the role of the Commonwealth Government in the Torres Strait Baseline Study was described and a briefing on the political, cultural and administrative background to the Baseline Study programme was given. The scientific programme was presented to the conference for consideration and discussion. The concluding remarks by Dr John Cordell from the Cultural Survival organisation described the growing empowerment of indigenous peoples and their need to appreciate the growing importance of environmentalism in their movement towards self-management and conservation of resources.

As a separate but related issue to the conference, the Papua New Guinea Department of Environment and Conservation also presented their proposal for a marine environmental management plan for western Papua.

It is difficult to evaluate the results of a conference such as this one. The complexities of scientific research, the multiplicity of views on environmental protection and sustainable use of biological resources as well as the myriad layers of social, cultural and economic systems in a diverse environment such as the Torres Strait region may seem to confuse issues rather than clarify them. However, it is rare for physical and biological scientists to have to explain their research to social scientists, traditional inhabitants and government officials. Similarly, social scientists rarely interact with biological and physical scientists. It is hoped, therefore, that the publication of these proceedings will enable Islanders, Papuans, academics, scientists and government officials to understand, more fully and at leisure, the problems and prospects of the Torres Strait from a variety of perspectives.

Acknowledgements

The conference was assisted by funding from the Queensland Government. The Great Barrier Reef Marine Park Authority is grateful to the Premier of Queensland, the Hon. Wayne Goss, MLA, for this assistance which was directed primarily at funding the travel of Torres Strait Islander representatives.

Dr Donald W. Kinsey, Executive officer of the Great Barrier Reef Marine Park Authority was Chairman of the conference. The organisers would also like to thank Mr Simon Woodley, Assistant Executive Officer, Research and Monitoring for assistance during the conference with the preparation and presentation of daily summaries of the proceedings. The Coordinator and editor of these proceedings would especially like to thank Beryl Dennis for her assistance with proof-reading the proceedings, and Tim Cansfield-Smith for his work in organising the programme, managing the operations of the conference and assisting with the publication of these proceedings.

The conference organisers would also like to thank the staff and management of the Kewarra Beach Resort for their cheerful assistance with many small, and some large problems during the meeting.

List of Participants and Speakers •

• *Bill Arthur*, Centre for Aboriginal Economic Policy Research, Australian National University

• *William Asigau*, Papua New Guinea Department of Environment and Conservation

• *Graham Baines*, Papua New Guinea Department of Environment and Conservation

• *Elaine Baker*, Ocean Sciences Institute, University of Sydney

Donald Banu, Boigu Island Council

• *Jeremy Beckett*, Department of Anthropology, University of Sydney

Philip Bigie, Dauan Island Council

Jaru Bisa, Papua New Guinea Department of Environment and Conservation

Anna Bissett, Island Coordinating Council

Terje Brantenberg, North Australia Research Unit, Australian National University

David Briggs, Planning and Management, Great Barrier Reef Marine Park Authority

Jon Brodie, Research and Monitoring, Great Barrier Reef Marine Park Authority

• *Mark Busse*, Papua New Guinea National Museum and Art Gallery

• *Michael Capra*, Department of Public Health and Nutrition, Queensland University of Technology

Alison Cole, Ocean Sciences Institute, University of Sydney

Noelene Cole, Far Northern Schools' Development Unit

• *John Cordell*, Cultural Survival Inc.

• *Wendy Craik,* Planning and Management, Great Barrier Reef Marine Park Authority

• *Chris Crossland,* CSIRO Institute of Natural Resources and Environment

• *Roger Benko,* National Analysis Laboratory, Papua New Guinea University of Technology

Trevor Daly, Greenpeace

Bob Densley, Queensland Fish Management Authority

• *Gary Denton,* Water & Energy Research Institute of the Western Pacific, University of Guam

• *Ian Dight,* Torres Strait Baseline Study, Research and Monitoring, Great Barrier Reef Marine Park Authority

• *John Douglas,* Papua New Guinea Department of Environment and Conservation

• *Murray Eagle,* Ok Tedi Mining Limited

• *Mark Elmer,* Queensland Fish Management Authority

Libby Evans, Port Lihou Research & Field Services

Colin Fish, Australian Quarantine & Inspection Service, Commonwealth Department of Primary Industries and Energy

• *Judith Fitzpatrick,* Tropical Health Program, University of Queensland Medical School

• *Andrew Flowers,* Department of Public Health and Nutrition, Queensland University of Technology

• *Miles Furnas,* Australian Institute of Marine Science

Ellie Gaffney, Mura Kosker Sorority

Sirini Gauga, Papua New Guinea Department of Western Province

Roger Green, Queensland Commercial Fishermans Organisation

• *Allan Haines,* Commonwealth Department of Arts, Sport, the Environment, Tourism and Territories

Wayne Hardy, Queensland Department of the Premier, Economic and Trade Development

• *Peter Harris,* Ocean Sciences Institute, University of Sydney

Eddie Hegerl, Australian Littoral Society

• *Clement Hesaboda,* Kiwai Local Government Council

Roger Higgins, Ok Tedi Mining Limited

Nicky Horsfall, Queensland National Parks and Wildlife Service

• *David Hyndman,* Department of Anthropology and Sociology, University of Queensland

• *Robert Johannes,* CSIRO Division of Fisheries

David Johnston, Australian Heritage Commission

Greg Jones, Queensland Department of the Premier, Economic and Trade Development

• *Peter Jull,* North Australia Research Unit, Australian National University

David Kay, Australian National Parks and Wildlife Service

Jock Keene, Department of Geology and Geophysics, University of Sydney

• *Sandi Kehoe-Forutan,* Gutteridge Haskins & Davey

• *Graeme Kelleher*, Chairman, Great Barrier Reef Marine Park Authority

Mike Kennedy, Papua New Guinea Department of Minerals and Energy

Lois Kesu, Papua New Guinea Department of Environment and Conservation

Jeffrey Key, Papua New Guinea Department of Foreign Affairs

Donald Kinsey, Executive Officer, Great Barrier Reef Marine Park Authority (Conference Chairman)

Hermien Hadiati Koewadji, Airlangga University, Surabaya, Indonesia

Peter Koorockin, Queensland Department of Environmentand Heritage

• *Donna Kwan*, Department of Zoology, James Cook University of North Queensland

• *Judith Laffan*, Commonwealth Department of Foreign Affairs and Trade

• *David Lawrence*, Torres Strait Baseline Study, Research and Monitoring, Great Barrier Reef Marine Park Authority

Tjamei Lawrence, Wau Ecology Institute

Eunice Liew, Papua New Guinea Department of Minerals and Energy

• *Getano Lui, Jnr.*, Island Coordinating Council, Yam Island Council

Wallace MacFarlane, Queensland National Parks and Wildlife Service

Francis Maibani, Papua New Guinea Department of Provincial Affairs

• *Helene Marsh*, Department of Zoology, James Cook University of North Queensland

Victor McGrath, Island Coordinating Council, Torres Strait Baseline Study

• *Jeff Miller*, Queensland National Parks and Wildlife Service

Patrick Mills, Torres Strait Fishermans Association

Augustine Mobiha, Papua New Guinea Department of Fisheries and Marine Resources

Joseph Mosby, Yorke Island Council

• *Gerry Murphy*, Queensland Department of Primary Industries, Animal Research Institute

George Mye, Erub Community Council, Darnley Island

• *Thomas Nen*, Papua New Guinea National Research Institute

Horace Nona, Australian Fisheries Service, Commonwealth Department of Primary Industries and Energy

Joseph Nona, Badu Island Council

Debra Palmen, Commonwealth Department of Arts, Sport, the Environment, Tourism and Territories

• *Mike Patchett*, Papua New Guinea Department of Environment and Conservation

Robert Pearson, Division of Fisheries and Wetlands Management, Queensland Department of Primary Industries

• *Roland Pitcher*, CSIRO Division of Fisheries

• *George Rayment*, Agricultural Chemistry Branch, Queensland Department of Primary Industries

- *Alistar Robertson*, Australian Institute of Marine Science

- *Charlie Ross*, Porgera Joint Venture

- *Ross Smith*, Ok Tedi Mining Limited

- *Derek Staples*, Bureau of Rural Resources, Commonwealth Department of Primary Industries and Energy

- *Marjorie Sullivan*, Department of Geography, University of Papua New Guinea

Marika Tako, Papua New Guinea Department of Minerals and Energy

- *Clive Turnbull*, Northern Fisheries Centre, Queensland Department of Primary Industries

Terry Waia, Saibai Island Council

- *T David Waite*, Australian Nuclear Science and Technology Organisation

Howard Wallace, Division of Environment, Queensland Department of Environment & Heritage

David Walter, Queensland National Parks and Wildlife Service

Kembi Watoka, Papua New Guinea Department of Environment and Conservation

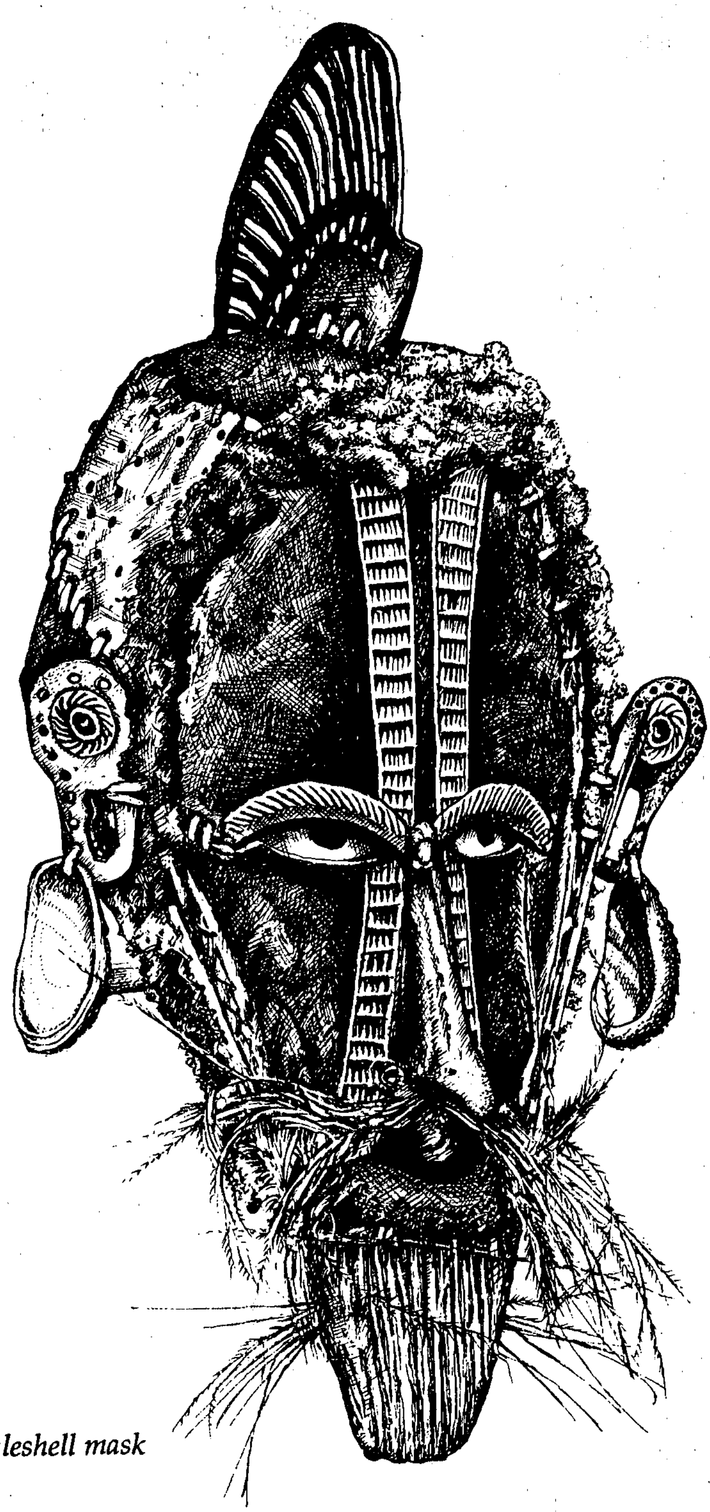
Reg Watson, Division of Fisheries and Wetlands Management, Queensland Department of Primary Industries

- *Eric Wolanksi*, Australian Institute of Marine Science

Simon Woodley, Research and Monitoring, Great Barrier Reef Marine Park Authority

Frank Ziolkowski, Commonwealth Department of Arts, Sport, the Environment, Tourism and Territories

KEYNOTE ADDRESS



Turtleshell mask

Sustainable Development for Traditional Inhabitants of the Torres Strait Region

Graeme Kelleher, Chairman
Great Barrier Reef Marine Park Authority

Introduction

The subject of this conference – Sustainable Development for the Traditional Inhabitants of the Torres Strait Region – provides the framework and justification for the Torres Strait Baseline Study, the management of which is the responsibility of the Great Barrier Reef Marine Park Authority. Many other agencies and people are vitally involved.

The description of the study as a "baseline" is in fact misleading. Because the study is being started after major mining operations have been in progress for some time, it is likely that it is a study of an ecosystem which is already in the process of change. This fact will make the study more difficult. Conclusions will be harder to derive. Costs will be increased. Nevertheless, we should be thankful that the study has been approved and funded. It will provide vital guidance to governments, private companies and individuals in making decisions that affect the people of the Torres Strait region.

In this introductory talk, I shall briefly outline the geography of the Torres Strait region and describe the various social groups which depend on the resources of this region. It is important to recognise that despite the critical need for development of the region, such development must be sustainable ecologically, socially and economically. I intend to mention the importance of the "Baseline" study in making sure that development is sustainable.

The Torres Strait Region

The Torres Strait, Fly estuary and the southwest coast of Papua New Guinea constitutes a vast area of considerable geographical, ecological and cultural diversity.

The Torres Strait can be generally described as the reef-strewn passage between Cape York Peninsula and the southwest coast of Papua New Guinea, west of the Fly estuary. This passage is only a little over 150 kilometres wide and contains approximately 150 islands, islets, coral reefs and cays. Of the multitude of islands in the Torres Strait, only about sixteen are presently inhabited, although use of uninhabited islands, either permanently or temporarily, has occurred during recent times. Island occupation is largely determined by access to fresh water.

The Torres Strait region, which consists of approximately 30,000 square kilometers of shallow waters, is a complex mosiac of different environments. Extensive seagrass beds occur in the western and northern areas and this is the area in which large numbers of dugong are found. The clear waters and coral reefs to the east, near the most northerly section of the Great Barrier Reef, are rich fishing grounds which contain large numbers of edible reef fish. In the muddy waters of the southwestern coast of Papua New Guinea and adjacent islands mullet, barramundi, prawns and crabs are common. Turtles are generally found throughout the region.

The Torres Strait Islanders are therefore fortunate in having access to a large variety of marine life. The myths and legends of the Islander people are rich in references to fish, turtles, dugong, shellfish and other sea creatures. Marine resources, particularly dugong, feature strongly in customary gift giving especially at important community ceremonies such as marriages and tombstone openings, and seafoods are still distributed among close family and through the kinship network.

The major industry in the region is, naturally, fishing. Recent history has shown this to be entirely unpredictable, dependent on national and international tastes and market-place decisions beyond the control of local fishermen. This is particularly true for the pearling, beche-de-mer and trochus industries. The Torres Strait has a long history of boom and bust marine industries.

Commercial fishing appears to be one of the only sections of the economy open to Islander participation. In a community where cultural patterns emphasise the importance of marine resources, and where economic opportunities revolve around exploitation of these marine resources, protection of the marine environment assumes a high profile in Islander social and political life.

It seems certain that marine resources will continue to provide both the backbone of commercial industry as well as an essential part of the lifestyle, nutrition and customary relations of the Islander people.

This is also true for the Papuan people inhabiting the neighbouring regions along the southwest coast and Fly estuary region of Papua New Guinea. These people also share access to the marine resources of the Torres Strait and have, over the centuries, maintained economic and cultural ties with the Torres Strait Islanders. The rights of both Torres Strait Islanders and Papuans are protected in the Torres Strait Treaty which was signed by both Australia and Papua New Guinea in 1978, and ratified in 1985.

In contrast to the reefs and islands of Torres Strait, the southwest coast of Papua New Guinea is generally flat and featureless, the only prominant feature being the hill at Mabudawan. The coastal plain is subject to seasonal and tidal flooding and the inshore waters are muddy and contain reefs, mudbanks and sandbars which hinder movement along the coast.

The Fly estuary consists of numerous channels separating low-lying islands of which Kiwai Island is the largest. Many of the other islands are tidal swamps and generally uninhabited except by fishing parties. Constantly changing shoals, and floating tree trunks, plague river journeys. The rapid rise and fall of floodwaters and an unpredictable tidal bore in the lower Fly River, especially during new and full moons in the south-easterly season, are hazards to the predominantly Kiwai-speaking people who live in this difficult riverine environment.

The Kiwai people also inhabit the six coastal villages of Parama, Katatai, Kadawa, Tureture, Mawatta and Mabudawan along the southwestern coast. Most of the people of Daru also speak Kiwai. The people of these coastal villages live on a narrow strip of land between the sea and the coastal swamp and savannah grasslands. With only limited gardening lands, and inhabiting a region of variable wet and dry climate, the coastal Kiwai have remained predominantly fishermen, sailing in large outrigger canoes into the Torres Strait to hunt turtle and dugong, and to fish the rich waters near the Warrior Reefs.

The constant supply of marine resources, in contrast to the fluctuating supply of garden and bush foods, has meant that both Torres Strait Islanders and Papuans have always depended on marine resources for their survival. The potential sustained yield of seafoods from Torres Strait can only be conservatively estimated at 20 000 tonnes per year. This is certainly enough to satisfy Islander and Papuan needs and also satisfy commercial demands if efficiently managed. Protection of this resource is therefore essential, not only to the local traditional inhabitants, but also to the wider Australian and Papua New Guinean communities.

The waters of the Torres Strait are one of the few tropical shallow-water environments that remains in a relatively good condition. However, local pollution problems such as the 'Oceanic Grandeur' accident in 1970 when large quantities of oil and non-biodegradable dispersant were poured into the ocean and the accidental loss of 24 ship containers of hydrogen peroxide in 1984 as well as the loss of 270 metric tons of sodium cyanide offshore from the Fly estuary only served to focus attention on environmental protection of the Torres Strait and Fly estuary region.

The Torres Strait Baseline Study

In 1989 the Prime Minister announced in his environmental statement that the Australian Government would fund a four year environmental programme in the Torres Strait to be called the Torres Strait Baseline Study. The Baseline Study was instigated in response to concerns expressed by Torres Strait Islanders, scientists and commercial fishermen at the Torres Strait Fisheries Seminar in February 1985, about the possible effects on the marine environment from current and proposed mining operations in the Fly River catchment area.

The marine ecological implications of the disposal of large volumes of mine tailings and overburden into tropical river systems are still largely unknown. Both the Ok Tedi Mining Limited and the Porgera Joint Venture companies have recognized the implications of large scale mining operations in difficult and unstable mountainous terrain and have developed important and scientifically sound environmental monitoring programmes in both the Fly and the Strickland River systems. The Torres Strait Baseline Study will operate in collaboration with the Papua New Guinea Government and the mining companies.

Possible effects on the marine environment of the Torres Strait include increased particulate loading of the river systems which may, due to increased water turbidity, cause a significant loss of productivity. Increased sediment in the rivers may also eliminate bottom dwelling species. However, the more serious problem may be the translocation and incorporation of residual metals from tailings waste into marine sediments, and marine organisms in the Torres Strait. Mining residue containing fluctuating high levels of copper, as well as quanities of cadmium, zinc, and lead may cause a rise in the background levels of heavy metals which are normally present in the natural, non-contaminated environments. The processes of bio-accumulation whereby these heavy metals are accumulated in marine organisms up the food chain are presently unknown. Details of the movements of ocean currents and the transportation of sediments from the river systems into the Fly estuary and the Torres Strait are currently being investigated by consultants to Ok Tedi Mining Limited.

Four oceanographic cruises between 1979 and 1982 found that water from the Fly River enters the Torres Strait through the Great North East Channel. The tongue of brackish water is vertically well-mixed by the tidal currents and extends from 70 to 100 kilometers in length. It is gradually dilluted by the waters of the Torres Strait so that the potential impact would, on these estimations, be greater in the northern area of the Torres Strait.

The Torres Strait is therefore at a critical point in its history. The traditional inhabitants' concerns over loss of environment, contamination by heavy metals, destruction of marine resources, cannot be dismissed lightly. We must remember that the Torres Strait has been the home to the Islander and Papuan people for many thousands of years. Both Torres Strait Islanders and Papuans are recognized, under the Torres Strait Treaty, as traditional inhabitants of the Torres Strait region. The traditional use, or exploitation, of marine resources prior to the coming of European commercial activity to the region after the middle of the 19th century was probably sustainable. It is now up to all of us to ensure that the environment is protected for future generations.

The theme of this conference is 'Sustainable Development for the Traditional Inhabitants of the Torres Strait Region'. I have spoken about the relationship between the traditional inhabitants and the marine environment. This conference will examine current information on the physical, biological and human environments of the Torres Strait region, having regard for the impact of current and future mining operations in the Fly River catchment area on the Torres Strait marine environment.

Papers presented during this conference will consider ways in which environmental protection and economic development of the Torres Strait region can be mutually compatible, rather than contrasting objectives. The sustainable development of the

Torres Strait region, for the long-term economic, social and environmental well-being of the traditional inhabitants, will be the primary focus of the conference.

The concept of sustainable development is not new. It has existed in virtually every group of humans who have lived and depended on the earth's natural bounty. One of the most important factors in eroding the commitment to sustainability in theory and practice in the 20th century has been the application of modern economic analysis incorporating the methods of benefit-cost analysis, net present worth and discount rates. Taken together, these methods tend to lead to decisions which state tacitly or explicitly that anything that happens more than twenty years hence is irrelevant. Recently there has been a dramatic realisation by world leaders that we must change our approach to development. Margaret Thatcher, Mikhail Gorbachev, George Bush and Australia's Prime Minister Bob Hawke have recognised the absolute dependence of development on protection of the natural environment. In the 1980s the term 'sustainability' appeared in a wide range of contexts and became an international catch-cry with the publication by the International Union for the Conservation of Nature and Natural Resources (IUCN) of the "World Conservation Strategy: living resources for sustainable development" report in 1980. More recently the Australian Government has published a discussion paper titled "Ecologically Sustainable Development" which defines ecologically sustainable development as the means of:

> using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased. (Australia. Department of the Prime Minister and Cabinet, 1990:1)

There are five general principles which are the key elements of ecologically sustainable development:

- Integrating economic and environmental goals in policies and activities;
- Ensuring that environmental assets are appropriately valued;
- Providing for equity within and between generations;
- Dealing cautiously with risk and irreversibility and;
- Recognising the global dimension.

Sustainable development requires fundamental changes in the way in which development is managed by shifting the emphasis of environmental policy towards anticipation and prevention. This can be achieved by reinforcing policy through the use of mandatory environmental impact assessments, development planning, commitment to the concept of sustainability and by having a strong environmental agency with sectoral agencies having open communication and commitment to national environmental goals.

The ecosystems and resources of the coastal zone are rapidly deteriorating due to intense human pressure, urban, commercial and industrial development and the over-exploitation of natural resources. Yet it is the coastal zone that has the highest biological productivity in the world. More than three-quarters of marine pollution comes from land-based sources, via rivers and direct discharges, and more than 90% of all chemicals, refuse and other materials entering the continental shelf and coastal waters remain in the sediments, wetlands, fringing reefs, and other coastal ecosystems (IUCN/UNEP and WWF 1980: 108).

There are sound reasons for the decision to make the Great Barrier Reef Marine Park Authority the managers of the Torres Strait Baseline Study. The Great Barrier Reef Marine Park Act is one of the first pieces of legislation in the world to apply the concept of sustainable development to the management of a large natural area. The Great Barrier Reef Marine Park is an example of the practical application of the principles defined in the "World Conservation Strategy" (ICUN 1980?) and in the "National Conservation Strategy for Australia" (National Conservation Strategy for Australia. Interim Consultative Committee 1985).

There are also similarities between the Great Barrier Reef Marine Park Act and the Torres Strait Treaty in approaches to marine resource management, in the recognition of the importance of protecting the marine environment, in conservation and management of fisheries resources and in the importance of protecting the traditional way of life and livelihood of the inhabitants of the Torres Strait region. It is regrettable that no comprehensive environmental management plan exists for this diverse and important region.

The process of exploration, mining and mineral processing inevitably involves some environmental and ecological impacts and changes. The issue, in the context of ecologically sustainable development, is not environmental change per se, but rather whether environmental impacts are irreversible. The impact of mining on water catchments is of particular significance. Issues of concern relate to access to land for resource exploration, the nature of resource use decision-making, the adequacy of standards and the ability of governments to enforce them, and the appropriateness of incentives for environmental protection and rehabilitation. Many of these topics will be discussed at this meeting.

The Torres Strait Baseline Study is another step towards the objective of maintaining the quality of the marine environment of the Torres Strait region to ensure the sustained use of its living resources, particularly by traditional inhabitants, and to protect the indigenous species and genetic diversity in the context of environmental changes arising from economic developments on land, sea, and seabed. The study, which is to be conducted in close collaboration with the Papua New Guinea Government, will collect data which will determine the background levels of metals and sediments in the Torres Strait marine environment and assist in determining whether there is evidence of contamination from mining operations in the Fly River catchment area. The study will aim to provide background information for options for managing and protecting the Torres Strait marine environment. The Baseline Study complements the concept plan for environmental monitoring of western Papua and Torres Strait regions which will be presented at this conference by officials of the Papua New Guinea Government.

In commencing this Baseline Study, we must recognise the complexity of the region, the many factors involved and the inadequacy of existing knowledge. A study which attempted to answer all of the scientific questions applying to the Torres Strait region would cost many times more than the funds that can be provided. It would take more time and require more scientists than will be available.

The great challenge for the Torres Strait Baseline Study team will be to define and address adequately, within the available resource limits, the questions vital to achieving ecological sustainability of the Torres Strait. Proirities will have to be set. Hard choices will have to be made. It will be a hard task. I wish them well.

Conclusion

In conclusion I should also like to thank the Queensland Government for their generous financial support for this conference. Their support will, I am sure, contribute substaintially to the success of this conference.

Thank you.

References

Australia. Department of Foreign Affairs (1978) , *Treaty between Australia and the Independent State of Papua New Guinea.* Canberra, Dept. of Foreign Affairs.

Australia. Department of the Prime Minister and Cabinet (1990), *Ecologically Sustainable Development.* Canberra, AGPS.

Gilmore, A.J. (1990), 'A sustainable approach to curbing environment risk' *Financial Review*, October 4, 1990, p.67.

Hanks, J. (1987), *Human Populations and the World Conservation Strategy.* Gland, IUCN, Commission on Ecology.

Heinsohn, G. and Wolanski, E. (1985), 'The Torres Strait'. *Habitat*, 13(6), 12-18

IUCN (1980?), *World Conservation Strategy.* Morges, IUCN.

IUCN/UNEP and WWF (1990), *Caring for the World: a strategy for sustainability.* Gland, IUCN.

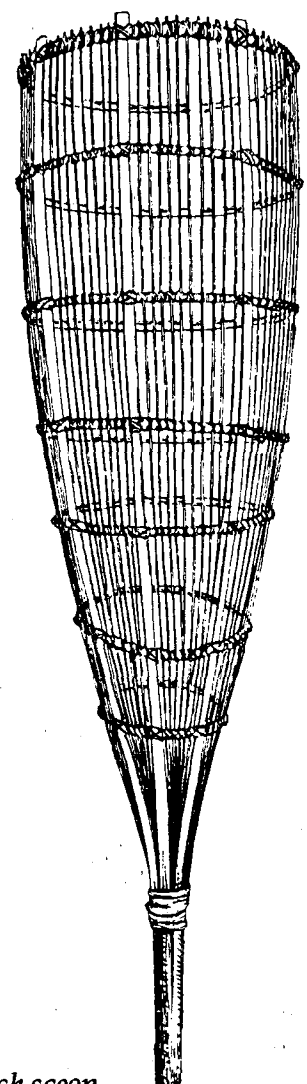
Kelleher, G. (1990), 'GBRMPA – its role in the use and care of the Great Barrier Reef.' unpublished paper presented to the 'Engineering in coral reef regions' conference, Magnetic Island, 1990.

National Conservation Strategy for Australia. Interim Consultative Committee (1985), National Conservation Strategy for Australia. Canberra, Department of Arts, Heritage and the Environment.

Turner, Kerry R. (ed) (1988), *Sustainable Environmental Management.* London, Belhaven Press.

World Commission on Environment and Conservation (1987), *Our Common Future.* Oxford, Oxford University Press

PHYSICAL ENVIRONMENT OF THE TORRES STRAIT REGION



Fish scoop

Planning and Management of the Great Barrier Reef Marine Park

Wendy Craik, Planning & Management
Great Barrier Reef Marine Park Authority

The Great Barrier Reef is the largest system of coral reefs and associated life-forms anywhere in the world. The Great Barrier Reef Region extends from just north of Bundaberg to the tip of Cape York and covers some 350,000 square kilometres. It contains 2900 reefs ranging in size from less than one hectare to greater than 100 square kilometres. The Reef Region contains 300 coral cays and about 600 continental islands.

In terms of fauna, the Great Barrier Reef is particularly rich and diverse. It contains an estimated 1500 species of fishes, some 350 species of hard coral and numbers of endangered species such as dugong and 6 species of turtle. An estimated 242 species of seabirds and 4000 species of molluscs are also found in the Great Barrier Reef Region.

Many people use the Great Barrier Reef for many things. The only activities which are prohibited are commercial mining and oil drilling. The major activities occurring in the Great Barrier Reef Region are tourism and fishing. In its early years reef tourism grew forty-fold between 1940 and 1980. Tourism is now the fastest growing activity in the Great Barrier Reef Region, growing at an estimated rate of 10% per year, and in some areas, for example, Cairns, growing at an estimated rate of 30% per annum until recently. Tourism, as well as undergoing a rapid increase in growth in the last five years or so, has also undergone a dramatic change in style. It has changed from unsophisticated, relatively inexpensive, generally slow, family styles of tourism to high technology, high speed, corporately financed and in many cases, up-market, tourism.

In terms of visitors, an estimated 5,000 visitors to the Great Barrier Reef Region generate an estimated 2.5 million visitor nights per annum in the Great Barrier Reef Region and these visitors produce an output estimated at $400 million per year including the adjacent mainland. The major activities undertaken by tourists in the Great Barrier Reef include diving, snorkelling, reefwalking and coral viewing.

The other major activity in the Great Barrier Reef Region, fishing, consists of both commercial and recreational fishing. Together they are estimated to generate $400 million of output per year. The main commercial fishery is trawl fishing for prawns and scallops. The other major fishery is the reef fishery for reef fish, usually coral trout, red emperor etc. It is estimated that some 70% of the reef fish catch is taken by recreational fishermen. It is also estimated that 30-40% of that catch is taken by about 10% of people recreationally fishing. In addition there are minor fisheries for aquarium fish, coral, beche-de-mer, trochus and there is of course a traditional fishery adjacent to Aboriginal deed of grant in trust lands.

The Great Barrier Reef began to figure in the national conscience in the 1960s when concern about limestone mining and oil drilling on the Great Barrier Reef generated two Royal Commissions and in 1975 the passage through Federal Parliament of the Great Barrier Reef Marine Park Act, supported by all political parties. The Act has a number of elements which are closely related to the success of the organisation. These important elements are:

- that the Authority consists of three members, two of whom are federally appointed (one a public servant and one independent) and a member of the Authority is a Queensland Government nominee.
- The Act also provides for the establishment of a Great Barrier Reef Consultative Committee, an advisory committee composed of Queensland and Federal nominees representing major user interest groups.
- The Act also provides for the Marine Park Authority to perform its functions in association with Queensland.
- The Act prohibits mining and oil drilling in the Great Barrier Reef Region.
- The Great Barrier Reef Marine Park Act prevails over conflicting legislation with the exception of the navigation acts.

The Great Barrier Reef Marine Park Authority has from its Act derived a goal and series of aims. The goal of the Great Barrier Reef Marine Park Authority is to provide for the wise use, protection and understanding of the Great Barrier Reef in perpetuity through the care and development of the Great Barrier Reef Marine Park. A number of subordinate aims have also been derived. These are:

- To protect the natural qualities of the Reef, whilst providing for reasonable use of the Reef's resources;

- To involve the community meaningfully in the care and development of the Marine Park;

- To achieve competence and fairness in the care and development of the Marine Park through the conduct of research, and the deliberate acquisition, use and dissemination of relevant information from research and other sources;

- To minimise regulation of, and interference in, human activities, consistent with meeting the goal and other aims of the Authority;

- To minimise costs of caring for and developing the Marine Park consistent with meeting the goal and other aims of the Authority;

- To achieve management of the Marine Park primarily through the community's understanding and acceptance of the provisions of zoning, regulations and management practices;

- To provide for economic development consistent with meeting the goal and other aims of the Authority;

- To adapt the Marine Park and the operations of the Authority to changing circumstances.

The Great Barrier Reef Marine Park is not a Marine Park in the sense of a terrestrial National Park. It is a multiple use protected area. The Great Barrier Reef has received considerable international recognition. It was listed in the World Heritage Register in 1981, it has recently been declared a "Particularly Sensitive Area" by the International Maritime Organisation and the various zones in zoning plans correspond to various categories in the IUCN system of protected areas. The Great Barrier Reef Marine Park also conforms with the requirements of the Biosphere Reserve concept although it has not been declared as such.

The Great Barrier Reef Marine Park is divided into four sections, each of which has a zoning or management plan which spatially regulates usage within the area.

The process involved in the development of the zoning plan is long (approximately two years) with a significant focus on public participation. The process involved includes:

- presenting the public with an outline of the area to be zoned along with information available to date on usage and resources and seeking comments on those aspects. Users are asked what uses are important to them and which areas are important to them and what they would like to see in the Marine Park plan;

- from this period of public participation, a detailed series of maps showing patterns of use and important resources is able to be put together;

- a draft zoning plan is then prepared using the guidelines presented in the Act and policies developed by the Authority.

The objectives to be borne in mind in establishing a zoning plan are set out in the Act. They are:

"(a) the conservation of the Great Barrier Reef;
(b) the regulation of the use of the Great Barrier Reef so as to protect the Great Barrier Reef while allowing the reasonable use of the Great Barrier Reef Region;
(c) the regulation of activities that exploit the resources of the Great Barrier Reef Region so as to minimise the effect of those activities on the Great Barrier Reef;
(d) the reservation of some areas of the Great Barrier Reef for its appreciation and enjoyment by the public; and
(e) the preservation of some areas of the Great Barrier Reef in its natural state undisturbed by man except for the purposes of scientific research."

Policy guidance developed by the Authority is also taken into account in drawing up a zoning plan; for example:

- the zoning plan should be as simple as practicable;
- the plan should minimise regulation of and interference in human activities, consistent with the goal of the Marine Park Authority;
- as far as practicable single zonings should surround areas with a desirable geographic description.

This draft zoning plan is put out for public comment for an extended period of at least three months. The Marine Park Authority makes particular effort to contact all user groups to obtain their input and comment on the plan because it strongly believes that user acceptance of the plan will result in behaviour which abides by the plan with the consequent reduction in the need for enforcement activity in the Marine Park.

The comments that the public provides on the draft zoning plan are taken into account in the production of the final zoning plan which is approved by the Great Barrier Reef Ministerial Council, the Federal Minister responsible for the Great Barrier Reef Marine Park and ultimately tabled before Federal Parliament for fifteen sitting days. If no motion disallowing the plan is passed within that period of time, the plan comes into effect at a subsequent date.

Important points to note in the production of zoning plans for the Great Barrier Reef Marine Park are that it is a complimentary process in both method and time with Queensland Marine Parks. As the Great Barrier Reef Marine Park extends in general into low water, areas between high and low water are zoned as far as possible in a complimentary fashion and according to the Queensland Marine Parks legislation. The development of zoning plans is undertaken simultaneously in an effort to reduce user confusion. Additionally the Great Barrier Reef Marine Park Authority works very closely with other Queensland and Federal Government Departments, for example fisheries departments, who have interests and responsibilities in the Great Barrier Reef Region.

Another important point is that while zoning plans provide broad-scale strategic guidance they are not proving to be adequate on a localised scale. As a result, with the Queensland National Parks and Wildlife Service, the Great Barrier Reef Marine Park Authority is beginning to prepare reef and island management plans which guide usage at individual reefs. A further important point is that initial preparation of zoning plans has largely focused on uses of the Marine Park in terms of extractive uses. The rapid growth in tourism which was not foreseen in the initial development of zoning plans is now being addressed through the introduction of a subzone in the Cairns Section in which no structures other than moorings, research, monitoring and navigation aids are permitted.

The implementation of zoning plans is largely undertaken by Queensland agencies, particularly the Queensland National Parks and Wildlife Service with an enforcement role for the Queensland Boating and Fisheries Patrol. The national coastal surveillance organisation, Coastwatch, also undertakes a significant amount of surveillance over the Great Barrier Reef Marine Park, along with its other aerial surveillance duties. A series of agreements between the Commonwealth and Queensland following from the 1979 Emerald Agreement between the then Premier of Queensland, Sir Joh Bjelke-Peterson and the then Prime Minister of Australia, Mr Malcolm Fraser, prescribed the arrangements under which management occurs. The Queensland National Parks and Wildlife Service have the equivalent of 92 full-time staff involved in day-to-day management in the Great Barrier Reef Marine Park and provide a field presence in the Marine Park. Their role also includes managing Queensland Marine Parks and National Parks in a unique agreement with the Commonwealth in which the capital funding for the first three years or so is provided by the Commonwealth with all recurrent funding and capital funding after the first three years or so and shared on a fifty-fifty basis. The cost of managing the Great Barrier Reef Marine Park is relatively small. Considering the budget of the Great Barrier Reef Marine Park Authority and the Queensland contribution to day-to-day management, the cost per Australian citizen per day works out to be less than a third of a cent for managing the Great Barrier Reef Marine Park.

Day-to-day management of the Great Barrier Reef Marine Park includes a number of functions:

- education and interpretation
- surveillance
- monitoring
- administration

Education and interpretation programs are, the Authority believes, the means for assuring the long-term future and security of the Great Barrier Reef Marine Park. The Marine Park Authority and the Queensland National Parks and Wildlife Service therefore have extensive information and education programs. These programs involve meeting with user groups, publication of brochures, pamphlets, television ads, signage and school programs. A major plank in the Marine Park Authority's education program is the Great Barrier Reef Aquarium which is a naturally functioning coral reef in a tank designed to enable those who cannot, and even those who can get to the Great Barrier Reef, to appreciate the reef without going to sea. Interpretive programs also provide an opportunity for the public to be able to understand management goals and strategies of the Great Barrier Reef Marine Park Authority.

Research and monitoring is also a function of the Great Barrier Reef Marine Park Authority. Under the Great Barrier Reef Marine Park Act, the Marine Park Authority can commission or carry out research which is relevant to the Marine Park. The Marine Park Authority has interpreted this fairly narrowly, particularly as it has a fairly circumscribed research budget and as a result it insists on the commissioning of specific pieces of research to answer specific management questions. Examples of questions which are addressed through the research and monitoring program are:

- determining whether the Cape Tribulation to Bloomfield Road through rainforest had an effect on the adjacent fringing reef;
- determining the effects of fishing on reef fish;
- determining attitudes of users to Marine Park zoning;
- determining the "health" of the reef;
- determining the oceanography of the Great Barrier Reef Region;
- investigating the status of endangered species.

In terms of research, the Great Barrier Reef Marine Park Authority believes that there are three major challenges in the years ahead which it must address. These are crown-of-thorns starfish outbreaks, the effect of nutrients (nitrates and phosphates) on the Great Barrier Reef, and the effects of fishing (particularly line fishing and trawling) on the Great Barrier Reef ecosystem.

Other challenges in the years ahead are attempting, with day-to-day management agencies, to develop more sophisticated methods of management of the Great Barrier Reef Marine Park. It is most unlikely that budgets will increase substantially in the next few years and efforts must be made to continue to take advantage of new techniques and practices.

The other major challenge in the years ahead is to prevent a major oil spill in the Great Barrier Marine Park. The Marine Park Authority has been particularly active in pressing for compulsory pilotage in the Great Barrier Reef Region and was recently achieved and is likely to come into effect in mid-1991. The maintenance and installation of navigation aids, the regular testing of Reefplan, the Oil Spill Contingency Plan, and participation in exercises and coordinating arrangements in the event of a spill are critical.

Conclusion

From this brief view of planning and management of the Great Barrier Reef Marine Park, the important points to note are:

- we are fortunate in that the Great Barrier Reef is located off Australia where subsistence use and other pressures are nowhere near as great as they are in other countries;

- the legislative provisions in the Great Barrier Reef Marine Park Act assist in providing a significant basis for protection and implementation of management provisions;

- the Great Barrier Reef Marine Park Authority has focused very heavily on user involvement in the development and operation of the Great Barrier Reef Marine Park;

- the Great Barrier Reef Marine Park Authority has demonstrated its willingness and preparedness to compromise as long as the objects of the Marine Park Authority are themselves not compromised;

- the Marine Park Authority is very willing to work with other agencies and attempts to demonstrate that it does not wish to intrude in their areas of responsibility providing the conservation of the Great Barrier Reef is assured;

- the Marine Park Authority emphasises the importance of education and information in attempting to inform and persuade people that responsible behaviour in the Great Barrier Reef Region is the most efficient and effective method of operation;

- the Great Barrier Reef Marine Park Authority constantly reviews its procedures and processes, attempts to remove inefficiencies and to introduce new and better methods of operation.

The Impacts of Projected Climate Change on Coastal Land Use in Papua New Guinea

Marjorie Sullivan, Department of Geography
University of Papua New Guinea

Abstract

Papua New Guinea is made up of a high island mainland (half of the island of New Guinea), three large high islands >100 km long, numerous small high island or raised coral islands, and even more numerous atoll or patch reef-based low island (motu or cays). Because of its near equatorial location, much of Papua New Guinea's coastline is currently protected by coral barrier or fringing reefs.

Approximately half the population of more than 3.5 million people live along the coastline. Subsistence or commercial agriculture are the main land uses, and many coastal communities also rely heavily on marine resources. The two largest cities, Port Moresby and Lae, are coastal ports. Coastal climates are hot and humid, with two wind and rainfall seasons.

Much of the coastline comprises cliffed or narrow coastal plain sectors, especially in tectonically active areas along the north coast and the high island coastlines. There are also large deltaic floodplains and lagoon systems (with extensive tracts of mangrove) and beachridge complexes, especially on the southern coast, and at the mouths of very large rivers draining both north and south.

For the mainland and large high island the coastline measured on maps at a scale of 1:100,000 is 17,100 kilometres, of which 25% comprises deltaic floodplains and barrier and lagoon complexes which would be severely impacted by a rise in sea level. In addition a coastal length in excess of 5,000 kilometres on small high or low island coasts would be considerably affected by such a sea level rise.

The major likely direct impacts of global warming and sea level rise for Papua New Guinea are: increased humidity and decrease in human comfort; coastal inundation; coastal flooding by storm surges; salt water intrusion of coastal groundwater systems; water table elevation; and changes to coastal landforms (especially if coral reef growth does not keep pace with sea level rise and wave action consequently increases). The associated socio-economic effects include: decreased agricultural productivity resulting from innundation, flooding, salt water intrusion and rising water tables; salt contamination of drinking water obtained from bores; economic costs for maintaining and rebuilding structures such as roads, seawalls, harbours, buildings, and sewage and storm water disposal systems; and re-settlement and out-migration of communities from areas which cease to be habitable. Loss of small outlying islands through inundation or accelerated erosion would result in a reduction in the size of PNG's exclusive economic zone.

Introduction

This report is a summary of work carried out by both myself and several other University of Papua New Guinea (UPNG) scientists who were members of the Association of South Pacific Environmental Institutions (ASPEI) Task Team on the implications of climate change in the Pacific region. Much of the material presented here is based on articles published as UNEP Regional Seas Reports and Studies No. 128, edited by Pernetta and Hughes (1990), and on a summary report by Sullivan and Hughes (1989) published as a UPNG Climate Change Studies Group Working Paper.

Projections of Global Climatic Change

A great deal has now been written on the projected changes in climate which are likely to develop from greenhouse-induced global warming (see eg. Hoffman 1984), Barth and Titus 1984). Such scenarios project a pattern of global warming over the next 30 years which ranges from 17°C in sub-Arctic to about 2°C near the equator. Consequent upon this warming will be a rise in world ocean levels, brought about about by both thermal expansion of the surface layers of the oceans and some melting of glacial ice (Thom 1989).

The Villach (Austria) Conference on the Greenhouse Effect in 1985 predicted a rise in sea level in the next 50 years of about 20 and 140 cm, this range being based on a number of scenarios or projections (Figure 1) for ocean thermal expansion and the melting of mountain glaciers and polar ice (Thom 1989). Recent evidence from world-wide monitoring of sea level rise presented by the Intergovernmental Panel on Climatic Change [IPCC] (IPCC 1990), has led to the general opinion amongst climatologists that the middle scenarios proposed at the Villach conference are the most likely, and are an appropriate basis for planning. Many countries, including Australia, are now basing their physical planning decisions on the presumption of such sea level rises (see eg. Figure 2). Current measured average world wide sea level rise is about 1.4mm annually. This rate could be expected to rise gradually in future, suggesting a likely sea level rise of about 25 to 40 cm by the year 2030.

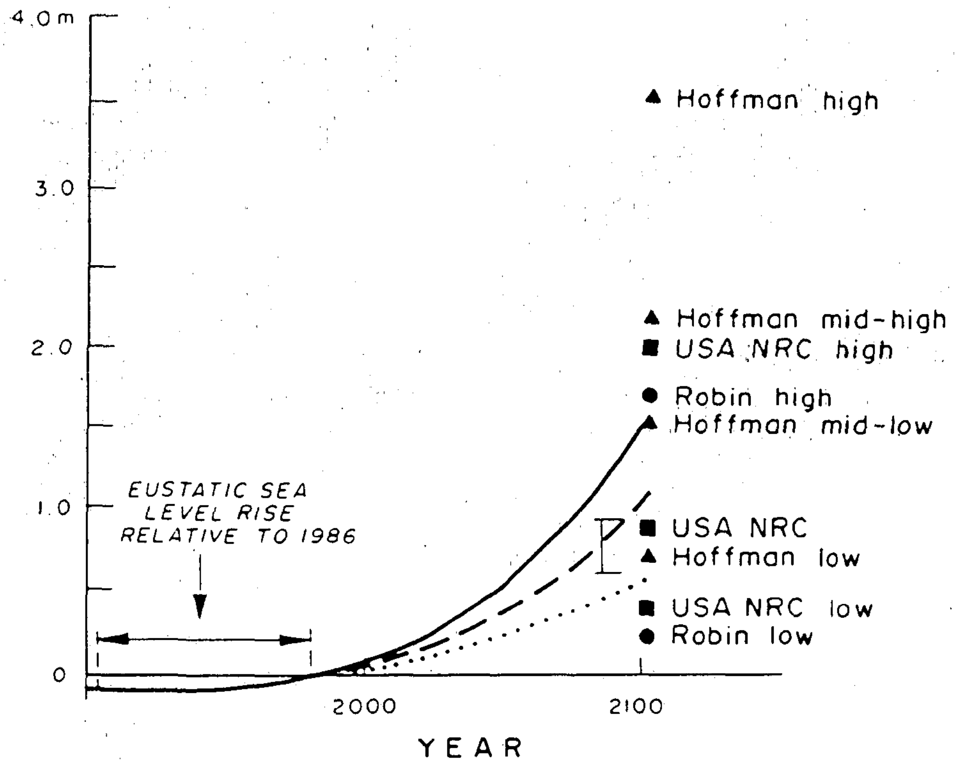


Figure 1. Sea level rise scenarios compiled by the USA National Research Council (after Thom 1989).

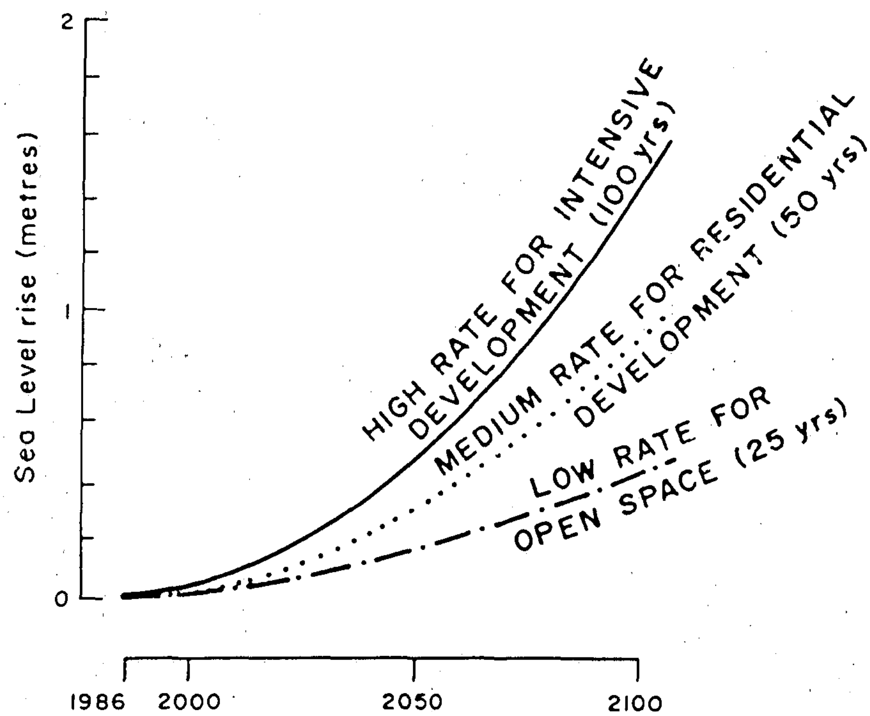


Figure 2. Examples of considering projected sea level rise in long-term planning (after Thom 1989).

As already pointed out by several workers in this field, this projection is merely a 'time slice', and unless greenhouse gas emissions are slowed down appreciably, sea level rise is likely to continue for an indefinite period beyond that time, and by a little more than 100 years from now sea level could well stand as such as 2metres above its present level.

McGregor (1990) summarised the likely climatic changes for the South Pacific region, based on world-wide general circulation models, and discussed various scenarios of likely climate change. These scenarios, like those used by Pittock (1988) for Australia, project a pattern of global warming over the next 30 years which ranges from 17°C in sub-Arctic regions to about 2°C near the equator. Associated with climatic warming will be changes in the general atmospheric circulation patterns. For the tropics this is likely to result in a weakening of pressure changes, and a subsequent weakening of both the trade wind patterns which prevail in the near-equatorial zones, and the intermittent occurrence of high tidal extremes and intense droughts in the western Pacific.

While there is expected to be an increase in the intensity, and possibly the frequency of tropical cyclones as sea surface temperatures rise, it will continue to be unlikely that cyclones will occur within 10° of the equator. The effect of increased cyclonic activity at higher latitudes and the associated increase in the occurrence of storm surges and climatic instability is however likely to have a major impact on many coastal areas in the tropics.

The Papua New Guinea Coastal Environment

Physical Features

Papua New Guinea extends over 1,300 kilometres from north to south, from the equator to 12° south latitude, and 1,200 kilometres from the border of Irian Jaya (Indonesia) in the west to 160° east longitude (Figure 3). Of the total land area of 465,000km^2, 85% is on the Papua New Guinea mainland and the remainder on some 600 islands (Economist Intelligence Unit [EIU] 1988). The coastline of Western Province, about 25% of the length of the southern mainland coastline, lies within a few kilometres of the Australian border through Torres Strait and the western part of the Gulf of Papua.

Coastal climatology

The climate of most tropical Pacific islands is determined by their oceanic near-equatorial setting, and is controlled by the presence of warm humid airmasses, the meridional or north-south movements across the equator of the Hadley Circulations which converge in the Inter Tropical Convergence Zone [ITCZ], and the zonal east-west moving Walker Circulation.

In the western Pacific, including Papua New Guinea, two distinct wind and rainfall seasons occur. During the southern hemisphere winter (April to October) when the ITCZ lies to the north, southeasterly trade winds prevail. As the ITCZ moves south (November-March), warm northwesterly monsoonal winds control the regional climate. The central highlands of the mainland, and flanking mountain ranges near the other island coastlines present barriers to the passage of these major broad-scale wind patterns (McAlpine and Keig with Falls 1983:49), and overall, Papua New Guinea is not windy.

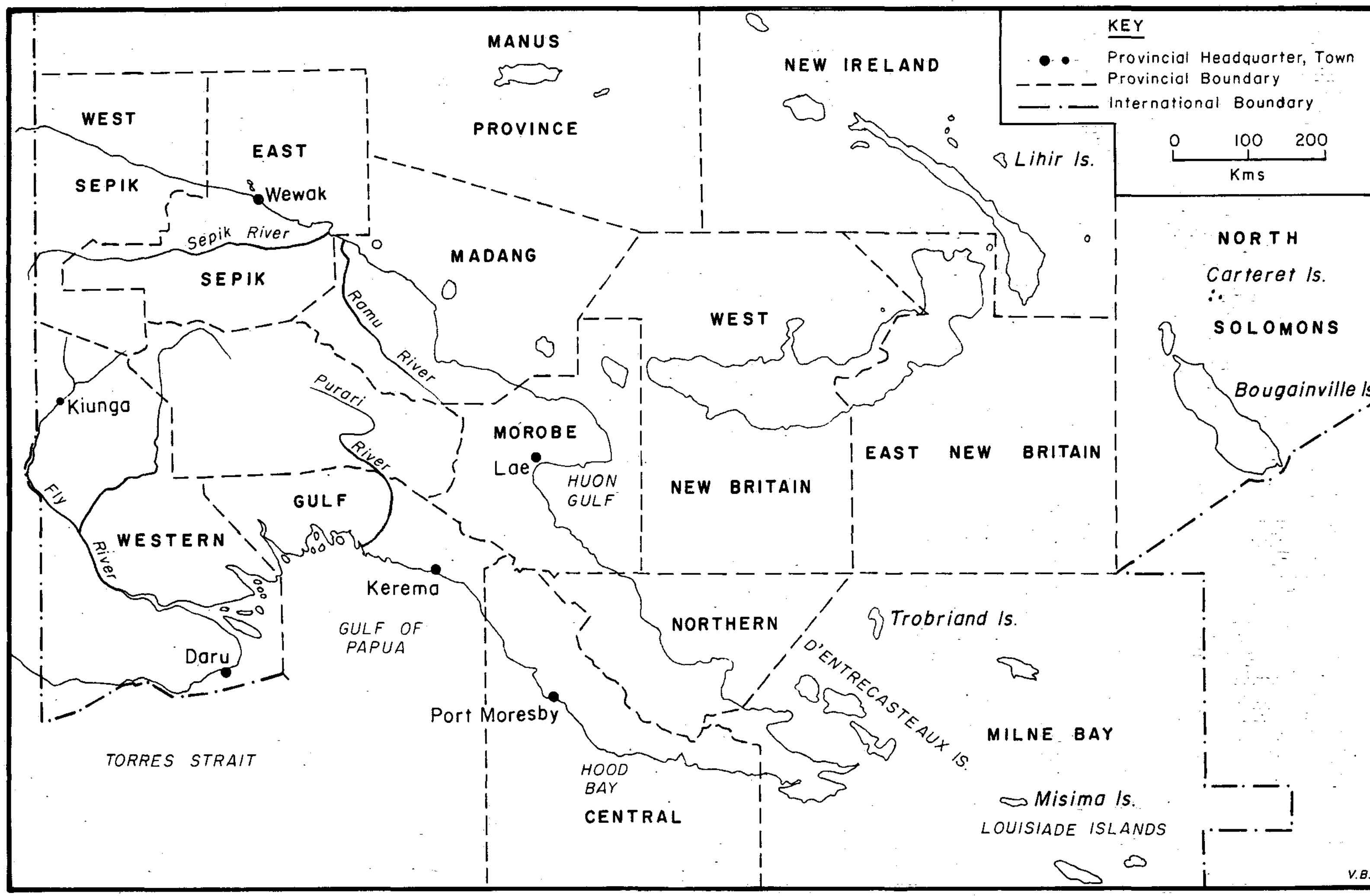


Figure 3. Locations of 14 coastal provinces, and places mentioned in the text.

Variations in these patterns occur when the zonal Walker Circulation, which brings cold easterly air across the Pacific, weakens. At such times moist equatorial westerlies penetrate into the region and the centre of maximum convective activity moves to the east, associated with rising sea surface temperatures. This phenomenon, known as El Nino, causes associated variations in the Southern Oscillation Index [SOI] and has a dramatic impact on climate. Positive index values bring dry easterly winds to the central Pacific. When index values are negative (as during El Nino events), moisture bearing winds blow from the west causing increased rainfalls in the central Pacific, and rises in local sea levels of up to 40cm. Such El Nino-Southern Oscillation [ENSO] phenomena have been well recorded in Papua New Guinea and other parts of the Pacific over the last two decades and correlated with higher tidal stands on the coastlines of many islands.

During the southeasterly season the southern coastline of the mainland, the Huon Gulf coastline, and the southern coastlines of New Britain and Bougainville Islands are affected by steady onshore winds which increase in velocity through the day, but rarely exceed 15km/hr on the mainland and 30km/hr on the provincial islands. Intermittent, more squally periods are experienced during the northwest monsoons, when onshore winds affect the north coast of the mainland, the northern coastlines of New Britain, and the west coast of New Ireland. Except during squalls, wind velocities during the monsoon season are generally less than 20km/hr on the southern coast, and reach 30km/hr on the northern coastlines (McAlpine and Keig with Falls 1983:50-55). Squalls are generally associated with local convective cells, or are due to localised katabatic, physiographic and temperature effects. Strong winds of 50-70km/hr may then last for up to 30 minutes.

The frequency of tropical cyclones, with sustained surface winds of greater than 60km/hr, is very low in Papua New Guinea. Tropical cyclones commonly develop in western Melanesia between November and April. Although common in the Solomon Islands to the southeast of Papua New Guinea, their tracks rarely extend further north than 13°S latitude, and hence only the most southeasterly areas of Papua New Guinea, chiefly the Milne Bay islands, are occasionally affected (McAlpine and Keig with Falls 1983:35, McGregor 1990).

The temperature pattern everywhere in coastal Papua New Guinea is one of moderately high temperatures with little seasonal variability (McAlpine and Keig with Falls 1983:89-93). Mean maxima (day temperatures) range around 28-32°C, dropping to 20-24°C at night. In Western and Gulf Provinces daily January temperatures are 30-32°C and July temperatures are around 26-28°. Humidity is high throughout the year around the coast. On the south coast January are generally 80-85% and July values higher, commonly exceeding 90% (McAlpine and Keig with Falls 1983:104-5).

The interplay of general and local atmospheric circulation patterns and synoptic disturbances with the altitude and alignment of physiography combine to produce a large number of possible rainfall regimes (McAlpine and Keig with Falls 1983:64), but except for the southwestern part of Western Province and pockets of seasonally dry land near Port Moresby, coastal areas are wet.

Waves, currents and tides
The entire southern mainland coastline of Papua New Guinea falls within Davies' (1972) classification of a protected sea environment. The northern mainland and offshore island coastlines, with their greater wave fetch and deeper water offshore, are subject to stronger effects from deflected east coast swells. Much of the country's coastline is protected by coral reefs, and the wave environment is in general a low energy one.

Except in the immediate vicinity of Port Moresby, other major ports or major development projects on the coast, there is virtually no information on inshore current patterns and few syntheses of tidal or water temperature data. Tide charts are available for some major ports: tides are both diurnal and semi-diurnal, and the tidal range is generally <2metres. At the UPNG Motupore Island Research Station, inside the Papuan Lagoon near Port Moresby, surface water temperature varies from about 25°C to 32°C, and the tides are of mixed amplitude and predominantly semi-diurnal, with a maximum tidal range of 2.8metres (Haig 1988). A higher tidal range of >3metres occurs in Western Province (Pernetta and Osborne 1990).

Tsunami have been recorded at several locations on the Papua New Guinea coastline, generally associated with volcanic eruptions; for example, Ritter Island 1888 and Rabaul 1937 and 1941 (Blong 1984). These tsunami all produced high elevation beachridge deposits. Similar strandline features are generated by cyclone storm surges, and remain for many years as dominant depositional coastal landforms, for instance on the shorelines of several Milne Bay Province islands. Such tsunami and storm wave events are highly damaging to coastline infrastructure or near-shore villages.

Lower magnitude but higher frequency storm surges occur when high tides or high water shifts associated with El Nino events coincide with local convective or frontal storms during the northwest monsoons. These high water events cause estuarine flooding and reworking of deltaic deposits, especially along the Gulf of Papua coastline.

Coastal geomorphology
Papua New Guinea is tectonically active, and is situated along the northern boundary of the stable Australian continental plate where it comes in contact with the oceanic Pacific plate. The New Guinea archipelago comprises young faulted and folded mountain chains, zones of former and contemporary volcanic activity, and curved chains of islands and oceanic rises of the Pacific rim volcanic arcs. The mainland coastline comprises block faulted areas, volcanic areas, zones of tectonically rising coral reef forms, and extensive depositional zones associated with the deltaic or estuarine mouths of major rivers. The chains of islands making up Manus, New Britain, New Ireland and the North Solomons are characterised by tectonically active blocks, volcanic areas, rising coral reefs and minor depositional areas. In addition there are numerous reef-based low islands, and raised reef and atoll islands.

An extensive barrier reef system runs along the southeastern coast of Papua New Guinea between two and twelve kilometres offshore. It begins west of Port Moresby, virtually as an extension of the Great Barrier Reef, and extends eastwards into the Coral Sea where it forms a discontinuous series of easterly-trending reefs (Loffler 1977:119-120). At its eastern extremity it surrounds the Louisiade Islands, continues northwest to the D'Entrecasteaux Islands, and loops north around the Trobriand Islands (Figures 2 and 4). Extensive barrier reefs are very much less common along the north coast of the mainland or around the larger islands. Where they occur they provide considerable shoreline protection against storm waves.

The coastline can be divided into five categories:

A. *Rocky shorelines*
Rocky shorelines are generally cliffed because of recent tectonic uplift, or have steeply rising slopes behind narrow coastal plains on which the sediment supply is largely controlled by terrestrial hillslope processes. Such shorelines have formed on a wide variety of rock types, including raised coral limestones, intrusives, volcanics and metasediments. Fringing reefs occur along most rocky shorelines, despite their generally mountainous hinterlands which produce considerable runoff and high sediment discharges (Loffler 1977:120). Rocky shorelines make up about 40% of the coastline of the mainland, and 90% of the coastlines of the major high islands. Narrow sandy beaches or mangrove flats are developed in embayments where smaller rivers breach the rocky shoreline reaches.

B. *Deltaic floodplains*
These occur at the mouths of all the major rivers entering the Gulf of Papua, and at the mouths of the Sepik and Ramu Rivers (see eg. Loffler 1977; Percival and Womersley, 1975; Petr 1983). This landform complex is widespread along the southern coastline of the Papua New Guinea mainland, where it accounts for more than 50% of the coastal length, and less important on the northern coastline, where it constitutes about 10% of the coastline, or the major islands where deltaic floodplains make up less than 5% of the shore lengths. In total, deltaic floodplains make up about 20% of the entire length of the coastline, and are mainly covered with mangrove or swamp forest (Percival and Womersley 1975; Petr 1983; Figure 5).

C. *Sand barrier and lagoon complexes*
Either in association with deltaic floodplains or as smaller, more restricted landforms, these complexes occur in areas of alluvial deposition. They are generally made up of sequences of beachridges, probably of Holocene age. Impounded coastal lagoons are uncommon, but extensive freshwater swamps are commonly perched behind the beachridge sequences (Bualia 1990). The largest such complex is the coastline in the Murik Lakes area of East Sepik Province, just west of the mouth of the Sepik River (Figure 2). Extensive areas of coastal dunes are rare in Papua New Guinea, mainly because of the lack of strong winds, high soil moisture and dense vegetation (Loffler 1977:115), but at Hood Bay on the southeast coast, coastal dunes are prominent and form an extensive zone covering more than $10km^2$. These dunes have formed on an even more extensive sand barrier which protects two coastal lagoons.

D. *Motu (cays) at sea level*
These are several hundred small low islands in Papua New Guinea, many of which are uninhabited and poorly surveyed. More than 200 low islands with areas exceeding $2km^2$ are intermittently occupied or support small, permanent village populations. These islands, known as motu in the Pacific or cays in the Caribbean, comprise accumulations of sand to gravel-sized coral rubble on a coral

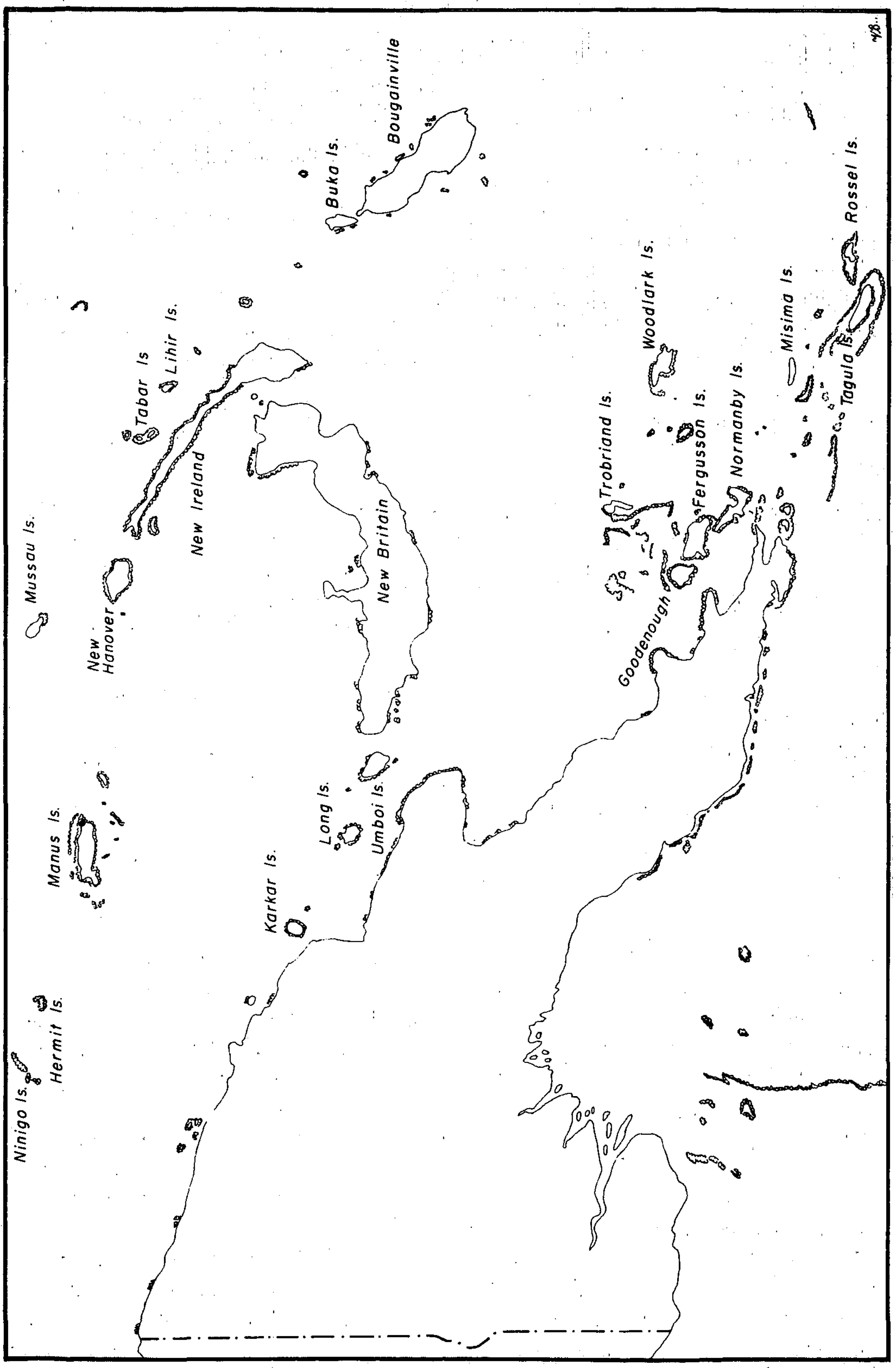


Figure 4. Occurrence of fringing reefs, barrier reefs, patch reefs and atolls in Papua New Guinea

reef base. They are distributed around atolls, and on platform reefs. Elevations on all are less than 4m asl, and on the smaller islands commonly <2m asl.

E. *Raised coral islands and high islands*
There are a variety of small raised coral islands and high islands formed on sedimentary, volcanic and metamorphic rocks, which make up part of the total Papua New Guinean land area. Their range in characteristics is extremely large, however on most a high proportion of their coastlines comprise steep hills or cliffs on raised coral fringing reefs.

For the Torres Strait and Gulf of Papua the coastline is dominated by deltaic flood-plains extending seaward from low-lying rocky shoreline zones. On the eastern side of the Gulf are stretches of sand barrier and lagoon complexes.

Cultural and Socio-economic Features

Demography

The populations of Papua New Guinea is more than 3.5 million and is growing at a rate of 2-2.5% per annum (EIU 1988:6-7). More than 85% of the population is rural. Port Moresby is the largest urban centre with a population exceeding 150,000; Lae has an estimated population of 62,000. The remaining coastal towns are very much smaller, and villages or hamlets with fewer than 1,000 residents are common.

Sullivan and Hughes (1989) estimated that about 40% of Papua New Guineans live in the coastal zone, ie. on traditionally-owned land that abuts the coastline or the tidal reaches of rivers and estuaries, or in coastal towns. About 75% of these people live in, or gain their livelihood from activities carried out in, the +1 to +5m asl range. Hence about 30% of the population, or more than one million people, would be affected by the impacts or rising sea level on low-lying areas below +5 metres.

Land Use

Agriculture

Commercial agriculture is the mainstay of the economy, contributing 34% of GNP in 1987 and providing wage employment for about 75% of the working population (EIU 1988:8). Equally important is the subsistence agricultural sector – rural Papua New Guineans are able to provide the bulk of their food requirements from their own gardens. Subsistence agriculture is uniformly important throughout the country, including the coastal zone where, except on small islands, food from gardens is generally more important than marine and estuarine food resources.

The major commercial crops produced in lowland Papua New Guinea are all tree crops which are grown mainly in commercial plantations rather than smallholder plots. Areas under coastal crops in 1985 were: copra, 85,000 ha; cocoa, 48,000 ha; oil palm, 10,000 ha (EIU 1988:16). Copra production has declined in recent years due to poor commodity prices, however production of cocoa and oil palm have continued to increase. Much of the copra is grown immediately behind the shore-line and therefore will be subject to impact by rising sea levels, however oil palm and to a lesser extent cocoa, will be much less affected as they are generally grown on more fertile soils on alluvial plains or footslopes away from the immediate coastal zone. Robusta coffee, another lowland crop, is also grown only away from the immediate coastal zone.

The forest industry's share of export earnings in 1986 was 7.5%, or K64 million (EIU 1988: 18). Much of the forestry activity is in rainforested lowlands, however apart from potentially valuable mangrove timbers, very little logging is carried out in areas less than +5 metres.

Fisheries
The largest commercially-exploited fish resources are pelagic species, especially tuna, but also Spanish mackerel (EIU 1988:18). These should be little affected by sea level rise. However coastal, estuarine and riverine species such as barramundi, prawns, turtles and crabs are caught for both commercial and subsistence exploitation. Mangrove forests and swamps provide a specialised habitat for these and other important resources (Pernetta and Osborne 1990, Sullivan and Hughes 1990). In the Gulf of Papua, for example, there is an important open water prawn fishery which supplies both the local and export markets. The juvenile prawns of all but one of the commercially valuable species live in coastal deltaic zones, especially the mangrove swamps.

Coastal modifications, port facilities, other installations
Papua New Guinea has a very low level of industrial activity and that which does occur is mainly light industry not tied to port facilities. Port Moresby and Lae are important ports and each has industrial zones in the immediate coastal area that would be affected by a rise in sea level (Sullivan 1990). The other major ports are associated with resource development projects such as mining (eg. until recently, Loloho Port on Bougainville Islands and Kiunga on the Fly River) or timber. Most coastal towns are focussed around port facilities which facilitate the export of coffee, copra, cocoa and timber.

Apart from protection works in towns and ports there has been very little structurally engineered modification of the coastal zone and its low-lying hinterland. The growth of most coastal settlements (except Port Moresby and Lae) is slow, and the rate at which rural coastal areas are being developed is also slow. The main infrastructure in the coastal zone comprises roads, particularly around the high islands, airports and airstrips, which are commonly constructed on drained swamps, barriers or beachridges.

The Likely Impacts of Sea Level Rise on Coasts

It is now clear that world-wide average temperatures are gradually increasing, and world-wide evidence indicates that sea level is currently rising at 1.4 to 1.5mm annually (IPCC 1990). As pointed out by McLean (1989) however, the meteorological and ocean circulation patterns along the equator mean that sea levels in the low latitudes have shown no consistent trend towards an overall rise. He also demonstrated from a preliminary evaluation of *Porites* microatoll sections from Kiribati that there, at times in the recent past, local sea level has stood up to 40cm higher than it does at present.

Given the local impact of ENSO events on tidal stands, it is likely this situation has also occurred in Papua New Guinea. If overall world sea levels are rising however, despite the delayed effect which can be expected in low latitudes, there will nevertheless be an eventual rise in sea levels in such areas.

The potential impacts of sea level rise in the tropics are likely to be far more dramatic than the direct climatic changes. Some climatic changes are however likely:

1. In his regional prediction of direct greenhouse-induced climatic changes, McGregor (1990) projected that by the year 2060 for all equatorial and sub-equatorial locations in the Pacific there will be year-round conditions of severe discomfort and thermal stress.

2. Decreases in thermal comfort, with the associated increase in heat stress while working outdoors, will mean that the patterns of work will need to change, so that people can avoid being outdoors during the hottest three hours around mid-day. There are economic implications in this unless plans are made to gradually change outdoor working hours.

3. Another direct implication of increasing thermal discomfort is the associated increasing need for atmospheric management in urban areas. McGregor (1990) noted that some changes could be made in commercial or office building design to encourage air circulation and avoid the need for expensive and energy-consuming air-conditioning. This also requires advanced planning.

4. An increase in storm surges and higher energy wave climates may be generated by intensified cyclonic activity.

5. A change in the pattern of temporary higher and lower sea level stands is likely as the ENSO pattern changes.

6. A direct change in local ocean water temperatures of 1 to 2°, may cause coral bleaching or die-back. Bleaching and death of coral colonies was noted in the Maldives by Brown and Dunne (1986) during a period in which the local sea surface temperature was 1 to 1.5°C higher than average, and in Hawaii (Jokiel and Coles 1990) and Indonesia (Brown and Suharsono 1990) with similar temperature rises. This suggests that Indo-Pacific coral communities are currently living near their upper levels of thermal tolerance. Such coral dieback has other implications, notably an expectable increase in the energy of coastal wave climates.

7. Changes can be expected in the agricultural potential for many food crops, and consequently in crop varieties which may be able to be grown, given a 2°C average rise in ambient air temperature (See Jacobs in press).

Sea Level Rise Risk Assessment

A 100cm risk assessment was carried out for Papua New Guinea by initially mapping a new shoreline on the basis of existing topographic maps at a scale of 1:100,000 with a contour interval of 40 metres (Bualia and Sullivan 1990). These maps, the largest scale series available for the whole of Papua New Guinea, were used for this exercise.

For the few areas where larger scale maps or additional contour information is available such sources were also used.

Cloud-free LANDSAT satellite imagery of Papua New Guinea is available, covering about half the coastline. This imagery was used, together with some aerial photographs and personal knowledge of the coastal zone to determine the general form of the coastline. From these data a one metre contour line was interpolated between the present shoreline and the near-shore 40 metre contour position. In general on rocky cliffed or sloping (erosional) shorelines the one metre level was interpolated approximately 1/40 of that distance inland. On coastal areas where a narrow coastal plain (either erosional or depositional) exists between the shoreline and any near-coastal hillslope zone, the one metre contour line was interpolated 1/20 of the distance inland to the 40 metre contour line.

This re-construction is a crude estimate of any likely future coastline. It is immediately apparent that inundation of coastal environments will be a widespread phenomenon in Papua New Guinea, the extent of which will be dictated by physical features such as underlying structure, existing landform, slope, the distribution of deposited sediments, and local water table levels. In the following discussion reference is made to length and types of coastline which will be affected, rather than to areas likely to be inundated.

Coastline were classified into three broad categories according to the degree of inundation:

Negligible where there was no discernible land area likely to be inundated by a one metre rise in sea level, mapping on a scale of 1:100,000. Such areas, which are generally rocky shorelines affected by recent tectonic uplift or controlled by terrestrial hillslope processes, will in fact suffer a shoreline regression of less than 20 metres in these circumstances.

Moderate where the total land area likely to be inundated was discernible when mapped at a scale of 1:100,000, but comprised either discrete land areas each of less than 1km^2, or strip of any length along the shoreline, but less than 500 metres wide.

Severe where contiguous land areas in excess of 1km^2, or strips of coastline more than 500 metres wide would be affected by inundation.

Rising Sea Level: Overall Geomorphic Effect

The results of the coastline reconstruction are summarised in Figure 6. The total length of the Papua New Guinea coastline, including the provincial islands, when measured on 1:100,000 scale maps, is 17,100 kilometres. Of that total length, approximately 4,500 kilometres (or about 26% of the entire coastline of the country) will be affected either moderately or severely, or will suffer significant inundation.

Landform Types Affected

In considering the effects of the predicted sea level rise on coastal landform types, the exercise has been carried out without attempting to predict the changes which may occur on active coral reefs, and the consequent effects on nearshore wave environments.

Four landform types or complexes were identified as areas which would suffer particularly from a one metre rise in sea level. These are:

- deltaic floodplains;
- sand barrier and lagoon landform complexes;
- motu or cays at sea level;
- raised coral islands and high islands.

In the coastline mapping exercise an approximate assessment was made of the relative proportions of the Papua New Guinean coastline occupied by each landform type (Sullivan and Hughes 1989). The distribution of landform types which will be affected varies markedly between provinces. Deltaic floodplains and sand barrier and lagoon complexes occur mainly in West and East Sepik, Western and Gulf Provinces, while small high islands and coral islands or atolls occur in the mainland Provinces of Madang, Morobe and Milne Bay, and in all the island provinces.

Impact on Coastlines
Increased wave height and increased storminess are both likely to cause erosion of unstable coastlines. Specific case studies were carried out of the likely impacts of sea level rise on each of these landform types in Papua New Guinea (Pernetta and Hughes 1990), and the general impacts of project short term (30 year) and possible longer term sea level rise can be summarised:

1. *Deltaic floodplains*
   Studies have been undertaken of the mangroves of the Gulf of Papua and the Fly River (Pernetta and Osborne 1990) and of the Sepik-Ramu basin (Chappel 1990, Hughes and Bualia 1990). Pernetta and Osborne (1990) argued that the mangrove habitats fringing the Gulf of Paper are likely to undergo substantial reduction in area with compression of existing zones as a result of sea level rise. Consequent upon this will be the loss of resources or loss of access to such resources on the part of some communities. The reduction in nursery areas for prawns may have a significant negative impact of this resource. It is likely that following a rise in sea level, flooding of the low-lying land along the Fly River will become more frequent and of longer duration. This will affect the availability of land (already in short supply) for habitation and cultivation.

   Chappell (1990) presented evidence that during late Holocene times the Sepik-Ramu floodplain accumulated at rates of up to 0.3 metres/100 years. If sea level rises more rapidly than 0.3 metres/100 years, flooding in the lower Sepik-Ramu will become more frequent and widespread. Most sea level rise scenarios envisage rates of sea level rise higher than this.

   Hughes and Bualia (1990) showed that in the Murik Lakes and Sepik River mouth areas, which support a population of about 3,000 people, the areas of productive land which are currently not or only slightly affected by inundation are very small, probably less than 20% of the total area of 1,160km^2. Hence a 1m sea level rise would have a severe and possibly catastrophic impact on the subsistence and commercial economy, and the settlement patterns of the area. The effects of flooding be especially severe if the sea were to rise at more that 0.3 metres/100 years.

2. *Sand barrier and lagoonal landform complexes*
   Two such complexes were investigated – the coastline in the Murik Lakes and mouth of the Sepik River area (Hughes and Bualia 1990), and the Gulf of Papua

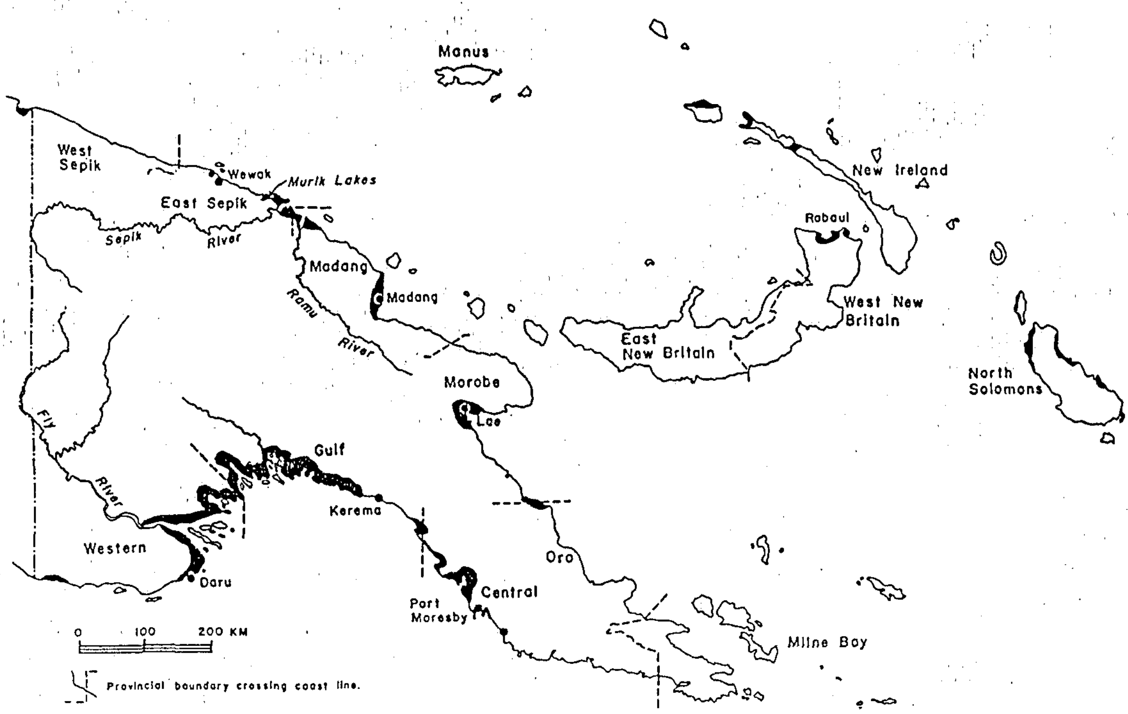


Figure 5. The locations of the main areas of mangrove (after Percival & Womersley 1985).

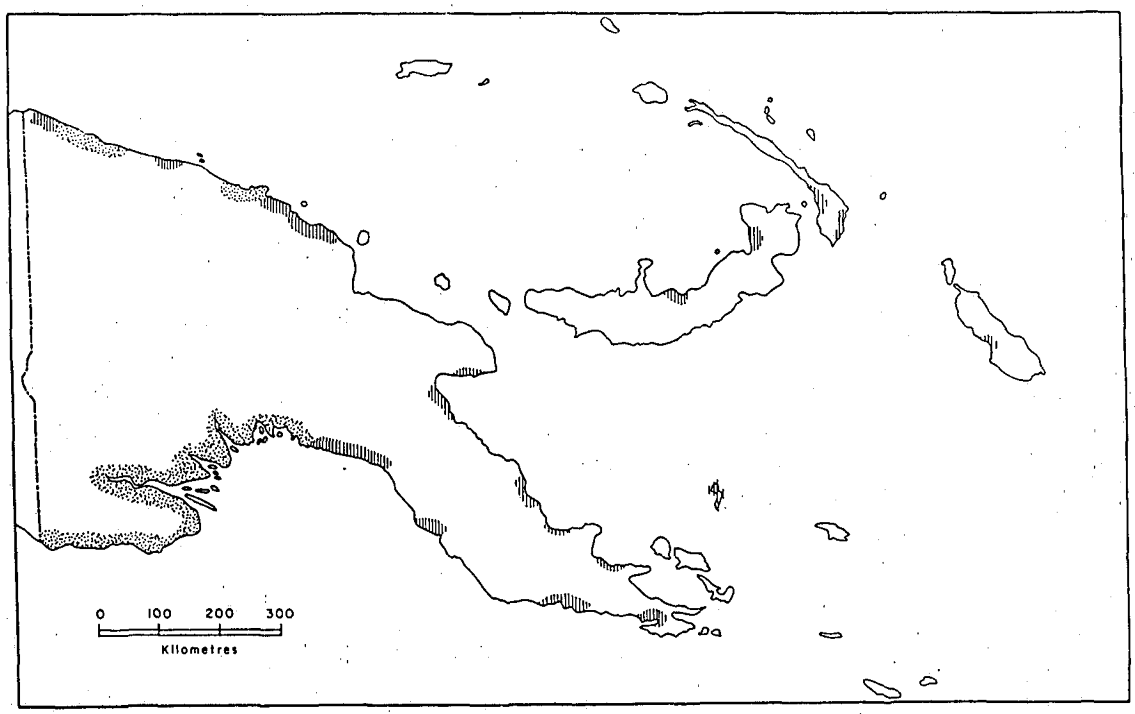


Figure 6. Predicting degree of inundation by sea level rise of 1 metre. Stippling represents severe inundation, vertical hatching represents moderate inundation.

east of the Purari River mouth (Bualia 1990). In the Murik Lakes area rising sea levels will cause erosion of the shoreline, putting coastal settlements at risk. Especially vulnerable will be villages on sand beach ridges directly fronting the ocean. Examples of such villages are Darapan (population about 260) and Medan (population about 140) which are located on the low, narrow sand barrier which encloses Murik Lakes. Groundwater on sand barriers and around estuaries will become tainted with brackish water. A sea level rise of more than one metre would make this low-lying coastal area virtually uninhabitable and most of the population would have to be re-located.

Bualia (1988, 1990) investigated the likely impacts of sea level rise on a 70 kilometre long, low-lying stretch of coastline in Gulf Province extending from Kerema in the east to near the mouth of the Purari River in the west. The population of the area is about 8,000 people. Two distinct types of settlement occur. On the littoral and alluvial plains settlement is nucleated, particularly on the coastal beach ridges where villages are relatively large, with several hundred people in each. Villages are usually situated on the first stable beach ridge near the sea. Where villages are situated in riverine alluvial areas they are smaller scattered hamlets built on levees; where they are situated in deltaic areas, they are raised on stilts along tidal channels. At present 65% of the area is subject to long-term flooding in the wet season, 20% to short to moderate-term flooding and only 15% is permanently well-drained. If the sea were to rise by one metre this would cause considerable coastal erosion and inundation of deltaic and riverine areas. It would also increase the degree of wet season flooding such that 85% of the area would be subject to long-term flooding and rest would be affected by short to moderate-term flooding. Virtually none of the area would remain permanently well-drained. These impacts in turn would mean that 27 villages (containing more than 50% of the population of the area) would have to be partially or totally relocated onto higher ground.

3. *Impact on Low Islands*
Clearly the impact of sea level rise on motu is closely related to the impact on their reef bases. It is possible to model the likely effects of prolonged sea level rise on low islands, based on various assumptions of coral growth rates.

4. *Impact on Coral Reefs*
The general impacts of sea level rise on reef bases and atolls have been outlined by Sullivan and Pernetta (1990). Much has also been written on rates of individual coral colonies and of coral reef growth (see eg. McLean 1989, Weins 1962, Marshall and Jacobsen 1985). Most reefs in the Pacific grew upward to their present level following the rapid post glacial rise in sea level in late Pleistocene and early Holocene times, between about 15,000 and 6,000 years ago, ie. they are 'catch up reefs' as described by Buddemeier and Smith (1988).

McLean (1989:15,62) presented evidence to show that reef growth in the Pacific is about 5 to 8mm annually. Reefs grow more slowly than individual coral colonies due to the compounded effects of storm damage and recovery, the interaction between the growth of coral and algal mantles and the rate of clastic sediment production to fill the interstices of the reef platform. Buddemeier and Hopley (1988) pointed out that predictions of reef growth rates must take into account the structure of the reef community, and the likely occurrence of local events such as cyclones or predator attacks which would temporarily inhibit reef growth. They noted that although rising sea levels generally favour reef growth, this growth may not keep up with predicted sea level rises due to global warming (1988:4). Buddemeier and Smith (1988) cited extremely high projections of sea level rises of 15±3mm annually over the next century, and commented that this is several times greater than the modal rates of vertical accretion on reef flats and 50% greater than maximum measured rates, although they acknowledged that Holocene data indicate that vertical reef growth rates of 14metres/100 years are possible in favourable circumstances.

Should sea level rise at a rate faster than 8mm per year, then that rate slow down, or should sea level stabilise as it did about 6,000 years ago, it would be expected that reef growth would initially lag behind the rising sea level then 'catch up'. If sea level continued to rise at a rate greater than 8mm/year coral reefs would be likely, in extreme circumstances, to 'give up'.

On the basis of available evidence it seems likely that enhanced greenhouse-induced warming of the ocean surface will lead to coral bleaching and die-back, and that sea level will rise faster than the rate of 'keep-up' reef growth. In either case some of the protective effect of the reefs will be lost, and tropical Pacific coasts will be subject to increased storm wave attack.

5. *Sea Level Rise – Models of Change in Atolls and Motu*
Based on the present state of knowledge of the formation and subsequent changes in atolls and low islands, Sullivan and Pernetta (1990) presented two simple models of changes which are likely to occur on Pacific motu should sea level continuously rise, or rise as much as two metres, then stabilise.

These models are based on the alternative assumptions that coral reef growth either will or will not keep up with rising sea level. This and the problem of reef dieback in water which exceeds the maximum temperature for coral growth (see eg. Brown and Dunne 1986, Jokiel and Coles 1990) require careful monitoring to make the models useful for planning purposes. The negative effects on coral growth of increasing surface water temperature may be sufficient, in either 'keep up' or 'catch-up' reefs, to maintain reef platform growth somewhat below the average tidal level. Slightly below the ocean surface water temperatures should remain near the optimum range for coral growth, but hotter surface layers may inhibit such growth. This would ensure that reef surfaces would remain submerged below mean low water level, which would in turn mean much less sediment would be deposited on the reef surfaces, and island building could not continue.

Model 1. Assuming coral growth keeps pace with sea level rise.

(i) Low island sediments will be swept either into atoll lagoons, where the sediment will be stored in the central depression, or off the leeward margins of platform reefs. In the case of platform reefs on a shallow shelf zone, this sediment will be stored on the leeward side of the reefs, but in deeper water conditions it will be lost to the ocean sediment sink.

(ii) Coral growth will be re-established, and there will be an upward and outward growth, resulting in the extension of atoll rings, and possibly the enlargement of knoll, patch and ribbon reef flats.

(iii) These reef flats may bear ephemeral low islands, but such islands are unlikely to establish stable vegetation communities or to maintain a lens of fresh groundwater.

(iv) If the sea level rise slows or stabilises, there will be a re-establishment of motu on atolls, possibly including the establishment of motu on the leeward side of lagoons due to the supply of stored sediment.

(v) There will be island growth on the leeward side of platform and ribbon reefs and a possible rapid development of motu on the windward side of such reefs if they lie downward of reefs currently bearing motu.

(vi) The end result will be a gain in low island land area, but in other than the current locations of low islands, and with the subsequent slow development of freshwater lenses. Biological communities, which may take 20-30 years to re-establish, will regain stability only when the rate of sea level rise falls below the rate of sediment production.

Model 2. Assuming coral growth does not keep pace with sea level rise.

(i) Low islands will (a) become saline swampy islands, then (b) undergo submergence, and their sediments will be swept into atoll lagoons or to the leeward side of platform reefs.

(ii) There will be a lagging upward and outward growth of atolls and platform reefs, but at a rate insufficient to support motu development.

(iii) Island coastlines which are presently protected from storm waves by offshore atolls and motu or by wide reef flats will become subject to storm wave erosion as the protective barriers are removed.

(iv) The overall effect of this will be a significant loss of land.

For either model, should sea level continue to rise, reefs would probably 'keep up' or 'catch up' but the sandy islands on their surfaces would be severely disturbed and displaced. In situations described by such models the removal of surface sediments may be followed by the upward growth of coral, the development of submerged atoll structures, and the re-establishment of new islands. Temporary removal or displacement of the low island land is inevitable, even if a later result is the formation of a new island land mass.

The social effects of this partial or complete island destruction, particularly the implications the re-settlement of entire communities, were discussed by O'Collins (1990) in relation to the Carteret Islands, an atoll group in North Solomons Province, and by extension to other similar islands.

6. *Raised coral islands and high islands*
A raised coral island, Kiriwina in the Trobriand Group, and two high islands, Lihir and Misima, were investigated by Sullivan (1990a) who concluded that the effects of a one metre rise in sea level would have severe economic, if not land pressure effects on islands such as these. This is because almost all of the settlements and associated infrastructure such as roads, and much of the productive land, is very close to the coastline. Although prior warning and the consequent careful planning of the siting of roads, buildings and other infrastructure may alleviate some of the direct costs of a rise in sea level, the inevitable proportional loss of land and specific resources will be large.

Nationwide Socio-Economic Impacts of Sea Level Rise
The effects of a rising sea level will be most profound for people living on depositional landforms on areas at and just above sea level, which are not backed by rising land. It is also worth noting that these are generally favoured areas of occupation, since such localities provide good access to fishing zones as well as to gardening land.

The effects of sea level rise and consequent loss of coastal land in Papua New Guinea can be summarised as:

- loss of useful land and traditional economic resources;
- loss of fresh water;
- impact on fishing zones;
- impact on traditional cultural resources;
- damage to roads and other infrastructure;
- damage to villages.

1. *Loss of land and traditional economic resources*
Together with land, itself a valuable resource for subsistence or cash cropping, for hunting and gathering, for pig husbandry or for security, other resources on it will be lost, primarily bushland resources, including food plants and building materials. There are likely to be land pressure problems in highly populated low-lying coastal areas of the country, such as the mouths of the Sepik and Ramu Rivers, on motu and on some of the smaller high islands. In such areas, especially where the pressure of increasing population is beginning to cause land degradation, intensified use of the remaining land may lead to soil fertility depletion which in turn will lead to decreased crop yields.

Those traditional resources which will be most directly affected by a rise in sea level are sago stands and mangrove forests. Sago is an important food source and building material in many coastal areas, particularly in the Gulf, Western and the two Sepik Province areas. Excessive salt water intrusion will deplete this important resource, by reducing the extent of present brackish water zones, forcing sago stands into more restricted areas upslope. Mangrove forests, which provide in themselves valuable building timbers and firewood, also harbour other food sources such as various types of molluscs and crustaceans, and as well are nursery sites for many marine organisms, as indicated by Pernetta and Osborne (1990). The structure of communities living in mangrove areas is likely to change with rising sea level.

Coral reefs, rock platforms and other intertidal rocky shoreline features, provide niches for food sources such as various molluscs and fish. Many rocky shoreline features and coral reef complexes (until and if they re-adjust to higher sea levels) will be inundated, thus destroying littoral ecosystems. Living reefs may suffer from increased sedimentation and turbidity that will inhibit coral growth, as may rising water temperatures. Loss of important food resources from such areas is anticipated, especially during periods of rapid sea level or temperature rise. Loss of small outlying islands through inundation or erosion would result in a reduction in the size of the nation's exclusive economic zones.

2. *Loss of fresh water*
A one metre rise in sea level will result in salt water incursion into the ground-water resources of many island and floodplain communities. Coastal villagers on the southern coast and on many motu are already faced with the problem of wells and taro pits becoming brackish during dry periods, and groundwater salinity will rise as sea levels rise.

The complex interaction between the groundwater lens of an atoll, recharge by rainwater and tidal mixing in the layers below the freshwater cap of that lens has been described by Buddemeier and Oberdorfer (1990) and Oberdorfer and Buddemeier (1986, 1988). Should sea level rise, the freshwater lens which, on coral based islands floats above a mixed and saltwater base, will be elevated and its slope and head increased. This is likely to result in increased lateral saline mixing, increased evaporation through taro pits and wells, increased loss of freshwater by coastal leakage, saline water being brought within the reach of coconut and other tree crop roots, or of pump intakes, and generally a loss of freshwater resource.

Island size and elevation are important in the development and maintenance of the freshwater lens. Should sea level rise be accompanied by increased storm surges, which will favour island building, wash processes will render ground-water saline until a state of stability returns. Such stability is possible only if sea level rise ceases. Motu growth involves the deposition of coral rubble onto the existing base through storm wave activity. Should such islands grow it is likely therefore that saline stormy waves will in fact deposit sediments onto the islands, but in doing so will exacerbate salt water intrusion into the acquifers from above. Should such island building reach a level of stability then cease, the layered groundwater lens would be expected to resume its normal form, however in the intervening period, or while ever sea levels continue to rise, it is likely that groundwater lenses will be rendered saline.

Low island agriculture, including the subsistence production of taro, coconuts, breadfruit, paw paw, and the commercial production of copra, are highly dependent on fresh groundwater supplies. Similarly, water for domestic purposes is mainly taken from sandy groundwater aquifers. Any change in groundwater resources would have a profound impact on island land use.

3. *Impact on fishing zones*
Very little has been done to model the complex current systems which circulate at ocean-wide and local scales. Fishing areas are closely tied to ocean circulations, zones of upwelling and tidal change areas.

4. *Cultural or traditional sites*
   Some traditional cultural sites, mostly relating to creation stories, mythological sites, graves of important figures or other notable locations are known and recorded by the National Museum. Additional records will undoubtedly be collated in the future. Prehistoric archaeological sites have been systematically but not comprehensively recorded in Papua New Guinea. The remains of early settlements and other sites of archaeological significance undoubtedly occur within archaeological sites which have yet to be discovered in coastal areas which are threatened with inundation or increased erosion. Many historical sites are not (fully) recorded. Papua New Guinea was the site of numerous battles fought during World War II. Some war relics, including ships, aircraft, guns and memorials at the sites of historic battles are preserved, and it is likely that additional restoration or protection work will be carried out on other decaying war relics at their present sites. Such sites will be regarded by historians as warranting protection from future environmental changes.

5. *Damage to roads and other coastal infrastructure, and to urban centres*
   Rugged terrain and limited construction funding in Papua New Guinea have resulted in relatively little road construction having been carried out in inland areas for any coastal locality where even a narrow coastal plain exists. Consequently coastal areas, particularly those fringed with depositional landforms, are relatively well serviced with roads. Rising sea level will however be disastrous to such roads, and money spent to safeguard roads threatened by rising seas will be wasted.

   Wharves and other coastal installations will also be directly affected by rising sea levels, and are likely to suffer from major sedimentation resulting from changed patterns of coastal erosion and deposition. Sea level rise will also have a major negative impact on sewage and storm water drainage systems, and underground telephone lines, in coastal areas. The effects of this will be most profound in Port Moresby and Lae, but will also be felt in all the smaller coastal towns, many in provinces without the income to replace damaged installations.

   In a case study of the likely impacts of sea level rise on Port Moresby and Lae, Sullivan (1990b) argued that in addition to the direct physical impacts of inundation and erosion on buildings, roads, wharves, sea walls, water supply systems, sewerage systems and storm water drains, there will be an increase in indirect impacts such as progressive rise in water tables and the increasing inability of storm water drains and sewerage systems to cope with loads at high tides. In both cities the loss of land will be relatively small, but it will affect a large number of people living in informal housing structures – in Port Moresby about 11,000 people, many in villages built on elevated platforms over tidal flats or on the adjacent beaches, and in Lae about 2,700 people in urban squatter settlements.

   The effects would initially be less severe for people living in dwellings built out over the water, but even these would eventually be affected as the sea rose progressively higher. Several kilometres of roads, wharf infrastructure, fuel storage tanks and about 30 commercial buildings, mainly in Lae, would be affected by these projected sea level rises.

   The need for resettlement of village communities from deltaic floodplains, coastal sand barriers and from motu and raised coral islands is foreseen due to both loss of land and of fresh drinking water from groundwater. There will be a particular problem for villages characteristic of the southern Papua New Guinea coastline, where rows of houses are commonly supported on poles over the tidal zones. Social problems will arise directly in such instances, where particular clans may hold land rights only along the coast, in areas where total inundations is anticipated. Attempts to resettle people affected directly by loss of village land is likely to result in land disputes. For island communities the initial loss will be of garden land, as salt water rises into taro pits and other gardens, or erosion removes coconut groves. Such losses will force many people to request resettlement. Some relocation in urban centres is also anticipated, with consequent high compensation costs for new land acquisition likely.

Socio-Economic Implications at the Provincial Level

Papua New Guinea is divided into 19 provinces, of which only the five highlands provinces do not have coastal access. The relative effects of a sea level rise have been summarised for the 14 coastal provinces (Table 1). In two provinces, Western and Gulf, it is likely that more than 90% of the coastline would be moderately or severely affected, that is, the effects of inundation or shoreline regression would extend more than 20 metres inland from the present coastline. In five other provinces 20-50% of the coast would be similarly affected whereas in the remaining seven the effects would be relatively small.

Table 1. Coastal provinces in Papua New Guinea showing the extent of impact that would result from sea level rise and correlation with levels of socio-economic development.

Province	Length of coastline (km)	% of coast length to be affected	Development level Rank*
Western	1330	>95	11
Gulf	1440	>90	9
West Sepik	1440	50	13
East Sepik	490	40	10
New Ireland	2400	30	5
Morobe	1020	20	8
Central	930	20	7
Manus	550	5	2
Madang	1000	<5	11
Milne Bay	3430	<5	8
Northern	550	<5	6
East New Britain	1110	<5	4
West New Britain	1420	<5	3
North Solomons	1000	<5	1

*13 = least developed   1 = most developed

Coastal data from Bualia and Sullivan (1990)
Ranking of socio-economic levels of development from de Albuquerque and D'Sa (1985, Table 11)

There is a strong inverse correlation between the levels of socio-economic developments of these provinces and the extent to which they will be affected by rising sea levels (Sullivan and Hughes 1989). The four most highly developed provinces, North Solomons, Manus, West New Britain and East New Britain, will be relatively unaffected. In contrast the four provinces which will be most affected by sea level rise, Western, Gulf, West and East Sepik, are all in the least developed group of provinces. Thus it is those provinces which are already socio-economically most disadvantaged that will suffer the greatest loss of land and other socio-economic disruption; impact which they will be less able to withstand than the most prosperous provinces.

References

Barth, M.C. and Titus, J.G. (eds) (1984,) *Greenhouse Effect and Sea Level Rise: A Challenge for This Generation*, Van Nostrand Reinhold, New York.

Bird, E.A. (1984), *Coasts*, ANU Press, Canberra.

Blong, R.J. (1984), *Volcanic Hazards*, Academic Press, London.

Brown, B.E. and Dunne, R.P. (1986), Report on a preliminary investigation into the environmental impact of coral mining on the reefs of the Maldives: an assessment and recommendations, Unpublished report to the Government of the Maldives.

Brown, B.E. and Suharsono (1990), 'Damage and recovery of coral reefs affected by El Nino related seawater warming in the Thousand Islands, Indonesia', *Coral Reefs*, 4,163-70.

Bualia, L. (1988), The impacts of global warming induced sea level rise on coastal environments in Papua New Guinea. B.A.(Hons) thesis, University of Papua New Guinea, Port Moresby.

Bualia, L. (1990), 'The impacts of sea level rise on a low-lying coastal landscape in Papua New Guinea: a case study from the Gulf of Papua,' In J.C.Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview*, UNEP, Nairobi, 224-237. (UNEP Regional Seas Reports and Studies, 128)

Bualia, L. and Sullivan, M. (1990), 'The impacts of possible global warming generated sea level rise on selected coastal environments in Papua New Guinea', In J.C. Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview*, UNEP, Nairobi, 193-199. (UNEP Regional Seas Reports and Studies, 128)

Buddemeier, R.W. and Hopley, D. (1988), 'Turn-ons and turn-offs: causes and mechanisms of the initiation and termination of coral reef growth', In J.H. Choat (ed), *Proceedings of the Sixth Internatioonal Coral Reefs Symposium, Townsville, Australia, 8-12 August 1988*, Executive Committee, Townsville, vol 1,253-261.

Buddemeier, R.W. and Oberdorfer, J.A. (1990), 'Climate change and island groundwater resources', In J.C. Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview*, UNEP, Nairobi, 56-67. (UNEP Regional Seas Reports and Studies, 128)

Buddemeier, R.W. and Smith, S.V. (1988), 'Coral reef growth in an era of rapidly rising sea level: predictions and suggestions for long term research' *Coral Reefs*, 7,51-56.

Davies, J.L. (1972), *Geographical Variation in Coastal Development*, Oliver and Boyd, Edinburgh.

de Albuquerque, K. and D'Sa, E. (1985), *Spatial inequalities in Papua New Guinea: a district level analysis*, PNG Institute of Applied Social and Economic Research, Port Moresby.

Economist Intelligence Unit (1988), *Country profile 1988-89: Papua New Guinea*, The Economist Intelligence Unit, London.

Haig, D.W. (1988), 'Distribution of miliolid formaninifera in marine sediments around Motupore Island, Papua New Guinea', *Science in New Guinea*, 14(2),54-94.

Hoffman, J.S. (1984), 'Estimates of future sea level rise', In M.C. Barth, and J.G. Titus (eds), *Greenhouse Effect and Sea Level Rise: A Challenge for this Generation*, Van Nostrand Reinhold, New York, 79-104.

Hughes, P. and Bualia, L. (1990), 'Murik Lakes and the mouth of the Sepik River, Papua New Guinea', In J.C. Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview*, UNEP, Nairobi, 243-246. (UNEP Regional Seas Reports and Studies, 128)

Hughes, P.J., Sullivan, M.E. and Asigua, W. (1986), 'Coastal erosion at Gabagaba village, Central Province, Papua New Guinea - a case study', *Ples* 2,33-40.

IPCC Response Response Strategies Working Group (1990), Chapter 1. Reasons for concern. Unpublished Draft Report presented to IPCC Meeting, Perth, February 1990.

Jacobs, I. (in press), 'CO_2, climate change and crop physiology in the South Pacific', In P.J. Hughes, and G. McGregor (ed), *Global warming-related effects on agriculture and human health and comfort in the South Pacific. A report to SPREP and UNEP.* ASPEI, UPNG, Port Moresby, np.

Jokiel, P.L. and Coles, S.L. (1990), 'Response to Hawaiian and other Indo-Pacific reef corals to elevated temperatures', *Coral Reefs* 4,155-62.

Loffler, E. (1977), *The geomorphology of Papua New Guinea,* Australian National University Press, Canberra.

Marshall, J.F. and Jacobsen, G. (1985), Holocene growth of a mid-Pacific atoll: Tarawa, Kiribati, *Coral Reefs* 4,11-17.

McAlpine, J.R. and Keig, G. with Falls R. (1983), *Climate of Papua New Guinea,* Australian National University Press, Canberra.

McGregor, G.R. (1990), 'Possible consequence of climatic warming in Papua New Guinea with implications for the tropical south west Pacific area', In J.C. Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview*, UNEP, Nairobi, 25-40. (UNEP Regional Seas Reports and Studies, 128)

McGregor, G.R. (in press), 'Possible impacts of climatic change on human thermal comfort in the western tropical Pacific', In P.J. Hughes, and G. McGregor (ed), *Global warming-related effects on agriculture and human health and comfort in the South Pacific. A report to SPREP and UNEP*. ASPIE, UPNG, Port Moresby, np.

McLean, R.F. (1977), no title. Unpublished course notes, Canterbury University, Christchurch.

McLean, R.F. (1989), Kiribati and sea level rise. Unpublished report to the Commonwealth Secretariat and the Government of Kiribati.

O'Collins, M. (1990), 'Carteret islanders at the Atolls Resettlement Scheme: a response to land loss and population growth', In J.C. Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview,* UNEP, Nairobi, 247-269 (UNEP Regional Seas Reports and Studies, 128)

Oberdorfer, J.A. and Buddemeier, R.W. (1986), 'Coral-reef hydrology: field studies of water movement within a barrier reef', *Coral Reefs* 5,7-12.

Oberdorfer, J.A. and Buddemeier, R.W. (1988), 'Climatic change: effects on reef island resources', In J.H. Choat, *Proceedings of the Sixth International Coral Reefs Symposium, Townsville, Australia,* 8-12 August 1988, Executive Committee, Townsville, Vol 3,523-527.

Percival, M. and Womersley, J.S. (1975), *Floristics and ecology of the mangrove vegetation of Papua New Guinea,* (Botany Bulletin No. 8), Department of Forests, Division of Botany Lae.

Pernetta, J.C. and Osborne, P.L. (1990), 'Deltaic floodplains: the Fly River and the mangroves of the Gulf of Papua, Papua New Guinea', In J.C. Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview,* UNEP, Nairobi, 200-217. (UNEP Regional Seas Reports and Studies, 128)

Pernetta, J.C. and Hughes, P.J. (eds) (1990), *Implications of Expected Climatic Changes in the South Pacific Region: an overview,* UNEP, Nairobi.

Petr, T. (ed) (1983), *The Purari - Tropical Environment of a High Rainfall River Basin,* (Monographiae Biologicae 51), Junk, The Hague.

Pittock, A.B. (1988), 'Actual and anticipated changes in Australia's climate', In G.I Pearman (ed), *Greenhouse Planning for Climate Change,* CSIRO, Melbourne, 35-51.

Stoddart, D.R. (1965), 'Re-survey of hurricane effects on the British Honduras reefs and cays,' *Nature* 207,589-92.

Sullivan, M.E. (1990a), 'The effects of sea level rise on raised coral and high islands', In J.C. Pernetta and P.J. Hughes (eds) *Implications of expected climatic changes in the South Pacific region: an overview,* UNEP, Nairobi, 218-223. (UNEP Regional Seas Reports and Studies, 128)

Sullivan, M.E. (1990b), 'The effects of sea level change on Port Moresby and Lae urban areas, Papua New Guinea', In J.C. Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview,* UNEP, Nairobi, 238-242. (UNEP Regional Sea Reports and Studies, 128)

Sullivan, M.E. and Gibson, L. (1990), Environmental planning, climatic change and sea level rise: report on a visit to Kiribati. Unpublished report to UNEP and the Government of Kiribati June 1990.

Sullivan, M.E. and Hughes, P.J. (1989), *Sea level rise report for Papua New Guinea: effects of and responses to a rising sea level.* (UPNG Climate Change Studies Working Paper, No 1), University of Papua New Guinea, Port Moresby.

Sullivan, M.E. and Pernetta, J.C. (1990), 'Coral reefs and atolls, In J.C. Pernetta and P.J. Hughes (eds), *Implications of expected climatic changes in the South Pacific region: an overview,* UNEP, Nairobi, 41-55. (UNEP Regional Seas Reports and Studies, 128)

Thom, B.G. (1989), 'Global climatic change: issues for the Australian coastal zone', In *Global Climatic Change - Issues for Australia,* Prime Minister's Science Council, Canberra.

Wiens, H.J. (1962), *Atoll Environment and Ecology,* Yale University Press, New Haven.

Sedimentation at the Junction of the Fly River and the Northern Great Barrier Reef

Peter T. Harris
Ocean Sciences Institute, University of Sydney

Abstract

Australia's Great Barrier Reef extends for some 2,000 kilometres along the eastern coastline of Queensland and ends abruptly at 9°S in the Gulf of Papua. Although workers have speculated that the sediment and freshwater discharge of the rivers which empty into the Gulf limit the growth of corals in the region (thus explaining the termination of the GBR at 9°S), few quantitative measurements were previously available to define the physical and sedimentological differences in the environments which occur to the north and south of "the 9° boundary".

On the basis of annual sediment discharge, the Fly River is by far the largest in the Australian region with a total sediment load estimated at 115 million tonnes/year. The Delta is tidally dominated, giving rise to a funnel-shaped estuary containing elongate sand banks; these are capped by mud and colonised by mangroves to form islands. Progradation of the Delta results in the burial of carbonate deposits on the adjacent Great Barrier Reef shelf.

Tidal currents dominate in the transport of sandy sediments throughout the Fly Estuary. On the delta front, however, surface waves rework the muds and sands, and fluvial discharge events deposit a mud layer, resulting in seasonal sand-mud interbeds. Pro-delta deposits occur in 17 to 45 metres water depth and contain massively bedded muds deposited in a low tidal- and wave-energy setting at rates of up to 6 cm/year. In the Torres Strait and barrier reef lagoon environments, tidal currents rework seabed deposits, dispersing any Fly River sediments over a wide area.

A preliminary sediment budget demonstrates that about 50% of Fly River sediment is deposited in the Fly Delta. A large portion is probably deposited in the Gulf of Papua. Less than 2% of the annual sediment discharge of the Fly appears to enter the Torres Strait area.

Introduction

Australia's Great Barrier Reef extends for some 2,000 kilometres along the eastern coastline of Queensland and ends abruptly at 9°S in the Gulf of Papua. It has been speculated that the sediment and freshwater discharge of the rivers which empty into the Gulf limit the growth of corals in the region, thus explaining the termination of the GBR at 9°S (eg. Gillet and McNeil, 1962; p. 4). In fact, the physical and sedimentological environments occurring to the north and south of "the 9° boundary" were poorly understood until recently (Wolanski *et al.*, 1984, 1988; Wolanski and Thomson, 1984; Harris, 1988, 1989a; Harris and Baker, *in press*; Harris *et al.*, 1988, 1989, 1990).

The sediment load of the Fly is increasingly becoming subject to change through human activity. Mining activities and deforestation in the Papuan highlands, coupled with a high rate of runoff (2,500 mm/year) in the Fly catchment, will increase fluvial sediment loads, a proportion of which will be transported downstream to be deposited in the Fly Delta and adjacent continental shelf environments. The impact of heavy metals derived from mining wastes (that are associated with the terrigenous sediment supply) on the fragile coral reef ecosystems of the adjacent continental shelf has been a subject of considerable concern (McGee, 1985; Mowbray, 1986; Harris, 1989b; Baker, this volume) and was a driving force behind the organisation of the present conference. These are but a few of the reasons for scientific interest in the Torres Strait and Fly River Delta region.

The aim of this paper is to review the available data regarding the deposition of Fly River derived sediments on the northern Great Barrier Reef continental shelf (Torres Strait) to answer the following questions: Where are Fly River sediments deposited in the marine environment? How much of this sediment finds its way into the delicate coral reef communities to the south of "the 9° boundary"? Does the input of this sediment (and/or freshwater) actually cause the GBR to end at 9°S? Finally, what processes control sediment transport and deposition at the junction of the Fly River and GBR?

This contribution is intended as a review of what is presently known about the sediment supply of the Fly River and sediment distribution in the estuary, delta and shelf areas. Much of this data is unpublished and some recently collected OSI data from the northern GBR and Fly Delta is included. The review will form the basis for a preliminary sediment budget of the dispersal of Fly sediments over the delta and adjacent shelf.

Geology and Physiography of the Fly Catchment

The Fly River takes its name from H.M.S. "Fly" which first surveyed the Estuary in the 19th century (Jukes, 1847). Using a small steam-powered launch, D'Albertis penetrated the Fly to its navigable limits in 1876 (to about Kiunga, Fig.ure1). He described outcrops of limestone and red clay along the river banks (see below) and noted the strong tidal currents in the Fly Estuary. The geological and topographic mapping of the region are outlined by Loffler (1977) and the results of deep seismic profiling and exploration petroleum wells, obtained in the Fly Delta area, are presented by Conybeare and Jessop (1972). The island of Papua New Guinea and Irian Jaya is the northern extension of the Australian continental plate, forming a continent/island-arc collision boundary

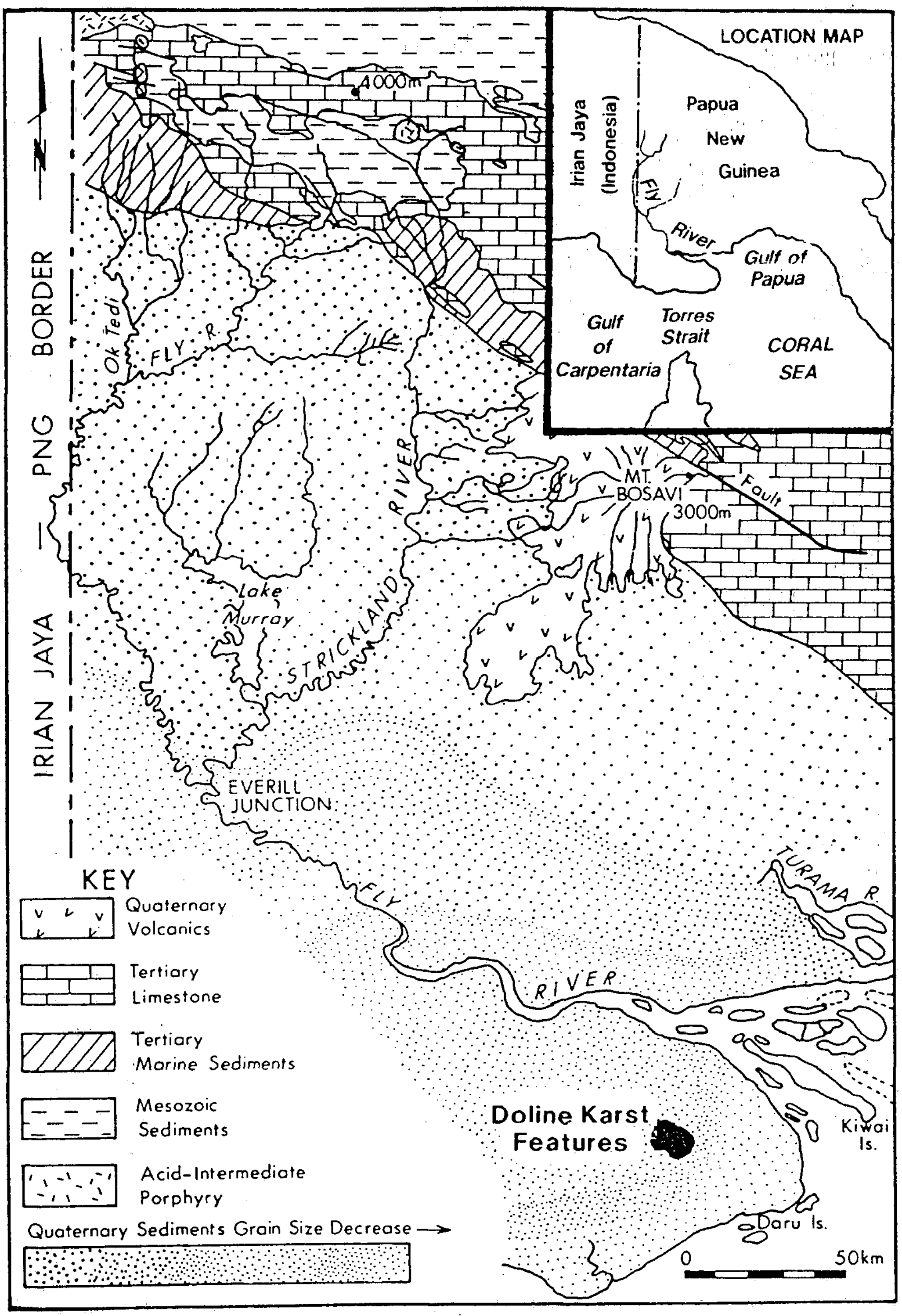


Figure 1. Location of the Fly River system in southwestern Papua New Guinea and the geological setting of the catchment (after Harris and Baker, in press).

(Jaques and Robinson, 1977). Present day Papua New Guinea has been suggested as a modern analogue for understanding the evolution of the Appalachian mountain system of the eastern United States (Dott and Batten, 1976; Baldwin and Butler, 1982).

The headwaters of the Fly River catchment extend southwards from the central cordillera of Papua New Guinea, characterised by Quaternary volcanics and uplifted Mesozoic sediments and Tertiary limestones (Figure 1). Elevations here exceed 4,000 metres and rainfall is as high as 10,000mm/year, although this decreases to about 2,000mm/year along the coast (2,072mm/year at Daru, see Figure 2). The extreme topographic relief gives way rapidly downstream to extensive alluvial flood plain, foreland basin deposits across which the Fly meanders for 800 kilometres with a drop of only 20 metres from Kiunga to sea level.

Blake and Ollier (1969, 1971) and Paijmans *et al.* (1971) examined the Quaternary deposits of the Fly River flood plain and described the Pleistocene and Recent geology of the region. The upper Pleistocene sequence is exposed at Kiunga (Figure 1). The "Kiunga Beds" (lowermost unit) were laid down by about 27,000 $\pm$ 1,100 years BP as determined from one radio carbon date; these are overlain by the "Eleval Beds" and by the "Lake Murray Beds" (uppermost unit). Erosion of these beds may provide a source of lithic fragments, quartz sand and crystal fragments of plagioclase, hornblende and diopside (derived from andesitic volcanics) to the fluvial system. Doline karst features have been noted by Loffler (1977, p. 61) located south of the Fly Estuary (Figure 1), where the nearly flat alluvial plain, underlain by limestone, is pitted with "circular to oval water filled depressions 40-60 metres in diameter".

The active flood plain is restricted to a "narrow belt between 10 and 15 kilometres wide on either side of the meandering channels" (Loffler, 1977, p. 89). Blake and Ollier (1971) described marginal backswamps and lakes connected to the main rivers by narrow channels. Elevated levels of particulate copper concentrations in lake sediments (about 500 ug/g), as a consequence of mining operations, indicate that these marginal lakes and swamps may act as sediment traps in some cases. In terms of the total sediment load of the Fly River, however, deposition in lakes is not significant. The lakes are thought to have formed as the result of fluvial down-cutting at times of lowered relative sea level in the Pleistocene (Blake and Ollier, 1971). Smaller tributaries would have similarly adjusted to the lowered base level, with fluvial incision being most extreme probably in the lower reaches of the Fly. The post-glacial sea level rise would have led to stream aggregation, but since the tributaries have much smaller sediment loads than the Fly (or Strickland) they were unable to keep pace with the filling of the main channel. They were consequently blocked near their entrance to the main river and thus formed a lake. Lake Murray (Figure 1) is thought to have formed in this way (Blake and Ollier, 1971).

Blake and Ollier (1969) have suggested that tectonism causing the "Oriomo Uplift" diverted the Fly to its present eastward course around 36 kyr BP, which was followed by the deposition of the upper Pleistocene units (described above). Torgersen *et al.* (1985) suggested that, prior to 36 kyr BP, the course of the Fly was towards the south west where it would have fed into what was then "Lake Carpentaria". However, Loffler (1977, pp. 20, 98) has questioned whether the Fly has been diverted or if it has simply flowed down slope along a (southeast dipping) depositional surface throughout the Quaternary.

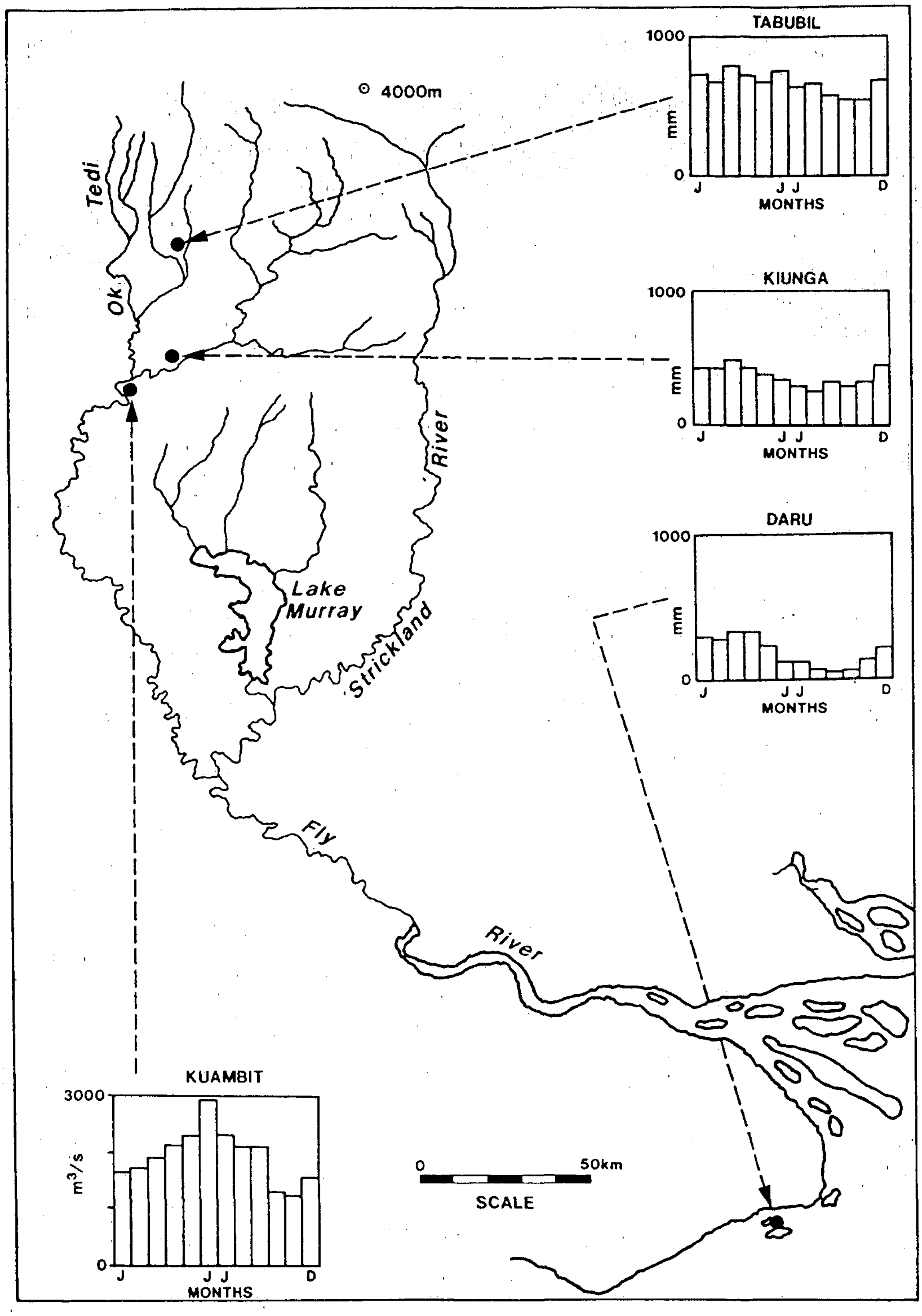


Figure 2. Average monthly rainfall at Tabubil, Kiunga and Daru (from Brown, 1983) and average monthly discharge of the Fly River at Kuambit, based on 10-years data obtained between 1978 and 1988 by Snowy Mountain Engineering Corporation Ltd., Cooma, NSW, Australia (data used with the permission of Ok Tedi Mining Ltd.). Over the period of measurement, a minimum daily value of 118 m3/s (on 20-11-82) and a maximum of 5220 m^3/s (on 13-4-83) were recorded.

Sediment and Water Discharge

On the basis of annual sediment discharge, the Fly River is by far the largest in the Australasian region and is a major fluvial system by world standards (eg. Harris and Baker, *in press*). Although it drains an area of only about 76,000 km^2, its total sediment load is estimated at 115 million tonnes/year, which is greater than the combined discharge of all rivers draining the Australian continent (cf. Milliman and Meade, 1983). The Fly River discharges 20 times more sediment per year than the Burdekin, which is the largest river entering the GBR lagoon from the Australian continent (Figure 3). As much as 80% of this sediment is considered to be supplied by the Strickland River, which joins the Fly at Everill Junction. The average annual discharge of the Strickland (4,000 m^3/s) is also larger than that of the Fly above Everill Junction (2,500 m^3/s; Figure 1); the total discharge of the Fly River system at its mouth is estimated to be about 7,000 m^3/s (Ok Tedi Mining Ltd., 1988).

Most of the sediment load is derived from the mountain areas as the result of landslides, often triggered by tectonic events. In such mountain areas, runoff is as high as 5,700 mm/year and denudation rates of 3 to 4mm/yr have been reported (Pickup, 1984). Most sediment is thought to be transported directly downstream to the Fly Delta and adjacent continental shelf environments, with little deposition in the flood plain or in the marginal lakes (as described above; Ok Tedi Mining Ltd., 1988). Mining activities at one site in the Fly catchment are expected to increase the total sediment load of the Fly to about 125 million tonnes/year by 1992 (Ok Tedi Mining Ltd., 1988). Deforestation and additional mining in the catchment occurring now will lead to further increases in sediment load. Prior to the mining activities which commenced in 1982-6, the Fly's sediment load may have been about 85 million tonnes/year.

Compilation of monthly river discharges measured at Kuambit (Figure 2) shows that the greatest average discharge occurs in June and the lowest is in November. The hydrograph is controlled by rainfall in the mountains (eg. at Tabubil) and is not related to the rainfall pattern in the coastal areas (eg. at Daru; see Figure 2). Suspended sediment concentrations vary as a fuction of discharge in the mountain areas, the greatest concentrations occurring in June-August (Pickup, 1984). With the changing nature of the river system in a downstream direction, the energy regime (and sediment transport capacity) is reduced; coarse sediment is consequently deposited in the meandering channels of the flood plain as scroll bars and mainly fine-grained silts and clays reach the Fly Delta (Higgins *et al.*, 1987). The sediment load of the Fly entering the estuary is about 90% suspension load (grains finer than 0.1mm) and only about 10% is transported as bed load (Ok Tedi Mining Ltd., 1988).

Estuarine Water Circulation and Sedimentation

In terms of Holocene sedimentation, investigations into the nature of sediments deposited in the Fly Estuary have been carried out by Taylor (1973) and Spencer (1975, 1978). Recently, environmental studies carried out by Ok Tedi Mining Ltd. (1988, 1989) have added to the available data on the Fly River, Delta and Estuary.

The Fly Estuary is a funnel-shaped, highly dynamic, tidally dominated system; the daily tidal flux through the estuary is 18 times the average fluvial discharge (Spencer,

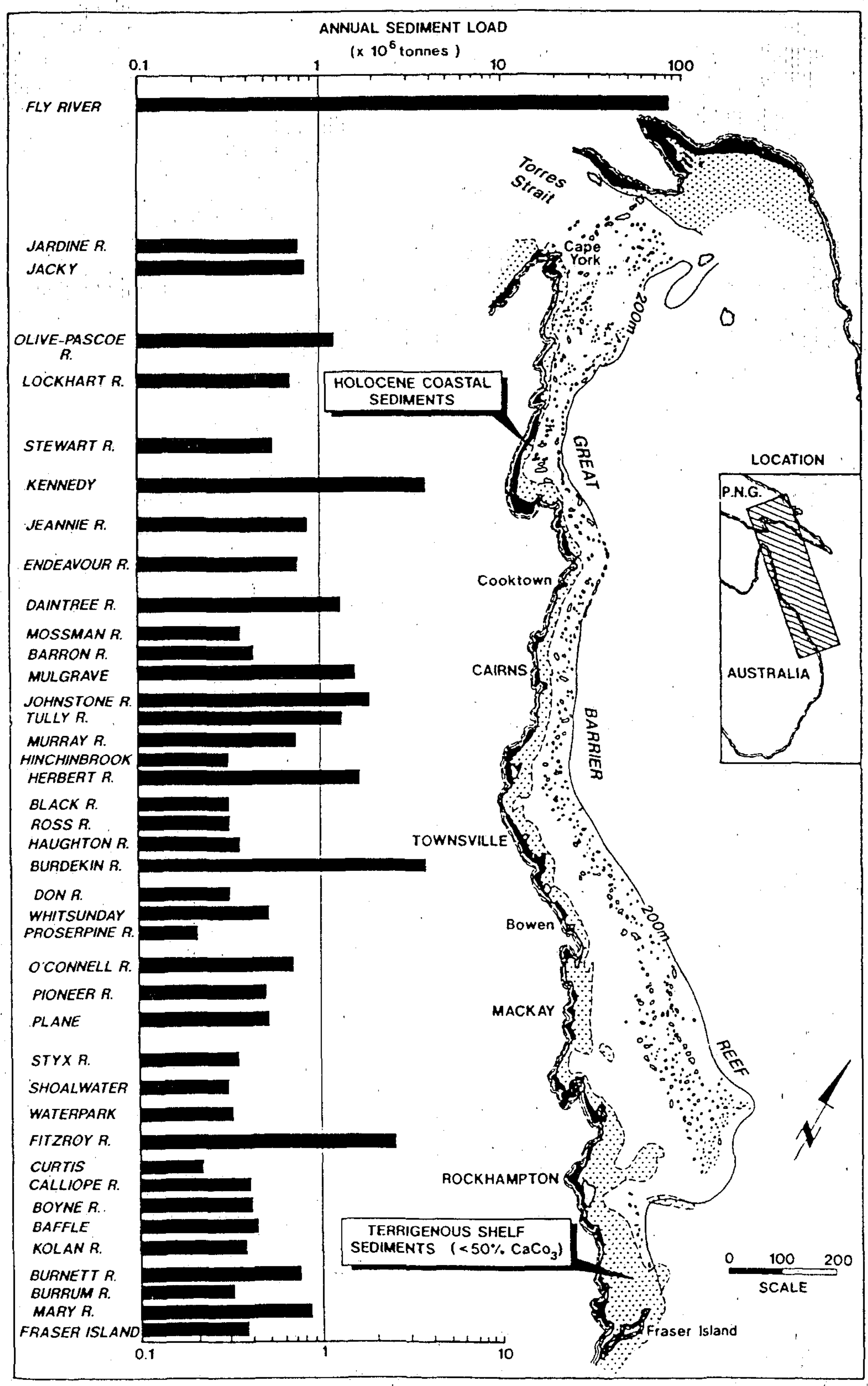


Figure 3. Sediment discharge of rivers entering the Great Barrier Reef lagoon and location of terrigenous shelf and Holocene coastal sediments (modified from Belperio and Searle, 1988, to include the Fly River and Torres Strait shelf area).

1978). Within the high energy regime of the Estuary, sand-sized sediments, comprised of up to 90% quartz, 20% chlorite with minor amounts of feldspar (which are often weathered to mica) predominate (L. Taylor, 1977). Strong tidal currents affect continuous reworking of sediments within the estuary, such that the turbidity of estuarine water is often greater than that of incoming river water (Pickup, 1984). Sandy sediments are deposited in the form of tidal sand banks which are capped by mud to form islands. Spencer (1975) concluded that mud deposition is affected through trapping by seagrasses, mangroves and other plants and by clay flocculation due to salinity changes (mechanism descibed by Postma, 1967). The islands undergo rapid lateral erosion and accretion; shoreline migration rates of up to 37m/year as measured from comparative aerial photographs (D. Taylor, 1973). Changing vegetation patterns observed between photos indicate that most of the island growth over the 20 year period preceding 1975 occurred among the islands which lie between the North and Far North Entrances (Figure 4).

Spencer (1975) suggested sediment recirculation and depositional sequence models for the Fly Estuary (Figure 4). Ebb flow dominates in the transport of sediment only in the southern channel as indicated by channel morphology and by salinity profiles, which show increased salinity in the northern channels as compared with the southern channel. Flood tidal flow dominates in the transport of sediment elswhere. The coriolis force is thought to affect an anti-clockwise deflection of currents within the Estuary (Spencer, 1978).

Depositional sequences in the estuary are dominated by tidal sand bank deposits which unconformably overlie pre-Holocene clays and Pliocene-Pleistocene limestones; these older deposits are thought also to act as "anchor points" and thus play a role in the formation of the sand banks and the deltaic islands (Figure 4). The predominance of sandy sediments in the estuarine deposits is consistent with observations made by Thom and Wright (1983) for the Purari Delta, located to the east in the Gulf of Papua, suggestive of similar modes of deposition. Offshore, foreset beds are deposited on the subaqueous delta slope. Spencer (1975) concludes "the geometry of the estuary and the patterns of sedimentation are mainly a function of tidal regime".

Oceanography and Bathymetry of the Adjacent Shelf (Gulf of Papua)

Oceanographic studies have shown the importance of tidal and wind-driven currents to the circulation of the Gulf of Papua and the adjacent Torres Strait regions (Pickard *et al.*, 1977, MacFarlane, 1980; Wolanski and Ruddick, 1981; Wolanski and Thompson, 1984; Wolanski *et al.*, 1984, 1988; Harris *et al.*, 1988, 1989; Mulhearn, 1989). Combining the results of these studies indicates the general variation in circulation and surface salinity between the NW Monsoon (December to March) and the SE Trade wind seasons (Figure 5). Low salinity estuarine water is transported towards the west along the coast of Papua New Guinea during the SE trade wind season. Wind-driven currents flow eastward into the Gulf of Papua at other times (see Figure 5).

Surface waves generated in the Coral Sea propogate towards the northwest about 70% of the time and have a significant height of between 1.6 metres (September-November) and 1.9 metres (December-August; Thom and Wright, 1983). Typical wave periods are between 8 and 9 seconds. Wave-rider buoy observations at Kerema (Figure 5)

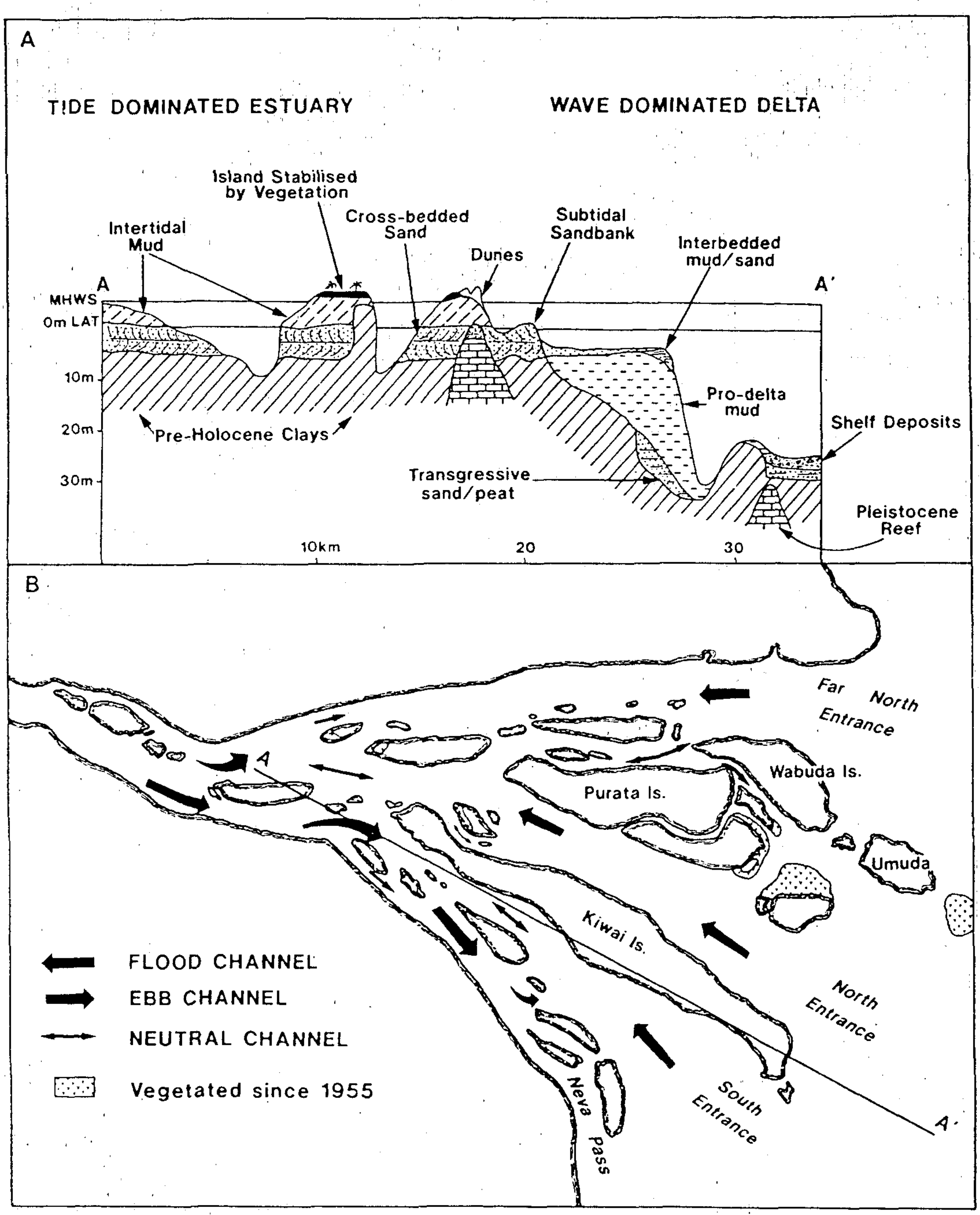


Figure 4. (A) Idealised longitudinal section showing relationship between pre-Holocene clays, cross-bedded estuarine sand bank deposits, intertidal muds and supratidal islands stabilised by vegetation (modified from Spencer, 1975, to include observations of the present study on the delta and adjacent shelf). The change in maximum spring tidal range, from about 3.5 metres at the mouth to 5 metres at the apex of the funnel-shaped coastline, is indicated. (B) Generalised sediment transport pattern in the Fly Estuary, showing ebb- and flood-dominated channels and areas vegetated since 1955 (after Spencer, 1975).

represent the coastal wave climate. Thom and Wright (1983, p.51) summarised these results and noted that "on an annual basis wave height exceeds 0.25 metres for 90% of the time, 0.7 metres for 50% of the time, 1.5 metres for 10% of the time and 2.0 metres for 1% of the time". Whereas the significant wave height at Kerema during the SE trade wind season is 1.3 metres, during the NW monsoon season it is only 0.3 metres (Thom and Wright, 1983).

Tides in the Gulf of Papua are of the semidiurnal-mixed variety. Tidal currents flow predominantly across isobaths and are amplified within the Fly Estuary. The maximum spring tidal range increases from about 4 metres at the mouth of the estuary to about 5 metres where the funnel-shaped coastline rapidly narrows (at about 143° longitude). Mean spring tidal ranges are 1 to 1.5 metres less than these maximum ranges, (MHWS - MLWS = 3.4 metres at Umuda Island, Figure 4) although only a few days of tidal observations have been obtained for the upper Fly Estuary and so exact tidal ranges are not known (Spencer, 1975).

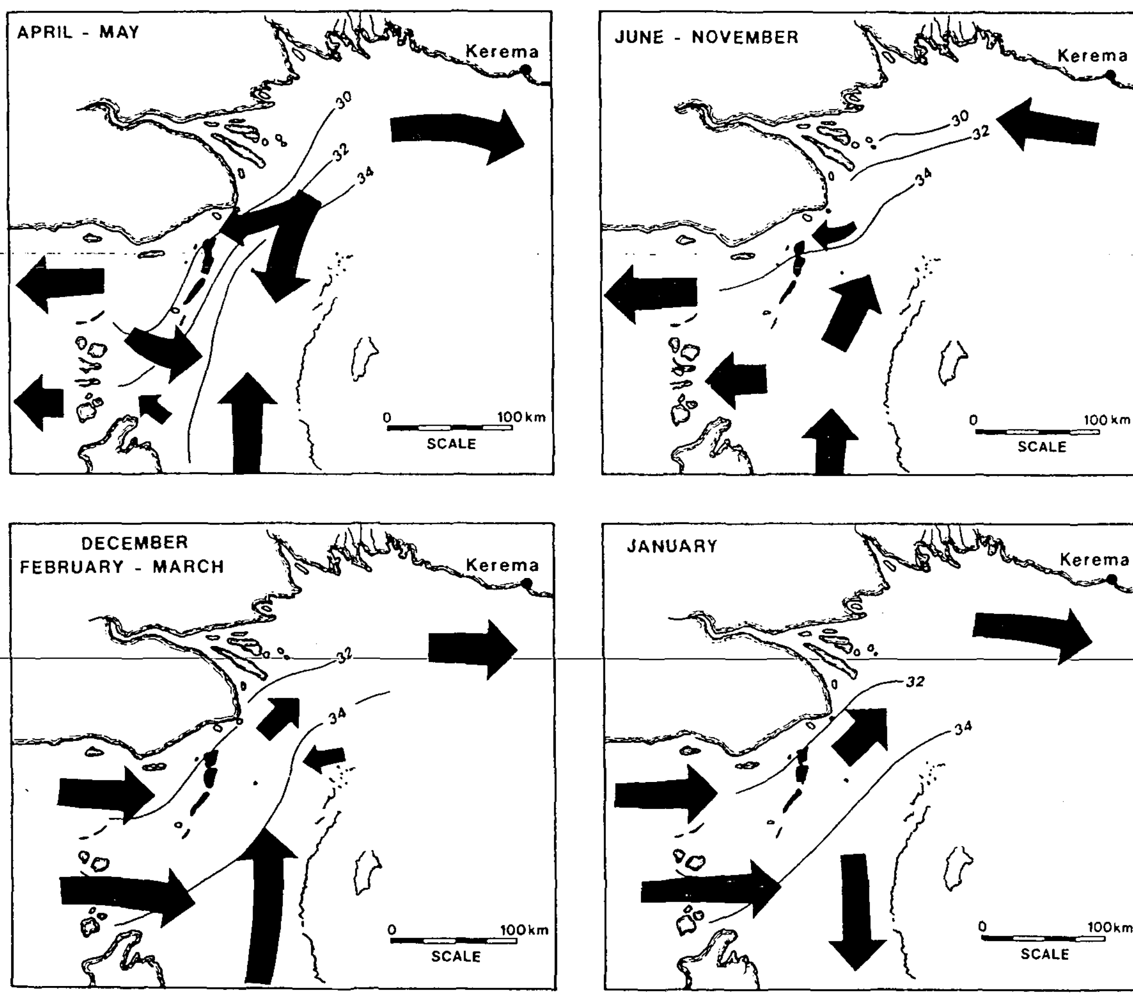


Figure 5. Synthesis of observations on wind-driven surface currents and typical surface salinity values in the Fly Delta region for different times of the year (references sited in text).

The available bathymetric data from the Fly Estuary and adjacent shelf (Figure 6) indicate the steep pro-delta slope is located between the 10 and 30 metre isobaths. The close spacing of the 10-20 metre isobaths to the west of Bramble Cay gives way to a wider spacing further north (Figure 6). This probably reflects the relative degree of sheltering afforded by the Great Barrier Reef to the southern Fly Delta, as compared with the northern Delta, where surface waves are able to propogate across the reef-free shelf of the Gulf of Papua (Figure 6). Long period gravity waves would affect sediment reworking at such depths (10 to 20 metres), thus explaining the change in delta morphology.

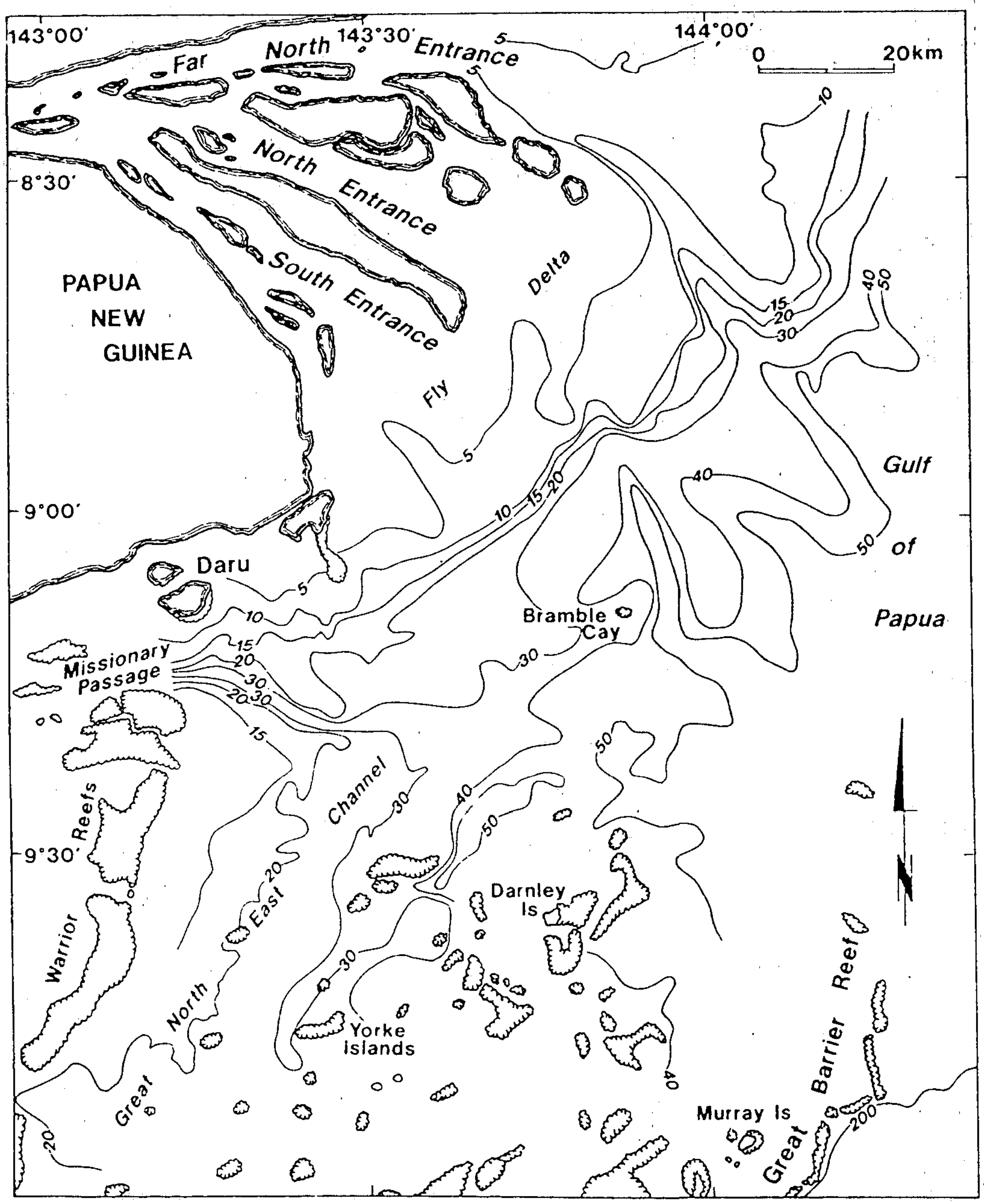


Figure 6. Bathymetry of the shelf area adjacent to the Fly Delta. Contours are in meters below chart datum (lowest astronomical tide level).

In the Fly Estuary, water depths of <5 metres are characteristic. Channels between the elongate, estuarine islands seldom exceed 12 metres depth and the mean depth of the estuary is probably about 8 metres (Spencer, 1975; Figure 6). Elongate, subtidal sand banks are noted on nautical charts of the Estuary (Royal Australian Navy Hydrographic Service, 1974). Submarine channels evident from the bathymetry (Figure 6) include one delimited by the 10 metre isobath. This channel leads into the Far North Entrance of the Fly Estuary near Umuda Island and was possibly formed by flood tidal currents as depicted in Figure 4. Another submarine gully (in 40 to 50 metre water depth) trends across the shelf near Bramble Cay and may be a relict Fly River channel formed during times of lowered relative sea level.

The Fly Delta

Mapping the distribution of mud content in the surficial sediments of the Fly Estuary and Delta (Figure 8) indicates the following: The Fly Estuary is dominated by sandy sediments as described by Spencer (1975) and mud constitute less than 20% of the bottom sediments on the delta front as far offshore as the limit of the 5 metre isobath (cf. Figures 6 and 7). Mud content exceeds 80% over only a very restricted area, in a zone trending SW-NE across the front of the Estuary and parallel with isobaths. A tongue of muddy sediments is seen also to be intruding into the Far North Entrance of the Fly Estuary in association with the 10 metre deep flood channel described above (cf. Figures 6 and 7). Mud content decreases southwards into the adjacent GBR shelf and appears to range between 40-60% over much of the Gulf of Papua where samples have been obtained (Figure 7).

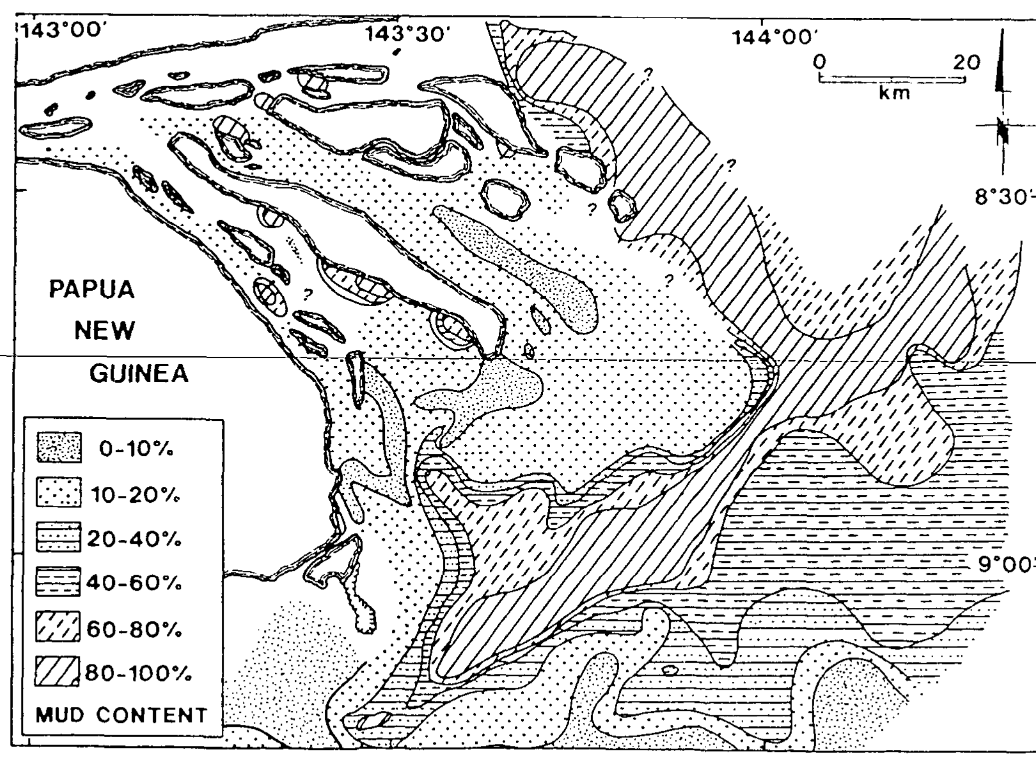


Figure 7. Percentage mud content in surficial sediments.

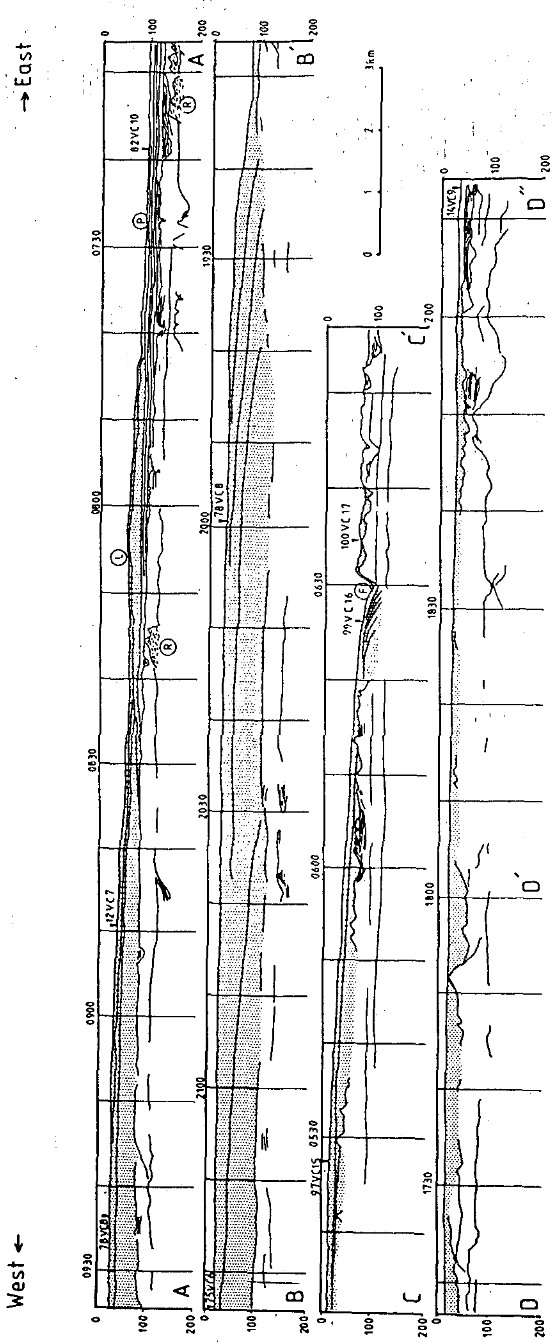


Figure 8. Interpretation of seismic lines (for locations see Figure 9) showing east-west trending profiles of prograding deltaic sediments (shaded area) and undifferentiated subsurface reflectors. The location of vibrocores are indicated. Vertical scale is in milliseconds, two-way travel time. Features noted are: (L) overlap of two prograding lobes; (R) buried reef features; (P) horizontal reflectors characteristic of shelf deposits in the Gulf of Papua; and (F) partially infilled submarine gully at the edge of the prograding delta lobe (see Figure 8; the gully was formed probably by fluvial down-cutting during times of lowered sea level in the Pleistocene).

High resolution seismic profiles indicate that the > 80% mud belt correlates with the prograding edge of the Delta, as shown by offshore dipping foreset beds identified in the seismic data (Figure 8). The seismic data were used to construct a sediment isopach map for this deltaic mud unit, (Figure 9) which indicates that the maximum thickness is of the order of 60 milliseconds two-way time (i.e. about 30 metres thickness of sediment). Thicknesses were not found to exceed 30 milliseconds at 10 metres water depth in the southern seismic lines (i.e. Line D-D'-D", Figure 9), suggesting that the Delta thins towards the south. The seismic data also indicated the presence of what are interpreted as buried reefs. They extend from Bramble Cay north and eastwards and underlie the prograding deltaic sediments.

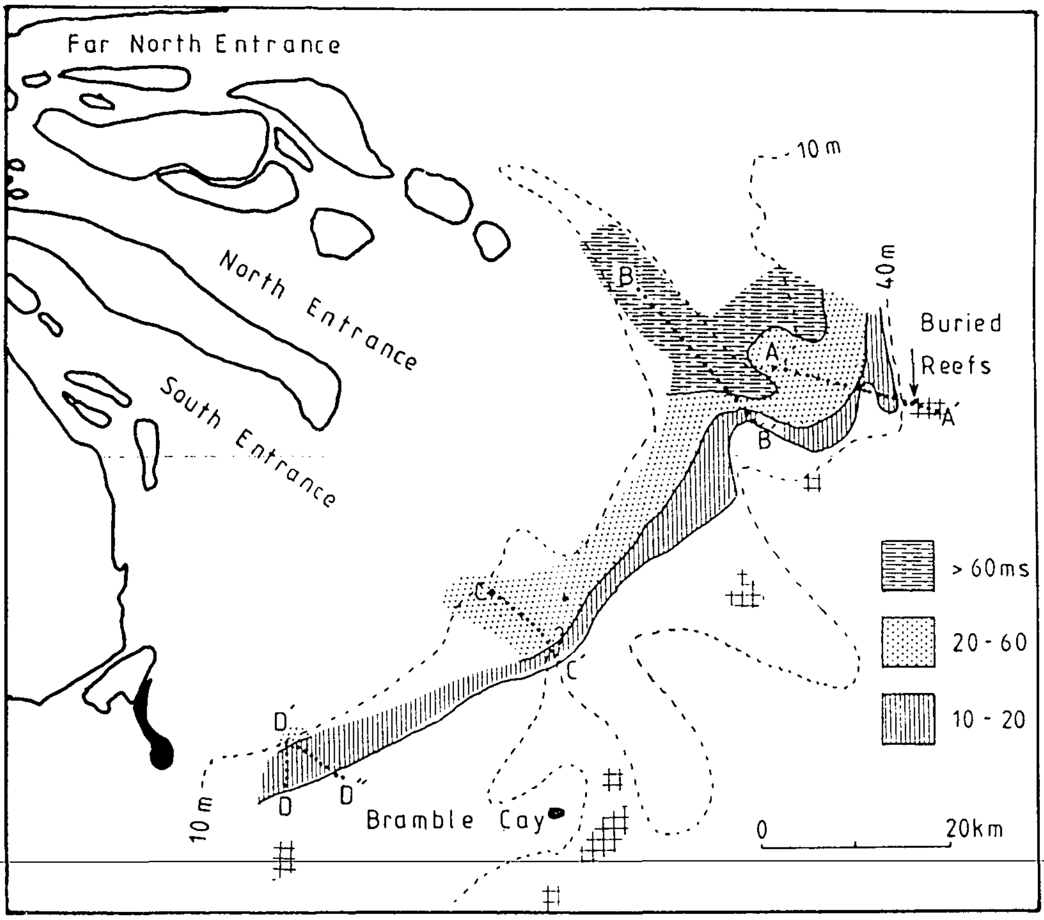


Figure 9. Isopach map of deltaic sediments, indicating the edge of the prograding deltaic sediments in relation to the Fly Estuary. The 10 and 40 metre isobaths, distribution of buried reef features and the locations of sections shown in Figure 7 are also shown.

Cores obtained in the deltaic and shelf deposits demonstrate the character of sediments in vertical sequence found at different locations. Subsamples from the cores have been dated using ^{210}Pb and ^{14}C techniques (Harris *et al.*, 1990) to derive sedimentation rates in relation to the water depth at each core site (Figure 10). The Delta Front cores contain sandy laminations of about 0.5cm thickness, which are absent in cores obtained on the Delta Front. Sedimentation rates are greatest in the Pro-delta cores (up to about 6cm/year) with lesser sedimentation rates found both inshore and offshore from this area (Figure 10).

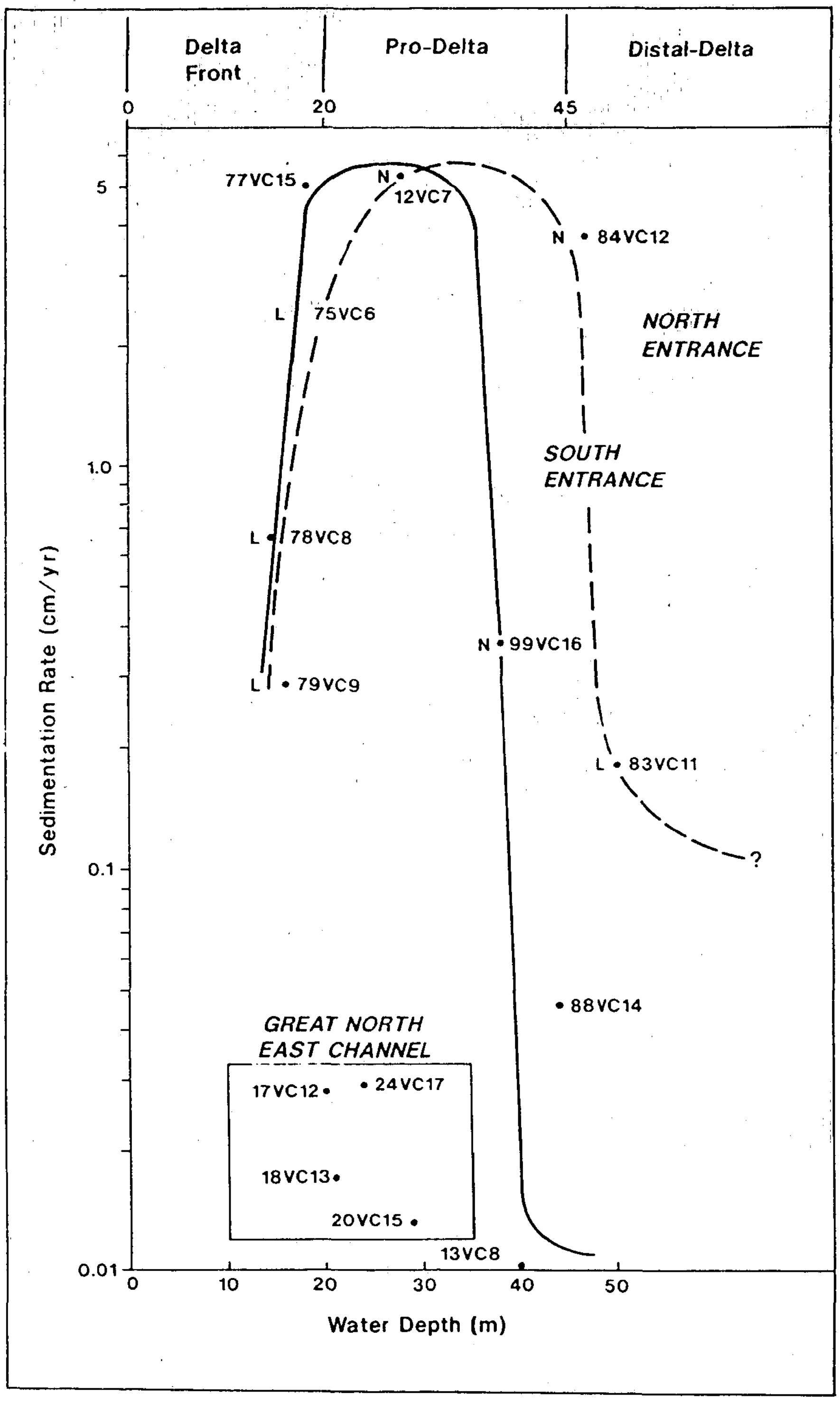


Figure 10. Plot of sedimentation rate versus water depth for 14 cores (8 rates determined by Pb-210 analysis and 6 by carbon-14 dating of shell and peat material). Cores containing laminations (L) and cores having no apparent bedding (N) are indicated. Extrapolated curves show relationships for core transects east of North Entrance (dashed line) and South Entrance (solid line). Sedimentation rates at various water depths obtained from shelf deposits of the Great North East Channel are shown for comparison (data from Harris *et al.*, 1990).

Sedimentation in the Northern Great Barrier Reef Shelf

The area of the GBR shelf which adjoins the 9° boundary includes the Great North East Channel, the northern end of the Warrior Reef complex and numerous reefs and high volcanic islands such as Bramble Cay, Darnley Island and the Murray Islands. Inter-reef (shelf) sediments of this area are derived primarily from benthonic foraminifers, supplemented with bryozoans, molluscs, the blue-green alga *Halimeda* and small amounts of corals (Harris, 1988; Bryce, 1989; Kracik, 1990). At the junction of the Fly River and the GBR, calcareous sediment is diluted with terrigenous mud (Figure 11). Sedimentation rates in this inter-reef zone are characteristically around 0.02 cm/year. This is a similar rate to that found in other parts of the Great Barrier Reef (eg. Harris, Davies and Marshall, 1990) but it is much lower than occurs in the Fly Delta (Figure 10).

Tidal currents play a major role in the dispersal of sediments in the northern GBR shelf. Currents are accelerated in the narrow inter-reef passes (such as those in the Warrior Reef complex) and the seabed is scoured clear of any unconsolidated sediment grains leaving a lag gravel or limestone pavement behind (Figure 12). With increasing distance away from the channels, sediment of decreasing grain size is deposited. Beyond the scoured zone, sand/gravel ribbons give way to dunes, which are located in association with the reef passages and possibly in the Fly Estuary (Figure 8). At greater distances from the reef passages, current strengths are diminished enough to allow the fine silt- and clay-sized particles to settle out (Figure 8). Such a pattern is similar to that found in the west European shelf seas and is characteristic of a tidally dominated shelf environment (Harris, 1988; Harris and Baker, *in press*).

Because of the slow sedimentation rates characteristic of the muddy deposits (0.02 cm/year), bioturbators have ample time to rework sediments and obliterate any sedimentary structures present before they can become buried (and preserved). In fact, this is what is observed in box cores obtained in the Great North East Channel (Harris *et al.*, 1990). The muddy sediment is always supplemented with the tests of benthonic foraminfers and mollucs, which comprise the sand and gravel size fractions. Cyclones may cause the upper 4 to 6cm of sediment to be eroded and redistributed over the shelf (Gagan *et al.*, 1990). The dune and gravelly-sandy-mud deposits of the Great North East Channel overlie a Pleistocene limestone (in proximity to reef passages) and a cohesive clay elsewhere, as sampled in vibrocores (Harris *et al.*, 1988, 1989, 1990; Figure 8).

Deltaic and Shelf Facies

It is evident that at least five distinct facies characterise deposits of the 9° boundary: (1) Fly Delta front facies; (2) Pro-delta facies; (3) Distal delta facies; (4) Gulf of Papua shelf facies; and (5) Great Barrier Reef shelf facies. The sediments are deposited in four distinct environments (Figure 14): (i) the tide-dominated estuary; (ii) wave-dominated delta; (iii) the low energy pro-delta and Gulf of Papua shelf; and (iv) the (high energy) tide-dominated lagoon. Descriptions of these different facies, based on the interpretation of available data, are as follows:

- Estuarine deposits consist mainly of the the tidal sand banks described by Spencer (1975; Figure 4). Fine-grained mud and sand are deposited in the delta

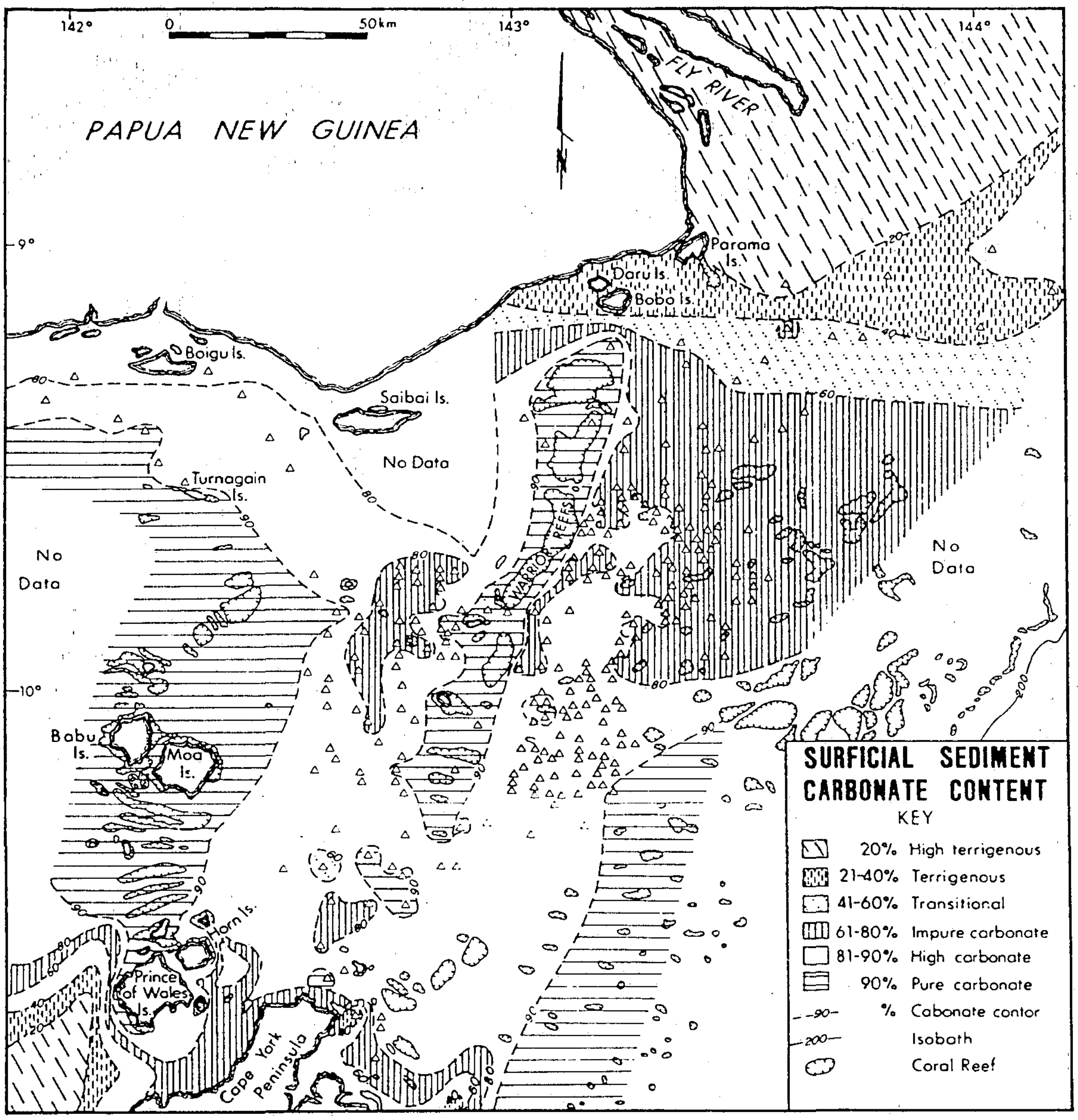


Figure 11. Surficial sediment carbonate content (After Harris and Baker, *in press*).

front facies (Figure 13), characterised by water depths <17 metres and attendant higher tidal and surface wave energy levels than offshore, deep water environments. Surface waves propogating from the Coral Sea combine with tidal currents causing delta front deposits to be reworked and bring into suspension much of the fine sediment fraction. Wave reworking results in the formation of sandy, bioturbated, lag deposits. During peak discharge events (in May to August; Figure 2) large volumes of sediment pass through the estuary and mud-drapes cover delta front deposits. This gives rise to bioturbated sand and mud interbeds. Typical laminae spacings of 0.5cm together with sedimentation rates of around 0.5cm/year (Figure 10) are indicative of annual cycles. Storm events may result in the erosion of several units causing a hiatus in the sequence. The eroded sediment would be removed offshore to the distal delta environment (Figure 13).

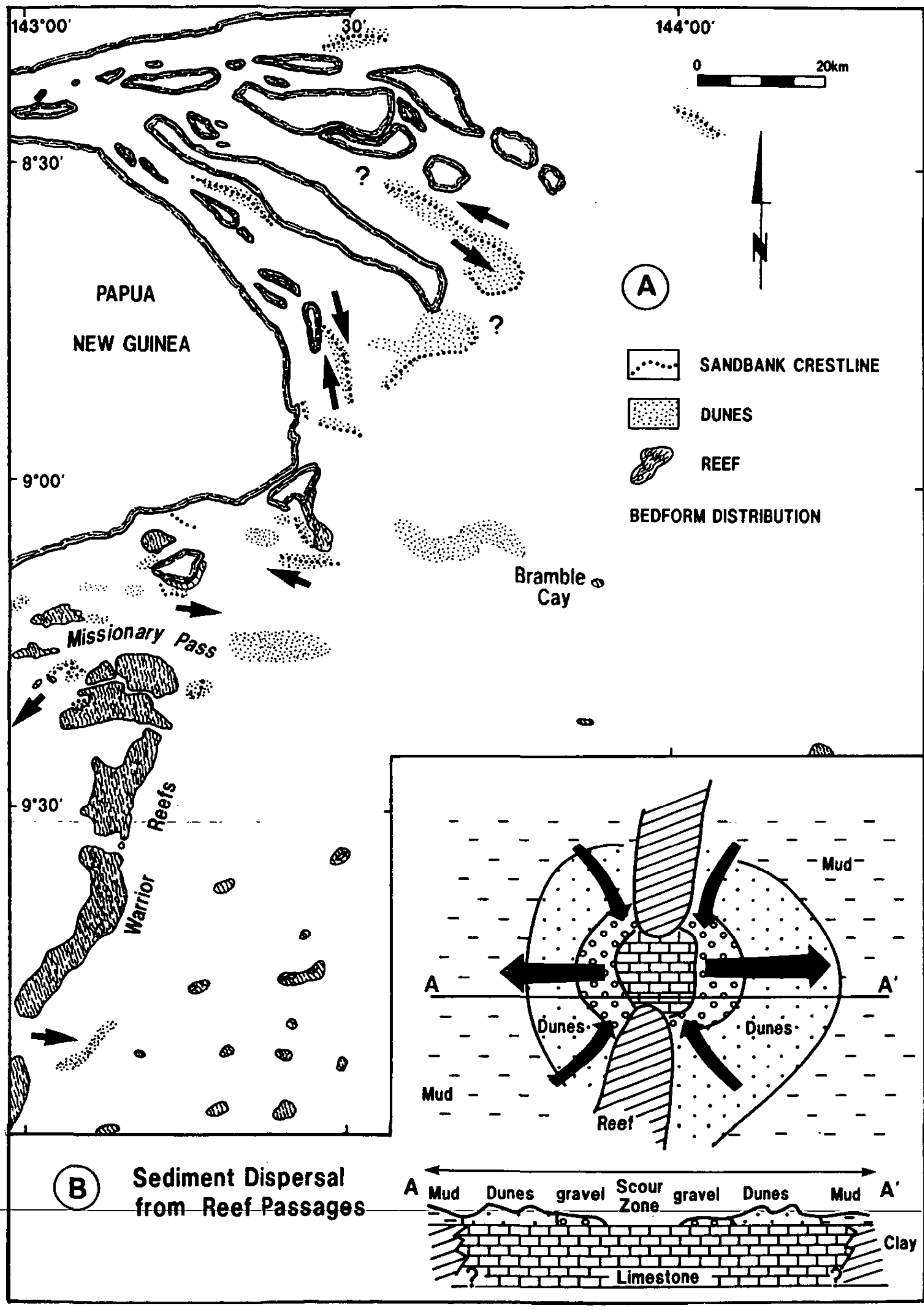


Figure 12. (A) Distribution of bedforms (dunes and sandbanks) in the study area. The existance of dunes in the Fly Estuary is purely speculative (indicated by "?"). Dunes may not exist here because of the fine-grained nature of estuarine sand (mean size about 0.13mm). Such fine sand may not be transported as bedload, since grains less that about 0.1mm become suspended immediately the threshold velocity is reached (eg. Leeder, 1982, p.72). (B) Idealised sketch showing the character of the seabed typical of reef passages. Strong currents in the passage result in a zone of deep scour. The grain size deposited decreases with increasing distance away from the zone of scour, in the form of gravel/sand ribbons, sand dunes, and eventually fine-grained mud deposits. Pleistocene limestones have been cored beneath dunes in such passages and pedogenic cohesive clays are known to underlie much of the gravelly-sand-mud deposits (Harris *et al.*, 1990).

- The pro-delta facies lies in 18-45 metres water depth, deep enough below the sea surface to escape reworking by all but the largest surface gravity waves. The absence of sediment reworking yields massively bedded to finely laminated deltaic muds. Deposition at rates of around 3 to 5 cm/year results in the progradation of the delta offshore across the adjacent shelf at about 6 metres/year, based on the geometry of the shelf and pro-delta slope. Fine-grained sediment is supplied to the pro-delta from the estuary and through the reworking and offshore removal of delta front sediments. The absence of fossils in this facies, apart from rare allocthonous specimens, indicates that the pro-delta region is largely devoid of a benthic fauna.

- The distal delta facies (Figure 13) delimits the offshore extent of deltaic sedimentation. Sedimentation rates here are relatively low (about 0.5 cm/year). This facies lies between 35 to 50 metres water depth and receives a steady (albeit much diminished) supply of sediment from the outer estuary and delta. Sediment arriving from the delta is supplemented by autochthonous sources (peloids and shell debris). Thick sand layers are deposited during extreme events (storms, floods, etc.). However, bioturbation obliterates most of these event marks.

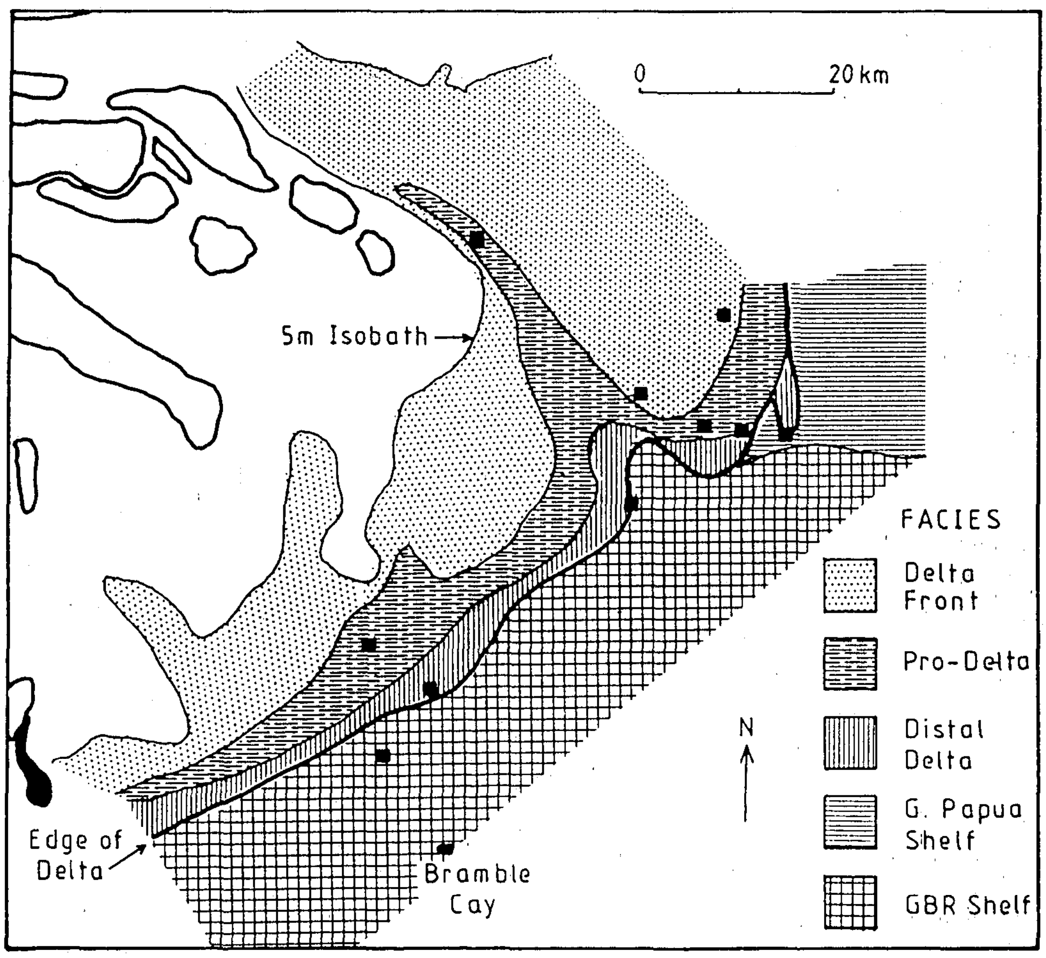


Figure 13. Facies distribution map based on data of the present study showing deltaic and shelf facies delimited by the edge of the delta (based on seismic data) and by change in sedimentation rates (based on indicated cores sites).

- The Gulf of Papua shelf facies is essentially an offshore extension of the distal delta facies (Figure 13). Sedimentation rates are around 0.2 cm/year (Figure 10). Sand beds deposited during storm events yield the series of horizontal parallel reflectors seen in seismic sections (Line A-A'; Figure 8). The source of the sediments, however, may not be restricted to the Fly Delta but may include other rivers which empty into the Gulf of Papua.

- The GBR shelf facies is characterised by subtidal dunes and foram-rich gravelly-sandy-mud (Figure 14). Carbonate content in the latter sediments increases southwards (Figure 11). This unit overlies an interbedded mangrove peat and sand transgressive unit which is restricted spatially to the region adjacent to the Fly Delta. Carbon-14 dating indicates that it was deposited during the landward retreat of the Fly Estuary caused by the post-glacial sea level rise, about 9,000 years BP. To the north, the transgressive unit may underlie the Gulf of Papua shelf facies (although it has not been penetrated in cores obtained to date). To the south there is no evidence for such a transgressive unit in cores obtained in the Great North East Channel. Rather, the gravelly-sandy-mud rests upon an erosional unconformity, consisting of cemented limestone (in proximity to reefs) and a cohesive pedogenic clay (Harris and Baker, *in press*; Figure 14).

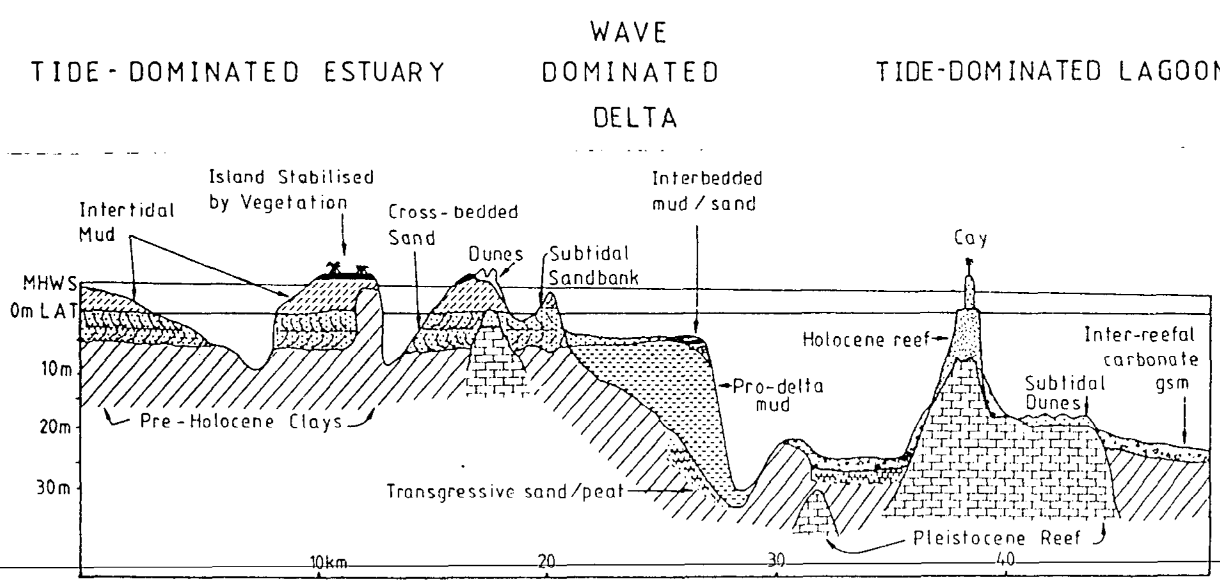


Figure 14. Idealised stratigraphic section showing the relationship between estuary, delta and GBR lagoon deposits. See text for explanation of different units.

A Preliminary Sediment Budget for the Fly Delta

The spatial relationship of facies (Figure 13) indicates that, within the area studied, about 2,200 km^2 is presently subject to deltaic sedimentation. Extrapolating the sedimentation rates assigned to each facies over respective areas, we may estimate a sediment budget for the Delta (assuming 1 m^3 = 1 tonne):

Delta front: $(1.44 \times 10^9 m^2) \times 0.5$ cm/yr = 7×10^6 tonnes/yr
Pro-delta: $(5.26 \times 10^8 m^2) \times 3$ cm/yr = 20×10^6 tonnes/yr
Distal delta: $(2.35 \times 10^8 m^2) \times 0.3$ cm/yr = 0.7×10^6 tonnes/yr

The budget indicates the importance of pro-deltaic sedimentation as a depositional facies in comparison with the delta front and distal delta facies. It shows, also, that the budget is most sensitive to the estimate of sedimentation rate in the pro-delta facies. For example, by increasing the pro-delta sedimentation rate from the mean value of 3cm/year to a maximum value indicated by the depth-sedimentation rate curve (Figure 10; i.e. about 5cm/year) yields 33 million tonnes/year deposited in the pro-delta. In any event, it follows that about 28 to 40 million tonnes/year of sediment reaches the delta. This is between 1/2 to 1/3 of the 85 million tonnes/year discharged by the Fly River prior to mining activities. The remaining amount may follow a number of possible pathways, including: (i) sediment retained in the Estuary; (ii) transported offshore for deposition in the Gulf of Papua; (iii) transported westward along the southern coast of Papua New Guinea; (iv) transported southwards into Torres Strait; (v) or some combination of these transport pathways occurs with relative degrees of importance.

Given that the water volume of the estuary remains constant, only the estuary coastline (and not estuarine island coastlines or channel depths) would be affected by progradation. If the estuary coastline is prograding offshore at the same rate as the delta front (i.e. about 6 metres/year) the volume of sediment accretion may be estimated. Beach gradients along the coastline are unknown. However, assuming a steep beach profile of 10°, net vertical accretion would be about 50cm/year. Progradation of the coastline requires 160 kilometres (length of coastline) x 6 metres (progradation per year) x 0.5 metres/year = 480,000 m^3/year. This demonstrates that the amount of sediment required for coastline progradation is very small compared with the discharge of the Fly.

A large portion of Fly sediments may also be transported northeastwards in suspension load advected via wind-driven currents, to be deposited in the Gulf of Papua and in the shallow waters to the north of 8° 30' (the northern limit of the present study area). Such a pattern is consistent with seismic profiling observations of the present study, which showed a 30 metre thick parallel bedded shelf sequence adjacent to the Delta (Figure 7 line A) together with an increasing thickness of deltaic sediments towards the north (Figure 7); only a relatively thin layer was found in the southern part of the Fly Delta.

Recent studies in the Fly Estuary have revealed the presence of fluid muds in the Southern and Northern Entrances (E. Wolanski, pers. comm.). Fluid mud could provide another transport pathway for sediments out of the Estuary and across shelf isobaths in the form of a density current. Such density currents would follow submarine drainage channels such as the submarine valley located to the north of Bramble Cay (Figure 5).

Sediment is transported in suspension load out of the Fly Estuary and to the west along the southern coastline of PNG, affected by wind-driven currents during the SE trade wind season (Figure 4). About 90 kilometres of the southern PNG coastline is thought to be supplied by the Fly River (Ok Tedi Mining Ltd., 1988) which would trap about 270,000 m^3/year of sediment assuming the same progradation and beach slope values as in the estuary (see above). Low lying offshore islands of the southern PNG coastline (such as Daru Is.; Figure 1) are comprised of 2.8 to 4.2 metres thickness of Holocene "swamp peats" overlying recrystallised carbonate bedrock (Barham and Harris, 1983); the islands probably do not trap a significant quantity of sediment.

It is not known how much of the sediment in transit from east to west bypasses the southern PNG coastline altogether and makes its way into the seagrass meadows of the northeastern Gulf of Carpentaria (see Harris, 1988, for distribution of seagrasses in the area), but this amount is probably small compared with the discharge of the Fly.

Sediment transported southwards from the Fly Delta and deposited in the Torres Strait area is also small in comparison with Fly discharge. Surficial sediments in Torres Strait contain generally less than 40% terrigenous mud (Harris, 1988) and are accreting slowly at about 0.02 cm/year (Figure 11). Extrapolating these average values over the Torres Strait area (about 22,500km^2) suggests that about 1.8 million m^3/yr of terrigenous mud is deposited (i.e. about 2% of the annual sediment discharge of the Fly).

It may be concluded, therefore, that of the 85 million tonnes/yr of sediment delivered to the Fly Estuary, about 1/2 to 1/3 is deposited in the adjacent Fly Delta and most of the rest is transported offshore into the Gulf of Papua. Further studies are required to define the depositional environments of the Gulf of Papua and other areas receiving Fly River mud before a more detailed sediment budget will be possible.

A Possible Explanation for the Termination of the GBR at 9°S

Does the input of Fly River sediment (and/or freshwater) actually limit the growth of corals north of 9°S? The present understanding of sediment transport pathways would seem to indicate that very little Fly River sediment is deposited south of Bramble Cay (Figures 7 and 11). Similarly, low salinity (<30°/oo) water appears to be trapped against the coast of Papua New Guinea during much of the year (Figure 5). Salinity at the northern end of the shelf-edge barrier reef does not fall below 34°/oo at any time during the year (Fig. 5). Areas where low salinity water has been reported (i.e. in the vicinity of the Warrior Reefs) also support living coral reefs. It would appear that there is no simple correlation between the dispersal of freshwater and terrigenous mud and the northern limit of coral growth in the GBR.

An alternative explanation may be provided by the high resolution seismic data (Figures 8 & 9). This shows what are interpreted as buried reefs occurring throughout the northern Great North East Channel and adjacent to the Fly Delta. The sediments which cover these buried reefs appear to have been deposited during low sea level stands by the action of fluvial processes, shown in seismic sections as cut and fill features. Thus the reefs were buried by prograding fluvial sediments during the Pleistocene. Buried reefs have been described in deeper seismic sections in this same general area (Davies *et al.*, 1989).

The fact that there are buried reefs is not meaningful in itself until it is realized that every reef which has been drilled in the GBR to date has been found to have Pleistocene reefal limestone as a foundation (Davies *et al.*, 1983). Upon the flooding of the shelf during the post-glacial sea level rise, reef growth was thus restricted to relict limestone surfaces. The reason there are no reefs north of the 9^{o} boundary might be that there were no exposed limestone surfaces available for coral colonisation in this area when the post-glacial sea level rise flooded the shelf around 9,000 years ago. In this context, the coral shingle banks described from submersible expeditions in the Gulf of Papua (R. Pitcher, this volume) represents coral growth in the absence of such limestone foundations.

Conclusions

Sediment supplied to the marine environment by the Fly River passes through a complex transport system. In the Fly Estuary, sediment is reworked and fine and coarse grained sediment fractions are separated, with sands trapped in sandbank deposits and muds removed offshore. The delta front is a transitional zone where tidal currents are supplemented by surface waves to further rework and winnow fine grained sediments (which are deposited offshore in the pro-delta environment). Fluvial discharge events yield seasonally varying, interbedded mud-sand sequences, accreting at rates of around 0.5 cm/year. With increasing distance offshore (and increasing depth) the wave and tidal energy diminishes, giving way to low energy pro-delta deposition.

Pro-delta deposits are located in water depths of between 17 to 45 metres. They accrete rapidly (at rates of 3 to 5 cm/year) and are massively bedded, showing little if any evidence of the sediment reworking processes affecting delta front deposits. Pro-delta muds represent about 65% of the deltaic sequence. The rate of deltaic sedimentation is one to two orders of magnitude greater than shelf accumulation rates. Over long time scales (1,000s of years), the delta will therefore prograde over the shelf deposits.

Less than 50% of the sediments entering the Fly system are deposited in the Delta, the rest being dispersed over the adjacent shelf regions. Preliminary estimates suggest that less than 2% of Fly River sediments are deposited in the Torres Strait area. A large proportion is deposited probably in the Gulf of Papua.

The present input of water and sediment by the Fly is restricted to a zone close to the coast of Papua New Guinea. There is no simple correlation between the occurrence of Fly River muds, low salinity water and the limited reef growth found north of the 9° boundary. Since modern reefs in the GBR have Plesitocene limestone foundations, it may be that the unavailabilty of comparable relict limestone exposures has restricted reef growth in the area.

Acknowledgements

The author is grateful to the Australian Defence Science and Technology Organisation and the CSIRO/University of Sydney grant scheme for financial support. The Royal Australian Navy provided the author with ship time on HMAS 'Cook' and HMAS 'Flinders' for this project. Vibro-coring and boomer seismic equipment used to collect data referred to in this contribution was purchased by a grant awarded by the University of Sydney. Thanks to my colleagues Elaine Baker, Alison Cole and Jock Keene who critically reviewed earlier versions of this contribution and to Brenda Durie who drafted the figures.

References

Baldwin, B. and Butler, J.R. (1982), Hamilton's Indonesia map and the Appalachian mountain system, *Journal of Geological Education*, 30,93-96.

Barham, A.J and Harris, D.R. (1983), 'Prehistory and palaeoecology of Torres Strait', In, P.M. Masters and N.C. Flemming (eds.), *Quaternary Coastlines and Marine Archaeology*, Academic Press, London, 529-557.

Belperio, A.P. and Searle, D.E. (1988), 'Terrigenous and carbonate sediments in the Great Barrier Reef province', In, L.J. Doyle and H.H. Roberts (eds.), *Carbonate - Clastic Transitions*, Elsevier, Amsterdam, 143-174.

Blake, D.H. and Ollier, C.D. (1969), 'Geomorphological evidence of Quaternary tectonics in southwestern Papua', *Rev. Geomorphol. Dyn.*, 19,28-32.

Blake, D.H. and Ollier, C.D. (1971), 'Alluvial plains of the Fly River, Papua. *Z. Geomorph. Neus Farbuch*, 12,1-16.

Bryce, S.M. (1988), Composition and distribution of surficial sediments in Torres Strait and the northern Great Barrier Reef. Unpublished B.Sc. (Hons.) Thesis, University of Sydney.

Conybeare, C.E.B. and Jessop, R.G.C. (1972), 'Exploration for oil-bearing sand trends in the Fly River area, western Papua', *The APEA Journal*, 12,69-73.

Davies, P.J., Marshall, J.F. and Radke, B. (1983), 'Growth Rates: Reefs of the central and northern province', In, J.T. Baker, R.M. Carter, P.W. Sammarco and K.P. Stark (eds.), *Proceedings: Inaugural Great Barrier Reef Conference*, Townsville, JCU Press, 95-98.

Davies, P.J., Symonds, P.A., Feary, D.A. and Pigram, C.J. (1988), 'Facies models in exploration - the carbonate platforms of north-east Australia', *The APEA Journal*, 28(1),123-141.

Dott, R.H. and Batten, R.L. (1976), 'Evolution of the Earth', 2nd ed., McGraw-Hill, New York.

Gagan, M.K., Chivas, A.R. and Herczeg, A.L. (1990), 'Shelf-wide erosion, deposition and suspended sediment transport during cyclone Winifred, central Great Barrier Reef, Australia, *Journal of Sedimentary Petrology*, 60,456-470.

Gillet, K. and McNeill, F. (1962), *The Great Barrier Reef and Adjacent Isles*, Coral Press, Sydney.

Harris, P.T. (1988), Sediments, bedforms and bedload transport pathways on the continental shelf adjacent to Torres Strait, Australia - Papua New Guinea', *Continental Shelf Research*, 8,979-1003.

Harris, P.T. (1989a), 'Sandwave movement under tidal and wind-driven currents in a shallow marine environment: Adolphus Channel, northeastern Australia', *Continental Shelf Research*, 9,981-1002.

Harris, P.T. (1989b), 'Metal pollution - fishermen pay', *Australian Fisheries*, April, 1989, 18.

Harris, P.T. and Baker, E.K. (in press), 'The nature of sediments forming the Torres Strait turbidity maximum', *Australian J. Earth Science.*

Harris, P.T., Baker, E.K. and Cole, A.R. (1990), *Sandwave movement, currents and sedimentation in Torres Strait: Results obtained during a cruise of HMAS Cook in April, 1990*, Ocean Sciences Institute, University of Sydney, Sydney. (Report No. 43)

Harris, P.T., Baker, E.K. and Schneider, P.M. (1989), *Sandwave movement, currents and sedimentation in Torres Strait: summary of data including results obtained during a cruise of HMAS Flinders in February, 1989*, Ocean Sciences Institute, University of Sydney, Sydney. (Report No. 40)

Harris, P.T., Davies, P.J. and Marshall, J.F. (1990), 'Late Quaternary sedimentation on the Great Barrier Reef continental shelf and slope east of Townsville, Australia', *Marine Geology*, 94,55-77.

Harris, P.T., Schneider, P.M. and Baker, E.K. (1988), *Currents, sedimentation and sandwave migration in the Great North East Channel and Adolphus Channel areas of Torres Strait: report on measurements taken during HMAS "Cook" cruises, 1988*, Ocean Sciences Institute, University of Sydney, Sydney. (Report No. 28)

Higgins, R.J., Pickup, G. and Cloke, P.S. (1987), 'Estimating the transport and deposition of mining waste at Ok Tedi', In, C.R. Thorne, J.C. Bathurst and R.D. Hey (eds.), *Sediment Transport in Gravel-bed Rivers*, John Wiley and Sons, New York, 949-976.

Jaques, A.L. and Robinson, G.P. (1977), 'The continent island/arc collision in northern Papua New Guinea', *BMR Journal of Australian geology and Geophysics*, 2,289-303.

Jukes, J.B. (1847), Narrative of the Surveying Voyage of H.M.S. Fly, Commanded by Captain F. P. Blackwood, R. N. in Torres Strait, New Guinea and Other Islands of the Eastern Archiplelago During the Years 1842-1846, T & W. Boone, London, Vols. I and II.

Kracik, M.E.P. (1990), Holocene Sea-Level Transgression on Carbonate - Fluvio - Deltaic Sediments, Torres Strait. Unpublished B.Sc. (Hons.) Thesis, University of Sydney.

Loffler, E. (1977), *Geomorphology of Papua New Guinea*, ANU Press, Canberra.

MacFarlane, J.W. (1980), *Surface and bottom sea currents in the Gulf of Papua and western Coral Sea*, Department of Primary Industry, Port Moresby. Research Bulletin No. 27.

Maxwell, W.G.H. (1968), *Atlas of the Great Barrier Reef*, Elsevier, Amsterdam.

McGhee, K. (1985), 'Remote PNG mine may threaten northern reef', *Bulletin*, Australian Littoral Society, 8(2),1-3.

Milliman, J.D. and Meade, R.H. (1983), 'World-wide delivery of river sediment to the oceans', *Journal of Geology*, 91,1-21.

Mowbray, D. (1986), 'Pollution problems in Papua New Guinea: Ok Tedi', *Siren*, 31,11-14.

Mulhearne, P.J. (1989), Turbidity in Torres Strait, Maritime Systems Division, Weapons Systems Research Laboratory, DSTO, Salisbury. (Technical Memorandum WSRL-TM-35/89)

Ok Tedi Mining Ltd. (1988), Sixth Supplemental Agreement Environmental Study, 1986-1988, Final Draft Report, Ok Tedi Mining Limited, Boroko and Tabubil. (Vols. I, II & III)

Ok Tedi Mining Ltd. (1989), Supplementaray Investigations Report, Ok Tedi Mining Limited, Boroko and Tabubil. (Vols. I, II & III)

Paijmans, K., Blake, D.H., Bleeker, P. and McAlpine, J.R. (1971), 'Land resources of the Morehead-Kiunga area', CSIRO Aust. Land Res. Ser., No. 29.

Pickard, G.L., Donguy, J.R., Henin, C. and Rougerie, F. (1977), *A review of the physical oceanography of the Great Barrier Reef and western Coral Sea*, Australian Institute of Marine Science, Townsville. (Monograph Series Vol. 2)

Pickup, G. (1984), 'Geomorphology of tropical rivers I. landforms, hydrology and sedimentation in the Fly and lower Purari, Papua New Guinea, In, A. P. Schick (Ed.), *Channel Processes - Water, Sediment, Catchment Controls*, (Catena Supplement 5)

Postma, H. (1967), 'Sediment transport and sedimentation in the estuarine environment', In G.H. Lauff (ed), *Estuaries*, (American Assoc. Adv. Sci., Publ. 73).

Royal Australian Navy Hydrographic Service (1974), Daru Roads to Kerema Bay, 1:300,000 scale nautical chart, AUS 378.

Spencer, L. (1975), The style and mechanisms of recent sedimentation in the sub-aerial estuary of the Fly River Delta, Papua New Guinea. Masters Preliminary thesis, University of Sydney.

Spencer, L. (1978), The Fly Estuarine Delta, Gulf of Papua, Papua New Guinea. M.Sc. Thesis, University of Sydney.

Taylor, D.J. (1973), A preliminary investigation of the marine geology of the Fly River estuary, Papua. Unpublished Report, University of Sydney, Department of Geology.

Taylor, L.W.H. (1977), The Western Coral Sea: Sedimentation and Tectonics. Unpublished Ph.D. Thesis, University of Sydney.

Thom, B.G. and Wright, L.D. (1983), 'Geomorphology of the Purari Delta', In T. Petr (ed.), *The Purari - Tropical environment of a high rainfall river basin*, Junk, The Hague, 47-65.

Torgersen, T., Jones, M.R., Stephens, A.W., Searle, D.E. and Ullman, W.J. (1985), 'Late Quaternary hydrological changes in the Gulf of Carpentaria', *Nature*, 313,785-787.

Wolanski, E.J., Pickard, G.L. and Jupp, D.L.B. (1984), 'River plumes, coral reefs and mixing in the Gulf of Papua and northern Great Barrier Reef', *Estuarine, Coastal and Shelf Science*, 18,291-314.

Wolanski, E.J., Ridd, P. and Inoue, M. (1988), 'Currents through Torres Strait', *Journal of Physical Oceanography*, 18,1535-1545.

Wolanski, E.J. and Ruddick, B. (1981), 'Water circulation and shelf waves in the northern Great Barrier Reef lagoon', *Australian Journal of Marine and Freshwater Research*, 32,721-740.

Wolanski, E.J. and Thomson, R.E. (1984), 'Wind-driven circulation on the northern Great Barrier Reef continental shelf in summer', *Estuarine, Coastal and Shelf Science*, 18:271-289.

Copper and Zinc Distribution in the Sediments of the Fly Delta and Torres Strait

Elaine K. Baker, Ocean Sciences Institute
University of Sydney

Abstract

The Fly delta extends for approximately 30 kilometers offshore from the southern coast of Papua New Guinea. The area is dominated by fine grained terrestrially derived muds. To the south the region of Torres Strait is represented by predominantly carbonate sediments.

High levels of zinc and copper (maximum values of 110 and 35 ppm respectively) were found to be associated with the terrigenous sediments. These concentrations are comparable to those reported for industrialized areas around the world. Possible sources of the metals include erosion and drainage of the highly mineralized rocks found in the catchment area and the input of contaminated mine waste into the system.

A linear correlation was found to exist between the copper and zinc concentration and the distance of sample sites from the estuary. A correlation was also found between the percentage of fine grained particles (< 63 mm) and copper concentrations.

This study indicates that future work should investigate historical changes in copper and zinc concentrations in the sediments and the ultimate fate of metals associated with the particulate matter in the Fly River.

Introduction

Torres Strait is an important ecosystem with a cultural identity that supports a subsistence fishery for indigenous peoples and more recently a commercial fishing industry. Changes to the integrity of the system, as a result of resource development, could have major repercussions for the island communities.

The Strait is a shallow stretch of continental shelf, transected by a number of passages, that separates Australia from Papua New Guinea to the north. Surficial sediment maps of the area illustrate a predominance of carbonate sediments, with terrestrially derived material mostly restricted to the north in the vicinity of the Fly River (Harris and Baker, 1989).

Recent mining developments in the catchments of the Fly and Strickland Rivers have the potential to increase metal levels in the sediments of the Strait. At present mine waste and overburden dumped into the river system contains elevated levels of both copper and zinc. Increased erosion and runoff caused by associated land clearing may also contribute to an increase in metal levels in the sediments.

This study is concerned with the distribution of copper and zinc in the offshore sediments. Both of these metals are essential for metabolic activity in marine and estuarine organisms. However, they become highly toxic when natural concentrations are exceeded. Acute toxicity is generally caused by interference in enzyme systems and death is fairly rapid (Bryan, 1976). Sublethal or chronic effects however, can be very subtle and not immediately discernible. They usually result in changes to growth and reproductive success (Bryan, 1976). Mammals are far less sensitive to copper and zinc than invertebrates, and freshwater organisms are more sensitive than marine organisms (Hart, 1982).

Heavy metals like copper and zinc can be transported down river in dissolved or particulate form. The suspended particulate material may be deposited when it enters the estuary and encounters the reduced energy conditions of the adjacent mangrove swamps, or it may continue to be carried in the water column out into the Strait. The process of deposition in the estuary is aided by the increasing salinity and pH which causes the colloidal clay particles to flocculate and settle. A large amount of the metal ions present may be adsorbed on to this particulate matter, which means that estuaries are often viewed as sinks for heavy metals (eg. Olsen *et al.*, 1982). The desorption of metals from particulates has also been observed in estuaries. This is important as metals in solution are generally more available to be taken up by organisms. The dissolved metals may exist as free metal ions, or form complexes with iron and manganese hydroxides and organic molecules. Evidence also exists indicating that metals associated with the mud accumulating in estuaries can escape (Summerhayes *et al.*, 1985). This remobilization can be bought about by changes in the chemical and physical conditions, which include resuspension by bottom currents, dissociation into pore water during diagenesis and the action of bacteria and bioturbating organisms.

The model of the Fly estuary as a sink for heavy metals is also complicated by the presence of strong tidal currents that continually rework the estuarine sediments, effectively winnowing away the finer grained material, leaving a predominantly sandy deposit (Spencer 1975). Fine grained material is deposited in the delta, or further off shore (Harris, this volume)

Methods

Surficial sediment grab samples were collected from the HMAS Cook and the HMAS Flinders during 1989 and 1990 (see Harris, this volume Figure 11), using a Shipek sediment sampler. Prior to analysis the samples were stored in double acid washed polycarbonate containers kept in a cool room at 3°. A portion of the sample was sieved to determine gravel/sand/mud ratios (reported in Harris *et al.*, 1990). The samples used for metal analysis were oven dried then crushed using a tungsten carbide mill. Following this, duplicates were digested in high purity NHO3 and HClO4. Measurements were carried out in triplicate using flame atomic absorption. A number of international standards were also analysed, the results of which were within ± 7% of the recorded values.

Results and Discussion

Copper distribution in the surficial sediments is illustrated in Figure 1. The isograms parallel the coastline, illustrating a general decline in concentration with distance from the Fly River. The highest concentrations, of greater than 35 ppm, are found in the fine grained muddy samples of the delta, whereas the carbonate rich samples to the south have less than 10 ppm of copper. These contour lines may also indicate that the major transport pathway for copper associated with sediments is to the east or west rather than south into Torres Strait. This is further indicated by the pattern of carbonate distribution in the surficial sediments (Harris and Baker, 1991) which shows that the terrestrially derived muds are primarily restricted to the delta in the study area. Calculations by Harris (this volume) also indicate that only a small percentage of the Fly River sediment is deposited in Torres Strait.

That the Fly River is the most important source of copper in the area is confirmed by the correlation (r^2= 0.64) of copper concentration with distance from the delta (Figure 2). The concentration of copper in the surficial sediments may be influenced by the release of copper from particulate matter as it encounters the increasing pH and salinity of the estuarine water. There is also a significant correlation (r^2=0.709) between copper concentration and percentage mud in the sediments (fraction < 63 µm; Figure 3). This demonstrates that the copper is associated with the fine grained fraction of material that originates from the Fly River.

The general distribution of zinc (Figure 4) is similar to that of copper (Figure 1). The highest concentrations of greater than 110 ppm are found in the delta samples and the lowest concentrations of less than 70 ppm are found in the samples away from the coast. As with copper, there is a significant correlation between zinc concentration and distance from the delta (r^2=0.724, Figure 5). However, unlike copper there is not a significant correlation between zinc concentration and percentage mud in the sediments (r^2=0.374, Figure 6). This is due to high zinc concentrations associated with a band of sandy sediments extending just south of the delta front (see Harris, this volume). These sands are composed of relic carbonate grains that have been reworked and deposited as a lag, most probably following storm activity. The reason for the high zinc content is not yet clear.

There is no evidence to indicate whether increases in the concentration of either copper or zinc have occurred in the sediments in recent times. Schneider (1990) examined copper concentrations in one 5 metre core from the Fly Delta, collected in 1988.

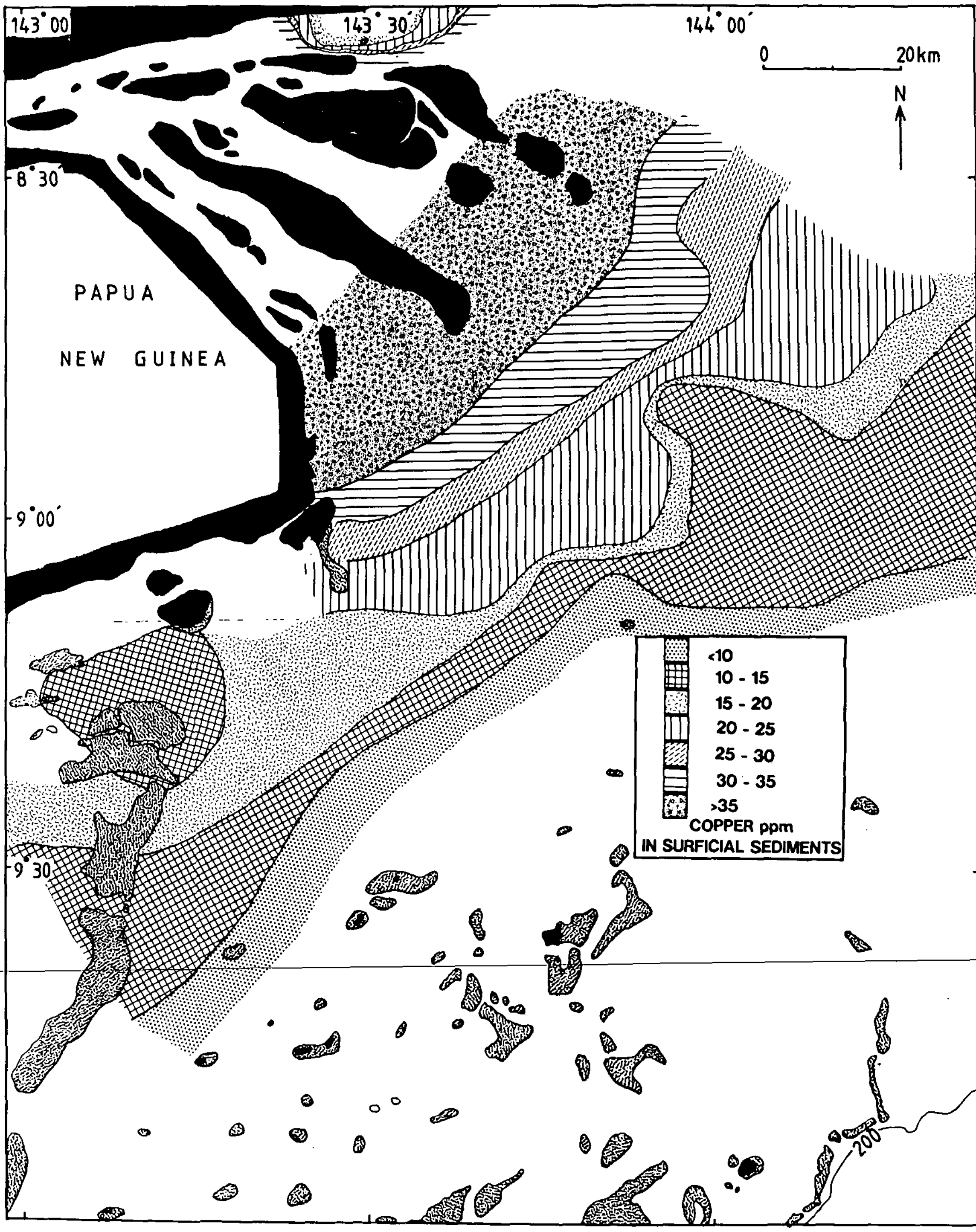


Figure 1. Map showing the distribution of copper (ppm) in the surficial sediments of the Fly River Delta and Torres Strait.

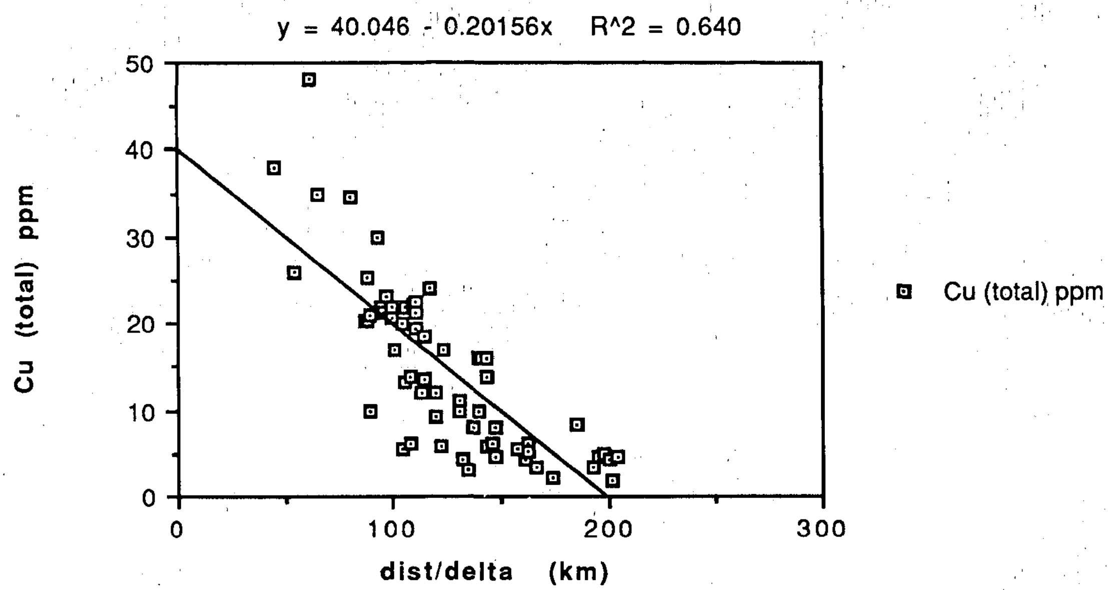


Figure 2. Graph of copper concentration (ppm) in the surficial sediments versus distance from the Delta (km).

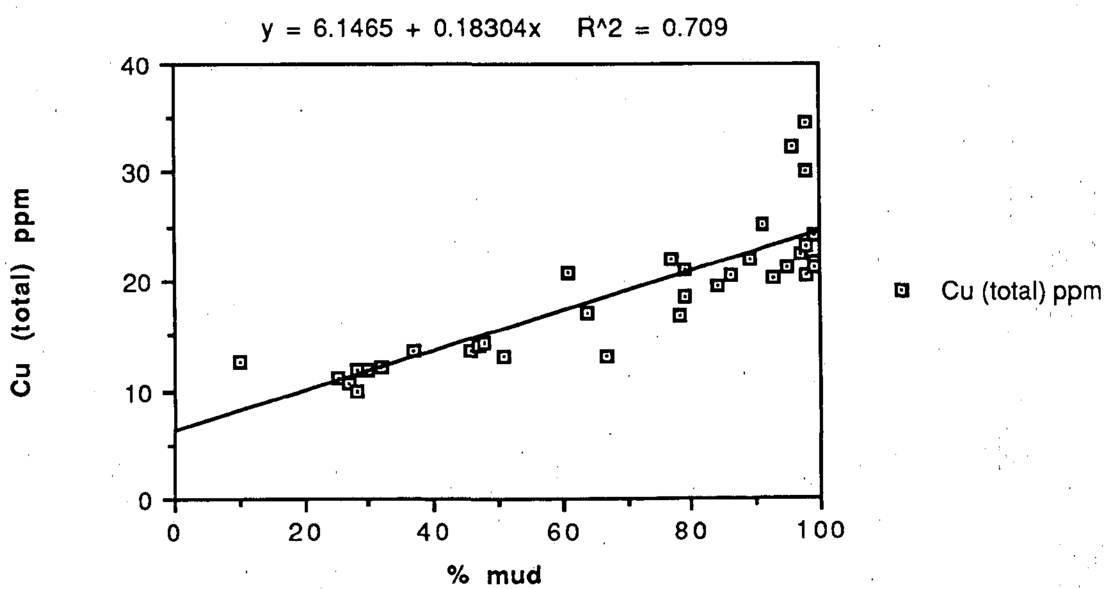


Figure 3. Graph of copper concentration (ppm) in the surficial sediments versus percentage mud (63 µm).

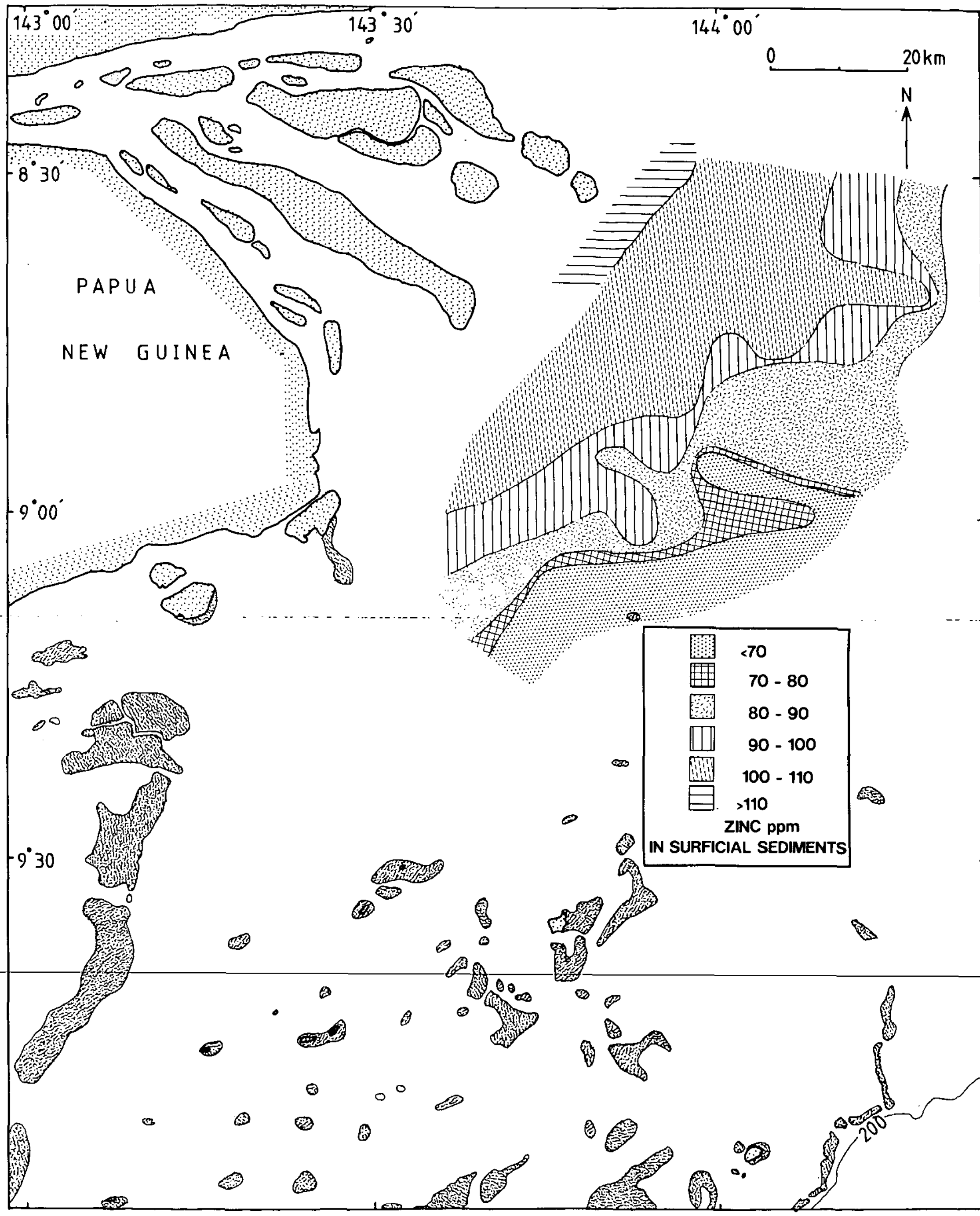


Figure 4. Map showing the distribution of zinc (ppm) in the surficial sediments of the Fly River Delta and Torres Strait.

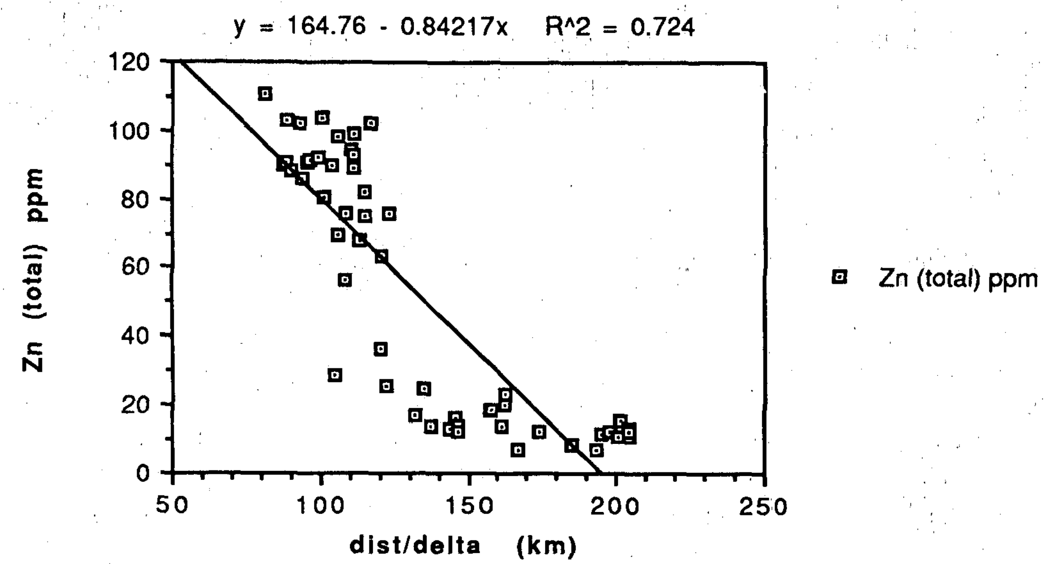


Figure 5. Graph of zinc concentration (ppm) in the surficial sediments versus distance from the Delta (km).

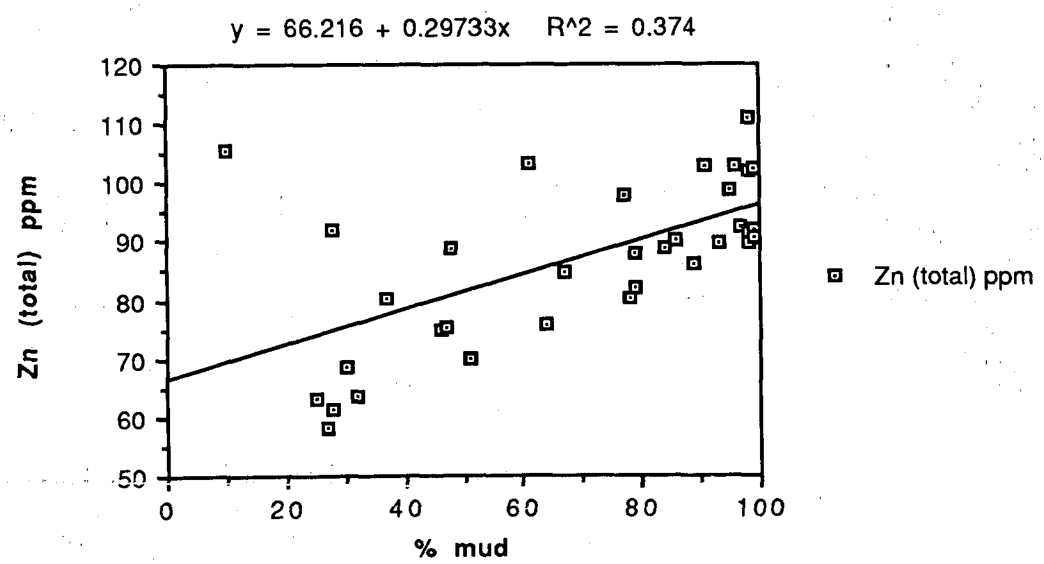


Figure 6. Graph of zinc concentration (ppm) in the surficial sediments versus percentage mud (63 µm).

Sedimentation rates calculated from Pb 210 ratios indicate this to represent over 100 years of sedimentation (Harris, this volume). Schneider (1990) found no apparent increase in metal levels at the top of the core. In fact this study found that there was a slight increase in concentration down the core. This may be due to mobilization of copper into the overlying water or migration of metals in the core following collection and exposure to oxidizing conditions. Alternatively, these values may represent background levels in this area, indicating that at least until 1988 there had been no effect on copper levels in the sediments as a result of mining activity or increased erosion and runoff in the catchment. However, this is the result of the analysis of one core and since 1988 there has been at least another 10 cm of sediment deposited in this location. Further work is required to generate a statistically meaningful conclusion.

If the concentrations of copper and zinc measured in the delta sediments represent background levels they may be naturally high due to the mineralized terrain of the catchment. Figure 7 compares the copper and zinc concentrations found in the Fly Delta with other locations around the world, illustrating that even if natural, these concentrations are on a par with many industrialized locations. The Ok Tedi mining company has constructed a model to predict the degree of copper contamination likely to occur in the delta sediments as a result of their operation. They have calculated a maximum value of 200ppm (Ok Tedi Mining limited, 1988), which is similar to the level found at the Los Angeles industrial outfall (Figure 7).

It should be noted that the copper and zinc concentration associated with the particulates may only represent a small fraction of the total metal input from the river. For example in the Gironde estuary it was found that 80% of the up-estuary trace metal input is in the particulate form, whereas the output to the ocean occurs mainly (80%) in dissolved form (Jouanneau, 1982). Such a situation may also occur in the Fly Delta (Solomons and Eagle, 1990).

Conclusions

The limited data collected to date point to the Fly River as the major source of copper and zinc in the Torres Strait area. The fate of sediment from the Fly River is not fully understood, although in the area examined the highest copper and zinc levels were found associated with the fine grained sediment of the delta. The relatively low levels of copper and zinc found in the Strait appear to indicate limited deposition of terrestrially derived sediments in this area. Levels of copper and zinc found in the delta sediments may represent background levels. This could be confirmed by analysis of core samples.

Specific conclusions of the present study are as follows:

- Copper and Zinc concentrations correlate well with distance from the delta, indicating that the Fly River is a point source for metals in the area.
- Copper is predominantly associated with the <63 μm fraction of the surficial sediments.
- Zinc correlates poorly with the fine grained fraction due to high concentrations associated with some sandy carbonate sediments.

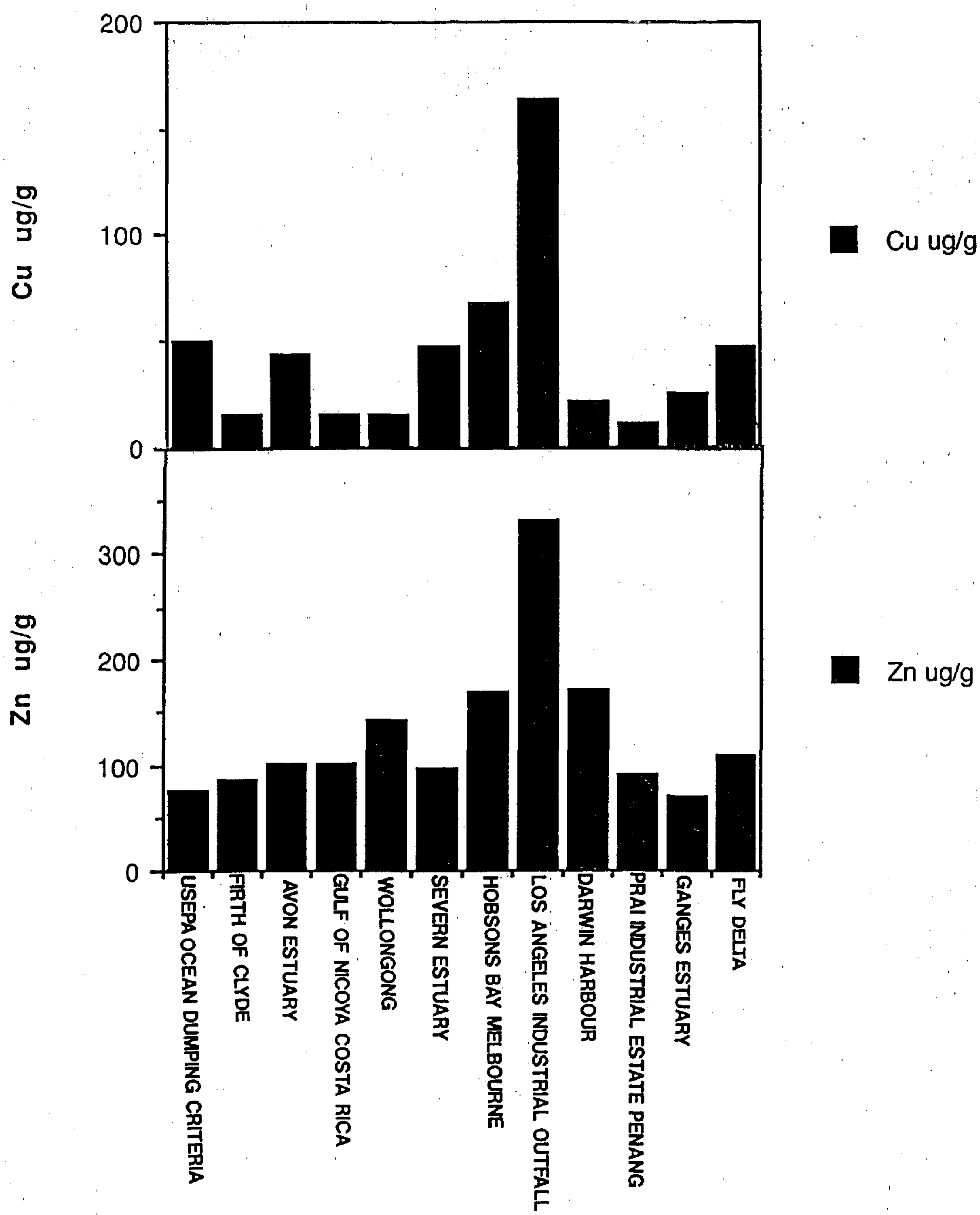


Figure 7. Bar Graphs showing copper and zinc concentrations in sediments from various locations including the Fly Delta (Adapted from Schneider, 1990)

References

Bryan, G.W. (1976), 'Heavy metal contamination in the sea', In R. Johnson (ed), *Marine Pollution.*, Academic Press, New York. 185-302.

Hart, B.T. (1982), *Australian water quality criteria for heavy metals* Aust Govt Pub Service, Canberra. (Australian Water Resources Council Technical Paper No. 77)

Harris, P.T. and Baker, E.K. (1991), 'The Nature of the Sediments Forming the Torres Strait Turbidity Maximum', *Aust. Jour. Earth Sci.* 38, 65-78.

Harris, P.T. Baker, E.K. and Cole A.R. (1990), *Sandwave movement, currents and sedimentation in Torres Strait: results obtained during a cruise of HMAS Cook in April, 1990,* Ocean Sciences Institute, University of Sydney, Sydney. (Report No. 43)

Jouanneau, J.M. (1982), Matières en suspension et oligo-éléments dans le système estuarien Girondin: comportement et flux. Thesis D.Sc., University of Bordeaux, no 732.

Olsen, C.R., Cutshall, N.H. and Larsen, J.L. (1982), 'Pollutant-particle associations and dynamics in coastal marine environments: A review', *Mar. Chem,* 11, 501-533 .

Ok Tedi Mining Ltd. (1988), *Sixth Supplemental Agreement Environmental Study. 1986-1988, Final Draft Report'*, OTML, Boroko and Tabubil. (Vols. I, II & III)

Salomons, W. and Eagle, A.M.(1990), 'Hydrology, Sedimentology and the Fate and Distribution of Copper in Mine-Related Discharges in the Fly River System, Papua New Guinea', *Sci. Tot. Environ,* 97/98, 315-334.

Schneider, P. (1990), Metal source and distribution in Torres Strait and related impacts to the Tiger Prawn Panaeus esculentus. Masters Thesis, University of Technology, Sydney.

Spencer, L. (1975), The style and mechanisms of recent sedimentation in the sub-aeriel estuary of the Fly River Delta, Papua New Guinea. Masters Prelim. Thesis, University of Sydney, Sydney.

Summerhayes, C.P., Ellis, J.P. and Stoffers, P. (1985), 'Estuaries as sinks for sediment and industrial waste – a case history from the Massachusetts coast, In *Contributions to Sedimentology.*

Fuchtbauer, H., Lisitzyn, A.P., Milliman, J.D., and Seibold, E. (eds.) (E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart), pp. 45.

Environmental Investigations of the Effects of the Ok Tedi Copper Mine in the Fly River System

A. Murray Eagle and Roger J. Higgins
Ok Tedi Mining Limited

Abstract

Environmental investigations have been undertaken by Ok Tedi Mining Limited (OTML) since 1981 when the Ok Tedi Environmental Study was commenced. An environmental monitoring and management program was implemented in 1983. The programs included water quality monitoring, river flow and sediment monitoring, surveillance of aquatic biological communities and a health and nutrition survey of the local people. These original programs have continued, and additional programs of work have been developed and revised to reflect changing operations and the need to focus investigations on specific areas and issues of concern. In April 1990, following the establishment by the Government of Papua New Guinea of environmental management criteria for the Fly River system, compliance monitoring programs were introduced. Details of the compliance and additional monitoring programs undertaken by OTML throughout the Ok Tedi and Fly catchments, including programs of investigation in the Fly River estuary, Gulf of Papua and Torres Strait, are presented.

Background

The Mount Fubilan ore-body is located in the headwaters of the Ok Tedi some 1000 kilometers inland from the Gulf of Papua (see Figure 1). The Ok Tedi drains to the south where it joins the Fly River approximately 200 kilometers downstream at d'Albertis Junction. Continuing to flow in a southerly direction, the Fly forms part of the border with Irian Jaya, and is joined by the Strickland River at Everill Junction

700 kilometers downstream of the mine. The combined system, flowing in a south-easterly direction, discharges to the Gulf of Papua 300 kilometres downstream of Everill Junction.

The Fly catchment is the largest in Papua New Guinea, occupying approximately 76,000 square kilometers. The Ok Tedi rises in an area of karst and ridge and ravine topography (Loffler, 1977), where mountains rise to more than 3,000 meters. Immediately south of Mount Fubilan, the ridge topography has a typical elevation of 600 meters decreasing to just 60 meters over a distance of 70 kilometers to Ningerum (see Figure 2). The Ok Tedi is cobble to gravel-bedded along this reach. The river is strongly constrained by the steep topography, and alternates between a single channel configuration in gorge-like reaches to a mildly braided configuration in wider reaches.

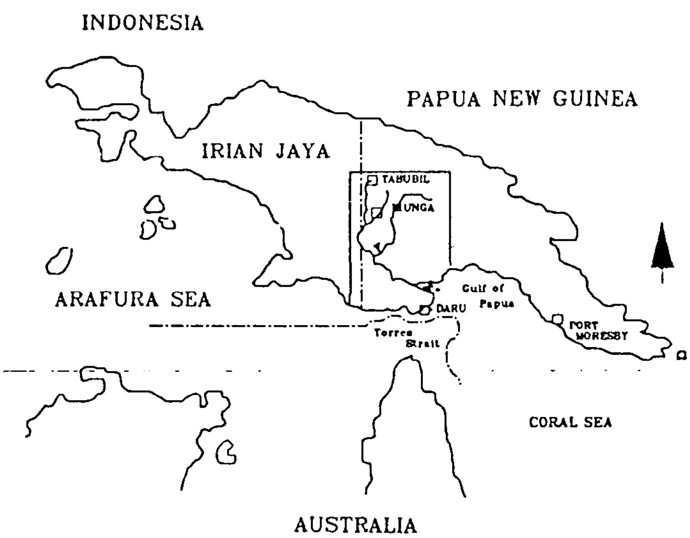


Figure 1. Locality Map

Ningerum is located on the border between the ridge and ravine topography and the northern limit of the Fly Platform. The Fly Platform is a vast alluvial plateau some 400 kilometers in width, with very little relief.

The morphology of the middle and lower reaches of the Fly River is strongly influenced by the geology of the Fly Platform. The platform is an extensive stable shelf area, comprising the vast plains and lowlands associated with the Fly and Strickland rivers, and a limestone plateau to the northwest of the lowlands. The sand-bedded Middle Fly is a low slope, meandering stream cut into the over-lying sediments. The floodplain is relatively narrow, widening from four kilometers near Kiunga, upstream of d'Albertis Junction, to over 14 kilometers near Everill Junction. Numerous oxbow lakes, well developed scroll bar complexes, and traces of old alluvial deposits occupy the inner floodplain. The outer floodplain is composed of backswamps, blocked valley lakes, and areas devoid of any evidence of channel migration. Lateral channel migration not exceeding a few meters per year is characteristic of the upper Middle Fly. River channel meander patterns gradually take on a stick-like configuration in the lower Middle Fly, characteristic of extremely slow channel migration rates. The lower Middle Fly is influenced strongly by backwater from the Strickland River.

The Fly is tidally influenced downstream of Everill Junction. Downstream of Lewada, the Fly rapidly fans out into a delta.

The Fly River estuary and delta cover an area of approximately 7100 square kilometers. The average water depth within the delta is less than 8 meters. Island formations and sediment distribution characteristics are symptomatic of a tidal current/river flow dominated system. These opposing forces result in a mass transport of water and sediments, which alternates in direction in accordance with tidal flows. It is expected therefore that the added mine-derived sediments are mixed extensively with resident estuarine sediments.

The waters of the Fly flow into the western portion of the Gulf of Papua, which is the shallow north-western extremity of the Coral Sea (see Figure 1). The western coast of the Coral Sea is fringed by the Great Barrier Reef, which extends north towards the Fly estuary. The Torres Strait forms a wide but shallow connection between the Gulf of Papua and the Gulf of Carpentaria to the west. The Gulf of Papua is also the receiving basin of a substantial volume of freshwater and natural sediments discharging from streams other than the Fly. These rivers include the Purari, Pie, Era, Kikori, Turama and Bamu, which have a combined freshwater discharge estimated at 8000 cubic meters per second, and an annual sediment load approaching 240 million tonnes per annum (Petr, 1983).

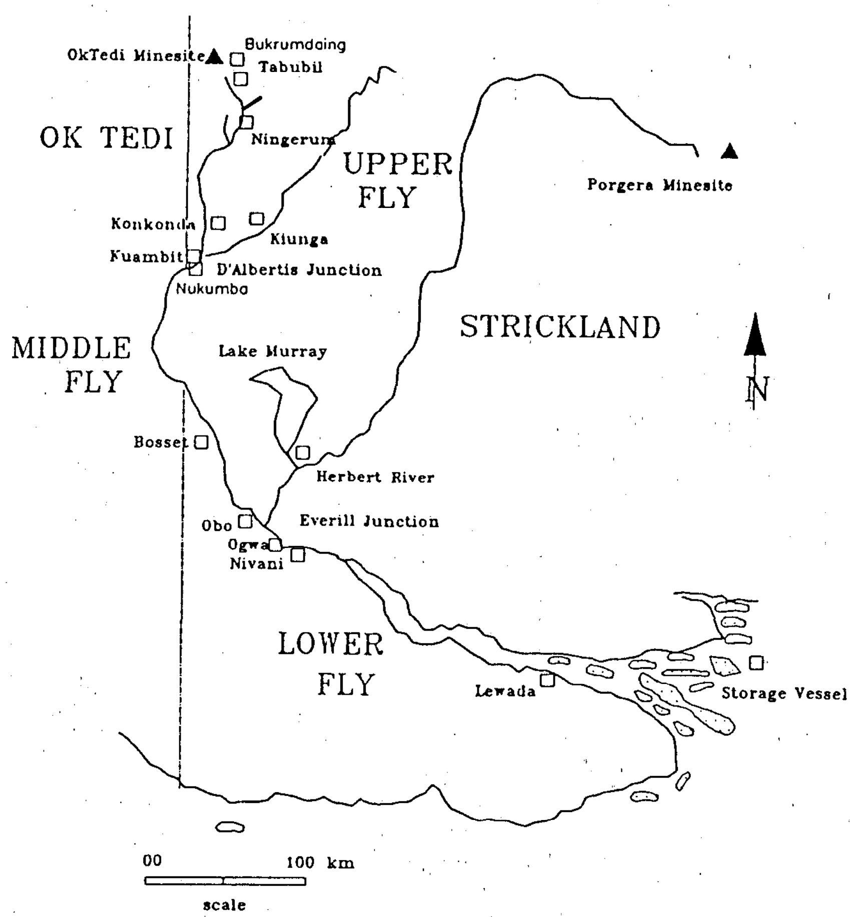


Figure 2. Fly River System

The ocean current circulations of the Gulf are influenced predominately by wind patterns and water depth. The winds of the area are monsoonal, with strong and persistant south-east winds from May to November and weaker more variable north-west winds from December to April. Current circulation patterns vary with the prevailing season. Current flows in the Torres Strait are also related to the prevailing season although current velocities are highly variable and therefore considerable deviations can occur throughout any year.

Rainfalls in excess of 10,000mm per annum are recorded in the upper catchments. Monthly rainfall totals vary little throughout the year. By contrast, in the south of the catchment, rainfall is influenced by the prevailing monsoons and trade winds which produce distinct wet and dry seasons. Rainfalls total 3,500mm per annum in these areas.

The high rainfalls recorded throughout the catchment lead to large surface runoffs. The hydrological parameters of the three major streams in the basin are summarised in Table 1, in terms of probability of exceedance. The locations of the various sites are shown in Figure 2.

Table 1. Flow Exceedances for Selected Stations Calculated from Daily Flow Data (m^3s^{-1})

Stream Location		Probablility of Exceedance				
		0.001	0.01	0.1	0.5	0.99
Ok Tedi	Bukrumdaing	380	80	50	23	3
	Ningerum	1060	810	480	240	21
	Konkonda	2080	870	1350	670	27
Fly River	Kiunga	2860	2460	1950	1110	57
	Kuambit		4430	3340	1820	120
	Obo			3500	2800	300
Strickland	Herbert			4500	3500	1200
Fly River	Nivani			7100	6000	1200

Natural sediment loads in the streams are also very large. The total annual sediment load at the mouth of the Fly is estimated to be 100 millions tonnes. The suspended sediment concentrations and sediment loads for various stations along the Ok Tedi, Fly and Strickland Rivers are presented in Table 2. The data show the importance of the Strickland River as the major sediment source for the Lower Fly. Large sediment loads result from the geological instability of the highland areas, the high rainfalls, steep slopes, seismic activity and cultivation of the land. Cultivation in the upper Strickland River catchment is particularly intense and is a major contributing factor to the sediment load of this major tributary of the Fly.

Landslides occur frequently in the upper Ok Tedi catchment. In 1977, a landslip estimated to contain 25 million tonnes of material occurred at the Hindenberg Wall, a vertical limestone escarpment in the headwaters of the Ok Kam, a tributary of the Ok Tedi. Debris from this landslip caused the bed of the Ok Tedi to rise by more than three metres some 50 kilometers downstream of the slide origin. More recently, in August 1989, a landslip totalling 160 million tonnes occurred in the Ok Gilor when a ridge adjacant to Mount Fubilan collapsed. The Ok Gilor is also a tributary of the Ok Tedi. Recent geomorphological investigations have identified the remnants of numerous other slides in the headwaters of the Ok Tedi, some of which are estimated to be orders of magnitude larger than recent recorded events.

Table 2. Suspended Sediment Loads for Selected Stations in the Fly Catchment

Stream	Location	Concentration (mgL^{-1})	Load ($Mtyear^{-1}$)
Ok Tedi	Bukrumdaing	50	0.04
	Ningerum	140	0.30
	Konkonda	140	6.90
Fly River	Kiunga	70	2.60
	Kuambit	110	8.00
	Obo	105	15.00
Strickland	Herbert	690	66.00
Fly River	Nivani	430	81.00
	Lewada	430	84.00

The aquatic fauna of the Ok Tedi and Fly River systems are dominated by species that have adapted to the physical characteristics of the catchment. For example, catfish species, a fish tolerant of high sediment concentrations, are endemic in the Fly and Strickland systems. On a recent geological timescale, severe physical disruptions have occurred to resident species habitats. Nonetheless, the Fly presently supports at least 120 species of fish and an equally diverse terrestrial fauna.

Vegetation in the catchment comprises alpine and montane forests in the upper regions, with the Middle Fly being a mixture of tropical swamp forests and savanna grasslands. To the south, vegetation is a mixture of forests, including extensive stands of mangrove and nipa palms, and more extensive grasslands to the west.

The high biological productivity of the Fly floodplains and associated wetlands provides major support for the aquatic fauna of the river system. Migratory fish species, such as the barramundi, depend largly on this productivity. Roaming almost the entire length of the Fly, barramundi seek out and reside in off-river water bodies during most of their migratory cycle. The barramundi, a large fish species of commercial value, does not spawn in the floodplains or river channel but migrates annually to the coastal areas west of the river mouth.

The interdependance between the river channel and floodplain in the maintenance of the fish resource is frequently interrupted by drought. Periods of drought, such as occurred during 1982 and 1986, result in a drying of the wetlands. The fish of the wetlands are significantly affected during these periods and populations have on occasions been substantially reduced. However, population recoveries are rapid with recolonisation occuring as a result of remaining resident stocks which have survived by taking refuge in stream channels.

High rainfalls, streamflows and sediment loads, frequent catastrophic landslips in the catchment highlands, the incidence of droughts and the diversity of the riverine fauna characterize this unique river system. The aquatic ecosystem is far from fragile and is substantially adapted to continuously changing conditions.

Mining Project

Mining of the orebody at Mount Fubilan commenced in 1984 following a lengthy period of project exploration, feasibility studies and construction. Initially, gold dore was produced using cyanide leach extraction. The gold production plant was decommissioned in September 1988 following the construction and commissioning of the copper processing facility. Copper production involves open pit mining of the ore followed by conventional froth flotation. A copper concentrate slurry is produced and transported by pipeline to the river port of Kiunga on the Fly River. At Kiunga, the concentrate is filtered and dried and shipped to a bulk handling trans-shipment port located off the Fly delta from where it is sold and shipped to overseas smelters.

Mine production involves copper bearing ores of a sufficiently high grade being excavated and hauled to a primary crusher before being transported by conveyor to a stockpile. The stockpiled material is progressively fed to a series of mills where the material is ground to fines. The fines are slurried and supplied to a flotation circuit in which copper and other precious metals are recovered. The process-residual materials are piped to the upper Ok Tedi headwaters (see Figure 3). The floatation process employed achieves copper recoveries in excess of 85% of the copper contained in the ore.

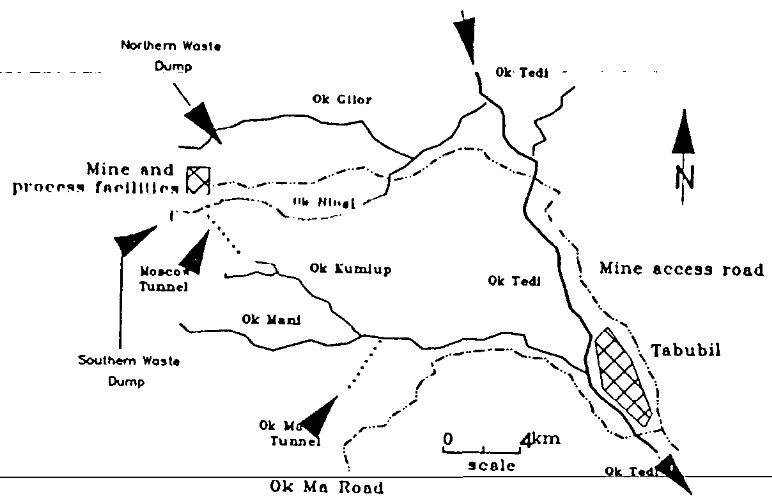


Figure 3. Minesite Localities

Overburden or waste rock is progressively removed from the mine in order to expose copper ore. This material is hauled to erodible waste rock dumps also located in the headwaters of the Ok Tedi.

The total planned tonnage of material to be mined in any year is around 66 million tonnes. Of this total tonnage, 30 million tonnes is processed as copper bearing ore and 36 million tonnes discharged as overburden. Although production can vary from time to time, these tonnages equate to 80,000 tonnes per day of processed ore and 100,000 tonnes per day of waste rock.

The material piped to the Ok Tedi as an ore residue is predominately fine with 76% of the material being less than 100 microns in diameter. The waste rock placed in eroding dumps is incompetent material and readily breaks down to fines. Approximately 55% of overburden breaks down to a size of less than 100 microns during transport in the Ok Tedi. Sediment transport studies have shown that the river systems are capable of transporting all material that is less than 100 microns in diameter as a suspended load through to the estuary and delta. Based on these size distributions, a calculated 31 million tonnes of mined material will enter the Fly River in an average year. The remaining 35 million tones of mined material is stored in the river valleys adjacant to the mine and in the channel of the Ok Tedi.

The environmental effects of the mining operation at Ok Tedi result from increased sediment loads and particulate copper concentrations associated with both ore residues and overburden.Process reagents used in the copper extraction process are non-persistant in the environment and are used in small quantities in terms of river flows and the effects of dilution.

Environmental Studies

Environmental investigations have been undertaken by OTML since 1981 when the Ok Tedi Environmental Study (Maunsell and Partners Pty. Ltd., 1982) was commenced. This study was the first comprehensive study conducted in the Fly River system and included an 18 month intensive monitoring period to establish the pre-operational chemistry of waters and sediments of the region. Biological sampling during the period of the study was expeditionary rather than routine.

An environmental monitoring and management program was implemented in 1983. The programs included water quality monitoring, river flow and sediment monitoring, surveillance of aquatic biological communities and a health and nutrition survey of the local people. These original programs have continued, and additional programs of work have been developed and revised to reflect changing operations and the need to focus investigations on specific areas and issues of concern.

In 1986, and following the abandonment of construction of a tailings dam due to a structural geological failure, further provisions were made for the management of wastes from mining and processing operations :

a) the deferral of a decision on permanent waste retention facilities until 1990, until which time much of the generated waste rock and mill ore residues would be allowed to be discharged to the river system, and;

b) the conduct of an environmental study to assess the impact of these discharges and to determine the extent of permanent facilities necessary to contain environmental impacts at acceptable levels during the remaining life of the mine.

Terms of Reference for the Study included revised schedules of monitoring and investigation agreed by OTML and the Government of Papua New Guinea (the State). This Study was designed to provide the data and analysis necessary for the determination of a level of suspended sediment in the Fly River (the Acceptable Particulate Level) considered by the State to provide an acceptable level of environmental protection for the system. Findings of the Study, including raw data, data analysis and interpretation, predictions of impact and implications for the disposal of ore residues and overburden were reported to the Government of Papua New Guinea as the Study progressed. The Study was completed in 1989 and the results and findings presented in full in a Final Draft Report (Ok Tedi Mining Limited, 1988) and Supplementary Investigations Report (Ok Tedi Mining Limited, 1989).

The Acceptable Particulate Level (APL)

Following receipt and evaluation of the study by the State, the Government advised the establishment of an APL of 940 mg/L. Compliance with the APL would be evaluated by reference to the upper 95% confidence limit of the mean suspended sediment concentration resulting from the Company's mining operations, determined over a moving period of 30 consecutive weeks.

An APL of 940 mg/L after allowing for sediment inputs from sources other than the mining operation, can be met notwithstanding the operation releasing mined sediments to the river systems at planned production rates.

The considerations in the setting of the APL were complex and included :

a) *Recognition of the Government's need to ensure that the Company's mining operations did not cause unacceptable environmental damage to the river system.*

b) *Recognition of the limited use of the area concerned, the need for it's development, the Governments desire for the project to proceed and be economically viable, and the effect the project must necessarily have on the environment.*

c) *That the APL should tend toward the maximum level at which significant environmental damage to the river system would not occur.*

d) *Recognition of a cost/benefit assessment of the facilities necessary to achieve compliance with incremental levels of suspended particulate matter.*

e) *Recognition that conventional data developed from studies in temperate regions and regions of lower rainfall may be of limited applicability to the river system.*

In setting the APL the State expressed a concern that the actual level of impact should not exceed the predicted impacts which formed the basis for the State's decision. To this end, and recognising that a single parameter (the APL) would not by itself provide a sufficient measure of an acceptable level of impact in the river system, additional environmental conditions were set in conjunction with the setting of the APL to ensure that:

a) *A useful and viable fish resource would be maintained in all parts of the Fly River channel by ensuring that:*

   i) *actual fish catches at sites specified by the Government do not decline below those of the Predictions.*

   ii) *copper contamination of the Fly River channel does not exceed the Predictions.*

b) The capacity of off-river water bodies to ensure the early recovery of the Fly River fish resource would be protected by ensuring that not more than 20% of the area of a representative selection of off-river water bodies is influenced by copper from mine wastes.

c) The biological resources of the Fly River delta, the Gulf of Papua and the Torres Strait would be protected by ensuring that the concentration of particulate copper entering the Fly River delta does not exceed the Predictions.

d) The navigability to an acceptable extent of the Fly River would be protected by ensuring that aggradation in the Fly River does not exceed the Predictions over the life of the mine.

A further provision of the APL decision was that an environmental monitoring program would be designed and implemented to allow the State to evaluate compliance with the APL and associated conditions. The compliance programs were designed by OTML in collaboration with the State and have three components, namely:

a) Monitoring suspended particulate concentrations and compliance with the APL.

b) Monitoring compliance with the four additional environmental conditions as specified.

c) Monitoring of additional environmental parameters throughout the Ok Tedi/Fly catchment to maintain continuity of the present data base. These additional programs would provide data needed for the calibration and further development of prognostic models to update and upgrade assessments of environmental impacts, and to observe and record the future variations in parameters which may or may not be influenced by OTML's operations.

The Predictions

The comprehensive database assembled through the monitoring, investigation and research programs, conducted since 1981, formed the basis for an assessment of the actual effects of the mining operation in the river systems since mining began. In order for the State to determine environmental compliance criteria for the future operation of the mine, an assessment of predicted impacts was necessary. Predicted effects to the end of mine life (2008) were based on projected mine plans and ore processing criteria. The methods employed are discussed below.

Sediment

Suspended sediment and river bed aggradation models were developed using a series of bedload sediment transport algorithms (Parker, 1990). The suite of models available comprised algorithms for the estimation of gravel transport, abrasion and deposition in the upper reaches of the Ok Tedi and sand transport and deposition in the lower reaches of the Ok Tedi and upper Middle Fly River. Both of these models calculated a finer fraction of material that is available for transport as a suspended sediment or wash load. The material was routed through the system using a third model producing estimations of the suspended sediment load per unit flow.

The sediment transport models used mine production tonnages, particle size distributions of the overburden and ore residues and abrasion coefficients as primary sources of input. The models have been extensively calibrated.

Geochemistry

The geochemical characteristics of copper in the river system and response to mined inputs were modelled based on a modification of the CHARRON water quality model developed specifically for OTML by Delft Hydraulics Laboratory (Ok Tedi Mining Limited, 1988). The model used a log-linear optimisation technique to calculate chemical equilibrium processes for segmented river reaches, recalculating the equilibrium composition as each system tributary was added. The model has been applied and calibrated to provide water quality predictions throughout the river system to downstream of the Strickland River junction.

The geochemical model used known chemical equilibrium process data, water quality characteristics of system tributaries and ore residue and overburden tonnages and their chemical characteristics as inputs.

Estuary

A simple flux model was developed that described potential particle bound-copper enrichment in estuary sediments (Ok Tedi Mining Limited, 1988). The model assumed static annual mine inputs, and by a discretisation process routed the annualised inputs through the estuary to ultimate deposition at the delta front. The model results showed a spatial and temporal distribution of copper enrichment in resident sediments.

Biology

Fish catch regression modelling was developed using a step-wise multiple regression procedure (Smith *et al.*, 1990). The variation in the Y variables (summary fish catch statistics such as total number or total biomass of fish caught) were explained as a function of a number of X variables (catchment area, suspended solids, dissolved copper, particulate copper and log(X+1) transformations of them. The X values were added to the models sequentially with the variable which could explain the greatest amount of variation added first. The variable which accounted for the next greatest amount of variation was added next and so on until the addition of another variable would not contribute significantly to the overall model. Using this general modelling procedure predictions for future fish catches in the river system were generated using predictions of suspended sediments, and dissolved and particulate copper based on the sediment transport and geochemical modelling described above.

The predictions to be used for testing whether or not the State's conditions for acceptable environmental protection of the Fly River system and offshore are met are given in Tables 3-5.

Table 3. Particulate and Dissolved Copper and Fish Catch for Kuambit/Nukumba, Obo and Ogwa

Year	**Kuambit/Nukumba**			**Obo**			**Ogwa**		
	pCu $ug\ g^{-1}$	*dCu* $ug\ l^{-1}$	*Fish* *kg*	*pCu* $ug\ g^{-1}$	*dCu* $ug\ l^{-1}$	*fish* *kg*	*pCu* *ug g-1*	*dCu* *ug l-1*	*Fish* *kg*
1990	1236	11	15	1202	17	35	524	3	95
1991	905	6	28	879	9	66	401	2	118
1992	715	3	38	693	5	94	321	1	135
1993	875	4	29	850	6	70	388	1	120
1994	581	3	49	564	4	119	270	1	147
1995	581	3	49	564	4	119	270	1	147
1996 to 2008	562	3	49	544	4	119	253	1	147

pCu=particulate copper dCu=dissolved copper Fish=standardised catch in 24 hours

Note: The predicted data presented in Table 3 show copper enrichment throughout the river system at a maximum in 1990 and declining significantly by 1996 and through to the end of mine life. The reason for this is that the proportion of oxide copper in the ore body reduces substantially by that time and is replaced by sulphide copper for the remainder of the mine life. Oxide ores are less amenable to the flotation process and therefore recoveries are lower. In addition, average ore head grades reduce as the ore body is developed and with planned production tonnages remaining nearly constant, a higher proportion of lower grade ore will be processed. Dissolved copper levels are shown to reduce to natural levels by 1992. The fish catch prediction data represent the biomass of fish caught during a standardised sampling period at these locations. As copper enrichment in the river system is reduced, the biomass of fish caught increases. By 1994, the biomass of fish caught is shown to be within the ranges of catches which may have been expected prior to the commencement of the mining operation. Although assessments have been made regarding a percentage fish reduction for the river system estimated relative to background levels, these are extrapolations and not actual direct effects in the river system or equivalent to the fish biomass predictions presented in Table 3. The compliance criteria established for the mining operation are designed and allow for the maintenance of a sustainable resource yield at which the subsistance and commercial use of the fish resource will be protected.

Table 4. Particulate Copper at Lewada and Mid-Delta

Year	*Lewada*	*35km d/s Lewada.*
1990	149	52
1991	174	64
1992	184	81
1993	201	100
1994	201	120
1995	200	139
1996	198	155
1997	195	168
1998	195	177
1999	192	184
2000	190	188
2001	189	190
2002	188	190
2003	187	191
2004	187	190
2005	186	190
2006	186	190
2007	185	188
2008	177	188

Table 5. Bed Aggradation at Kuambit

2.2 meters above 1984 bed level in 2008

Note: River cross-sectional surveys have been conducted on a regular basis since the mining operation began. In Table 5, the 1984 mean bed level is shown as the reference to which compliance will be measured. Annual compliance is measured by reference to a straight line interpolation between the indicated points.

APL Compliance Monitoring

For the purpose of measuring compliance with the APL, sediment sampling is carried out at weekly intervals by a standard depth integration method at eight vertical profiles in the river cross section at Nukumba in the Fly River (see Figure 4) Each measured suspended sediment concentration is corrected by discounting an estimated value for the concentration of suspended sediment arising from sources other than the Company's mining operation (Ok Tedi Mining Limited, 1990). The weekly results reported to the State include the cross-section suspended sediment concentration, stream flow, the suspended sediment concentration for each profile, the estimated contribution of suspended sediments from sources other than the mining operation and estimated concentrations and mass flows used in obtaining the discount.

Fish catch sampling is conducted at Kuambit, Obo and Ogwa using the standardised methods adopted during the 1986/1989 Environmental Study (Smith *et al.*, in press). Sample frequency is monthly at Kuambit and quarterly at Obo and Ogwa. Replicate sampling sites have been established at each station.

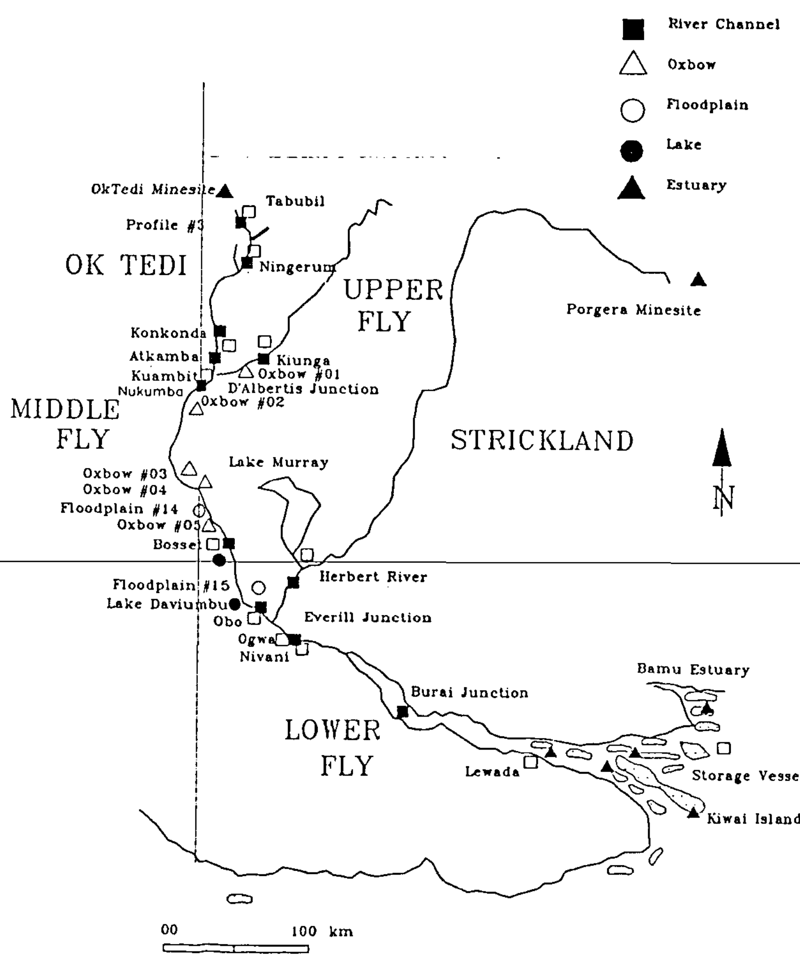


Figure 4. APL and Additional Monitoring Localities

Water samples for the analysis of dissolved copper are collected weekly at Nukumba and monthly at Obo and Ogwa. At all sites, samples are collected 0.5m below the water surface.

Water samples for the analysis of particulate copper at Nukumba are those collected for measuring suspended sediment concentrations for APL compliance monitoring. The cross-section concentration of particulate copper is determined by analysis of a composite sample formed by combining the depth integrated sediment samples at each profile.

At Obo and Ogwa, water samples are collected as gulp samples from 0.5m below the water surface at an appropriate number of locations in the cross section to obtain sufficient sediment for analysis.

The Fly River flood plain has been delineated and segmented into 50 sections of approximately equal area. Four deposited sediment samples are collected from each section, two each from an established water body and a floodplain location, using a core sampler. The material retained for analysis is the top 5mm wherever possible. Sampling frequency is annual.

Deposited sediments are collected quarterly from the Fly River estuary at four separate sites upstream of the outermost estuary island. A grab sampler suitable for sampling only the uppermost 150mm is used and three replicate samples are collected at each site.

Cross-section surveys are conducted at the Kumabit river gauging cross-section using standardised methods. Surveys are conducted quarterly.

The compliance monitoring program is summerised in Table 6.

Table 6. APL and Conditions Monitoring Programs

Stream	*Location*	*Frequency*	*Purpose*
Fly River	Kuambit/ Nukamba	Weekly	SS,pCu,dCu
		Monthly	Fish Catch
		Quarterly	Bed Level
Fly River	Obo/Ogwa	Monthly	pCu,dCu
		Quarterly	Fish Catch
Off-River Waters	Middle Fly	Annually	pCu(deposted)
Estuary	3 Sites	Quarterly	pCu(deposited)

pCu = particulate copper
dCu = dissolved copper
Fish catch = standardised biomass data
pCu (deposited) = particulate copper in sedimentary deposits
SS = suspended solids

Additional Monitoring and Investigations

Ok Tedi and Fly River System

In addition to programs of compliance monitoring, additional data collection is being carried out throughout the Ok Tedi and Fly River systems (see Tables 7 and 8). These programs are designed to supplement the compliance programs and provide the information necessary to allow the timely identification of potential and actual effects of the mining operation during the life of the mine.

Table 7. Additional Environmental Monitoring Program

Locality (1)	Biology							Geochemistry				Hydrology				
	Sampling (2)	Metals	Processing	Barramundi	Prawns	Fish	Crabs	Type 1	Type 2	Type 3	Type 4	Water Level	Flow	Bed Samples	Susp.Seds	X-Sections
Ok Tedi																
Profile #3								1	3							
Ningerum	6 (3)	6	6					1	3			C (4)	1		1	
Konkonda								1	3			C	1	1	1	1
Atkamba	1	3														
Upper Fly																
Kiunga	1							1	3			C	1	1	1	1
Oxbow #01	3							1	3							
Middle Fly																
Kuambit	1	3						1	3			C	1	1	1	1
Oxbow #02	3	12						1	3							
Oxbow #03	3	12														
Oxbow #04	3	12														
Bosset Lagoon	6	12							3		1					
Bosset	6	12						1	3				3	3	3	3
Flood FLD #14	6	12														
Oxbow #05	3	12						1	3							
Daviumbu	3	12							3		1					
Obo	3	12						1	3			C	3	3	3	3
Flood FLD #15	3	12						1	3							
Strickland																
D/S Herbert R	3	12						1	3			C	3	3	3	3
Lower Fly																
Ogwa	3	12						1	3				3	3	3	3
Burai Junction										3			6	6	6	6
Lewada										3			12	12	12	12
Estuary																
Bamu River		12			6	3	3			3						
Estuary #01		12		6	6	3	3			3						
Estuary #02		12			6	3	3			3						
Estuary #03		12			6	3	3			3						

(1) See Figure 4 for locations
(2) See Table 8 for definitions
(3) Numbers denote months between samples
(4) Continuous analogue record

Table 8. Sample Types and Analyses

Biology	Hydrology/Sediment Transport
Sampling – fish catch statistics	Water Level – continuous water level record
Metals – metals in tissues and organs	Flow – stream discharge measurements
Processing – diet analysis and condition indicies	Bed Samples – bottom grab samples
Barramundi – large commercial fish species	Susp. Sediments – depth intergrated samples
Prawns – prawn catch statistics	X-Sections – aggradation/deposition data
Fish – fish catch statistics	
Crabs – crab catch statistics	

Geochemistry					
Location	Type 1	Type 2	Type 3	Type 4	Legend
Profile #3	M	Q			Type 1 – pH, alkalinity, conductivity
Ningerum	M	Q			suspended solids, dissolved oxygen.
Konkonda	M	Q			dissolved Ca, Mg, Cu, Zn, Fe, Mn.
Kiunga	M	Q			particulate Cu, Zn, Mn, Fe, CEC
Nukamba	M	Q			
Bosset	M	Q			Type 2 – Type 1 analysis plus
Obo	M	Q			dissolved organic carbon, total
Strickland	M	Q			organic carbon, particulate aluminum
Ogwa	M	Q			particulate sulphur
Burai Junction			Q		Type 3 – Type 2 analysis plus
Lewada			Q		dissolved Na, K, silica, sulphate
Oxbow #01	M#	Q			and chloride
Oxbow#02	M#	Q			Type 4 – pH, conductivity, alkalinity
Bosset Lagoon		Q		M	dissolved oxygen.
Oxbow #05	M#	Q			M = monthly
Floodplain #15	M#	Q			M# = monthly for dissolved component of Type 1.
Lake Daviumbu		Q		M	Q = quarterly

Estuary and Gulf of Papua Coastal Waters

Programs of geochemical, biological and hydrodynamic process investigations and research are being conducted in the Fly estuary, Gulf of Papua and the Torres Strait. The objectives of these studies are to:

1. Investigate and monitor the geochemical and biological response to mined sediments.

2. Assess the fate of mined sediments in the estuarine and offshore regions.

The studies are being supported by Delft Hydraulics Laboratory (DHL) in collaboration with the Institute for Soil Fertility and Research (ISFR) of the Netherlands, the Australian Institute of Marine Science (AIMS) and Australian National University (ANU). Logistical support is provided by the OTML research vessel 'Western Venturer'.

The following summary outlines the programs of work being conducted in the Fly River estuary, Gulf of Papua and Torres Strait (see also Figures 5 and 6).

Geochemical Program

A variety of geochemical experiments were conducted in 1988 by DHL and ISFR to assess the kinetics of metal release processes in the estuarine inter-tidal zone of the Fly estuary. In addition, a water quality model based on these experiments was developed by DHL for the estuary and Gulf of Papua waters. The model lacked detailed information on the hydrodynamics and current circulation patterns of the systems but enabled impressions to be formed of the likely fate of copper in these waters. This information was used as a basis for formulating the monitoring and research requirements of the present programs.

The geochemical program has laboratory experimentation and system surveys and monitoring as separate components.

Laboratory

The laboratory component includes:

(a) Batch experiments using a series of samples from mine overburden, ore residues and natural sediments to:

(i) distinguish between rapid kinetic processes (cation exchange) and slower processes (desorption of tightly-bound copper). These experiments involve removal of the exchangeable copper fraction from samples and subsequent leaching in sea water.

(ii) determination of the effect of observed pH changes in the estuarine environment on copper desorption rates.

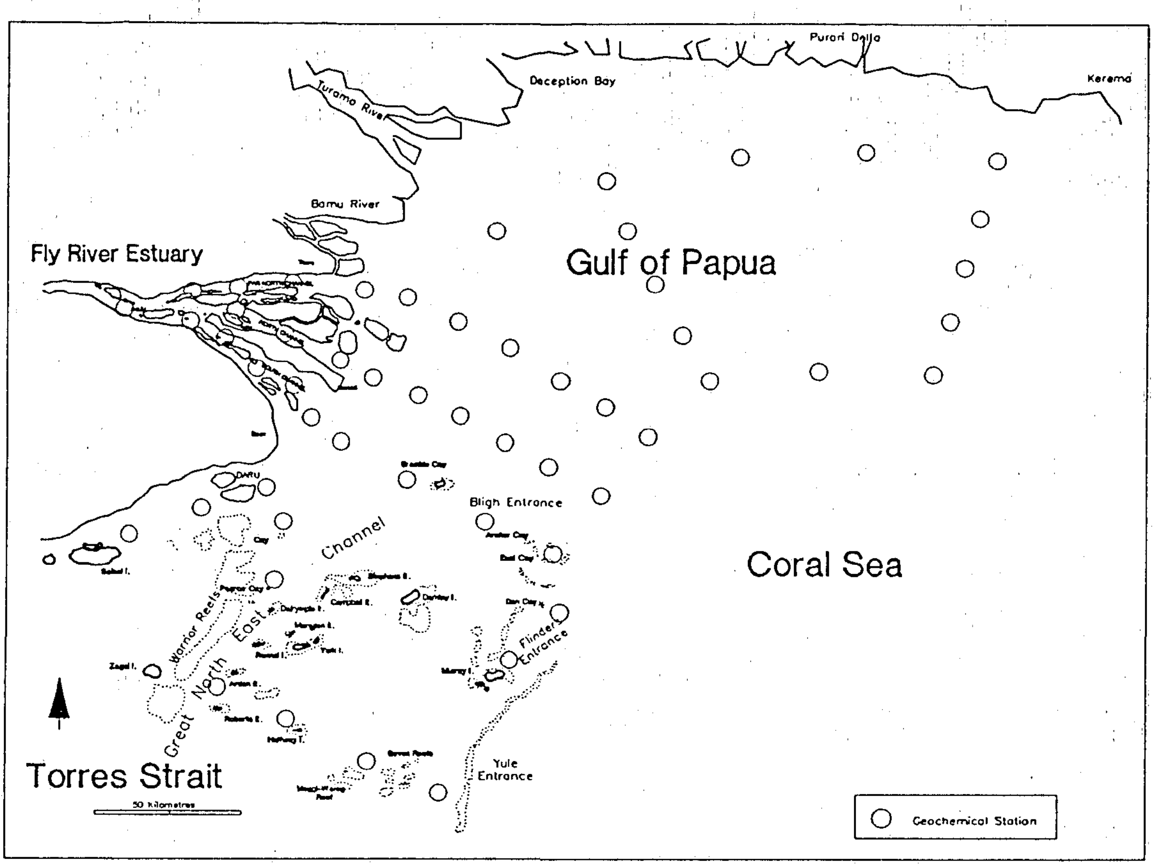
(iii) comparison of rates of release of artificially adsorbed copper on sediments to those of mined sediments.

(b) Flow-through experiments to simulate the transport of mined sediments through a salinity gradient to determine the influence of estuarine processes on particulate copper.

(c) Based on the experimental results of (a) and (b) above, developement of an algorithm for estuarine release processes for incorporation in the geochemical dispersion model DELWAQ.

Data Collection and Monitoring

Systematic collection of deposited and suspended sediments and waters in the estuarine and offshore environments is being undertaken to determine existing metal and water quality characteristics for model calibration. The field data collection programs and sampling protocols are shown in Figures 5 and 6.



Sample Frequencies

Off-shore: Six-monthly over one tidal cycle

Estuary: Six-monthly over two tidal cycles

Parameters

Salinity

Temperature

Suspended Solids (concentration,%>63um,%>16um)

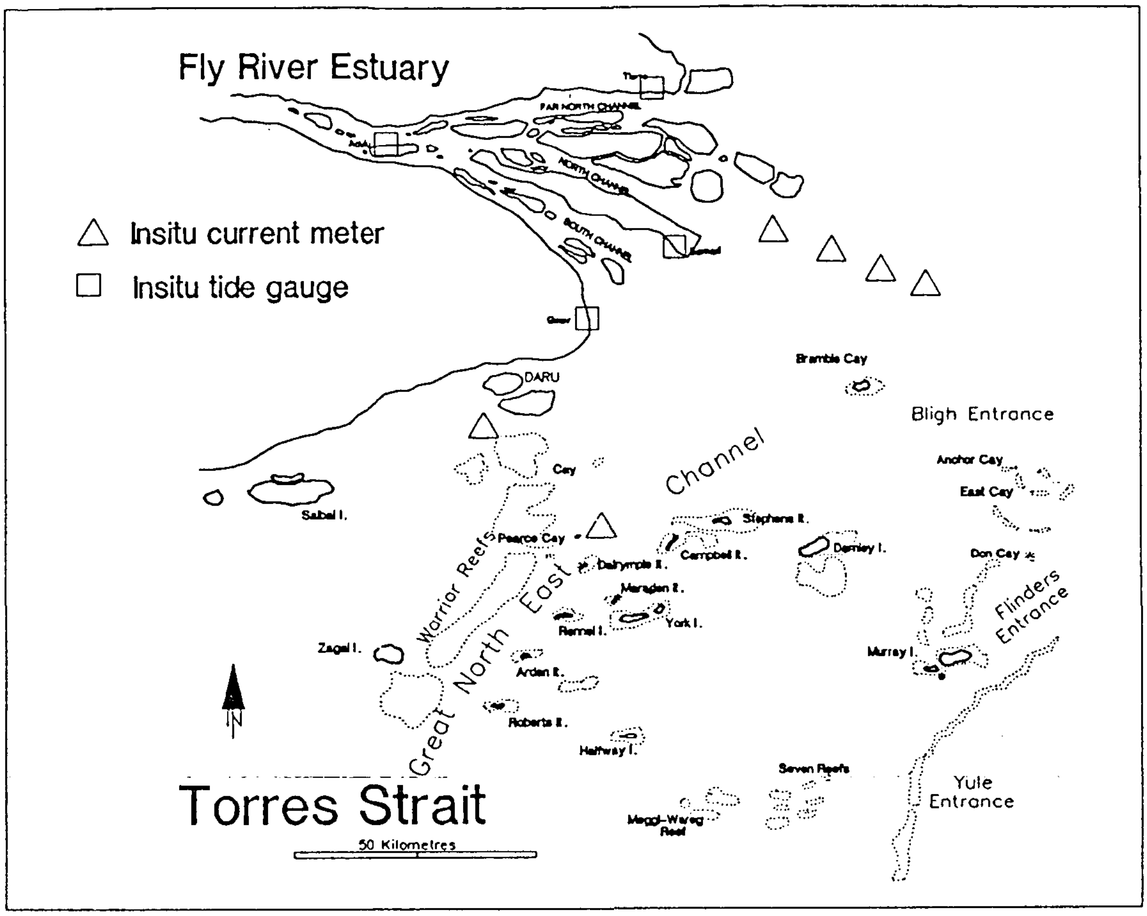
Copper (total,dissolved, particulate in water and bottom sediments

pH, alkalinity,DOC,POC,CEC

Figure 5. Geochemical Station Localities and Analyses

The laboratory and field studies associated with the geochemical program will be integrated with the hydrodynamic modelling programs to:

a) simulate dissolved and particulate copper transport in the estuary and offshore environment for the present (calibration) period and
b) simulate dissolved and particulate copper concentrations in the estuary and offshore environment for the life of the mine given mine operational parameters.



Note: Data will be supplemented with discrete current velocity, direction, salinity, temperature, depth and turbidity information during each cruise

Cruises are scheduled on a quarterely basis.

Figure 6. Hydrodynamic Station Localities

Hydrodynamic Program.

Programs of oceanographic data collection commenced in December 1989 with an expeditionary cruise in the Fly estuary and coastal waters. This work is being undertaken by AIMS and ANU.

Data collection is aimed at :

(i) determination of mixing rates and times of residence of the river plume in the coastal waters of the Gulf of Papua and northern Torres Strait to assess dilution factors and spatial limits.

(ii)determination of net circulation patterns and mixing/flushing rates in the principal channels of the estuary including assessments of sediment trapping, reworking and redistribution.

The physical oceanographic measurements necessary to determine (i) and (ii) above will encompass a sufficient time span to reflect seasonal variations and include:

a) deployment of submersible current meters to test the hypothesis that wind driven currents force part of the plume to the west along an inshore zone and that a permanent eastward offshore drift occurs in this region; and a deployment of a further three meters located on a cross-slope transect offshore from the delta front and extending to sea due east of the estuary.

b) installation of a self compensating/recording weather station on the permanently located bulk handling concentrate ship located off Umuda Island.

c) deployment of self-recording submersible tide gauges in the estuary mouth at the entrance of each of the principal channels and at its apex.

d) insitu measurements of current direction and velocities, temperature, salinity and suspended and deposited sediment data including concentrations, particle size distributions and copper concentrations.

e) sediment core collection from locations in each of the principal channels for the determination of net sedimentation rates and effective mixing depths. The cores will be carbon dated and geologically classified.

These data will be synthesized in hydrodynamic models to analyse the mixing and residence times of sediments in waters in the estuary and offshore. Predictions of the fate of residual copper in these sediments will be made following the integration of the results of the hydrodynamic and the geochemical models.

The geochemical and hydrodynamic programs are designed to determine the transport and fate of mined sediments in the estuary and Gulf of Papua. The programs will provide both confirmation or otherwise of qualitative professional assessments and baseline information from which future assessments may be made of any impacts resulting from the mining operation.

Discussion

The continuing data collection programs undertaken by OTML since 1981 have resulted in a large assemblage of environmental information on the Ok Tedi and Fly River systems. Because of the geographical extent of the Fly system and the natural variabilities that occur, however, uncertainty remains surrounding any interpretation of system characteristics and responses to the mining operation.

APL compliance monitoring results show that the effects of the mining operation are within acceptable levels of environmental impact (Ok Tedi Mining Limited, in press) throughout the system. The fisheries resources of the river system are being maintained.

Results from the geochemical and hydrodynamic programs to date (early1991) show no increase in either dissolved or particulate copper concentrations in the estuary and coastal waters of the Gulf of Papua or the northern Torres Strait. Data collected show no net current flows in the direction of the Torres Strait although a brackish water plume has been shown to intrude into the Great North Eastern Channel at least to the extent of the Warrior Reef complex (Wolanski *et al.*, 1983). A small but identifiable fraction of the freshwater discharge from the Fly River is transported along the littoral zone west of the estuary. Copper concentrations in sediments collected from areas west of the estuary show no elevation above background levels.

Net offshore currents are shown to flow in an easterly direction in the Gulf of Papua. Copper concentrations in deposited or water column sediments are not elevated above background levels.

A significant finding of the research being conducted in the estuary has been the identification of a large volume of fluidised muds. Preliminary surveys estimate that the quantity of material involved could be a high as 10×10^9 million tonnes. As particle bound copper entering the estuary is preferentially distributed on the finer fraction of sediments and principally associated with clay particles (Salomons *et al.*, 1990), copper enriched sediments are diluted substantially by these unconsolidated sediments. This is shown by data that indicates that no detectable enrichment above background copper levels has occurred despite the fact that copper processing at the mine was commenced in 1987.

The rate of contamination of resident sediments can be estimated if a mixing depth is known. Preliminary estimations (Wolanski *et al.*, 1990) show that for estuarine areas where mixing depths are less than 0.1 meters copper concentrations could be expected to increase to 120ppm. Similiarly, mixing depths to 1.0 meters result in predicted concentrations marginally exceeding background levels that are for all practical purposes unquantifiable. As the volume of fluidized muds in the estuary is essentially constant an amount is exported equal to annual inputs from the river. Sediments collected from the prograding delta front indicate that there is a depositional zone for the bulk of fine sediments with export to the Gulf of Papua the most likely direction of transport for sediments remaining in the water column.

While uncertaintities exist, particularly with extrapolations of response information over the life of the mine, particular emphasis has been placed on the quality of information collected. To this end, internationally recognised protocols have been used in all data collection and sample analysis activities and where necessary, expert advice has been sought concerning all monitoring and investigative activities, data analysis and interpretation of results.

The information presented to the State and used in the evaluation and formulation process to establish an acceptable level of suspended sediment for the river system, has been subject to ongoing and independent reviews. These reviews have confirmed the scientific findings of OTML's investigations. Judgements regarding acceptable environmental impacts take into account the considerable benefit of the project to the Western Province and to Papua New Guinea and the practical balance between these benefits and environmental effects. The findings of the Sixth Supplemental Agreement

Environmental Study and Supplementary Investigations provided the State with a basis to make these judgements and establish the APL. The purpose of the APL is to ensure that OTML's mining operations do not cause unacceptable environmental damage to the river system.

The study findings predict that some environmental impacts within the river system will result from the discharge of mine ore residues and overburden. These impacts have been quantified to the maximum extent possible. Increases in suspended sediment concentrations as a result of mine discharges will cause a decrease in the fisheries resources of the Middle Fly; these resources will, however, continue to exceed the demand placed on them by users, principally artisinal fishermen, although increased effort may be needed to achieve present catches. No other significant impacts have been identified to date, although monitoring and further environmental study will be continued.

References

Loffler E. (1977), *Geomorphology of Papua New Guinea*, ANU Press, Canberra.

Maunsell and Partners Pty.Ltd. (1982), *Ok Tedi Environmental Study: Report to Ok Tedi Mining Limited.* 7 Vols.

Ok Tedi Mining Limited (1988), *Sixth Supplemental Agreement Environmental Study 1986-1988: Final Draft Report*, OTML, Boroko and Tabubil.

Ok Tedi Mining Limited (1989), *Supplementary Environmental Investigations*, OTML, Boroko and Tabubil.

Ok Tedi Mining Limited (1990), *APL and Additional Monitoring Program*, OTML, Boroko and Tabubil.

Ok Tedi Mining Limited (in press) *APL and Environmental Monitoring - Annual Report*, OTML, Boroko and Tabubil.

Parker G. (1990), *The "Ok" Series of Pascal Programs for Computing Change in Bed Elevation and Sediment Transport in the Ok Tedi Fly River System in Response to Mine Loading*, New Brighton, Minnesota. (Report to Ok Tedi Mining Limited)

Petr, T. (Ed.) (1983), *The Purari-Tropical Environment of a High Rainfall River Basin*, Junk, The Hague.

Salomoms W. and Eagle A.M. (1990), 'Hydrology, Sedimentology and the Fate and Distribution of Copper in Mine-Related Discharges in the Fly River System, Papua New Guinea', *The Science of the Total Environment*, 97/98, 315-334.

Smith R.E.W., Ashanulla M. and Batley G.E. (1990), 'Investigations of the Impact of Effluent from the Ok Tedi Copper Mine on the Fisheries Resource of the Fly River, Papua New Guinea', *Environmental Monitoring and Assessment*, 14, 315-331.

Smith R.E.W. and Hortle K.G.(in press), 'Assessment and Prediction of the Impacts of the Ok Tedi Copper Mine on Fish Catches in the Fly River System, Papua New Guinea', *Environmental Monitoring and Assessment*.

Wolanski E., Pickard G.L. and Jupp D.B.L. (1983), 'River Plumes, Coral Reefs and Mixing in the Gulf of Papua and Northern Great Barrier Reef', *Estuarine, Coastal and Shelf Science*, 18, 291-314.

Wolanski E., Trenorden M. and King B. (1990), *Fly River Estuary and Gulf of Papua: Oceanography and Sediment Dynamics Data Report*, Australian Institute of Marine Science, Townsville. (Report to Ok Tedi Mining Limited)

Staged Development and Environmental Management of the Porgera Gold Mine, Papua New Guinea

Charles W. Ross
Placer (PNG) Pty. Limited

Abstract

The Porgera Gold Mine is presently being constructed in the Central Highlands of Papua New Guinea. The mine is located within the catchment of the Porgera River which drains into the Lagaip, Strickland and Fly River system. Stage I of the mine and ore processing plant commenced production in September 1990.

The staged development of the mine and ore processing plant are described. Information is presented on management of mine wastes, with particular reference to chemical treatment of mill tailings. The predicted environmental effects resulting from riverine disposal of tailings are discussed.

Introduction

The Porgera Gold Mine is located in Enga Province, in the central mountainous region of Papua New Guinea. The Porgera gold/silver deposit has been the subject of mineral exploration since 1960, by a number of companies working singly and jointly. Commencing in 1980, active exploration and development planning have been conducted by a consortium of companies known as the Porgera Joint Venture (PJV). RGC (Papua New Guinea) Pty Limited, Highlands Gold Properties Pty Limited and Placer (PNG) Pty. Limited are equal partners in the venture, with the Papua New Guinea Government holding a 10 percent share.

At an early stage of project planning, the joint venturers made a commitment to ensuring that the environmental effects of the mine were given careful consideration, and that an acceptable balance was achieved between the responsibilities of protecting the environment and extracting minerals economically. Investigations began in 1980, with the collection of preliminary baseline information on the land surrounding the ore body and the river basin containing the proposed mine (NSR, 1980; NSR, 1982).

This was followed by a more detailed baseline survey in 1984 and a series of studies on the characterisation of effluent, the development of methods for treatment of tailing and the assessment of effects on the receiving river system. Detailed environmental investigations culminated in the preparation of an Environmental Plan for the mine (NSR, 1988). In May 1989 the Papua New Guinea Government approved the Project Proposal for Development and the Environmental Plan for the mine. Construction of the mine commenced shortly thereafter.

Physical Setting

The Porgera valley is a high-altitude basin ringed with rugged mountains, with a floor level of about 2000 metres and rising to a maximum height on the rim of 3850 metres. The Porgera gold/silver ore body lies in and adjacent to Mt. Waruwari, elevation 2800 metres.

The predominant climatological feature of the region is rainfall. Mean annual rainfall is approximately 3600 mm and precipitation occurs on over 300 days each year. Rainfall tends to be heavier during the December to February period, and extensive cloud cover is common.

Temperatures in the Porgera area range from a daily average minimum of 11°C to an average maximum of 22°C. Relative humidity is quite high and averages between 80 and 90 percent.

The geology of the upper Strickland catchment is dominated by the Jurassic Maril Formation, comprising fine grained marine sediments in the form of dark grey and black shales. These rocks weather rapidly and are extremely unstable. Landslides are a characteristic feature of the steep valleys of the catchment. River sediment loads consequently are high.

Hydrology

The ore body is located in the headwaters of the Porgera River, which drains into the Lagaip, Strickland and Fly River system (Figure 1). Hydrological records from five gauging stations (SMEC, 1985) have been used to estimate discharge. Daily mean discharges are shown in Table 1, together with corresponding total suspended solids (TSS) concentrations. The variation in flow between low and high extremes at each station is not exceptionally large.

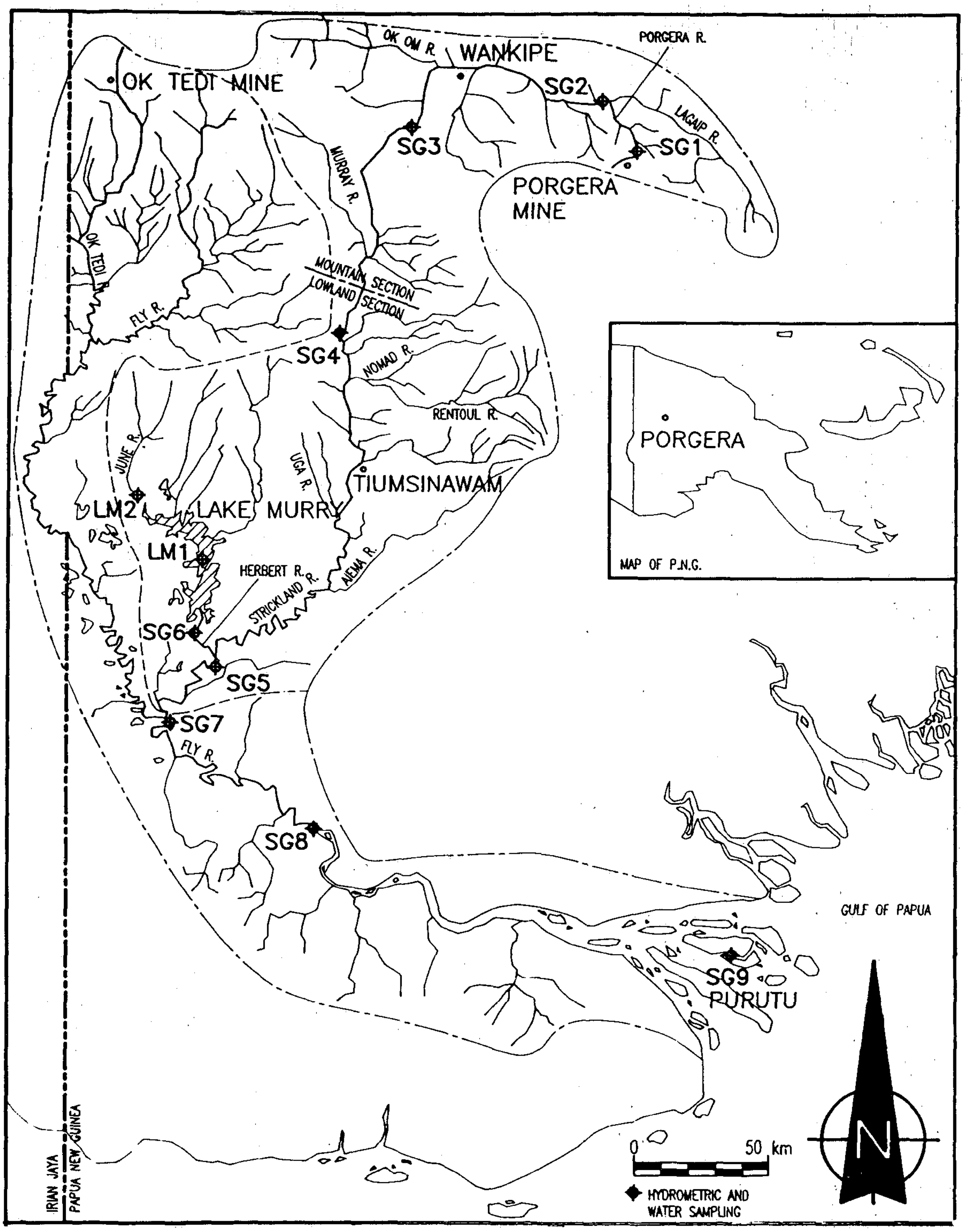


Figure 1. Riverine Sampling Locations.

Table 1. Baseline Flow and Total Suspended Solids concentrations at SG1, SG2 and SG3

STATION	TSS(gm^{-3})	FLOW(m^3s^{-1})
90% E FLOW		
SG1	275	6.2
SG2	165	70
SG3	197	319
10% E FLOW		
SG1	995	28
SG2	7885	320
SG3	6020	1243
MEAN FLOW		
SG1	615	16
SG2	1185	180
SG3	1440	704

Water Quality

The predominant and most variable characteristic of river water quality is TSS. Suspended solids loadings are high, with turbid water always present in the rivers (Table 1). TSS is strongly correlated with discharge (Figure 2).

The waters of the rivers are calcium bicarbonate dominated, characteristic of limestone catchments. The pH is high, at around 8, as are suspended solids and organic carbon. Total heavy metal concentrations of water are high, reflecting the high sediment loading. However, the metal concentration of the solids (Table 2) and the level of dissolved metals are low (PJV, 1990).

Table 2. Background Particulate Metal Concentrations ($mgkg^{-1}$)

STATION	As	Cd	Cu	Fe	Pb	Hg	Zn
SG1	6.8	0.3	30	55000	29	0.2	131
SG2	3.1	0.1	30	45000	23	0.1	108
SG3	6.2	0.5	22	47500	17	0.1	88

The high pH, bicarbonate, suspended solids and organic carbon are all indicative of a system well buffered against the dissolution of heavy metals into the aqueous phase.

Mine Development

The mine is being developed in stages, with a combination of underground and open pit operations. The optimum mining strategy involves the development of an underground mine to extract the higher grade ore during the first seven years of production. The extraction of this deep, higher than average grade ore early in the mine's life is vital to the economic viability of the project.

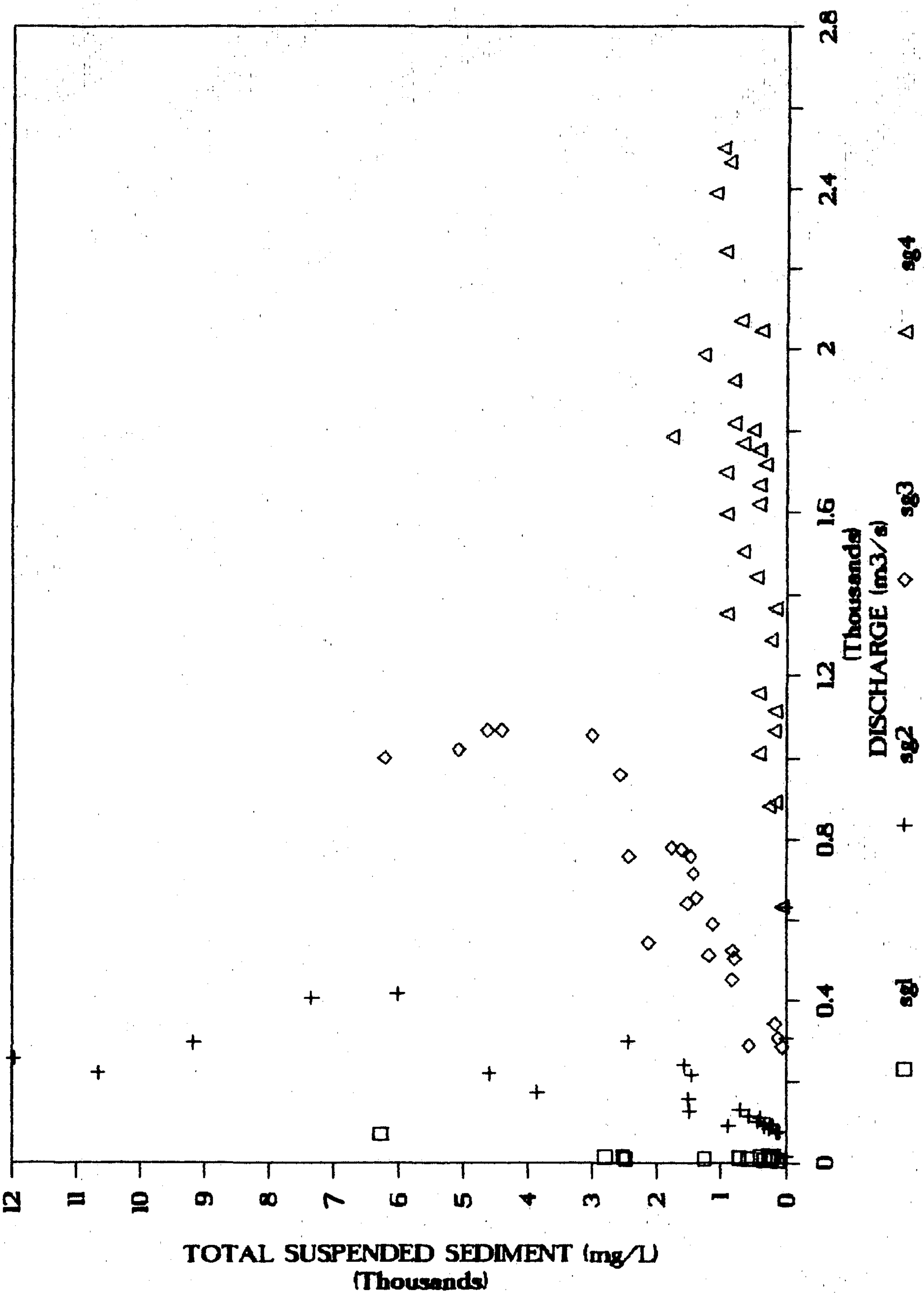


Figure 2. Variation of suspended sediment with discharge.

The open pit will be developed in three stages over the production period of 18 years and will involve the removal of a substantial part of Mt. Waruwari. Approximately 48 million tonnes of ore will be mined from the pit, with 313 million tonnes of waste rock generated.

Both soft and hard waste rock from the pit will be stored in a waste dump immediately to the west of the pit. The proposed dump area is a bowl shaped valley with a downward slope from south to north averaging 9° over a distance of 2.3 kilometres. Foundation conditions in the dump area vary from reasonable to poor. Weak foundation conditions and high rainfall preclude conventional methods of dump construction. Special dump design measures are required to overcome the poor foundation conditions and the weakness of the materials to be stored (Klohn Leonoff, 1986).

Ore Processing

Most of the Porgera ore is highly refractory and requires a complex treatment process to achieve satisfactory gold recovery. Early on, it was clear that direct cyanidation would yield poor recovery because most of the submicroscopic particles of gold were locked within the crystal structure of pyrite. Destruction of pyrite by acid pressure oxidation was selected as the most favourable method of accomplishing this. The ore processing plant is being developed in two stages.

The Stage I plant processes 1500 tonnes of ore per day from the underground mine. It comprises crushing and grinding, followed by gravity recovery of coarse free gold (Figure 3). The sulphide minerals are recovered by conventional flotation then subjected to cyanidation leaching to extract part of the gold. Cyanidation tailing, containing the refractory part of the ore is stored in a lined pond for later treatment by pressure oxidation.

Stage II plant involves the addition of pressure oxidation to the treatment process, commencing in mid-1991 (Figure 4). The sulphide flotation concentrate will be oxidised under pressure in autoclaves, rendering the contained gold amenable to dissolution by cyanide. The residue of oxidised solids will be washed by countercurrent decantation. The gold and some of the silver in the washed solid residue will then be recovered by cyanidation leaching and carbon-in-pulp.

The concentrator capacity will be increased to 4500 tonnes of ore per day in 1993. Underground ore production will increase to 3500 tonnes per day, with 1000 tonnes per day mined from the open pit. Twelve months later the concentrator capacity will be increased to 8000 tonnes per day, with open pit ore production increased to 4500 tonnes per day. The underground mine will cease operation in 1997.

Effluent Disposal

The ore processing produces three main effluent types. These are flotation tailing, acid wash effluent and cyanidation tailing. Individually, these streams will contain a variety of potentially toxic environmental contaminants, including cyanides, acids, alkalis and dissolved trace metals. Mercury present in the ore body is considered the priority trace metal because of the potential for bioaccumulation and bioconcentration. Also there is the potential of increased physical loading of waste solids on the environment.

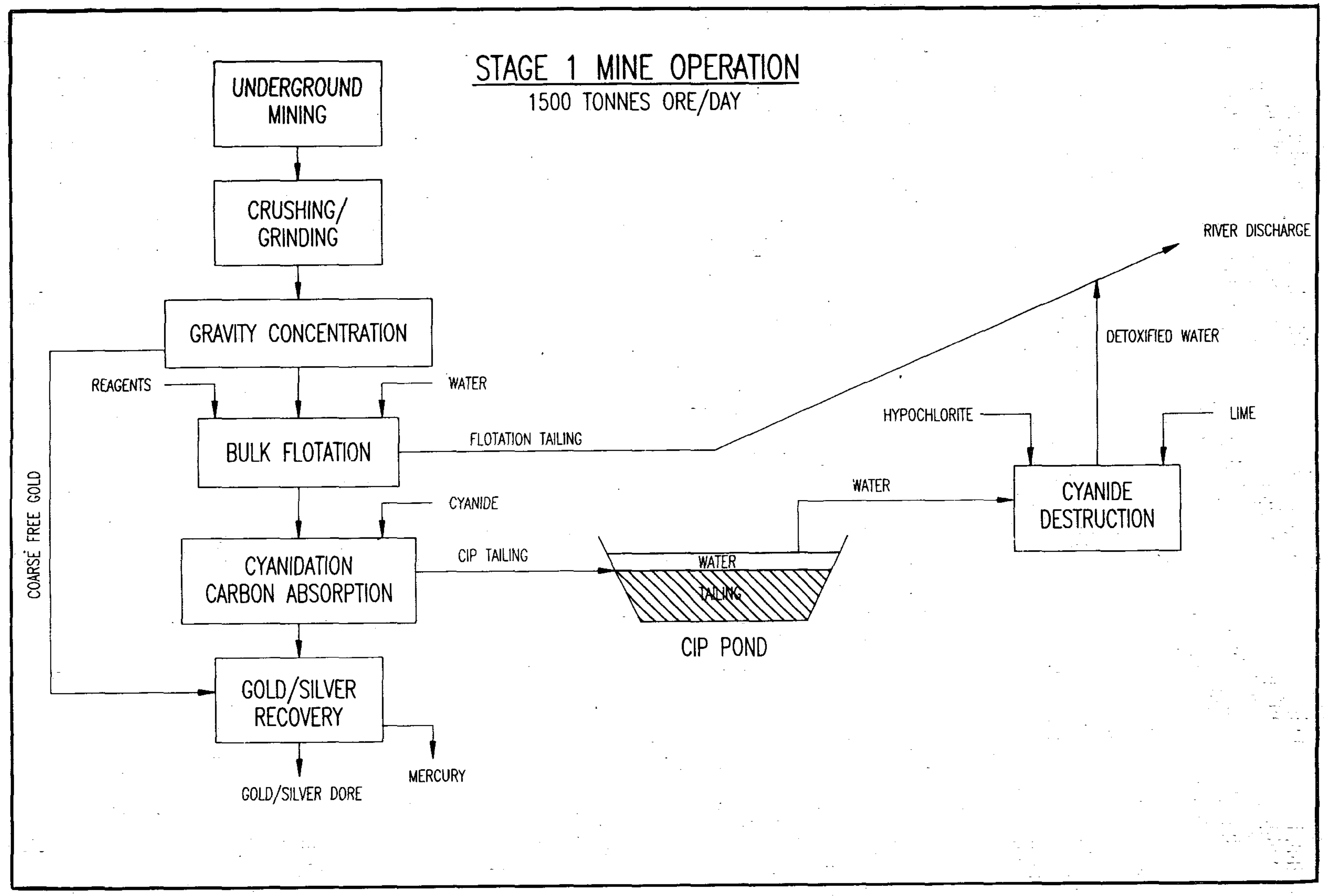


Figure 3. Stage I process flow sheet.

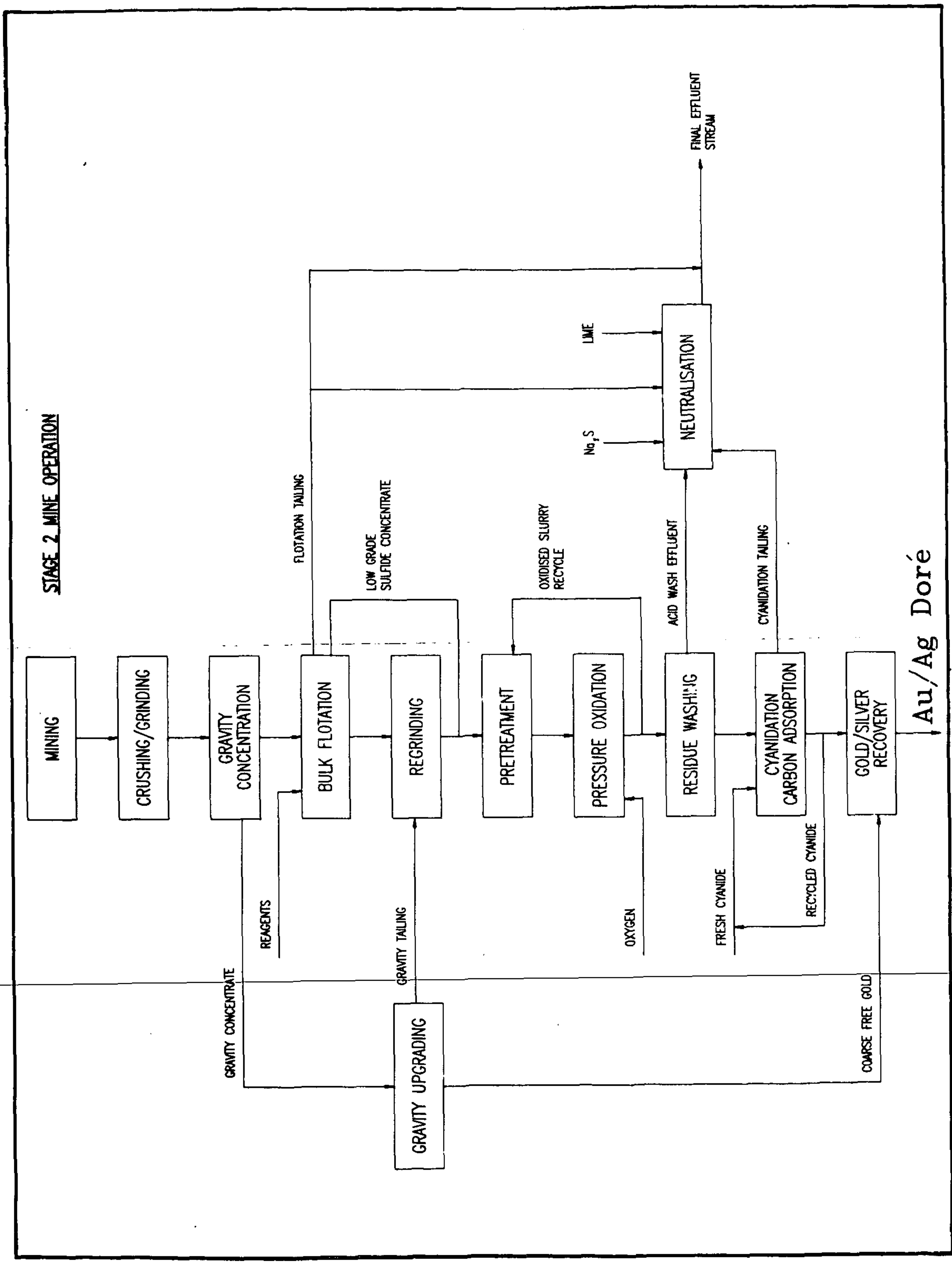


Figure 4. Stage II process flow sheet.

At an early stage of development planning it was recognised that the foundation conditions of the Porgera valley were unable to support an impoundment for safe, permanent storage of tailing (Klohn Leonoff, 1984). The implications of river disposal of tailing have been investigated in detail and this is the main issue addressed in the Environmental Plan.

Laboratory Testwork

The extensive metallurgical program to test the processing of ore provided an ideal opportunity to optimise in-plant treatment of wastes to minimise the downstream impact of riverine disposal. The components of the environmental testwork were:

- Determination of the chemical characteristics of process waste streams for different ore types.
- Optimisation of waste treatment, in particular residual cyanide destruction, neutralisation of acid autoclave effluent and precipitation of dissolved metals.
- Laboratory simulation of downriver water quality and analysis of mixed and diluted effluent for chemical indicators of toxicity.
- Acute toxicity testing of waste streams by bioassay screening.
- Determination of particle size and settling characteristics of tailing solids.
- Assessment of the deportment of mercury through the process.
- Determination of the potential for the transformation of metals from the solid phase of the waste stream to the liquid phase of the receiving river system.

Effluent Treatment

Flotation tailing consists of waste rock and residual alkaline flotation reagents. Bioassay tests demonstrated that flotation tailing has low toxicity, and does not require treatment prior to discharge (Rescan, 1987a).

However, the acid wash effluent from the pressure oxidation circuit contains high concentrations of trace metals, while the cyanidation tailing contains significant concentrations of residual cyanide. An effluent treatment process has been developed which involves neutralising the acid wash effluent and precipitating dissolved trace metals by addition of alkaline flotation tailing and lime.

Cyanide destruction testing has demonstrated that "Prussian Blue" precipitation offers a reliable means of cyanide detoxification. This in-situ process involves the formation of highly insoluble and stable ferric-ferro-cyanide complexes under acid conditions. Additional testwork has shown that treatment of the acid wash effluent and cyanidation tailing with sodium sulphide will precipitate mercury as mercury sulphide of low solubility and inherently low biological availability.

Toxicity of Mine Waste

The potential toxicity of mine wastes can be attributed to trace metals, cyanide and the physical effects of sediment.

The environmental testwork programme has demonstrated the feasibility of treating tailing chemically to produce an effluent with low concentrations of trace metals in the aqueous phase (Rescan, 1987b). The river conditions of high pH, alkalinity and suspended solids concentrations are such that mobilisation of metals into the liquid phase will be minimal.

Since the acute toxicity of metals depends primarily on the concentration of the free, uncomplexed metal in solution, rather than the total metal concentration, toxicity in the main river system from trace metals is expected to be of minor importance.

Bioassay tests of the "Prussian Blue" treated final effluent showed low toxicity associated with the solids fraction of tailing. The toxicity was attributed mainly to residual concentrations of ammonia. Upon discharge, the residual ammonia present in tailing will be diluted rapidly to innocuous levels with the receiving waters.

Predicted Environmental Impacts of the River System

The zone of mine waste impact on the river system is determined by the physical effect of solids on biota rather than by chemical effects.

Approximately 74 million tonnes of mine-derived sediments, comprising construction spoil, tailing and solids eroded from the waste rock dump, are expected to enter the river over the 18 year mine life. All tailing and 90 percent of the soil, totalling 63 million tonnes are finer than 0.2 mm. Sediment transport calculations show that the entire river system can easily transport the anticipated 3.4 million tonnes annually of the fine sediments. Coarser materials are expected to be deposited in some sections of the rivers during low flow. However the deposition is expected to be minimal over the very large surface area of the river system.

The natural sediment load of the river system already is high due to numerous slope failures in the catchment. In order to assess the aquatic biological impacts of mine sediments, predictions have been made of the increase of suspended solids concentrations above background levels, for a range of river flows. With the exception of the Porgera River, operational inputs of mine sediments will increase TSS concentrations fractionally, and most of these predicted TSS concentrations lie within the background range of concentrations already experienced by Lagaip River mainstream fish populations.

The predicted biological impact zones shown in Figure 5 have been derived from consideration of the increment of mine derived sediment above background levels. For mean flow conditions at SG2 on the Lagaip River, mine derived sediment will increase TSS by approximately 51 percent above background levels (NSR, 1986). This reduces to a 10 percent increment of TSS at SG3 on the Strickland River. The biological impact of mine derived sediment decreases downstream from the mine, with no predicted effects below the Lagaip-Ok Om confluence.

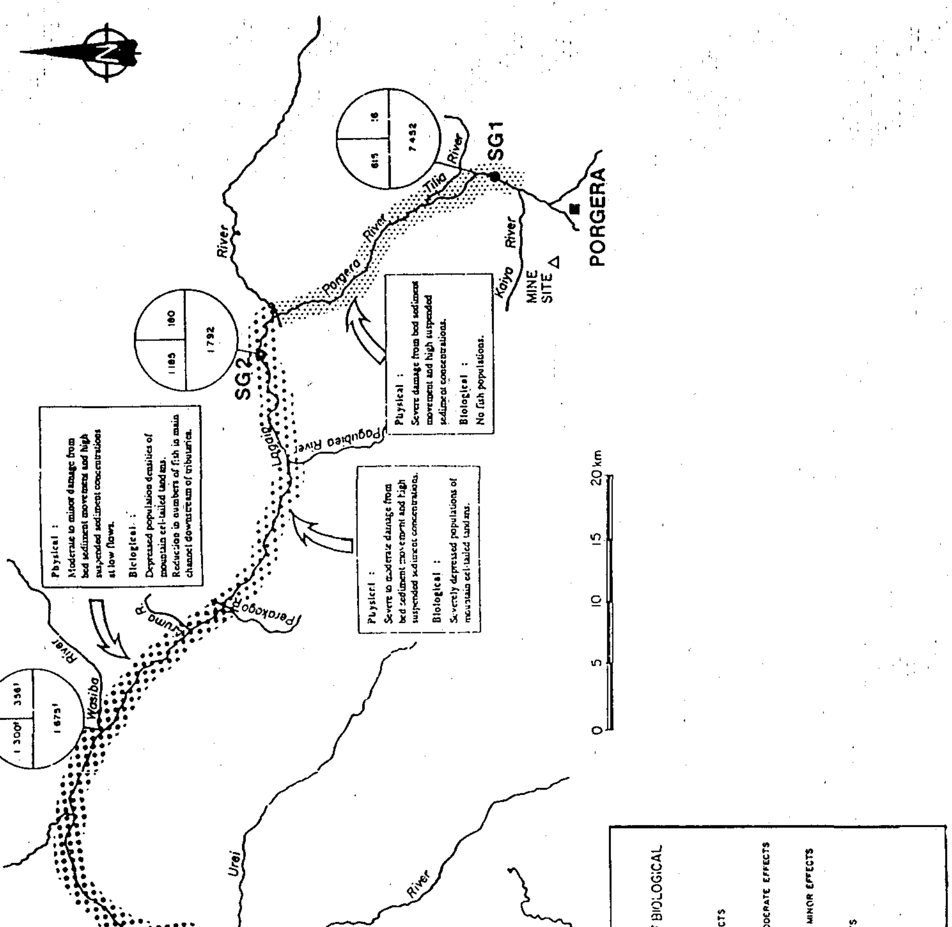


Figure 5. Biological Impact Zone of mine sediment on the river system (After NSR, 1988).

Effects on Lake Murray

A pathway exists for mine tailing to enter Lake Murray, a large off river water body. Lake Murray normally drains into the Strickland River via the Herbert River. However, when the Strickland River floods and the water level in Lake Murray is low, back flow can occur up the Herbert River.

The extent and significance of increased mercury loading on Lake Murray has been investigated in detail by means of hydrological data collection, suspended and bed sediment sampling, geomorphological analysis and geochemical analysis. The results of the investigations show that for bio-available mercury, bed sediment concentrations in Lake Murray may increase by less than one percent over background levels after 18 years of mining. Although this predicted increase is small, mercury levels will be monitored closely to check for any changes.

Effects on the Fly Delta

Given the sediment transport capacity of the river system and the very fine size of the tailing particles, all tailing solids are predicted to be carried in suspension to the Fly Delta. Assuming that all tailing solids reach the Fly Delta, the average annual loading on the Delta from Porgera is estimated at 3.16 Mta^{-1}. This represents an increase of 3.2% above the estimated natural sediment loading at the Delta of 100 Mta^{-1}. The small increase in suspended sediment derived from Porgera will have negligible physical effects on the biota of the Delta.

The increment in mine derived mercury is unlikely to be environmentally significant for the following reasons:

- There will be high dilution of Porgera tailing by natural deltaic sediments and by solids from the Ok Tedi Mine, low in mercury.
- Tailing solids from the mine will not be permanently resident in the Delta, but will be reworked within the high energy deltaic environment prior to eventual deposition in deep waters off the Gulf of Papua.
- Mercury will be either in the residual mineral phase in the solids, or as mercuric sulphide, and is unlikely to be available to estuarine and marine biota.
- There will be little mercury in the ion-exchangeable fraction, which is the component most likely to be released in saline environments.
- The eventual burial of mine solids in the low-oxygen bottom sediment will maintain the chemical stability of mine derived mercuric sulphides.

Effects on Torres Strait

Tailing and sediment from the Porgera Mine are predicted to have no significant effect on the Torres Strait. Because of the large dilution by natural sediment, mine derived tailing will comprise but a small fraction of solids moving through the deltaic front.

These solids will be deposited in deep waters off the Gulf of Papua. For the same reasons outlined above for the Fly Delta, mercury present in tailing is predicted to have no significant effect on Torres Strait.

Monitoring

The receiving river system is being monitored closely to check the predictions made in the Environmental Plan and to assess the significance of any changes brought about by riverine disposal of tailing. The monitoring program includes collection of data on hydrology, water quality, sediment transport, fish biomass and trace metals.

Summary

The Porgera Gold Mine is a relatively small scale operation in terms of the quantity of ore mined and processed.

Consideration of environmental effects at an early stage of mine planning and design enabled the optimisation of on site treatment of tailing.

A method has been developed for chemical treatment of tailing to produce a low toxicity effluent.

Mercury present in tailing will occur as mercuric sulphide of low solubility and inherently low biological availability.

The river conditions of high pH, alkalinity and suspended solids concentrations inhibit the mobilisation of trace metals into the aqueous phase.

The main impact of the mine on the receiving river system will be due to the physical effect of increased solids on biota.

Apart from the Porgera River, mine sediments will increase TSS fractionally.

Most of the predicted TSS concentrations lie within the background range of TSS already experienced by the Lagaip River fish population.

There are no predicted effects of solids on biota below the Lagaip-Ok Om confluence.

Although a pathway exists for tailing to enter Lake Murray, the increase in bio-available mercury in bed sediments is expected to be insignificant.

All tailing solids are predicted to be carried to the Fly Delta.

The increment of mine derived mercury is unlikely to be environmentally significant in the Fly Delta.

Tailing from the mine is predicted to have no significant effect on the Torres Strait.

References

Klohn Leonoff (1984), *On land tailing disposal study, Porgera Project, PNG,* Klohn Leonoff Ltd, for Placer Development Limited.

Klohn Leonoff (1986), *Geotechnical assessment of waste rock dump and tailing disposal in Mungarenk Creek Valley,* Klohn Leonoff Ltd, for Placer (PNG) Pty Limited.

Natural Systems Research (1980), *Porgera Project: Environmental review and investigations plan,* Natural Systems Research Pty Ltd, for Placer (PNG) Pty Limited.

Natural Systems Research (1982), *Porgera Gold Prospect: Environmental investigation report for 1981,* Natural Systems Research Pty Ltd, for Placer (PNG) Pty Limited.

Natural Systems Research (1986), *Physical and biological impacts of mine sediments entering the river system,* Natural Systems Research Pty Ltd, for Placer (PNG) Pty Limited.

Natural Systems Research (1988), *Porgera gold Project. Environmental Plan. Volume B,* Natural Systems Research Pty Ltd, for Placer (PNG) Pty Limited.

Porgera Joint Venture (1990), *Environmental baseline, Porgera gold mine. Volume 1. Main Report,* Placer (PNG) Pty Limited.

Rescan (1987a), *Porgera Gold Project environmental assessment: Riverine discharge of process effluent. Volumes 1 & 2,* Rescan Environmental Services Ltd, for Department of Minerals and Energy, PNG.

Rescan (1987b), *Porgera Gold Project environmental assessment: Riverine discharge of process effluent. Addendum,* Rescan Environmental Services Ltd, for Department of Minerals and Energy, PNG.

Snowy Mountains Engineering Corporation (1985), *Porgera Project. Flow estimates of Porgera, Lagaip and Strickland Rivers,* Snowy Mountains Engineering Corporation.

A Review of the Physical Oceanography of Torres Strait

Eric Wolanski
Australian Institute of Marine Science

Introduction

The Torres Strait is a topographically very complex, shallow, body of water, heavily studded with reefs and islands. The water circulation is influenced by runoff from Papua New Guinea, Australia, and Irian Jaya, the local winds, and tidal and other oceanographic events in the Arafura and Coral seas. There has been an increasing interest in the physical oceanography of the Torres Strait for the last 10 years. This is reflected in a rapidly growing scientific literature. This literature is reviewed below.

Figure 1 shows a chart of the northern Great Barrier Reef, the Torres Strait, the Fly River estuary and the Gulf of Papua. The Fly River estuary has four major channels forming a delta. These are the far northern, northern, southern and far southern channels. The northwestern region of Torres Strait (stipled in Figure 1) is uncharted but reported to be very shallow (depth <10 m) with numerous shoals and reefs.

Review

Gulf of Papua and the Northwest Coral Sea

Wyrtki (1960) showed the monthly surface salinity distribution by one degree in the northwest Coral Sea. The data suggested southeastward flow of brackish water at the surface. Scully-Power (1973) conducted more detailed field studies that implied, from geostrophic calculations, the existence of an eastward flow in the northern Coral Sea. Pickard *et al.*, (1977) further reviewed the very sketchy knowledge of the circulation in the northwestern Coral Sea.

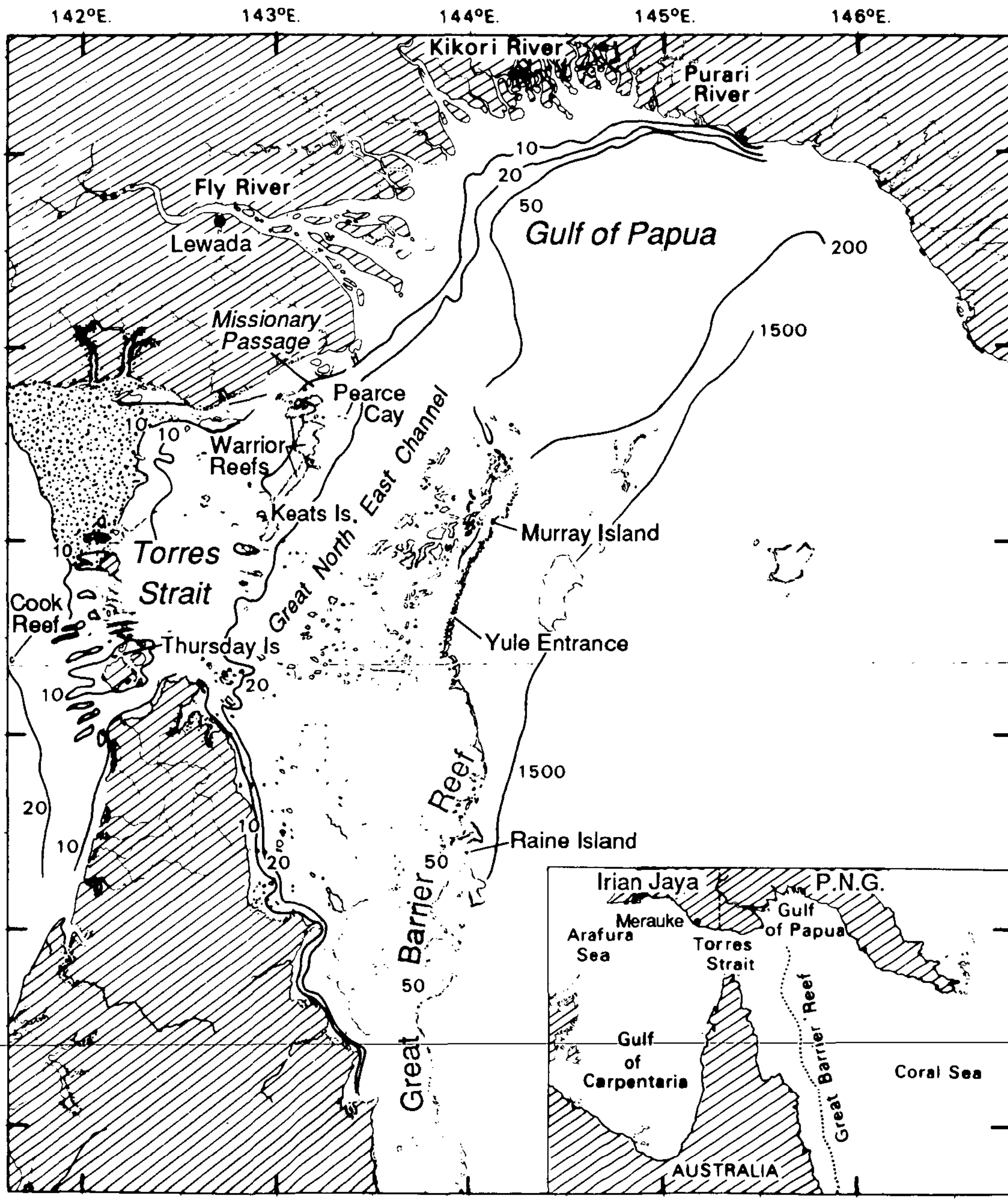


Figure 1. Map of the Torres Strait and surrounding waters. The insert is a general location map. The stipled area represents an uncharted area believed to be between 5 and 10 metres deep with numerous reefs and shoals.

Andrews and Clegg (1989) demonstrated the existence of the Coral Sea coastal current, flowing north along and offshore from the Queensland shelf break and turning eastward in deep water offshore from the Gulf of Papua. More recently CSIRO and AIMS scientists (Burrage, pers. com.) have carried out oceanographic cruises in the north-western Coral Sea confirming this surface circulation. These data also suggest the existence of a westward current in shallow coastal waters off Port Moresby during strong southeasterly tradewinds.

Rochford's (pers. com.) surface salinity data also suggest a clockwise circulation at the surface in the northwest Coral Sea.

MacFarlane (1980) studied the circulation in the Gulf of Papua using bottom and surface drifters. The drogues were left to drift with the currents in the Gulf of Papua and the experiment depended on people finding and returning the drogues from along the coast of the Gulf of Papua. This coast is sparsely populated and the return rate of the drifters was very small. But, for those drogues that were returned, there was evidence for a (wind-driven?) westward flow along the coast of the Gulf of Papua during southeasterly trade winds. The surface currents were eastward the rest of the year. Because so few drogues were returned, it is not possible to say if this pattern is typical of the bulk of the flow.

Wolanski and Ruddick (1981) mapped the salinity distribution in the Gulf of Papua and the northern Great Barrier Reef and showed that Torres Strait waters were vertically well-mixed. Brackish waters from the Gulf of Papua were found to intrude in the Great North East Channel as a tongue of water 70 kilometres long squeezed between the Warrior Reefs to the west side, and the matrix of reefs to the east of the Great North East Channel. In the Gulf of Papua, the river plumes extended up to 100 kilometres offshore. The surface waters were highly stratified in salinity, the plume being confined to the top 20 metres or so of the water column.

Wolanski *et al.*, (1984) estimated the mean freshwater runoff in the Gulf of Papua to be about 13,000 $m^3 s^{-1}$. The residence time of this water in the Gulf of Papua was estimated to be about one to two months, with the bulk of the water flowing eastward.

Torres Strait

Easton (1970) showed some tidal data in the southern region of the Torres Strait implying that the tides do not appear to propagate much across the Torres Strait but the data was inconclusive for a quantitative analysis.

Amin (1978) showed that storm surges (meteorological tides) do not propagate across the southern region of the Torres Strait.

The Australian Department of Transport in the late 1970s is known to have undertaken a study of tidal currents in the southern Torres Strait using Decca current metres, but no data or report seem to have been published.

Wolanski and Ruddick (1981) deployed current meters and tide gauges in the northern and far northern Great Barrier Reef, including a meter in the shipping channel off Thursday Island and another meter near Yorke Island in the Great North East Channel.

Long waves (waves of low-frequency, with period of one to several weeks) were found and these raised and lowered the low-frequency sea level by up to 0.5 metre peak to trough. Low-frequency currents were also associated with such waves. Evidence was presented indicating that the matrix of reefs east of the Great North East Channel largely blocks the longshore currents on the continental shelf of the Great Barrier Reef.

Wolanski (1982) showed that the trade winds over the western Coral Sea, including Torres Strait, are coherent over long distances of the order of 1000 kilometres.

Wolanski and Thomson (1984) reported data from a five month deployment of a weather station, several tide gauges and current meters in the far northern Great Barrier Reef continental shelf. Additional current meter data were obtained for five months at two sites in the Great North East Channel (near Pearce Cay and Keats Island). Low-frequency currents were found and could be attributed to wind-driven arrested topographic shelf waves. These authors modeled the circulation in the Great North East Channel and were able to reproduce with some success the time-series of low-frequency currents near Pearce Cay. The net currents were always small (<0.1 m s^{-1}), reversing direction at periods of days to weeks. Over 140 days of observations, the net currents were too small to be measured reliably. They also showed that the low-frequency currents were small because of the non-linear interaction due to bottom friction between tides and low-frequency currents in these shallow waters.

Wolanski *et al.*, (1984) confirmed the finding of Wolanski and Ruddick (1981) of the intrusion of brackish Gulf of Papua waters in the Great North East Channel and found this intrusion even in May 1982 during the southeast tradewind season. This finding suggests that this intrusion is a permanent feature. Some brackish water from the Gulf of Papua also intruded into the Torres Strait through Missionary Passage (the smaller passage between the mainland of Papua New Guinea and the Warrior Reefs, see Figure 1). Tidal mixing, enhanced by the trapping effect from island wakes, appears to be the dominant process responsible for the intruding tongue of brackish water in the Torres Strait.

Wolanski (1983) argued that the tides in the northern Great Barrier Reef continental shelf, including the Great North East Channel, are controlled by the Coral Sea, not the Gulf of Carpentaria and the Arafura Sea located west of the Torres Strait. Wolanski (1986) reviewed the physical oceanography literature for this area up to 1983.

Wolanski *et al.*, (1988a) undertook a detailed field and numerical study of the flow through the central and southern region of Torres Strait, with five months of field data on sea levels and currents at several locations. They showed that tides and low-frequency sea levels fluctuations were incoherent on either side of the Strait; that the low-frequency currents through the Strait were very small and reversed direction at periods of days to weeks; that these currents were dependent on both the sea level slope across the Strait and the local wind stress. Their analysis also showed that these low-frequency currents were very small because of the non-linear interaction due to bottom friction between weak low-frequency currents and very strong tidal currents in the shallow waters of the Strait. High-frequency sea level fluctuations were also observed and were attributed to waves moving northward or southward, with the reefs and islands of Torres Strait acting as a weakly porous solid boundary.

Clarke (1990) showed that the tidal currents in the Prince of Wales Channel, in the southern region of Torres Strait, are controlled primarily by the acceleration, the bottom friction and the sea level slope.

Upwelling at the Shelf Break

Thomson and Wolanski (1984) showed that tidal period upwelling, a phenomenon first proposed by Thompson and Golding (1981) for the Ribbon Reefs further south on the Great Barrier Reef, is an important mechanism for effectively upgrading nominally low nutrient levels on the continental shelf near Raine Island (11°38'S latitude). Temperature data from a current meter deployed one kilometre inshore from Yule Entrance (9°40'S latitude) along the axis of the channel, also suggest tidal period upwelling (Wolanski and Ruddick, 1981). Presumably tidal period upwelling occurs all along the outer reef of the far northern Great Barrier Reef from Murray Island to Raine Island. It is believed that reef growth should be more prolific near the shelf break where the time-integrated contribution of the upwelling is greatest. However, in a study of tidal period upwelling further south at the Ribbon Reefs offshore Cooktown, Wolanski *et al.*, (1988b) showed that the bulk of the upwelled nutrients may not be available for corals on the shelf break but is instead advected shoreward by a tidal jet - vortex pair system. This mechanism explains the presence of extensive *Halimeda* meadows near the shelf break in the far northern Great Barrier Reef, such as near Raine Island Entrance. Wolanski (1987) suggested, from an examination of Landsat images, that some of the upwelled material and detritus from the reefs at the shelf edge around Raine Island Entrance may then drift back offshore and enrich the reefs of Raine Island, an important rookery for sea turtles.

Gulf of Carpentaria and Irian Jaya

While CSIRO undertook oceanographic studies in the Gulf of Carpentaria in the 1970s, these studies were concentrated in the southern region of the Gulf of Carpentaria.

Mulhearn (1989) found in February and March 1988, that a brackish water tongue west of the Warrior Reefs did not seem to originate from the brackish waters in the Gulf of Papua. He attributed this finding to an intrusion of brackish water from the Irian Jaya coast, in the northern region of the Torres Strait.

Wolanski and Ridd (1990) undertook a detailed field and numerical study of the barotropic circulation, driven by tides and wind, in the Gulf of Carpentaria. The study was based on five months of current meter data at seven sites, sea level data at three sites, and weather data. These data, together with tidal data from Cook Reef and several locations in the Torres Strait, were used to calibrate and verify a numerical model of the water circulation in the Gulf of Carpentaria including the coastal waters of Irian Jaya. They showed that a coastal boundary layer forms, trapping water in shallow water (depth <15 m) for a long period (months). This water flows along the western side of Torres Strait and would be coastal water from the Gulf of Carpentaria in the tradewind season and coastal water from Irian Jaya in the monsoon season. This finding may explain the observations of Mulhearn (1989) who found Irian Jaya coastal waters in Torres Strait west of the Warrior Reefs in the monsoon season.

Wolanski (unpubl. data) found that the waters in the northern region of the Gulf of Carpentaria near Cook Reef are vertically stratified in temperature with a sharp thermocline at typically 15 metres depth, in the monsoon season, unless a tropical cyclone has passed over the area, and that the thermocline oscillates both at tidal and low frequencies. The bottom waters do not appear to be entrained eastward in the Torres Strait.

Little oceanographic data appears to have been collected in the northern region of the Gulf of Carpentaria, north of Cook Reef, including the coastal waters of Papua New Guinea and Irian Jaya west of the Torres Strait. Zijlstra *et al.*, (1990) and Ilahude *et al.*, (1990) reported oceanographic observations in coastal waters of the northwest Arafura Sea, west of 138RE (ie. over 500 kilometres west of Torres Strait), where they found that river plumes from Irian Jaya extended over 100 kilommetres offshore. They suggested that the coastal currents were eastward on the monsoon season and westward in the southeasterly tradewind season, a finding that is reproduced by the numerical model of the water circulation by Wolanski and Ridd (1990).

Fly River

SMEC (1978) used a rainfall-runoff model, calibrated using five years of data, to estimate the monthly runoffs of the Fly River from 1928 to 1977, using the available rainfall data at Merauke in Irian Jaya.

Taylor (1978) conducted an exploratory oceanographic cruise in the far southern and far northern channels of the Fly River estuary. Because the water was fresher in the far southern channel than in the far northern channel, he suggested that the bulk of the freshwater flows through the far southern channel. He attributed that to Coriolis effects, but this interpretation is incorrect since the Coriolis force alone would deflect the Fly River plume to the east in order for the plume to travel with the coast on its left hand side.

Harris *et al.*, (1988) discussed observations of sand waves in the shipping channel near Cape York, as well as sediment sorting in a north-east direction in the Great North East Channel. Harris and Baker (1988) described the different mineralogy prevailing respectively east and west of the Warrior Reefs and the sediment sorting in coastal waters in the Gulf of Papua and in the Torres Strait as affected by the Fly River. The Warrior Reefs appeared to be a significant barrier to sediment transport.

SMEC (1982) undertook detailed bathymetric surveys in the freshwater region of the Fly River and in the far northern channel of the estuary. SMEC also collected some tidal information along the far northern channel for one month. The data showed the dominance of semi-diurnal tides, up to five metre peak to trough, with a strong diurnal inequality. SMEC showed that the flood tidal wave progressively steepens as it propagates up-river. Upstream of Lewada (the junction between the channels of the estuary), a tidal bore has been observed at spring tides.

OTML (1988) summarised their data on freshwater discharges and suspended sediment concentration entering the estuary. OTML also reported occasional data on suspended sediment concentration in the far northern channel. A field and modelling study is underway since February 1990, sponsored by OTML and carried out by AIMS, of the water circulation and the transport of fine sediment in the Fly River estuary, the western region of the Gulf of Papua, and the far northern Torres Strait.

Discussion

The last ten years has seen a rapid increase in the understanding of the water circulation in the Torres Strait. The area is topographically extremely complex and forced nearly independently by the Arafura Sea and the Coral Sea through the continental shelf of the Great Barrier Reef. Additional local forcings are river runoff and the local wind effects. A clear picture is rapidly emerging and some confidence can now be given to modelling the water circulation in Torres Strait as the open boundary forcings are better understood.

References

Amin, M. (1978), 'A statistical analysis of storm surges in Torres Strait', *Aust. J. Marine Freshwater Res.*, 29, 479-496.

Andrews, J.C. and Clegg, S. (1989), 'Coral Sea circulation and transport deduced from modal information models', *Deep Sea Research*, 36, 957-974.

Clarke, A.J. (1990), 'Application of a frictional channel flow theory to flow in Prince of Wales Channel, Torres Strait', *J. Physical Oceanography*, 20, 890-899.

Easton, A.K. (1970), *The tides of the continent of Australia*, Horace Lamb Centre for Oceanographic Research, Adelaide. (Res. Paper No. 37).

Harris, P.T., Schneider, P.M. and Baker, E.K. (1988), *Currents, sedimentation and sandwave migration in the Great North East Channel and Adolphus Channel areas of Torres Strait: report on measurements taken during HMAS "Cook" cruises, 1988*, Ocean Sciences Institute, University of Sydney, Sydney. (Report No. 28).

Harris, P.T. and Baker, E.K. (1988), *Sources of turbidity in Torres Strait: comparison of suspended and seabed sediment properties*, Ocean Studies Institute, University of Sydney, Sydney, (Report No. 39).

Ilahude, A.G., Komaz, and Mardanis (1990), 'On the hydrology and productivity of the northern Arafura Sea', *Neth. J. Sea Res.*, 25, 573-583.

MacFarlane, J.W. (1980), *Surface and bottom currents in the Gulf of Papua and western Coral Sea,* Department of Primary Industry, Port Moresby. (Papua New Guinea, Res. Bull. No. 27).

Mulhearn, P.J. (1989), *Turbidity in Torres Strait,* Defence Science and Technology Organisation, (Technical Memorandum WSRL-TM-35/89).

OTML (Ok Tedi Mining Limited) (1988), *Interim Report.*

Pickard, G.L., Donguy, J.R., Henin, C. and Rougerie, F. (1977), *A review of the physical oceanography of the Great Barrier Reef and western Coral Sea,* Australian Institute of Marine Science, Townsville. (Monographs Series, Vol. 1).

Scully-Power, P.D. (1973), *Oceanography of the Coral Sea: the winter regime,* Royal Australian Navy Research Laboratory, (Technical Note No. 13/73).

SMEC (Snowy Mountains Engineering Corporation) (1978), *Hydrologic investigations for the Ok Tedi project,* Snowy Mountains Engineering Corporation for Dampier Mining Co. Ltd.

SMEC (Snowy Mountains Engineering Corporation) (1982), *Ok Tedi Project: Hydrographic Survey of the Fly River,* Snowy Mountains Engineering Corporation for Ok Tedi Mining Limited.

Taylor, L.W.H. (1978), A preliminary investigation of the marine geology of the Fly River estuary, Papua. Unpublished Rep., University Sydney, Dept. of Geology, Sydney.

Thompson, R.O.R.Y. and Golding, T.J. (1980), 'Tidally induced upwelling by the Great Barrier Reef', *J. Geophysical Research,* 86, 6517-6521.

Thomson, R.W. and Wolanski, E. (1984), Tidal period upwelling within Raine Island Entrance, Great Barrier Reef', *J. Marine Research,* 42, 787- 808.

Wolanski, E. (1982), 'Low-level trade winds over the western Coral Sea' *J. Applied Meteorology,* 21, 881-882.

Wolanski, E. (1983), 'Tides on the northern Great Barrier Reef continental shelf, *J. Geophysical Research,* 88, 5953-5959.

Wolanski, E. (1986), 'The physical oceanography of Torres Strait', In A.K. Haines, G.C. Williams and D. Coates (Eds.), *Torres Strait Fisheries Seminar, Port Moresby 11-14 February 1985,* Australian Government Publishing Service, Canberra, 275-292.

Wolanski, E. (1987), Landsat views Raine Island. A report to the Raine Island Corporation.

Wolanski, E. and Ruddick, B. (1981), 'Water circulation and shelf waves in the northern Great Barrier Reef lagoon', *Aust. J. Marine Freshwater Res.,* 32, 721-740.

Wolanski, E. and Thomson, R.W. (1984), 'Wind-driven circulation on the northern Great Barrier Reef continental shelf in summer', *Estuarine, Coastal Shelf Sci.,* 18, 271-289.

Wolanski, E., Pickard, G.L. and Jupp, D.L.B. (1984), 'River plumes, coral reefs and mixing in the Gulf of Papua and the northern Great Barrier Reef', *Estuarine, Coastal Shelf Sci.*, 18, 291-314.

Wolanski, E., Ridd, P. and Inoue, M. (1988a), 'Currents through Torres Strait', *J. Physical Oceanography*, 18, 1535-1545.

Wolanski, E., Drew, E., Abel, K.M. and O'Brien, J. (1988b), 'Tidal jets, nutrient upwelling and their influence on the productivity of the alga Halimeda in the Ribbon Reefs, Great Barrier Reef', *Estuarine, Coastal Shelf Sci.*, 26, 169-201.

Wolanski, E. and Ridd, P. (1990), 'Mixing and trapping in Australian tropical coastal waters', In R.T. Cheng (ed), Residual currents and long-term transport, Springer-Verlag, Berlin, (Coastal and Estuarine Studies, Vol. 38).

Wyrtki, K. (1960), *Surface circulation in the Coral Sea and Tasman Seas*, CSIRO Division of Fisheries and Oceanography, (Technical Paper No. 8).

Zijlstra, J.J., Baars, M.A., Tijssen, S.B., Wetsteyn, F.J., Witte, J.I.J., Ilahude, A.G. and Hadikusumah. (1990), 'Monsoonal effects on the hydrography of the upper waters (< 300 m) of the Western Bander Sea and northwestern Aratura Sea with special reference to vertical transport processes', *Neth. J. Sea Res.*, 25, 431-447.

South Pacific Regional Environmental Programme Marine Coastal Pollution Study (SPREP-POL)

Nicholas A. Currey and Walter I. Benko
National Analysis Laboratory
Papua New Guinea University of Technology

Abstract

The South Pacific Region represents a substantial area of the world's major ocean. In response to concerns expressed by South Pacific Governments over the state of the marine environment, a proposal to undertake a marine coastal pollution study was initiated in 1989. As a part of the Regional Seas programme of UNEP, the project will attempt to assess the extent of pollution and quality trends by a series of monitoring and research activities at "clean" reference and known polluted areas. Areas to investigate include; ocean processes and properties, heavy metals, sewage and nutrients, pesticides and hydrocarbons. The paper will review previous work undertaken in the region of direct relevance to the Torres Strait and outline the SPREP-POL programme proposals.

Background

The action plan for the South Pacific Regional Environmental Programme (SPREP) was adopted at a conference on the "Human Environment in the South Pacific" in New Zealand 1982. All South Pacific States and Territories including Australia, New Zealand, as well as the United Kingdom, the United States and France participated in the SPREP Action Plan and Convention. It is considered as the overall framework for regional co-operation on environmental matters related to the marine, coastal and territorial environment of the South Pacific Region.

The Convention specifically requires the contracting parties to prevent, reduce and control pollution from any source and to co-operate in scientific research, environmental monitoring and the exchange of data and other scientific and technical information. The Action Plan and the Convention was a joint activity of the South Pacific Commission (SPC), the South Pacific Bureau for Economic Co-operation (SPEC), the Economic and Social Commission for Asia and the Pacific (ESCAP) and the United Nations Environmental Programme (UNEP).

A number of projects relevant to the monitoring, research and control of pollution in coastal and open ocean waters of the SPREP Convention area have been undertaken in the past four years, by a formally established network of research and monitoring institutions of the SPREP area with UNEP's support through a project with SPC.

On the recommendation of the Fourth Consultation Meeting of the SPREP Research and Training Institutions (Noumea, June 1988) the Intergovernmental Meeting on the SPREP Action Plan approved the consolidation of future and ongoing activities relevant to monitoring, research and control of marine pollution into a coordinated regional project called SPREP-POL.

SPREP-POL

The South Pacific Region represents a substantial area of the world's major ocean, covering an area of almost 30 million square kilometers (Morrison, 1990). Encompassed are a large number of small countries or territories separated by substantial stretches of ocean. The small size and the remoteness of many of the islands is an environmental hazard, since any mistakes in environmental management may be extremely difficult to rectify, at least in the short term.

The South Pacific has an attractive image internationally, an image that has been exploited for tourism development. The pictures of white sandy beaches, clear lagoon waters, thriving coral reef communities are used widely to attract travellers from all over the world. This picture is valid in many places, but some areas are under considerable environmental pressure. If much care is not taken, the coastal resources that form the basis of foreign exchange earning capacity may cease to be the country's lucrative source of income.

The SPREP-POL meeting in Sydney in 1989 looked at a number of reviews for the region (eg. Dahl and Baumgant, 1983; Dahl, 1984; Brodie and Morrison, 1984; Brodie *et al*, 1990) and concluded that the priority marine pollution problems are:

- Destruction of coastal ecosystems
- Lowering of water quality
- Changing ocean processes and properties
- Climate change and sea level rise.

The first three problems can be addressed directly by regional agencies and governments. The climate change and sea level rise is a global effect, not easily addressed by island nations.

The primary cause of the problems have been identified as:

1. **Disposal of domestic water (sewage and solid wastes)**

   In many countries, especially small ones, the disposal of sewage and solid wastes is difficult. If marine disposal is not to cause major pollution (both chemical and microbiological) then expensive pretreatment is required. A recent study in a number of Pacific Island Lagoons showed that contamination due to sewage was the major marine pollution problem (Naidu *et al.* 1989). The report also showed that nitrate and phosphate levels were elevated and could have adverse effects on the coral reefs.

2. **Disposal and management of non-domestic waste**

   The materials include solid waste, agricultural chemicals, waste oils and mine tailings. Pesticides have been reviewed in the region (Mowbray, 1988) as much is used on the coastal plains and washed into the marine environment. Shellfish are known to be bio-accumulators of pesticides and these accumulated toxins can present a potential health hazard. Mining is limited to only a number of countries. Ocean disposal of tailings and wastes must have an effect on the immediate environment.

3. **Increased sedimentation due to land use changes, mining and construction**

   The land use changes usually include logging projects and intensification of agriculture in the steeper zones resulting in increased sedimentation. Increased populations in coastal areas which require housing, shipping and industrial activity have also contributed to increasing sediment loads.

4. **Coastal development activities**

   These include sand and gravel extraction, dredge and fill activities, port development and tourism related activities of resort construction, airport enlargement and road upgrading. Blasting of coral reefs and mangrove removal all have had detrimental effects on the local environment.

5. **Over exploitation of living marine resources**

   This is a problem near major population centres where reef-gleaning is a major food source.

6. **Natural disasters**

   These include cyclones, volcanic eruptions and cyclical/regional events such as El Nino oscillation.

The SPREP-POL project will attempt to assess the extent of pollution and quality trends by a series of monitoring and research activities. The long term objectives of the project are:

1. To analyse the causes of marine pollution degradation in the SPREP convention area and to formulate recommendations for pollution control measures suitable for the socioeconomic development of the SPREP regions on a sustainable basis.

2. To provide the scientific and technical information needed by the Governments of the Region for the control of marine pollution as envisaged by the SPREP Convention, its protocols and the SPREP Action Plan.

3. To build up constant and comparable time series of data relevant to the state of the marine environment, including the sources, amounts, pathways levels and effects of pollutants in the SPREP Convention Area.

4. To enhance the indigenous capability for monitoring and analysis of marine pollution and informed decision making concerning the control of such pollution.

5. To contribute through the Regional Seas Programme of UNEP to the Global Environment Monitoring systems (GEMS) of UNEP.

Funding has been sought from a number of sources to support this project which is estimated to cost approximately USD $2 million over 2 years. The first $200,000 is expected to be released late 1990.

The SPREP-POL monitoring activities will include:

1. **Ocean Processes and Properties**

   Circulation patterns, thermal structure, salinity distribution, plankton productivity, nutrient fluxes, larval distribution patterns.

2. **Heavy Metals**

   Activities will concentrate on mercury, cadmium, lead and tin but other metals where appropriate.

3. **Pesticides**

   In particular organochlorine pesticides.

4. **Sewage related parameters**

   Study nutrients and microbiological contamination.

5. **Hydrocarbons and detergents**

A series of review papers on recent research and monitoring activities has been produced on each of the above topics for the region as an addenda to the SPREP-POL working paper. The review paper (Currey, 1990) on heavy metal monitoring includes the Fly River and Port Moresby areas of Papua New Guinea. These are of direct relevance to the Torres Strait Baseline Study.

Heavy metals in Torres Strait

Fly River Delta

The Fly River naturally discharges about 7000m^3/s of water and 85,000,000 tonnes/annum of sediment. The OK Tedi copper and gold mine has been operating since May 1984. The principal metals in the wastes are copper, lead, cadmium, and zinc. The metals are usually associated with the particulate material. Dent (1985) predicted that the copper concentrations in the sediment reaching the sea would be 320 mg/kg.

Work undertaken by OK Tedi (OTML, 1988) has shown that most of the water entering the Gulf of Papua from the Fly and Strickland Rivers flows to the northeast. Wind is the main cause of currents in surface waters of the North-Western part of the Coral Sea and through Torres Strait. This coupled with the shallow waters in Torres Strait, means part of the water discharged from the rivers into the Gulf of Papua, leaves via Torres Strait, especially during the S.E. monsoon. In the water, total copper concentrations range from >50 ug/L at Lewada, which is approximately 100km from the Gulf of Papua to <1ug/L at the Gulf. Dilution and sedimentation would cause this decrease in total metal concentration. OTML data shows that the greatest proportion of copper was found in the particulate phase. Concentrations in the water column ranged from 81 mg/kg at Lewada decreasing to 35 mg/kg, 123 km out to sea from the delta mouth. Copper in the sediments (<63 um fraction) decreased from 40 mg/kg at Lewada to 8 mg/kg 160 kilometres out to sea.

Harris (1989) analyzed 20 seabed sediments moving from the Fly Delta to 267 kilometres out to sea. The copper concentrations ranged from 22.3 - 1.1. mg/kg (Table 1). Both copper and zinc concentrations decreased on moving away from the Delta mouth. Water samples were filtered and the retained filtrate analyzed for copper. The copper concentrations ranged from 13.3 ug/L to 0.9 ug/l on moving away from the Fly River mouth.

Prawn specimens were also collected in 1986 and 1988 and analyzed for copper, zinc and cadmium. Zinc concentrations were 22 - 28 mg/kg, well below the Australian consumption recommended standard level of 150 mg/kg. Copper, with a mean of 22 mg/kg, exceeded the recommended standard level of 10 mg/kg and cadmium with a range of 0.78 - 1.86 mg/kg also exceeded the Australian consumption recommended standard of 0.2 mg/kg.

Port Moresby

Several studies have been undertaken in the Port Moresby coastal region by staff of the University of Papua New Guinea. Haei (1985) studied heavy metals in mussels, oysters and giant clams. The results (Table 2) for oysters showed low concentrations for cadmium and lead, with elevated copper (27 mg/kg and zinc (248 mg/kg) concentrations. All of the results were within the Australian recommended standards for consumable shellfish.

Kaluwin and Haei (1988) measured metal concentrations in shellfish in Port Moresby and at Bootless Bay, which is a small marina-type development. The copper and cadmium results were both elevated when compared with the previous work of Haei (1985). The zinc concentrations for all Port Moresby sites were relatively high ranging between 228-468 mg/kg, but still below the Australian recommended consumption standards of 1000 mg/kg. Balat (unpublished) measured copper in coastal sediments from 4 sites near Port Moresby. The concentrations ranged from 0.18 - 35 mg/kg dry weight (Table 1).

National Analysis Laboratory Capabilities

The National Analysis Laboratory (NAL) is a semi-commercial laboratory operating under the commercial consulting company of the PNG University of Technology in Lae, PNG. The Laboratory offers an extensive range of professional analytical testing

Table 1. Heavy Metal concentration in sediments, mg/Kg (dry weight).

SITE/LOCATION	CADMIUM	COPPER	CHROMIUM	LEAD	MERCURY	ZINC	REFERENCES
Solomon Islands (Marovo Lagoon)	0.8 - 2.6	6.2 - 164	1.1 - 86	18.7 - 79.5	na	na	Naidu *et al.*, (1989)
French Polynesia (Tahiti)	mean results 0.08 - 0.98	0.8 - 1140	9.5 - 262	<0.2 - 81	<0.05 - 5.7	35 - 339	DeNardi *et al.*, (1989)
French Polynesia (Huahine)	mean results 0.04 - 0.45	0.45 - 31	8.8 - 70	0.07 - 3.7	0.30 - 0.67	18 - 162	DeNardi *et al.*, (1989)
French Polynesia (Takapoto)	mean results 0.03 - 1.29	0.42 - 1.4	2.2 - 3.0	<0.08 - 0.98	na	0.6 - 7.5	DeNardi *et al.*, (1989)
PNG - Port Moresby	na	0.18 - 35	na	na	na	na	Balat
PNG - Fly River Delta	na	10 - 48 in <100um fraction		na	na	na	OTML (1989)
PNG - Fly River Delta	0.019 - 0.18	1.1 - 22	na	na	na	8.8 - 94	Harris (1989)
PNG - Empress August Bay	na	25 - 1500	na	na	na	na	Brodie *et al.*

Table 2. Heavy Metal concentration in Shellfish, mg/Kg (wet weight).

SITE/LOCATION	SPECIES	CADMIUM	COPPER	CHROMIUM	LEAD	MERCURY	ZINC	REFERENCES
Fiji - Laucala Bay - Suva Harbour	Crassostrea mordax	<0.1 - 0.25	15 - 161	<0.1 - 1.75	<0.5 - 5.48	<0.001 - 0.062	na	Naida *et al.* (1989)
Fiji - Vigo River estuary	Bivalves	0.03 - 0.21	1.7 - 3.0	0.34 - 0.4	0.12 - 0.18	0.01 - 0.04	6 - 10	Gangaiya *et al.* (1986)
Fiji - Teidamu River estuary	Bivalves	0.04 - 0.06	1.5 - 2.5	0.27- 0.7	0.09 - 0.15	0.02 - 0.04	7.3 - 9.0	Gangaiya *et al.* (1986)
French Polynesia Tahiti - Yacht Club	Mussels	mean results 0.14 - 0.54	5.45 - 8.0	2.0 - 8.9	0.54 - 1.96	0.09 - 0.74	93 - 590	DeNardi *et al.* (1989)
French Polynesia Takapoto	Mussels	mean results 0.45 - 3.3	3.4 - 6.7	3.1 - 19.8	0.35 - 1.35	<0.05 - 0.30	14 - 38	DeNardi *et al.* (1989)
French Polynesia Tahiti - Papeete	Mussells	mean results 0.16 - 0.31	6.7 - 38.6	2.0 - 6.85	0.67 - 2.3	0.16 - 0.40	140 - 590	DeNarid *et al.* (1989)
Vanuatu - Vila Bay Star Wharf	Crassostrea spp &	<0.01 - 0.31	32.6 - 79	<0.1 - 0.2	0.72 - 0.9	0.02	na	Naida *et al.* (1989)
Erakor lagoon International Hotel	Anadera spp	<0.01 - 0.2	13.9 - 16	<0.1 - 0.13	0.91 - 0.94	0.01	na	Naida *et al.* (1989)
PNG - Morobe	Saccostrea	0.24 - 1.0	3 - 177	na	0.03 - 0.69	na	9 - 298	Balat (1989)
PNG - Port Moresby	Saccostrea spp	0.14 - 0.43	26 - 38	na	0.11 - 0.24	na	430 - 468	Kuluwin & Haei (1988)
PNG - Port Moresby Bootless Bay	Saccostrea spp	0.23 - 0.53	51 - 98	na	0.08 - 0.81	na	236 - 279	Kuluwin & Haei (1988)
PNG - Port Moresby	Saccostrea spp	0.008 - 0.076	16.6 - 27	na	0.11	na	228 - 298	Haei (1985)
PNG - Fly River Delta	Saccostrea spp	0.1 - 1.7	9 - 191	na	0.60 - 1.2	na	10 - 4029	SPREP (1985)
PNG - Daru Bobo Island	Saccostrea spp	0.70 - 3.0	73 - 573	na	na	na	976 - 3349	Hortle *et al.* (1984)

facilities to clients in Papua New Guinea. NAL services are available to agriculture, commerce, industry, governmental departments and private individuals.

The laboratory is accredited under the PNG laboratory accredation scheme and assessed by the National Association of Testing Authorities, Australia for a wide range of analytical testing including waters, soils, sediments, biota, foliar, and foodstuffs. The laboratory has extensive experience and expertise in the following environmental fields:

- General water quality parameters to WHO drinking standards;
- Trace metals, total and dissolved in fresh and marine waters to microgram per litre detection limits;
- Microbiological examination of raw, waste and natural waters;
- Sediment and soil analysis for metals, cyanide contamination and nutrient status;
- Analysis of biological materials for trace metals including mercury.

The laboratory provides a quality service ensuring accurate and precise results. Strict quality control procedures involving the inclusion of appropriate external reference materials (NBS, IAEA and USEPA) with each analysis batch, use of quality control charts and a laboratory instrument calibration programme, ensure the accuracy and precision of results generated by the laboratory. Participation in inter-laboratory round robins such as the International Soil and Plant Exchange run by the Agricultural University at Wageningen in the Netherlands, the Association of American Cereal Chemists Stockfeed Program, the Standards Australian Cadmium and Lead in Blood program and NATA programs allow on-going verification of laboratory procedures.

NAL's location at the PNG University of Technology gives it ready access to the specialists in the University's teaching departments, as well as the Matheson Library and the University Computer Centre.

The laboratory is well equipped with state of the art instrumentation, and has a continuing programme of updating and renewing equipment. A Perkin Elmer PE3100 Atomic Absorption Spectrophotometer with flow injection and mercury amalgamation unit has been recently purchased. This will allow mercury analysis with detection limits in the region of <0.02ppb. The Perkin Elmer enhanced data system in conjunction with an IBM PC is used to provide complete control of all data handling and accessories.

Other major items of equipment in the laboratory include a Varian SpectrAA-40 atomic absorption spectrophotometer with hydride generator and graphite furnace atomizer, which is dedicated to trace metal analysis. A HPLC ion chromatography system including conductivity, fluorescence, refractive index and UV-VIS detectors, for the determination of low concentrations of anions in water samples, vitamins, sugars, organic acids etc in various foodstuffs. A PDV-2000 polarography unit allows trace metal analysis in the field. The laboratory also is equipped with standard instrumentation such as UV-Visible spectrophotometers, ion-selective electrodes, pH meters etc.

In addition, instrumentation such as gas chromatographs, FTIR and additional atomic absorption spectrophotometers are available in the Department of Applied Science, ensuring a wide range of analytical techniques to meet specific or customized analysis requirements according to clients needs.

All trace metal analysis sample preparation is performed in the laboratory's clean room facilities, which include laminar flow cabinets, and a Barnstead high purity water system. The use of over-shoes, tacky mats, particulate free laboratory coats and gloves by personnel in the clean room environment ensure contamination free preparation of samples for trace metal analysis.

The clean room facilities are of particular importance. Furness and Rainbow (1990) in their authorative volume on trace metals in the marine environment, point out that major advances in knowledge of the concentrations and distributions of trace metals in the seas and oceans have only occurred since the mid 1970s. This is largely due to the adoption of clean methodologies for handling and analysis of samples.

NAL currently provides an environmental testing service to many major clients including Placer Pacific in their environmental baseline studies and ongoing compliance monitoring at Porgera and Misima Island gold mines. The laboratory has performed the majority of the analyses for the pre-mining environmental impact statements undertaking by Natural Systems Research, environmental consultants for the majority of the mining developments in Papua New Guinea.

Other projects conducted by NAL staff have included studies for SPREP on "Monitoring of Papua New Guinea Waters Receiving Inputs from the Mining Industry" (Hilton *et al*, 1988) and investigations into metal concentrations of waters, sediments and biota from Lake Murray and the Strickland River (Currey and Yaru 1990). Currently, a paper titled "Total As, Cd, Cu, Cr, Fe, Hg, Mn, Ni, Pb, Se, and Zn Concentrations in Barramundi, *Lates calcarifer*, from Lake Murray, Papua New Guinea" (Currey *et al*, 1990) is to be published in the *Science of the Total Environment* journal.

Conclusion

The PNG University of Technology through its ongoing research programmes, has the ability to input a significant contribution to the Torres Strait Baseline Study. The National Analysis Laboratory has the proven capability and expertise to undertake the analysis of waters, sediments and biota for trace metals including mercury and the metalloids arsenic and selenium.

SPREP coordinators are willing to be associated with the Torres Strait Baseline Study which in conjunction with the SPREP-POL project, can monitor marine pollution in a concerted regional effort, producing a comparable time series of data. This will produce valuable information for governments, allowing timely and cost-effective action to correct pollution problems, and to plan for sustainable development and management.

Bibliography

Balat, N. (nd), A Preliminary Analysis of Copper Concentrations in Water and Sediments of the Papuan Coastal Lagoon, Papua New Guinea. (Unpublished report)

Brodie, J.E., Morrison, R.J. (1984), *Coastal and Inland Water Quality in the South Pacific,* South Pacific Commission, Noumea. (SPREP Topic Review No. 16)

Brodie, J.E., Arnould, C., Eldridge, L.G., Hammond L.A., Holthus, P., Mowbray, D.L., Tortell, P. (1990), *Review of the State of the Marine Environment: South Pacific Regional Report,* UNEP, Nairobu.

Currey, N.A. (1990), *Trace (Heavy) Metal Concentrations in the Marine Environment of the South Pacific,* Unpublished paper presented at the Third SPREP Intergovernmental Meeting, Noumea, New Caledonia.

Currey, N.A., Yaru, B.T. (1990), Monitoring of Papua New Guinea Waters Receiving Input from the Mining Industry: Lake Murray and Strickland Rivers Investigation, Final report prepared for the South Pacific Regional Environmental Programme.

Currey, N.A., Benko, W.I., Yaru, B.T., Kabi, R. (in press), Determination of Heavy Metals, Arsenic and Selenium in Barramundi (*Lates calcarifer*) from Lake Murray, Papua New Guinea, Unpublished paper.

Dahl, A.L., Baumgart, I.L. (1983), *The State of the Environment in the South Pacific,* UNEP Nairobi. (UNEP Regional Seas Reports and Studies No. 31)

Dahl, A.L. (1984), 'Oceania's most pressing Environmental Concerns', *Ambio,* 13, 296-301.

Dent, J. (1985), 'Possible impact of OK Tedi mining wastes on the waters of Torres Strait', In A.K. Haines, G.C. Williams, D. Coates (eds) (1986), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February, 1985,* Australian Government Publishing Service, Canberra, 293-298.

DeNardi, J.L., Jowen, R., Gignon, J.L., Lenfant, A., Mabila, L., Corre, L. (1989), *A Study of the Characteristics of the Lagoon Waters Utilised in French Polynesia,* Commissariat a l'Engerie Atomique, France. (Report CEA-R-5487)

Furness, R.W., Rainbow, P.S. (1990), *Heavy Metals in the Marine Environment,* CRC Press, Boca Raton, Florida.

Gangaiya, P., Brodie, J.E., Morrison, R.J. (1986), *Initial Report on the Quality of the Vitogo River and Associated Environment before the Construction of an Integrated Sawmill/Chipmill Complex at Drasa, Western Viti Levu, Fiji,* INR, USP, Suva. (INR Technical Report 86/5)

Haei, P. (1985), *Determination of Heavy Metal Residues in Mussels, Oysters and Clams by Atomic Absorption Spectroscopy and Differential Pulse Anodic Stripping Voltammetry in Coastal Water Quality Monitoring and Control Baseline Studies of Port Moresby Harbour Area,* University of Papua New Guinea, Port Moresby.

Harris, P., (1989), *Metal Levels in Tiger Prawn Specimens from Torres Strait,* Ocean Science Institute, University of Sydney, Sydney.

Hilton, D.F., Yaru, B.T., Currey, N.A. (1988), Monitoring of Papua New Guinea Waters Receiving Input from the Mining Industry, unpublished progress report prepared for the South Pacific Regional Environmental Programme.

Hortle, K.G., Ballock & Maie, A.K. (1984), Unpublished data.

Kaluwin, C., Haei, P. (1988), Preliminary Report on Heavy Metal Studies, unpublished paper presented at the Fourth Consultative Meeting of Research and Training in the South Pacific Region. SPC, Noumea.

Morrison, R.J., (1990), Assessment and Control of Pollution in Coastal and Open Ocean Areas of the SPREP Convention Region, unpublished paper presented at the Third SPREP Intergovernmental Meeting, Noumea, New Caledonia, 24-28 September 1990.

Mowbray, D.L. (1988), Pesticides in the Marine Environment of the SPREP Region, unpublished paper presented at the Third SPREP Intergovernmental Meeting, Noumea, New Caledonia, 24-28 September 1990.

Naidu, S., Aalbersberg, W.G.L., Brodie, J.E., Fuavoa, V.A., Maata, M., Naqasima, M., Whippy, P., Morrison, R.J. (1989), *Water Quality Studies on Selected South Pacific Lagoons,* Institute of Natural Resources, Univeristy of the South Pacific, Suva.

OTML (1988), *Sixth Supplemental Agreement Environmental Study, 1986-1988,* Draft Final Report, November 1988: Volume 2 (appendices). OK Tedi Mining Limited, Boroko and Tabubil.

OTML (1989), *Supplementary Environmental Investigations, June 1989,* OK Tedi Mining Limited, Boroko and Tabubil.

SPREP/UNEP Workshop on Development of a Marine Pollution Assessment and Control Programme for the SPREP Region (SPREP-POL), University of New South Wales, Sydney, Australia, 16-20 January 1989, Unpublished data.

Australian and Some International Food Standards for Heavy Metals

George E. Rayment
Queensland Department of Primary Industries

Abstract

Heavy metals are potential environmental contaminants with the capability of causing human health problems if present to excess in the food we eat. There may be no visible sign of an illegal or unacceptable level of residue, particularly for toxic elements such as cadmium, lead and mercury. At higher concentrations heavy metals may poison their hosts. Those which obviously damage their host before they adversely affect human health are of lesser concern to the wider community. Well known examples of human heath problems arising from excess heavy metal accumulations in food sources are mercury toxicity from fish consumption at Minemata, and Itai-itai disease associated with excessive cadmium intake. At lower but still unacceptable levels of exposure, effects may be restricted to the physiological or biochemical level, such as behaviour disturbances and learning difficulties.

Regulatory agencies in most countries now seek to protect public health by exercising controls over the chemical composition of specific food types. The process typically involves setting appropriate standards for potentially toxic chemicals in foods; standards which by law should not be exceeded. These or similar agencies then undertake or overview random and/or periodic chemical testing of appropriate samples to ensure compliance.

Many countries have now set legal or at least provisional guideline levels for maximum permitted concentration (MPCs) for one or more heavy metals. A listing with emphasis on cadmium and seafoods has been compiled. There are wide differences, ranging, for cadmium, from 0.05 mg/kg for 'fish and fish products' in several countries to 6.0 mg/kg for 'all foods' in Bangladesh and Pakistan. The Australian MPC for 'fish and the fish content of products

containing fish' is 0.2 mg/kg, based on the fresh weight of the edible portion, expressed as the metal. Australia has adopted an identical MPC for cadmium in crustaceans whereas several countries have adopted higher values. This may reflect the tendency of crustaceans to at times accumulate cadmium, even in apparently pristine marine waters. The Australian MPC for copper in all seafoods with the exception of molluscs is 10 mg/kg fresh weight of the edible portion, expressed as the metal; the corresponding MPC for molluscs is 70 mg/kg.

With respect to food standards in Australia, the Commonwealth and States have agreed 'that uniform food standards should apply across the nation and be regulated by a National Food Authority', a statutory authority answering to the Commonwealth Minister for Community Services and Health. Currently, a combination of Federal and States/Territories arrangements apply. The 'Food Standards Code' of the National Health and Medical Research Council (NHMRC), prepared by direction of the NHMRC Public Health Committee underpins the Australian food standards. The National Food Standards Council was established to give final State/Territory approval or rejection of NHMRC recommendations. Moreover, all NHMRC proposals to amend the Food Standards Code must be endorsed by the National Food Standards Council. Internationally, the Codex Alimentarius Commission of FAO/WHO (Codex) plays a major role in the setting of food standards to ensure fair practices in international trade, and to protect the health of consumers. Both Australia and Papua New Guinea are member countries of Codex, along with 135 other.

Introduction

It is well recognised that chemicals capable of causing human health problems can be present in the food we eat. Among these are a wide range of pesticides, veterinary chemicals, heavy metals, and metalloids such as arsenic. In many cases there may be no visible sign in the food plant or animal of an illegal or unacceptable level of chemical residue, particularly for toxic elements such as cadmium, mercury and lead. At even higher concentrations the same chemicals may poison their hosts. Those which poison their host before they adversely affect human health are of lesser concern to the wider community.

Pesticides and veterinary chemicals have positive benefits when deliberately used to effect controls over particular pests and diseases which would otherwise destroy or disfigure potential food sources. However, if their use is inappropriate or in excess of label recommendations, illegal residues may result. In contrast, concerns about the ingestion of toxic heavy metals (including metalloids) are seldom associated with their deliberate application to potential food sources.

The case against heavy metals has built up over time. For example, the harmful effects of lead were recognised by the Greeks by at least the second century BC (Waldron 1973). Close examination by toxicologists studying cases of poisoning from heavy metals revealed that visible clinical symptoms were likely only in cases of high exposure, as may occur at an occupational level or following gross contamination of the environment. Well known Japanese examples of the latter are mercury toxicity from fish consumption at Minemata and Itai-itai disease from consumption of excess cadmium.

At lower but still unacceptable levels of exposure – typically from consumption of certain foods – effects may be restricted to the physiological or biochemical level (Hutton 1987). Behaviour disturbance and learning difficulties in children are recognised symptoms of lead poisoning in children (Lansdown 1979), whereas there is some evidence for the association of cadmium, chromium, copper, selenium and zinc in cardiovascular disease (Shaper 1979). Some such as nickel and chrome and perhaps cadmium may be potential human carcinogens (Garner 1979, Tanenaka *et al.* 1983). Table 1 provides summary information on metabolic factors associated with some heavy metals.

Table 1. Key metabolic factors following environmental exposure to heavy metals (adapted from Hutton 1987)

Factor	Lead	Mercury	Cadmium	Arsenic
Key entry pathway	Ingestion, inhalation	Ingestion, inhalation of metal	Ingestion, inhalation; eg. tobacco	Ingestion
Gastrointestinal absorption (%)	approx 10	approx 95	approx 5 *	> 80
Organs accumulating	bone, kidney, liver	brain, liver, kidney	kidney, liver	keratinous tissue
Major routes of excretion	urine	faeces	urine	urine
Biological half-life	approx 20 y	approx 70 d	> 10 y	10-30 h

* Individuals with low iron store or on a calcium deficient diet may absorb as much as 20% (WHO 1985). This is an example that figures on absorption of heavy metals can vary widely for a variety of reasons.

Hamilton (1988) noted that the first legislation to control the adulteration of food or drink occurred in Britain in 1860, in response to a series of exposes on the use of heavy metal salts as colouring matter in food. Regulatory agencies in most countries now seek to protect public health by exercising controls over the chemical composition of specific food types. The process typically involves setting appropriate standards for potentially toxic chemicals in foods; standards which by law should not be exceeded. These or similar agencies then undertake or overview random and/or periodic chemical testing of appropriate samples to ensure compliance. Some details are reviewed in this paper, with emphasis on heavy metal contaminants.

Setting Food Standards

Agencies Relevant to Australia

There is agreement between the Commonwealth of Australia and Australian State Governments 'that uniform food standards should apply across the nation and be regulated by a National Food Authority' (Anon 1990). This will be a statutory authority answering to the Commonwealth Minister for Community Services and Health. When fully operational, work now done by the National Health and Medical Research Council (NHMRC) in the food area will probably pass to the Authority.

At present, a combination of Federal and States/Territories arrangements apply, with States/Territories responsible for administration of Food Law in their own areas of jurisdiction. In Queensland, the *Food Act 1981-1984* and *Food Standards (Adoption of Food Standards Code and General) Regulations 1987* apply.

Responsibility for the quality of food exports and compliance sampling of food imports is a Commonwealth responsibility. The Commonwealth could also regulate the quality of food moving in interstate trade, but has never implemented these powers.

Underpinning Australian food standards is the 'Food Standards Code' of NHMRC, prepared by direction of the NHMRC Public Health Committee (Anon 1987). By Agreement in 1987, the States and the Northern Territory use the NHMRC food standards but retain the right to deviate or not to take into legislation. The National Food Standards Council was established to give final State/Territory approval or rejection of NHMRC recommendations. Moreover, all NHMRC proposals to amend the Food Standards Code must be endorsed by the National Food Standards Council. Industry, consumers, toxicologists, and experts from the States and Northern Territory have input and are represented on NHMRC food committees. The NHMRC itself – now administered by the Minister for Aged, Family and Health Services – was established about 50 years ago to advise the governments of Australia on health matters.

Another significant advisory body, particularly for pesticide residues but increasingly for other contaminants of food – including heavy metals – is the Codex Alimentarius Commission of FAO/WHO (Codex). The primary purposes of Codex, which was established in 1962, are to ensure fair practices in international trade, and to protect the health of consumers. Both Australia and Papua New Guinea are member countries of Codex, along with 135 others (Anon 1989a). Codex has established mechanisms for governments to agree on such things as maximum residue limit (MRL) values for pesticides in foods, extraneous residue limit (ERL) values for pesticides in non-target foods such as fish, and maximum permitted concentrations (MPCs) for heavy metals in foods.

Process and Problems

Establishing MRLs (Anon 1989b,c; Hamilton 1988) and MPC's for specific chemicals and food types typically requires the coordination of two sets of scientific studies as follows:

- toxicological studies on animals, used to set an acceptable daily intake (ADI); and
- residue studies, based on 'good agricultural practice' (or perhaps information from broadly-based surveys in the case of toxic heavy metals).

When established, these legal food standards are intended to reassure consumers, while offering a division between food which is legally (though not necessarily scientifically) fit or unfit to eat and/or move in international trade.

At the international level, the Codex Committee on Fish and Fishery Products has discussed guidelines for mercury contamination in fish (Anon 1987b, 1989a), particularly methyl mercury for which guideline levels of 0.5 mg/kg methyl mercury for fish in general and 1.0 mg/kg methyl mercury for predatory fish (Anon 1989a) were proposed. It has since been decided that further in-depth discussion is necessary (Anon 1989a).

Moreover, the Joint WHO/FAO Codex Committee on Food Additives and Contaminants (CCFAC) at its March 1989 meeting considered proposals for a range of permitted concentrations of lead and cadmium, including 1.0 mg/kg of cadmium in both molluscs and crustaceans, and 0.1 mg/kg of cadmium in fish and fish products. The proposal represented a five-fold increase relative to the present Australian MPC for cadmium in crustaceans (Table 2) but those for molluscs and fish/fish products were half those applicable in Australia. In March 1990, CCFAC took the view that the establishment of international limits for cadmium and lead may be unnecessary and may create new barriers to external trade.

The issue of setting MPCs (or equivalent) for heavy metal contaminants in foods is particularly sensitive, as is any process to effect or recommend changes to existing levels. Moreover, proven violations of heavy metal MPCs attract media attention. This has occurred with such things as cadmium in spanner crabs (The Courier Mail, Feb 18, 1990, p.1 and Feb 25, 1990, p.5) and heavy metals in prawns from Torres Strait (Anon 1989d).

Australian Food Standards for Heavy Metals

Australian food standards for heavy metal contaminants of fishery and some other foods types from the Food Standards Code (Anon 1987a), together with those which previously applied in Queensland in 1982 (Food Standards Regulations 1982) are summarised in Table 2. Conditions which apply to the present MPC's include the following:

- 'metal' includes compounds of a metal;
- antimony, arsenic, and selenium are deemed to be metals;
- MPCs apply to the edible content that is ordinarily consumed
- MPCs for food in dried, dehydrated, or concentrated form are calculated with respect to mass of food following dilution or reconstitution.

It is apparent from Table 2 that different MPCs apply to the various heavy metals and among food types for a given metal. Moreover, an 'all other foods' category is common to all metals. For example, as crustaceans were not specifically mentioned in the 1982 Queensland food regulations for cadmium, the 'all other foods' category of 0.05 mg/kg fresh weight of the edible portion would have applied at that time. For copper, the 'all other foods' category currently applies to all seafoods other than molluscs, the relevant MPC being 10 mg/kg fresh weight of the edible portion.

Table 2. Selected present Australian (Anon 1987a) and superseded 1982 Queensland food standards for heavy metals (mg/kg, calculated and expressed as the metal).

Metal	Food type	Present Australian MPC	Superseded Qld MPC
Antimony	Foods other than beverages and other liquid foods	1.5	1.5
Arsenic	Fish, crustaceans and molluscs (inorganic arsenic only)	1.0	1.0
Cadmium	Crustaceans & the crustacean content of products containing crustaceans	0.2	-
	Fish & fish content of products containing fish	0.2	0.2
	Molluscs & the mollusc content of products containing molluscs	2.0	2.0
	Foods not specifically mentioned in the code	0.05	0.05
Copper	Molluscs & the mollusc content of products containing molluscs	70.0	70.0
	Foods not specifically mentioned in the code (would include crustaceans and fish)	10.0	10.0
Lead	Fish in tinplate containers	2.5	2.5
	Molluscs	2.5	2.5
	Foods not specifically mentioned in the code (includes crustaceans)	1.5	1.5
Mercury	Fish, crustaceans, molluscs & the fish content of products containing fish	Mean of 0.5	Mean of 0.5
Selenium	Foods other than beverages (& other liquid foods) & edible offal	1.0	1.0
Tin	Foods not packed in tinplate containers	50.0	50.0
Zinc	Oysters	1000.0	1000.0
	All other foods excluding beverages & other liquid foods	150.0	150.0

Note: Mean value for mercury as specified applies to a prescribed number of sample units: see Anon (1987a) for further details.

It is possible that at least a few of these MPCs will change over time as more information comes to hand. For example, some already believe it appropriate to review the MPCs for cadmium in food types such as crustaceans. Average weekly intakes of cadmium assessed from surveys (Anon 1988a) and typical Australian diets (Anon 1986) suggest that intake is generally below the Joint FAO/WHO Expert Committee on Food Additives (JECFA) provisional tolerable weekly intake level of 7 µg/kg bodyweight (applicable to both adults and children).

International Food Standards for Heavy Metals

Walker (1988) has summarised international food standards for cadmium applicable in 1986. These were obtained from a British Food Manufacturing Industries Research Association survey reported by L.E. Parker. On that evidence, 19 countries had set regulatory limits for cadmium in foods, but only Australia, Denmark, the Netherlands, and Hungry had set limits for cadmium in particular foods. New Zealand, however, specifically excludes shellfish and probably fish and fish products from its 'other foodstuffs' MPC of 1.0 mg/kg of cadmium, presumably on a fresh weight-edible portion basis. There is emerging evidence that member countries of the Council for Mutual Economic Assistance (Bulgaria, CSSR, Cuba, GDR, Mongolia, Poland and USSR) have set 'maximum allowable concentrations' of cadmium in a wide range of food types. Further details are summarised in Table 3, with emphasis on seafoods.

Surveys of Heavy Metal Residues

Apart from random compliance testing undertaken by state health departments and departments of agriculture, regular surveys are undertaken at the national level to assess chemical contaminants in food, including some heavy metals. The most significant of these are the Australian Market Basket Survey of NHMRC and the National Residue Survey coordinated by the Federal Department of Primary Industries and Energy.

Australian Market Basket Surveys were conducted in 1970, 1973, then annually until 1987. The next is a two-year survey, covering 1988/89. Reports of the 1985, 1986, and 1987 surveys, published during and since 1987 (e.g. Anon 1988a), have included results for the heavy metals lead and cadmium. Lead has been included in all surveys since 1970; the first survey for cadmium was conducted in 1974 (Anon 1988b).

Copper levels in butter were examined in the 1975 Market Basket Survey only, while monitoring of zinc in foods has not occurred since 1978. Levels of selenium and aluminium were determined in selected foods sampled for the 1987 Market Basket Survey. The practice for these Market Basket Surveys has been to purchase food samples in the capital cities in each of three randomly selected metropolitan areas in three buying seasons during the survey period. Foods are washed and processed as necessary to a 'table-ready' condition, and analysed following removal of inedible material.

In contrast, the Australian National Residue Survey (NRS), which has operated since the mid-1960s, is designed to monitor chemical contaminants – including cadmium, lead and mercury – in agricultural food commodities. It was expanded in November 1985 to cover produce intended for the domestic market (Anon 1988c). The four food

Table 3. Some maximum international food standards for heavy metals with some bias to seafoods and cadmium (Cd).

Country	Details	Reference
Bangladesh	Cd: 6 mg/kg in all foods	1
Brazil	Cd: 1 mg/kg for foodstuffs other than beverages, including fruit juices	1
Bulgaria	Cd: 0.05 mg/kg in fish and fish products	2
Chile	Cd: 0.05 mg/kg in all foods	1
Colombia	Cd: 5 mg/kg for all foods	1
CSSR	Cd: 0.05 mg/kg in fish and fish products	2
Cuba	Cd: 0.05 mg/kg in fish and fish products	2
Denmark	Cd (mg/kg): monitoring limit of 0.3 for fish and 0.5 for molluscs; 0.5 for fish products (river fish; flounder, tuna, bonito or cod)	1
	Cd (mg/kg): rejection limit of 0.5 mg/kg for fishliver; action levels of 0.05 for fish and fish products, 0.5 for crustaceans and molluscs	3
	Hg (mg/kg): rejection limits of 0.3 for fish and fish products, 0.5 for flounder, tuna, bonito or cod, 1.0 for eel, halibut and freshwater fish; action limits of 1.0 for porbeagle and 0.3 for crustaceans/molluscs	3
	Pb (mg/kg): action levels of 0.3 for fish & fish products, 1.0 for crustaceans/molluscs.	3
GDR	Cd: 0.05 mg/kg in fish and fish products	2
Hong Kong	Cd: 2 mg/kg for fish and fish products	1
Hungary	Cd: 0.3 mg/kg in fish and fish products or 0.05 mg/kg in same	1 2
India	Cd: 1.5 mg/kg in all foods	3
Korea	3 mg/kg for total heavy metals	3
Malaysia	Cd: 1.0 mg/kg in all foods	1
Mongolia	Cd: 0.05 mg/kg in fish and fish products	2
Netherlands	Cd (mg/kg): guideline levels of 0.05 for fish, 0.3 for crustaceans, and 1.0 for other shellfish	1
Pakistan	Cd: 6 mg/kg for all foods	1
Poland	Cd: 0.05 mg/kg in fish and fish products	2
Spain	Cd (mg/kg): 1.0 for crustaceans & provisional 1.0 for other shellfish	1
Uruguay	Cd: 5 mg/kg for all foods	1
USSR	Cd: 0.05 mg/kg in fish and fish products	2

1. Walker (1988)
2. Unpublished UNEP/WHO data from Council for Mutual Economic Assistance
3. Anon (1989e)

commodity groupings covered are meat, dairy products, grains and grain products, and fruit and vegetables. Fresh seafoods have been neglected but this situation is likely to change in the near future.

Objectives of the NRS are to confirm the acceptability of agricultural food commodities for export and domestic markets, to provide residue data for trade negotiations, to offer objective assessment of contaminant risks associated with different food commodities, to give early warning on potential contaminant problems, and to provide background information to facilitate control of undesirable contaminants. The commodities are surveyed on a state by state basis to obtain a national perspective.

References

Anon (1986), *National dietary survey of adults: 1983, No. 1, Foods Consumed,* Australian Govovernment Publishing Serervice, Canberra.

Anon (1987a), *Food Standards Code 1987,* Australian Government Publishing Service, Canberra.

Anon (1987b), *Codex Alimentarius Commission - Report of the seventeenth session, Rome, 29 June-10 July 1987,* FAO/WHO, Rome.

Anon (1988a), *The Market Basket (Noxious Substances) survey 1986,* Australian Government Publishing Service, Canberra.

Anon (1988b), *Review of the Australian Market Basket Survey,* Unpublished Draft Report.

Anon (1988c), *Report of the National Residue Survey 1986 Results,* Australian Government Publishing Service, Canberra.

Anon (1989a), *Codex Alimentarius Commission - Report of the eighteenth session, Geneva, 3-12 July 1989*, FAO/WHO, Rome.

Anon (1989b), Requirements for Clearance of Agricultural and Veterinary Chemical Products, First Addition. Australian Agricultural and Veterinary Chemicals Council, Australian Government Publishing Service, Canberra.

Anon (1989c), *Controls on the clearance, registration and use of agricultural and veterinary chemicals*, Victoria Dept. of Agriculture and Rural Affairs, Melbourne. (Technical Report Series No. 182)

Anon (1989d), 'This Week. Polluted prawns on paradise islands', *New Scientist*, 18 November.

Anon (1989e), Joint FAO/WHO Food Standards Programme, Codex Committee on Food Additives and Contaminants, 21st Session March 1989, unpublished draft report.

Anon (1990), 'Towards a closer partnership', *The Australian*, 1 November.

Hamilton, D. (1988), Setting MRL values for pesticides in foods. *Queenslandd Agricultural Journal*, Jul.-Aug., 225-8.

Hutton, H. (1987), 'Human health concerns of lead, mercury, cadmium, and arsenic', In *Lead, Mercury, Cadmium and Arsenic in the Environment*, T.C. Hutchinson and K.M. Meema (eds), John Wiley & Sons, Brisbane.

Lansdown, R. (1979), 'Moderately raised blood lead levels in children', *Proceedings of the Royal Society*, London, 205, 145-51.

Shaper, A.G. (1979), 'Cardiovascular disease and trace metals', *Procedings of the Royal Society*, London, 205, 135-43.

Tanenaka, S., Oldiges, H., Konig, H., Hochrainer, D. and Oberdorster, G. (1983), 'Carcinogenicity of cadmium chloride aerosols in Wistar rats', *Journal of the National Cancer Research Institute*, 70, 367-73.

Waldron, H.A. (1973), 'Lead poisoning in the ancient world', *Medical History*, London, 17, 391-9.

Walker, J.M. (1988), 'Regulation by other countries of cadmium in foods and the human environment', *Proceedings No 2 "Cadmium Accumulations in Australian Agriculture: National Symposium, Canberra, 1-2 March 1988"*, Australian Government Publishing Service, Canberra, 176-85.

WHO (1985), *Review of potentially harmful substances - cadmium, lead and tin.*, WHO, Geneva. (Reports and Studies No. 22. IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/ UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution)

Processes Influencing the Fate of Trace Metals in Torres Strait: A Review of Current Data and Concepts

T. David Waite and Ron Szymczak
Australian Nuclear Science and Technology Organisation

Abstract

In this presentation, the exisiting data on trace metals concentrations in Torres Strait waters and sediments is compiled, methods reviewed and the data briefly discussed. Physico-chemical processes likely to be important in the supply to and mobilization within Torres Strait are then reviewed and, on the basis of exisiting data, attempts are made to refine the range of possibilies for source, transformation processes and fate of heavy metals in the Torres Strait system. A brief compilation of additional data requirements to satisfactorily develop predictive modelling capability is also included.

Introduction

Assessment of the fate of trace metals introduced by natural or anthropogenic activities to the marine environment is often exceedingly complex and requires an understanding of the chemical, physical and biological processes influencing the forms and amounts of trace metal species. Typically, a spatial and temporal description of the interdependence of chemical, physical and biological processes, unique to each system, is ultimately required. Such an interplay of processes is certainly appropriate to the Torres Strait system.

While hypotheses regarding the source, mobilisation processes and subsequent transport of metals in a system such as Torres Strait can easily be formulated, the hypotheses must be tested against actual data for the system of interest. In addition, assessment of the importance of certain processes may require parameters such as rates of metals release and rates of transformation of sediments. Once feasible models of potential metals fate have been constructed for the elements of interest, they must be tested against actual water column and benthic sediment data.

Existing data on trace metals content of waters and sediment may be adequate for model development and testing. However, experience shows that historic chemical data, particularly at the trace level, suffers seriously from deficiencies in sampling and analysis methodologies and statistical veracity.

In this presentation, the exisiting data on trace metals concentrations in Torres Strait waters and sediments is compiled, methods reviewed and the data briefly discussed. On the basis of exisiting data, attempts are made to refine the range of possibilies for source, transformation processes and fate of heavy metals in the Torres Strait system. Physico-chemical processes likely to be important in the supply to and mobilization within Torres Strait are then reviewed in more detail and a brief compilation of additional data requirements to satisfactorily develop predictive modelling capability is noted.

Review of Trace Element Concentration Data for Waters and Sediments of Torres Strait

While extensive monitoring of waters and deposited and suspended sediments in the Ok Tedi and Fly River systems is undertaken by the mining industry for assessment of compliance with regulatory limits, very few broader scale studies of the trace element composition of waters and sediments throughout Torres Strait have been undertaken. Much of the data that is available has been collected with a view to assessing the extent of transport of the riverine metals load through the estuarine region to the Gulf of Papua. The scope of relevant documented studies, the methods used and results obtained are summarised below.

Ok Tedi Mining Limited Environmental Investigations

Environmental investigations have been undertaken by Ok Tedi Mining Lmited (OTML) since 1981 when the Ok Tedi Environmental Study was commenced (Maunsell and Partners, 1982) and an environmental monitoring program has been in place since 1983. The initial study was focussed particularly on the immediate environment of the Ok Tedi and Fly Rivers but was broadened considerably in 1986 following abandonment of construction of a tailings dam by OTML due to structural geologic problems (Eagle and Higgins, 1991). The study was completed in 1989 and the results presented in a Final Draft Report (OTML, 1988) and in a Supplementary Investigations Report (OTML, 1989).

As part of the ongoing environmental monitoring program, surface sediment samples were collected at intertidal mangrove sites and at locations on reefs in the northern Torres Strait (see Figure 1) and analysed for particle size distributions and copper fractionation between the various size classes. Samples were collected from the following locations:

- Dibiri Island
- Puruto Island
- Kiwai Island

- 11km west of Sigabadiru
- Bristow Island
- Parama Island
- Sagero Village
- Warrior Reefs (9 locations)

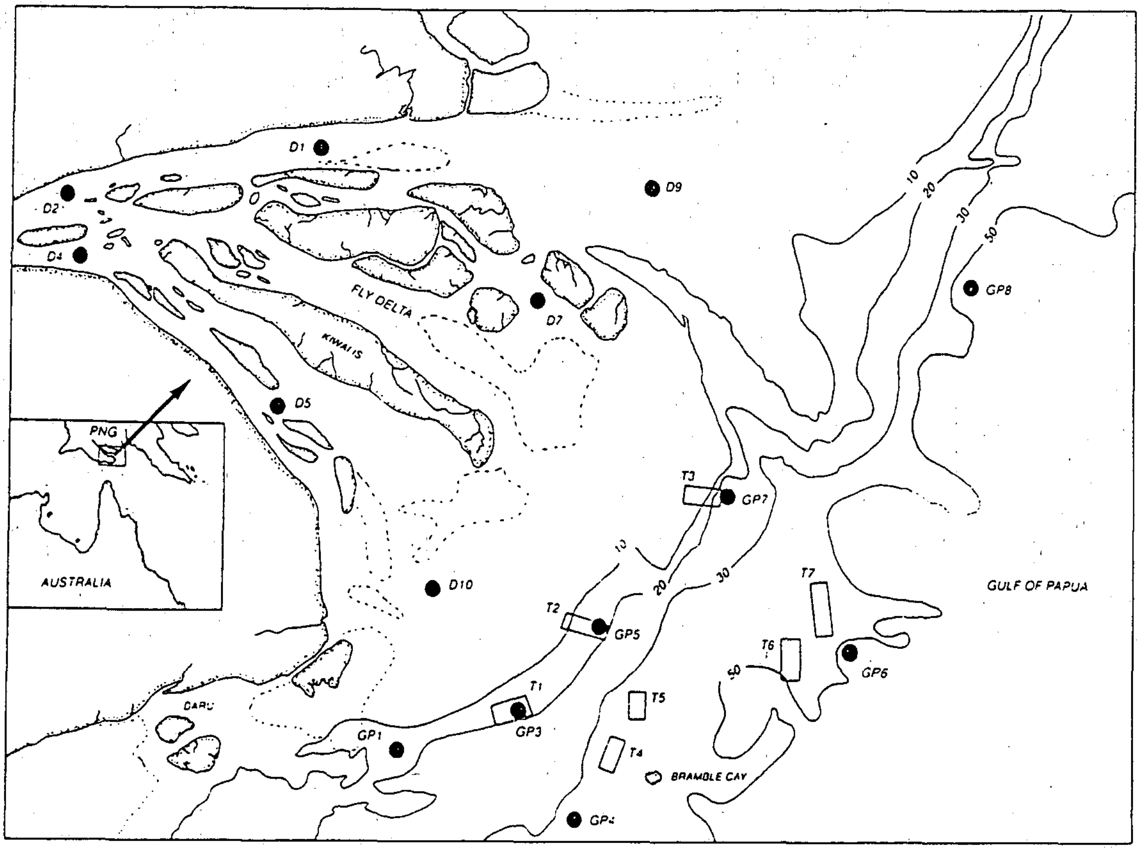


Figure 1. Locations of the 14 benthic stations sampled by AIMS personnel in July-August 1989 and February 1990 in the Fly delta and Gulf of Papua.

Samples were wet sieved through 100 and 63 µm sieves using deionised water. The less than 63 µm fraction was mixed with dispersant in an Andreason sedimentation pipet to obtain a size fractionation down to 10 µm. Samples from each size class were dried at 105°C overnight and copper concentrations determined using acid digestion followed by flame AAS. All samples from the reef sites were analysed for calcium carbonate in order to determine the origins of these sediments.

While minimal replication of sampling at each site has been performed, some general conclusions can be drawn from the results presented (Tables 1 and 2). In all cases, the fine fraction of sediment (<10 µm) is significantly enriched in copper. Such an observation is expected since the surface area and hence the concentration of surface

Table 1. Copper concentrations in various size classes of sediments obtained from intertidal mangrove sites and at locations on reefs in the northern Torres Strait (from OTML, 1989)

Location	Size (μm)	Weight (g)	% Wt	Copper Assay (μg/g)
1. Dibiri Island	<10	18.874	57.8	39
	<20	25.972	79.6	28
	<63	31.252	95.7	26
	<100	32.052	98.2	26
	Total	32.658	100	
2. Puruto Island	<10	17.359	36.1	51
	<20	24.656	51.2	45
	<63	39.249	81.6	34
	<100	47.655	99.0	38
	Total	48.122	100	
3. Kiwai Island	<10	0.794	1.4	71
	<20	1.094	1.9	53
	<63	1.459	2.6	45
	<100	6.906	12.1	48
	Total	56.968	100	
4. Sigabadiri (11 km west)	<10	2.120	4.2	41
	<20	3.464	6.9	33
	<63	39.679	59.3	22
	<100	48.338	96.6	34
	Total	50.028	100	
5. Bristow Island	<10	0.747	1.7	92
	<20	0.968	2.2	86
	<63	1.209	2.7	69
	<100	19.438	44.0	10
	Total	44.138	100	
6. Parama Island	<10	3.095	6.1	53
	<20	3.701	7.3	48
	<63	5.056	10.0	31
	<100	17.488	34.6	35
	Total	50.597	100	
7. Sagero Village	<10	0.702	1.2	65
	<20	0.928	1.6	65
	<63	1.117	2.0	54
	<100	16.547	29.2	15
	Total	56.739	100	

sites available for binding of copper and any other surface reactive species increase on decreasing particle size. Concentrations of copper in sediments of the Warrior Reefs complex are relatively low with values in the 16-28 μg/g range in the <10 μm fraction. Concentrations are significantly higher in the intertidal and mangrove sites with values in the range 39-92 μg/g in the <10 μm fraction. Highest values are reported at Kiwai Island (71 μg/g) and Bristow Island (92 μg/g).

Table 2. Copper concentrations in various size classes and calcium carbonate content of sediments obtained from locations around the Warrior Reefs in Torres Strait (from OTML, 1989).

Location	Size (µm)	Weight (g)	% Wt	Copper Assay (µg/g)	$CaCO_3$ (% Wt)
1. Wappa Reef north of Moon Passage - Site 1	<10	0.972	0.4	26	not determined
	<20	1.022	0.4	24	
	<63	1.262	0.5	16	
	<100	1.624	0.7	14	
	Total	244.7	100		
2. Wappa Reef north of Moon Passage - Site 2	<10	0.876	0.3	28	not determined
	<20	1.085	0.3	25	
	<63	1.340	0.4	20	
	<100	1.896	0.6	16	
	Total	23.67	100		
3. Kimusu Reef - Site 1	<10	3.044	1.5	16	78.7
	<20	3.777	1.8	14	
	<63	5.022	2.4	12	
	<100	10.86	5.2	10	
	Total	210.9	100		
4. Kimusu Reef - Site 2	<10	2.219	0.6	16	70.7
	<20	2.730	0.7	15	
	<63	3.4405	0.9	14	
	<100	5.471	1.5	11	
	Total	370.0	100		
5. Gemini Reef - Site 1	<10	1.297	2.8	23	45.4
	<20	1.552	3.4	21	
	<63	2.021	4.4	18	
	<100	10.32	22.5	10	
	Total	45.96	100		
6. Gemini Reef - Site 2	<10	5.334	2.5	19	38.9
	<20	7.191	3.3	16	
	<63	8.184	3.8	13	
	<100	33.30	15.4	10	
	Total	217.4	100		
7. Gemini Reef - Site 3	<10	2.024	20.4	16	37.2
	<20	2.457	24.7	12	
	<63	2.662	26.8	16	
	<100	5.080	51.2	16	
	Total	9.920	100		
8. 1.5 km north of Gemini Reef - Site 1	<10	9.910	12.7	28	32.9
	<20	12.18	15.6	21	
	<63	14.25	15.6	16	
	<100	39.38	50.4	20	
	Total	78.20	100		
9. 1.5 km north of Gemini Reef - Site 2	<10	1.274	2.5	18	25.9
	<20	1.307	2.5	22	
	<63	1.543	3.0	16	
	<100	12.70	24.7	16	
	Total	51.38	100		

Monitoring work by OTML is continuing both in the Fly River delta where compliance with predicted increases in sediment copper content is required and in the Fly River estuary, Gulf of Papua and Torres Strait. The objectives of studies at these latter sites are to:

- investigate and monitor the geochemical and biological response to mined sediments, and
- assess the fate of mined sediments in the estuarine and offshore regions.

In the estuarine region, sites are sampled six-monthly over two tidal cycles while at the off-shore sites, samples are taken each six months over one tidal cycle. While results of recent monitoring at these sites are not yet available, Eagle and Higgins (1991) report that "no increase in either dissolved or particulate copper concentrations in the estuary and coastal waters of the Gulf of Papua or the northern Torres Strait is evident".

Benthic Studies in Fly River Delta and Gulf of Papua by AIMS

Studies of the net flux of organic carbon and several other elements from the Fly River and investigation of the influence of exported materials on water column and benthic processes in the adjacent Gulf of Papua have been undertaken by personnel of the Coastal Processes and Resources Program at the Australian Institute of Marine Science (AIMS). The methods used and results of field expeditions in July-August, 1989 and February, 1990 are reported by Robertson *et al.* (1990).

Boxcorer samples were taken at 14 subtidal stations within the region (Figure 2) and analysed for a range of parameters including dissolved and extractable particulate iron, manganese and copper. Particulate metals concentrations were determined by ICP/AES on 0.5 g of oven dried, milled samples after digestion with a mixture of perchloric and nitric acids for 6 hrs. Dissolved iron, manganese and copper concentrations were determined on porewater samples using ICP/AES.

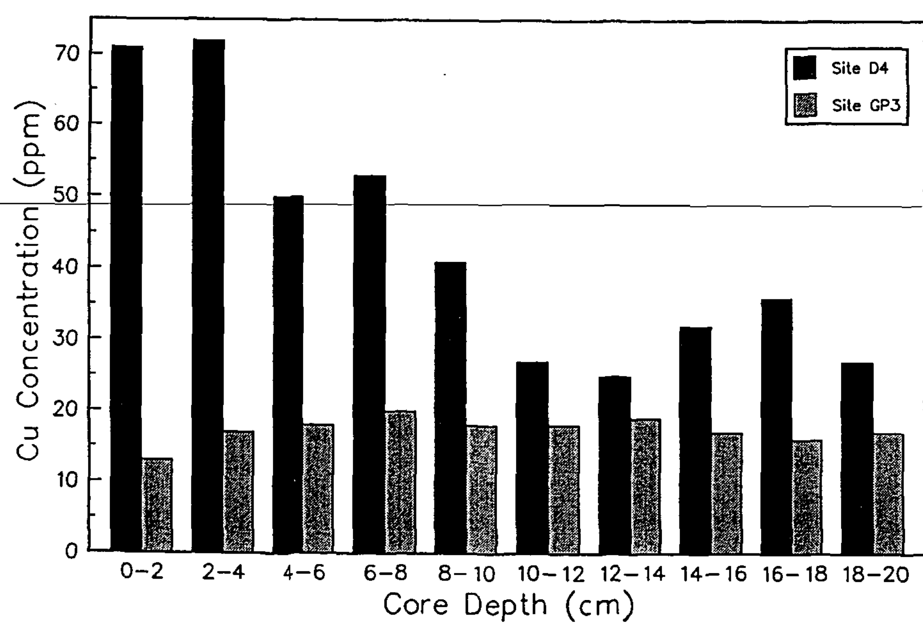


Figure 2. Variation of copper concentration with depth in sediment cores obtained at stations D4 and GP3 (from Robertson *et al.*, 1990)

Pore water dissolved metal concentrations were, in all cases, very low with dissolved copper at or below detection limit (0.01µg.mL^{-1}). Concentrations of particulate metals were determined in all cases as a function of depth however significant variations or trends with increasing depth were not generally observed. From the surface (0-2 cm) sediment concentrations reported in Table 3, it can be seen that particulate copper concentrations were generally higher in the delta than in the Gulf of Papua and were highest at delta stations D4 and D5. At these stations, some depth dependence of particulate copper concentration was observed while at other sites, the copper concentration was relatively uniform with depth (Figure 3). As so clearly shown by the OTML results, significantly higher concentrations of copper (in mass of copper per unit mass of sediment) than reported for the bulk sediment are likely to be associated with the finer sediment fractions.

Table 3. Concentrations of particulate iron (% dry weight), manganese (µg/g) and copper (µg/g) in the top 2 cm of cores obtained at various locations. Values are mean ± 1σ (from Robertson *et al.*, 1990).

Station	Fe (% DW)	Mn (µg/g)	Cu (µg/g)
D1	9.83±0.83	1100±82	10±2
D2	4.65±0.08	535±27	12±1
D4	5.07±0.19	725±50	71±10
D5	5.53±0.10	794±38	48±7
D9	6.74±0.34	1600±282	30±3
D7	5.56±0.16	819±29	40±2
D10	4.68±0.33	523±34	8±3
GP1	5.17±0.09	587±18	22±1
GP3	4.69±0.08	551±9	13±1
GP4	4.28±0.03	435±10	7±1
GP5	5.08±0.07	570±21	22±1
GP6	5.96±0.20	1004±69	10±1
GP7	5.58±0.12	741±22	19±1
GP8	5.53±0.09	825±22	24±1

Ocean Sciences Institute Studies of Torres Strait Benthic Sediment Metals Content

As reported by Schneider (1990), sediment samples at 20 locations in Torres Strait (see Figure 4) were collected using either a Van Veen grab or a Shipek sediment sampler. At one site (Site 1), subsamples from a vibrocore were obtained for metals analysis. Sediment samples were analysed for gravel (>2.00 mm), sand (< 2.00 mm and > 0.063 mm) and clay (< 0.063 mm) content with the clay and sand fractions being further analysed for carbonate content (the gravel fraction was assumed to be formed entirely of carbonate). Metals content of complete sediment samples was determined by atomic absorption spectrometry (Cu, Zn - flame AAS; Cd - graphite furnace AAS) following homogenisation and acid digestion.

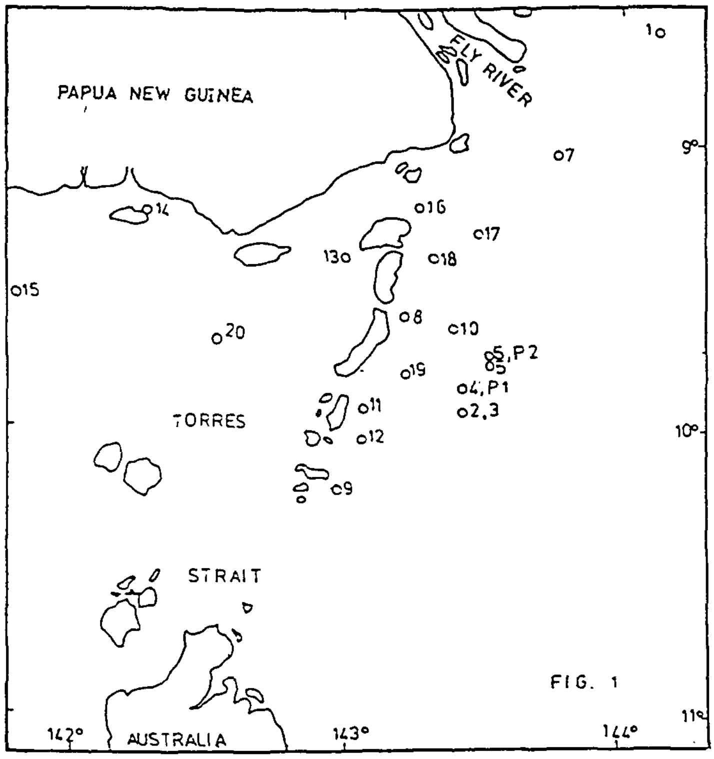


Figure 3. Location of the 20 sediment sampling sites used by Schneider (1990).

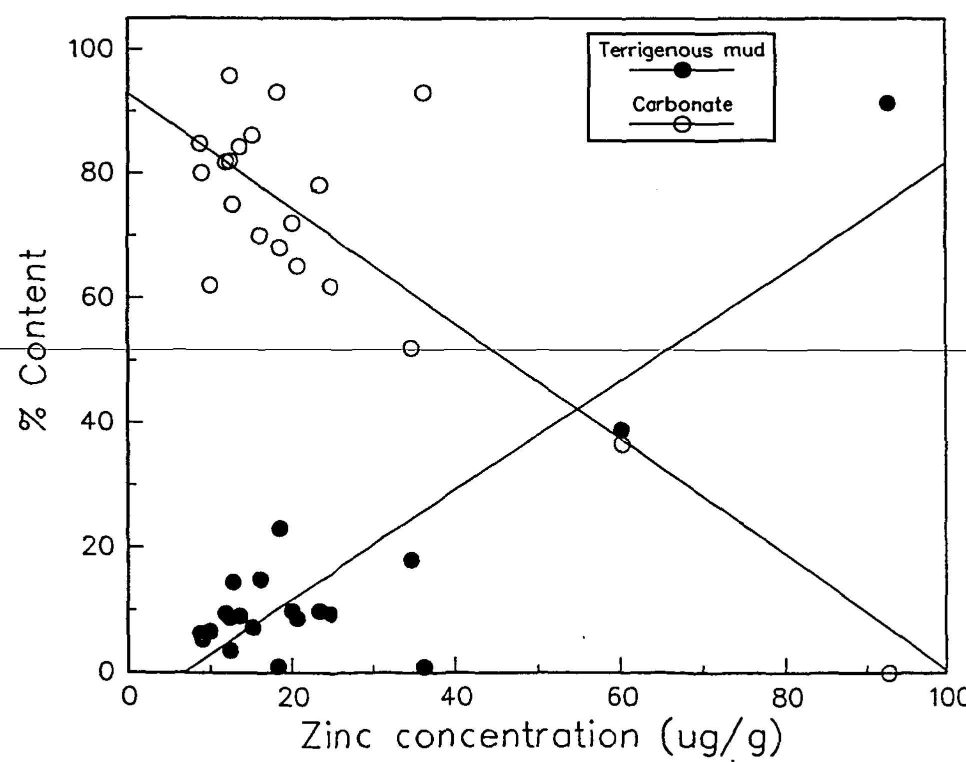


Figure 4. Correspondence between surficial sediment zinc concentrations and the percentage of terrigenous mud and carbonate in the sediments. Linear regression lines of best fit are also shown (data from Schneider, 1990).

The results of sediment analyses are given in Table 4 as are the carbonate and terrigenous mud contents (as percentages of the total sample). The distances of Sites 2 to 20 from Site 1 (located in the Fly River delta) are also given. No significant correlation between core depth and metal concentration was found at Site 1. Schneider reports that significant correlations (at the $p = 0.005$ level) were found for decreasing surficial copper and zinc content (but not cadmium content) with increasing distance from Site 1. Copper and zinc (but not cadmium) concentrations were also reported to be significantly correlated to terrigenous mud content. The correspondence between sediment zinc concentrations and the sediment composition from the complete set of sediment data reported by Schneider (1990) is shown in Figure 5.

Table 4. Metal concentrations and carbonate and terrigenous mud content in dried surficial sediments from Torres Strait locations identified in Figure 3. Values represent the mean of duplicates (from Schneider, 1990).

Site No.	Distance from delta (km)	Metal concentration (µg/g)			Carbonate content (%)	Terrig. mud content (%)
1	0	18.4	0.032	92.8	0.0	91.4
2	147	6.08	0.019	20.1	72.0	9.9
3	147	5.17	0.025	23.4	78.0	9.9
4	140	5.58	0.020	18.6	68.0	23.0
5	128	6.09	0.022	16.2	70.0	15.0
6	126	6.00	0.021	12.8	75.0	14.5
7	56	13.3	0.091	60.2	36.5	38.8
8	130	8.00	0.053	13.7	84.2	9.1
9	196	2.00	0.182	15.3	86.1	7.3
10	123	3.20	0.057	24.7	61.8	9.5
11	168	2.10	0.070	12.5	81.9	8.8
12	176	8.30	0.057	8.8	84.7	6.3
13	138	8.00	0.069	12.0	81.8	9.5
14	198	13.7	0.115	34.7	52.0	18.0
15	267	8.67	0.108	12.5	95.7	3.5
16	112	9.20	0.064	36.2	93.0	0.9
17	95	1.10	0.116	20.7	65.1	8.7
18	113	2.30	0.099	18.3	93.0	1.0
19	150	1.50	0.018	10.0	62.0	6.6
20	192	1.80	0.055	9.0	80.0	5.3

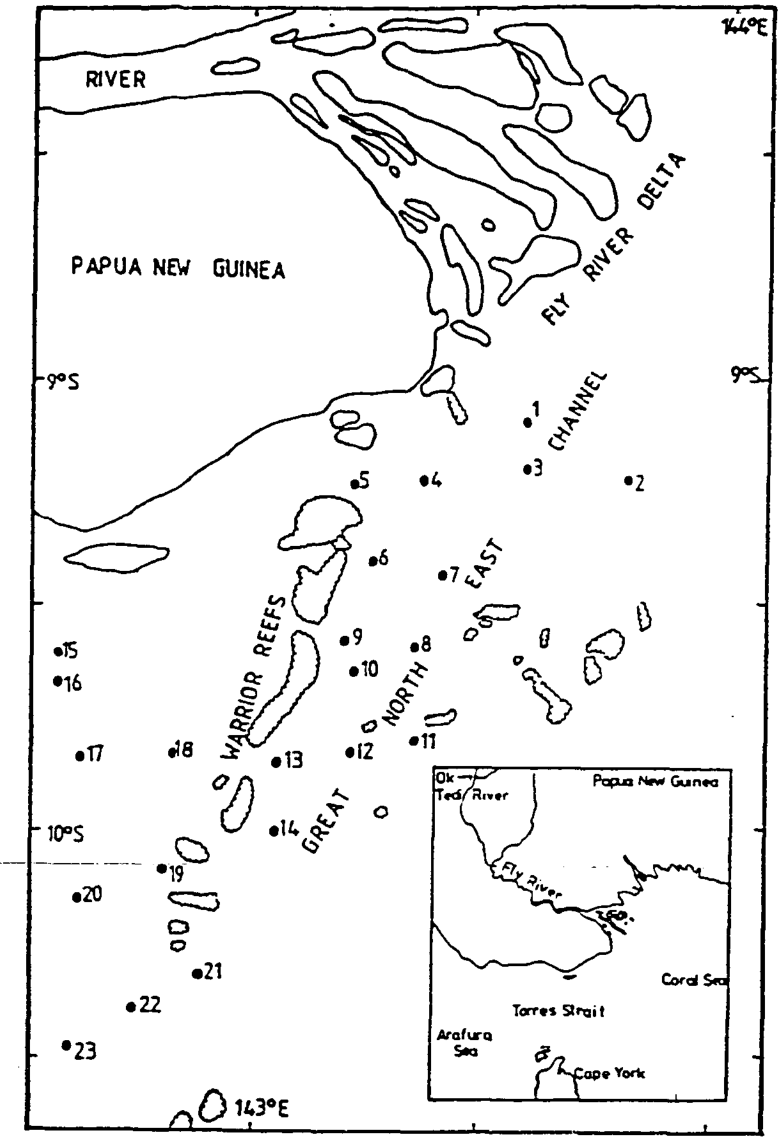


Figure 5. Locations at which water samples obtained for separation of suspended sediment and subsequent analysis of particulate copper and cadmium by Baker (1990).

Ocean Sciences Institute Studies of Torres Strait Suspended Sediment Metals Content

Studies of the concentration of copper and cadmium associated with suspended matter obtained at locations in the northeastern section of Torres Strait and the mouth of the Fly River delta during March 1989 have been undertaken by Baker (1990a, 1990b). At each location (see Figure 6), 250 mL of seawater was filtered through 0.80 µm membrane filters within 3 minutes of collection and stored for later analysis. The particulate matter and filter membranes were digested using high purity acids and analysed by carbon furnace AAS. The grain size and mineralogical composition ofsuspended matter were determined and extensive studies of the mineralogy and possible source of surficial sediments at a wider range of locations were also undertaken by Baker (1990a).

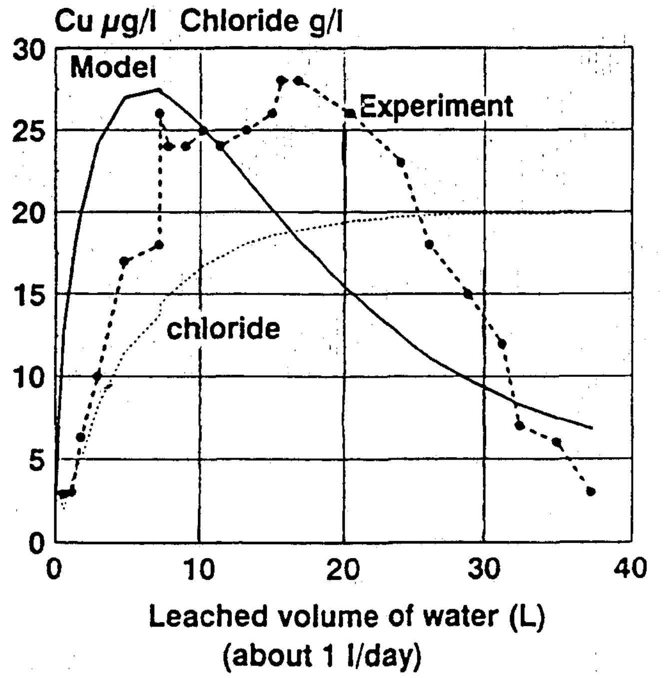


Figure 6. Release of copper from contaminated sediments from the Middle Fly in a salinity gradient. The results of a model assuming instantaneous cation exchange (equilibrium conditions) is shown by the solid line (after Salomons and Eagle, 1990).

The concentrations of copper and cadmium retained on the 0.80 µm pore size filters (per litre of seawater) are given in Table 6. While highest concentrations of metals are observed at stations closest to the Fly River, the lack of information on relative suspended sediment concentrations or on extent of mixing of fresh and saline waters renders interpretation difficult. Waters near the mouth of the Fly River contained subrounded to subangular particles of detrital kaolinite clays and occasional crystals of sucrosic gypsum and rutile needles similar to surficial sediments of the delta. Samples taken from west of Warrior Reefs also corresponded to surficial sediments from that region and were typically comprised of abraded skeletal fragments, conglomerate clays and plankton. A small quantity of fine clays (< 10%), either as discrete particles or as surface coatings on other particles were also detected. These fine clays were concluded to originate from erosion and resuspension of earlier seafloor deposits by tidal currents.

A number of conclusions based on the mineralogical identity of suspended and surficial sediments have been noted by Baker (1990):

- persistently turbid water located west of the Warrior Reefs is caused by the erosion and resuspension of local carbonate deposits and not by terrigenous material from the Fly River;

- most of the suspended sediment output of the Fly River (much of which comes from the Strickland River arm) appears to be retained within the delta area though some evidence suggests the occurrence of tidally driven sediment transport in a westerly direction along the coast and east into the Gulf of Papua, and

- monsoonal activity may extend the influence of the Fly River southwards into the Great North East Channel.

Table 6. Mean copper and cadmium concentrations associated with particulate matter in Torres Strait sea water collected in March, 1989. Mean values are based on two determinations for Cu and three for Cd. (After Baker, 1990b).

Sample No.	Mean Cu (µg/L)	Mean Cd (µg/L)
1	13.3	0.80
2	2.4	0.03
3	4.2	0.15
4	3.5	0.09
5	6.8	0.06
6	0.9	0.16
7	5.8	0.16
8	2.0	0.06
9	3.4	0.09
10	3.0	0.06
11	3.0	0.20
12	2.5	0.16
13	2.6	0.04
14	1.8	0.07
15	1.6	0.10
16	1.4	0.20
17	0.9	0.05
18	1.5	0.08
19	3.1	0.03
20	1.6	0.08
21	3.4	0.04
22	2.7	0.23
23	3.3	0.01

Review of Data on Processes Controlling Trace Element Composition of Waters and Sediments of Torres Strait

Overview of Processes

The sources of metals to the waters and sediments of Torres Strait will be dominated by the large riverine inputs to this relatively wide but shallow connection between the Gulf of Papua and the Gulf of Carpentaria to the west. In addition it should be noted that the Gulf of Papua is also the receiving basin for a number of other significant streams and rivers other than the Fly including the Purari, Pie, Era, Kikori Turama and the Bamu. Obviously, mining operations in the headwaters of these rivers increases the sediment and metals load of these rivers with the potential for increased input to the marine environment.

Studies of the Fly River system by Salomons *et al.* (1988) and Salomons and Eagle (1990) indicate that the bulk of copper, a metal that is significantly enriched in the area (and obviously for that reason mined by OTML), is associated with particulate matter. A significant portion of this particle bound copper represents mine-derived ore residues and overburden. Copper is not distributed uniformly over the various size ranges of ore residues. For example, the very fine grained < 2 µm fraction, whilst constituting only 5% of the total ore residue tonnage, contains 25% of the total copper. Approximately 70% of the copper load is associated with the < 100 µm fraction. Given the flow characteristics in the river system, most of this material will ultimately be transported to the estuary and delta front and Gulf of Papua (Salomons and Eagle, 1990).

On reaching the more saline estuarine environment, the fine colloidal particles carrying the bulk of the metals will be destabilised by the high ionic strength medium (mainly as a result of double layer compression) and will begin to flocculate and settle out of the water column. The extent of sedimentation within the estuarine and deltaic environment will be determined by the energy of mixing and dispersal and will obviously be influenced significantly by riverine flow, tidal regime, large scale circulation patterns and wind mixing effects.

In addition to the processes of flocculation, sedimentation and dispersal of particles in the estuarine environment, the marked difference in water chemistry between the fresh and estuarine environments may result in significant redistributions of metals between particulate and solution phases. In particular, the concentrations of magnesium, calcium and sodium are much higher in the estuarine than freshwater system and may lead to release of metal to solution phase as a result of cation exchange processes. Higher chloride and carbonate concentrations may also lead to a change in speciation of both disolved and particulate metal and, in the latter case, increase the solubility of the metal. The results of preliminary experimental studies of such processes conducted by OTML are discussed briefly below.

Transformations in Trace Metal Partitioning in the Estuarine Environment

The effects of increasing admixtures of seawater on potential copper releases have been studied in a series of flow-through experiments by OTML (1988). The admixtures comprised copper enriched sediments obtained from the river system, ore residues from the OTML copper circuit and mixtures of ore residues and river sediments. The experimental method was designed to simulate the transport of particulates through a salinity gradient, and thus simulate likely estuarine processes. A simultaneous and identical experiment using freshwater was carried out for control purposes.

The control experiment showed little release of copper from the admixtures with concentrations of dissolved copper in the test solution remaining within the range of 1-5 µg/L. Lower concentrations of dissolved copper were evident where the admixtures contained proportionally higher concentrations of river sediments, due to the presence of adsorbing clay fractions. In the experiments with seawater, the release of copper increased significantly and in proportion to increased chlorinity.

Results of such studies indicated that only a portion (9-14%) of the total copper was released from the sediments tested. An attempt was made to simulate the results of the experiments using an estuarine numerical modelling technique based on assumptions of chemical equilibrium, however, as shown in Figure 7, this model did not reproduce the shape of the release curve well owing to the relatively slow kinetics of the reactions involved. Salomons and Eagle (1990) note that an understanding of the chemical kinetics of such release processes is important in assessing the likely impact of deposition of copper enriched sediments in the estuarine environment. For example, if the release mechanisms are slow, copper enriched particulates entering the estuarine environment will be subject to a high rate of dispersion prior to significant copper mobilisation. A present lack of information on the kinetics involved precludes reliable numerical assessment of dissolved copper levels in this environment.

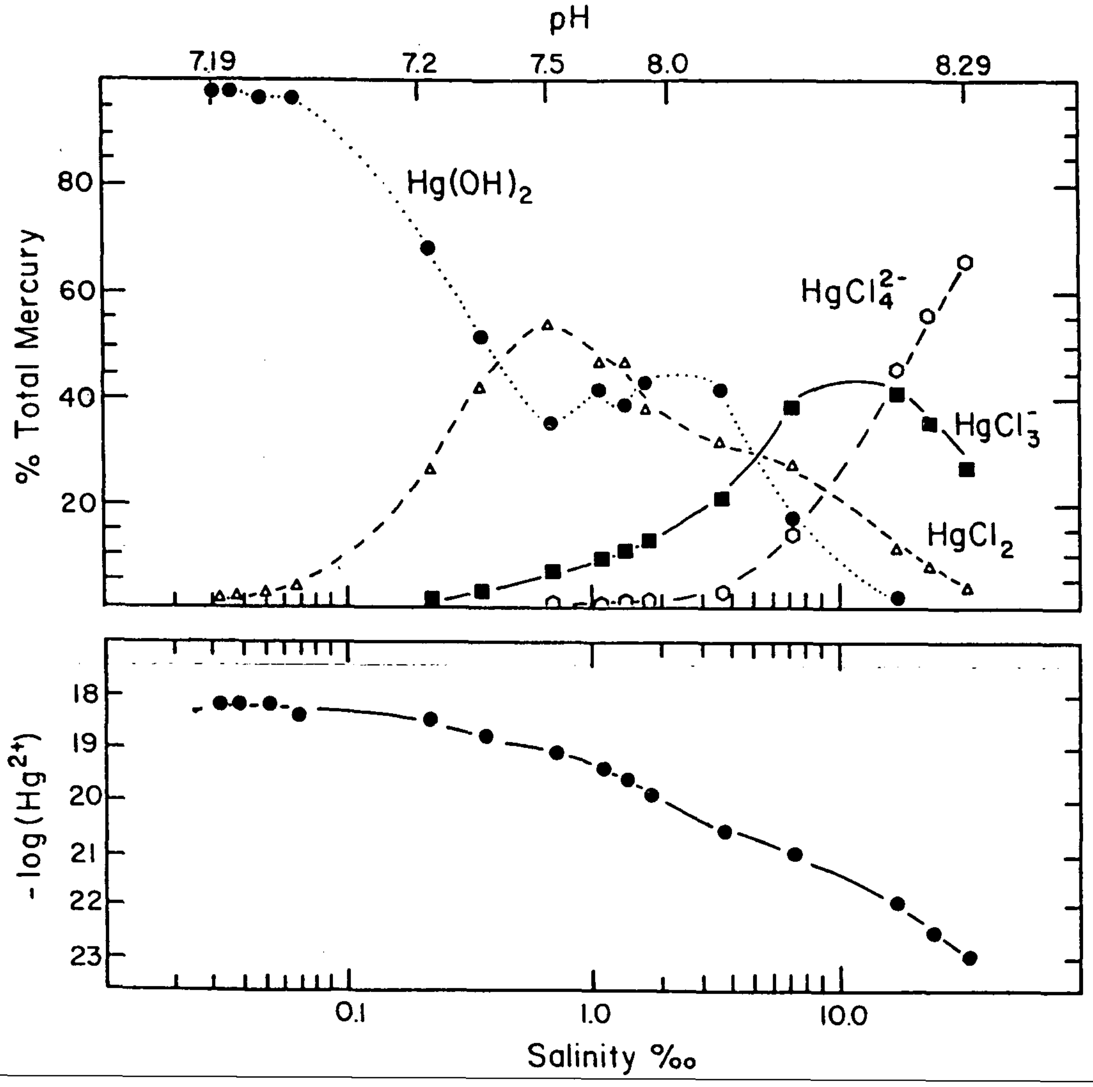


Figure 7. Inorganic speciation of mercury in an estuary as a function of salinity. Example calculated by considering the mixture of a freshwater ($[Cl^-]=5x10^{-4}M$, $Alk=1.3x10^{-4}M$, pH=7.2) with seawater (salinity=36‰, pH=8.20) and maintaining the total mercury concentrations at 1 nM (after Morel, 1983).

A variety of chemical reactions may be involved in release of copper from such sediments including ion exchange, desorption of specifically bound metal and oxidation of sulfide minerals with subsequent possible release of copper. A model suitable for prediction of release rates must incorporate kinetic expressions for these processes (or, at least, justify why certain processes should be excluded). Other particle-associated trace elements, if present, may also be released on changing from a freshwater to a high ionic strength marine environment though the driving forces for transformation and the rates of associated chemical processes will be element specific (Salomons, 1980; Li *et al.*, 1984; Ackroyd *et al.*, 1986; Davies-Colley *et al.*, 1984).

The inorganic speciation of trace elements in the estuarine environment is one determinant of solid-liquid partitioning and, as a driving force for exchange, can often be determined using equilibrium concepts (Bourg, 1987) (though of course the rates of any exchange processes cannot). Metals that form important chloride or sulphate complexes in seawater (such as Cd2+ and Hg2+), may pass through a series of dominant species as freshwater mixes with seawater and salinity (and possibly pH) increases. Computed changes in the speciation of mercury as a function of salinity shown in Figure 7 (after Morel, 1983) well illustrates this point.

While the large sediment loads of rivers such as the Fly suggest a dominace by inorganic processes, these tropical environments are also very productive and significant quantities of detrital organic matter are likely to be present, both in dissolved and particulate forms. Some metals such as copper exhibit high affinity for such organic matter and their speciation may be significantly influenced by complexation (Kuwabara *et al.*, 1989; van den Berg *et al.*, 1987).

Sediment Movement

While a proportion of the trace elements associated with particulate matter in the riverine environment may be relatively rapidly released on entering the estuarine region, a significant proportion is likely to remain with the sediment phase. This initially retained fraction may undergo slow release from benthic sediments as transformations of the sediments occur (e.g. as a result of oxidation of sulfidic minerals, onset of anoxia or organic complexation) (Eaton, 1979), may be transported further afield with suspended or resuspended sediments or may simply remain in some particulate refractory form.

A first step in assessing the likely fate of sediment bound metals is to determine the fate of the sediments with which they are associated. An understanding of the physico-chemical processes that may induce release or transformation in form of the associated metals will then be a function of the environment to which these sediments are transported.

Excellent reviews of the fate of waters and sediments from the Fly River system are available (Wolanski *et al.*, 1984; Wolanski *et al.*, 1990; Harris, 1988 and 1991). In brief, it appears that about 50% of Fly River sediment is deposited in the Fly River delta and most of the remaining sediment transported offshore into the Gulf of Papua. Only about 2% of the annual sediment discharge of the Fly River appears to enter the Torres Strait area (Harris, 1991). In addition, and as indicated earlier from the results of mineralogical investigation, a small portion of the Fly River sediment is transported as suspended load out of the Fly and to the west along the southern coastline of PNG under the influence of wind-driven currents during the SE trade wind season (Harris, 1991). The existence of vast areas of unconsolidated fluid mud in the estuary has recently been highlighted by Wolanski (1990). Harris (1991) notes that these fluid muds could provide a significant transport pathway for sediments out of the estuary in the form of density currents.

Essentially no information is available on the nature of metals associated with these sediments (present as distinct mineral phases, adsorbed to iron oxides or clays, etc) or of the likely extent and timescale of any transformation processes leading to eventual release or increased availability to organisms.

Additional Physico-chemical Data Requirements

It should now be clear from this brief review of available data on metals in Torres Strait and on processes that may be influencing metals transport that significant gaps exist in compiled data on metals form and concentration and in our understanding of mechanisms controlling fate (let alone impact) of metals in this region. Suggested areas requiring further attention are given below.

Dissolved and Particulate Metals Concentrations

While some data on the concentration of trace metals in benthic and suspended sediments is available, the data set is not yet complete enough to enable firm conclusions to be drawn regarding the extent of metal contamination in the Torres Strait, or indeed, if elevated levels are observed, the source, fate and impact of these metals. Ideally, a data set containing the following components could be developed:

- elemental composition (including both major and minor constituents) and mineralogical composition of size fractionated surficial sediments from a wide range of locations throughout the Fly River delta, Gulf of Papua, Torres Strait and coastal margins. Sampling and analysis should be conducted such that variability in mineral form and metals content at any one location and between locations can be identified;

- elemental composition (including both major and minor constituents), mass and mineralogical composition of suspended sediments at sampling stations throughout the Fly River delta, Gulf of Papua, Torres Strait and coastal margins. Sampling and analysis should be conducted such that variability in mineral form and metals content at any one location as a function of time of day, tide, season or dominant current regime and between locations (with due regard to the same variables of time of day, tide, etc) can be identified. Dissolved metals concentrations should also be determined on samples collected at the same locations and time as the particulate fractions;

- identity of the mineralogical form or nature of the association of trace metals with particulate phases. Such information could possibly be obtained through use of SEM/EDX, electron diffraction or secondary ion mass spectrometry (SIMS). Leaching studies would also assist in identifying the nature of the metal association with particulate matter.

Metals Transport Processes

While concentration data such as that identified above will provide some insight to likely transport processes, more specific studies of processes likely to influence the fate (and to some extent the effects) of trace metals in the Torres Strait and surrounding environs are required. In particular, data of the following form would assist in hypothesis testing and in development of predictive capability:

- rate of aggregation and settling of metal-rich particles in the estuarine/deltaic environment of the Fly River;

- size distribution of settled sediments in the delta region and estimation of likely mobility and/or resuspension;

- kinetics of transformation processes influencing the solubility or availability of particle-bound metals. Such proceses may include oxidation of sulfide minerals, desorption of specifically bound metals, readsorption of metals on fresh oxyhydroxides, anion exchange with subsequent release of metals from particles and cation exchange;

- the availability or reactivity of particle-associated metals over a range of time scales and reaction conditions (particularly of pH and DO). Sequential extraction methods may also be used to identify the major metal binding sites on particles and sediments, estimate the biological availability of metal pollutants or estimate the effect of waste disposal conditions on metal mobility but limitations in the selectivity of extractants must be kept in mind (Kersten and Forstner, 1989);

- residence time of particles in the water column as determined from sediment trap techniques or natural radioisotopes such as the disequilibria between thorium-234 and uranium-238 activities (Bruland and Coale, 1986).

Summary

While a significant body of data has now been collected on metals in Torres Strait (with particular attention given to the likely impact of mining in Papua New Guinea on this region), additional data is clearly required in order to properly define the transformation pathways and transport routes for trace metals in this environment. In order to focus the requirement for additional data, hypotheses concerning the potential sources, transformations and fate of metals in the Torres Strait system should be developed. The preliminary collection of trace metals data in a rigorous fashion over a range of sites should assist significantly in hypothesis development at this stage of our understanding.

References

Ackroyd, D.R., Bale, A.J., Howland, R.J.M., Knox, S., Millward, G.E. and Morris, A.W. (1986), 'Distribution and behaviour of dissolved Cu, Zn and Mn in the Tamar estuary', *Est. Coast. Shelf. Sci.*, 23, 621-640.

Baker, E.K., Harris, P.T. and Beck, R.W. (1990b), 'Cu and Cd associated with suspended particulate matter in Torres Strait', *Mar. Poll. Bull.* 21, 484-486.

Baker, E.K. (1990a), Origin, distribution and toxicological implications of suspended particulate matter in Torres Shelf seawater. M. App. Sci. Thesis, Ocean Sciences Institute, University of Sydney, Sydney.

Bourg, A.C.M. (1987), 'Trace metal adsorption modelling and particle-water interactions in estuarine environments', *Cont. Shelf Science*, 7, 1319-1332.

Bruland, K.W. and Coale, K.H. (1986), 'Surface water 234Th:238U disequilibria: spatial and temporal variations of scavenging rates within the Pacific Ocean', In J.D. Burton, P.G. Brewer and R. Chesselet (eds), *Dynamic Processes in the Chemistry of the Upper Ocean*, Plenum Press, New York, pp. 159-172.

Davies-Colley, R.J., Nelson, P.O. and Williamson, K.J. (1984), 'Copper and cadmium uptake by estuarine sedimentary phases', *Environ. Sci. Technol.* 18, 491-499.

Eagle, A.M. and Higgins, R.J. (1991), 'Environmental investigations of the effects of the Ok Tedi copper mine in the Fly River system' This volume.

Eaton, A. (1979), 'Leachable trace elements in San Francisco Bay sediments; indicators of sources and estuarine processes', *Environ. Geol.*, 6, 333-339.

Harris, P.T. (1988), 'Sediments, bedforms and bedload transport pathways on the continental shelf adjacent to Torres Strait, Australia-Papua New Guinea', *Continental Shelf Research*, 8, 979-1003.

Harris, P.T. (1991), 'Sedimentation at the junction of the Fly River and the northern Great Barrier Reef', This volume.

Kersten, M. and Forstner, U. (1989), 'Speciation of trace elements in sediments', In G.E. Batley (ed.), *Trace Element Speciation: Analytical Methods and Problems*, CRC Press, Boca Raton, Florida.

Kuwabara, J.S., Chang, C.C.Y., Cloern, J.E., Fries, T.L., Davis, J.A. and Luoma, S.N. (1989), 'Trace metal associations in the water column of South San Francisco Bay, California', *Est. Coast. Shelf Sci.*, 28, 307-325.

Li, Y.H., Burkhardt, M. and Teraoka, H. (1984), 'Desorption and coagulation of trace elements during estuarine mixing', *Geochim. Cosmochim. Acta*, 48, 2011-2019.

Maunsell and Partners (1982), *Ok Tedi Environmental Study. Report to Ok Tedi Mining Limited*, Maunsell and Partners Pty. Ltd., Volumes 1-7.

Morel, F.M.M. (1983), *Principles of Aquatic Chemistry*, Wiley-Interscience, Chapter 6.

OTML (1988), Sixth Supplemetal Agreement Environmental Study 1986-1989. Final Draft Report, Ok Tedi Mining Limited.

OTML (1989), Supplementary Environmental Investigations. Ok Tedi Mining Limited.

Salomons, W., Eagle, M., Schwedhelm, E., Allersma, E., Bril, J. and Mook, W.G. (1988), 'Copper in the Fly River system (Papua New Guinea) as influenced by, discharges of mine residue: overview of the study and preliminary findings', *Environ. Technol. Lett.*, 9, 931-940.

Salomons, W. (1980), 'Adsorption process and hydrodynamic conditions in estuaries', *Environ. Technol.*, 1, 356-365.

Salomons, W. and Eagle, M. (1990), 'Hydrology, sedimentology and the fate and distribution of copper in mine-related discharges in the Fly River system, Papua New Guinea', *Sci. Tot. Environ.*, 97/98, 315-334.

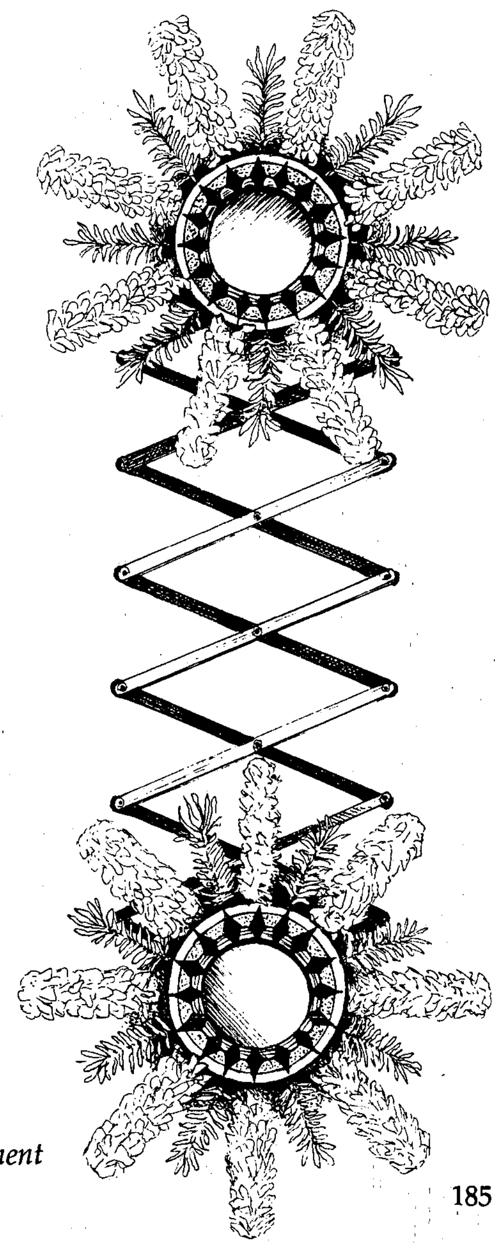
Schneider, P. (1990), Metal source and distribution in Torres Strait and related impacts to the tiger prawn Penaeus esculentus. M. App. Sci. Thesis, Ocean Sciences Institute, University of Sydney, Sydney.

van den Berg, C.M.G., Merks, A.G.A. and Duursma, E.K. (1987), Organic complextion and its control of dissolved concentrations of copper and zinc in the Scheldt estuary, *Est. Coast. Shelf Sci.*, 24, 785-797.

Wolanski, E., Pickard, G.L. and Jupp, D.L.B. (1984), 'River plumes, coral reefs and mixing in the Gulf of papua and the northern Great Barrier Reef', *Estuarine, Coastal Shelf Sci.*, 18, 291-314.

Wolanski, E., Trenorden, M. and King, B. (1990), *Fly River estuary and Gulf of Papua: Oceanography and sediment dynamics data report: November 1990*, Australian Institute of Marine Science.

BIOLOGICAL ENVIRONMENT OF THE TORRES STRAIT REGION



Dance instrument

The Status of the Dugong in Torres Strait

Helene Marsh and Keith Saalfeld
Zoology Department,
James Cook University of North Queensland

Abstract

In November 1987, dugongs were counted from the air at an overall sampling intensity of 7.4% over a total area of 30,533km² in the Torres Strait region and adjacent waters of the Great Barrier Reef Marine Park. About half the survey was repeated in March 1988: persistently bad weather prevented its completion. We corrected for perception bias (the proportion of animals visible in the transect which are missed by observers), and standardized for availability bias (the proportion of animals that are invisible due to water turbidity) with survey-specific correction factors. The resultant minimum population estimate in November 1987 was 12,522 ± S.E. 1,487 dugongs at an overall density of 0.41 ± S.E. 0.05 km^{-2}, a precision of 12%.

Although there were no significant differences between population and density estimates obtained from the repeat surveys of the same areas, relatively more dugongs were sighted close to the major western islands in the March survey. Our data suggest that if the dugong population were increasing maximally, this region could support an unselective man-induced mortality of 700 dugongs per year at most. If the current rate of increase is similar to that estimated from the Daru dugong catch between 1978 and 1982, the maximum unselective harvest will be of the order of 300 dugongs. If significantly more females than males are being caught, these figures are overestimates.

In the absence of adequate catch statistics and current life history information, it is impossible to confirm whether the current dugong harvest in Torres Strait is likely to be below the sustainable yield. A high priority should therefore be placed on public education in an attempt to pre-empt any increase in catch. The resultant maps of distribution and density

suggest that, if the Torres Strait dugong sanctuary area is to be effective, its boundaries should be renegotiated or an additional protection area established around Buru (Turnagain) Island.

Background

The dugong, *Dugong dugon*, listed as vulnerable to extinction by the International Union for the Conservation of Nature (IUCN, 1986), has traditionally been important in the culture and diet of the peoples of Torres Strait (see Johannes and MacFarlane, in press). In recent years, both some local people (see Johannes and MacFarlane, in press) and scientists (e.g. Hudson, 1986; Marsh, 1986) have been concerned by an apparent decline of dugong numbers in the area.

This concern was fuelled by the decrease in the number of dugongs passing through the local market at Daru (9° 05'S, 143° 22'E) on the Papuan side of Torres Strait from 208 in 1979 to 81 in 1981, despite an increase in the availability of motorized craft, an extension of the hunting grounds, and an apparently sustained hunting effort (Marsh, 1986). The statistics of Johannes and MacFarlane (in press) suggest a parallel slump in the dugong catch of the Western Islanders; fewer than one-fifth as many dugongs were caught in the Western Islands during their study in 1983-84 as were caught during the same months in 1976-78 (Nietschmann, 1984). In addition, a dugong hunter based on Thursday Island who kept records indicating that he had caught 41 dugongs between October 1975 and June 1976, claimed in November 1983 that he had not been able to catch a dugong for four to five years despite that fact that his catch effort remained the same and he continued to catch turtles (Marsh *et al.*, 1984a).

A dedicated aerial survey of the major dugong hunting grounds in Torres Strait in November 1983 produced a minimum population estimate of 1,455 ± S.E. 276 dugongs (Marsh, 1986). It was appreciated that this was 'an underestimate, probably a gross underestimate of the Torres Strait dugong population' because the proportion of dugongs that were sighted under aerial survey conditions had not been calibrated. However, the difference between this estimate and the estimate of 22,000 required to support an annual unselective harvest of 500 dugongs, the lower limit of the estimated annual catch for at least some years between 1975 and 1982 (see Tables 1 and 2) was huge. In view of the decline in catch rates, this discrepancy led to serious doubts about there being enough dugongs in Torres Strait to sustain the level of hunting that had apparently taken place, especially as the estimate of a required population of 22,000 was based on population parameters obtained from the animals harvested by the hunters from Daru (Marsh, 1986).

Some Islanders claimed, however, that more dugongs would have been sighted if the 1983 survey had been carried out during (rather than immediately before) the wet season, and that a substantial proportion of animals occurred west of the 1983 survey area.

In view of improvements in aerial survey methodology (Marsh and Sinclair, 1989a and b), it was decided to conduct further surveys in 1987-88 to determine the distribution and abundance of dugongs in Torres Strait. These surveys were designed to take account of the Islanders' criticisms of the design of the previous survey.

Table 1. Dugong catch statistics from five Torres Strait communities 1975-82.

Collection Period	Location	Number caught Total	Average per month	Source
October 1987 - June 1976	Thursday Island	41	4.6	Personal records kept by one hunter for Dr G.E. Heinsohn
September 1976 - August 1978	Mabuiag	227	9.5	Records collected by Nietschmann during his stay on Mabuiag plus records kept for him by an Islander in Kubin and Badu – March. (Neitschmann 1984)
January 1977 - December 1977	Kubin	50	4.2	
October 1976 - 1979	Badu	227	7.8	
July 1978 - March 1982	Daru	454	10.1	Records of dugongs sold in Daru market collected by PNG Division of Wildlife (Hudson, 1986)

Table 2. Estimates of the dugong catch of Islanders on crayboats in 1983 on the basis of interviews conducted in late 1983 by Marsh *et al.*, (1984) and MacFarlane (see Johannes and MacFarlane, in press).

Informant	Interviewer	Estimate	Basis of Estimate
Islander leader not involved with fishery	Marsh	>100	discussions with other Islanders
Islanders who owned and operated crayboats	Marsh	~500	30 taken one week [1] from several boats; maximum of 11 per day; last week (Nov. 12-18 1984) four taken from one boat
Crayboat crews plus personal involvement with cray industry 1980-81	MacFarlane	~240	Assumed 2 dugongs per week per boat. 4 boats, 30 week season. [2]

[1] Probably an overestimate; the Islanders wished to emphasise their prowess as hunters.
[2] This is probably an overestimate of the length of the crayfishing season and of the weekly catch. Peter Channells (pers. comm. 1988) reports that the average number of days per year worked by a freezer boat in 1981-86 was 109 and that vessels do not work continuously in areas where dugongs occur.

Results of the 1987-88 Surveys

In November 1987, dugongs were counted from the air at an overall sampling intensity of 7.4% over a total area of 30,533 km^2 in the Torres Strait region and adjacent waters of the Great Barrier Reef Marine Park (Figure 1). About half the survey was repeated in March 1988; persistently bad weather prevented its completion.

Corrections were made for perception bias (the proportion of animals visible in the transect which are missed by observers), and availability bias (the proportion of animals that are invisible due to water turbidity) with survey-specific correction factors as outlined in Marsh and Sinclair (1989a). The resultant minimum population estimate in November 1987 was 12,522 $\pm$ S.E. 1,487 dugongs at an overall density of 0.41 $\pm$ S.E. 0.05 km^{-2}, a precision of 12%.

This estimate is, of course, substantially higher than the minimum estimates obtained for part of the same area by Marsh (1986). The difference is due to the improved survey methodology; Marsh's (1986) estimate was uncorrected for the biases inherent in the survey technique.

We consider that even the estimate of 12,522 $\pm$ S.E. 1,487 dugongs is more likely to be an underestimate than an overestimate. The correction for availability bias for each survey is based on the ratio of the proportion of dugongs sighted that are at the surface during the survey to the proportion sighted in a clear water area when all dugongs present were potentially available, and assumes that the proportion of dugongs at the surface is the same for all habitats and at all times (Marsh and Sinclair, 1989a). This assumption may not be valid in Torres Strait, where in contrast to the east coast of Australia where our other dugong surveys have been carried out, significant numbers of animals are seen in relatively deep water (see below). Observations by Paul Anderson (unpublished data) suggest a trend for dugongs to remain submerged longer in deeper water. A more accurate correction for availability bias in Torres Strait will require further investigation of dugong diving behaviour in this area.

Although there were no significant differences between population and density estimates obtained from the November 1978 and March 1988 surveys of the same areas, relatively more dugongs were sighted close to the major western islands in the March survey. This result is consistent with the Islander's perceptions that dugongs are more abundant in the area from Cape York to Mabuiag during the North-West monsoon (Johannes and MacFarlane, in press).

The survey results indicate that Torres Strait is a very important area for dugongs with a population comparable to that of the entire Great Barrier Reef Marine Park (Marsh and Saalfeld, 1989, 1990).

In November 1987, dugong density was highest on the seagrass beds around Badu and extending north across Orman Reef around Buru Island and east to Gabba Island (9° 46'S, 142° 37'E) (Figure 1). The next highest density was observed over the Warrior Reef complex. Densities were very low along the coasts of Papua New Guinea and Cape York including the northernmost waters of the Great Barrier Reef Marine Park.

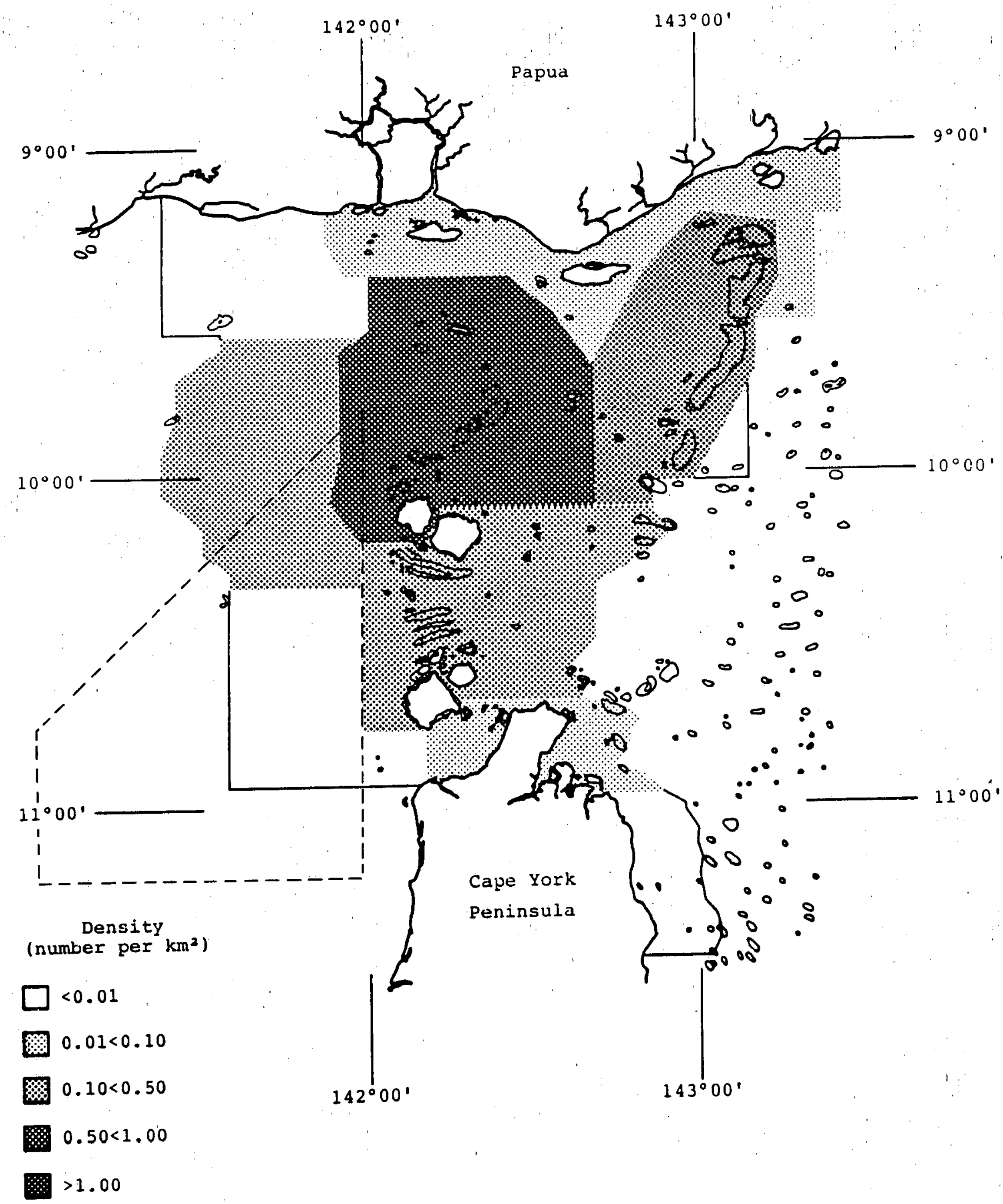


Figure 1. The distribution of dugong density in the survey area in November 1987. The broken line shows the boundaries of the Protected Zone Joint Authority Dugong Sanctuary Area.

High densities of dugongs were observed in the Buru Island/Orman Reef area in both November 1987 and March 1988. This was also the area supporting the highest densities of dugongs in November 1983 (Marsh, 1986). Large numbers of dugongs were also sighted in this area on a Coastwatch flight on June 17 1988 (M. McCarthy, pers. comm). It seems likely that the extensive seagrass beds in this area are consistently important dugong habitat, despite the essentially seasonal nature of the dugong catch from this area by Boigu Islanders (Johannes and MacFarlane, in press).

As much of the Orman Reef area is uncharted, we were able to estimate the depth of water in which only about 45% of dugongs were sighted in the November 1987 survey. Nonetheless, the survey indicates that significant numbers of animals are sighted in relatively deep water (>l0m), in contrast to the northern waters of the Great Barrier Reef Marine Park where 56% of dugongs are sighted in water less than 5m deep (Marsh and Saalfeld, 1989). Significant numbers of dugongs are seen more than l0km from land in Torres Strait, in contrast to their essentially inshore distribution in most other areas. Dugong distribution in Torres Strait undoubtedly reflects the extensive beds of both intertidal and subtidal seagrass beds in this area.

Is the Dugong catch in Torres Strait sustainable?

On the basis of experience in Torres Strait in the late 1970s, Nietschmann (1984), 'guesstimated' an average annual dugong catch in Torres Strait of about 750 animals. We do not know whether this estimate was restricted to the Australian Islands or whether it included dugongs caught by Islanders who operate crayboats. From the limited statistics available (see Tables 1 and 2), Marsh (1986) estimated that the total annual dugong catch for the Torres Strait area for at least some years between 1975 and 1982 was at least 500 to 1000 animals. She then estimated the minimum populations required to support an annual unselective harvest of 500 and 1000 dugongs assuming a population sex ratio of 1:1 on the basis of a simple population model which was constructed to determine the annual rate of increase of stable dugong populations with various combinations of life-history parameters in the range observed for several populations.

Marsh (1986) calculated that, even with the most optimistic combination of life history parameters, a dugong population was unlikely to increase at more than about 5% per year. If the parameters calculated from the dugongs passing through the Daru market in 1978-1982 are operable, the maximum rate of increase is likely to be only about 2%. It is likely, however, that the rate of increase of the Torres Strait dugong population is currently higher than this latter figure which was obtained soon after anecdotal evidence suggests there was a period of extensive seagrass dieback in Torres Strait (Johannes and MacFarlane, in press). The mean calving interval (the parameter to which the dugong population model is most sensitive) decreased significantly from nine years in 1978-79 to three years in 1981-82, coincident with the reported recovery of the Torres Strait seagrass beds (Marsh and Hudson, unpublished data).

Marsh's (1986) population model indicates that 12,500 dugongs are likely to be able to sustain an unselective harvest of only 700 animals per year when dugongs are breeding optimally. If the population parameters calculated on the basis of the dugong specimens obtained from the Daru harvest in 1978-82 are currently valid, the maximum sustainable harvest is of the order of 300 per year. Johannes and MacFarlane (in press) reported that adult females outnumbered adult males in the 'unselective' catch of the Boigu Islanders recorded by Mrs Pabai from Boigu by a ratio of 5:2. Dugong tusks are sexually dimorphic and the small sample which has been forwarded to us by Mrs Pabai indicate that her records are correct. Nonetheless, we find this sex ratio surprising, as the (much larger) catches from Mabuiag, Badu and Kubin (Nietschmann, 1984), and from Daru (Hudson, 1986) indicated a ratio close to parity. However, if the Torres Strait dugong catch as a whole is currently biased in favour of females, the sustainable harvest figures of between 300 and 700 dugongs are substantial overestimates.

It is impossible to evaluate whether the dugong is currently being over-exploited in Torres Strait without reliable catch figures from all the major hunting communities in the region. All the evidence available suggests that the number caught is now much lower than for the period between 1975 and 1983 as summarized in Tables 1 and 2. Johannes and MacFarlane (in press) estimate that the total legal harvest of dugongs by members of the Australian communities in Torres Strait in the mid-1980s was of the order of 120-140 animals per year. (In 1985-87, the annual average catch from Boigu, a major hunting community, averaged about 45 animals per year (Johannes and MacFarlane, in press)). Johannes and MacFarlane also consider that the illegal harvest of dugongs for cash in the course of crayfishing activities has declined substantially from the 1983 level (Table 2). We have no information about the current dugong catch by the people of the Western Province of Papua New Guinea except that it is believed to have declined substantially since the sale of dugong meat was banned in 1984 (Hudson, 1986).

We believe that there is no cause for complacency about the dugong situation in Torres Strait, despite the apparent decline in catches and the substantially higher population estimate resulting from the November 1987 survey. The situation has the potential to deteriorate rapidly if catches increase. It is clearly important to continue with the public education campaign in an attempt to pre-empt such an increase, and to encourage the Government of Papua New Guinea to do likewise. It would also be desirable to continue monitoring the legal catch by communities on both sides of the border and to repeat the aerial surveys at five yearly intervals as recommended by Marsh and Saalfeld (1989). Such data are central to a reliable assessment of the status of the dugong in Torres Strait.

Acknowledgements

We thank the Australian Fisheries Service and the Great Barrier Reef Marine Park Authority for funding this research; the Fisheries Management Branch of Queensland Department of Primary Industries for providing two observers; the observers: B. Barker-Hudson, P. Corkeron, D. Couchman, P. Luck, and P. Tomkins; the pilots: W. Liddel and A. Serenc; P. Channells, J. Vanderkamp and the keeper of the Booby Island Light Station for logistical support; and James Cook University for allowing us to stay at the Horn Island Research Station at a reduced rate.

References

Hudson, B.E.T. (1986), 'The hunting of dugong at Daru, Papua New Guinea, during 1978-82: Community management and education initiatives', In A.K. Haines, G.C. Williams and D. Coates (eds), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985*, Australian Government Publishing Service, Canberra.

IUCN (1986), *1986 IUCN list of threatened animals*, International Union for the Conservation of Nature and Natural Resources, Gland, Switzerland.

Johannes, R.E. and MacFarlane, W. (in press), *Traditional fishing in the Torres Strait Islands*, CSIRO Division of Fisheries, Hobart.

Marsh, H. (1986), 'The status of the dugong in Torres Strait', In A.K. Haines, G.C. Williams and D. Coates (eds), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985*, Australian Government Publishing Service, Canberra.

Marsh H., Barker-Hudson, B.E.T., Heinsohn, G.E. and Kinbag, F. (1984a), Status of the dugong in the Torres Strait area; results of an aerial survey in the perspective of information on dugong life history and current catch levels. Unpublished report to the Australian National Parks and Wildlife Service.

Marsh H. and Saalfeld, W.K. (1989), 'The distribution and abundance of dugongs in the northern Great Barrier Reef Marine Park', *Aust. Wildl. Res.* 16, 429-40.

Marsh H. and Saalfeld, W.K. (1990), 'The distribution and abundance of dugonds in the Great Barrier Reef region south of Cape Bedford', *Aust. Wildl. Res.* 17, 511-24.

Marsh H. and Sinclair, D.F. (1989a), 'Correcting for visibility bias in strip transect aerials surveys of aquatic fauna', *J. Wildl. Manage.* 53, 1017-1024.

Marsh H. and Sinclair, D.F. (1989b), 'An experimental evaluation of dugong and sea turtle areal surevy techniques', *Aust. Wildl. Res.* 16, 639-50.

Nietschmann, B. (1984), 'Hunting and ecology of dugongs and green turtles in Torres Strait', *Natn. Geog. Soc. Res. Rep.*, 1984, 625-652.

A Review of QDPI Research on Commercial Prawn Species in Torres Strait

Clive Turnbull, Fisheries Branch
Queensland Department of Primary Industries

Abstract

The Torres Strait Project, which is funded by the Queensland state government, was initiated in July 1985 to investigate the movement and distribution of the commercial prawn species in Torres Strait and to assess seasonal and area closures to ensure that they are being applied in the most effective way. The findings of the research project are of international importance as the Torres Strait prawn fishery is jointly fished and managed by Australia and Papua New Guinea.

Data from monthly otter and beam trawl samples taken between January 1986 and December 1989, and from prawn tagging, is being used to investigate the life cycles of the brown tiger (P. esculentus), endeavour (M. endeavouri) and red spot king (P. longistylus) prawns in Torres Strait. Due to tidal constraints in Torres Strait it was necessary to use a daytime water jet beam trawl to sample the seagrass nursery areas on the Warrior Reefs.

An unusual feature of the Torres Strait prawn fishery is that the juvenile seagrass nurseries are located on coral reef platforms (mainly the Warrior Reefs) rather than coastal estuarine mud-flats.

Our data indicates that brown tiger prawns move off the seagrass nurseries on the Warrior Reefs into the shallow silty waters to the west of the reefs, at a very small size, then grow and migrate from the closed area west of the Warrior Reefs, eastward into the fishery.

Spawning in brown tiger prawns in Torres Strait occurs year round with three distinct peaks of activity that vary considerably in intensity and duration between years. The yearly spawning pattern produces a series of age classes within each year that results in a complex pattern of recruitment into the fishery. Due to the complexity of the recruitment pattern it is difficult to set an optimal seasonal closure period. As the fishing fleet is highly mobile, a difference in closure timing to that in other areas could result in an extreme "pulse fishing" effect that may negate any beneficial effect of the closure.

Industry believe that the seasonal closure in Torres Strait opened too late in 1990 and that they missed the main recruitment into the fishery. Catches have been much lower than usual this year. Brown tiger prawns tagged in a closed area to the west of the fishery, moved to the eastern side of the fishery before being recaptured. This indicates that the season may have opened later than the optimal time to harvest that particular pulse of recruiting prawns.

Our data indicates that areas with high densities of undersized prawns are restricted to the western side of the fishery so an extension of the area closures may be a more appropriate management strategy than a total area seasonal closure. The whole system of area and seasonal closures for both Torres Strait and the eastern Queensland coast is currently being reviewed at meetings involving industry, management and research.

Our future research will be aimed at investigating spawning and recruitment patterns of endeavour and red spot king prawns and using fisheries simulation models to assess various closure strategies for the Torres Strait fishery.

The findings of the first three years of the project are detailed in a QDPI Information Series publication, Q190018, titled Torres Strait Prawn Project: A Review of research 1986-88, edited by J.E. Mellors.

Biological Oceanographic Measurements in the Torres Strait and far northern Great Barrier Reef

Miles J. Furnas
Australian Institute of Marine Science

Abstract

Relatively little is known regarding the biological and chemical oceanography of the Torres Strait and far northern Great Barrier Reef. In addition to its traditional marine-based cultures, the Torres Strait now supports several commercial fisheries, is an international shipping route and serves as a political boundary between Australia and Papua New Guinea. To date, oceanographers from AIMS have conducted three chemical/biological surveys within the eastern Torres Strait and bordering zones of the far northern GBR and Gulf of Papua.

Waters of the eastern Torres Strait and far northern GBR are characterized by moderately, but not extremely low dissolved and particulate nutrient concentrations. Elevated concentrations of silicate and nitrate are associated with extensions of low salinity waters of the Fly River plume into the northeastern Torres Strait region. Extensive mixing caused by tidal currents through the reef matrix results in a well mixed water column for most biological/dissolved chemical parameters and enhanced suspended solids concentrations. No clear onshore-offshore or north-south gradients of water quality parameters were observed in the far northern GBR.

Because of their clarity and general shallowness, a significant proportion of light reaches the bottom, regardless of depth on the shelf. On a volume basis, shelf waters of the far northern GBR are highly productive, but water column primary production per unit area (0.6 - 1.65 g C $m^{-2}d^{-1}$ is low to moderate because of the shallowness of the water column. Biomass specific production rates indicate that water column populations of phytoplankton are growing at high rates.

Introduction

Traditional inhabitants and regional seafaring peoples have used the marine resources of the Torres Strait and far-northern Great Barrier Reef (hereafter FNGBR) over millenia. Increasingly, these resources are being utilized by modern commercial fishing interests. Despite the intensified recent interest in the commercial and traditional fisheries of the Torres Strait (e.g. Haines *et al.*, 1986; Mellors, 1990, Johannes and MacFarlane, in press), relatively little is known about the underlying biological and chemical oceanography of the Torres Strait and the adjoining far northern GBR and Fly River delta systems. To date, only three studies have been carried out which address these latter subjects in more than a cursory fashion.

Oceanographers from the Australian Institute of Marine Science (AIMS) first surveyed physical, chemical and biological characteristics of waters of the Gulf of Papua, eastern Torres Strait and far northern GBR (Figure 1) during late November, 1979 (Mitchell, 1982). Wolanski *et al.* (1984) presented and discussed aspects of this data set. AIMS oceanographers (Furnas *et al.*, 1990) have continued with a survey of biological and chemical characteristics of the far northern GBR shelf (11.5°-13° S) under mid-summer conditions (Figure 2). Robertson *et al.* (1990, this volume) carried out an extensive study of biological and geochemical processes in the Fly River delta and adjoining coastal waters. Providing a contextual backdrop for these data sets, Wolanski and his co-workers have provided useful discussions of the physical oceanography of the Torres Strait (Wolanski, 1986; Wolanski *et al.*, 1984, 1988). Harris (1988) addressed aspects of the dynamic sedimentology of the Torres Strait, proper, which ultimately bear upon the biology and geochemistry of the region.

Results and Discussion

Detailed descriptions of sampling and analytical methods for the individual studies are given in the pertinent data reports (Mitchell, 1982; Furnas *et al.*, 1990; Robertson *et al.*, 1990). Primary production measurements in the FNGBR were made according to Furnas and Mitchell (1987), with the exception that "metal-clean" sampling techniques (e.g. Chavez and Barber, 1987) were followed to a greater extent. Robertson *et al.* (1990) also measured surface productivity in the Fly River system using a similar approach.

The data presently available on distributions of dissolved nutrients and plankton biomass in the Torres Strait and FNGBR region are sufficiently limited as to preclude making more than basic generalizations regarding biological processes in the water column. In particular, time series data are lacking, which limits discussions regarding the dynamics of processes in the region.

Because of the shallowness of the Torres Strait region and the intensity of tidal mixing through the complex bathymetry, temperature variations in Torres Strait waters are relatively small (Figure 3). Some upwelling of cool water from the thermocline in the Coral Sea was noted at the shelfbreak on some cross-shelf transects in the FNGBR (SHL28; Figure 3). This cool water was dispersed through the water column within a few miles of the shelfbreak (SHL29; Figure 3) and did not penetrate far across the shelf as a recognizable water type (SHL30-33; Figure 3). Under calm, high insolation conditions, near-surface diurnal heating does occur (>1 C), producing temporary thermoclines in the surface layer.

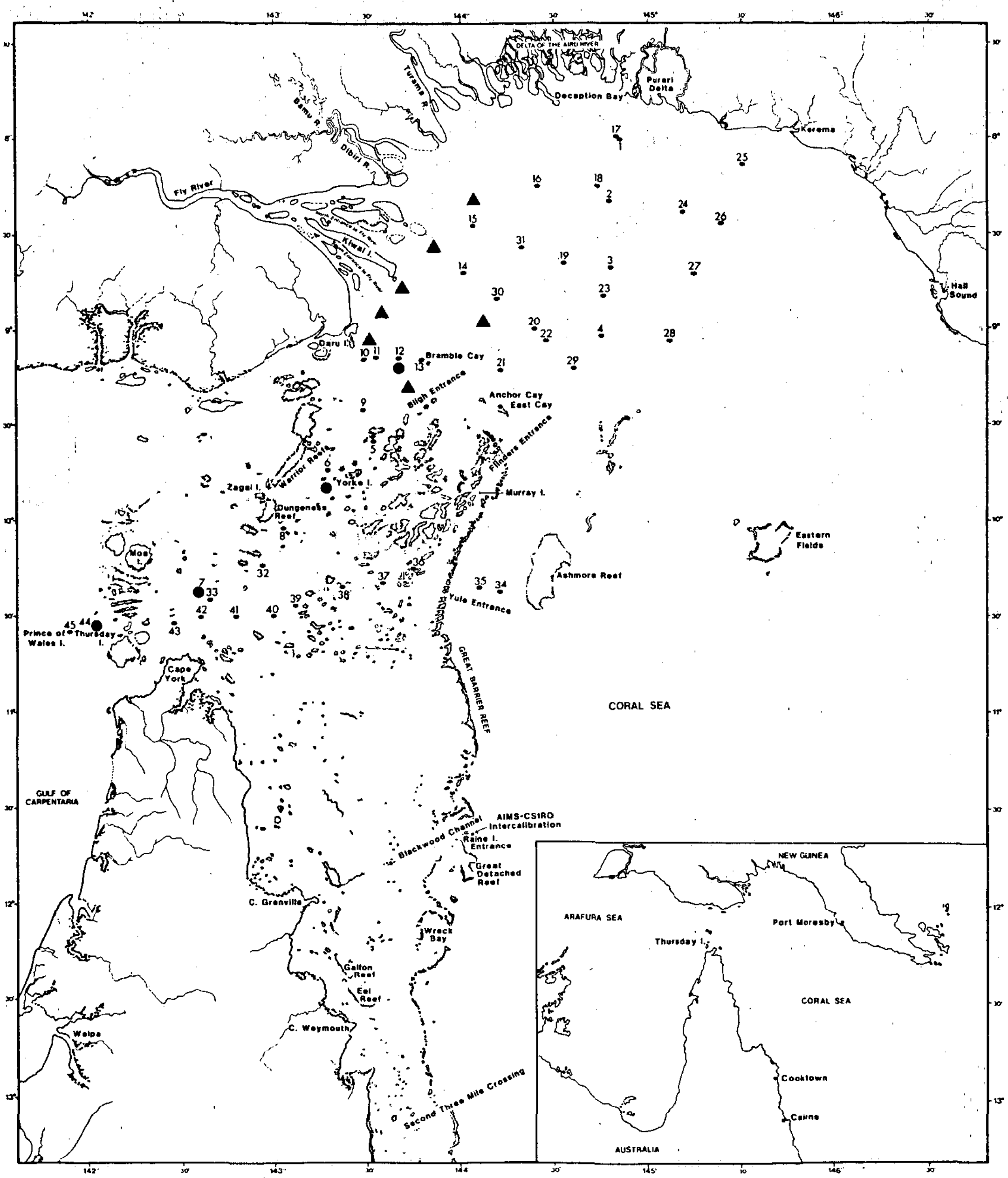


Figure 1. (▲) indicates stations occupied in the Torres Strait and NW Gulf of Papua during December 1989. Large filled symbols (●) identify stations shown in later figures. Stations occupied during November-December 1979 are shown by smaller dots. The base map and station locations for 1979 stations were taken from Mitchell (1982).

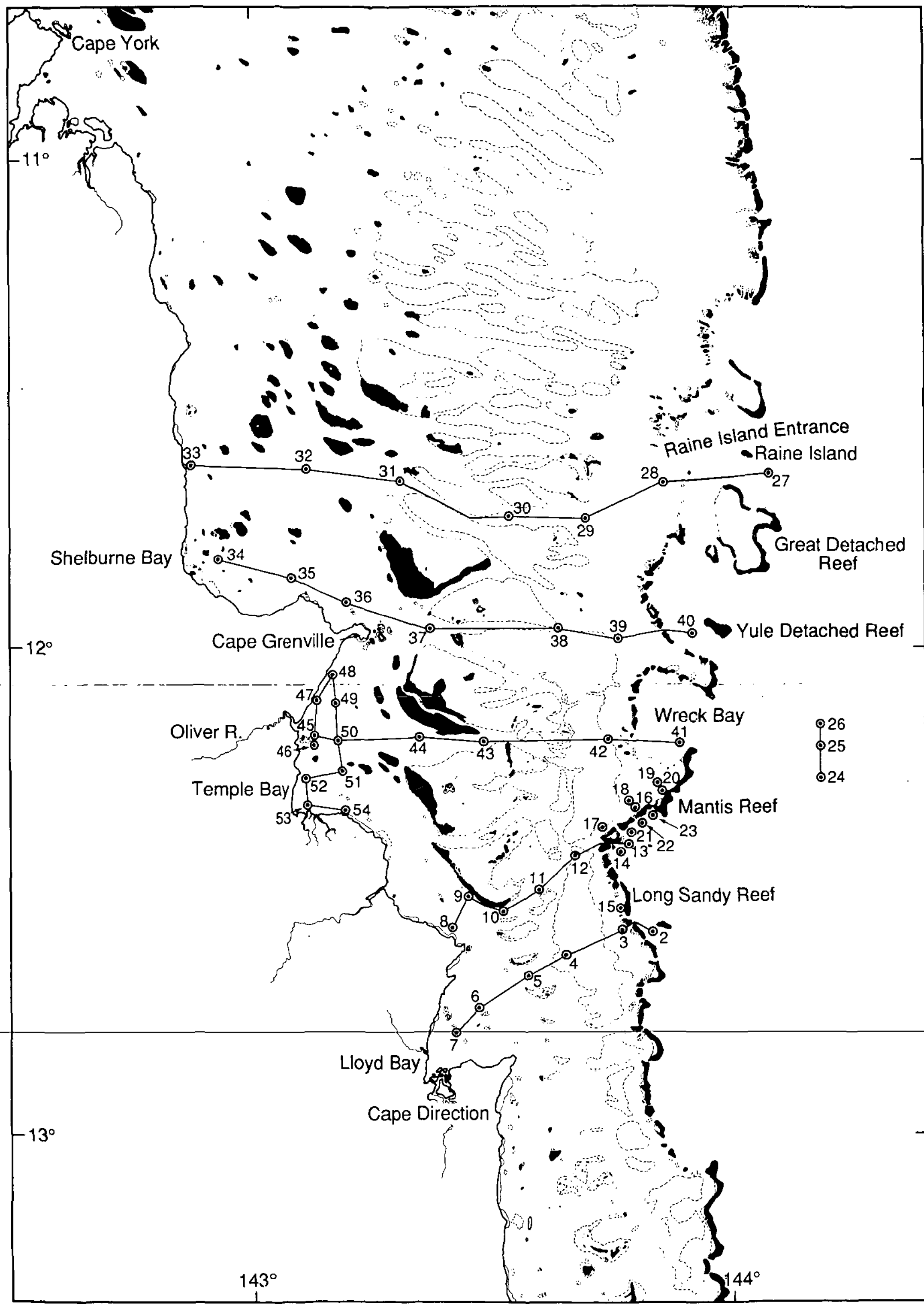


Figure 2. Stations occupied in the far northern GBR during February, 1990 (from Furnas *et al.*, 1990). Large filled symbols identify stations used for comparative figures.

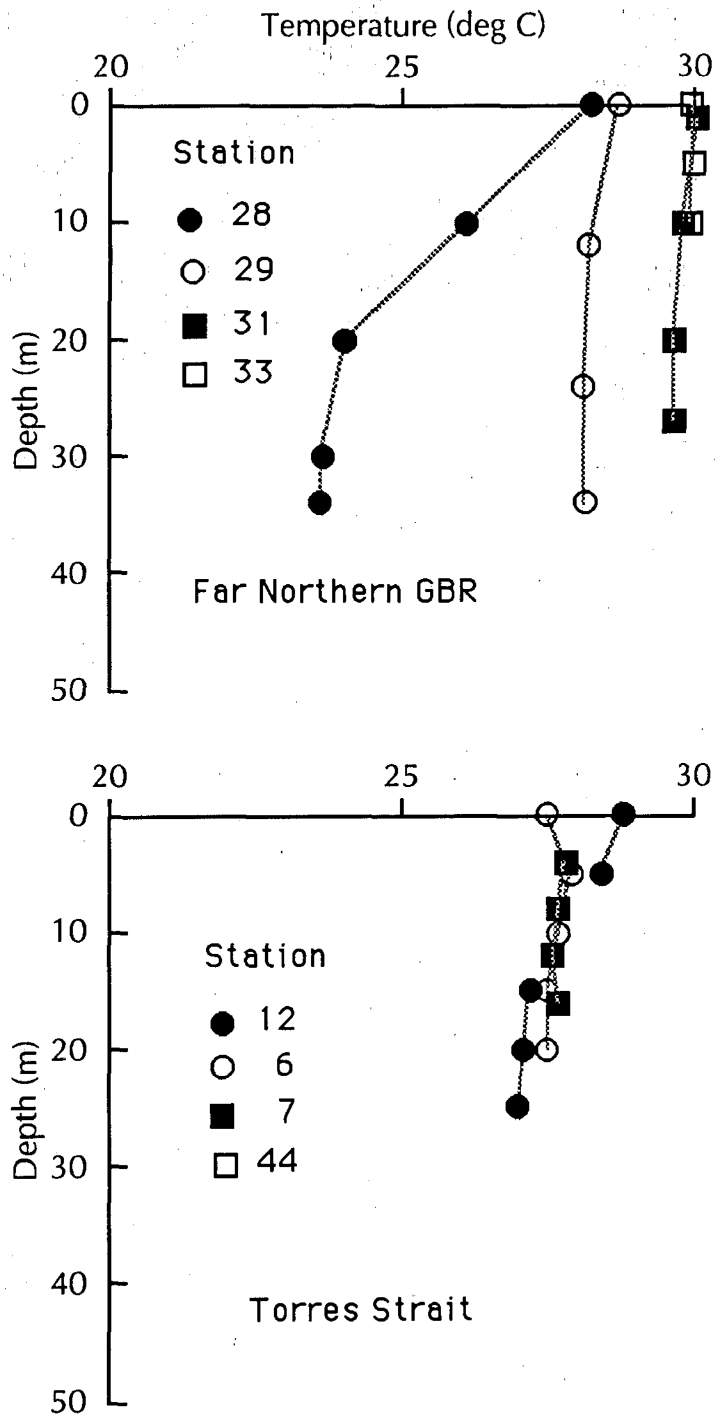


Figure 3. Vertical profiles of water temperatures at stations in the far northern GBR (February, 1990) and eastern Torres Strait (November, 1979).

The large inputs of freshwater into the Gulf of Papua (ca. 13,000 m^3 sec^{-1}; Wolanski *et al.*, 1984) lead to the formation of an extensive near-surface low salinity layer in the Gulf of Papua, which penetrates to some degree into the northeastern Torres Strait region. No evidence of this low salinity water was noted in the FNGBR transects occupied in 1979 and 1990. Comparable surveys in the western Torres Strait have yet to be made.

With the exception of silicate ($Si(OH)_4$), concentrations of dissolved inorganic nutrients (NH_4, NO_2, NO_3, PO_4) are generally low (Table 1), but significantly, readily measureable throughout the Torres Strait, Gulf of Papua and FNGBR. Based on single cruises to the respective areas, dissolved inorganic nitrogen (DIN = NH_4+NO_2+NO_3) concentrations were on average, two-fold higher in the Torres Strait than the FNGBR. DIN concentrations in both regions were much higher than found off Cooktown in October, 1987, but were closer to DIN levels found within the Whitsunday Island group (January, 1988). Shelfbreak intrusions and mixing processes inject relatively small amounts of nitrate (NO_3) onto the outer shelf in the FNGBR (Figure 4). This NO_3 appears to be rapidly utilized by local algal populations. Relatively little variability in nitrate concentrations was observed elsewhere in the Torres Strait region or FNGBR. Ammonia concentrations off the Fly River were similar to those measured in the FNGBR, but lower than measured in the Torres Strait . Nitrate concentrations were higher. This generalization does not account for any short-term variability associated with the individual cruises or systematic differences between data sets.

Dissolved organic nitrogen (DON) and particulate nitrogen (where measured) make up the largest pools of fixed nitrogen within the water column. DON concentrations in the Torres Strait are little different than those in the FNGBR.

Dissolved phosphorus concentrations also appear to be two-fold higher in the Torres Strait than immediately to the south, but were lower than in the northwestern Gulf of Papua. Vertical structure in PO_4 concentrations was generally absent. Particulate phosphorus was the predominant P species in FNGBR waters. Particulate P in the water column was not measured on the 1979 Torres Strait or 1990 Fly River cruises.

Silicate concentrations measured in Torres Strait waters are two- to greater than ten-fold higher than Si concentrations found elsewhere in the GBR (Figure 5; Table 1). In most cases, the highest silicate concentrations in the Torres Strait (maximum observed =12.3 *u*M) were measured at or near the surface. Higher concentrations still (to >30 *u*M) were measured during 1979 in the northern Gulf of Papua. Similar high levels were not reported by Robertson *et al.* (1990). Wolanski *et al.* (1984) demonstrated an inverse relationship between Si concentrations and salinity (Figure 6), indicating that the rivers flowing into the Gulf of Papua were the major source of this silicate. Similar relations were not found for chlorophyll or the other major nutrient species. As such, silicate offers considerable promise as a regional tracer for budgeting freshwater inputs to and residence times within the Torres Strait region and for estimating residence times of other dissolved chemical species.

Despite the presence of readily measureable nutrients in Torres Strait and FNGBR waters, pronounced blooms of phytoplankton associated with large nutrient inputs are not apparent. Inorganic N and P inputs from the Fly River system are not large,

Table 1. Summary of depth-weighted mean water column concentrations of dissolved and particulate nutrients in the NW Gulf of Papua, Torres Strait and northern GBR. Chlorophyll and suspended solids values from the Gulf of Papua are surface values only.

	NH4	NO2	NO3 umol/litre	DON	PON	PO4	DOP umol/litre	POP	Si(OH)4 umol/litre	Chl a ug/litre	Susp. Solids mg/litre
NW Gulf of Papua											
Mean	0.18		0.45			0.18			4.50	0.52	103.6
Std. Dev.	0.09		0.42			0.10			2.72	0.25	5.2
n	6		6			6			6	6	7
Torres Strait											
Mean	0.58	0.05	0.33	4.2		0.10	0.13		3.36	0.41	
Std. Dev.	0.34	0.04	0.13	1.1		0.03	0.05		1.82	0.22	
n	19	20	19	19		19	19		20	20	
F.N. GBR											
Mean	0.19	<0.01	0.10	4.1	3.7	0.05	0.02	0.10	1.14	0.66	1.1
Std. Dev.	0.09	0.01	0.39	1.3	1.3	0.04	0.02	0.04	1.31	0.38	0.4
n	55	55	55	43	55	55	42	55	55	55	52
Ribbon Reefs											
Mean	0.02	<0.01	0.06			0.01			0.06	0.31	
Std. Dev.	0.03	<0.01	0.09			0.02			0.07	0.13	
n	63	63	63			63			63	52	
Whitsunday Is.											
Mean	0.22	<0.01	0.20	4.1	2.0	0.23	0.42	0.09	1.72	1.17	
Std. Dev.	0.14	<0.01	0.14	0.6	0.3	0.03	0.07	0.03	0.41	0.25	
n	20	20	20	9	17	20	9	16	20	21	

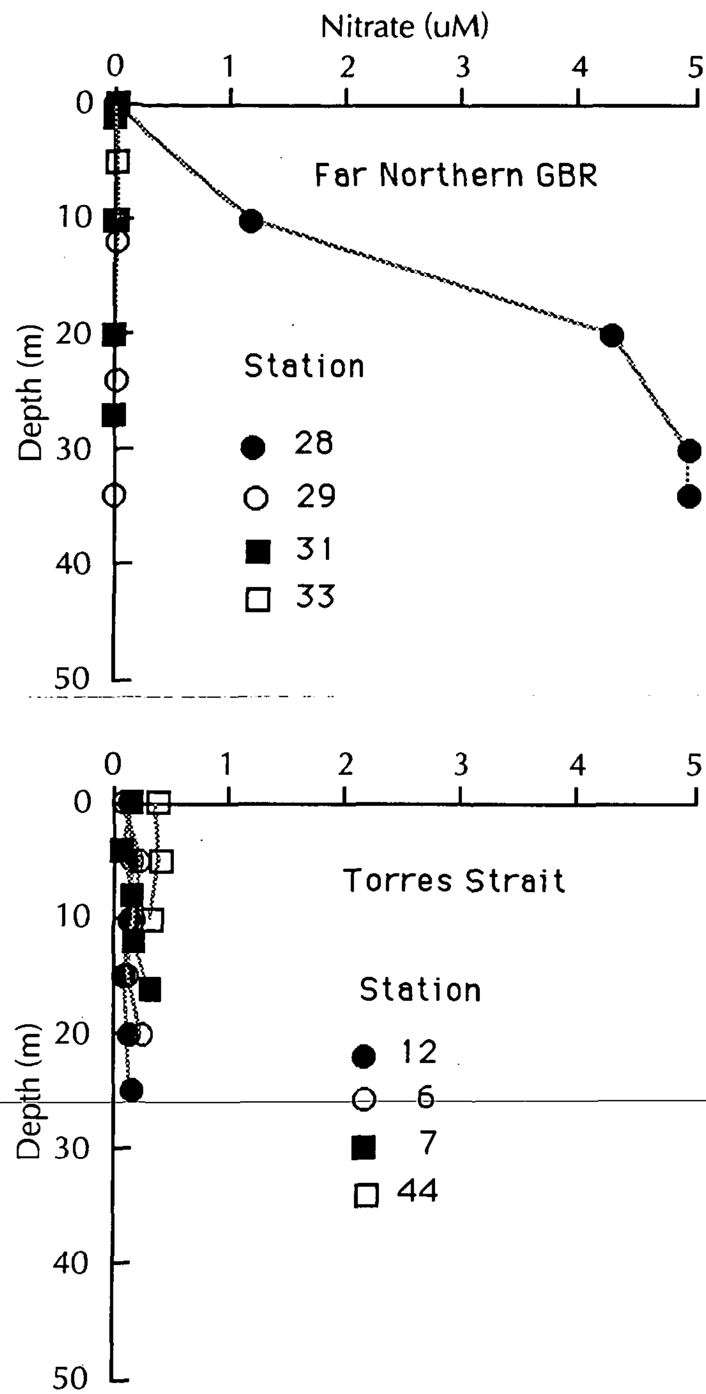


Figure 4. Vertical profiles of nitrate at stations in the far northern GBR (February, 1990) and eastern Torres Strait (November, 1979).

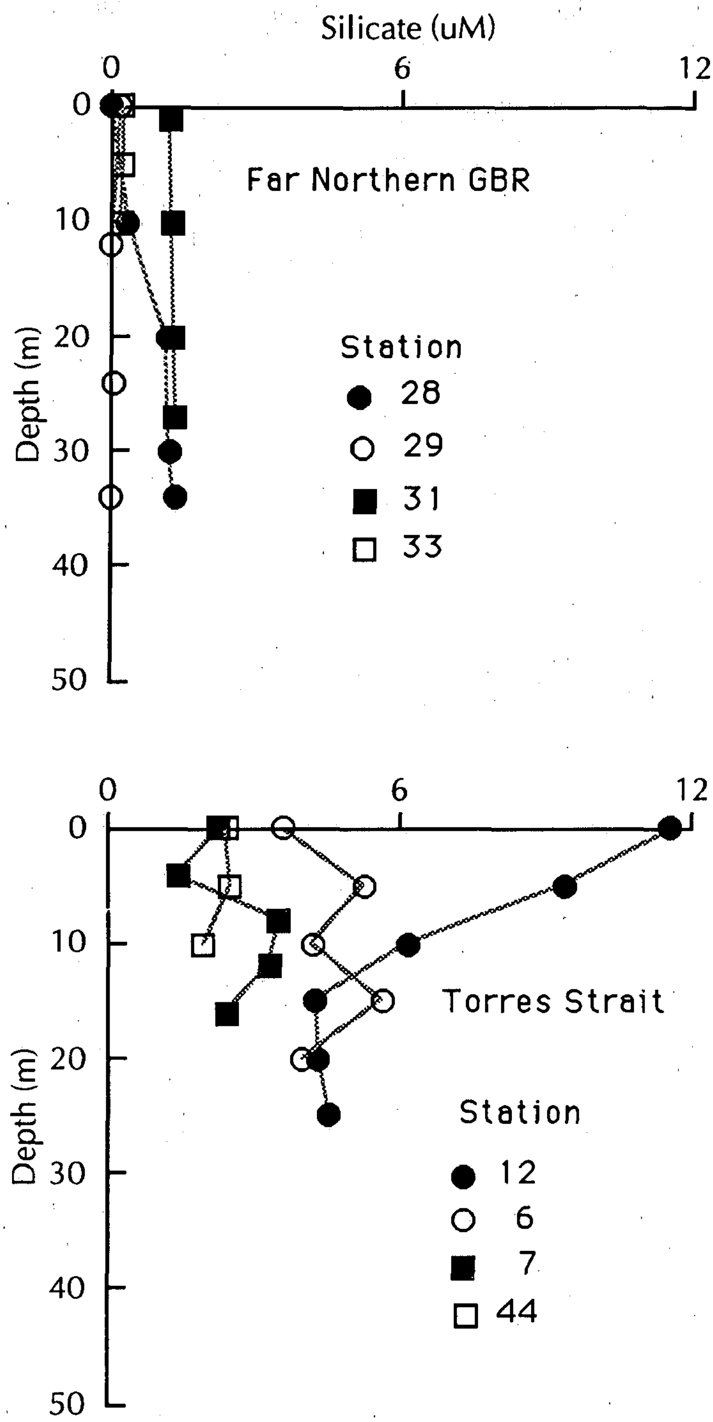


Figure 5. Vertical profiles of silicate at stations in the far northern GBR (February, 1990) and eastern Torres Strait (November, 1979).

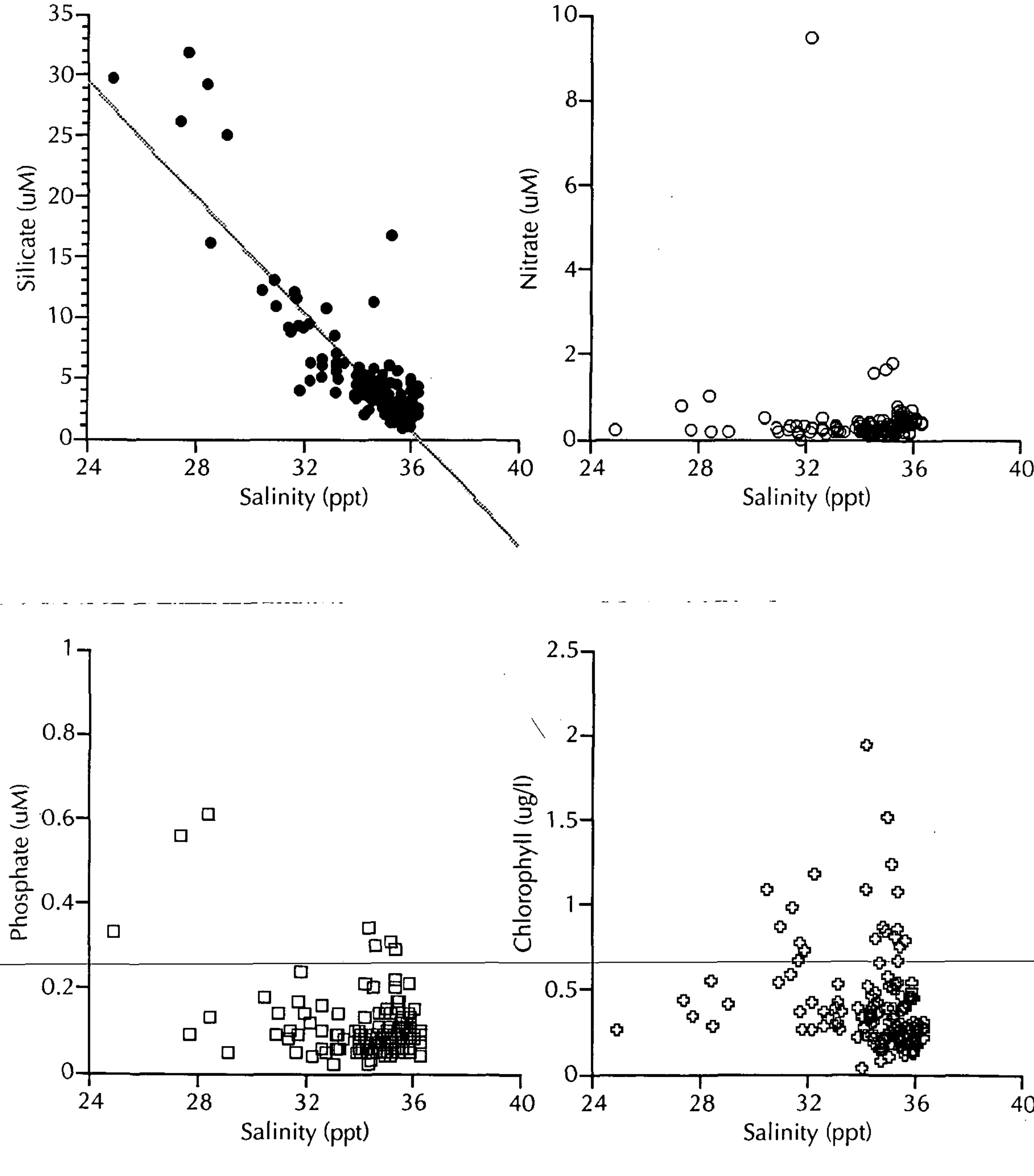


Figure 6. Scatter plots of near-surface (depth $\leq$ 20 m) silicate, nitrate, phosphate and chlorophyll concentrations in relation to salinity at Torres Strait and Gulf of Papua stations (November, 1979).

but substantial amounts of organic N and P enter the Gulf of Papua from the rivers flowing into it (Robertson *et al.*, 1990, this volume). Depth-averaged chlorophyll concentrations in the northwestern Gulf of Papua, Torres Strait and FNGBR are similar to near-shore chlorophyll concentrations found elsewhere in the GBR (Figure 7; Table 1). Maximal chlorophyll concentrations in vertical profiles were most frequently measured in near-bottom or midwater samples. With the exception of anecdotal observations by Hallegraeff and Jeffrey (1984), nothing is known regarding phytoplankton community structure in this area.

Vertical profiles of subsurface light intensity in the FNGBR indicate that concentrations of suspended particulate matter are low and that substantial irradiance fluxes reach the bottom to support the growth of rich benthic algal communities (E. Drew, pers. comm.). In contrast, water clarity varies considerably in the northwestern Gulf of Papua. Robertson *et al.* (1990) report Secchi disk depths off the Fly River delta ranging from 1.6 to 26 m (k = 0.055 to 0.9 m^{-1}). Comparable light profiles are not available for the Torres Strait, which should be a transition zone between the two regimes. Wolanski *et al.* (1984) report that poor water clarity in some portions of the Torres Strait limited the usage of satellite imagery. In contrast, Harris (1988) was able to use aerial photographs to study sediment bedforms. In the southwestern Torres Strait, the presence of substantial beds of seagrass at depths on the order of 15 metres (Poiner *et al.*, 1989) vouches for the general clarity and low suspended matter loads of waters in particular areas.

To date, no measurements of water column productivity and associated biological processes: grazing, organic sedimentation, nutrient uptake and mineralization have been reported for the Torres Strait proper. Mid-day water column primary production rates measured at five shelf sites in the FNGBR during February 1990 ranged between 73.6 and 205.8 mg C m^{-2} hr^{-1}. These rates translate to daily primary production rates of 0.59 - 1.65 g C m^{-2}, approximately equivalent to annual production rates of 215 - 600 g C m^{-2}. Such an annual production rate is similar to calculated primary production rates in temperate shelf systems supporting established fisheries (Yoder *et al.*, 1985) or seagrass beds in Australia (Larkum *et al.*, 1989), though the latter estimates are strongly biased toward temperate and sub-tropical systems. The highest water column production rates measured in the far-northern GBR (610-675 mg C $m^{-2}hr^{-1}$) occurred within deeper embayments immediately seaward of the reef, likely through high production rates occurring over a deeper water column and assisted by episodic upwelling of nutrient at the shelfbreak. Robertson *et al.*, (1990) measured water column primary production rates between 0.13 and 0.34 g C m^{-2} d^{-1} in the northwestern Gulf of Papua (annual production equivalent 47 - 124 g C m^{-2}). Although low relative to production rates measured in the FNGBR, these rates are dwarfed by water column respiration rates (0.14-2.1 g C m^{-2} d^{-1}) fuelled by riverine carbon inputs. The extent to which water masses influenced by this this balance of production and consumption processes intrude into the Torres Strait is unknown.

Information on plankton communities and dynamics in the Torres Strait region is very limited. Macrozooplankton populations at stations in the southeastern Torres Strait were found to be dominated numerically by copepods, gastropod larvae and larvaceans. Zooplankton community standing crop estimates at Torres Strait stations ranged between 17 and 411 mg m^{-3} (mean = 110 $\pm$ 113 mg m^{-3}, 1 SD, n=12 sta.).

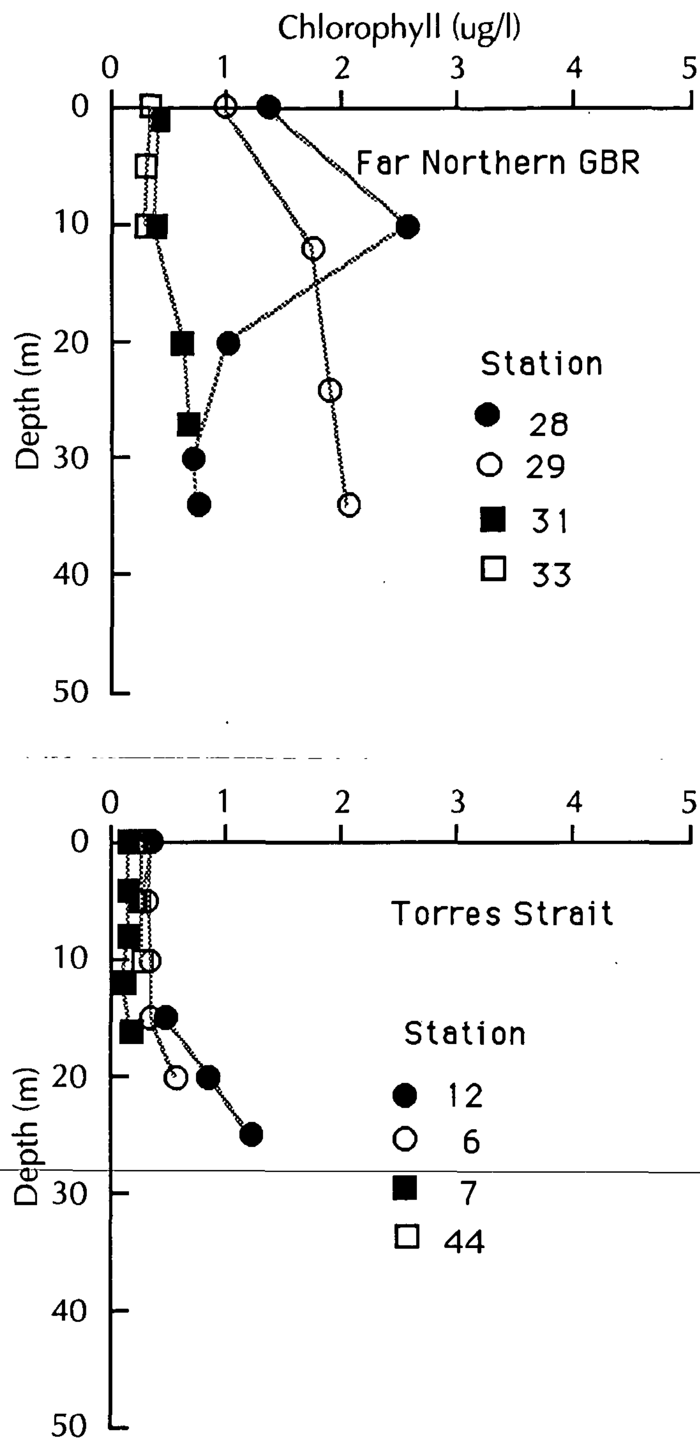


Figure 7. Vertical profiles of chlorophyll at stations in the far northern GBR (February, 1990) and eastern Torres Strait (November, 1979).

The numerical dominance of copepods mirrors the pattern found elsewhere in the GBR (Liston, unpubl.) and Gulf of Papua (Robertson *et al.*, 1990). Zooplankton standing crops in the FNGBR were found to be lower, ranging between 2.0 and 49.5mg dry weight m^{-2} (mean = 18.5 $\pm$10.9 : 1 SD, n=40 sta.). In the turbid waters of the northwestern Gulf of Papua, zooplankton standing crops ranged between 44 and 83 mg m^{-3} (mean = 69 $\pm$ 21 mg m^{-3}, n=3).

Benthos – water column interactions – within the Torres Strait system are likely to be complex and to play an important role in biological and geochemical processes within the region. Sediment and bottom types within the region are spatially variable, ranging from riverine muds deposited in basins to hard coral reef substratum (Harris, 1988). Strong tidal currents in some areas (Wolanski, 1986; Wolanski *et al.*, 1988) have winnowed sediments in high transport areas to less mobile gravels (Harris, 1988). Because of the overall shallowness of the region, the Torres Strait system has a high benthic area to volume ratio. Benthic influences upon water column biological and chemical processes can therefore be expected to be significant. Apart from measurements related to fisheries investigations, little is known regarding benthic biogeochemical processes in the Torres Strait proper. Poiner *et al.*, (1989) estimated that 3579 km^{-2} of seagrasses were present within the Torres Strait region. Microbial rate processes within seagrass beds, as measured by Moriarity and Boon (1989) in the Gulf of Carpentaria should be applicable to these areas, provided that sedimentation and overlying production rates are roughly similar. Robertson *et al.*, (1990) reported that offshore sediments in the Gulf of Papua are active sites of organic material processing and nutrient diagenesis. Sediment – water column and benthic biogeochemical processes – within the Torres Strait region will therefore fall along a number of gradients between end-members typified by seagrass beds, fine riverine sediments, coral reefs and relict carbonate sediments. Whether metabolic rates similar to those found elsewhere in the GBR (Alongi, 1989) are applicable remains to be determined.

In summary, relatively little is known regarding the biological and chemical oceanographic characteristics of the Torres Strait region. The published data is largly derived from three cruises, only one of which was actually carried out within the Torres Strait proper. Within the Torres Strait, there exists a dynamics boundary between the freshwater influenced Gulf of Papua, the open Arafura sea and the far northern GBR shelf system. As such, water column properties exhibit some features of all adjoining systems.

References

Alongi, D.M. (1989), 'Benthic processes across mixed terrigenous-carbonate sedimentary facies on the central Great Barrier Reef continental shelf', *Cont. Shelf Res.* 9, 629-649.

Chavez, F.P. and Barber, R.T. (1987), 'An estimate of new production in the equatorial Pacific', *Deep-Sea Res.* 34, 1229-1244.

Furnas, M.J. and A.W. Mitchell (1987), 'Phytoplankton dynamics in the central Great Barrier Reef - II. Primary production', *Cont. Shelf Res.* 7, 1049-1062.

Furnas, M.J., Mitchell, A.W., Liston, P., Skuza, M., Drew, E. and Wellington, J.T. (1990), Biological and chemical oceanographic measurements in the far northern Great Barrier Reef - February, 1990. Rept. to the Great Barrier Reef Marine Park Authority, Townsville, September, 1990.

Haines, A.K., Williams, G.C. and Coates, D. (1986), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 September, 1985*, Australian Government Publishing Service, Canberra.

Hallegraeff, G.M. and Jeffrey, S.W. (1984), 'Tropical phytoplankton species and pigments of continental shelf waters of north and north-west Australia', *Mar. Ecol. Prog. Ser.* 20, 59-74.

Harris, P.T. (1988), 'Sediments, bedforms and bedload transport pathways on the continental shelf adjacent to Torres Strait, Australia - Papua New Guinea', *Cont. Shelf Res.* 8, 979-1004.

Johannes, R.E. and McFarlane, W. (in press), *Traditional Fisheries in the Torres Strait.*

Larkum, A.W.D., McComb, A.J. and Shepard, S.A. (eds) (1989), *Biology of Seagrasses: A Treatise on the Biology of Seagrasses with Special Reference to the Australian Region*, Elsevier, New York.

Mellor, J.E. (ed) (1990), Torres Strait Prawn Project: a review of research 1986-1988, Qld. Dept. of Primary Industries, Brisbane. (Information Series QI90018)

Mitchell, A.W. (ed.) (1982), *Oceanographic observations in the Gulf of Papua and Torres Strait, 1979.* AIMS Data Report AIMS-OS-82-1.

Moriarity, D.J.W. and Boon, P.I. (1989), 'Interactions of seagrasses with sediments and water', In; A.W.D Larkum, A.J. McComb and S.A. Shepard (eds) (1989), *Biology of Seagrasses: A Treatise on the Biology of Seagrasses with Special Reference to the Australian Region*, Elsevier, New York.

Poiner, I.R., Walker, D.I. and Coles, R.G. (1989), 'Regional studies - Seagrasses of tropical Australia', In: A.W.D Larkum, A.J. McComb and S.A. Shepard (eds) (1989), *Biology of Seagrasses: A Treatise on the Biology of Seagrasses with Special Reference to the Australian Region*, Elsevier, New York.

Robertson, A.I., Alongi, D.M., Christoffersen, P., Daniel, P., Dixon, P., and Tirendi, F. (1990), *The influence of freshwater and detrital export from the Fly River system on adjacent pelagic and benthic systems*, Australian Institute of Marine Science, Townsville. (AIMS Report No. 4).

Wolanski, E.J. (1986), 'The physical oceanography of Torres Strait', In *Torres Strait Fisheries Seminar, Port Moresby, 11-14 September, 1985*, Australian Government Publishing Service, Canberra. 275-291.

Wolanski, E.J., Pickard, G.L. and Jupp, D.L.B. (1984), 'River plumes, coral reefs and mixing in the Gulf of Papua and the northern Great Barrier Reef', *Est. Coast. Shelf Sci.* 18, 291-314.

Wolanski, E.J., Ridd, P. and Inoue, M. (1988), 'Currents through Torres Strait', *J. Phys. Oceanogr.* 18, 1535-1545.

Yoder, J.A., Atkinson, L. P., Bishop, S.S., Blanton, J.O., Lee, T.N. and Pietrafesa, L.J. (1985), 'Phytoplankton dynamics in the southeastern continental shelf during summer 1981', *Cont. Shelf Res.* 4, 611-635.

Torres Strait Marine Turtle Resources

Jeffrey D. Miller and Colin J. Limpus
Queensland National Parks and Wildlife Service

Abstract

Three of the six species of marine turtles that occur in the Torres Strait are represented by both nesting and foraging groups. Genetic uniqueness has been demonstrated for the regional green turtle nesting group but not for any of the other species. The number of nesting green turtles is correlated with an index on the Southern Oscillation. Pesticides and heavy metals do accumulate in the bones, soft tissues and eggs of marine turtles but the impact cannot be evaluated. International cooperation will be necessary for a regional conservation efforts to be successful.

Introduction

The marine turtle resource of Torres Strait was last reviewed in 1985 (Limpus & Parmenter, 1986). Six species of marine turtles occur in the Torres Strait region (Table 1). Two of these, the leatherback and the olive ridley, are only known from occasional sightings. The remaining four species are resident in foraging areas throughout the region. Only three species of marine turtles breed in Torres Strait and for two of these, flatback and hawksbill turtles, the rookeries are of international significance.

Table 1. Sea turtle species of Torres Strait.

FAMILY: CHELONIIDAE	
Eretmochelys imbricata	Hawksbill turtle
Natator depressa	Flatback turtle
Caretta caretta	Loggerhead turtle
Chelonia mydas	Green turtle
Lepidochelys olivacea	Olive Ridley turtle
FAMILY: DERMOCHELIDAE	
Dermochelys coriacea	Leatherback turtle

Key Breeding Sites

Eretmochelys imbricata

The rookeries were last surveyed in 1978 (Table 2). At that time significant nesting aggregations were recorded in central and eastern Torres Strait: Long, Aukane, Mimi and Kabbikane (Limpus, 1980a; Limpus *et al.* 1983a). Other rookeries identified since 1986 as being potentially important include Johnson Island, Bet Island and western Albany Island. This Torres Strait hawksbill nesting and that of the adjacent northern Great Barrier Reef constitutes one of the few remaining large nesting populations for the species worldwide. Although the size of this nesting population has never been accurately assessed, it is estimated that over three thousand females may nest annually throughout the region. Limpus and Parmenter (1986) expressed concern over the potentially excessive harvest of hawksbill eggs on some of the islands. This harvest remains unquantified.

Natator depressa

The rookeries of western Torres Strait (including Crab, Deliverance, Turu Cay and Kerr Islands) support the largest known nesting population of the Australian endemic flatback turtle (Limpus *et al.* 1983b, Limpus *et al.* 1989), with an annual nesting population of several thousand females. The size of the annual nesting population at these rookeries has never been accurately quantified. Crab Island has supported an annual egg harvest by residents of the Bamaga community (Limpus *et al.* 1983b). The regional impact of this egg harvest and that on the other islands has not been quantified.

Chelonia mydas

Bramble Cay supports the largest green turtle rookery in Torres Strait with an annual nesting population of several hundred nesting females (Parmenter, 1977, 1978).

Table 2. Sea turtle nesting populations in north-eastern Australia.

Based on Limpus 1979. Species: G = green turtle, H = hawksbill turtle, F = flatback turtle, R = Olive ridley turtle. Abundance: a = 0-10, b = 10-20, c = 20-30, d = 30-50, e = 50-100, f = 100-500, g = 500-1000, h = 1000+. Rookery Description Code: VSC = Vegetated Sand Cay, VSC-T = Vegetated Sand Cay - Trees, SSB = Submerging Sand Bank, MI = Mangrove Island, SC-M = Sand Cay - Mangroves, CSD = Coastal Sand Dune, SB-M = Sand Bank - Mangroves, CI = Continental Island.

LOCATION	BREEDING SEASON SURVEY				ROOKERY DESCRIPTION CODE
	75/76	76/77	77/78	78/79	
OUTER BARRIER ISLANDS					
Bramble Cay		Gd/e	Gc	Gd Ha	VSC
Anchor Cay				Gb	VSC
East Cay				Nil	SSB
Don Cay				Gc	VSC
Underdown Cay			Gb/c		VSC
Dower Is.			Nil	Gb	CI
Maer Is.			Nil	Nil	CI
Wyer Is.			Nil	Nil	CI
Maclennan Cay				Gc	VSC
Pandora Cay		Gg	Gc/d		VSC
Raine Is.	Gf	Gh	Gf	Gg	VSC
INNER SHELF CAYS					
Sinclair Is.		Gb,Hb			VSC-T
Milman Is.		Hc/d, Gb		Hc, Gb	VSC-T
Aplin Is.				Nil	MI
Wallace Is.		Hb, Gb			VSC-T
Little Boydong Is.		Hb			VSC-T
Boydong Is.		Hc, Gb			VSC-T
Bird Is.		Hc, Gb			VSC-T
Fife Is.		Hb/c			VSC-T
Hannah Is.		Nil			SC-M
Pelican Us.		Hb			VSC-T
EASTERN CAPE YORK PENINSULA COAST					
False Orford Ness to Ussher Point		Gb, Hb			CSD
TORRES STRAIT ISLANDS					
Stephens Is.			Nil	Nil	CI
Darnley Is.			Nil		CI
Campbell Is.				Hc,Gb	VSC-T
Keats Is.				Hb,Gb	VSC-T

Table 2 continued over

Table 2 continued

LOCATION	BREEDING SEASON SURVEY				ROOKERY DESCRIPTION CODE
	75/76	76/77	77/78	78/79	
TORRES STRAIT ISLANDS/continued					
Yorke Is.			Ha	Nil	VSC-T
Kabikane Is.				Hc,Gc	VSC-T
Aukane Is.				Hc,Gc	VSC-T
Mimi Is.				Hc,Gb	VSC-T
Rennel Is.				Hb	VSC-T
Long Is.				Hd/e	SB-M
Coconut Is.			Ha/b		VSC-T
Sue Is.			Ha/Hb		VSC-T
Little Adolphus Is.				Hb/c	CI
Lacey Is.				Hc	CI
Salter Is.				Hb	CI
Mt. Adolphis Is.				Hc,Gb	CI
Thursday Is.				Nil	CI
NORTHEASTERN GULF OF CARPENTARIA					
Crab Is.		Fd,Hb		Fd/e, Hb,Ra	VSC-T

Almost all the green turtle nesting of Torres Strait occurs in the eastern islands. Although regionally important, none of these green turtle rookeries of eastern Torres Strait are of international significance (Table 2). An undetermined number of nesting females and eggs are harvested annually from Bramble Cay, Dowar and other islands.

Identification of Turtle Stocks

The green turtle nesting population of eastern Torres Strait has been demonstrated to be part of the northern Great Barrier Reef (GBR) breeding unit, centered on Raine Island, using mitochondrial DNA analysis (Norman *et al.* in press) and inter-island movement of tagged nesting females. The northern GBR breeding unit has been demonstrated to be a separate breeding unit from that of the southern GBR breeding unit with both GBR breeding units completely isolated genetically from the Western Australian breeding unit (Norman *et al.* in press). The genetic relationships of the Wellesley Group green turtle nesting population and that of the Aru Island nesting population have yet to be determined.

Limpus *et al.* (1989) demonstrated a difference in size of nesting females and their eggs between the flatback turtles nesting in western Torres Strait including Crab Island and those nesting in the southern Great Barrier Reef. While this suggests that these rookery regions are separate breeding units it has not been confirmed through genetic analysis.

There has been no determination of the limits of breeding units for hawksbill turtles in the Torres Strait/northern GBR region.

Foraging Area & Migration

The geographical distribution of adult female marine turtles recaptured in Torres Strait following their migration from rookeries in eastern Australia (Limpus *et al.* in press) is summarised in Table 3. Green turtles captured in Torres Strait nest at rookeries in eastern Torres Strait (Bramble Cay, Campbell Island), the northern GBR (Raine Island, Moulter Cay, No. 7 and No. 8 Sandbanks) and islands of the Capricorn-Bunker Groups of the southern GBR. Most of the tags recovered in Torres Strait have been from turtles tagged in the northern GBR breeding unit (97%), in particular at Raine Island and Moulter Cay and recaptured as resident feeding turtles or as migrating courting turtles. Torres Strait acts as a corridor through which turtles must migrate from feeding grounds in eastern Indonesia, the Arafura Sea region and the Gulf of Carpentaria en route to the rookeries of eastern Torres Strait and the northern GBR (Limpus and Parmenter, 1986). It is assumed that most of the green turtle courtship recorded in Torres Strait is by turtles migrating to rookeries of the northern GBR breeding unit.

Table 3. The geographical distribution of post-nesting tag recoveries of green and loggerhead turtles that were originally tagged while nesting at Queensland rookeries (from Limpus *et al.* In Press). Numbers in brackets refer to turtles captured by rodeo in selected foraging areas of the Great Barrier Reef (GBR).

	Chelonia mydas (n=273)			***Caretta caretta*** (n=118)	
Rookery / Recapture Location	Eastern Torres Strait	Raine Island	Capricorn Bunker Islands	Mainland	Capricorn Bunker Islands
Indonesia	2	9	0	1	0
Gulf of Carpentaria & Arnhen Land	0	18	2	5	4
Torres Strait (PNG side)	10	69	1	2	1
Torres Strait (Australia)	4	50	3	1	1
PNG & Solomon Islands	3	7	1	3	7
Vanuatu & New Caledonia	0	2	12	0	2
Northern GBR (<17 S)	0	7 (+2)	12 (+2)	3	3
Southern GBR (17 S - 24 30 S)	0	1	22 (+25)	5 (+16)	3 (+2)
South of GBR (>24 30 S)	0	0	9	45	15
TOTAL	19	163 (+2)	62 (+27)	34 (+16)	66 (+2)
% International Recaptures	79	53	16	12	15

Substantial numbers of tagged turtles from the northern GBR green turtle breeding unit are captured outside of Torres Strait in Northern Territory, Indonesia, southeastern and northeastern Papua New Guinea, Vanuatu and New Caledonia (Figure 1; Table 3). Tag recoveries of loggerhead turtles captured while feeding on reefs and inter-reefal habitats of Torres Strait demonstrate that these turtles are part of the southern GBR loggerhead breeding unit (Limpus *et al.* in press). Loggerhead turtles that migrate from the Gulf of Carpentaria also pass through Torres Strait en route to the southern GBR rookeries.

One of the few hawksbill turtles tagged while feeding on reefs in eastern Torres Strait has been recaptured nesting in the Solomon Islands (Parmenter, 1983). The foraging region utilised by the hawksbill turtles that nest within Torres Strait is unknown.

There has been one tag recovery in Torres Strait of a flatback turtle tagged while nesting at a central Queensland rookery (C. J. Parmenter, pers. comm.). Although over 500 nesting flatback turtles have been tagged at Crab Island and Deliverance Island, none have been recovered. The foraging distribution of the western Torres Strait nesting flatbacks remains unknown.

ENSO Regulation of Green Turtle Breeding Density

Nesting numbers vary dramatically from year to year at green turtle rookeries within eastern Australia (Limpus, 1989) (Figure 2), with the fluctuations at all rookeries being in synchrony. A significant correlation exists between an index of the El Nino Southern Oscillation (ENSO) measured two years before the commencement of the nesting season and the annual green turtle nesting numbers at both Heron Island and Raine Island (Limpus and Nichols, 1988, in press) (Figure 3). The two year time lag is the result of adult female marine turtles typically taking in excess of a year to prepare for a breeding season. The annual fluctuations in nesting numbers are primarily the result of different proportions of the available adult females coming into breeding condition in some years and not in others, rather than the result of intrinsic changes in the number of adult females in the population (Limpus and Nichols, in press). Because of these irregular annual fluctuations, it will require a database gathered over some two decades of monitoring of nesting numbers at a rookery before significant changes in the size of the population can be detected. There is no database to assess whether or not the nesting numbers of hawksbill or flatback turtles show similar interseasonal fluctuations.

In high density nesting seasons, which occur two years following big ENSO events, there are also large numbers of mating green turtles seen in Torres Strait, notably in September to November prior to the nesting season. Correspondingly, in nesting seasons that follow two years after small ENSO events very reduced numbers of mating turtles are seen.

Impact of Pollution on Turtles

As immature and adult animals, marine turtles utilize the shallow waters of the continental shelf, including the Great Barrier Reef, Torres Strait and the Gulf of Carpentaria, as foraging areas. Because of the environments which they inhabit and their position in the food chain, marine turtles are likely to be exposed to wastes that are dumped into the marine environment.

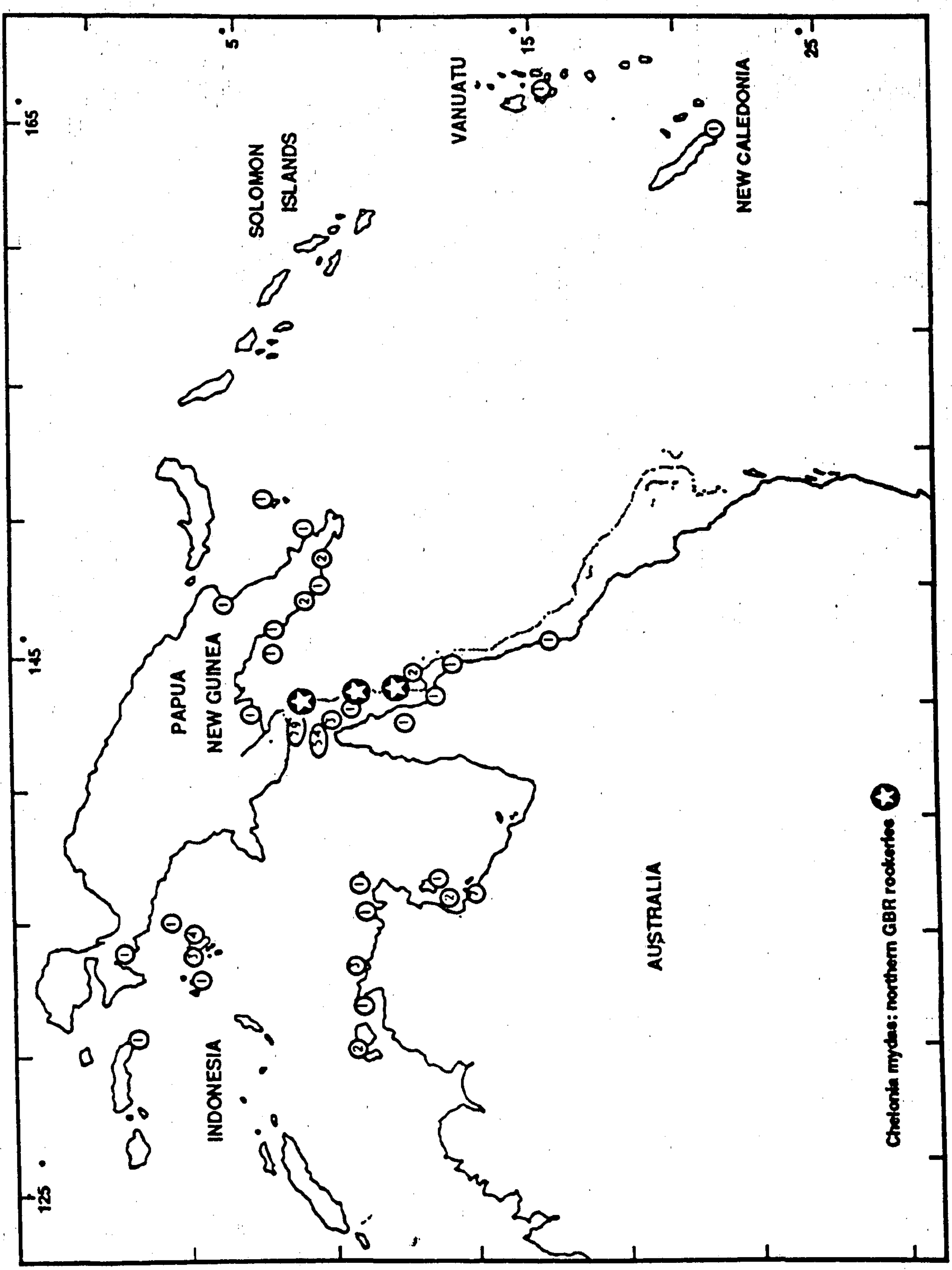


Figure 1. Pattern of recaptures of turtles tagged at the northern Great Barrier Reef green turtle breeding unit. Stars indicate nesting/tagging locations. Circled numbers indicate location and number of recaptures.

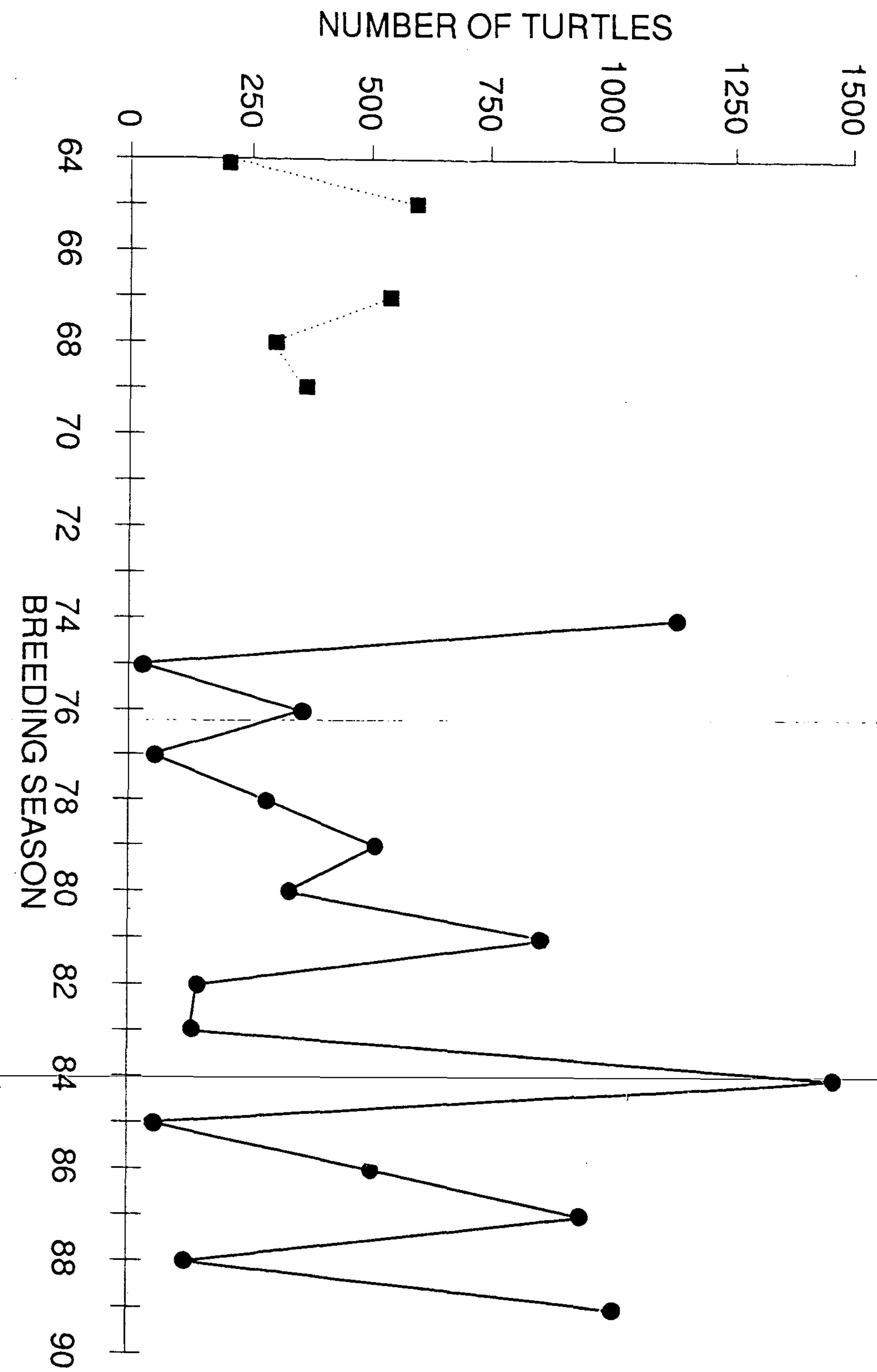


Figure 2. Fluctuations in the number of green turtles nesting at Heron Island. Squares represent approximate values obtained from various publications by Dr. H.R. Bustard. Circles represent data collected within the QTR project since 1974.

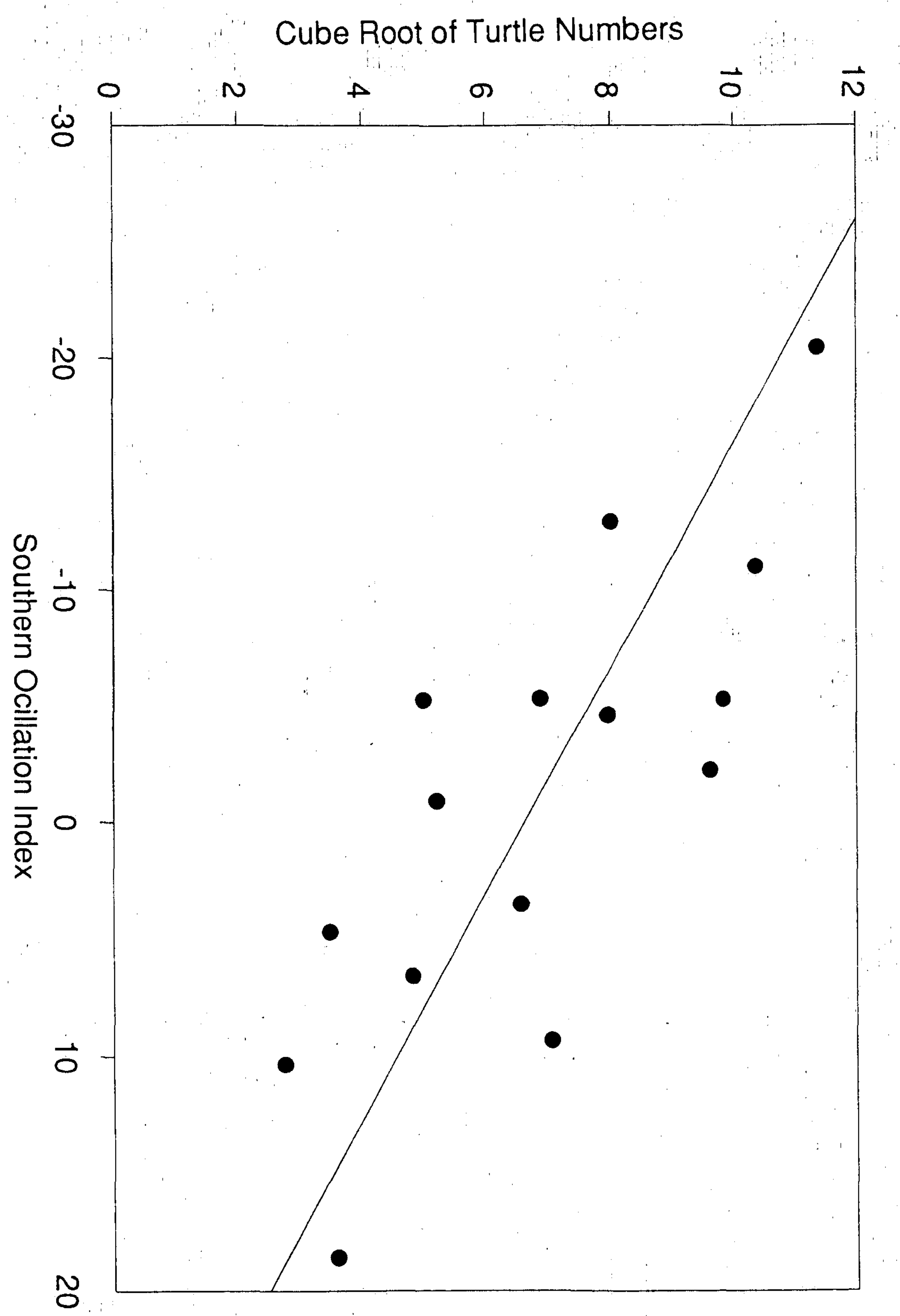


Figure 3. Correlation between the cube root of the number of nesting turtles and an index of the Southern Oscillation measured two years before. (See Limpus & Nichols, *in Press*, for details).

Plastic and other debris which are undigestible are, at least occasionally, eaten by turtles and when this happens the turtle eventually starves to death when its gut becomes clogged (Frazier, 1980).

Oil slicks may cause fouling of skin and obstruct breathing and feeding of turtles in the water. There are a few experimental data which describe the impact of petroleum on developing embryos (Fritts & McGehee, 1989). The minimum lethal tolerance levels, as well as LD50, teratogenic effects have not been determined for any of the known contaminants.

Table 4. Trace metals and pesticides found in marine turtle parts. Single values are MEANS; hyphenated values are RANGES. Codes are T = trace; Y = yolk; A = Albumen. Sources: A = Hillestad *et al*, 1974; B = Stoneburner *et al*, 1980; C = Witkowski & Frazier, 1982.

SOURCE	A	B	C
MEASURE	ppm	ug/g	ug/g
MATERIAL	yolk & albumen	yolk only	bone only
SUBSTANCE			
TOTAL DDT	0.06 - 0.31		
DIELDRIN	T - 0.056		
Al		3.56 - 6.01	
Ba		2.08 - 6.86	
Cd	0.17 Y 0.56 A	0.02 - 0.19	
Co		0 - 0.07	
Cr		1.04 - 1.71	
Cu	2.08 Y 6.0 A	4.96 - 6.6	9.1 8.6 8.9
Fe		71.2 - 74.6	78.5 198.3 309.0
Hg	0.02 - 0.09 Y 0.01 - 0.03 A	0.41 - 1.39	
Mn			8.4 35.6 33.5
Mo		2.66 - 17.9	
Ni		0 - 2.27	
Pb	2.87 Y 12.0 A	1.13 - 2.18	41.5 86.6 97.2
Sr		66.1 - 74.0	
Zn	32.2 Y 26.0 A	73.5 - 80.5	

Only a few opportunistic studies have considered the accumulation of contaminates such as heavy metals by sea turtles (Table 4). For the most part these few studies have reported concentrations but have been unable to put their work into a meaningful context (Hillestad *et al*, 1974; Stoneburner *et al*, 1980; Witkowski & Frazier, 1982; Davenport *et al*, 1990). As a result the general physiological impacts of heavy metals, pesticides and other pollutants in marine turtles are unknown; the tolerance of sea turtles to burdens of these contaminants is also unknown.

Hillestad *et al*, (1974) reported a set of baseline results obtained from egg yolks and albumen and found significant differences in the contained levels for Cd, Cu, and Pb but could not interpret the results. The concentrations of 13 heavy metals were determined in eggs of 40 loggerhead turtles (Stoneburner *et al*, 1980). Barium, cobalt, chromium, mercury, molybdenum, and nickel exhibited significant variation among the samples; however, aluminum, copper, iron, strontium, and zinc did not. The meaning of these results could not be determined. Witkowsky & Frazier (1982) reported the results from analysis of unidentified marine turtle bones. Again they had no context into which they could place their findings. Recently Davenport *et al*, (1990) reported on heavy metal analysis from a leatherback turtle. The liver contained the highest concentrations of Hg, Cd, Zn, and Ni; concentrations of Cu, Pb, and Se were higher in pectoral muscle tissue or blubber (As). None of the values reported were elevated above levels reported for other organisms (see Bryan, 1984, for review).

Other workers have had the same problem interpreting levels of pesticide accumulation. In each report the question of 'What does it mean if levels of DDE found are low (loggerhead turtles :0.091 ppm, Witkowski & Frazier, 1982; 0.05 ppm, Clark & Krynitsky, 1980, 1985; 0.003 ppm, Thompson *et al*, 1974; 0.034 ppm Fretemeyer 1980; 0.002 ppm in green turtles, Clark & Krynitsky, 1980)?' remains unanswered.

Because turtles migrate from several foraging areas to nest at specific locations, the concentration of heavy metals in eggs can serve as an indicator of variation among foraging areas. However, unless specific turtles can be traced to specific foraging areas, the only direction for the research to take is to examine the impact of various concentrations on development. This has intrinsic scientific and some practical value; however, this should not be emphasized over the determination of concentrations in specific foraging areas. Because the foraging areas provide the energy for vitellogenesis, the concentration of heavy metals found in eggs reflects the accumulation of elements from the foraging areas.

The presence of heavy metals in eggs and bone demonstrates that females can and do accumulate such contaminants in a manner that is at least superficially similar to that of other marine animals. Whether their exposure is indirect, from the environment, or more directly via food, has not been investigated.

Not enough is known to evaluate the impact of heavy metals and pesticides on marine turtles during any life stage. The information available provides some background levels for future comparison; however, they do not have direct application on the situation in Torres Strait. Because turtles are a part of the diet of the people in Torres Strait, regionally-based detailed studies need to be conducted to determine the background levels in the turtles being harvested and to monitor for any changes.

Population Dynamics Constraints on Turtle Utilization

Almost all of the marine turtles harvested for food within the Torres Strait region are green turtles. Additionally, the catch is strongly biased to large female turtles (Parmenter, 1980; Kwan, 1989). Although some estimates of the size of the annual harvest have been attempted with varying precision (Limpus, 1980b; Parmenter, 1980; Kaowarsky, 1982; Johannes and MacFarlane, in prep; Kwan, 1989), no study has been made which links the harvest to the turtle population(s) being harvested. There is no database against which to judge whether the turtle populations (resident and migratory) in Torres Strait are being depleted by the harvest.

Additionally, the data required for understanding green turtle population dynamics (and those of other species) are incomplete. In particular, reliable estimates of recruitment to and survivorship of turtles of the various size classes are unavailable. Size classes of marine turtles are used to describe marine turtles because age cohorts can not presently be recognised.

Tag recoveries have demonstrated that the Torres Strait inhabitants are not the only people harvesting substantial numbers of turtles from the northern GBR green turtle breeding unit. If the people of Torres Strait wish to maintain turtles for their descendants to hunt, more emphasis should be placed on gathering data relevant to maintaining the turtle population within the context of sustained harvesting. Because of the international migration of turtles from the northern GBR green turtle breeding unit and the position of Torres Strait as a migratory corridor for many of these turtles, cooperative assessment and management of this turtle resource by Australian, Papua New Guinean and Indonesian Governmental agencies is to be encouraged.

Literature Cited

Bryan, G. (1984), 'Pollution due to heavy metals and their compounds, 1289-1431', In O. Kinne (ed.), *Marine Ecology. Vol. 5, Part 3*,. John Wiley & Sons Ltd.

Clark, D.R., Jr., and Krynitsky, A.J. (1980), 'Organochlorine residues in eggs of loggerhead and green sea turtles nesting at Merritt Island, Florida—July and August 1976', *Pestic. Monit. J.* 14,7-10.

Clark, D.R. and Krynitsky, A.J. (1985), 'DDE residues and artificial incubation of loggerhead sea turtle eggs, *Bull. Environ. Contam. Toxicol.* 34,121-125.

Davenport, J., Wrench, J., McEvoy, J. and Camacho-Ibar, V. (1990), 'Metal and PCB concentrations in the "Harlech" leatherback', *Marine Turtle Newsletter* 48,1-6.

Fletemeyer, J. (1980), 'A preliminary analysis of sea turtle eggs for DDE' *Mar. Turtle Newsl.* 15,6-7.

Frazier, J. (1980), 'Marine turtles and problems in coastal management', In B. Edge (ed.), *Coastal Zone '80. Vol. III. Proceedings of the Second Symposium on Coastal and Ocean Management*, 2395-2411.

Fritts, T. and McGehee, A. (1989), 'Effects of petroleum on the development and survival of marine turtle embryos' In *Proceeding of the Second Western Atlantic Turtle Symposium*, 321-322. (NOAA Technical Memorandum NMFS-SEFC-226).

Hillestad, H.O., Reimold, R.J., Stickney, R.R., Windom, H.L., and Jenkins, J.H. (1974), 'Pesticides, heavy metals and radionuclide uptake in loggerhead sea turtles from South Carolina and Georgia', *Herp .Rev.* 5(3),75

Johannes, R. and MacFarlane, J. (In Prep.), Traditional fisheries of Torres Strait Islanders, Australian Government Publishing Service, Canberra.

Kowarsky, J. (1982), 'Subsistence hunting of sea turtles in Australia', In K. Bjorndal (ed.), *Biology and conservation of sea turtles*, Smithsonian Institution Press, Washington.

Kwan, D. (1989), 'Torres Strait turtle project. Vol. 1. The status of the Daru turtle fishery from October 1984 to December 1987: with implications and recommendations for management and conservation', Report to the Raine Island Corporation.

Limpus, C. (1979), Queensland sea turtle project, February 1976-May 1979. Unpublished Internal Q.NPWS Report to A.NPWS, May 1979.

Limpus, C. (1980a), 'Observations on the hawksbill turtle nesting along the Great Barrier Reef', *Herpetologica*, 36,265-271.

Limpus, C. (1980b), 'The green turtle, Chelonia mydas (L), in eastern Australia', In *Management of turtle resources. Research Monograph 1*, James Cook University of North Queensland, Townsville.

Limpus, C. (1989), 'Environmental regulation of green turtle breeding in eastern Australia', In *Proceedings of the Ninth Annual Workshop on Sea Turtle Conservation and Biology*, (NOAA Technical Memorandum NMFA-SEFC-232).

Limpus, C., Miller, J., Baker, V. and McLachlan, E. (1983a), 'The hawksbill turtle, Eretmochelys imbricata (L.) in north-eastern Australia: the Campbell Island rookery', *Aust. Wildl. Res.* 10, 185-197

Limpus, C., Miller, J., Parmenter, C., Reimer, D., McLachlan, N. and Webb, R. (in Press), 'Migration of green (Chelonia mydas) and loggerhead (Caretta caretta) turtles to and from eastern Australian rookeries', *Aust. J. Wildl. Res.*

Limpus, C and Nichols, N. (1988), 'The Southern Oscillation regulates the annual numbers of green turtles (Chelonia mydas) breeding around eastern Australia', *Aust. Wildl. Res.* 15,157-161.

Limpus,. C. and Nicholls, N. (in Press), 'Progress report on the study of the interaction of the El Nino Southern Oscillation on annual Chelonia mydas numbers at the southern Great Barrier Reef rookeries', Australian Marine Turtle Workshop, November 1990.

Limpus, C. and Parmenter, C. (1986), 'The sea turtle resources of the Torres Strait region', *Torres Strait Fisheries Seminar, Port Moresby February, 1985*, 95-107.

Limpus, C., Parmenter, C., Baker, V. and Fleay, A. (1983b), 'The Crab Island sea turtle rookery in the north-eastern Gulf of Carpentaria' *Aust. Wildl. Res.* 10,173-184.

Limpus, C., Zeller, D., Kwan, D. and MacFarlane, W. (1989), 'Sea-turtle Rookeries in North-western Torres Strait', *Aust. Wildl. Res.* 16,517-525.

McKim, J.M. and Johnson, K.L. (1983), 'Polychlorinated biphenyls and P,P' DDE in loggerhead and green post-yearling Atlantic sea turtles', *Bull. Environ. Contam. Toxicol.* 31(1),53-60.

Norman, J., Moritz, C., Limpus, C. and Prince, R. (in Press), 'Population genetics as a tool for managing marine turtles', *Aust. Marine Turtle Workshop*, November 1990.

Parmenter, C. (1977), Techniques for turtle culture and environmental impact in the Torres Strait region. Research Report 1976-77. Unpublished report, Northern Fisheries Committee Research Session, Brisbane, 12-14 July 1977.

Parmenter, C. (1978), Turtle culture and environmental impact in Torres Strait. Research Report 1977-78. Unpublished report Northern Fisheries Committee Research Session, Townsville, July 1978.

Parmenter, C. (1980), 'Environmental Factors in turtle farming', In *Management of turtle resources. Research Monograph 1*, James Cook University of North Queensland, Townville.

Parmenter, C. (1983), 'Reproductive migration in the hawksbill turtle (Eretmochelys imbricata)', *Copeia* 1983,271-273.

Stoneburner, D.L., Nicora, M.N., and Blood, E.R. (1980), 'Heavy metals in loggerhead sea turtle eggs (Caretta caretta): evidence to support the hypothesis that demes exist in the western Atlantic population', *Jour. Herpet.* 14(2),171-175.

Thompson, N.P., Rankin, P.W., and Johnston, D.W. (1974), 'Polychlorinated biphenyls and p,p'-DDE in green turtle eggs from Ascension Island, South Atlantic Ocean', *Bull. Environ. Contam. Toxicol.* 11(5),399-406.

Witkowski, S.A. and Frazier, J.G. (1982), 'Heavy metals in sea turtles', *Marine Poll. Bull* 13,(7)254-255.

Ciguatoxin in the Marine Biota as a Model for the Movement of Metals

Michael F. Capra, Andrew E. Flowers and Scott T. Hahn
School of Life Sciences,
Queensland University of Technology

Abstract

Giguatoxin is a lipid soluable, non-protein toxin which causes both gastrointestinal and neurological disorders in man after the ingestion of certain reef and pelagic fish. Ciguatoxin is produced by a dinoflagellate Gambierdiscus toxicus and has been shown to pass along the food wed from one animal to another and can ultimately produce severe poisoning in humans. Gambierdiscus toxicus is known to be both benthic and epiphytic in nature and is usually associated with a variety of macro algae.

Ciguatoxin is extracted and purified on silicic acid where it is eluted in a 9:1 chloroform: methanol fraction. At our laboratories a toxic 9:1 fraction has been isolated not only from fish but a number of herbivorous molluscs such as the Ass's Ear abalone, Haliotis asinina and the Sea Hare, Aplysia dactylomela. The 9:1 toxic fraction has also been found in the carnivorous Red Eye crab, Eriphia sebana and the herbivorous Shawl Backed crab, Atergatus floridus as well as in a number of bivalve molluscs Black Lip Pearl oyster, Pinctada margaritifera; Cocks-comb oyster Lopha cristagalli; and Crenulated oyster, Ostrea nomades.

Certain heavy metals (Cu, Zn and Cd) are known to bind to metallothioneins (low molecular weight proteins) in the storage organs of numerous invertebrates and vertebrates. We contend that the uptake and storage of metals will be similar to that of ciguatoxin. We believe that the passage of ciguatoxin through the marine biota is an excellent model for the movement of metals and we propose to use simlar suitable organisms in assessing the passage of metals in the biota.

Australia's Fisheries Research in the Torres Strait Protected Zone

Geoff C. Williams and Derek J. Staples
Bureau of Rural Resources

Abstract

Fisheries in Torres Strait constitute the most important industry of the area, with a commercial value of approximately $21.5 million (excluding pearls). The main commercial resources are prawns and lobsters. The $15 million prawn fishery is fished mainly by boats operated from outside the straits, while the lobster fishery forms the basis of a Torres Strait Islander dive fishery. Other commercial fishery resources include mackerel, pearl shell and trochus. Traditional fishing for reef fish, dugongs and green turtles provides an important food source and a way of life for Torres Strait Islanders. The Torres Strait Fishery Scientific Advisory Committee (TSFSAC) provides scientific advice to the Projected Zone Joint Authority (PZJA) through the Torres Strait Fisheries Management Committee (TSFMC).

The TSFSAC is responsible for a large research effort into Torres Strait fisheries resources. These include biological research into lobsters (CSIRO), prawns (QDPI) effects of fishing (CSIRO), seagrass (CSIRO), dugongs (JCUNQ) and monitoring of traditional fishing (CSIRO). The National Residue Survey (NRS) is also investigating heavy metal contamination of prawn stocks. In general, these projects tend to be strategic research aimed at the longer term sustainable development of the fisheries resources of the Torres Straits. For example, seagrasses which provide the essential food and shelter to a large number of important resources such as prawns, turtles and dugongs have been mapped and their changes over time are being monitored. Surveys on lobster stocks and prawns have led to assessments of their current stock status. Management of prawn fisheries by such techniques as seasonal closures requires detailed knowledge of the prawn's life history and timing of migration which is being provided by scientists. Future priorities of the TSFSAC include monitoring of both commercial

and traditional fisheries, further research on lobsters, prawns, dugongs and turtles, assessment of fishery habitats and the impacts of environmental changes on the fishery resources.

Background

The Torres Strait Treaty and the Fisheries

The Torres Strait Treaty between Australia and Papua New Guinea was signed on 18 December 1978 and ratified on 15 February 1985. The Treaty establishes the jurisdictions and responsibilities of both countries in the Torres Strait border area. While the principal purpose of the Treaty is to define the limits of the two countries' maritime jurisdictions where they overlap, the fact that fisheries are the most important natural resources in the region makes the Treaty as important for fisheries management as it is for delimitation.

Establishment of the Torres Strait Protected Zone (TSPZ)

The establishment of the Torres Strait Protected Zone confers both rights and responsibilities on the two countries (Haines 1986). The principal purpose of the Protected Zone, as stated in article 10 of the Treaty, is to protect the traditional way of life and livelihood of the traditional inhabitants, including traditional fishing. As well as recognising the importance of traditional fishing, the Treaty acknowledges the contribution of valuable commercial fisheries in the Protected Zone to the Torres Strait economy.

Joint Management of Fisheries

The most important fisheries relationship that Australia has with Papua New Guinea is joint fisheries management in the Torres Strait Protected Zone. Articles 20 and 21 of the Treaty require Australia and PNG to cooperate and consult on the conservation, management and optimum utilisation of Protected Zone commercial fisheries. In other words, the objective is to achieve an agreed level of sustainability in those fisheries.

Article 22 of the Treaty provides for Australia and PNG to manage particular fisheries jointly if either country considers this necessary or desirable. Under the provisions of this article, the two countries have entered into joint management arrangements for the tropical rock lobster, prawn, Spanish mackerel, dugong, turtle and pearl shell fisheries in the Protected Zone, and a defined "outside but near area" surrounding the Protected Zone that is considered to be the actual extent of each fishery. In addition, the Commonwealth and Queensland Governments have entered into a formal legal arrangement whereby the above fisheries, traditional fishing and the barramundi fishery around Australian islands near the PNG coast, are managed under Commonwealth law. This is done under the auspices of the Protected Zone

Joint Authority (PZJA), whose members are the Queensland and Commonwealth Ministers for Primary Industries. The remaining fisheries, (e.g. trochus, reef fish, beche-de-mer), in the Protected Zone are managed by Queensland.

Sharing Commercial Catches

With the benefit of joint ownership of the Protected Zone fisheries comes the responsibility of sharing the catch on an equitable basis. The Treaty stipulates that this should be done by apportioning a Total Allowable Catch (TAC) according to geographic criteria, to be determined at the beginning of each fishing season. However, although we have almost ten years of catch monitoring data and extensive biological research information, it is still difficult to provide accurate yield assessments on which to base the TAC. This is partly due to the large natural fluctuation in stock numbers which are difficult to predict. Sharing of catches in the jointly managed fisheries, therefore, is based on input, (i.e. boat numbers, rather than output or quota). This is described in detail in the paper by Elmer (this volume).

The Role of the Torres Strait Fisheries Scientific Advisory Committee (TSFSAC)

The Torres Strait Fisheries Scientific Advisory Committee was established as a subsidiary body to the Protected Zone Joint Authority and the Torres Strait Fisheries Management Committee. Its broad objectives are to identify and investigate key biological parameters of fish and fish stocks, and provide advice on which to base rational and effective fisheries management programs. The consultative structure (Figure 1) reflects the aim of the PZJA to involve the Islanders and industry in establishing the most appropriate management and research priorities and strategic directions. Formal lines of communication and a schedule of regular meetings exist between the respective bodies. Informal communication links are equally well-developed and information flow is encouraged.

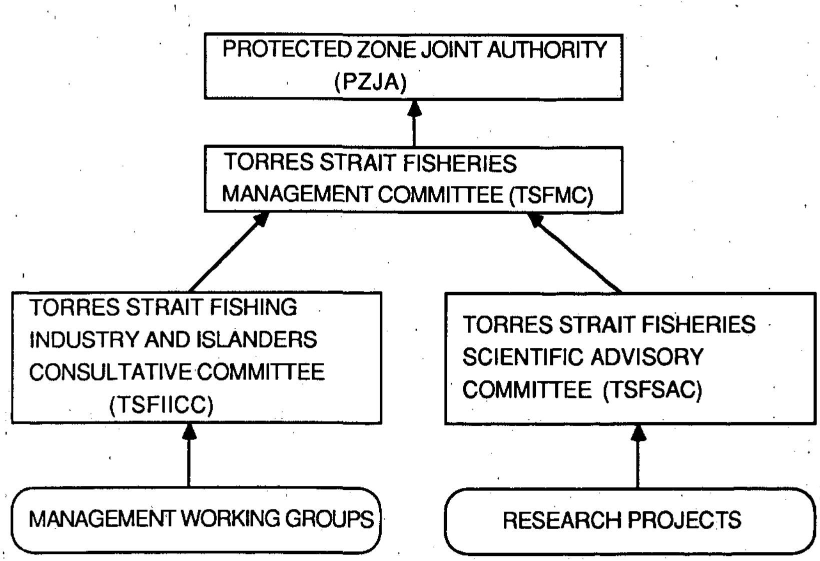


Figure 1. Consultative structure of the Protected Zone Joint Authority

The terms of reference under which the Torres Strait Fisheries Scientific Advisory Committee operates are as follows:

- Coordinate research into Torres Strait Protected Zone fisheries;
- Provide the Torres Strait Fisheries Management Committee and PZJA with scientific advice from research programs for the management, conservation and development of the commercial fisheries and the management and conservation of traditional fishing in the TSPZ;
- Provide analyses of fisheries data and data collection systems and refine procedures for monitoring the resources and evaluating the effectiveness of management action.

The consultative process referred to above provides several fora for communication between managers, scientists, Islanders, fishermen and other interested people. It is therefore important that Islanders and industry take the opportunity to make their views known when the chance arises so that resources can be directed in the most appropriate and cost-effective manner.

Coordination of the Fisheries Research Program

The Commonwealth and Queensland governments have provided an average of 0.8 million dollars per year for fisheries research and monitoring in Torres Strait since 1985. The Commonwealth component of these funds has been allocated to several organisations, mainly the CSIRO, which has undertaken work on behalf of the Department of Primary Industries and Energy. All the fisheries research programs funded under the Protected Zone Joint Authority report through TSFSAC at biannual meetings where the results, progress and direction of the research is assessed. Any changes in direction or updates to research priorities are then determined with the combined expertise of project leaders, senior scientists and managers with direct experience of the important issues facing Torres Strait fisheries. Research proposals are solicited by the TSFSAC to address priority issues, and funds are allocated on a competitive basis.

Setting Priorities

Because there will always be more scientific and management issues than there is funding to support research, it is necessary to determine realistic and achievable priorities and to develop an overall program that will provide answers to the most important questions in a reasonable time-frame and at reasonable cost. It is not practical or cost-effective to develop the complete program in advance and it is essential that the program has the flexibility to institute additional research as priorities change. The present program is based on a triennium cycle of research planning which is reliant on annual funding from the governments' budgetary processes. Fisheries research priorities in Torres Strait are largely determined on the basis of the importance of the resource to the traditional inhabitants and to the Torres Strait economy. The lobster fishery is therefore the most important fishery in terms of Islander participation and value and consequently has attracted the majority of research effort.

Research Projects

Tropical Rock Lobster

Like other palinurid lobsters, the ornate or tropical rock lobster, *Panulirus ornatus* is characterised by a long larval life, a time to maturity of several years and breeding that occurs in deeper offshore waters. The lobster is distributed throughout the Indo-west Pacific, but reaches its greatest concentrations in Torres Strait where it supports a dive fishery that yields an average of 250 tonnes per year (Figure 2) (Channells *et al.* 1987) worth around 5 million dollars to the Torres Strait economy.

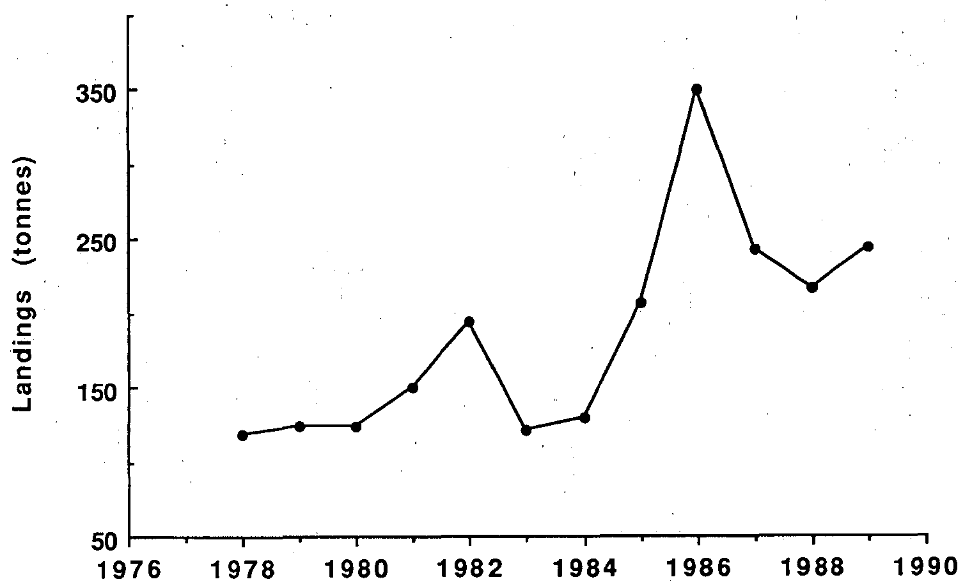


Figure 2. Tropical rock lobster catch by Australian divers 1978-1989

Tropical rock lobster research has been funded by PNG and Australia as far back as 1960, and by the Commonwealth government continuously since 1980. The first three years of the current program concentrated on documentation of the fishery, including landings, areas fished, and methods of operation. Biological studies which were initiated at the same time included an extensive tagging program to determine migration paths, reproductive biology, puerulus settlement, growth rates, food and feeding, genetic variation between geographically separated stocks and nocturnal movements. The results of these studies were used to determine whether Australia and PNG share the same stock, to institute arrangements to protect the annual breeding migration from excessive exploitation by trawling, and to set preliminary Total Allowable Catches for both the Australian and PNG fisheries.

The direction of research into the fishery for the triennium 1984-87 was determined jointly by Australia and PNG, and joint studies were initiated. Priority research concentrated on the effect of the dive fishery on reef populations, prediction of the timing and size of the annual beeding migration, the fate of lobsters that have completed the migration, exploration for additional breeding grounds and continued tagging and stock discrimination studies.

In 1988 the project underwent a review to synthesise the large amount of information collected to that date and to respond to the issues then considered by the Australian Fisheries Service and the TSFSAC to be most important for management (i.e the danger of the stock being over-exploited by divers, and the potential for the stock to sustain heavier exploitation and therefore increase income from the fishery). The major new research directions which resulted included stock assessment (a task previously considered impossible for this fishery), measurement of post larval recruitment and the possibility of predicting future catches. The results of this work are reported by Pitcher (this volume).

Prawns

The prawn fishery in Torres Strait is the most valuable Torres Strait fishery in monetary terms. It yielded an average catch over the past five years of over 1000 tonnes per year (Figure 3), worth around $15 million at first sale.

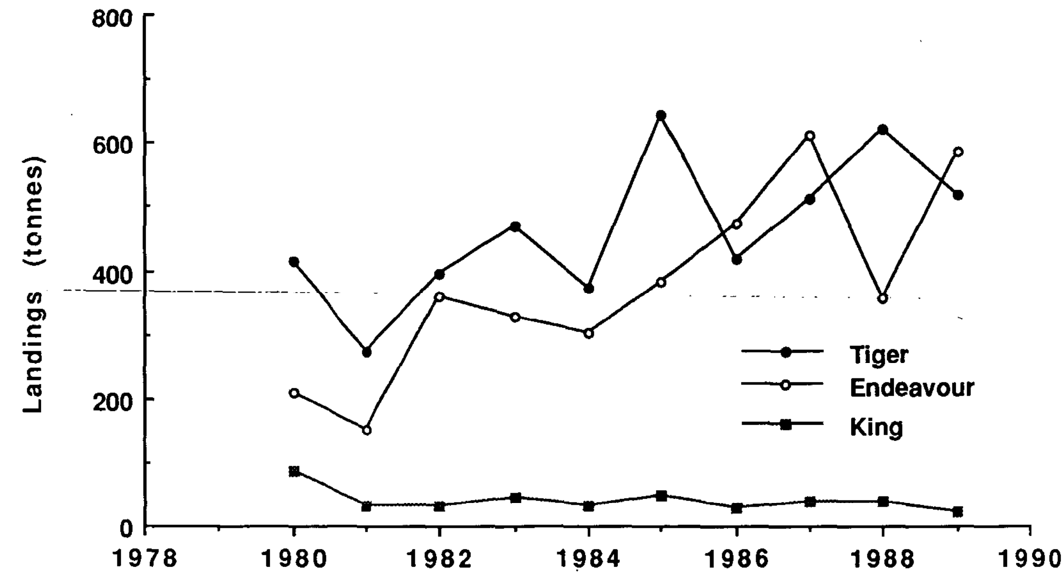


Figure 3. Torres Strait prawn catches 1980-1989

In July 1985, a Queensland government-funded research project was initiated to determine the recruitment patterns, movement and distribution of the tiger and endeavour prawns which make up the Torres Strait prawn fishery (Watson and Mellors 1990). Provision of information on prawn growth and movement was the primary objective of the study, so that the effectiveness of spatial and seasonal closures, that in some cases had been in place for several years, could be assessed. To date, this work has formed the basis for fine-tuning the management measures to achieve the Treaty's fishery management aim of optimal utilisation of the stock, and also to provide advice for catch-sharing of stocks between Australia and PNG.

The study has looked at the most important aspects of the prawns' life history as they relate to the commercial fishery, including distribution and abundance of juveniles in seagrass beds, pathways of recruitment and migration to and from the fishing grounds, spawning periodicity and fishery catch and effort data. Detailed reports of these studies can be found in Mellors (1990).

The Effects of Prawn Trawling on Fish Abundance

This project was initiated in response to Islanders' concerns that commercial prawn trawling was depleting catches of fish species that are important to the island communities' traditional and artisanal fisheries. In addition, the pearling industry complained that trawlers were doing physical damage to pearl shell habitat.

The aim of the Effects of Trawling project was to determine whether prawn trawling has a significant effect on the fish populations of Torres Strait, particularly those which are used for food by the Islanders. The impact of trawling on turtles and selected invertebrate populations was also studied.

The results of this project demonstrated that prawn trawling has affected the fish and benthic communities on the trawl grounds in Torres Strait, but that there are limited direct impacts on Islander fisheries (Poiner and Harris 1989). Prawn trawling has also altered the species composition of the fish communities on the trawl grounds: the density of bottom fishes is significantly reduced and the density of small predatory and midwater species is significantly increased. Most of the the fish caught by prawn trawlers on the trawl grounds are small non-commercial species, but there are some, though relatively small, catches of commercially important reef fishes such as sweetlips and snappers in prawn trawls. The trawl catch of turtles and commercial mackerel species is relatively insignificant.

Traditional Fishing

A study of traditional fishing was conducted by CSIRO between 1983 and 1987. Its objectives included documenting the the use of fish and fisheries products by traditional inhabitants and identifying existing and potential problems. The project also included a study of the impact of commercial fishing on traditional fishing. Competition among traditional fishermen from different areas in Torres Strait and other socio-economic and biological problems facing traditional fishermen were also examined. In summary, the study showed that Torres Strait Islanders are among the highest seafood consumers in the world, in terms of percentage consumption of seafood in their diet (Johannes and MacFarlane, in press). It also confirmed that the Torres Strait area is an area of exceptionally high seafood productivity. From the islands where statistics were collected, green turtles were the the most important seafood. The study showed that there is a need to improve catch information if future management is to be able to take the protection of traditionally important seafood species into account. The current Australian Fisheries Service data collection program based in Thursday Island is now addressing this need.

Dugong

Torres Strait supports one of the world's largest populations of dugong, a species of sirenian or sea-cow that is classified as vulnerable to extinction.

In November 1987 and again in March of 1988 aerial surveys of dugong were carried out by Dr Helene Marsh and a team of observers from James Cook University of North Queensland. The regional densities of dugongs in the Torres Strait region and adjacent waters of the Great Barrier Reef Marine Park were estimated by sampling 7.4 per cent of the total survey area of 30,533 km^2. A resultant minimum population of around 12500 dugongs was estimated for Torres Strait (see Marsh & Saalfeld, this volume).

The survey and the resulting population estimate highlight the need for reliable dugong catch information. The biological sustainability of the annual Torres Strait dugong harvest depends on whether a population of the present size can support the number of animals harvested, and that number is not known, though various estimates exist. A catch monitoring system for dugong is currently being established by the Australian Fisheries Service in Thursday Island.

Seagrass

The seagrass resources of Torres Strait are very important in the life histories of prawns, dugongs and green turtles. Tiger and endeavour prawns rely on seagrass communities for their nursery grounds, dugongs feed exclusively on seagrass, and green turtles depend on seagrass for a substantial part of their diet (Poiner, Walker and Coles, 1989).

A CSIRO study between 1985 and 1990 has provided information on the distribution, quality and quantity of seagrasses in Torres Strait. The study showed that Torres Strait supports a large number of species and a diversity of seagrass communities. Seasonal and interannual variability in these communities, which has important implications for the species which depend on seagrasses, was the main focus of the study.

Within the Protected Zone over 3500 km^2 of seagrass-supporting habitat associated with 295kilometres of coastline or reef have been identified, mapped and sampled (Poiner 1989).

Data Collection Systems

In 1987 a study was undertaken to ascertain the level and content of catch and effort data required to fulfill the needs of research and management and to determine the most appropriate and effective ways of collecting the data.

Fisheries data collection in Torres Strait is complicated by the variety and movement of fishing operations, the diverse cultural background of Torres Strait fishermen and changing fishing technology.

The study drew extensive input from researchers, managers and fishers, and led to the design and development of logbooks for the collection of catch and effort statistics in the tropical rock lobster, mackerel and pearl fisheries. The logbook system that was developed over many years and has been used for data collection in the Northern prawn fishery was implemented in the Torres Strait prawn fishery. Data collected in the various logbooks are available to scientists and managers through the Australian Fishing Zone Information System (AFZIS), but the information's confidentiality is protected so that individual operations cannot be monitored.

Future Research

The conduct of future fisheries research relies on the Commonwealth and Queensland's continued commitment to funding. However, assuming that funding is maintained at present levels, the Torres Strait Fisheries Scientific Advisory Committee has identified the following priority areas for research effort over the next three years:

- continued monitoring of catch and effort in commercial fisheries;
- stock assessment, yield and recruitment studies of tropical rock lobster;
- prawn stock and recruitment studies;
- development of environmental and critical habitat monitoring strategies;
- development of reliable traditional fisheries monitoring strategies that can be carried out at the community level;
- a repeat dugong population survey in 1992/93;
- continued participation in broad environmental issues in Torres Strait, in particular the Baseline Study, oceanographical work and the development of strategies to combat oil spills.

References

Channells, P.W., Phillips, B.F. and Bell, R.S. (1987), *The Rock lobster Fisheries for the Ornate Rock Lobster in Torres Strait and on the NE Coast of Queensland, Australia,* (Fisheries Paper 87/8), Australian Fisheries Service, Canberra.

Haines A.K. (1986), 'Background to management', In AK Haines, GC Williams, and D Coates (eds), *Torres Strait Fisheries Seminar, Port Moresby,* AGPS, Canberra.

Johannes, R.E. and MacFarlane W.J. (in press), *Traditional Fishing in the Torres Strait Islands,* CSIRO Division of Fisheries, Hobart.

Mellors, J.E. (ed) (1990), *Torres Strait Prawn Project: a review of research 1986-88,* Queensland Department of Primary Industries, Brisbane, (Information Series QI90018).

Poiner, I.R. and Harris A.N.M. (1989), 'Effects of Trawling', In *Torres Strait Protected Zone Annual Report 1989,* AGPS , Canberra, 12.

Poiner I.R. (1989), 'Change in Seagrass Communities', In *Torres Strait Protected Zone Annual Report 1989,* AGPS , Canberra, 13.

Poiner I.R., Walker, D.I. and Coles, R.G. (1989), 'Regional studies - seagrasses of tropical Australia', In AWD Larkum, AJ McComb and SA Shepherd), *Biology of Seagrasses,* Elsevier, Amsterdam, 279-303.

Watson, R.A. and Mellors J.E. (1990), 'General Introduction', In JE Mellors (ed), *Torres Strait Prawn Project: a review of research 1986-88,* Queensland Department of Primary Industries, Brisbane, 3-9, (Information Series QI90018).

The Artisanal Sea Turtle Fishery in Daru, Papua New Guinea

Donna Kwan, Zoology Department
James Cook University of North Queensland

Abstract

Marine turtles are traditionally hunted by coastal and island people in Papua New Guinea for subsistence and cultural purposes. Today, artisanal fisheries for marine turtles operate at Daru (the provincial capital of the Western Province) and Port Moresby (the national capital) where they are an important source of income for many of the local people.

This paper describes the turtle fishery in Daru during 1984-1987 and discusses these findings in terms of management implications.

The fishery is largely operated by the Kiwais, the traditional turtle hunters and inhabitants of the coastal area around Daru. More than 500 fishermen were estimated to be involved in turtle hunting annually in 1985-1987. During this period, there has been an increase in the number of turtle fishermen, with an increasing proportion from areas which have no history of turtle hunting.

Turtle hunting is usually seasonal, with generally more than 60% of the annual catch taken during September to December, the period corresponding to the summer breeding season in eastern Australia. However, this varied according to the local abundance of turtles and/or lobsters. The motorised canoe and harpoon are the most popular method used in turtle hunting.

Turtles harvested in the Daru area are believed to be taken from at least three groups: one which is resident in Torres Strait, another which migrates to the area to breed and a third which migrates through the area to various rookeries on the Great Barrier Reef.

During 1984-1987, fishermen from Daru caught turtles at four major reefs: Podomaza, Bobo, Auomaza and Wapa. Podomaza and Bobo are fringing reefs around the islands of Parama and Bobo respectively, and are traditional fishing grounds for Parama, Kadawa and Katatai villages. Although Parama villagers accounted for up to 100% of the catch from Podomaza, an increasing proportion of the catch from Bobo was taken by the non-traditional turtle fishermen. Similarly, although, Auomaza and Wapa are traditional common fishing grounds of the coastal Kiwais, there was also increasing non-traditional usage at these reefs.

Most of the turtle catch in Daru is butchered and sold as "strings" which are approximately 2kg of meat, fat and offal tied together. Strings are sold for A$2.30-2.70 each. Some turtles not butchered were sold whole for A$56.00-71.00 each. In economic terms, the turtle fishery which grossed between A$32,729 - 55,379 in 1985-1987, is only minor compared to the lucrative lobster fishery which grossed A$672,750 - 866,250 annually during the same period. The gross earnings from turtle sales by village group shows that although the traditional villagers were generally receiving the greater proportion, the proportion of the earnings by the non-traditional villagers increased from 1985-1987.

Although four species of marine turtles were caught by Daru fishermen: the flatback, loggerhead, hawksbill and green turtle, green turtles were most dominant in the catch. This probably reflects both the high local abundance of this species (which was increased considerably during the breeding season, when a large seasonal migration of turtles transit through the area to Great Barrier Reef rookeries) and the local preference for the meat and fat of green turtles, especially females in breeding condition. The annual catch in Daru was estimated to be 953 in 1985, 1323 in 1986 and 1363 in 1987. Based on estimates of a total annual subsistence harvest in Torres Strait (4000) and the mean turtle consumption rate of residents in the Daru region, the total annual harvest of the Torres Strait region was estimated to be between 5100-6700.

Examinations of gonadal specimens from turtles butchered in Daru indicated that over 60% of the females examined were preparing for breeding. Tag returns and the reproductive status of turtles at the time of capture indicated that most of the Daru catch is being taken from the eastern Australia breeding assemblage, in particular the Raine Island breeding unit. These results suggest that a significant proportion of the eastern Australian breeding assemblage is being removed each year by the Daru turtle fishery. There are also some indications that some components of breeding assemblages in the Gulf of Carpentaria and Indonesia are also being harvested by Daru fishermen. Unfortunately, the impact of this harvest rate on the breeding stock from which it was taken cannot be answered without much more research.

Some changes detected in the fishery between 1984-1987 may have potential management implications. These included an increasing number of fishermen who catch turtles; with an increasing proportion from areas with no traditional history of turtle hunting. The catch composition is dominated by large females. Gonadal examinations indicated that over 60% of the females were preparing to breed. Tag returns and the reproductive status of turtles at the time of capture indicated that most of the catch is being taken from the eastern Australian breeding assemblage, in particular the Raine Island breeding unit, whose international significance requires special attention. The turtle stock harvested in Daru is also being extensively harvested in its foraging areas in Indonesia where the annual harvest is in the tens of thousands.

Unfortunately, it was not possible to determine the impact of the Daru turtle harvest on the turtle resources of Torres Strait. Consequently restrictive measures were considered unjustified. However, continued monitoring of the turtle fishery is strongly recommended.

Benthic and Pelagic Processes in the Fly River Delta and the Nearshore Gulf of Papua

Alistar I. Robertson and Daniel M. Alongi
Australian Institute of Marine Science

Introduction

Rivers in the tropics and subtropics contribute ~70% of the freshwater runoff and ~74% of the sediment discharge to the worlds oceans (Milliman, 1981; Meade, 1981). Little is known about how these high discharge rates and amounts of exported material influence ecological processes in adjacent nearshore habitats.

The Fly River, which lies at the northern boundary of the Torres Straits, has the potential to have a major influence on pelagic and benthic processes of the region. The Fly is approximately the tenth largest tropical river in the world, releasing ~238 km^3 of freshwater and 74 x 10^6 tonnes of suspended material annually into the Gulf of Papua (Alongi, 1990a).

Since 1984, a large gold and copper mine has been operating on the Ok Tedi, an upper tributary of the Fly, and has been depositing increasing amounts of suspended mining effluents into the Fly catchment area. Predictions for 1992 are for a 55% increase in mine-derived suspended load (see Eagle, this volume). This enormous tailings burden, plus the effluents being produced by the Porgera Joint Venture gold mine on the Strickland River, which enters the Fly approximately half way along its length, when coupled with the very high annual precipitation (up to 13 $m.y^{-1}$) in the headwaters of the catchment, suggest the potential for metal pollution and changes to the sedimentary regime of the Fly delta and the nearshore Gulf of Papua. Understandably, considerable attention has been focused on the potential impact of these mining activities on the environment, fisheries and health of the people inhabiting the Fly River and Torres Strait region (Dent, 1986; Pernetta, 1988; Georg, 1989).

During the last decade the Coastal Processes and Resources Program at the Australian Institute of Marine Science has concentrated on measuring the extent and influence of exported material from coastal habitats, mainly mangrove forests, in tropical Australia (eg. Wolanski *et al.*, 1980; Boto and Bunt, 1981; Robertson, 1986; Robertson *et al.*, 1988; Alongi, 1990 b, c; Alongi *et al.*, 1989). Recently, in order to study the influence of a major tropical river on adjacent shelf ecosystems, we mounted two, month-long expeditions to the Fly River estuary and nearshore regions (< 60 m depth) of the Gulf of Papua (July-August, 1989 and February, 1990). Sampling was performed at a number of sites in the river and the Gulf, and there were extensive examinations of mangroves on all islands within the delta (Figure 1).

The aims of these expeditions were to, (1) make first-order estimates of the net flux of carbon, nitrogen and phosphorous from the Fly River, (2) to study the influence that exported materials have on biological processes in the water column and the sediments of the Gulf of Papua and (3) to examine the vertical profiles of dissolved and particulate copper concentrations in the sediments of the region. Detailed results of this work are available in Robertson *et al.* (1990), Alongi (in press), Alongi *et al.* (in press a, b) and Robertson *et al.* (in press). Here we present a brief summary of some of the major findings of the work and suggest priority areas of future research.

Mangrove Forests: Extent and Productivity

There are 87,400 ha of mangrove forest in the Fly delta. These forests occur mainly on the delta islands (except Kiwai, which has few mangroves). Although there are at least twenty-nine mangrove plant species in the delta there are only three dominant forest types (Robertson *et al.*, in press). Forests of *Rhizophora apiculata, Bruguiera parviflora* and *B. gymnorhiza* predominate in regions where river salinity was >10 o/oo. These forests cover ~31,500 ha. Forests dominated by the mangrove palm, *Nypa fruticans*, cover 38,400 ha mainly in regions of the delta where salinity ranges from ~1 to <10 o/oo. On accreting banks of sediment throughout the delta there are extensive stands of *Avicennia marina* and/or *Sonnaratia species*. *Sonneratia lanceolata* forms large monospecific stands in regions of the delta with salinity <1 o/oo, and can be found as isolated trees up to 300 kilometres from the river mouth.

Potential net primary production (cf. Bunt *et al.*, 1979) is estimated to be 26.7, 27.1 and 19.0 for *Rhizophora-Bruguiera, Nypa* and *Avicennia-Sonneratia* forests, respectively. Total daily production by all mangroves is ~2,214 tonnes C. Using assumption about litter processing and export derived from work in tropical Australia (see Robertson *et al.*, 1990) we estimate that ~678 tonnes C. (or 31% of primary production) is exported daily from the mangrove forests to the waters of the delta.

Water Column Processes

In the delta, suspended sediment concentrations varied over an order of magnitude, depending on river flow conditions. Mean concentrations over all sites, depths and times of tide in the delta were 451 $mg.l^{-1}$ and 100 $mg.l^{-1}$ in July/August and February, respectively. Suspended loads at nearshore Gulf of Papua stations in February (a period of record low river flow) were similar to those in the delta. The suspended

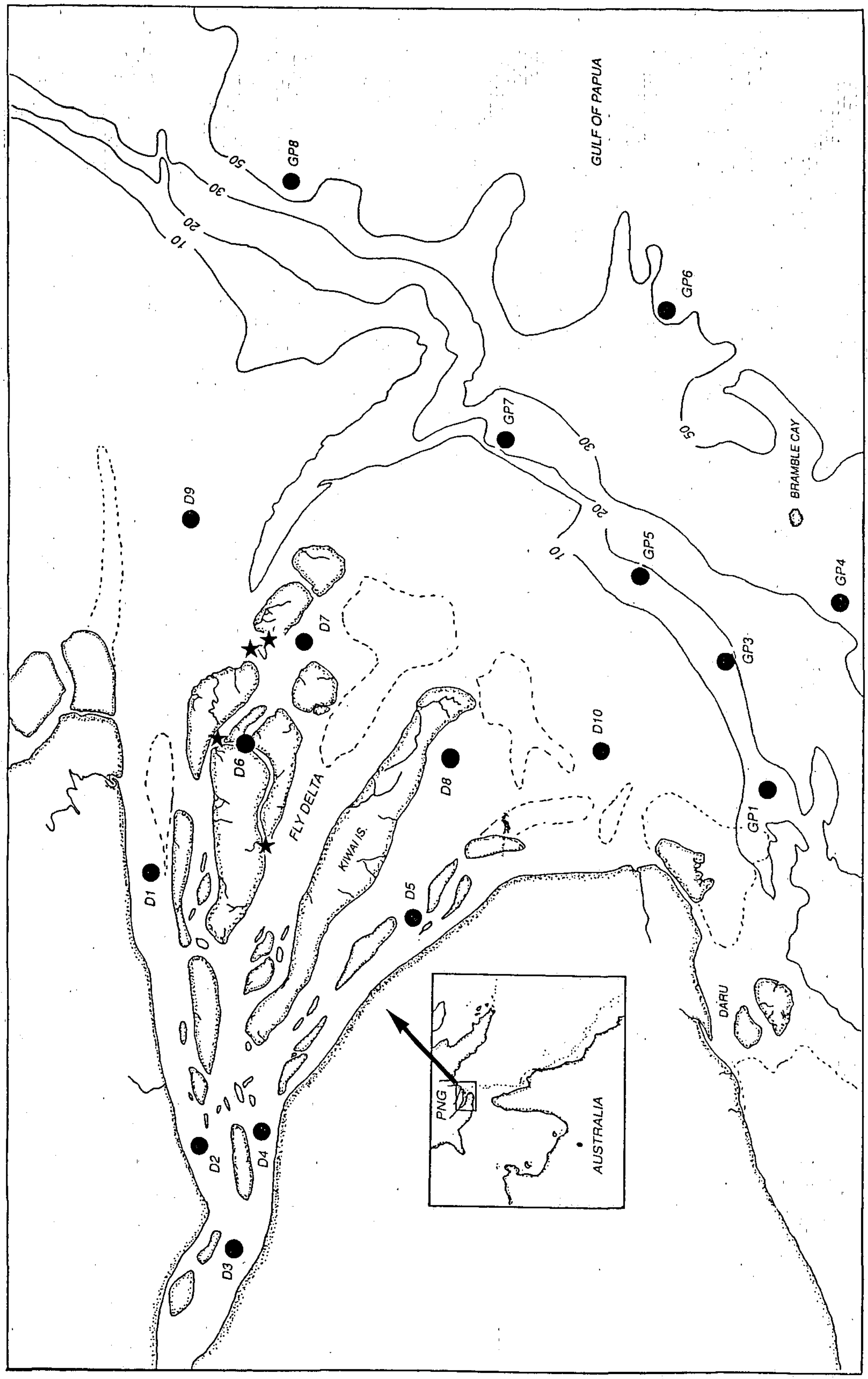


Figure 1. Location of sampling stations in the Fly Delta (D) and Gulf of Papua (GP) where water-column and subtidal sediment processes were measured. Stars mark the sites where intertidal sediment processes were measured. Contours are water depths in meters.

loads measured in the delta in the July/August period are similar to those in other large tropical rivers such as the Amazon, Niger and Mekong (Milliman, 1981; Meade, 1981).

The carbon to nitrogen ratios of suspended material showed a wide range of values (1-80), but mean values were low. In July/August 1989 mean C:N ratios in the delta were all <7, while in February, most delta station averaged $\leq$8. The worldwide C:N ratio for riverborne particulates is 8.8 (Maybeck, 1982).

As in all large rivers, there is a large quantity of floating plant tissue in and near the Fly. Except for the more freshwater stations we sampled, most of this material in the delta and coastal regions is of mangrove origin. The overall mean mass of macro-particulate detritus in the surface waters of the delta was ~200 $mg.m^{-3}$ (or ~80 mg C and 2.2 mg N per m^3).

Zooplankton species richness (total number of taxa at each station) ranged from 11 in the freshwater regions of the delta to 57 at 50 metres depth in the Gulf of Papua. Lowest densities (range 153-4155 $individ.m^{-3}$) and biomasses (<1-14 $mg.m^{-3}$) of zooplankton were recorded in the freshwater regions of the delta, but there was no clear relationship between salinity and densities or biomasses. Grand mean densities and biomasses of zooplankton in the delta and Gulf of Papua were 4798 $individ.m^{-2}$ and 157 $mg.m^{-3}$ and 8892 $individ.m^{-2}$ and 54 $mg.m^{-3}$, respectively.

Water column primary productivities from 0.4-28.0 $mgC.m^{-3}.h^{-1}$ were recorded in the delta and nearshore Gulf of Papua in February 1990. Daily production (integrated over depth) was lowest at the low salinity delta stations (22.1-94.5 $mgC.m^{-2}.d^{-1}$) and highest at stations at or beyond the highly stratified salinity zone near the river mouth (134.0-693.2 $mgC.m^{-2}.d^{-1}$). Production rates at most Gulf of Papua stations were similar to those from inshore samples near other large river plumes (see also Furnas, this volume).

The Fly delta and inshore Gulf of Papua waters are highly heterotrophic as evidenced by the very high community metabolism rates (0.8-36.0 $gC.m^{-2}.d^{-1}$), which are 1-2 orders of magnitude higher than *in situ* production (see above). Oxygen consumption rates in the study area (0.6-3.2 $g0_2.m^{-3}.d^{-1}$) are amongst the highest recorded for estuarine and coastal systems (Hopkinson, 1985).

Water column bacterial production ranged from 20-43 $mgC.m^{-2}.d^{-1}$ in the low salinity regions of the delta and from 143-2089 $mgC.,^{-2}.d^{-1}$ at the front of the delta and in the Gulf of Papua. We estimate that bacterial respiration accounts for ~9-49% of total community metabolism, implying the presence of a very active protozoan community in the water column.

Benthic Processes

Intertidal Mudbanks

Intertidal mudbanks are a prominent feature of the Fly delta region and appear to be a major site for the deposition of sediment and associated organic matter. A summary of data for intertidal mudbanks is given in Table 1.

Table 1. Summary of sedimentary, inorganic nutrient and biological characteristics for intertidal mudbanks in the Fly Delta. Source Alongi (in press).

A. Sedimentary characteristics

Vary from sites with rapid sediment deposition and erosion to more biologically controlled sites.

B. Particulate nutrients (C, N, P)

1. Range of values; carbon 0.7-1.9% DW, nitrogen 0.11-0.26% DW, phosphorous 5.8-7.3% DW.
2. C:N ratios, 3.9-8.5.
3. No depth profiles.

C. Dissolved nutrients (porewaters).

1. Range of values; DOC 2.9-29.5 $mgC.l^{-1}$, DON 7.9-79 μM, DOP 0.01-8.0 μM, NH_4 3-461 μM, NO_2 + NO3 0.8-3.8 μM, PO_4^{3-} 0.3-6 μM, $Si(OH)_4$ 41-99 μM.
2. Nutrient flux rates mostly undetectable.

D. Infauna

1. Meiofauna density 29-340 individ.10 cm^{-2} (other tropical sites, range 3-5380, mode ~800).
2. Macrofauna
   (a) density 174-6185 $individ.m^{-2}$
   (b) biomass 0.17-1.38 $gDW.m^{-2}$
   (other tropical sites; density 200-6000 $individ.m^{-2}$, biomass 1-40 $gDW.m^{-2}$).

E. Biological Processes

1. Bacterial production 187-413 $mgC.m^{-2}.d^{-1}$ (other tropical sites, 100-651 $mgC.m^{-2}.d^{-1}$).
2. Community respiration 145-206 $mgC.m^{-2}.d^{-1}$ (other tropical sites, 47-1200 $mgC.m^{-2}.d^{-1}$).

Our studies reveal that the intertidal mudbanks in the Fly delta possess a combination of characteristics rarely, if ever, observed in temperate intertidal muds, including; (1) a general lack of vertical profile in dissolved and particulate nutrients and in bacterial numbers and activity; (2) high bacterial growth rates; (3) lack of detectable nutrient fluxes; (4) low faunal biomasses; and (5) low net primary production.

The lack of solid-phase and porewater nutrient profiles in sediments are usually attributed to low sediment accumulation rates or to low reactivity of deposited organic matter. In most temperate muds, recycling of labile organic matter attenuates rapidly with sediment depth, leaving only the refractory matter to be deposited, and observed as an increase in organic content with depth. In the Fly mudbanks, it appears that the high rates of bacterial productivity throughout the sediment led to the observed pattern of vertical distribution and exchange of particulate and dissolved nutrients. It is likely that organic detritus is rapidly deposited onto the mudbanks and is very rapidly remineralised by bacteria. Rapid rates of decomposition over the depth profile may be maintained by remixing due to physical processes and/or bioturbation. Both high temperatures and low grazer (meiofauna) populations lead to high bacterial production rates.

It thus appears that the highly active bacterial communities in intertidal mudbanks sequester, mineralise and recycle most of the labile organic detritus. These mudbanks therefore function as net sinks for organic matter, rather than as net exporters of nutrients to the pelagic portion of the system.

Subtidal Sediments

In the delta there are two main types of subtidal sediment (Table 2). In exposed regions, there are compacted, very fine sands with high iron (up to 9.8% DW) and low water content. On the leeward side of delta islands there are highly laminated muds and muddy sands without any biogenic structures. There are three major categories of sediments in the nearshore Gulf of Papua. Close to the delta there are muds and muddy sands with high sedimentation rates, obvious layering and some biogenic structures. Towards Bramble Cay there are mixed terriginous-carbonate sediments with lower sedimentation rates and some biogenic structures. In deeper waters to the north-east of the delta there are fluid muds which are well bioturbated.

There are noticeable differences in the stocks of fauna and the rates of biological processes between subtidal sediments in the delta and the nearshore Gulf of Papua. For instance, meiofaunal and macrofaunal densities are generally greater in the Gulf than the delta, as is bacterial production and community respiration (Table 2). In addition, there is little or no net flux of nutrients between the sediment and water in the delta, but significant fluxes in the Gulf of Papua. It appears that most organic material is remineralised at sites with the muddiest sediments in the delta and at the deeper (>50 m) sites in the Gulf, where lower water motion and lower sedimentation rates have allowed a stable seabed and benthic community to develop.

Faunal densities in the Gulf are low compared to most other shelf regions, but equivalent to faunal abundances near the Amazon (Alongi, 1990a). Low densities in the delta are probably due to the compacted, eroded nature of the main channels and low organic resources.

There are no clear increases or decreases in the concentrations of particulate carbon, nitrogen or phosphorous with depth in subtidal sediments. This is identical to the situation for sediments in the central Great Barrier Reef region, but in contrast to the benthic chemistry off the Amazon and Changjang Rivers, where sharp vertical profiles have been measured for most elements. X-radiographs indicate that the lack of profiles in the Fly is due to vertical mixing either from physical disturbance, bioturbation or both.

Table 2. Summary of sedimentary inorganic nutrient and biological characteristics for subtidal sediments in the Fly delta and nearshore Gulf of Papua. Source Robertson *et al.*, (1990).

A. Sedimentary characteristics

1. Exposed regions of the delta – compacted, very fine sands with high iron and low water content.
2. Leeward side of delta islands – highly laminated muds and muddy sand with no biogenic structures.
3. Nearshore Gulf of Papua – (a) mud-muddy sands, with high sedimentation rates, layering and biogenic structures; (b) mixed terriginous – carbonate sediments with low sedimentation rates and some biogenic structure; (c) fluid muds, well bioturbated and low sedimentation rates.

B. Particulate nutrients (C, N, P)

1. Range of values; carbon 0.14-1.39% DW, nitrogen 0.05-0.24% DW, phosphorous 0.062-0.113% DW.
2. Nutrient concentrations greater in muds than sands.
3. No clear vertical profiles in C, N or P, indicating strong vertical mixing from physical disturbance, bioturbation or both.

C. Dissolved nutrients (porewaters)

1. Range of values; NH_4 <1->500 µM – increasing with depth; NO_2 +NO_3 <1-44 µM – no depth profile, PO_4 <1-6.9 µM – no depth profile, $Si(OH)_4$ 22.5-180 µM - no depth profile.
2. Fluxes; (a) delta – with the exception of silicate, no flux or net uptake by sediments, (b) Gulf of Papua – net flux to water for all nutrients, (c) dissolved organic carbon – net uptake by sediments, particularly in the delta.

D. Infauna

1. Meiofauna; (a) delta 5-107 individ.$10cm^2$, (b) Gulf of Papua 81-750 individ.$10cm^2$.
2. Macrofauna; (a) delta 86-811 individ.m^{-2}, (b) Gulf of Papua 726-5555 individ.m^{-2}.

E. Biological Processes

1. Bacterial production 325-2108 $mgC.m^{-2}.d^{-1}$.
2. Community respiration; (a) delta mean 102 $mgC.m^{-2}.d^{-1}$, (b) Gulf of Papua mean 406 $mgC.m^{-2}.d^{-1}$.

Copper Concentrations

Particulate copper concentrations and dissolved copper in porewaters were measured at 2 cm intervals in 20 cm sediment cores at all subtidal stations (Figure 1). Trends in particulate copper levels with sediment depth were not consistent among stations. For most stations there was no change with depth. Two stations in the southern channel of the delta had the highest mean concentrations of copper (means of top 2 cm, 71 and 48 $mg.g^{-1}$ DW), but other delta stations did not contain significantly higher levels of copper than stations in the Gulf of Papua (Table 3).

Table 3. Concentrations of copper in the surface (2 cm) sediment of the Fly delta and nearshore Gulf of Papua in July/August 1989 and February 1990. Also shown are ranges of values for other tropical coastal areas.

Site		Particulate copper ranges (ppm)
Fly River region	(a) delta	8-71 (mean 30)
	(b) nearshore Gulf	7-24 (mean 17)
Upper Gulf of Thailand*		0.5-20
Malay Peninsular coast*		10-38
Coastal Java Sea*		9-58

* Source Everaats (1989)

Dissolved copper concentrations in the porewaters and in the bottom waters near sediments were consistently less than or at the detection limits for our techniques (0.01 $mg.ml^{-1}$; Alongi *et al.*, in press a). Fluxes of dissolved copper across the sediment-water interface were detected only at two of the stations in the delta and were low and in different directions (uptake and efflux of 6 $mg.m^{-2}.d^{-1}$), indicating that diagnesis of deposited copper was minor.

Average total copper concentrations cited as baseline levels for coastal habitats are often not necessarily comparable, as these levels are based on samples taken mainly from temperate areas. Comparisons with copper levels in other tropical sediments is more appropriate (Table 3) and indicate that particulate copper levels in the region of the Fly delta for July/August 1989 and February 1990 were not abnormally high.

Copper concentrations need to be determined from sediments of other Papuan rivers, where no mining exists, in order to develop appropriate baseline levels. It is likely that metal concentrations will eventually increase in the Fly River region as mining operations are expected to reach peak production by the mid-1990s. The slightly greater concentrations of particulate copper in actively accreting sediments of the southern channel in the Fly delta (see Wolanski, this volume) may represent the first evidence of tailings input from the mine.

Conclusions

Given the increase in the activities of mining and petroleum industries in the Gulf of Papua region during the last 2-3 years there has arisen a legitimate concern for the environment of the Gulf of Papua and the Torres Strait region, including the northern parts of the Great Barrier Reef.

From a biologist's point of view, a key problem in trying to assess the possible impacts of developments in the region is the lack of any background information on biological processes within the water column and benthos of most of the Gulf of Papua. Of particular concern is our ignorance of the way in which materials exported from rivers in the Gulf are processed through food chains supporting the important demersal fisheries in the northern Torres Strait and the northern Gulf of Papua. We suggest that in addition to the proposed baseline study of heavy metal concentrations in the Torres Strait, support be given for more process-oriented research in the region.

Acknowledgements

All results reported here would not have been collected if not for the efforts of Paul Christoffersen, Paul Daniel, Paul Dixon and Frank Tirendi and the Masters and crew of the R.V. The Harry Messel.

References

Alongi, D.M. (1990a), 'The ecology of tropical soft-bottom benthic ecosystems', *Oceanogr. Mar. Biol. Ann. Rev.* 28, 381-496.

Alongi, D.M. (1990b), 'Effects of mangrove detrital outwelling on nutrient regeneration and oxygen fluxes in coastal sediments of the central Great Barrier lagoon', *Est. Coast. Shelf Sci.* 31, 581-598.

Alongi, D.M. (1990c), 'Abundances of benthic microfauna in relation to outwelling of mangrove detritus in a tropical coastal region', *Mar. Ecol. Progr. Ser.* 63, 53-63.

Alongi, D.M. (In press), 'The role of intertidal mudbanks in the diagenesis and export of dissolved and particulate materials from the Fly Delta, Papua New Guinea', *J. Exp. Mar. Biol. Ecol.*

Alongi, D.M., Boto, K.G. and Tirendi, F. (1989), 'Effect of exported mangrove litter on bacterial productivity and dissolved organic carbon fluxes in adjacent tropical nearshore sediments', *Mar. Ecol. Prog. Ser.* 58, 133-144.

Alongi, D.M., Tirendi, F. and Robertson, A.I. (In press a), 'Vertical profiles of copper in sediments from the Fly delta and Gulf of Papua (Papua New Guinea)', *Mar. Poll. Bull.*

Alongi, D.M., Christoffersen, P., Tirendi, F. and Robertson, A.I. (In press b), 'The influence of freshwater and material export on sedimentary facies and benthic processes within the Fly delta and adjacent Gulf of Papua (Papua New Guinea)', *Cont. Shelf Res.*

Boto, K.G. and Bunt, J.S. (1981), 'Tidal export of particulate organic matter from a northern Australian mangrove system', *Est. Coast. Shelf Sci.* 13, 247-255.

Bunt, J.S., Boto, K.G. and Boto. G. (1979), 'A survey method for estimating potential levels of mangrove forest primary production', *Mar. Biol.* 52, 123-128.

Dent, J. (1986), 'Possible impact of Ok Tedi mining wastes on the waters of Torres Strait', In A.K. Haines, G.C. Williams and D. Coats (eds.), *Torres Strait Fisheries Seminar*, Australian Government Printing Service, Canberra. 293-298.

Everaats, J.M. (1989), 'Heavy metals (Cu, Za, Cd, Pb) in sediment of the Java Sea, estuarine and coastal areas of East Java and some deep-sea areas', *Neth. J. Sea. Res.* 23, 403-413.

Georg, D. (1989), 'Government accepts pollution levels from Ok Tedi', *Engineers Australia* 61(21), 28-29.

Hopkinson, C.S. Jr. (1985), 'Shallow-water benthic and pelagic metabolism: evidence of heterotrophy in the nearshore Georgia Bight', *Mar. Biol.* 87, 19-32.

Meybeck, M. (1981), 'River transport of organic carbon to the ocean', *Am. J. Sci.* 282, 401-450.

Meade, R.H. (1981), 'A cautionary note on the absence of steady state between soil erosion, sediment transport in rivers, and the delivery of river sediment to the oceans', In J.-M. Martin, J.D. Burton and D. Eisma (eds.), *River inputs to ocean systems*, UNEP/UNESCO, Rome. 309-310.

Milliman, J.D. (1981), 'Transfer of river-borne particulate material to the oceans', In J.-M. Martin, J.D. Burton and D. Eisma (eds.), River inputs to ocean systems, UNEP/ UNESCO, Rome. 5-12.

Pernetta, J.C. (ed). (1988), 'Potential impacts of mining on the Fly River', UNEP, Rome. (UNEP Regional Seas Reports and Studies, No. 99) .

Robertson, A.I. (1986), 'Leaf-burying crabs: their influence on energy flow and export from mixed mangrove forests (Rhizophora spp.) in northeastern Australia', *J. Exp. Mar. Biol. Ecol.* 102, 237-248.

Robertson, A.I., Alongi, D.M., Daniel, P.A. and Boto, K.G. (1988), 'How much mangrove detritus reaches the Great Barrier Reef lagoon?', In J.H. Choat et al., *Proceedings of the VIth International Coral Reef Conference, Vol. 2,* J, 6th Int. Coral Reef Exec. Comm., Sydney.

Robertson, A.I., Alongi, D.M., Christoffersen, P., Daniel, P., Dixon, P., Tirendi, F. (1990), *The influence of freshwater and detrital export from the Fly River system on adjacent pelagic and benthic systems.*, Australian Institute of Marine Science, Townsville. (AIMS Report No. 4).

Robertson, A.I., Daniel, P.A. and Dixon, P. (In press), 'Mangrove forest structure and productivity in the Fly River estuary, Papua New Guinea', *Mar. Biol.*

Wolanski, E., Jones, M. and Bunt, J.S. (1990), 'Hydrodynamics of a tidal creek-mangrove swamp system', *Aust. J. Mar. Freshw. Res.* 31, 431-50.

Research for Sustainable Development of the Tropical Rock Lobster Fishery in Torres Strait

Roland Pitcher
CSIRO Division of Fisheries

Introduction

The commercial fishery for the rock lobster, *Panulirus ornatus*, in Torres Strait began in the late 1960s and is now a major source of income for Torres Strait Islanders. It is a diver spear-fishery as these lobsters will not enter pots. Divers operate from 4-5 metres outboard powered dinghies, sometimes using hookah equipment but often simply free-diving with a short spear. Most divers return their catch to island based processors or semi-permanently moored mother vessels. There are, however, about a dozen smaller mobile freezer boats which each support a team of 2-6 dinghies. Since the fishery began effort has increased substantially, whether in terms of number of participants, boats, days worked per year, or hours worked per day. Current catch per hour is about one-third of historic levels, hence there is a continuing need for quality assessment and monitoring of the lobster stocks to provide advice to management.

Lobster Life History

Past research has provided basic information on the life history of the rock lobster. Larval development occurs in the open ocean and takes about six months, after that lobsters settle into small holes in the seabed in Torres Strait and grow very quickly, recruiting into the fishery about one year later at ~100 mm tail length. These juvenile lobsters are fished until they are just over 2.5 years old; at this time (August-October) most emigrate from Torres Strait and catch rates decline markedly. Tagging studies have shown that some of the emigrating lobsters moved north-east into the Gulf of

Papua (GoP), undergoing reproductive development at the same time. The emigration causes major changes in the lobster population on reefs in Torres Strait:

- nearly all the larger (> 2+ yrs) lobsters disappear, those remaining are mostly small;
- more females emigrate than males, leaving an excess of males; and
- there is a major synchronous moult before the emigration.

The tagging studies also showed that lobsters on reefs off the north-east Queensland coast do not participate in the migration across the Gulf of Papua but in general tended to move to the south-east. Nevertheless, despite the different movement patterns, the Torres Strait and Queensland coast populations are part of the same genetic stock. The migration into the Gulf of Papua used to be targetted by trawlers and catches up to ~200 t were recorded, but this activity was banned in 1984. Some of the migrating lobsters move as far as the coastal reefs of the eastern Gulf of Papua where there is a breeding ground. This breeding population forms the basis of a seasonal artisinal fishery which lasts only a few months during the summer.

This fishery existed in traditional form prior to written history but the origin of the lobsters became known only in the early 1980s. The lobsters on these Papuan coastal reefs are in very poor condition – the muscle tissue is wasted and the body tissues are mostly water. Measurements of the water content of the tissues confirm that the physiological condition of lobsters declines as the migration moves across the Gulf of Papua and through the breeding season. This lead to the hypothesis that almost all lobsters die after breeding and is why the Papuan artisinal fishery lasts only 2-4 months.

More recently, research has confirmed the catastophic mortality of the Papuan breeding population and the focus of current research is to quantify parameters such as lobster abundance, fishing and natural mortality, settlement and recruitment, and the extent of the breeding grounds. This information is essential for sustainable development of the fishery through sound stock assessment.

Mortality of Breeding Lobsters

It was important to establish the fate of the Papuan breeding population as this affects understanding of the fragility of the stock. The disappearance of the population each year could be due to very high natural mortality, or over-exploition by fishermen, or emigration off the coastal reefs into deeper water. In the summer of 1988/89, several complementary research methods were used to distinguish between these alternatives.

The catch of the artisinal fishery was monitored – it was low early in the summer, but increased abruptly following two major influxes of lobsters into the shallow fishing grounds; each pulse was followed by rapid decline.

Tangle nets were deployed off the main fishing grounds to reveal whether lobsters moved off the reef into deeper water. Lobsters were caught in the nets, but the catches occurred in two pulses around the full moons of January and February, prior to major influxes into the fishery. These lobsters were all females that had moved off the reef to hatch their eggs and tagging showed they moved back onto the reef. The tangle nets did not catch any lobsters when the fishery declined through March, and it was concluded that lobsters do not emigrate off the reefs into deeper water.

The effort in the fishery was also monitored and the declining catch per unit effort (CPUE) following the two influxes was used to estimate mortality rates. For males the total mortality rate (Z) was ~12 and for females it was almost 12. These rates are extremely high, as a Z of ~4.6 corresponds to 99% mortality in a year, and for lobsters in Torres Strait Z is estimated at only ~0.4.

Several hundred lobsters were tagged and their recapture rate was recorded; from this it was estimated that 20-30 thousand lobsters were present on the coastal reefs at the start of the season and another, independent, total mortality estimate of Z~10 was obtained. About one-third of the tags were returned, suggesting that the fishermen were responsible for about one-third of the decline; the remainder was attributed to catastrophic mortality probably due to the stress of migration and breeding.

This conclusion was supported by measurements of the water content of digestive gland tissue which confirmed that most lobsters were in very poor physiological condition. The important implication from this conclusion is that each year, settlement into the fishing grounds may depend entirely on the breeding success of the preceding years migration which should therefore be protected; there is no buffer against poor recruitment that would exist if there were several year-classes of breeding lobsters.

Source of Recruitment

It was important also to examine whether larvae hatched from coastal reefs in the eastern Gulf of Papua could be carried by the currents and later settle back into Torres Strait. Ocean current drifters were deployed in deep water off the Papuan coastal reefs, these buoys were tracked by satellite and revealed a clockwise gyre in the north-west Coral Sea that could potentially return larvae to Torres Strait. A buoy released by AIMS also showed this pattern.

Stock Abundance

In any fishery, knowledge of the abundance of the stock is very valuable, it is also the central parameter in fisheries science. In 1989, lobster abundance in Torres Strait was estimated using almost six hundred 4x500 metre transects distributed over the ~25,000 square kilometre area of the fishery. The methods involved laying a 500 metre transect line onto the seabed from a dinghy. Two divers swam down each side of the line with a two metre measuring rod counting all lobsters in the four metre wide path. The narrow path meant that the habitat could be searched intensively and in any case lobsters were generally conspicuous. Lobsters were seen virtually throughout Torres Strait (including areas that are rarely, if ever, fished), with densities varying from ~2 to > 100 per hectare. The exception was the north-central area mid-way between the Warrior and Orman Reef complexes where the silty-muddy seabed was unsuitable for lobsters. From the transect data it was estimated that there were between 11-17 million lobsters in Torres Strait, of which about 8 million were legal sized. The population was sampled as it was surveyed; thus, the relative abundance of year-classes in the survey population could be compared with the fishery catch. In 1989, divers fished about 10% of the stock, which indicated that fishing mortality (F) was about 0.1. With knowledge of the stock abundance and the average catch, and estimates of the natural mortality rate from a number of sources, it was possible to make a rough estimate of the potential long-term sustainable yield. These estimates averaged just over 600 tonnes, and contrast with the current average catch of ~250 t.

In June each year after the stock survey, monitoring of the lobster population has continued at 100 of the 600 sites used in 1989, to determine the relative abundance of all the year-classes and provide an index of stock abundance relative to 1989. This smaller survey showed that the 1990 fishable (>legal size) stock was only about half of that in 1989. It also indicated the size of the year-class about to enter the fishery (recruitment); the 1990 recruiting year- class was about the same size as the 1989 recruiting year-class suggesting that the 1991 fishable stock would be about the same as in 1990. This annual monitoring survey is an ongoing project and will also provide estimates of growth and mortality rates.

Catch Monitoring

The island-based sector of the fishery is likely to be the most susceptable to over-fishing as it lacks mobility. Consequently, the catch and effort of the Islander fishery based around Mabuiag Island is monitored annually during June and July. The CPUE of the Islanders in mid-1990 was similar to 1988, but significantly less than in 1989. This decline was expected from the results of 1989 stock survey which revealed a relatively small pre-fishery (1 +) year-class that became the fishable stock in 1990. The catch monitoring also enables comparison of the CPUE of hookah and free-divers and has shown that the catch-rate of hookah-divers is greater than free-divers. However, the disparity in catch rate of divers using the two methods has steadily reduced over the last three years; there does not appear to be any reduction in catch-rate of free divers associated with continued use of hookah.

Breeding Grounds Survey

Until recently, the coastal reefs of Papua were the major known breeding grounds. Yet only a few tens-of-thousands of lobsters arrive on these reefs each year though several million emigrate from Torres Strait. It was suspected that most lobsters move to other, largely unknown, breeding grounds. In the 1989/90 summer, a small submarine was used to survey deeper waters of the Gulf of Papua and far northern GBR for other lobster breeding grounds. The five metre submarine was able to dive to 400 metres and had been used for similar work in the USA. The Gulf of Papua was divided into more than a dozen sectors and two echo-sounder transects were run across each sector, a sub dive was made at the edge of the continental shelf and at two other random points on the shelf and at other sites where the seabed profile looked suitable. Very few lobsters were found in deep water near the coastal reefs of the eastern Gulf of Papua or in the remainder of the Gulf of Papua, but high densities were seen on a number of deep reef habitats (~75m) on the edge of the shelf of the far northern GBR. It is possible that this area supports the major breeding population for the Torres Strait fishery. However, it is necessary to confirm the extent of the far northern GBR breeding grounds and the abundance of these breeding lobsters, as well as determine whether these lobsters suffer catastrophic mortality after breeding as occurs in the breeding population of the eastern Gulf of Papua.

Modelling

Data collected in the field research projects is continually synthesized to provide up-to-date outputs relevant to management. During the past year information has become available for a preliminary analysis of yield-per-recruit (YPR), (ie. an estimate of how many grams each recruiting 1.5 year-old lobster is likely to contribute to the fishery in future). This involved examining the balance between growth rates and death rates and calculating the change in catch at different minimum sizes and fishing intensity. Currently, with natural mortality (M) estimated at about 0.4, minimum size at 100 mm and fishing mortality (F) at ~0.1 the calculated YPR is ~20gms, which is very low compared with other lobster fisheries. If the current fishing pressure is not changed, the yield would increase slightly if the minimum size was reduced, but very small tails are difficult to market. Nevertheless, the minimum size certainly does not improve yield. It is also possible to increase yield by increasing the amount of fishing (then a minimum size eventually becomes important), but care must be taken not to overfish and reduce future recruitment to the fishery. Exactly how much fishing is appropriate is probably the most important question to answer. After the stock survey it was estimated that the potential average yield may be about 600 tonnes, but the method used was only intended to give a preliminary result.

Another method of estimating potential yield involves consideration of escapement, (ie. the proportion of the population that escapes fishing to emigrate and breed). At present, the average annual catch of the fishery is around 240 t, fishing mortality is about F=0.1, and natural mortality is probably about M=0.4; thus, on average about seven million lobsters emigrate from the Torres Strait fishing grounds each year. This is about 93% of the numbers that could emigrate and breed if there was no fishing at all; in comparison with almost all other fisheries, this is a very high escapement rate. Theoretical fisheries yield models predict that production is maximized when the breeding stock is reduced to half (50%) of unfished levels, though empirical studies suggest that this level may lead to overfishing. For many stocks, a 30% reduction may be more appropriate (this is very conservative compared with the situation for western rock lobster where the exploitation rate is about 60%). Even so, an escapement of 70% in the tropical rock lobster fishery would permit a substantial increase in catch as, with four times more fishing mortality (F=0.4), the projected yield would be just over 800 tonnes on average and escapement would be about 74%. The projected yield would vary from year to year, but could be assessed annually by the research program. These considerations suggest that increased Islander effort should be encouraged in the diver fishery without concern about reducing subsequent recruitment.

Summary of Ongoing and Proposed Research Activities

Islander catch will be monitored (annually) to provide size-frequency distributions of the catch, and catch and effort information.

The lobster population will be sampled in the middle of each year to provide an unbiased annual index of the relative abundance of all year-class in the Torres Strait population, an index of the strength of the recruiting year-class, and growth and mortality estimates.

Studies of the ecology of newly settled juvenile lobsters will document the distribution of puerulus settling sites, micro-habitat use by post puerulus, early growth and mortality, and assess the potential impact of trawling on settlement grounds.

Devices intended to collect the last larval stage, or puerulus, are being trialled. The settlement of the puerulus stage is the earliest that recruitment to the fishery can be assessed. In future, these devices could be deployed widely and sampled regularly to provide an index of settlement, the first feedback of changes in the fishery, catch forecasting, and the timing of settlement.

The information arising from field research will continue to be synthesized into models of the fishery and outputs from these models will provide information of value for management.

References

Bell, R.S., Phillips, B.F., Prescott, J.H. (1986), 'Migration of the ornate rock lobster, *Panulirus ornatus*, in Torres Strait and the Gulf of Papua', In A. K. Haines, G. C. Williams, and D. Coates, (eds.), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985*, Australian Government Publishing Service, Canberra. 190-199.

Bell, R.S., Channells, P.W., MacFarlane, J.W., Moore, R., Phillips, B.F. (1987), 'Movements and breeding of the ornate rock lobster, *Panulirus ornatus*, in Torres Strait and the northeast coast of Queensland', *Aust. J. Mar. Freshw. Res.* 38,1 97-21 0

Dennis, D.M., Pitcher, C.R., Skewes, T.D., Prescott, J.H. (in press), 'Severe mortality of breeding tropical rock lobsters, *Panulirus ornatus*, near Yule Island, Papua New Guinea', *J. Exp Mar. Biol. Ecol.*

Joll, L.M., Phillips, B.F. (1986), 'Foregut contents of the ornate rock lobster *Panulirus ornatus*', In A.K. Haine, G. C. Williams, and D. Coates (eds.), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985,* Australian Government Publishing Service, Canberra. 212- 217.

MacFarlane, J.W., Moore, R. (1986), 'Reproduction of the ornate rock lobster, *Panulirus ornatus* (Fabricius), in Papua New Guinea', *Aust. J. Mar. Freshw. Res.* 37,55-65.

Moore, R., MacFarlane, J.W. (1984), 'Migration of the ornate rock lobster, Panulirus ornatus (Fabricius), in Papua New Guinea', *Aust. J. Mar. Freshw. Res.* 23,1 33-141.

Pitcher, C.R., Dennis, D.M., Skewes, T.D., Prescott, J.H. (1991), 'Catastrophic mortality of breeding tropical rock lobsters', *Proc. Internat. Crustacean Conference*, Brisbane, 1990.

Pitcher, C.R., Skewes, T.D., Dennis, D.M., Prescott, J.H. (in press), 'Estimation of the abundance of the tropical rock lobster, *Panulirus ornatus*, in Torres Strait, using visual transect survey methods', *Mar. Biol.*

Pitcher, C.R., Skewes, T.D., Dennis, D.M., Prescott, J.H. (in press), 'Distribution of seagrasses, substratum types and epibenthic macrobiota in Torres Strait, with notes on pearl oyster abundance', *Aust. J. Mar. Freshw. Res.*

Prescott, J.H., Phillips, B.F., Bell, R.S. (1986), 'Rock lobster research in Torres Strait', *Aust. Fish.* 45(1),2-4.

Salini, J., Rintoul, G., Shaklee, J.B., Phillips, B.F. (1986), 'An electrophoretic analysis of stock structure in the ornate tropical rock lobster, *Panulirus ornatus*', In A. K. Haines, G. C. Williams, and D. Coates (eds.), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985,* Australian Government Publishing Service, Canberra. 218-232.

Skewes, T.D., Pitcher, C.R., Trendall, J.T. (1991), 'Changes in the composition and moult frequency of the ornate rock lobster, *Panulirus ornatus*, population in Torres Strait associated with an annual breeding emigration' submitted to *Bull. Mar. Sci.*

Trendall, J.T., Bell, R.S., Phillips, B.F. (1988), 'Growth of the spiny lobster, *Panulirus ornatus*, in the Torres Strait', *Proc. Workshop on Pacific Inshore Fisheries*, South Pacific Commission, Noumea.

Trendall, J.T., Bell, R.S. (1989), 'Variable patterns of den habitation by the ornate rock lobster, *Panulirus ornatus*, in the Torres Strait', *Bull. Mar. Sci.* 45,564-573.

Trendall, J.T., Prescott, J.H. (1989), 'Severe physiological stress associated with the annual breeding emigration of *Panulirus ornatus* in the Torres Strait', *Mar. Ecol. Prog. Ser.* 58,29-39.

Turnbull, C.T. (1989), 'Pleopod cuticular morphology as an index of moult stage in the ornate rock lobster, *Panulirus ornatus* (Fabricius)', *Aust. J. Mar. Freshw. Res.* 40,285-293.

Biological Investigations into the Impact of the Ok Tedi Copper Mine

Ross E.W. Smith
Ok Tedi Mining Limited

Abstract

Biological investigations on behalf of Ok Tedi Mining Limited commenced with an expeditionary survey of the fish assemblages of the Fly River System in 1981. The company established biological monitoring and investigation programs in 1983. These programs have been revised and updated several times since their inception, in response to the improved understanding of the biota and the potential impacts. This has lead to a general increase in the extent of the work done.

The programs have concentrated largely on field sampling of the fish stocks, but have also included the assessment of the invertebrate assemblages, monitoring of the concentrations of heavy metals in fish tissues and bioassays for the toxicity of dissolved and particulate copper to fish and invertebrates. The investigations have provided insight into the nature of the impacts which have occurred, the chemical parameters responsible for those impacts, the biological processes associated with the impacts and prediction of the likely extent of impacts in the future.

Introduction

The Ok Tedi gold and copper mine is located in the upper catchment of the Ok Tedi (Ok means water in the language of the Yongom people), a major tributary of the Fly River in the west of Papua New Guinea. The region is characterised by rugged terrain and very high rainfall, with an average of 10000mm per year at the mine site. Much of the upper catchment is highly erodible, resulting in high natural concentrations of suspended solids.

Construction for the project commenced in 1981, gold production commenced in 1984 and copper production in 1987. The gold leach circuit was decommissioned in late 1988, and gold is now recovered from the copper flotation circuit into the copper concentrate.

The development plan for the Ok Tedi project included the construction of an ore residue retention dam in the Ok Ma valley, with incompetant overburden placed in an erodible storage area. However, large landslips in 1983 and 1984, after construction of the dam had commenced, proved that the site was geologically unsuitable for such a containment facility. The regulatory authorities approved an interim tailings scheme, which allowed the release of ore residues less than 150 μm in diameter into the river system, after detoxification of the cyanides, whilst a major environmental study was undertaken. A set of stringent water quality criteria were applied during that period. Subsequent to the completion of that study, approval was granted for the continuation of riverine disposal of wastes, under compliance with an Acceptable Particulate Level of 940mg/L of mine derived suspended solids in the Fly River below the Ok Tedi junction, and a set of environmental conditions. The current conditions are contingent on an extensive environmental program (see Eagle, this volume).

Prior to the monitoring programs of Ok Tedi Mining Limited a small number of environmental studies of the Fly River system were done on an expeditionary basis. In 1974, the Cambridge expedition (Boyden *et al*, 1975) investigated the metal concentrations in the Ok Tedi and upper Fly River and in the biota of the rivers. Although the expedition was on-site for only a two month period, it provided useful background information on metal concentrations, and qualitative information of the composition of the aquatic communities of the sites sampled. Unfortunately, most of the information is only available as an unpublished report (Boyden *et al*, 1975), although the bulk of the metal concentration information is contained in Boyden *et al* (1978).

Roberts (1978) conducted an extensive ichthyological survey of the Fly River system, listing 103 species collected in freshwater. His work greatly increased the knowledge of the fish species to be found in the system, and also provided some background information of the distribution of those species prior to mine operations.

In early 1981, Robertson and Baidam (1983) examined the fish fauna in the upper Ok Tedi, a region not sampled by Roberts (1978), and assessed the utilisation of the fish by the local people. They found that the number of fish species and the density of fish in the region was low, and this was reflected in low consumption by the people. Their work also indicated pre-mine fish distributions, although little quantitative data were presented.

The mercury content of fish in the Fly River system has been well studied (eg Lamb, 1977; Kyle and Ghani, 1982a, 1982b, 1984), but as the concentrations of mercury in the Ok Tedi ore body are not above background, this metal is not of direct relevance to the Ok Tedi project.

This paper examines the biological investigations that have been carried out by Ok Tedi Mining Limited since those early studies, and briefly overviews the impacts that have been observed. It is not the aim of this paper to present all the previous data and analyses, all of which have been published in some form. Rather, the purpose is to inform the reader of the extent of the work which has been carried out, and to summarise the major conclusions drawn. Ok Tedi Mining Limited's biological programs do not extend into the Torres Strait region. However, it is felt that the work done in the freshwater and marine ecosystems in the Fly River system indicates the amount of attenuation of impacts downstream of the mine, and are therefore of interest to those concerned with Torres Strait itself.

Sampling Programs

Environmental Impact Study

Maunsell and Partners (1982) undertook an environmental impact study on behalf of Ok Tedi Mining Limited in 1981. Figure 1 shows the sites that were sampled during the biological survey between 16 June and 22 July 1981. The survey was primarily concerned with fish, although some of the larger invertebrates were also examined. Samples were collected by a variety of means, including gill netting, seine netting, cast netting, electrofishing, angling, rotenoning, long lining, trapping, trawling and purchase from locals. As the effort varied between sites, it is difficult to use the data for comparisons of abundances between sites, but valuable insight is given into the distribution of fish species. A total of 73 species were collected.

A considerable amount of information was obtained on the concentrations of zinc, lead, copper, cadmium, molybdenum, arsenic and mercury in fish flesh and liver. Some information was also obtained on the concentrations of these metals in the tissues of crabs, mussels, clams and prawns, principally from the delta region.

The study provided a wealth of background information on the fish fauna that existed before the mine, but as the methods used in collection were variable, and differed from those employed afterwards, the fish abundance data has been of little quantitative analytical use subsequently. The authors did provide constructive suggestions for future monitoring, which provided the basis of the longer-term biological programs.

1983-1985

Following the submission of the Maunsell and Partners report, Ok Tedi Mining Limited established its own biology section to conduct long-term environmental monitoring. Sampling commenced in April 1983, and has continued up to the present date. It is forseen that sampling will continue in some form at least until the end of mine life in 2008, and presumably for some time thereafter.

The sampling program instigated in 1983 closely resembled that recommended by Maunsell and Partners (1982), with some modifications to the methods used as experience was gained. The sampling sites are shown in Figure 2. The two Bosset stations were below the section of the Fly River that forms the border between Papua New Guinea and Indonesia. Fish were sampled by gill netting at all sites, using the standard net sets listed in Table 1. At the two most upstream sites, the larger net meshes were not used due to the lack of large fish and the restricted space available for net placement. Seine netting was also used at all sites except the two Bosset sites, which did not have suitable sand banks. Rotenone sampling was used in a qualitative fashion at Bosset Lagoon. Initially, electrofishing and longlining were used, but they

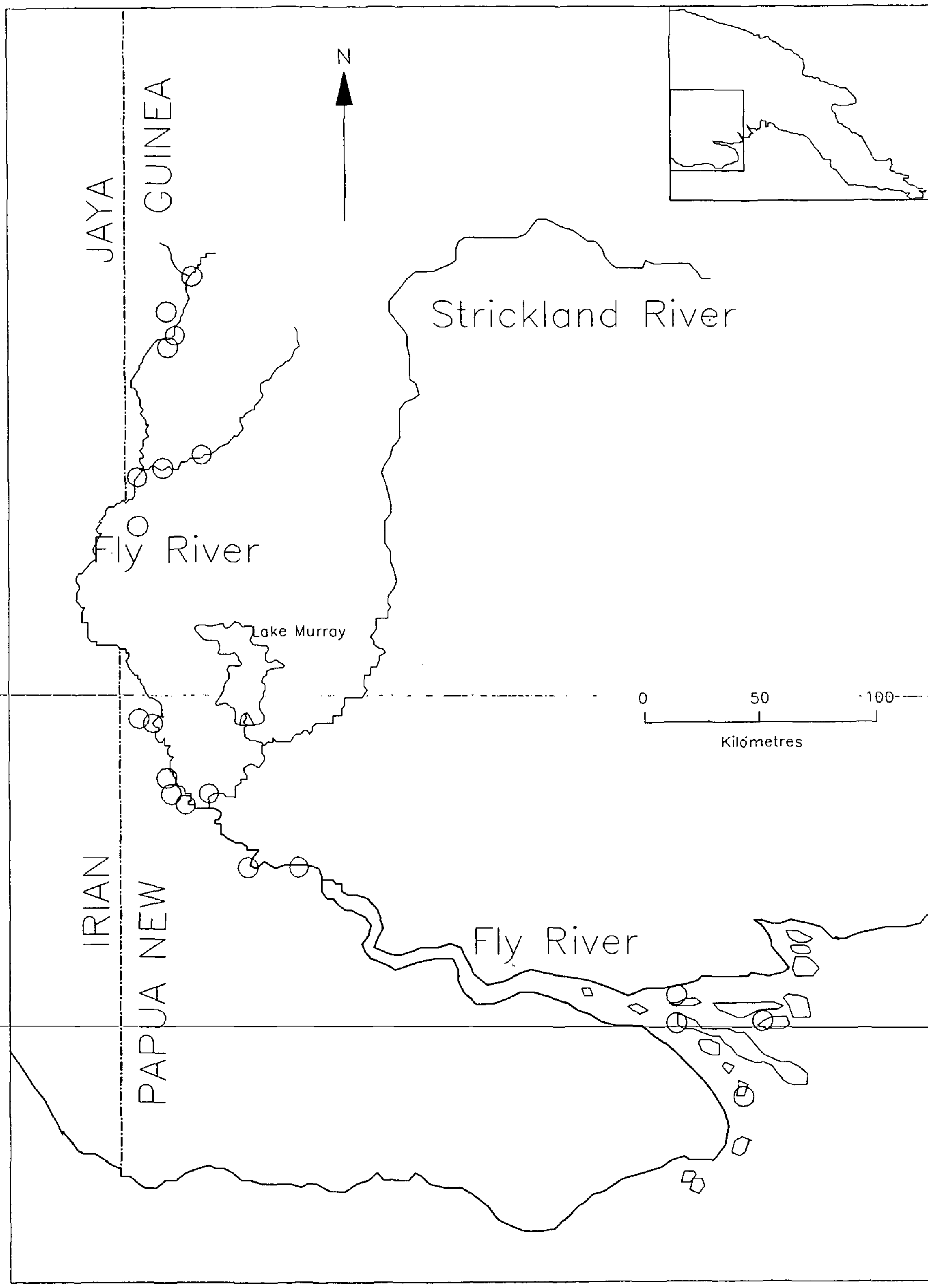


Figure 1. Map of the Fly River system showing the positions of sites sampled by Maunsell and Partners (1982). Inset shows the position of the Fly River System in Papua New Guinea.

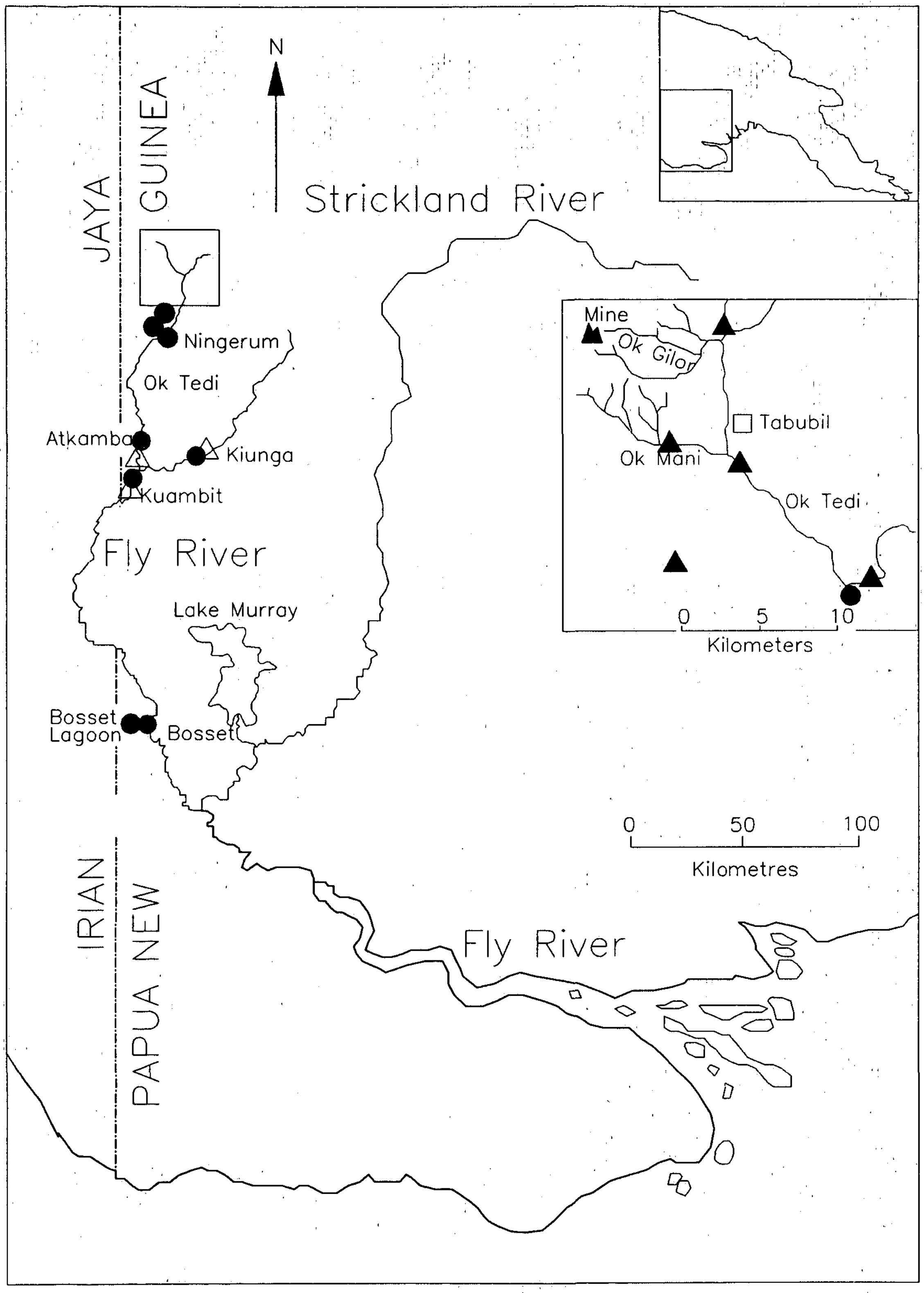


Figure 2. Map of the Fly River system showing the positions of the sampling sites used by the Ok Tedi Mining Limited Biology Section between 1983 and 1986. Triangles represent invertebrate sampling sites, circles represent fish sampling sites. Hollow symbols represent expeditionary sampling. Small inset shows the position of the Fly River in Papua New Guinea. Larger inset shows detail of the area around Tabubil.

Table 1. Gill nets used in fish sampling. Mono indicates net constructed from nylon monofilament, multi indicates nylon multifilament.

Mesh Size (mm)	Type	Length (m)	Depth (m)	Area (m^2)	Number Used
25	mono	40	2.3	92	1
38	mono	40	1.7	68	1
50	mono	45	2.1	95	1
63	mono	40	2.8	112	1
75	mono	45	3.2	144	1
88	mono	45	3.5	158	1
100	mono	45	4.2	189	1
125	mono	45	4.9	221	1
150	mono	50	6.0	300	1
150	multi	25	2.8	70	2
175	multi	25	3.1	78	2

were discontinued by 1984 (Ok Tedi Mining Limited, 1985a) and 1985 (Ok Tedi Mining Limited, 1985b) respectively due to the low catches recorded. Small pyramidal traps were used to sample *Macrobrachium* spp. prawns at all fish sampling sites. Other invertebrates were sampled by kick netting for a ten minute period in riffle areas at the sites indicated in Figure 2. The sites were sampled every three months. The time period was constrained by the logistical difficulties in getting to each site, and the amount of samples that could be stored and processed in the facilities then available.

Muscle, liver and kidney tissue samples were taken from the most abundant fish species, and analysed for copper, zinc, cadmium and lead concentrations.

1986 to 1990

In 1986 the Sixth Supplemental Agreement was reached, which called for an extensive environmental study to investigate the impact on the River System (defined as the Fly River downstream of the junction with the Ok Tedi) of disposal of the mine wastes. This called for a change in the emphasis of the biological investigations (Hortle, 1986b) which commenced in 1986, and continued thereafter.

The sampling program for that year is shown in Figure 3. The invertebrate sampling stations in the upper catchment were dropped, as were some of the upstream fish sampling stations. This was due to the small amount of information gained from those sites for a large effort. The man hours so gained were directed into an investigation of the invertebrate fauna of the potamon sections of the river, and an expedition to sample fish at a station in the Strickland River. The invertebrate sampling

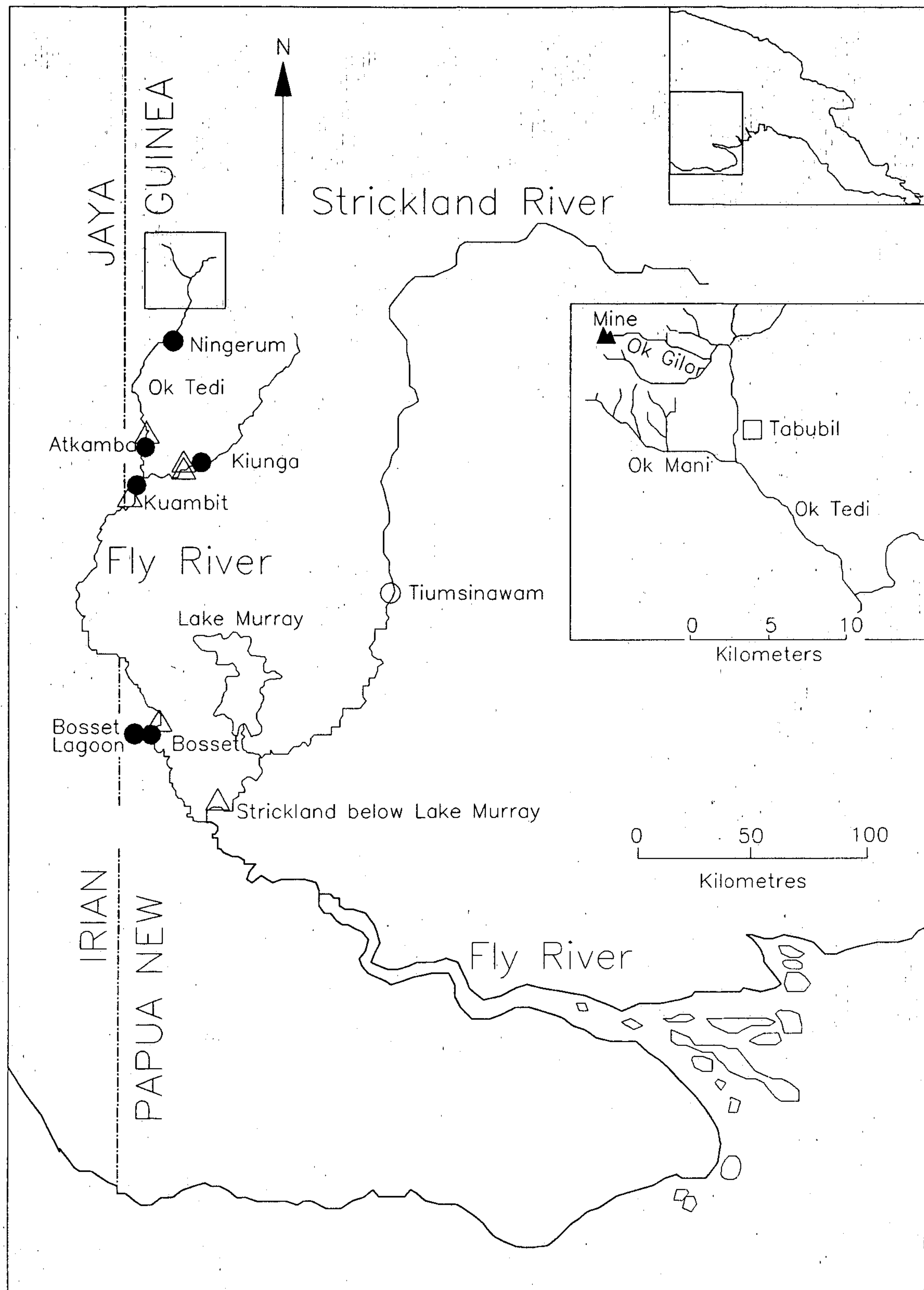


Figure 3. Map of the Fly River system showing the positions of the sampling sites used by the Ok Tedi Mining Limited Biology Section during 1986. Symbols and insets as for Figure 2.

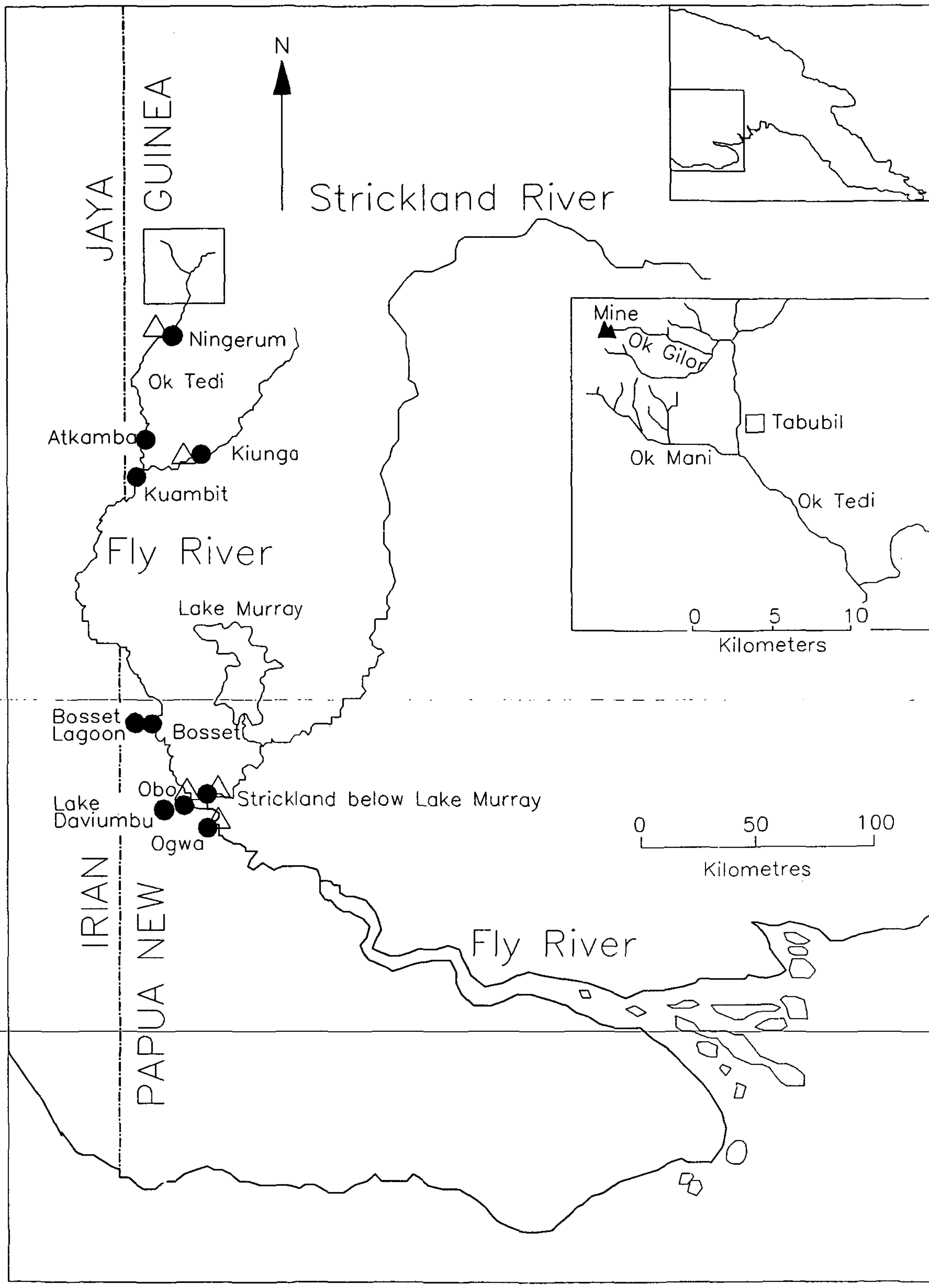


Figure 4. **Map of the Fly River system showing the positions of the sampling sites used by the Ok Tedi Mining Limited Biology Section during 1987. Symbols and insets as for Figure 2.**

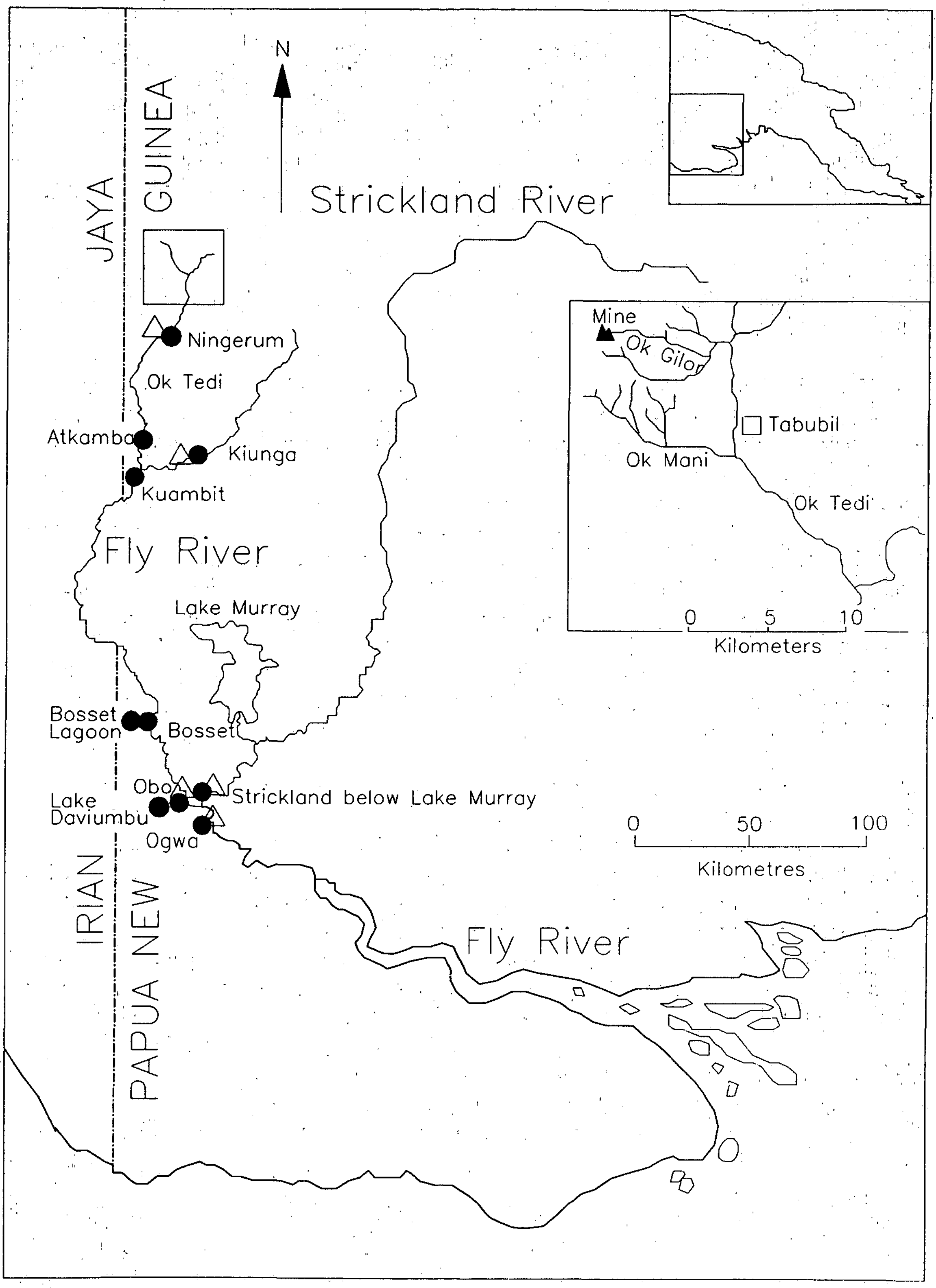


Figure 5. **Map of the Fly River system showing the positions of the sampling sites used by the Ok Tedi Mining Limited Biology Section during 1988. Symbols and insets as for Figure 2.**

demonstrated that the densities in most substrates were very low (Hortle, 1987b). The exception was the very high density of a burrowing mayfly, *Plethogenesia pallida*, in some steep clay banks. Unfortunately, these habitats were not effectively sampled by the equipment used.

The single expedition to Tiumsinawam on the Strickland and Tomu River junction (Hortle, 1986a) clearly demonstrated a dominance of the fish fauna in that area by the Ariidae catfish.

The invertebrate investigations continued in 1987 (Hortle, 1987a). In addition, four new fish sampling stations were added near the junction of the Fly and Strickland Rivers (Figure 4).

In 1988, artificial substrates were trialed as a means to sample *P. pallida*. The trial indicated that the system could work, but that an adequate program would require more resources than were then available. Two fish sampling stations in the Strickland River were added (Smith, 1988) at Tiumsinawam and near Bebelubi (Figure 5). These were used to investigate what effects that high suspended solids concentrations had on the fish fauna of the Fly River system. The two sites were very difficult to sample because of the high current speeds in the region, and they were dropped at the end of the year. A series of bioassay experiments were conducted to examine the relative toxicity of particulate copper from ore and ore residues on *Macrobrachium rosenbergii*, *M.* sp, *Neosilurus ater*, *Ceriodaphnia dubia*, and *Penaeus merguiensis* (Smith *et al*, 1990). The Draft Final Report of the Sixth Supplemental Agreement Environmental Study was submitted to the Government in December 1988 (Ok Tedi Mining Limited, 1988).

Following appraisal of the Draft Final Report, the Government requested that some additional investigations be carried out to provide further information to assist in the setting of the Acceptable Particulate Level (APL). These investigations included further investigation of the use of floodplain water bodies by the fish fauna of the Fly River system. To that end, five oxbow lake sites and two floodplain sites were added to the fish sampling program in 1989 (Ok Tedi Mining Limited, 1989; Figure 6). Also, the sampling frequency at Kiunga, Kuambit and Atkamba was increased to monthly to provide more statistical power for data analysis, and to better examine seasonality. To compensate somewhat for the increased effort, the frequency of sampling at the two Bosset stations and Ningerum was reduced to six monthly. Some further bioassays were carried out to assess the chronic toxicity of particulate copper to *Penaeus merguiensis*. The Supplementary Investigations Report (Ok Tedi Mining Limited, 1989) was submitted to the Government in June 1989, and the APL was set on 1 October 1989.

The APL had several conditions associated with it, which included a maintenance of specified levels of fish catch at Kuambit, Obo and Ogwa, to be tested on an annual basis. To increase the power of the statistical tests to be applied, replicate sampling stations were established at those three sites in 1990 (Figure 7) upstream and downstream of the standard stations. Concern was also expressed over the potential for impact to several possible fisheries resources in the Fly River Delta. These were as follows:

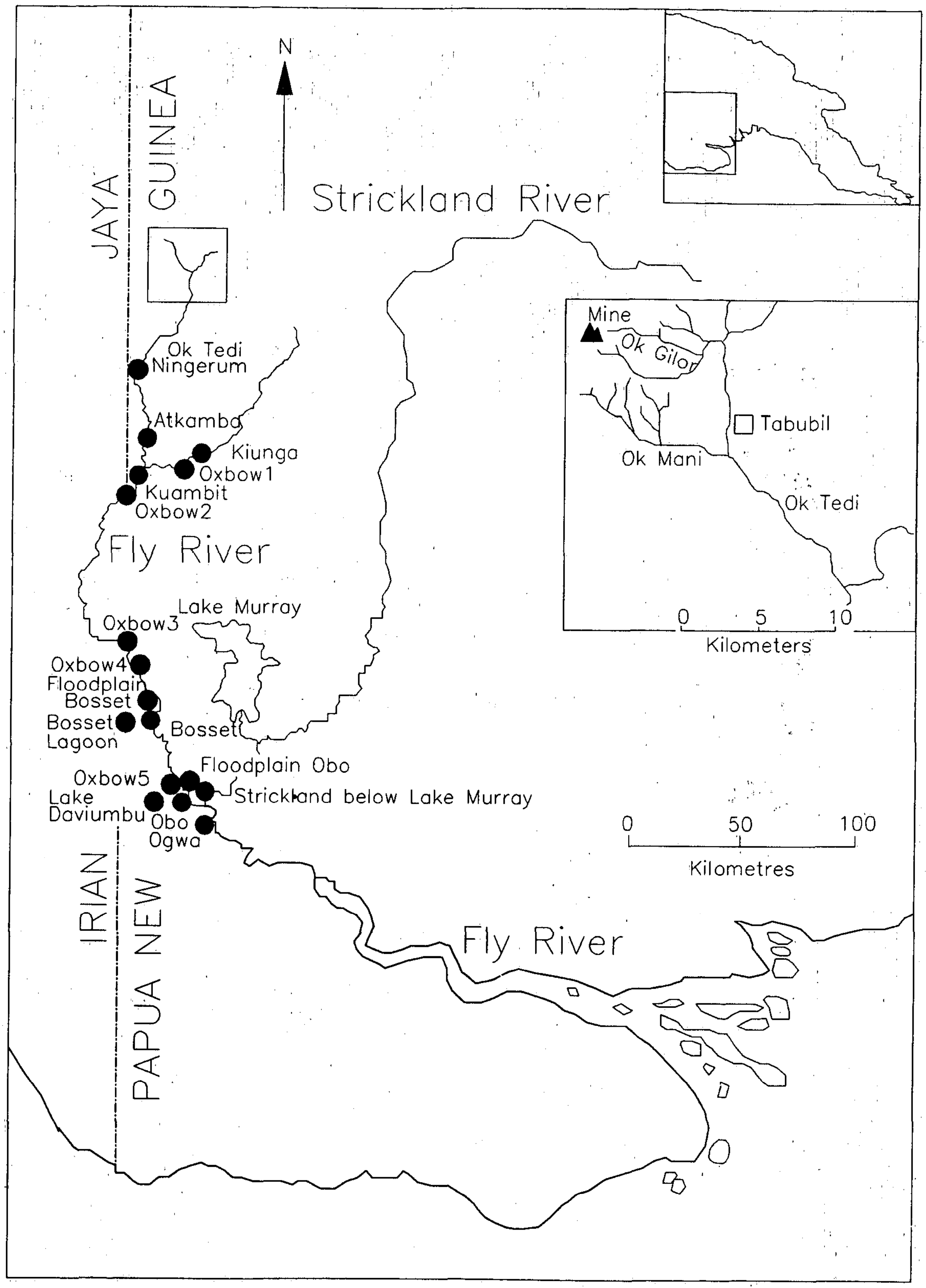


Figure 6. Map of the Fly River system showing the positions of the sampling sites used by the Ok Tedi Mining Limited Biology Section during 1989. Symbols and insets as for Figure 2.

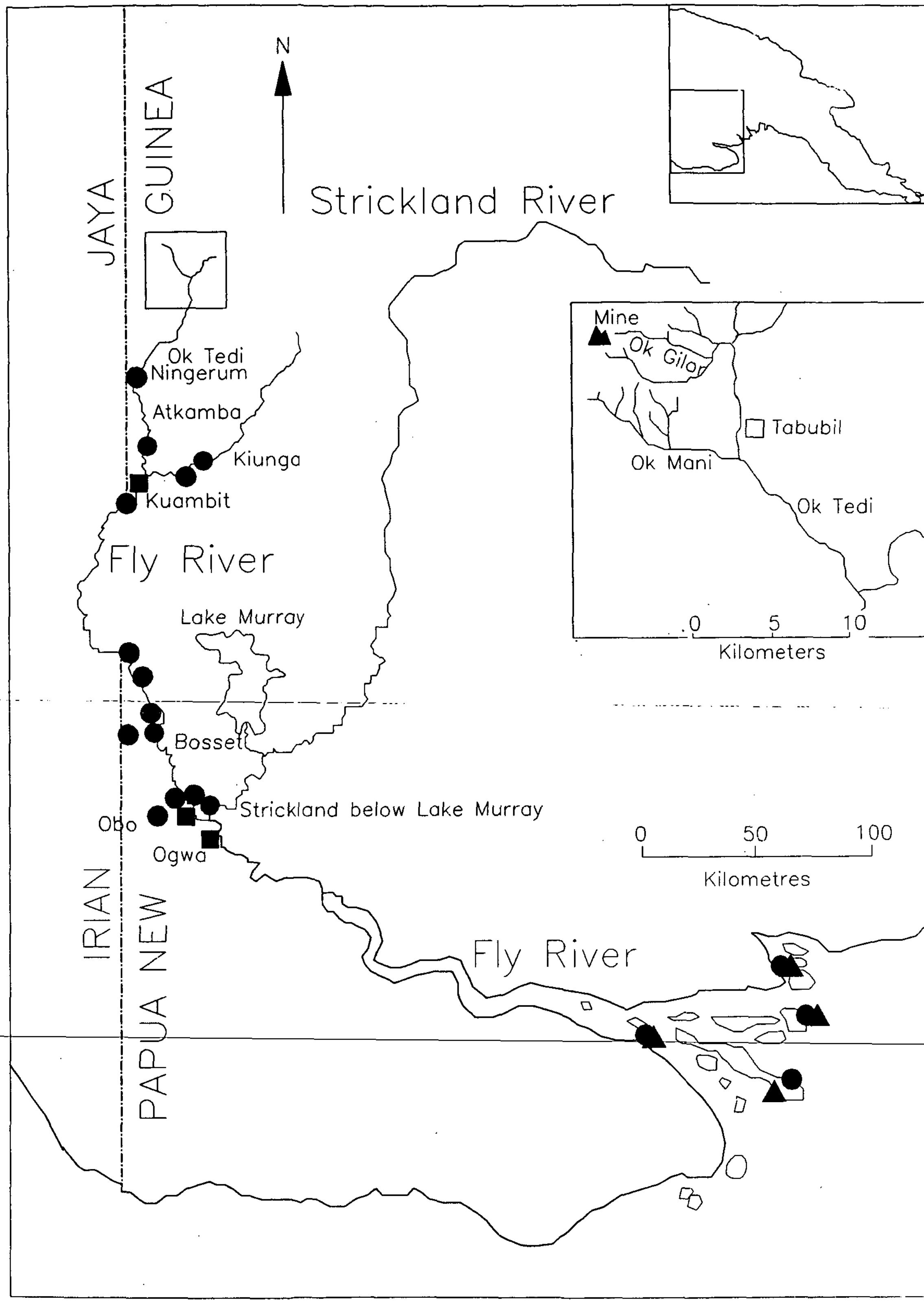


Figure 7. Map of the Fly River system showing the positions of the sampling sites used by the Ok Tedi Mining Limited Biology Section during 1990. Symbols and insets as for Figure 2. Squares indicate replicate fish sampling sites (see text for details).

- nursery areas for the banana prawn, *Penaeus merguiensis*, stocks which were the subject of an extensive trawl fishery in the Gulf of Papua – the presence of nursery areas in the Fly was inferred, but had not been demonstrated;

- mud crabs, *Scylla serrata*, for which a local market fishery existed in Daru;

- the local subsistence fishery;

- a nursery area for barramundi, *Lates calcarifer*, which was believed to exist on the south-eastern end of Kiwai Island (Moore, 1980);

- the breeding migration route for the tropical rock lobster, *Panilurus ornatus*, which passes across the mouth of the Fly River is a major source of recruits for the Great Barrier Reef and Torres Strait fishery.

As the Department of Fisheries and Marine Resources had an extensive program investigating the lobster fishery, and had access to commercial catch records, Ok Tedi Mining Limited set up programs in 1990 to investigate the first four aspects. This included the establishment of three stations in the Fly River estuary, and one in the adjacent Bamu River estuary as a control site. At each station, fish were sampled by beach seining with two seines, one 50 metres long as used at the freshwater sites, and one 187 metres long designed to match that used by the Department of Fisheries and Marine Resources barramundi studies in the seventies (Reynolds, 1978; Moore, 1980).

Crabs were sampled by trapping in two types of traps, used widely in northern Australia for the same species, except for the upstream site which does not have sufficient salinity for *S. serrata*. Juvenile prawns were sampled by a beam trawl, matching that used by Staples (1980) for his investigations of the development of *P. merguiensis* in the Gulf of Carpentaria in Australia. The possible barramundi nursery was examined by rotenoning within a circle of net. For long term biomonitoring of the effects if any of copper in the delta, investigations are under way to select a suitable species for regular copper content analysis. The species selected will be one that is known to actively accumulate copper within its tissues. This will also serve to act as an early warning indicator of potential impacts outside the delta area.

1991 Onward

An internal review of the sampling programs in 1989/90 highlighted some possible improvements. The primary concern was that quarterly sampling would only detect very large changes in abundances over the short time frames of most management use. However, it was well understood that the programs as they existed were both extensive and required a large amount of resources. It was also perceived that greatly increasing the sampling frequency could deleteriously affect the fish stocks, as destructive methods of sampling were used. These problems were addressed in two ways. Firstly, sampling frequency was increased at the riverine sites, which are most prone to impacts from the mine, by the inclusion of replicate stations (see above), and in 1991, bimonthly sampling will be instigated at Ningerum. Secondly, non-destructive hydroacoustic sampling is to be investigated as an alternative sampling technique in 1991. Trap netting will also be investigated, but in the high water temperatures it is unlikely to be entirely non-destructive.

Another concern was that the aquatic invertebrates, which were known to be of major importance as a food source to the fish (Hortle, 1986b) were no longer being monitored. As the main reason for this lack was the labour intensive nature of most invertebrate sampling, less labour intensive techniques such as artificial substrate sampling will be re-investigated in a variety of habitats (Figure 8). Trapping of *Macrobrachium* spp. will be re-instigated, although a new, larger trap will be used which will be capable of capturing the full size range of specimens.

Finally, as the only site in the lower Fly River, upstream of the delta was Ogwa, which is very close to Everill Junction, another fish and possibly invertebrate sampling site is to be added at Gilim Island (Figure 8). This site will have replicate stations, and both gill and seine nets will be used.

It is also planned to undertake further bioassay experiments to provide more information on the relative toxicity of dissolved copper and particulate copper (from the different ore types in the ore body).

Results of the Investigations

It was apparent in 1983 that the elevated concentrations of suspended solids, which were a result of the construction activities, had depleted the invertebrate fauna in the streams draining the mine area, as far downstream as the lower Ok Tedi Bridge (Ok Tedi Mining Limited, 1985a). The invertebrate fauna in the Ok Mani were rapidly depleted once tailings release had commenced (Ok Tedi Mining Limited, 1985b). Reductions of the fish fauna was first demonstrated in the Ok Tedi below the Ok Menga junction and at Ningerum in 1984 (Ok Tedi Mining Limited, 1985a). Reductions at Atkamba were first detected in 1986 (Hortle, 1986b). Certain species, notably the fringe lipped mullet, *Crenimugil labiosus*, which was a dominant species at the Ok Tedi stations sampled prior to the mine (Maunsell and Partners, 1982; Robertson and Baidam, 1983) was absent or in low numbers from 1983 onward (Hortle, 1986b).

In the Fly River, changes in the fish fauna were first detected at Kuambit in early 1988 (Smith, 1988). Both the total catches and the composition of the fauna were affected (eg. Figures 9 and 10). In the Draft Final Report (Ok Tedi Mining Limited 1988), a series of models were presented that related changes in the biomass of fish caught to the suspended sediments concentration and the catchment area for the river at each site (eg. Figure 11). This went against the conclusions of Smith *et al* (1990) that based on the catches at the Strickland river sites, elevated suspended solids would reduce species diversity, but not greatly affect biomass. This was presumed to be due to the dominance of the Ariidae catfish at those sites. A problem with the multiple regression approach used by Ok Tedi Mining Limited (1988), was that the majority of the variance was explained by catchment area, and very little by the chemical parameters. This was addressed in Ok Tedi Mining Limited (1989) by the use of analyses of covariance, with site as the class variable, and the chemical parameters as covariates. This produced a series of models for biomass caught as a function of the dissolved and particulate copper concentrations, with correction factors for the site effects (Smith and Hortle in press). As dissolved and particulate copper were highly correlated in the data set used, it was not possible to determine which was the primary cause. However, bioassay experiments had indicated that particulate copper was much less toxic to the biota tested than was dissolved copper (Ok Tedi Mining Limited, 1989;

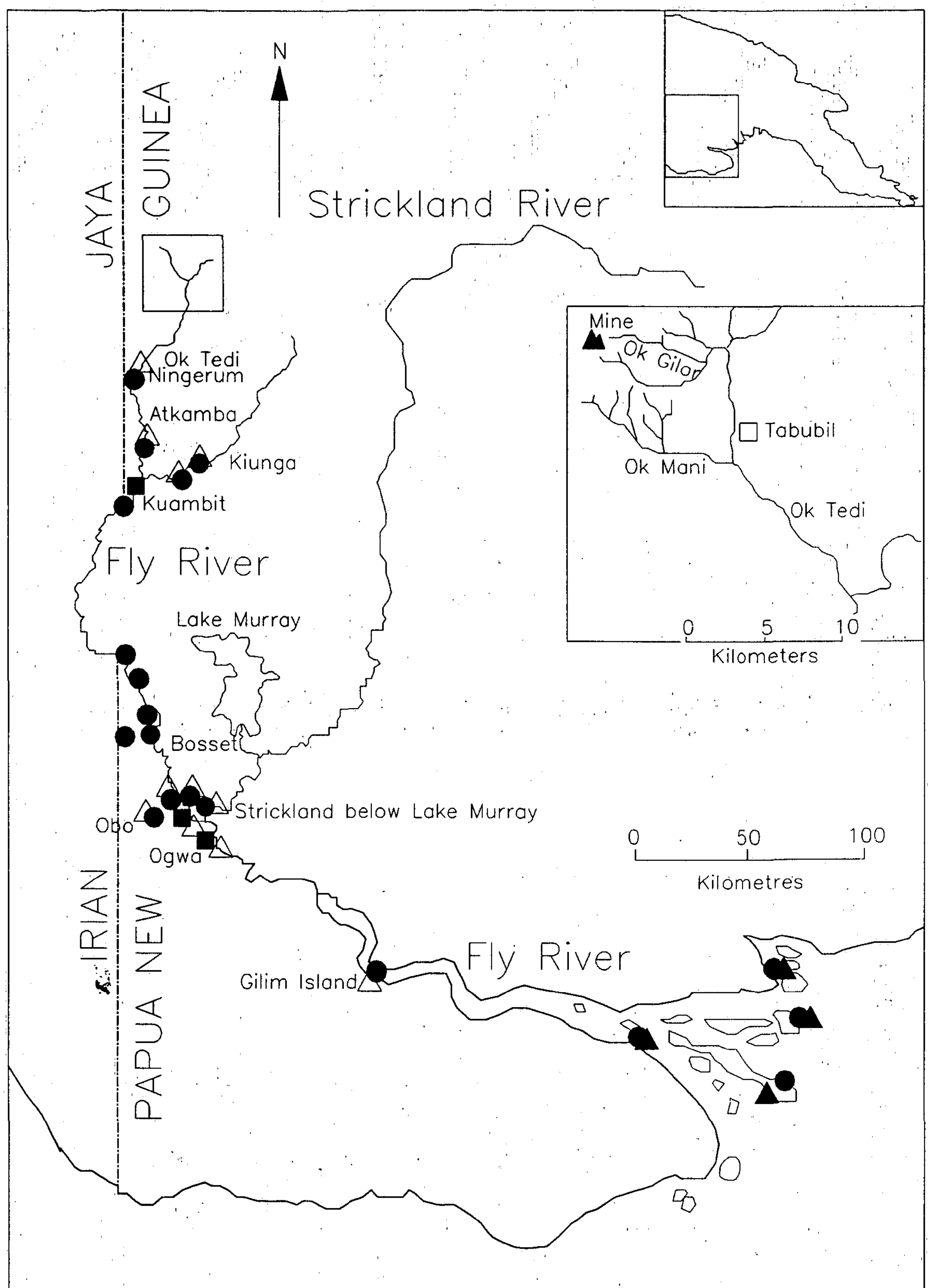


Figure 8. Map of the Fly River system showing the positions of the sampling sites to be used by the Ok Tedi Mining Limited Biology Section during 1991. Symbols and insets as for Figure 7.

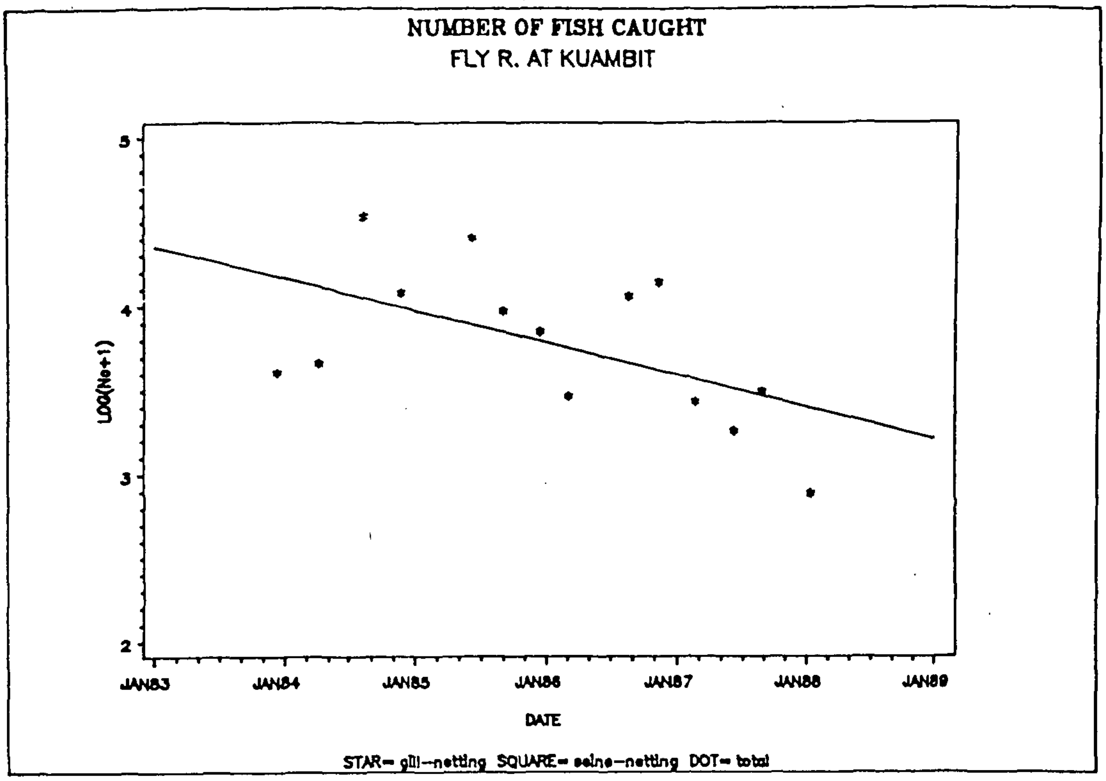


Figure 9. Plot of Log (number of fish caught by gill netting + 1) versus time for the Fly River at Kuambit. The line is the regression line. From Smith (1988).

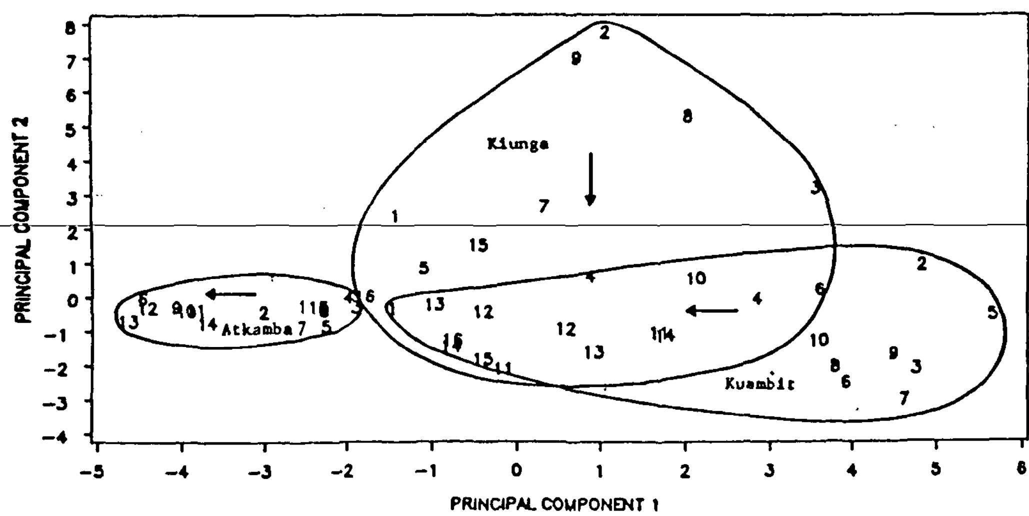


Figure 10. Principal components ordination of samples from Atkamba, Kiunga and Kuambit by Log (biomass + 1) for each species caught. Arrows indicate the direction of the time vector at each site as determined by non-parametric correlation. From Smith (1988).

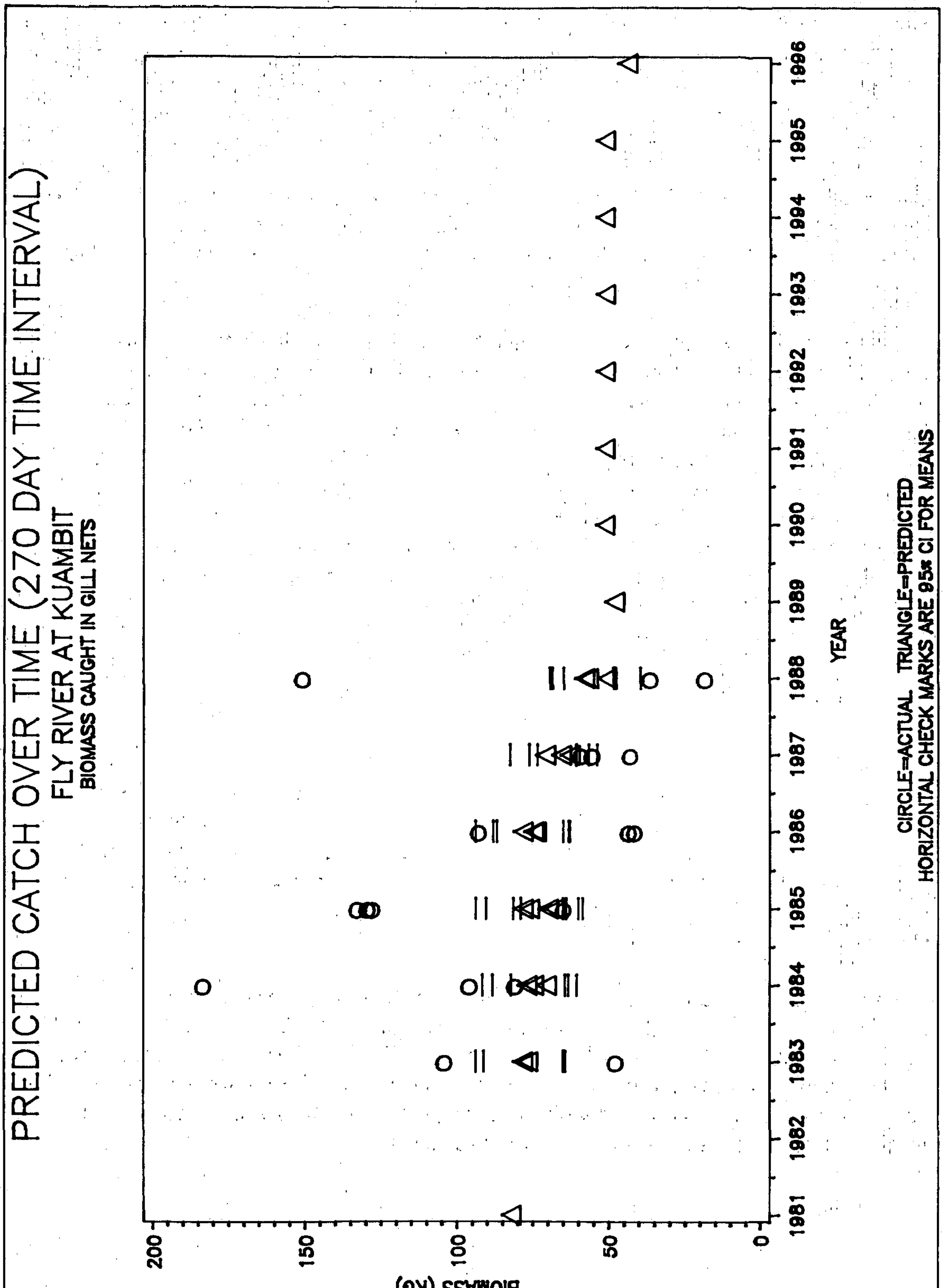


Figure 11. Plot of actual total biomass caught by gill netting in the Fly River at Kuambit and the predicted biomass caught as determined by multiple linear regression with catchment area and suspended solids concentration. Modified from Ok Tedi Mining Limited (1988).

Smith *et al*, 1990). As the relationship between dissolved and particulate copper has changed since August 1988, the cut off date for the data used in the modelling, as a result of changes in the composition of the ore, subsequent sampling has indicated that the dissolved copper models do in fact explain the biomass caught better than the particulate copper models (Smith and Hortle, in press).

Interestingly, the ANCOVA models for aquatic invertebrate feeding fish included suspended solids as the covariate. As noted above, the aquatic invertebrate assemblages in the upper Ok Tedi stations were severly impacted by suspended solids during the construction phase.

Recently, Smith and Morris (in submission) examined the changes in the fish assemblages at Ningerum, Atkamba and Kuambit during the changing phases of mine operation. They found that at Ningerum the fish community was reduced rapidly after the mine commenced operations, and was reduced to such a low level that stochastic processes masked any further changes (Figure 12). At Atkamba, the composition of the catches was distinctly different during the different phases (Figure 13), and the fish assemblage responded in a similar fashion to high cyanide concentrations and to combined high suspended solids and particulate copper concentrations, but the response to high dissolved copper concentrations was quite different. At Kuambit, where the mine discharges were greatly diluted, the changes in the fauna were more gradual, with no separation of responses to the different parameters.

Conclusions

The biological programs of Ok Tedi Mining Limited have gone through a process of regular review and updating, which has lead to a general increase in the extent of the programs. The investigations have provided insight into the nature of the impacts that have occurred, the chemical parameters responsible for those impacts and the biological processes associated with those impacts. Predictive models have been derived to assess likely future impacts, and subsequent monitoring has demonstrated the validity of those models.

The investigations have also highlighted areas which are at present not well enough understood to accurately forcast the likely future impacts. Two areas of the most concern are the off-river water bodies in the middle Fly floodplain, and the areas downstream of Ogwa, including the Delta and offshore. These areas have been the subjects of the most recent expansions of the sampling programs, and it is hoped that further light will be shed on them in the near future.

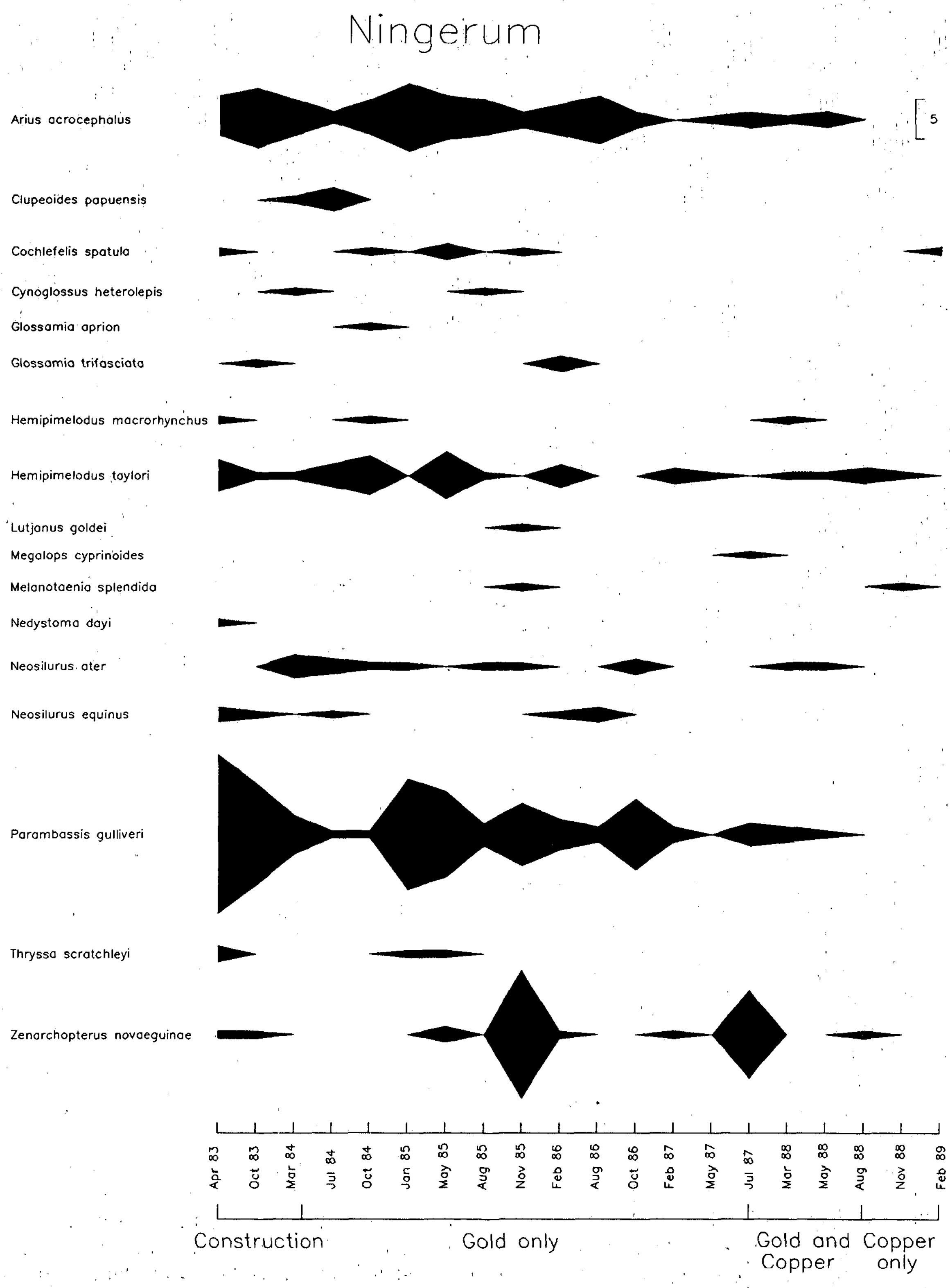


Figure 12. Kite diagram of the number of each species caught by gill netting in the Ok Tedi at Ningerum over time. From Smith and Morris (in submission).

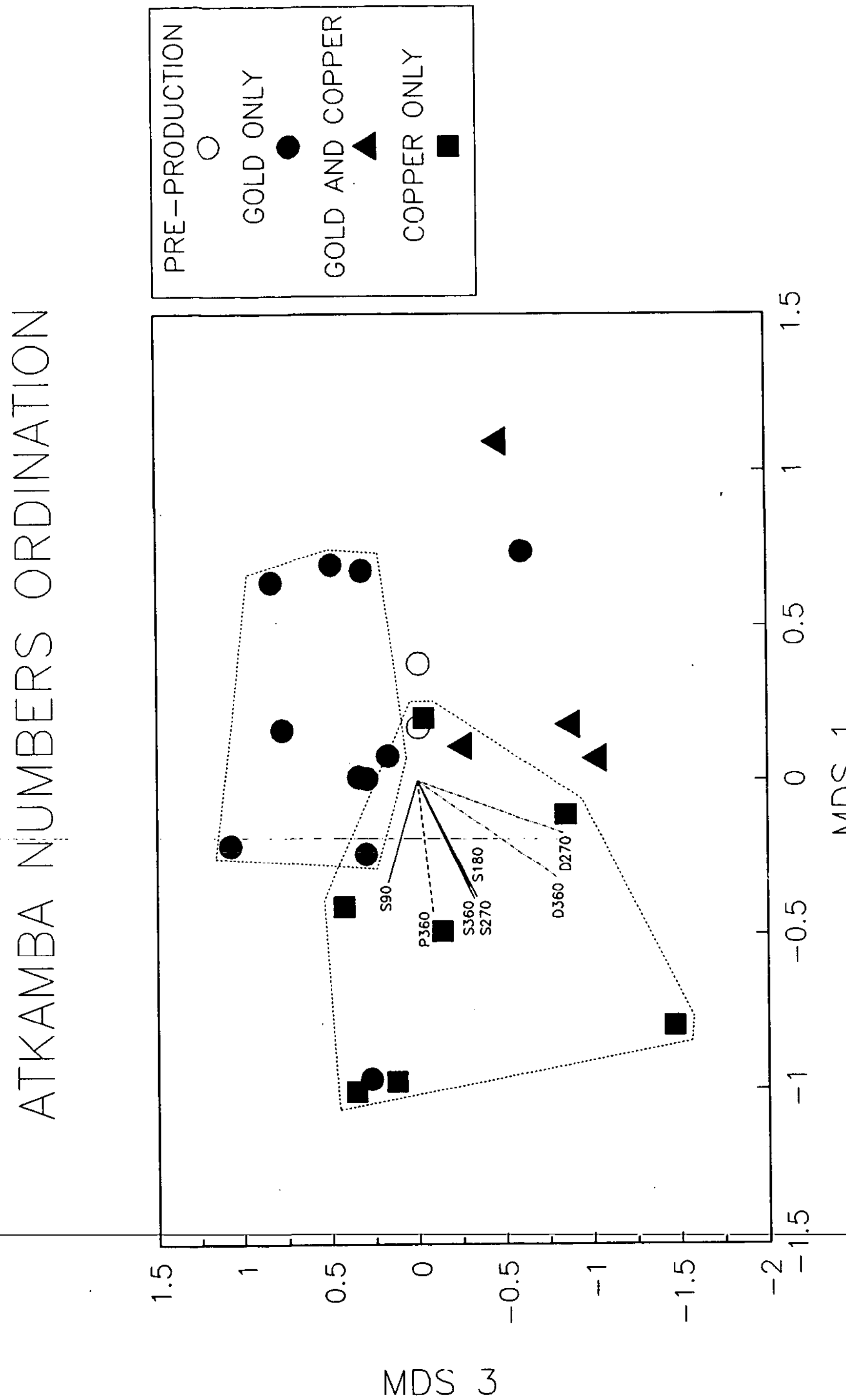


Figure 13. **Multidimensional scaling ordination of gill net samples from the Ok Tedi at Atkamba by the number of each species caught. Samples are identified by mine operation period. Dashed lines encircle sample groups which are significantly different from the remainder of the samples (L(permute), p<0.05). Lines indicate the direction of the vectors of best fit for selected physico-chemical parameters, denoted by parameter and time interval of averaging. S indicates suspended solids, D indicated dissolved copper and P indicates particulate copper. From Smith and Morris (in submission).**

References

Boyden, C.R., Brown, B.E., Drucker, R.F. and Tutt, S.J. (1975), 'Ok Tedi Environmental Study', Report of the 1974 Cambridge Expedition to the Western District Papua New Guinea.

Boyden, C., Brown, B.E., Lamb, K.P., Drucker, R.F. and Tutt, S.J. (1978), 'Trace elements in the Upper Fly River, Papua New Guinea', *Freshwater Biology*, 8, 189-205.

Hortle, K.G., (1986a), *Survey of the Fish Fauna of the Strickland River at Tiumsinawam with Reference to Sediment Tolerance*, Ok Tedi Mining Limited, Port Moresby and Tabubil. (Report ENV 86-6).

Hortle, K.G. (1986b), 'A Review of Biological Sampling of the Ok Tedi and Fly River Systems, April 1983 to June 1986', Ok Tedi Mining Limited, Port Moresby and Tabubil. (Report ENV 86-9).

Hortle, K.G. (1987a), 'Six-monthly Biology Review 1 July 1986 to 09 April 1987', Ok Tedi Mining Limited, Port Moresby and Tabubil. (Report ENV 87-08).

Hortle, K.G. (1987b), *Studies of the Benthic Fauna of Lowland (Potamon) Localities of the Ok Tedi and Fly River system*, Ok Tedi Mining Limited, Port Moresby and Tabubil. (Report ENV 87-11).

Kyle, J.H. and Ghani, N. (1982a), 'Mercury concentrations in ten species of fish from Lake Murray, Western Province', *Science in New Guinea*, 9, 48-58.

Kyle, J.H. and Ghani N. (1982b), 'Elevated mercury levels in people from Lake Murray, Western Province', *Papua New Guinea Medical Journal*, 25, 81-88.

Kyle, J.H. and Ghani N. (1984), 'Mercury in barramundi (*Lates calcarifer*) from the Gulf of Papua', *Science in New Guinea*, 11, 105-113.

Lamb, K.P. (1977), 'Mercury levels in nine species of fish from the Ok Tedi and upper Fly River,' *Science in New Guinea*, 5, 7-11.

Maunsell and Partners Pty. Ltd. (1982), *Ok Tedi Environmental Study. Working Paper 16. Biological and Heavy Metal Reconnaissance Survey of the Ok Tedi-Fly River System*, Ok Tedi Mining Limited, Port Moresby and Tabubil.

Moore, R. (1980), 'Migration and Reproduction in the Percoid Fish *L. calcarifer* (Bloch)', PhD Thesis, University of London, England.

Ok Tedi Mining Limited (1985a), *Environmental Monitoring Programme Six Monthly Report. July - December 1984*, Ok Tedi Mining Limited, Port Moresby and Tabubil. (Report PA/03/85-5).

Ok Tedi Mining Limited (1985b), *Environmental Monitoring Programme Six Monthly Report. January - June 1985*, Ok Tedi Mining Limited, Port Moresby and Tabubil. (Report PA/03/85-14).

Ok Tedi Mining Limited (1988), *Sixth Supplemental Agreement Environmental Study 1986-1988. Final Draft Report,* Ok Tedi Mining Limited, Port Moresby and Tabubil.

Ok Tedi Mining Limited (1989), *Supplementary Environmental Investigations,* Ok Tedi Mining Limited Port Moresby and Tabubil.

Reynolds, L.F. (1978), The population dynamics of barramundi *Lates calcarifer* (Pisces: Centropomidae) in Papua New Guinea, MSc Thesis University of Papua New Guinea.

Roberts, T.R. (1978), 'An icthyological survey of the Fly River in Papua New Guinea, with descriptions of new species', *Smithsonian Contributions to Zoology,* 281, 1-72.

Robertson, C.H. and Baidam, G. (1983), 'Fishes of the Ok Tedi area with notes on five common species', *Science in New Guinea,* 10, 16-25.

Smith, R.E.W. (1988), *Six-monthly Biology Review 11 October 1987 to 30 March 1988,* Ok Tedi Mining Limited, Port Moresby and Tabubil. (Report ENV 88-05).

Smith, R.E.W. Ahsanullah, M and Batley, GE, (1990), 'Investigations of the impact of effluent from the Ok Tedi copper mine on the fisheries resource in the Fly River, Papua New Guinea', *Environmental Monitoring and Assessment,* 14, 315-331.

Smith, R.E.W. and Hortle, K.G. (in press), 'Assessment and prediction of the impacts of the Ok Tedi copper mine on fish catches in the Fly River system, Papua New Guinea' *Environmental Monitoring and Assessment.*

Smith, R.E.W. and Morris, T.F. (in submission), 'The impacts of changing geochemistry on the fish assemblages of the lower Ok Tedi and Middle Fly River, Papua New Guinea', *The Science of the Total Environment.*

Staples, D.J. (1980), 'Ecology of juvenile and adolescent banana prawns, *Penaeus merguiensis,* in a mangrove estuary and adjacent off-shore area of the Gulf of Carpentaria. I. Immigration and settlement of postlarvae', *Australian Journal of Marine and Freshwater Research,* 31, 635-652.

Torres Strait Fisheries Management

Mark Elmer
Queensland Fish Management Authority

Robert Coles
Australian Fisheries Service

Introduction

The purpose of this address is to set out the management arrangements for fisheries resources in Torres Strait and the way in which those arrangements facilitate the sustainable development of those resources, whilst catering for the needs and desires of traditional inhabitants of the region.

The arrangements are extremely complex, reflecting not only the diverse participation in and dependence on those resources by local inhabitants, but also the involvement of State and Commonwealth Australian Governments and the international obligations of Australia in its border relationships with its close neighbour, Papua New Guinea.

Fisheries management arrangements now in place are governed by the provisions of a Treaty with Papua New Guinea ratified by both governments in February 1985, known as the Torres Strait Treaty (see Laffan, this volume). The fisheries themselves within Torres Strait gross some $20-$30 million per year, the prawn and crayfish (or tropical rock lobster) fisheries being the most valuable of those resources.

Three governments are involved in management of those resources:

- Australian Commonwealth;
- Queensland State;
- Papua New Guinea;

whilst four groups of fishermen use those resources, namely:

- Australian traditional inhabitants;
- Australian commercial fishermen;
- Papua New Guinea traditional fishermen;
- Papua New Guinea commercial fishermen.

Torres Strait Treaty

The Torres Strait Treaty has specific effects on management of fisheries in the region. The Treaty:

- defines an area called the Torres Strait Protected Zone (TSPZ) to be separately managed;
- allows for traditional fishing rights and free movement in the zone;
- defines commercial fishing rights but requires that those fisheries be managed in a way which will protect the traditional way of life;
- defines seabed jurisdiction between the two countries, Australia and Papua New Guinea, and;
- defines the fisheries jurisdiction between the two countries.

The Treaty also provides for the concept of "Outside but Near Areas" to enable management arrangements to apply to fisheries resources which are distributed beyond the limits of the Protected Zone.

These characteristics are detailed on the map on the following page. Note:

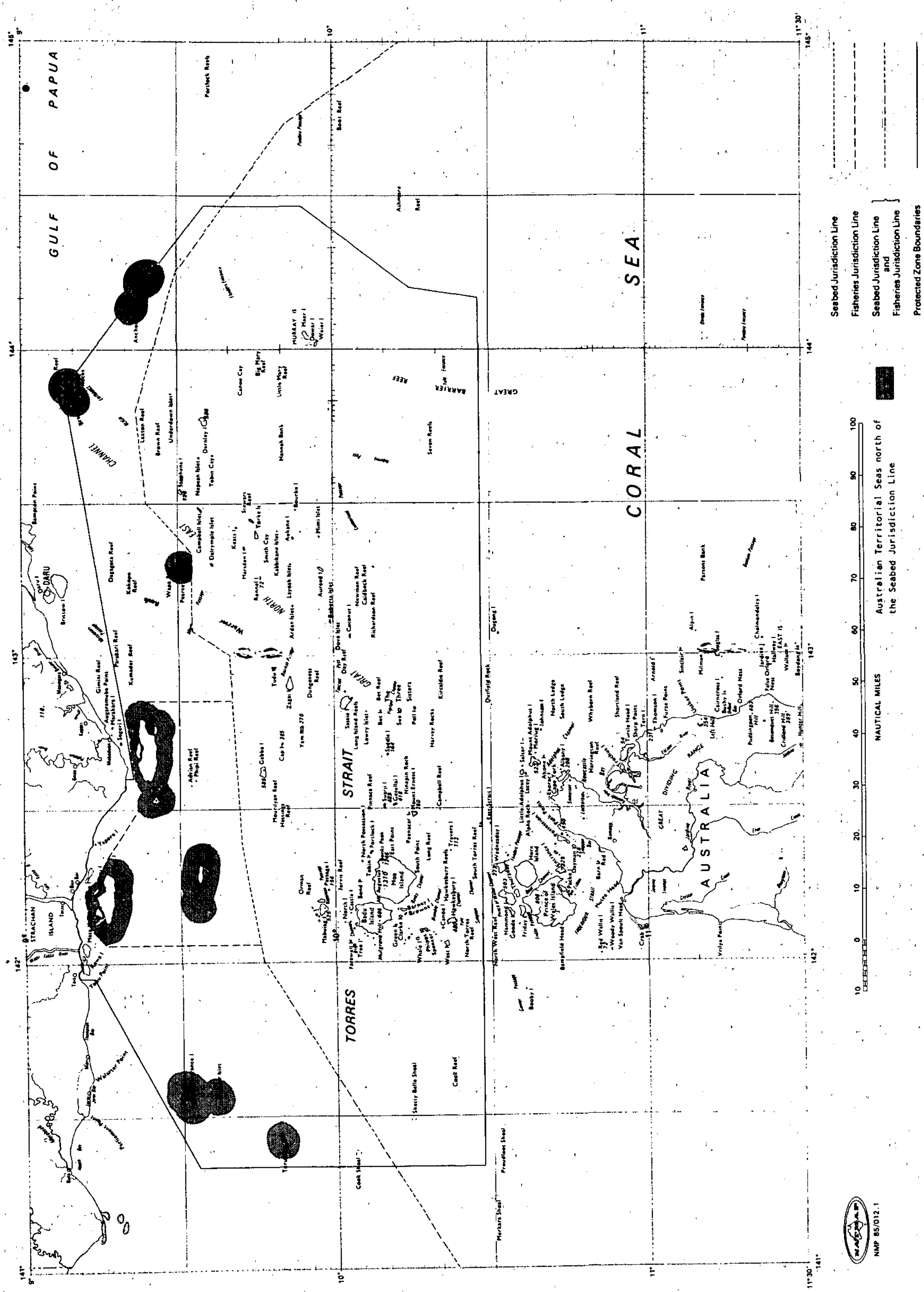
- the boundary of the TSPZ to which the thrust of all management measures apply;
- the seabed jurisdiction line, and;
- the fisheries jurisdiction line, both delineating the area of responsibility of each country.

In addition, Australian jurisdiction extends to a three mile territorial sea around all islands on the PNG side of those jurisdiction lines.

In the case of sedentary animals for example Pearl Shell, jurisdiction is determined by the seabed line. For swimming species, the fisheries jurisdiction line applies. Note also the Outside but Near Areas. These differ from species to species but, on the Australian side for example, on the east coast north from Cape York, they share the same boundary which coincides with the northern limit of jurisdiction of the Great Barrier Reef Marine Park Authority.

Treaty Fisheries and the Protected Zone Joint Authority

Article 22 of the Treaty provides for both countries to enter into agreements to jointly manage specific fish stocks of the Torres Strait. Both governments have entered into agreements to jointly manage six fisheries in the region, namely:


GULF OF PAPUA
CORAL SEA
TORRES STRAIT
AUSTRALIA
Seabed Jurisdiction Line
Fisheries Jurisdiction Line
Seabed Jurisdiction Line and Fisheries Jurisdiction Line
Protected Zone Boundaries
Australian Territorial Seas north of the Seabed Jurisdiction Line
NAUTICAL MILES
NMP 85/012.1

- prawns
- crayfish (tropical rock lobster)
- spanish mackerel
- pearl shell
- dugong
- turtle

together with special arrangements for traditional fishing, and the barramundi fishery adjacent to six Australian islands near the coastline of PNG.

These fisheries are managed within Australian jurisdiction in accordance with Commonwealth law by a body known as the Protected Zone Joint Authority. This Authority is comprised of the federal and Queensland Ministers for Primary Industries.

Remaining fisheries in Torres Strait, including for example reef fish, estuary species, trochus, are managed under Queensland fisheries laws.

Catch Sharing between Australian and Papua New Guinea

The Treaty recognises the rights of both countries to the commercial fisheries of the Torres Strait Protected Zone. This recognition is implemented via the concept of catch-sharing in Article 22 fisheries for prawns, crayfish and pearl shell. Briefly summarised each country's share is determined by a 75%-25% access to an Allowable Catch from its respective jurisdiction, with a 50%-50% share in territorial waters adjacent to certain Australian islands.

Initial schemes for catch sharing on a catch quota basis for each fishery proved extremely difficult to implement. A scheme has now been agreeded upon and in place based on input control, ie. a number of vessels, the number of which can be adjusted on an annual basis given the experience of average catches per day of the five proceeding years. Both countries have agreed to this net sharing scheme whereby one country nominates a number of vessels to fish in the others' waters estimated to be sufficient to take the net catch intended by the Treaty for each fishery.

Australian Prawn and Rock Lobster fishermen agreed not to fish in Papua New Guinea waters in return for an equivalent reduction in the number of Papua New Guinea fishermen allowed to fish in Australian waters.[1] The results of catch sharing arrangements for 1990 are that:

- 8-9 Papua New Guinea prawn trawlers are allowed to fish in Australian waters;
- 27 Papua New Guinea lobster dinghies are allowed to fish in Australian waters;
- 3 Australian pearling boats are allowed in Papua New Guinea waters.

To date, neither country has sought cross endorsement for their commercial vessels. It is likely, given the agreed formulae for catch sharing, that these arrangements will apply until 1993; although not necessarily as both countries could seek to vary the arrangements if an alternative scheme was desired.

It is extremely important to understand that cross border endorsed fishing vessels under these arrangements must comply with all Customs, Quarantine and Immigration controls applying in each country.

Consultative Arrangements

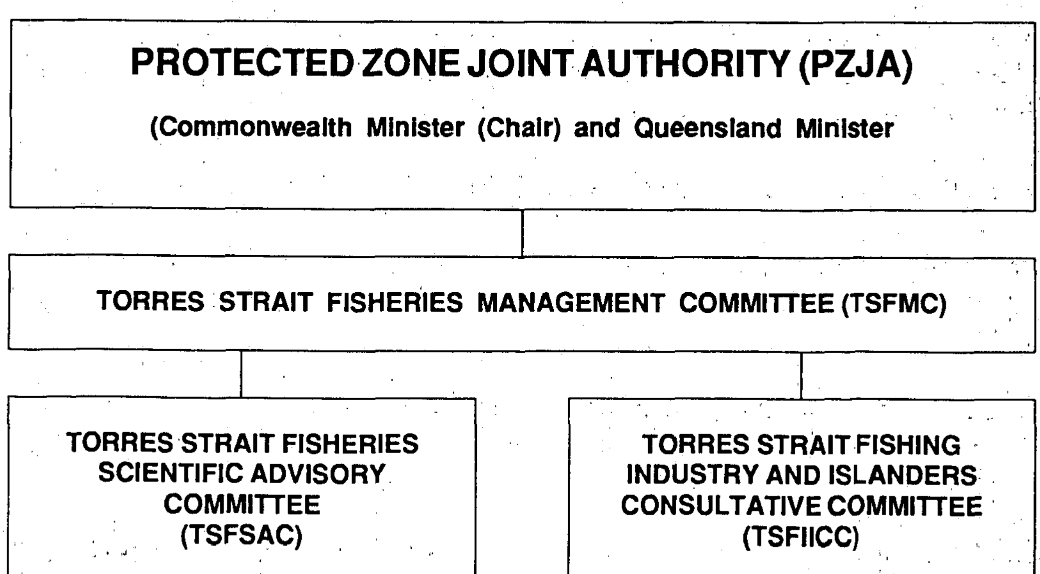
Highly developed arrangements have been implemented for consultation between Australia and Papua New Guinea, between Australian federal and state governments and traditional inhabitants and fishermen.

The Treaty requires Australia and Papua New Guinea to co-operate in the conservation, management and optimum utilisation of fisheries in the Protected Zone. Fisheries management officials of the two countries meet yearly to review arrangements in place and make recommendations to the respective governments on policies and programs of the jointly managed fisheries. Similarly, scientists from the two countries meet annually to review technical and scientific aspects of Protected Zone fisheries. An even greater frequency of co-operation between the two countries fisheries enforcement agencies has been achieved, with shared training and exchange of fisheries officers now in effect.

The Protected Zone Joint Authority has developed a formidable consultative structure with Australian traditional inhabitants and commercial fishermen, for fisheries within the Australian jurisdiction of the Protected Zone.

The following table (Table 1) sets out this structure. You will note that the Joint Authority (PZJA) is advised by the Torres Strait Fisheries Management Committee. This Committee comprises representatives of Islanders and commercial fishermen, with Commonwealth and Queensland fisheries managers and the Chairman of the Scientific Advisory Committee.

Table 1. Protected Zone Joint Authority - Advisory and Consultative Bodies



The Scientific Advisory Committee provides recommendations and advice on fisheries matters to the Management Committee as well as co-ordinating research activities of fisheries agencies in the Zone. Those research activities are dealt with elsewhere in the proceedings of this conference. However the Committee co-ordinated research activities to the value of some $750,000 during 1989/90, for research and monitoring of traditional fishing and the major commercial fisheries in Torres Strait, in accordance with a program determined by the Joint Authority.

The Torres Strait Fishing Industry and Islanders Consultative Committee also advises the Management Committee on fisheries matters. Membership of this Consultative Committee comprises representatives of:

- both the Commonwealth and Queensland governments (5);
- the Queensland Commercial Fishermen's Organisation (7);
- Torres Strait Islander Co-ordinating Council, (7);
- the Scientific Advisory Committee (1).

Deliberations of the Consultative Committee are facilitated by the activity of fishery or issue-specific Working Parties, for Protected Zone fisheries.

These Committees have met at least annually over the past six years since the Treaty came into force. The Working Parties, a relatively new innovation, meet more frequently, enabling greater refinement of management principles adopted by the Joint Authority in its more formative years.

Officers on behalf of the Joint Authority also participate in and contribute to the Foreign Affairs Consultative structure attending meetings of:

- the Treaty Implementation Committee (Australian);
- the Treaty Liaison Committee (Australia and PNG);
- the Joint Advisory Council (established by the Treaty);
- the Environmental Management Committee (Australia and Papua New Guinea).

Members of those other Committees are frequently invited to attend and advise members of the Joint Authority's Industry and Islander Consultative Committee to facilitate consultation and co-operation on Treaty matters.

Status of Torres Strait Joint Authority Fisheries

The foregoing demonstrates an extensive consultative approach adopted by the Protected Zone Joint Authority in its management responsibilities for fisheries of the Torres Strait.

Commercial fishing is clearly the most economically important activity in Torres Strait, and provides the greatest opportunity for financial independence and stability of Islander communities in the region.

Furthermore, contrary to some opinion, fish stocks of Torres Strait have been stable with consistent annual harvests. Variability does occur seasonally, but the greatest fluctuations are market driven.

The Joint Authority has a policy of maximising the opportunities for Islander participation in all sectors of the fishing industry. Non-Islander participation is well established in the Protected Zone particularly in the prawn fishery.

However the Joint Authority has frozen further expansion of non-Islander involvement in fisheries where there is scope for additional expansion. In effect no additional non-Islander participants will be licensed to fish in Joint Authority fisheries. Furthermore, as ownership of existing non-Islander owned vessels changes, elements of licences are required to be forfeited to reduce non-Islander participation in fisheries in the longer term.

The prawn fishery which has developed as an extension of the East Coast fishery by non-Islanders, is considered to be over-capitalised. The Joint Authority has implemented policies which set out to redress this problem, by removing effort from the fishery; but it has set aside an opportunity for Islanders to trawl for prawns in the future.

Status of stocks

Some features of management arrangements for Torres Strait fisheries and the status of stocks are as follows.

The prawn fishery has a catch value of $17-$20 million annually. Some 130 vessels are licensed to engage in this fishery and that number is reducing annually by 10% through management intervention. The main species targetted are tiger, endeavour and king prawns with catches in excess of 1000 tonnes per year (see Table 2). Tiger and king prawn catches have been relatively constant over time with endeavour prawn catches slowly increasing. Catch per unit of effort has averaged 15-20kg per hour over recent years. In addition to the restrictive policy to reduce the level of participation in the fishery through licensing measures, the Joint Authority has set aside large areas of Torres Strait free from trawling to protect nursery and juvenile prawn stocks from exploitation. These areas include the entire Protected Zone west of the Warrior Reef complex, together with the recent addition of a large area of the "old pearling ground" adjacent to Darnley and Murray Islands in the East.

Table 2.

Penaeid Prawn Catch (Tonnes)

YEAR	CATCH
1987	1094
1988	1151
1989	1164

These permanent closures are complemented by seasonal closures in the Great North East Channel, adjacent to Warrior Reef for the first five months of each year; coupled with a total closed season in the zone for the months of December, January and February. Various other restrictions such as net mesh size and vessel dimensions are also in force in the prawn fishery.

Joint Authority management objectives for the Tropical Rock Lobster Fishery and agreed with Papua New Guinea are:

- to conserve stocks of the species;
- to maximise the opportunities for traditional inhabitants of both Australia and New Guinea to participate in the fishery, including the strategy of managing the fishery as a dive fishery, and;
- to promote the dive fisheries for the species in Torres Strait and in the waters near Yule Island.

The strategy for growth of the Islander sector relies on containing growth of the non-Islander sector, co-incidentally encouraging expanded participation in the fishery by Islanders.

Catches from the fishery are valued at $4-$5 million annually with approximately 200 Islander boats and 30 European boats operating in the fishery. Annual production has averaged 200 tonnes, with an occasional peak season for example 350 tonnes in 1986 (Table 3). Various other controls apply in the fishery, including a minimum legal size prohibition for protection of juveniles of the species, and a ban on trawling for rock lobster in the zone.

Table 3. Tropical Rock lobster catch kg/month (From processor and shipping company records).

	Year							
Month	1983	1984	1985	1986	1987	1988	1989	1990
JAN	4711	5485	6707	16654	13178	16988	6925	11302
FEB	9749	8896	18416	34759	11347	14587	16897	27046
MAR	12364	11790	11379	51139	34879	18927	34554	12900
APR	8066	8956	22276	44677	29087	25617	25566	27752
MAY	13584	10793	17404	62105	13832	29279	41314	15887
JUN	8462	8549	13995	32321	19419	27488	33267	23644
JUL	9148	18320	18254	42724	19511	16952	17613	24427
AUG	8775	12863	17529	34951	27712	15750	30267	13388
SEPT	9038	4956	10103	18112	28010	20617	20323	9298
OCT	2606	3773	16080	4124	22361	10944	3444	
NOV	704	2111	17740	2741	13753	9701	5610	
DEC	2202	4033	30255	4869	9040	9813	7109	

An important seasonal fishery for spanish mackerel also occurs in Torres Strait, and is managed by the Joint Authority. Again a principal management objective is to reserve expansion into this fishery for Islanders, and licensing policies are in force to give effect to that objective. Some 30 boats are licensed to operate in this fishery by the Joint Authority although only a few actively participate, and catches are valued at $500,000 annually.

Measures for the Rock Lobster fishery have been broadly replicated in the Pearl Fishery by the Protected Zone Joint Authority. On the basis of recent surveys, the abundance of pearl shell is low and present catches are primarily incidental to rock lobster and trochus fishing activities. Minimum and maximum shell size prohibitions are presently in force. The continued viability of local pearl culture farms is viewed by participants as crucial to the continuity of local pearling activities, and measures in force effectively direct catches from the fishery to those farms. Other measures including a three month closed season on pearling are also in force.

More detailed discussion of Turtle and Dugong stocks in Torres Strait is presented in other papers in these proceedings. Protection and conservation of these animals is the responsibility of the Protected Zone Joint Authority, which has active management measures in force.

In the case of dugong, commercial fishing is prohibited throughout both the Australian and Papua New Guinea sections of the Torres Strait Protected Zone. Traditional fishing for consumption (but not for sale) is permitted and catches are monitored by the Australian Fisheries Service. A survey conducted in 1987/88 indicated the population to be some 11,000 to 14,000 individuals and further surveys together with catch data will be used to monitor changes if any in the status of dugong stocks. A dugong sanctuary has been implemented in the western areas of Torres Strait.

Commercial fishing for turtle is prohibited by the Protected Zone Joint Authority. Green turtle stocks are considered endangered on a global basis, however available data suggests that traditional fishing activities in Torres Strait is unlikely to be a major contributor to a decline in such stocks. There is little exploitation of other turtle stocks in Torres Strait.

To encourage conservation of dugong and turtle, the Joint Authority has developed and implemented an extensive education program in Torres Strait Islander communities. This program, combining personal meetings and educational videos in appropriate Islander dialects, is presented for all ages in Islander communities. It has also been provided to Papua New Guinea fisheries officers for presentation in their western provinces, with appropriate amendments for local language dialects.

Other Fisheries

As mentioned earlier in this paper, remaining fisheries in Torres Strait other than those managed by the Protected Zone Joint Authority fall within the ambit of Queensland fisheries legislation. These fisheries include commercial activities for trochus, reef fish species and all recreational fisheries.

The focus on fisheries management in Torres Strait has moved over the past year to new initiatives in these other fisheries and appropriate consultative mechanisms are in the process of adoption. Those mechanisms will most likely complement the structure now in place and administered by the Joint Authority.

The trochus fishery is arguably the most economically important of these fisheries. Management arrangements for that fishery, which is valued at approximately $2 million annually, comprise:

- a total allowable catch quota of 150 tonnes annually, together with;
- a minimum and maximum shell size prohibition.

All commercial exploitation of this resource in Torres Strait has been set aside for the benefit of Torres Strait Islanders. A conservative catch quota has been adopted recognising previous experience with the fishery and based on research advice. The quota for 1990 in Torres Strait has been reached recently and the fishery closed for the remainder of the year.

A line fishery for demersal fish species also exists but has been subjected to only low levels of fishing effort. Whilst the fishery is subject to all of the management controls applying in the general Queensland fishery, for example minimum fish size prohibitions, licensing requirements etc., it is perceived as being under-developed at this time.

A similar situation is considered to exist for recreational fisheries. The conditions of such fisheries are usually reflected by population densities in adjacent areas and/or tourism growth. At present, recreational fishing is an important pastime for local residents but fishery effort levels are viewed as sustainable. A future challenge for fisheries managers will be the measurement and monitoring of that fishing effort and moves are presently underway to meet that challenge on the east coast.

Surveillance and Enforcement

There are times when it is necessary for management arrangements to be enforced if conservation strategies for our resources are to be successful. The Queensland Boating and Fisheries Patrol is the agency charged with this responsibility in Torres Strait on behalf of the Joint Authority and for fisheries under Queensland jurisdiction.

Duties are carried out using personnel at the Thursday Island operations centre and the purpose-built fisheries patrol boat "Wauri". Coastwatch surveillance flights complement the activities of these personnel. The programs are carried out on a graduated response basis which seek to achieve voluntary compliance through education and extension efforts before resorting to legal mechanisms. Some 30% of human resources are dedicated to extension and community education efforts.

Assistance is also provided by Patrol staff to facilitate the expansion of Islander involvement in commercial fisheries, in line with Joint Authority policy to that effect.

Summary

Fisheries resources of the Torres Strait are an important part of the economy and traditional way of life in Torres Strait. Complex legislative measures are now in place and fisheries management agencies have visibly demonstrated a commitment to ensuring their success. Those measures reserve in no small way the benefits obtainable from the sustained managed development of those resources for the people of Torres Strait.

Note

[1] Brochures providing greater details of the fisheries issues of the Treaty and Catch Sharing Arrangements are available.

Rock Lobster Fisheries : Enhanced commercial yields by artificial shelters?

Bruce F. Phillips
CSIRO Marine Laboratories

Chris Crossland
CSIRO Institute of Natural Resources & Environment

Abstract

Globally, wild-stock fisheries of rock lobsters are considered to be essentially fully exploited. Fishing methods based on use of artificial shelters in juvenile nursery areas are being applied to increased catches of tropical rock lobsters, especially in Cuba and the Mexican Caribbean. Since the 1960s, annual catches in Cuba have risen from about 500 tonnes to 12 000 tonnes (value US$100 million) and this appears to be correlated with the use of increasing numbers of artificial shelters. Similarly in Quintana Roo, Mexico with increases from 25 tonnes to 350 tonnes per year.

Comparison is made between the habitat and lobster species of the Caribbean and the Torres Strait regions. The present catch of the tropical rock lobsters in Torres Strait is valued at about $5 million annually. The use of artificial shelters in Cuba and Mexico is outlined and also the increased catches apparently associated with use of shelters. The possibility and practicability for application of artificial shelters to the Torres Strait rock lobster fishery is discussed, including the potential for at least a five-fold increase in catch. However, the need for tactical research to address the mode of operation of the shelters (do they increase yield or only aggregate existing stocks?) and the extent of environmental impact of shelters on habitat is emphasised. The necessity to understand these two key elements before application of shelters to rock lobsters fisheries in Australian waters is emphasised.

Introduction

Rock (or spiny) lobster fisheries are associated with coastal and continental shelf habitats in temperate and coastal waters of most of the world's seas (Morgan 1980). Subsistence fishing of rock lobsters is common, especially in tropical and subtropical localities. Major fisheries are found in the tropics (e.g. *Panulirus argus* in the Caribbean and *P. polphagus* in South East Asia), in the subtropics (e.g. *P. cygnus* in Western Australia) and for *Jasus* spp. in temperate waters, particularly off southern Africa and off southern Australia and New Zealand.

In Australia, the rock lobster fisheries yielded 17 000 tonnes in 1987-88, worth A$240 millions (Smith 1989); about one third of the annual gross value of Australian fisheries production. This catch was predominantly from the Western Australia fishery for *P. cygnus* (60%), with 35% of the catch from *Jasus* spp. in temperate waters and some 5% of the catch from *P. ornatus* in the Torres Strait.

World market demand for rock lobsters remains high and continues to increase in volume of demand and price of product, despite a recently reduced demand in Japan for Australian product which was associated with the Emperor's demise. Globally, rock lobster fisheries are considered to be fully exploited, within the limits of usual fishing methods.

A number of options are being actively researched to try to enhance the availability of lobsters. These include evaluation and trials to develop aquaculture techniques (Phillips 1988). Various approaches have been used for intervention to increase wild-stock yields, including partial aquaculture of juveniles that can be "seeded" into nursery areas (e.g., the American lobster, *Homarus americanus*, in the north eastern United States (Van Olst et al. 1980)). However, there is no evidence to show that this approach has contributed to the catch of the commercial fishery. Of particular interest and apparent value has been the application of artificial shelters in benthic habitats, as applied to *Panulirus argus* in Caribbean waters of Mexico (Miller 1982, Lozano *et al.* 1989), Cuba (Cruz *et al.* 1987) and Bermuda (Evans 1987).

The following describes the artificial shelter fisheries in the Caribbean region and considers the high potential for increased yield in the Torres Strait fishery through use of artificial shelters. It also addresses current problems and research which is necessary before the introduction of artificial shelters, to ensure that the technique will be both applicable and ecologically sustainable.

Artificial Shelters

Over the last two decades, the introduction of artificial shelters into the Cuban and Mexican Caribbean lobster fisheries has correlated with increased catches of tropical rock lobsters (mainly *Panulirus argus*). Ten-fold improvements are characteristic of some areas. In the Caribbean, artificial shelters have been placed in large embayments which have extensive and rich seagrass beds but few reef or rock outcrops to provide shelter.

What are they?

The artificial shelters in the Caribbean region – known as *pesqueros* in Cuba and *casita cubana* in Mexico – have been used since the 1940s in Cuba and were introduced to Mexico by Cuban migrants during the 1960s. The shelters are of variable but simple and cheap construction, and are generally constructed as a flat timber or ferrocement surface (about 4m^2) supported about 20 to 40 cm above the substratum. In Bahia de la Ascension, Quintana Roo, Mexico palm trunks are used as supports; in the Gulf of Batabano, Cuba hardwood (mangrove) logs are commonly used as supports along with other materials. The shelters are operated as permanent seabed habitats which provide shelter for rock lobsters in seagrass foraging grounds.

How do they work?

The artificial shelters apparently provide a critical refuge from predators yet allow optimum foraging in the food-rich seagrass ecosystems. The shelters may:

- reduce predation, thereby increasing the yield of lobsters;
- increase food accessibility by providing shelter in locations near food sources, leading to increased growth and survival;
- concentrate the lobsters, making them more vulnerable to capture;
- provide a combination of some or all of these factors.

Little applied research has been done to understand the detailed function of the shelters (eg. reduced predation rates, greater aggregation of existing animals at different growth stages, recruitment to shelters). Preliminary studies show that there is a relationship between the size of the shelter and the mortality of *Panulirus argus* (Eggleston *et al.* 1990). However the optimum design and placement of shelters for maximal catch (eg. form and construction of shelter, depth, position, density of shelters on the seabed) are essentially unknown. In Bahia de la Ascension, Mexico evaluations have indicated an optimum inter-casita spacing of 20 m (Miller and de la Torre 1987), but this density value is based on empirical rather than experimental evidence.

How are they used?

The artificial shelters are positioned in the shallow seagrass-dominated habitats. The shelters are regularly checked by fishermen, working from small day-trip dinghies in Mexico and from larger (18 metre) boats in Cuba where fishing trips to a large number of pesqueros last about ten days followed by a five day rest period (Anon 1989).

The shelters are lifted by divers, usually after a net has been placed around the shelter, and size animals are collected by gaff or from the nets. Up to 200 lobsters are caught per shelter, which is higher than any other gear used in the Cuban and Mexican fisheries.

In Cuba, a range of fishing gear is used for rock lobsters including various types of traps, bully nets, trap nets (jaulons, especially during the mass migration) and car tyres (Cruz *et al.* 1987). During the 1970s the Cuban fishery introduced large numbers of artificial shelters which now comprise some 66% of the total fishing gear and produce about 50% of the catch (6000 tonnes annually, in the 1984-88 period).

What are the yields?

Since the late 1960s, the annual catch of the Cuban rock lobster fishery has risen from about 500 tonnes to 12 000 tonnes (value US$100 millions) and most of this increased yield appears to be correlated with the use of increasing numbers of pesqueros. A similar increase from about 25 tonnes to 350 tonnes (value U$7 millions) has occurred in Quintana Roo, Mexico again apparently correlated with the use of casitas.

Potential for Shelters in the Torres Strait Fishery

Application

High potential exists to significantly increase the rock lobster catch of the Torres Strait fishery through application of artificial shelters to the extensive seagrass communities of the nursery areas of the ornate rock lobster *Panulirus ornatus*. Indeed, there is evidence that this would not represent an importation of technology, but rather would be an enhancement of an original invention by the Torres Strait Islanders. Murray Islanders operate *keiar meta* (rock lobster houses); areas in which lobsters obtain shelter in holes and crevices of reef rock. In the past, additional shelter had been built in these areas by piling up coral to form shelters (Johannes and Macfarlane 1990).

The biology and fishery characteristics of *P. ornatus* in Torres Strait (Phillips and Trendall 1989) show many similarities to *P. argus* of the Caribbean (Lozano *et al.* 1989), including:

- habitats of tropical seagrass communities with apparently limited natural shelter;
- rapid growth rates (with entry to the fishery being rapid and ensuring a rapid response by the fishery to introduction of shelters);
- annual migration pattern is characteristic of both species;
- fishing operations are based on small fishing units and operate from cooperatives or village enterprises, and;
- harvesting techniques are based on a diver fishery (hence no new technology would be needed in Torres Strait to harvest the catch).

These analogous factors contribute to the potential for application of artificial shelters to enhance the Torres Strait rock lobster fishery. In addition, the collection and marketing infrastructure exists, and will be able to handle increased yields.

Economics

Catches of rock lobster in the Torres Strait are currently low, with an annual value of the order of A$5 millions. The management objective of this fishery is to preserve the stock for the indigenous people of the area, hence any increase in production would have an important impact on the economy of the area.

Calculation of a dollar value that could be achieved by introduction of the artificial shelter technique to the Torres Strait fishery is difficult, as we do not understand how the shelters operate. A very conservative estimate suggests that catches would be at least doubled, representing on current values, an additional A$5 million per year. By analogy with Cuba and Mexico experiences, it is reasonable to expect a higher return, with potential for at least a five-fold increase in catch (i.e., a value improvement up to A$25 million per year).

Dangers

In Cuba, large numbers of pesqueros have been put into the lobster grounds annually. The lack of research to understand function and operation of the artificial shelters, has resulted in too many pesqueros being put into the fishery and a dramatic drop in the catch-per-unit-effort (by about one-third per pesqueros, 1980-1988). Obviously, this is not leading to maximum economic efficiency for the rock lobster fishery in Cuba. We must ensure that this pattern does not occur when artificial shelters are introduced into Australia; the appropriate scientific knowledge must be gained before such introduction.

Problems and Need for Tactical Research

Currently there are limitations militating against the introduction of the artificial shelter technique. First, despite the use of pesqueros in Cuba since the 1940s and casitas in Caribbean Mexico since the 1960s, their function is unknown. Do they just concentrate existing stocks of rock lobsters and make them more vulnerable to fishing, or do the shelters increase production of the lobsters in the coastal ecosystems? There is common belief amongst fishermen, and some managers, that the latter applies, however, there is no scientific evidence to support this belief.

Second, we do not know the effect of artificial shelters on the stability and structure of seagrass beds, which are the common habitats for placement.

Answers to these questions are imperative before application of the artificial shelter technique in Australia, in part to ensure that from knowledge of function, appropriate management options are developed for placement and operation, and in part to ensure that the fishing technique is environmentally sustainable.

To make certain that these questions are met, we have developed an experimental field program with Cuban and Mexican scientists to scientifically evaluate the key elements, viz:

- How artificial shelters enhance rock lobster yields (in Mexico);
- Optimum density of placement of artificial shelters for maximum yields (in Mexico, by introduction to "virgin" areas; in Cuba, by experimentation in existing catch-monitored fishing areas);
- Effects of artificial shelters on the stability and structure of seagrass habitats (in Mexico and Cuba, different tropical seagrass communities);

This program builds on our earlier association with Mexico and Cuba (supported by DITAC, FAO, CSIRO), and our recent visits to each country in 1990.

The most cost-effective way to find answers to these questions is to do the scientific work in Cuba and Mexico, where the necessary catch statistics for the experimental areas are now available and data from preliminary assessments exist. We are currently seeking support from DITAC, through the Bilateral Science Agreements, and from other funding agencies to carry out the work with a view to seeking implementation of the artificial shelter technique three years from now, assuming a successful outcome from the research.

Literature Cited

Anon (1989), 'The Cuba connection', *Western Fisheries*, July-August, .26-28.

Cruz, R., Baisre, J.A., Diaz, E., Brito, R., Garcia, C., Blanco, W. and Carrodegas, C. (1987), *Atlas, Biologico-pesquero de la langusta en al archipelago Cubana*, Department of Fisheries, Havana, Cuba. 125 .

Egglestone, D.B., Lipcius, R.N., Miller, D.L. and Coba-Cetina, L. (1990), 'Shelter scaling regulates survival of juvenile Caribbean spiny lobster *Panulirus argus*', *Mar. Ecol. Prog. Ser.* 62,79-88.

Evans, C. (1987), Population dynamics of spiny lobsters, *Panulirus argus* and *Panulirus guttatus* (Latreille) at Bermuda, 1986/87, University of Southhampton, Southhampton, U.K. (Final report)

Johannes, R.E. and MacFarlane, J.W. (1990), 'Assessing customary marine tenure systems in the context of marine resource management: A Torres Strait example', In K. Rundle and R.E. Johannes (eds.), *Contending with Global Change. Study No. 2. Traditional Marine Resource Management in the Pacific Basin: An Anthology*, UNESCO/ ROSTSEA, Jakarta, Indonesia. 243-261.

Lozano, E., Briones, P. and Phillips, B.F. (1989), 'The spiny lobster fishery in Bahia de la Ascension, Quintana Roo, Mexico', In E. Chavez (ed.), *Proc. Workshop Mexico-Australia Mar. Sci., Merida, Mexico, 6-17 July 1987*, 378-391.

Miller, D. (1982), 'Construction of shallow-water habitat to increase lobster production in Mexico', *Proc. Gulf and Caribb. Fish. Instit.* 34, 168-179.

Miller, D. and de la Torre, R. (1987), Update on the Mexican Caribbean's artificial habitat-based spiny lobster (*Panulirus argus*) fishery: the evaluation of design, material and placement options. (Unpublished Technical Report).

Morgan, G.R. (1980) 'Population dynamics of spiny lobsters', In J.S. Cobb and B.F. Phillips (eds.), *The Biology and Management of Lobsters. Vol. 11. Ecology and Management*, Academic Press Inc., New York. 189-217.

Van Olst, J.C., Carlberg, J.M. and Hughes, J.T. (1980), 'Aquaculture', In J.S. Cobb and B.F. Phillips, *The Biology and Management of Lobsters. Vol. II. Ecology and Management*, Academic Press Inc., New York. 333-384.

Phillips, B.F. (1988), 'The potential for rock lobster mariculture in Australia', *Proc. First Aust. Shellfish Aquaculture Conf., Perth 1988*, 294-300.

Phillips, B.F. and Trendall, J.T. (1989), 'Management of the ornate rock lobster (*Panulirus ornatus*) resources in the Torres Strait', In E. Chavez (ed.), *Proc. Workshop Mexico-Australia Mar. Sci., Merida, Mexico, 6-17 July 1987*, . pp. 424-432.

Smith, P. (1989), 'Outlook for the fishing industry', In *National Agricultural Outlook Conference, 17-19 Jan. 1989*, Australian Bureau of Agricultural and Resource Economics, Canberra. 1-11.

Trace Element Profiles of Clams (*Tridacna crocea*) Gathered from Various Sites in Torres Strait

Gerry M. Murphy, Animal Research Institute
Queensland Department of Primary Industries

Clive Turnbull, Northern Fisheries Centre
Queensland Department of Primary Industries

Robert A. Manning, Animal Research Institute
Queensland Department of Primary Industries

Robert Pearson, Division of Fisheries and Wetlands Management
Queensland Department of Primary Industries

Abstract

A total of 43 specimens of Tridacna crocea were collected from eight sites in the Torres Strait. After dissection and digestion cadmium (Cd), lead (Pb), mercury (Hg), copper (Cu) and zinc (Zn) were determined in samples of adductor muscle, mantle and visceral mass. The levels of lead, mercury, copper and zinc were not considered biologically significant and all levels were less than one tenth (1/10) of the relevant maximum permitted concentrations (MPC) in food intended for human consumption. Significant levels of cadmium (range 0.29 - 1.85 mg kg^{-1} Fresh Weight) were found in adductor muscle and mantle tissue at all sites. However no adductor muscle or mantle tissue levels of cadmium exceeded the MPC of 2.0 mg kg^{-1} Fresh Weight. The highest levels of cadmium (3.31 mg kg^{-1}) were found in visceral samples.

Introduction

This study was undertaken in response to the continuing uncertainty about the impact on the marine resources of the Torres Strait, of large scale mining operations in the Fly River catchment area of Papua New Guinea and within the strait itself (Horn Island). Its prime objective was to establish preliminary trace element profiles of suitable indicator species and to assess these results in terms of the standards established for food for human consumption.

The burrowing clams, *Tridacna maxima* and *T. crocea* are acknowledged (Denton and Heitz, 1990) as fulfilling several of the prerequisites for bio-indicators (Phillips, 1980).

In this paper we report the levels of cadmium (Cd), lead (Pb), Mercury (Hg), copper (Cu) and zinc (Zn) in *T. crocea* collected at a number of sites throughout the Torres Strait area.

Materials and Methods

Sample Collection

A total of 43 specimens of *T. crocea* were collected from eight sites within the Torres Strait during the period March to November 1989. The location of each site, its allocated site number, the date of sampling and the number of clams collected at that site, are given in Table 1.

Clams, 10 to 12 cm in length, were dislodged from their surroundings with a short steel bar. The level of force used was kept to a minimum to prevent damage to the clam. Once dislodged, clams were sealed in individual plastic (PVC) bags and snap frozen for transport to the analytical laboratory. On-board processing at the time of collection was considered but rejected as impracticable, due to the lack of appropriate facilities on the collection vessel. It should be noted that samples were collected opportunistically during scheduled prawn abundance research activities.

Table 1. Sampling demographics for *T. crocea* survey in the Torres Strait

Site No.	Location	N° Clams collected (n=)	Date
1	South Ledge	10	27/04/89
2	West Island	5	28/04/89
3	Horn Island (A)	5	27/04/89
4	Horn Island (B)	5	27/04/89
5	Caldbeck Reef	6	25/03/89
6	Coconut Island	5	25/03/89
7	Marakai Reef	3	28/09/89
8	Robert Island	2	30/11/89
9	Campbell Island	2	01/12/89

Sample preparation and analysis

Prior to analysis the shells of frozen (-40°C) clams were scrubbed free of any loosely adhering material using surgical nylon scrubbing brushes and ultrapure analytical grade water (>18 megohm cm^{-1} resistivity). Clams were then placed in a horizontal laminar flowhood and partially thawed. In this condition (part frozen), the clams were physically opened and sub-samples of mantle and posterior adductor muscles were removed using plastic forceps and ground quartz scalpels. The digestive gland was removed and a sample of the visceral mass but excluding the kidney tissue was collected. This required the use of stainless steel surgical scalpels. As stated, the tissue mass surrounding the kidney and the kidney *per se* were not sub-sampled due to the obvious tissue changes and consequent leakage of excreta into surrounding areas during the freezing and partial thawing process. At all times care was taken to prevent within and between sample cross contamination. Precautions included pre-soaking of all sample containers and dissection apparatus, including poly-propylene dissection boards, in 10% V/V A.R. nitric acid, and frequent washing/rinsing of dissection apparatus in ultrapure analytical water. Disposable surgical gloves were worn at all stages of the sampling procedure.

Depending on the tissue sampled, one to two gram aliquots of material were weighed into PTFE digestion vessels, ultrapure nitric acid added, the vessel sealed and the sample digested in a microwave device (CEM Corporation, USA – Model MDS 81D). Analytes of interest were measured by appropriate atomic absorption spectroscopy techniques (Cu and Zn by flame; Hg by cold vapour; and Cd and Pb by graphite furnace) using a Varian Spectra 40 system.

Accuracy and reproducibility within and between analytical procedures were verified by the continuous use of a certified reference material (DORM-1 – National Research Council, Canada).

Results

Table 2 shows the level of reporting (LOR) and the maximum permitted concentration (MPC) for each of the elements of interest. It should be noted that all results are expressed on an 'as received' fresh weight basis. This permits meaningful comparisons with the relevant MPC's. In addition, the LOR values for Cu and Zn of 0.5 mg kg^{-1} F. Wt. were set with their respective MPCs in mind (70 and either 1000 or 150 mg kg^{-1} F. Wt respectively). These higher LOR values (0.5 mg kg^{-1}) should not be confused with the respective detection limits which are typically 50 fold lower in the AAS system described in this paper.

Table 2. Reporting criteria for *T. crocea* analyses in the Torres Strait

Element	Level of Reporting (LOR) (mg kg^{-1} Fresh Wt.)	Maximum Permitted Concentration (MPC) (mg kg^{-1} Fresh Wt.)
Cadmium	0.005	2.0
Mercury	0.01	0.5
Lead	0.05	2.5
Copper	0.05	70.0
Zinc	0.05	1000.*
		150.**

* MPC for molluscs ** MPC for fish

Tables 3, 4, 5, 6 and 7 indicate the mean concentration (±SD) of Cd, Pb, Hg, Cu and Zn respectively for each of the three tissue types at the various sampling locations.

With the exception of Cd, none of the elements analysed in either of the muscle portions or the visceral mass exceeded one tenth (1/10) of the MPC value. Clams from site 3 (Horn Island A) showed the highest Pb levels in both muscle and gut tissues. Comparable gut Pb levels were present at both sites 8 and 9 but these were not reflected in muscle samples. Horn Island samples (sites 3 and 4) were consistently high for Zn compared to the rest of the sampling locations, although the highest individual Zn levels were found in one clam from site 9 (Robert Island). In keeping with the distribution of Zn levels, Cu concentrations were highest at both of the Horn Island sites and also at Caldbeck Reef (site 5). Mercury levels appeared uniformly low at all sampling sites.

Significant Cd levels (≥1/2 MPC) were found in muscle tissues at four sites (West Island, Horn Island, Caldbeck Reef and Coconut Island). The highest muscle Cd level of 1.85 mg kg^{-1} F. Wt. was found in mantle tissue from Caldbeck Reef. Visceral tissue Cd levels clearly indicate the origin of these relatively high muscle levels.

Discussion

The opportunistic nature of this survey necessarily restricts the inferences that can be drawn from these results. Nevertheless the results do provide indicative profiles of some heavy metals and biologically critical trace elements in a wide range of environments.

The results for Cd are significant in the context of the MPCs for this element in food substances for human consumption (Rayment, 1990) and are in keeping with levels found in another species (*Penaeus esculentus*) from this general area (Murphy unpublished data). Given this background, it would seem prudent to determine with some priority the Cd status of other Torres Strait marine sourced products intended for either local or export consumption.

Sites 3 and 4 on Horn Island were adjacent to areas recently mined for gold. Associated activities are a plausible explanation for the Pb and Zn levels found in clams at these sites. However it is less evident as to what factor(s) may account for the Pb and Zn levels found at Robert and Campbell Islands. Originally these were included to represent pristine or at least minimally disturbed locations.

The Cu levels found in this survey appear to be consistent with the limited results for this element in *Tridacnid spp.* in other environments. Our limited sampling shows no evidence of any gross Cu accumulation at this juncture that might be attributed to large scale mining activities. However such assertions can only be substantiated through a much higher intensity sampling effort.

Overall this study does add support to Denton's proposed use of *T. crocea* as appropriate bio-indicators for this area (Denton and Heitz, 1990). Just as importantly, it has helped us establish manageable protocols for the retrieval of such indicators from remote areas and their subsequent transport to, and analysis in, appropriately equipped laboratory facilities.

Table 3. Mean (± SD) cadmium content of *T. crocea* sampled at various sites in the Torres Strait

SITE (n=)*	Mean Tissue Level (± SD) (mg kg^{-1} Fresh Wt.) Adductor	Mantle	Visceral Mass
1 (n = 10)	0.347 (.078)	0.484 (.08)	1.81 (.34)
2 (n = 5)	0.452 (.039)	0.85 (.208)	2.56 (.44)
3 (n = 5)	0.616 (.195)	0.712 (.386)	1.15 (.38)
4 (n = 5)	0.63 (.118)	1.054 (.278)	1.476 (.822)
5 (n = 6)	0.387 (.069)	0.97 (.44)	1.68 (.696)
6 (n = 5)	0.688 (.41)	0.864 (.253)	1.834 (.45)
7 (n = 3)	0.47 (.136)	0.53 (.30)	2.3 (.408)
8 (n = 2)	0.41, 0.30	0.52, 0.29	3.31, 1.35
9 (n =2)	0.61, 0.31	0.57, 0.38	2.96, 1.63

* Where less that 3 samples were collected at any one site individual values are given.
** Maximum permissible concentration for human consumption is 2.0 mg kg^{-1} Fresh Wt.

Table 4. Mean (± SD) lead content of *T. crocea* sampled at various sites in the Torres Strait

SITE (n=)*	Mean Tissue Level (± SD)** (mg kg^{-1} Fresh Wt.) Adductor	Mantle	Visceral Mass
1 (n = 10)	≤ 0.05	<0.05	≤ 0.05
2 (n = 5)	<0.05	<0.05	≤ 0.05
3 (n = 5)	0.062 (.027)	0.144 (.127)	0.104 (.053)
4 (n = 5)	≤ 0.05	≤ 0.05	<0.05, 0.09 [n=1]
5 (n = 6)	≤ 0.05	≤ 0.05, 0.11 [n=1]	<0.05
6 (n = 5)	≤ 0.05	0.07, 0.10, <0.05	<0.05
7 (n = 3)	≤ 0.05	≤ 0.05	≤ 0.05
8 (n = 2)	0.03, 0.05	0.01, 0.05	0.13, 1.28
9 (n = 2)	0.03, 0.05	0.04, 0.05	0.12, 0.06

* Where less than 3 samples were collected at any one site individual values are given.
** Where no (Standard Deviation) is quoted, all samples contained ≤0.05 mg kg^{-1} Fresh wt and statistical analysis was not carried out.
*** Maximum permissible concentration for human consumption is 2.5 mg kg^{-1} Fresh Wt.

Table 5. Mean (± SD) mercury content of *T. crocea* sampled at various sites in the Torres Strait

Mean Tissue Level (± SD)** (mg kg^{-1} Fresh Wt.)			
SITE (n=)*	Adductor	Mantle	Visceral Mass
1 (n = 10)	≤ 0.01	≤ 0.01	0.016 (.008)
2 (n = 5)	≤ 0.01	≤ 0.01	0.024 (.005)
3 (n = 5)	≤ 0.01	0.016 (.005)	0.026 (.011)
4 (n = 5)	≤ 0.01	0.012 (.004)	0.026 (.011)
5 (n = 6)	≤ 0.01	0.014 (.008)	0.013 (.005)
6 (n = 5)	≤ 0.01	0.016 (.009)	0.014 (.005)
7 (n = 3)	≤ 0.01	≤ 0.01	0.03 (.01)
8 (n = 2)	0.02, <0.01	<0.01, <0.01	0.03, 0.02
9 (n =2)	0.01, <0.01	0.01, <0.01	0.01, 0.03

* Where less than 3 samples were collected at any one site individual values are given.
** Where no (Standard Deviation) is quoted, all samples contained ≤ 0.01 mg kg^{-1} Fresh wt and statistical analysis was not carried out
*** Maximum permissible concentration for human consumption is 0.5 mg kg^{-1} Fresh Wt.

Table 6. Mean (± SD) copper content of *T. crocea* sampled at various sites in the Torres Strait

Mean Tissue Level (± SD)** (mg kg^{-1} Fresh Wt.)			
SITE (n=)*	Adductor	Mantle	Visceral Mass
1 (n = 10)	≤ 0.5	≤ 0.5	1.19 (.384)
2 (n = 5)	≤ 0.5	≤ 0.5	1.26 (.261)
3 (n = 5)	≤ 0.5	0.6 (.12)	1.46 (.95)
4 (n = 5)	≤ 0.5	0.78 (.31)	1.36 (.48)
5 (n = 6)	≤ 0.5	0.86 (.66)	1.34 (.21)
6 (n = 5)	≤ 0.5	≤ 0.5	1.06 (.182)
7 (n = 3)	≤ 0.5	≤ 0.5	1.77 (.058)
8 (n = 2)	<0.5, <0.5	<0.5, <0.5	3.0, 0.9
9 (n =2)	<0.5, <0.5	<0.5, <0.5	1.1, 1.1

* Where less than 3 samples were collected at any one site individual values are given
** Where no (Standard Deviation) is quoted, all samples contained ≤ 0.5 mg kg^{-1} Fresh wt and statistical analysis was not carried out.
*** Maximum permissible concentration for human consumption is 70.00 mg kg^{-1} Fresh Wt.

Table 7. Mean (± SD) zinc content of *T. crocea* sampled at various sites in the Torres Strait

Mean Tissue Level (± SD)** (mg kg^{-1} Fresh Wt.)			
SITE (n=)*	Adductor	Mantle	Visceral Mass
1 (n = 10)	0.757 (.22)	1.34 (.447)	2.83 (.24)
2 (n = 5)	0.9 (.29)	1.26 (.36)	2.38 (.34)
3 (n = 5)	3.64 (1.49)	2.84 (.83)	4.38 (.98)
4 (n = 5)	3.24 (.55)	2.58 (.327)	3.34 (.68)
5 (n = 6)	1.03 (.585)	1.67 (.58)	2.67 (.78)
6 (n = 5)	1.36 (1.21)	2.02 (1.02)	2.94 (.658)
7 (n = 3)	.93 (.75)	1.00 (.7)	2.83 (.50)
8 (n = 2)	2.1, 0.5	2.5, 1.0	7.7, 5.4
9 (n =2)	6.4, 1.0	5.7, 0.8	7.6, 4.0

* Where less than 3 samples were collected at any one site individual values are given
** Where no (Standard Deviation) is quoted, all samples contained ≤ 0.5 mg kg^{-1} Fresh wt and statistical analysis was not carried out.
*** Maximum permissible concentration for human consumption is 150 mg kg^{-1} Fresh Wt.

References

Denton, G.R.W. and Heitz, L.F. (1990), '*Tridacna*: Sentinels of heavy metal pollution in Torres Strait waters - a critical evaluation', (this volume).

Phillips, D.J.H. (1980), *Quantitative aquatic biological indicators*, Applied Science Publishers Ltd., London.

Rayment, G.E. (1990), 'Australian and some international food standards for heavy metals', (this volume).

Tridacna: Sentinels of Heavy Metal Pollution in Torres Strait Waters - a Critical Evaluation

Gary R.W. Denton and Leroy F. Heitz
Water and Energy Research Institute of the Western Pacific,
University of Guam

Abstract

There is an urgent need to evaluate the impact of Papua New Guinea's gold and copper mining activities on the biotic components of the Torres Strait. Increased metal mobilization within this region will undoubtedly result in the increased accumulation of metals in certain species. Although the ecological implications of this are uncertain at the present time, metal enrichment of vital subsistence, commercial and recreational species could prove significant from a public health viewpoint and have devastating economic repercussions for the peoples of the region. The regular monitoring of metal levels available to the biota within this area is, therefore, of critical importance if such consequences are to be avoided. Surveillance studies of this nature should include those species whose elemental concentrations reflect changes in the ambient metal availability of their immediate surroundings. While such bio-monitor organisms for tropical regions of the world have received less attention than their temperate water counterparts, some candidate species have been suggested. Among these, the tridacnid clams, Tridacna maxima *and* T. crocea *rank very highly and fulfil several of the necessary bio-monitor prerequisites. As a consequence, studies were undertaken with the latter species to identify uptake and depuration kinetics of copper, zinc, cadmium, lead and mercury. The objectives of these investigations were to fine-tune the clam's role as a monitoring tool with respect to sampling frequency and interpretive capacity. The findings of the study are evaluated here along with some inherent weaknesses and limitations of their use.*

Introduction

Trace metals are a normal component of the world around us and at least 12 are known to be essential for life (George 1990). The natural processes primarily responsible for their mobilization in the environment include volcanic eruptions and the physical and chemical weathering of rocks (Turekian 1971). Principal anthropogenic processes responsible for their mobilization include mining, smelting and refining, which collectively outweigh contributions achieved by natural forces (Brian 1976).

Although not all mined metals pose an immediate threat to the aquatic environment, those of greatest concern (based on toxicity, background concentrations and industrial needs) are copper, lead, cadmium, zinc and mercury (Phillips 1980). These metals are being mined and mobilized, on a world wide basis, at rates which exceed simple geological processes of weathering by factors of 32, 29, 16, 15 and 4 respectively (Bryan 1976). They are also the same metals currently impacting upon the marine resource of the Gulf of Papua and adjacent waters of the Torres Strait as a result of mining activities in Papua New Guinea.

The two major areas of concern associated with elevated inputs of trace metals into aquatic environments, like the Torres Strait, are direct toxicity to sensitive species and excessive metal accumulation by species harvested for human consumption. Impacted areas should therefore be continually monitored if spatial and temporal trends in metal abundance and bioavailability are to be adequately identified.

Such monitoring strategies may involve the analysis of water, sediments and biota. Each of these components presents certain problems either from a sampling, analytical or interpretive standpoint (Phillips 1977, 1980, 1990). In general, however, the analysis of biota is by far the most preferred single method of approach being generally simpler, quicker and cheaper than the other two. It also provides a measure of a metal pollutant's bioavailability, a feature which is not readily identified by water or sediment analysis alone.

Although considerable emphasis has been placed on the development and refinement of bio-monitoring programs for temperate waters, little comparable data exists for tropical reef waters. Problems associated with the selection of bio-monitors from tropical regions include the generally low abundance and often patchy distribution of promising species, whose biology is often poorly known and whose reliability as an indicator organism remains to be established.

Recognizing these constraints Burdon-Jones and Denton (1984 a and b) attempted to evaluate the monitoring potential of over 120 marine species from the Great Barrier Reef (Denton and Burdon-Jones 1986a, b, c). Based on abundance, metal accumulation capacity, and apparent indicator ability, six organisms ultimately emerged as potentially useful indicator species. They included one species of green algae (*Chlorodesmis fastigiata*), a fish (*Lutjanus carponotatus*) and four species of bivalve mollusc, (the chamid, *Chama iostoma*; the mytilid, *Septifer bilocularis*; and the tridacnid clams *Tridacna crocea* and *T. maxima*). Of these, the tridacnid clams clearly stood out as the most promising candidates for future monitoring work in this region and adjacent waters of Torres Strait (Denton 1986) on the basis that:

- One or both species were found at all sites visited in numbers sufficient to sustain an ongoing monitoring programme.

- They were readily identifiable, easy to collect and provided ample tissue for analysis.

- They showed an extraordinary capacity to accumulate a wide range of metals and reflect areas of metal enrichment.

- Being sedentary, metals accumulated by them reflected available levels in their immediate surroundings.

- They were geographically widespread and could, therefore, be incorporated into pollution monitoring networks elsewhere in the Indo-Pacific region.

- As phototrophs they were especially well suited to monitoring trace metals in the clear, relatively barren waters of the Great Barrier Reef where other bivalve bio-monitors may fail to survive.

- Current interest in the culture of clams for food and restocking reefs has greatly increased our understanding of their biology and facilitated their availability as transplant organisms for bio-monitoring purposes.

Although the above work clearly identified tridacnid clams as extremely valuable indicators of trace metal pollution, additional research was necessary to determine metal turnover times and the precise relationship between levels accumulated and those in the overlying water column. Such information was considered essential for quantitative interpretation purposes. In addition, the prescription of a sampling frequency necessary to provide a reasonably continuous record of a metal's time-averaged bioavailability could not proceed without it.

Subsequent metal kinetic studies were therefore conducted with *T. crocea* and the findings and implications of these results from a monitoring viewpoint, together with relevant earlier work, are reviewed here.

Trace Element Dynamics in Tridacnid Clams

Accumulation Capacity

Most of the limited information on the trace metal accumulation capacity of tridacnid clams reflects the endeavours of the Soviet scientists, Khristoforova and co-workers (Khristoforova 1980, Khristoforova *et al.*1979, 1983).

In Australia, attention first focused on this group in 1974 following the discovery of unusually high nickel concentrations in the tissues of *T. maxima* from Orpheus Island, north of Townsville (Burdon-Jones *et al.*,1975). The possible connection between these findings and the close proximity of a recently established nickel refinery stimulated an interest in the group as potentially useful bio-monitors of nickel pollution. However, the connection proved to be unfounded as clams taken well away from the area in later studies also demonstrated a similarly high accumulation capacity for this element. Nevertheless, the monitoring potential for several other metals was indicated and gave impetus to further investigations in which clams were analyzed from a number of other locations along the entire length of the Great Barrier Reef between 1976 and 1983 (see Table 1).

Table 1: *Tridacna* Sampling Locations Along the Great Barrier Reef

Far Northern Section:	***Northern Section:***
York Island (19/11/78) [1,2]	Carter Reef (12/2/81) [1,2]
Murray Island (18/11/78) [1]	Lizard Island (Feb 81-Jan 83) [1,2]
Great Detached Reef (14/11/78) [1]	Linnet Reef (11/2/81) [1,2]
Corbett Reef (12/11/78) [1,2]	Low Island (10/11/78) [2]
Haughton Island (11/11/78) [2]	
Central Section:	***Southern Section:***
Orpheus Island (Dec 80-Jan 83) [1,2]	Heron Island (14/1/81) [1]
Myrmidon Reef (27/8/81) [1]	Wistari Reef (12/1/81) [1]
Flinders Reefs (29/8/81) [1]	Sykes Reef (13/1/81) [1]
Havannah Island (5/12/76) [1]	
Kelso Reef (5/12/76) [1]	
Herald Island (22/2/76) [2]	
Acheron Island (18/3/77) [1,2]	
Wheeler Reef (2/9/78) [1]	
Davies Reef (23/11/76) [1]	
Broadhurst Reef (23/11/76) [1]	
Bowden Reef (4/12/75) [1]	
Magnetic Island (30/10/83) [1,2]	

Superscript [1] and [2] denote the collection of *Tridacna maxima* and *T. crocea* respectively.

Table 2 summarizes the data for levels of copper, zinc, cadmium, lead and mercury in *T. maxima* tissues from four locations in the central region of the Great Barrier Reef. The chosen metals have high pollution potential in the Torres Strait region and, were therefore considered to be of greatest importance here. The four locations were selected on the basis that the corresponding data encompasses 95% of data obtained from all other locations. Thus, the values for Myrmidon and Flinders Reefs are typical for pristine environments, well away from coastal and anthropogenic influences, whereas those for Orpheus and Magnetic Islands reflect nearshore environments exposed to mild and moderate degrees of trace metal impaction respectively.

Of the tissues examined, the kidney clearly demonstrates the highest accumulation capacity and greatest inter-location variability for the elements listed. It is noteworthy that this organ also accumulates high concentrations of several other metals as summarized in Figure 1.

The ability of the kidney to concentrate a diversity of metals infers an abundance of non-specific metal binding sites in this tissue which immobilize and retain metals for relatively long periods of time. Of central importance here are the numerous laminate concretions (nephroliths) which lie in the large central vacuole of the ciliated columnar cells (nephrocytes) lining the renal tubules. These granular bodies are

Table 2. The Combined Influence of Offshore Distance and Proximity to the Nearest Major City (Townsville) on Trace Element Levels in the Tissues of the Clam, *Tridacna maxima* (data are range and (geometric mean)); ND = no data; BDL = below analytical detection limits[a])

Location and (Distance Offshore)	Distance from Townsville	N	Tissue	Metal Concentrations ug g^{-1} Dry Weight[b]				
				Copper	Zinc	Cadmium	Lead	Mercury
Flinders Reefs (200 km)	220 km	10	Kidney	2.04-7.15 (3.16)	0.35-8.61 (2.41)	0.66-17.2 (4.52)	9.34-24.7 (15.3)	0.380-0.804 (0.588)
		6	Gills	2.41-3.58 (2.80)	8.57-15.7 (11.9)	3.48-4.96 (4.37)	BDL	<0.002-0.004 -
		6	Visceral Mass	2.95-4.23 (3.49)	5.53-9.46 (7.48)	4.52-9.13 (6.07)	BDL	0.014 (0.002-0.026)
		6	Mantle	0.81-1.05 (0.94)	1.58-4.28 (2.99)	1.51-1.84 (1.68)	BDL	<0.002-0.004 -
		6	Adductor Muscle	0.23-0.42 (0.28)	0.94-1.82 (1.27)	0.89-1.25 (1.05)	BDL	<0.002-0.003 -
Myrmidon Reef. (110 km)	130 km	6	Kidney	2.58-4.18 (3.35)	1.09-6.25 (3.75)	0.41-19.9 (3.89)	8.33-12.4 (10.2)	0.273-0.492 (0.363)
		6	Gills	2.96-3.68 (3.19)	12.45-25.5 (18.0)	3.56-6.02 (4.26)	BDL	<0.002-0.025 -
		6	Visceral Mass	3.05-6.75 (4.70)	8.55-18.3 (11.4)	4.06-7.59 (5.56)	BDL	0.014 (0.004-0.024)
		6	Mantle	0.88-1.03 (0.98)	3.17-7.68 (5.14)	1.49-2.45 (2.00)	BDL	0.007 (0.001-0.015)
		6	Adductor Muscle	0.29-0.63 (0.43)	1.56-5.58 (2.60)	0.88-1.42 (1.07)	BDL	<0.002-0.025 -
Orpheus Island (10 km)	50 km	10	Kidney	2.91-7.66 (3.95)	51.6-425 (215)	6.22-38.4 (15.3)	27.6-83.5 (60.3)	0.633-1.130 (0.824)
		10	Gills	3.04-4.32 (3.67)	18.0-31.8 (22.8)	2.18-4.42 (2.96)	BDL	ND
		10	Visceral Mass	4.15-21.4 (9.15)	15.0-23.3 (18.4)	3.69-5.37 (4.54)	BDL	ND
		10	Mantle	1.06-1.75 (1.37)	8.09-15.6 (10.6)	1.73-3.36 (2.56	BDL	ND
		10	Adductor Muscle	0.43-0.72 (0.55)	4.50-16.9 (9.19)	1.39-2.89 (1.85)	BDL	ND
Magnetic Island (4 km)	6 km	5	Kidney	5.21-13.0 (7.82)	443-1555 (903)	2.66-8.64 (5.31)	160-251 (189)	ND
		5	Gills	4.10-4.26 (4.16)	29.6-33.9 (31.6)	0.93-1.34 (1.16)	BDL	ND
		5	Visceral Mass	9.77-16.8 (12.2)	26.2-33.1 (28.6)	1.30-1.97 (1.68)	BDL	ND
		5	Mantle	1.47-1.73 (1.58)	18.4-21.7 (19.6)	1.00-1.54 (1.31)	BDL	ND
		5	Adductor Muscle	0.58-0.66 (0.60)	14.8-15.7 (15.2)	0.87-1.28 (1.08)	BDL	ND

[a] Analytical detection limit for lead ranged from around 0.2-1.5 ug g^{-1} dry weight, depending on tissue weight examined.
[b] Mercury concentrations expressed on a wet weight basis

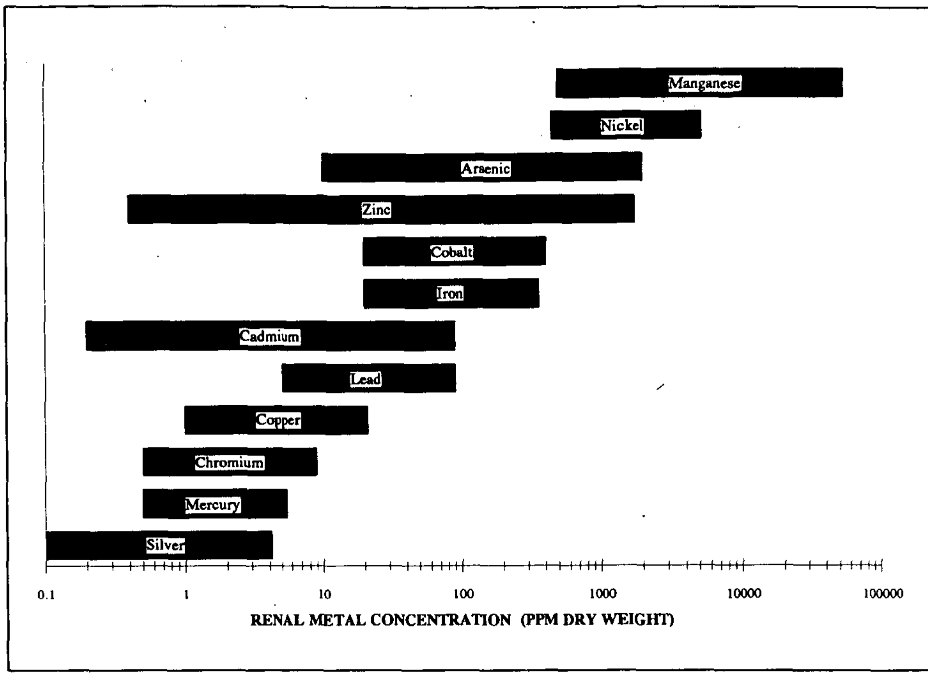


Figure 1. The ranges of trace element concentrations found in the kidney of *Tradacna maxima* from within the Great Barrier Reef Province (1974-1983).

composed primarily of calcium phosphate and contain high concentrations of a variety of metals (Hignette 1978, Gold *et al.* 1980, Reid *et al.* 1984). They are the dominant anatomical feature of bivalve kidneys generally and are considered to play a major role in metal detoxification and excretion (Doyle *et al.* 1978, George *et al.* 1980, Mauri and Orlando 1982, Simkiss and Mason 1983).

We have analyzed very few clams from Torres Strait waters and what data there are has been summarized in Table 3. Renal concentrations of copper, zinc, nickel and lead are similar to those found in clams from the Great Barrier Reef (Table 2), although cadmium levels are considerably higher. The fact that all specimens analyzed were collected prior to the commencement of Ok Tedi operations in Papua New Guinea, suggests that the high renal cadmium levels reflect contributions from natural sources and represent major geological and hydrological differences between the two areas.

Bio-monitoring Potential

There seems little doubt that the soft tissues (including those normally consumed by man) of tridacnid clams accumulate at least certain elements to levels which are dependant on, and therefore reflective of, the concentrations available to them from their immediate surroundings. Outstanding in this respect is the large, bilobed kidney which appears to be particularly sensitive to a relatively broad spectrum of metals. The relatively high renal concentrations of zinc and lead in clams from the nearshore locations, in Table 2, are considered to reflect a greater ambient abundance of these metals from both natural and anthropogenic (urban, agricultural and industrial) sources.

A most impressive demonstration of the tridacnid kidney's bio-monitoring potential for zinc was seen at Lizard Island in October 1982. This small continental island is located approximately 30 km from the coast, 60 km from the nearest river and around

Table 3. Trace Element Levels in Kidney Tissue of the Clams, *Tridacna maxima* and *T. crocea* from Torres Strait (data are range and (geometric mean)).

				Metal Concentrations ug g-1 Dry Weight				
Species	**Location**	**Sampling Date**	**N**	**Copper**	**Zinc**	**Cadmium**	**Nickel**	**Lead**
T. maxima	Murray Island	18/11/78	2	2.3-4.1 (3.1)	1.1-4.1 (2.2)	1.0-2.1 (1.5)	1536-2569 (1986)	6.4-9.4 (7.8)
	York Island	19/11/78	2	2.4-2.6 (2.5)	65.2-94.4 (78.5)	59.0-85.2 (70.9)	474-1313 (789)	8.7-25.4 (14.9)
T. crocea	York Island	19/11/78	4	3.8-4.9 (4.5)	6.2-8.8 (7.7)	2.9-27.5 (12.6)	1762-4284 (3018)	27.8-34.6 (31.1)
	York Island[a]	15/8/85	7	1.7-4.6 (3.0)	242-1389 (727)	44.5-243 (111)	547-1566 (1023)	28.2-37.3 (29.9)
	Marakai Island	15/8/85	8	2.7-19.0 (4.6)	1.8-98.1 (5.9)	70.3-252 (140)	911-2922 (1414)	22.2-60.3 (47.7)
	Zagai Island	28/6/85	4	4.1-6.0 (4.3)	4.3-114 (14.3)	75.7-173 (119)	256-1324 (801)	21.5-35.2 (28.4)

[a] York Island clams were collected close to a popular mooring site for large fishing vessels and other water craft. Clams from all other locations were collected well away from any known localized sources of trace metal pollution.

250 km the nearest major city of Cairns. For all intents and purposes, the island and its surrounding waters are regarded by many as pristine. However, renal zinc concentration in both *T. crocea* and *T. maxima* from the landward side of the island indicated a very definite point source of zinc contamination in the Anchor Bay/ Watson's Bay area (Figure 2a). A similar profile though considerably less pronounced was also apparent for cadmium (Figure 2b), a chemically similar metal, known to coexist with zinc in nature and in metallurgical products.

At first, the source of contamination was not readily identifiable; a problem which was compounded by the lack of tell-tale evidence of zinc and cadmium enrichment in water samples collected simultaneously from each site. However, it was later learned that from mid October to January, every year, both bays are heavily congested with fishing boats and various support vessels in pursuit of black marlin (*Makaira indica*) and other large game fish in the area. Zinc and, to a lesser extent, cadmium contributions from anti-fouling and anti-corrosive marine paints, sacrificial anodes, galvanized structures, brass fittings, mooring gear etc., therefore, seemed to be the logical explanation for the profiles depicted by the clams.

Assuming this hypotheses to be correct, the lack of supporting evidence for metal enrichment in surface waters from Watson's Bay and Anchor Bay may be explained by the fact that both clam and water samples were collected just prior to the opening

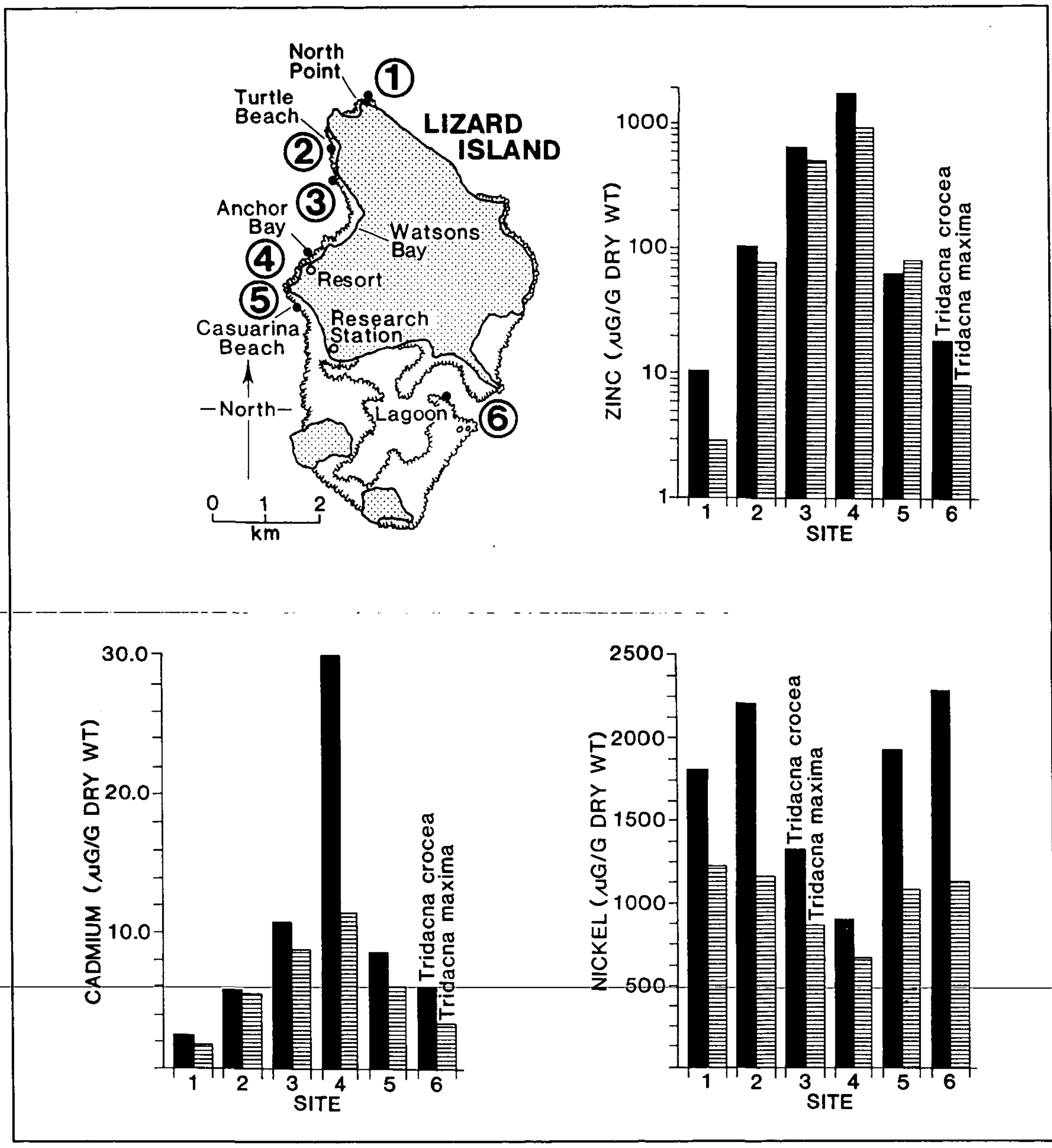


Figure 2. Zinc, cadmium and nickel profiles depicted by the kidney of *Tridacna maxima* and *T. crocea* from Lizard Island (Oct. 1982) on the Great Barrier Reef. (values are geometric means; n = 5).

of the 1982 marlin fishing season. Hence, elevated zinc and cadmium levels in the water column from the previous year had long since been flushed from the bays during the intervening period of relatively low boating activity. The fact that both metals were retained by the clam kidney long after ambient levels had returned to normal, highlights the importance of these bivalves in providing the investigator with information which might otherwise be lost by the analysis of water alone.

The renal nickel profiles determined in clams from Lizard Island (Figure 2c) deserve comment here insofar as they appear inversely related to those for zinc and cadmium. Nickel is naturally concentrated by the tridacnid kidney and levels found in clams from sites 1, 2, 5 and 6 at Lizard Island are typical of clean, outer barrier sites, (see Burdon-Jones and Denton 1984 a). Quite possibly, the diminished levels found in clams from the Watson's Bay/Anchor Bay region (sites 3 and 4) reflect displacement of nickel from renal binding sites by zinc. In any event, the utility of tridacnid clams for monitoring changes in ambient nickel availability is questionable and requires further evaluation.

Uptake and Depuration Kinetics

Although greatly encouraged by the Lizard Island study, several important questions emerged from this work regarding metal turnover times, and the precise relationship between levels accumulated by the clam kidney and those in the surrounding water. Answers to these were essential in order to fine tune the organism's use as a monitoring tool.

Subsequent kinetic studies with *T. crocea*, indeed, revealed that time related changes in renal concentration factors, for mercury, cadmium and lead, were independant of the concentration changes in the surrounding water (Figure 3). Expressed another way, renal accumulation rates, for all three metals, were directly proportional to their ambient concentrations. Such a relationship indicated little to no metabolic regulation of these elements and fulfilled one of the basic requirements of a bio-monitor (Haug *et al.* 1974).

Loss rates for all three metals were approximately linear with time, when plotted on semi-log graph paper, implying that the kidney acts as a single compartment and obeys first-order kinetics (Klaassen *et al.* 1986). This is the simplest of kinetic models describing residue dynamics and requires that uptake and depuration rates are directly proportional to levels in water and tissues respectively. As both requirements appeared to have been satisfied by the clam kidney, the uptake and depuration curves were, fitted to the respective data sets (Figure 4) following the estimation of the appropriate rate constants (k_u and k_d) as described by Spacie and Hamelink (1985).

The continued accumulation of all three metals (cadmium in particular) by the kidney during the first few weeks of the depuration reflects amounts offloaded from the other tissues.

Often, organisms behave quite differently in the field compared with the laboratory. However, the first-order kinetics model adequately described copper, zinc and lead uptake and depuration in *T. crocea* translocated and relocated between relatively clean (Orpheus Island) and polluted (Townsville Harbour) environments at different

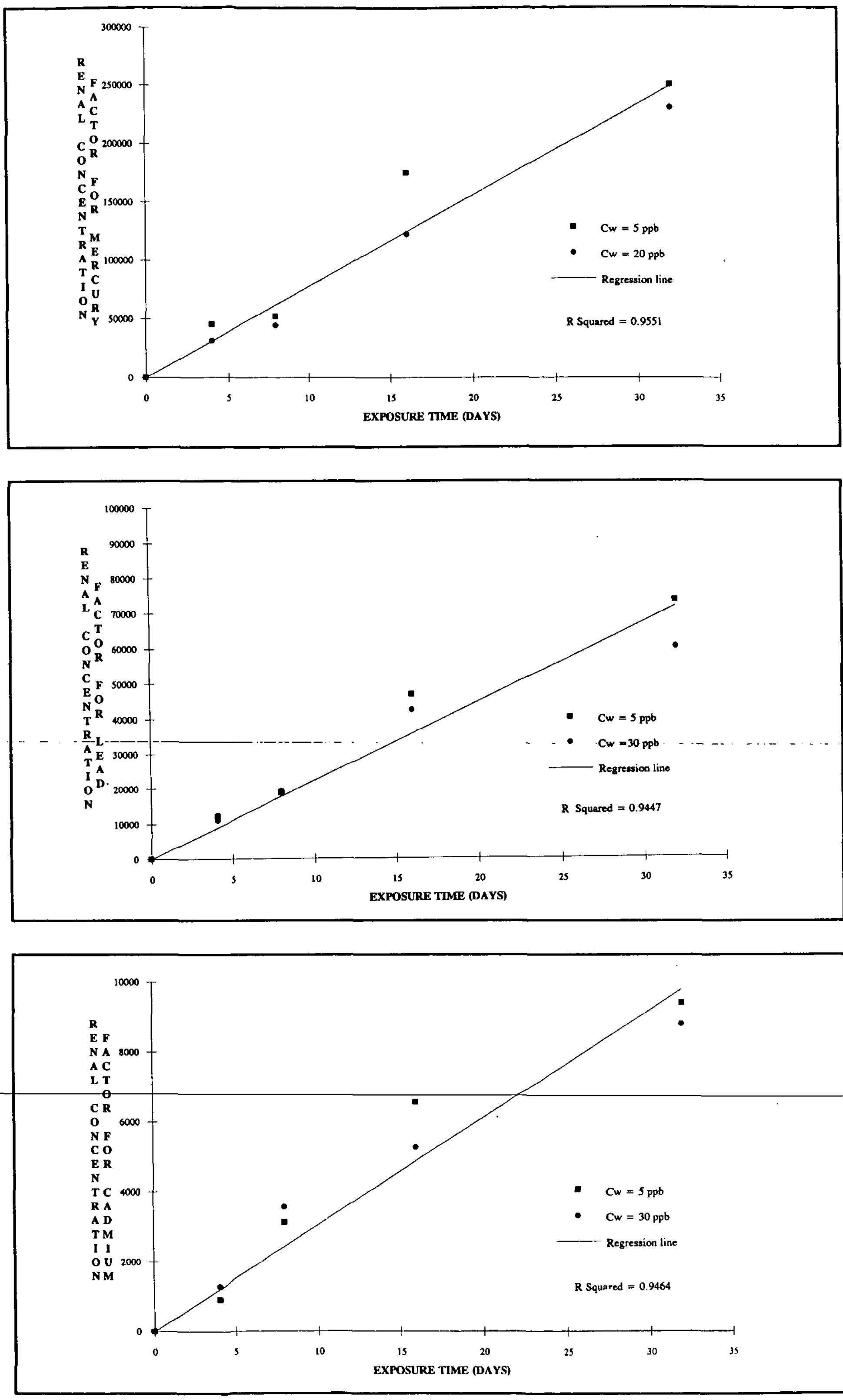


Figure 3. *Tridacna crocea* renal concentration factors for mercury, lead and cadmium as a function of time. (Each plot represents the geometric mean; n = 10. Cw = test concentration ($\mu g l^{-1}$) of metal in seawater).

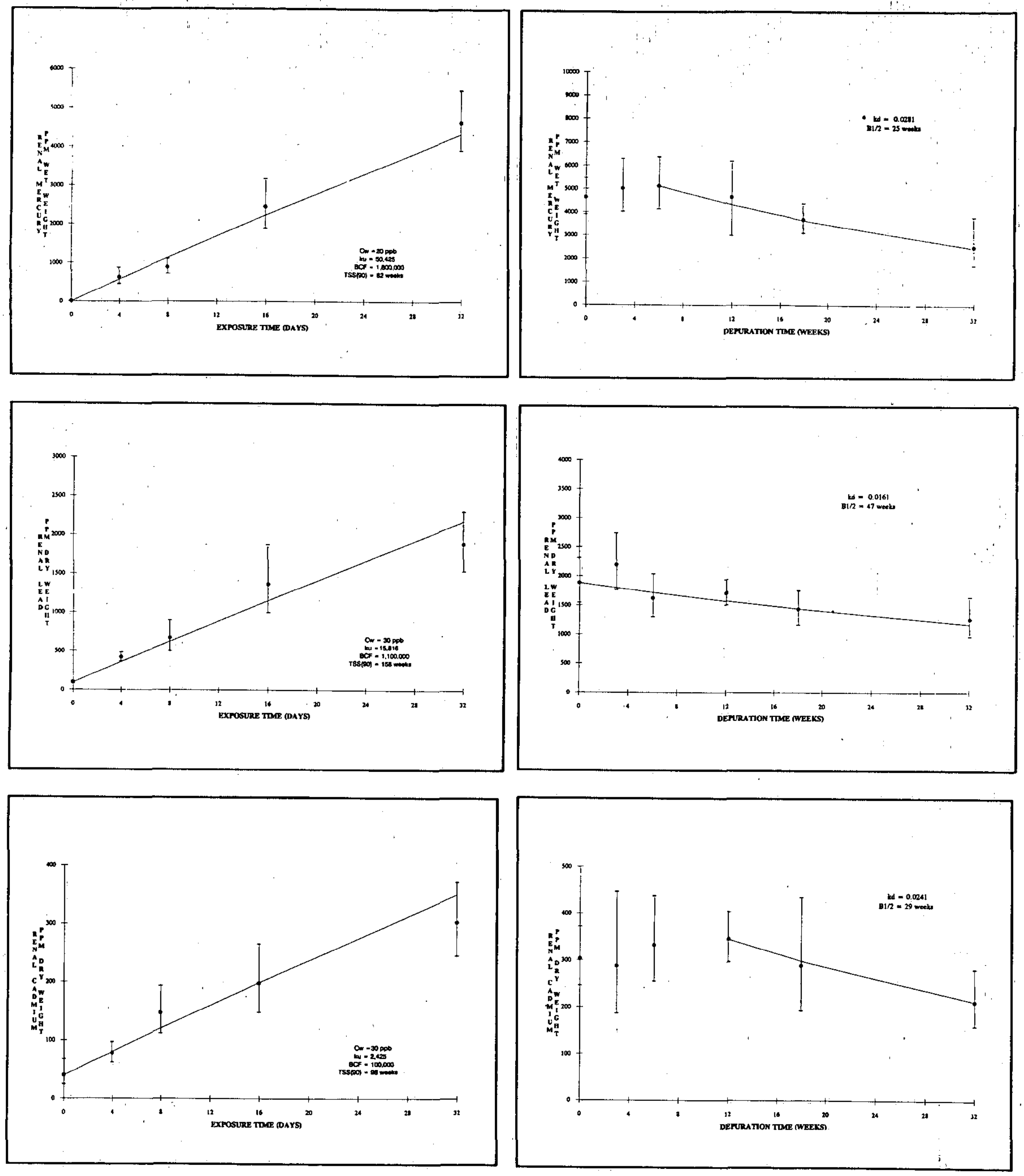


Figure 4. Uptake and depuration of mercury, lead and cadmium by the kidney of *Tridacna crocea*. (Each plot represents the geometric mean of 95% confidence interval; n = 10. Cw = test concentration ($\mu g l^{1}$) of metal in seawater; ku = uptake rate constant (wks^{-1}); BCF = biological concentration factor at steady state; TSS(90) = time to reach 90% of steady state concentration; kd = depuration rate constant (wks^{-1}); B1/2 = biological half-life).

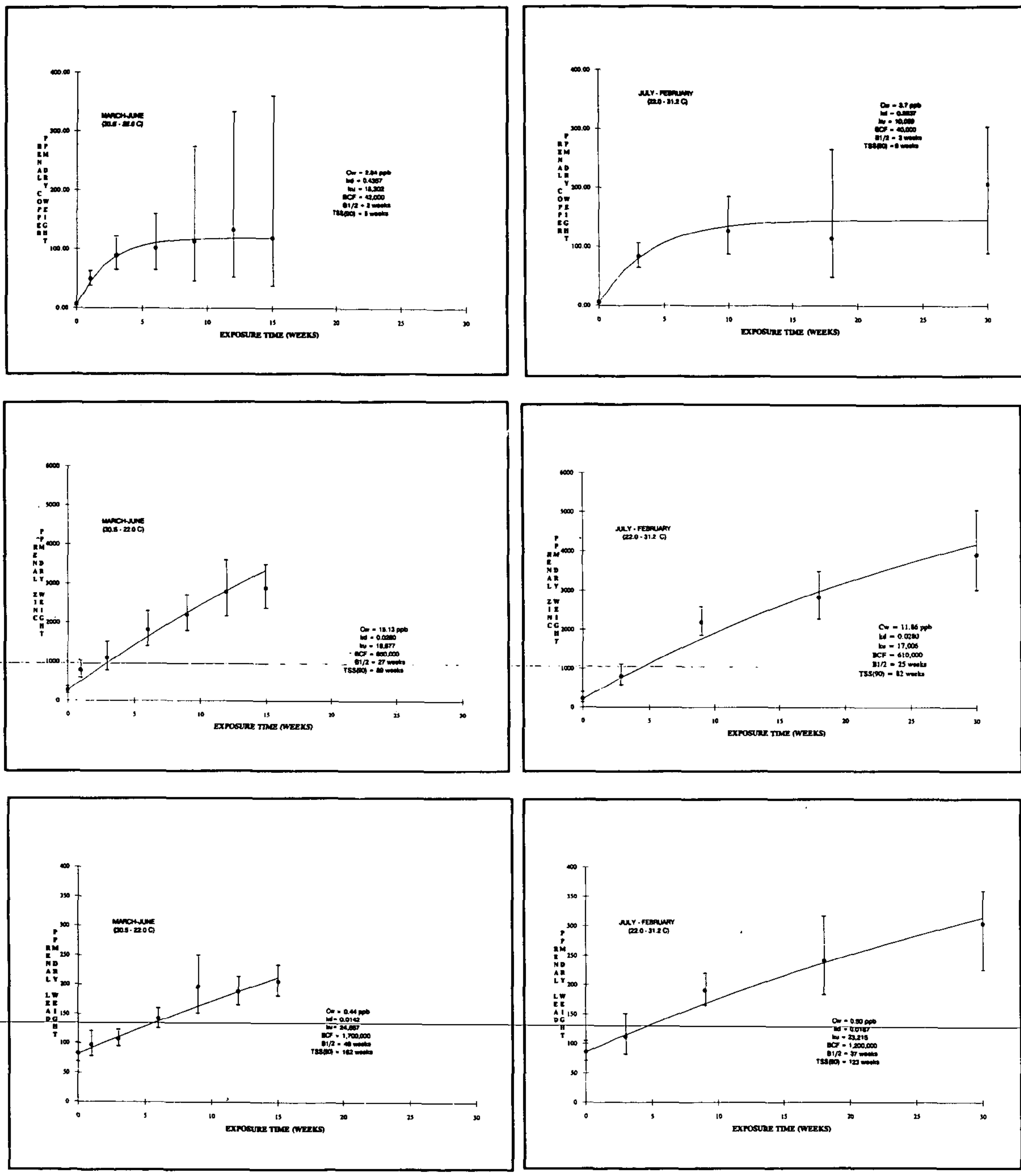


Figure 5. Uptake of copper, zinc and lead by the kidney of *Tridacna crocea* held in Townsville Harbour at different times of the year. (Each plot represents the geometric mean and 95% confidence interval; n = 10. Cw = test concentration of metal in seawater ($\mu g l^{-1}$); ku = uptake rate constant (wks^{-1}); kd = depuration rate constant (wks^{-1}); BCF = biological concentration factor at steady state; B1/2 = biological half-life; TSS(90) = time to reach 90% of steady state concentration).

times of the year (Figure 5). Moreover, rate constants, calculated separately for all data sets, were very similar implying that seasonal fluctuations in temperature impart a negligible influence on metal kinetics within the clam kidney.

Quantitative Assessments of Metal Abundance

An understanding of contaminant kinetics greatly increase the power of a bio-monitor by allowing qualitative differences, both within and between sites, to be interpreted in more quantitative terms. For example, kinetic estimates of a contaminant's biological concentration factor (BCF), attained at steady state, may, under certain conditions, be used to predict its time-averaged, bioavailable concentration in the water column. In adopting this approach the assumptions are made that the contaminant levels in the bio-monitor are derived from, and are in equilibrium with, levels in the surrounding water. These assumptions may be satisfied by certain hydrophyllic, organic contaminants that are primarily accumulated from water by partitioning across body membranes and rapidly approach steady state. However, trace metals may be derived from several other sources (food, sediments, suspended particulates) besides water and are unlikely to have achieved steady state if ambient levels fluctuate markedly and/or turnover rates within the organism are very slow. In addition, trace metals in water can exist in a variety of chemical forms which may have widely differing biological availabilities and residue kinetics. Such consideration place a number of constraints on the concept of relating tissue levels in a bio-monitor to ambient available levels in the surrounding water. Nevertheless, the approach may provide estimates that are accurate to within an order of magnitude for some metals under certain conditions (see for example, Schulz-Baldes 1974).

Table 4 lists ambient, available estimates for copper, zinc, cadmium, lead and mercury in seawater from Orpheus Island. The data were calculated using the BCF values obtained with *T. crocea* (Figures 4 and 5) and only that for cadmium appears to be unrealistically high. One reason for this is the possibility that *T. crocea* derive their cadmium load predominantly from sources other than water. In keeping with this suggestion, it is noteworthy that high cadmium levels have been reported in *Trichodesmium*, a planktonic species of blue-green algae that blooms prolifically, for several months of the year, along the entire length of the Great Barrier Reef (Jones 1981).

Pulse or episodic inputs of metals into the aquatic environment, coupled with the inability of the bio-monitor to attain equilibrium, is a major failing in the use of BCF estimates to assess background metal availability in the water column. For these reasons monitoring the rate of change of contaminant concentrations in the selected organism (Majori and Petronio 1973, Ritz *et al.* 1982) is an alternative which is referred to in the following section.

Identifying Temporal Trends in Trace Metal Abundance

Quantitative estimates of metal availability, using rates of contaminant change, do not require that levels in the bio-monitor have reached steady state. They do, however require that the kinetics of metal uptake and depuration in the selected organism be known and that some prior knowledge of contaminant levels in its tissues exist. The monitoring strategy involves the repeated collection of samples for analysis at discrete intervals of time. The kinetics model can then be used to determine the contaminant level in the water necessary to produce the temporal change observed in tissue concentrations.

Table 4. Quantitative Assessment of Time-Averaged, Bioavailable Trace Element Concentrations in Seawater From Orpheus Island, Using Steady State, Biological Concentration Factor (BCF) Estimates Attained by the Kidney of the Clam *Tridacna crocea.*

Metal	Geometric Mean Concentration in the Kidney of *T. crocea* (ug g^{-1} dry weight)	Biological Concentration Factor at Steady State[b] (k_u/k_d)	Predicted Time-Averaged Available Concentrations in Seawater (ug l^{-1})	Measured Concentration Ranges in Seawater (ug l^{-1})
Copper	5.17	4.0-4.2 x 10^4	0.12-0.13	0.16-0.23[c]
Zinc	210	6.1-6.5 x 10^5	0.32-0.34	0.04-0.26[c]
Cadmium	30.2	1.0 x 10^5	0.30	<0.01-0.04[c]
Lead	85.4	1.1-1.7 x 10^5	0.05-0.08	<0.06[c]
Mercury	0.851[a]	1.8 x 10^6	0.0004	<0.001[d]

[a] Mercury concentrations expressed on a wet weight basis. [b]BCF derived from experimental data (Figs 4-5)
[c] According to procedures described by Denton and Burdon-Jones (1986 d)
[d] According to procedures described by Topping and Pirie (1972)

Just how close the time-integrated values in the bio-monitor relate to average, available concentrations in the water depend on a number of factors not least of which is the frequency of sampling in relation to contaminant turnover rates. To maximize the efficiency of the bio-indicator in this regard, a relatively short sampling interval is necessary for elements which are rapidly eliminated by the bio-monitor compared with that required for elements with slower rates of turnover. We therefore recommend that sampling frequencies should correspond to the biological half-life of the contaminant of interest if a continuous estimate of its ambient availability is required. Thus, *T. crocea* should be collected at 2-4 week interval for a continuous assessment of copper. In contrast, it would only be necessary to sample at intervals of approximately six months to achieve the same degree of continuity for zinc, cadmium, lead and mercury.

Identifying Spatial Variations in Trace Metal Abundance

In areas that have not been studied before, the investigator has no way of knowing whether contaminant levels in the bio-monitor are representative of a current or past situation. Long-term integrators of ambient contaminant levels, although extremely useful in providing information not available using bio-indicators with shorter time-integrating capacities, may reflect pulse inputs which occurred several months or even years beforehand. The zinc and cadmium levels in the kidney tissue of clams from Lizard Island (Figure 2) provide such a case in point.

One way of circumventing this problem is, of course, to examine bio-monitors which integrate trace metal availability over much shorter time scales, although the limited choice of other, well tested organisms from tropical regions, places a major constraint on this suggestion. Alternatively, some insight into the problem may be achieved by examining resident metal levels in other tissues within the clams themselves. As previously mentioned above, all edible tissues show some degree of response to trace metal gradients, and, although their concentration capacity and sensitivity is poor compared to the kidney, trace element turnover times are generally much shorter (Denton unpublished data). For example, the gills rapidly turn over zinc, lead, mercury and cadmium (B1/2 1-4 weeks). Thus, a combination of both gill and kidney analyses[1] will enable the investigator to determine whether the information stored in the kidney is representative of exposure to low-level, chronic or acute episodic metal inputs.

Sample Variability

How well a bio-monitor reflects changes in the ambient availability of a contaminant is determined largely by the degree of variability encountered in the population sampled. The more variable the tissue levels, the less reliable the organism becomes and the greater the number of individuals required to detect a given level of change. Such variability can essentially be divided into two broad categories: namely that which can be reduced or eliminated by the investigator as opposed to that which cannot. Controllable variation includes that associated with parameters such as the age/size, growth, fitness, sex and reproductive condition of the individuals sampled, in addition to differences related to their position on the shore and/or in the water column. Uncontrollable variation may be ascribed to regional and seasonal differences in temperature and salinity, and includes the inherent, natural variability, normally encountered between individuals of the same species as a result of subtle variations in genetic make-up, metabolic efficiencies, health and well-being.

Fortunately, the available data reported here (Figure 5) and elsewhere (Burdon-Jones and Denton 1984 b) suggests that seasonal changes in temperature have little to no effect on trace metal kinetics in the tridacnid kidney. However, the effects of salinity remain to be evaluated in this regard, and may play a much more important role, at least for some metals (see Denton and Burdon-Jones 1981).

Perhaps the most important controllable variable influencing metal levels in the tridacnid kidney is age. A pooled analysis of *T. crocea* samples collected from the Torres Strait, for example, indicated a significant size-dependant relationship for lead and nickel but not copper zinc or cadmium (Figure 6). Such relationships may vary on both a temporal and spatial basis, as have been demonstrated in other bivalves (Gordon *et al.* 1980), and have obvious interpretive repercussions if not accounted for in the initial design of a monitoring program.

The selection of a standard size clam should, therefore, be an early priority in the establishment of a monitoring programme for the Torres Strait, if age-dependant variability in metal concentrations is to be eliminated. In this respect it is pertinent to note that tridacnid clams are relatively long-lived bivalves and grow most rapidly during the early years of life. Thus, in older specimens, comparatively small differences in shell length represent considerable differences in age. In *T. crocea*, for example,

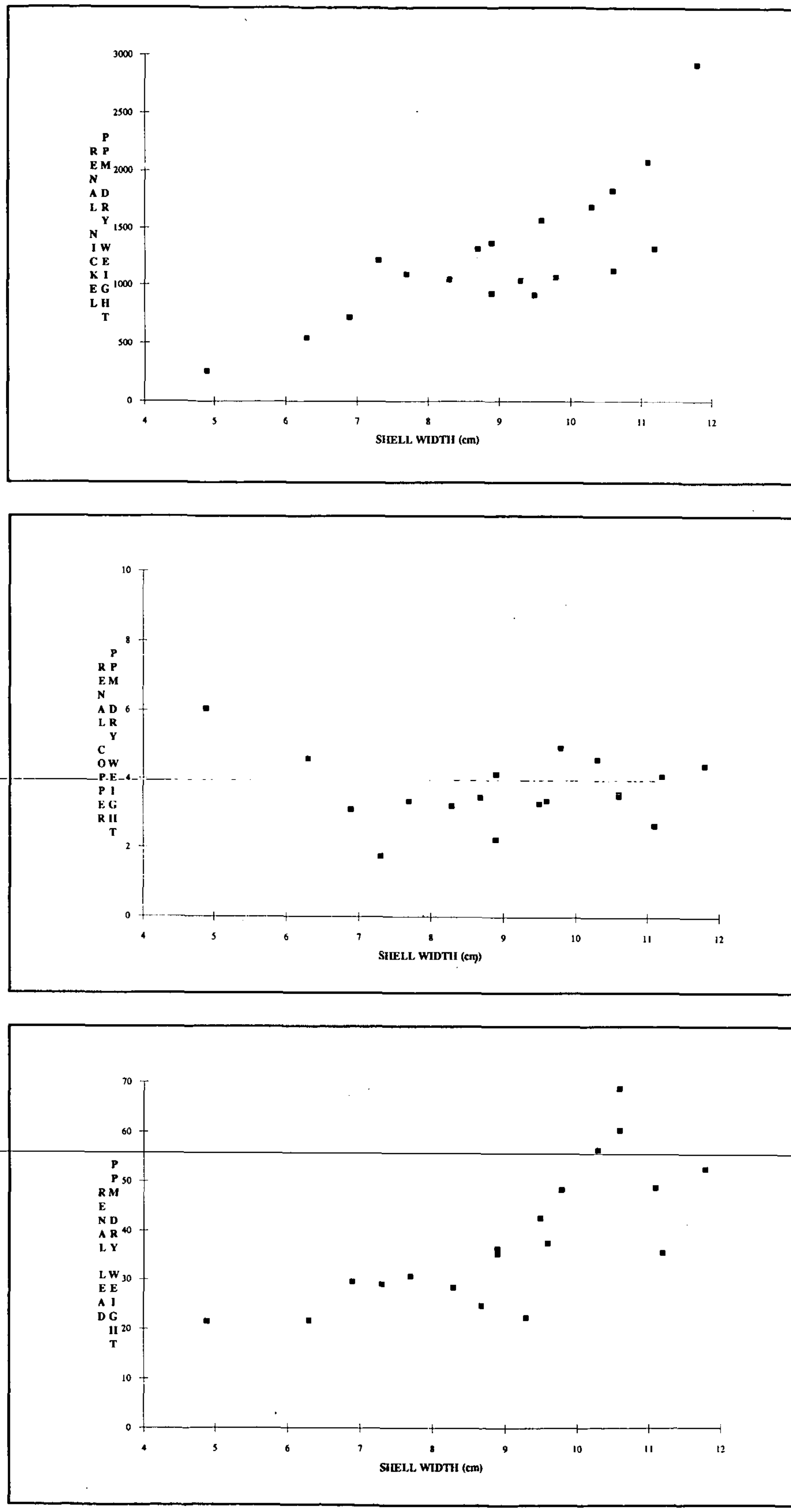


Figure 6. The relationship between size and trace metal concentrations in the kidney of *Tridacna crocea* from Torres Strait.

individuals having a shell lengths of 2, 4, 8 and 12 cm have corresponding ages of 1, 2, 7 and 30 years respectively (Hamner and Jones 1978). For monitoring purposes, then, the selection of small rather than large sized individuals is more appropriate. Specimens with shell lengths of 5-6 cm (3-3.5 years old) are ideal in terms of providing a combination of sufficient tissue for analysis with minimum age variability. Samples older than 5 years are not recommended as growth declines rapidly after this point in time (Hamner and Jones 1978).

Age-dependant variability in trace element levels no doubt accounts for some of the "noise level" reported in Tables 2 and 3. However, it does not adequately explain the high renal copper variability observed during the kinetic studies (Figure 5) in which only clams of a specific size range (shell length 6-7 cm) were used. Metal stressed bivalves sometimes release their renal nephroliths in an erratic and unpredictable manner which, in turn, increases the individual variability for those elements associated with them (Carmichael and Fowler 1981). However, the high mobility of copper in the clam kidney suggests this element is predominantly associated with metal binding proteins rather than calcium phosphate concretions. Biological variation in cellular activities of discrimination, induction and ligand turnover (Simkiss and Mason 1984) would therefore seem to be a more likely reason for this phenomenon. The fact that renal copper levels become increasingly more variable with increased exposure time lends support to this hypothesis.

From a monitoring viewpoint, the implications of the copper studies are clear. The low renal copper levels found in clams from unpolluted waters coupled with the kidney's sensitivity and speed of response to copper enrichment, will permit the identification of small departures from normal background concentrations, but, by the same token, small differences at high levels of contamination will be totally obscured by the kidneys inherent variability.

The use of cultured clam stocks for monitoring purposes offers an excellent means of minimizing age and genetic based variations in trace element levels normally encountered with wild populations. This technique also allows for the transplantation of individuals into areas where they do not normally occur and extends their utility as bio-monitors considerably.

The, as yet, unexplored option of biopsying tissue samples from selected clams at regular intervals provides an additional means of reducing individual variability in trace element levels. Such techniques would, however, only really be suitable for larger members of the group.

Concluding Remarks

The bio-monitoring potential of *T. crocea* for the trace elements copper, zinc, lead cadmium and mercury has been unequivocally established. Hence the widespread occurrence of this bivalve in Torres Strait makes it an ideal candidate for monitoring the impact of these metals in this region. The identification of kinetic data, provided here, assists the investigator in formulating sampling frequencies suitable for the continuous assessment of each metal ambient bioavailability. If such records are required for copper, time-bulking samples for analysis is an option worth considering in view of this element rapid turnover in the clam kidney. This technique, originally suggested by Phillips and Segar (1986), involves pooling samples collected at different times from the same site. It can, therefore, be used to provide the desired level of continuity without placing excessive demands on analysis (often the most expensive component of a monitoring program).

Quantitative interpretation of renal metal levels in relation to ambient availability, though now theoretically possible, should be approached with caution in view of the many constraints outlined above. In addition, it should be realized that because trace metal uptake in the clam kidney is a balance between two kinetic processes, namely uptake and depuration, renal concentrations project a time-integrated rather than a time-averaged picture of metal availability. The two terms, although used synonymously in the literature, are clearly different. For clams to truly time-average requires that uptake is the only kinetic process in operation, (i.e., there is no depuration going on). Using the first order kinetics model, the only occasion when time-averaged ambient concentrating can be calculated with absolute certainty is when they have remained constant throughout the sampling interval. Departures from the accuracy of this estimate are dependant upon the rate, duration and magnitude of change in contaminant levels in the water column in relation to the time that the bio-monitor is removed for analysis. Nevertheless, under the severest combination of these variables, we estimate an error of around $\pm$ 30% providing the sampling interval coincides with the biological half-life of the metal in question.

Acknowledgements

This work was undertaken within the Department of Marine Biology, at the James Cook University (JCU) of North Queensland, Australia. The use of facilities at Orpheus Island Research Station, the specialist analytical and laboratory facilities provided by the School of Biological Sciences and the technical and administrative services provided by the University are gratefully acknowledged. Thanks also go to Steve Bell (CSIRO, Division of Fisheries, Cairns) and Pete Channells (Australian Fisheries Service, Thursday Island) for providing clams for analysis from Torres Strait, and to Professor Howard Choat (Head of Department of Marine Biology, JCU), Dr Joe Baker (Director, Australian Institute of Marine Science, Townsville) and Dr David J.H. Phillips (Mott MacDonald, Environmental Services, London U.K.) for their support and continued interest in the programme. G.R.W.D. wishes to express his sincere appreciation and thanks to Professor Cyril Burdon-Jones (Retired Head of Department of Marine Biology, JCU), for his encouragement, guidance and unfailing support during this author's stay at JCU.

The research was supported, in part, by the Water Quality Council of Queensland and Australian Marine Science and Technologies research grants (# 80-0078R and 84/1962).

Note

[1] A cautionary note is warranted here in the event that tissues other than the kidney are analyzed for trace metals. Freezing clams prior to analysis is not recommended as renal fluids cross-contaminate other tissue during the thawing process.

Bibliography

Bryan, G.W. (1976), 'Heavy Metal Contamination in the Sea', In R. Johnston (ed.), *Marine Pollution*, Academic Press, London, New York, San Francisco. 185-302.

Burdon Jones, C. and Denton, G.R.W. (1984 a), *Metals in Marine Organisms from the Great Barrier Reef Province: Part 1. Baseline Survey,* Final Report to the Australian Marine Science and Technologies Grant Awarding Body, Canberra.

Burdon Jones, C. and Denton, G.R.W. (1984 b), *Metals in Marine Organisms from the Great Barrier Reef Province: Part 2. Regional and Seasonal Variations,* Final Report to the Australian Marine Science and Technologies Grant Awarding Body, Canberra.

Burdon Jones, C., Denton, G.R.W., Jones, G.B., and McPhie, K.A. (1974), *Long-Term, Sub-lethal Effects of Metals on Marine Organisms: Part 1. Baseline Survey,* Report to the Water Quality Council of Queensland, Brisbane.

Carmichael, N.G. and Fowler, B.A. (1981), 'Cadmium Accumulation and Toxicity in the Kidney of the Bay Scallop Argopecten irradians', *Marine Biology*, 65, 35-43.

Denton, G.R.W. (1986), 'Guidlines for Trace Metal Surveillance Studies in Torres Strait and Adjacent Waters' In A.K. Haines, G.C. Williams and D. Coates (eds.), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985,* Australian Government Publishing Service, Canberra. 299-307.

Denton, G.R.W. and Burdon-Jones, C. (1981), 'Influence of Temperature and Salinity on the Uptake, Distribution and Depuration of Mercury, Cadmium and Lead by the Black-lip Oyster, Saccostrea echinata', *Marine Biology*, 64, 317-326.

Denton, G.R.W. and Burdon-Jones, C. (1986 a), 'Trace Metals in Algae from the Great Barrier Reef', *Marine Pollutuion Bulletin*, 17, 98-107.

Denton, G.R.W. and Burdon-Jones, C. (1986 b), 'Trace Metals in Fish from the Great Barrier Reef', *Marine Pollutuion Bulletin*, 17, 201-209.

Denton, G.R.W. and Burdon-Jones, C. (1986 c), 'Trace Metals in Corals from the Great Barrier Reef', *Marine Pollution Bulletin*, 17, 209-213.

Denton, G.R.W. and Burdon-Jones, C. (1986 d), 'Trace Metals in Surface Waters from the Great Barrier Reef', *Marine Pollution Bulletin*, 17, 96-98.

Doyle, L.J., Blake, N.M., Woo, C.C., and Yevich, P. (1978), 'Recent Biogenic Phosphorite: Concretions in Mollusc Kidneys', *Science*, 199, 1431-1433.

George, S.G., Pirie, B.J.S. and Coombes, T.L. (1980), 'Isolation and Elemental Analysis of Metal-rich Granules from the Kidney of the Scallop, Pecten maximus (L.)', *Journal of Experimental Marine Biology and Ecology*, 42, 143-156.

George, S.G. (1990), 'Biochemical and Cytological Assessments of Metal Toxicity in Marine Animal', In R.W. Furness and P.S. Rainbow (eds.), *Heavy Metal in the Marine Environment*, CRC Press, Inc., 123-142.

Gold, K.G., Cariulo, G. and Keeling, K. (1982), 'Variability in the calcium phosphate concretion load in the kidney of Mercenaria mercenaria', *Marine Ecology Progress Series*, 10, 97-99.

Gordon, M., Knauer, G.A. and Martin, J.H. (1980), 'Mytilus californianus as a Bioindicator of Trace Metal Pollution: Variability and Statistical Considerations', *Marine Pollution Bulletin*, 11, 195-198.

Hamner, W.M. and Jones, M.S. (1976), 'Distribution, Burrowing and Growth Rates of the Clam Tridacna crocea on Interior Reef Flats', *Oceologia*, 24, 207-224.

Haug, A., Melsom, S. and Omang, S. (1974), 'Estimation of Heavy Metal Pollution in Two Norwegian Fjord Areas by Analysis of the Brown Algae Ascophyllum nodosum', *Environmental Pollution*, 7, 179-192.

Hignette, M. (1978), 'Accumulation de Metaux dans les Concretions Minerales des Reins des Mollusques Lamellibranches', In, *Actualities de Biochimie marine. Vol. 2.* Colloque G.A.B.I.M. - C.N.R.S. La Rochelle. 195-206.

Jones, G.B. (1981), Environmental Factors Influencing Trace Metal Concentrations in a Tropical Estuarine Ecosystem, Ph.D. Thesis, James Cook University of North Queensland.

Khristoforova, N.K. (1980), 'Heavy Metal Content in Soft Tissues of Three Bivalve Species of the Bagaman Island', *Soviet Journal of Marine Biology*, 6, 51-55.

Khristoforova, N.K., Bogdanova, N.N., and Obukhov, A.I. (1979), 'The Content of Certain Metals in Soft Tissues of the Bivalve Mollusc Tridacna squamosa from Islands of the Tropical Zone of the Pacific in Connection with Environmental Conditions', *Soviet Journal of Marine Biology*, 3, 67-73.

Khristoforova, N.K., Cham, L.N., and Maslova, L.M. (1983), 'Content of Heavy Metals in the Bivalve Mollusc Tridacna crocea from the South China Sea', *Soviet Journal of Marine Biology*, 9, 338-344.

Klaassen, C.D. (1980), 'Absorption, Distribution and Excretion of Toxicants', In J, Doull, C.D. Klaassen and M.O. Amdur (eds.), *Toxicology: The Basic Science of Poisons, 2nd Edition*, Macmillan Publishers, New York. 28-55.

Majori, L. and Petronio, F. (1973), 'Marine Pollution by Metals and Their Accumulation by Biological Indicators (Accumulation Factor)', *Rev. Int. Oceanogr. Med.*, 31-32, 55-90.

Mauri, M. and Orlando, E. (1982), 'Experimental Study on the Renal Concretions in the Wedge Shell Donax trunculatus L', *Journal of Experimental Marine Biology and Ecology*, 63, 47-57.

Phillips, D.J.H. (1977), 'The Use of Biological Indicator Organisms to Monitor Trace Metal Pollution in Marine and Estuarine Environments - A Review', *Environmental Pollution*, 13, 281-317.

Phillips, D.J.H. (1980), *Quantitative Aquatic Biological Indicators. Pollution Monitoring Series* (K. Mellanby: Advisory Ed.)', Applied Science Publishers Ltd. London.

Phillips, D.J.H. (1990), 'Use of Macroalgae and Invertebrates as Monitors of Metal Levels in Estuaries and Coastal Waters', In R.W. Furness and P.S. Rainbow (eds.), *Heavy Metal in the Marine Environment*, CRC Press, Inc. 81-99.

Phillips, D.J.H. and Segar, D.A. (1986), 'Use of Bio-indicators in Monitoring Conservative Contaminants: Programme Design Imperatives', *Marine Pollution Bulletin*, 17, 10-16.

Reid, R.G.B., Fankboner, P.V. and Brand, D.G. (1984), 'Studies of the Physiology of the Giant Clam Tridacna gigas Linne - II. Kidney Function', *Comparative Biochemistry and Physiology*, 78A, 103-108.

Ritz, D.A., Swain, R. and Elliott, N.G. (1982), 'Use of the Mussel Mytilus edulis (Lamarck) in Monitoring Heavy Metal Levels in Seawater', *Australian Journal of Marine and Freshwater Research*, 33, 491-506.

Schulz-Baldes, M. (1974), 'Lead Uptake from Seawater and Food and Lead Loss in the Common Mussel Mytilus edulis', *Marine Biology*, 25, 177-193.

Simkiss, K. and Mason, A.Z. (1983), 'Metal Ions: Metabolic and Toxic Effects', In P.W. Hochachka (Ed,), *The Mollusca Vol. 2. Environmental Biochemistry and Physiology*, Academic Press, New York. 101-157.

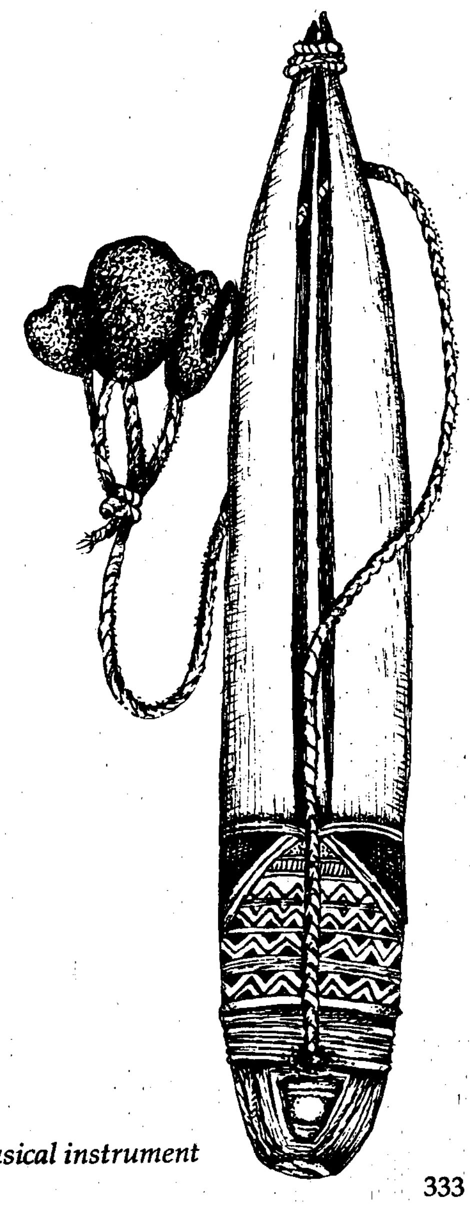
Simkiss, K. and Mason, A.Z. (1984), 'Cellular Response of Molluscan Tissues to Environmental Metals', *Marine Environmental Research*, 14, 103-118.

Spacie, A. and Hamelink, J.L. (1985), 'Bioaccumulation', In G.M. Rand and S.R. Petrocelli (Eds.), *Fundamentals of Aquatic Toxicology*, Hemisphere Publishing Corp. Washington. 495-525.

Topping G. and Pirie, J.M. (1972), 'Determination of Inorganic Mercury in Natural Waters', *Analytica Chimica Acta*, 62, 200-203.

Turekian, K.K. (1971), In D.W. Wood (Ed.), *Impingement of Man on the Oceans Wiley Interscience*, 9-73.

HUMAN ENVIRONMENT OF THE TORRES STRAIT REGION



Musical instrument

Maza: A Legend about Culture and the Sea

Judith Fitzpatrick, Tropical Health Program
University of Queensland Medical School

Abstract

A Western Torres Strait myth is used to illustrate the connection between sea territories and culture; the social links among people; and the value of the seascape. It is a story about Aukum, a legendary woman, who symbolises the fertility of the reef. Her abundant, daily fish catch is shared with relatives and while she traverses the numerous marine zones – deep water passages, platform reefs and the fringing home-island reefs – she stocks many reefs of Western Torres Strait with fish. This paper documents how peoples' lives are dependent upon the vitality of the local seascape and in particular the reef, maza. It is argued that cultural identity is based upon historical, symbolic and social associations with the sea and interminable use of the marine environment by Western Torres Strait Islanders.

Introduction

We have been confronted with the issue of rhetoric here at this conference. At the onset I want to point out the obvious: knowledge is power. Much of science is expressed within a very technically based vocabulary. We should be asking ourselves if this is absolutely necessary and realize that the ability to explain and communicate one's scientific work to a diversified audience is a skill and in a setting like this, enhances the exchange of ideas and is a key to equitable relationships. In deference to this I have decided to delete as much jargon as possible so that you will not hear words like epistemology, discourse, deconstructionist, postmodern polyphonic analysis, amibilineal descent system, or fictive kinship – all in common usage among anthropologists. There is one activity however that anthropologists do; it is very much a part of the jargon. It is something we call ethnography; we do ethnography by learning from the people we live and work among. Later we use the observations, interviews and quantitative data collected during the ethnographic fieldwork as a basis for description and analysis of culture and society. This is our data base. Crucial to its integrity is local knowledge – information placed with a cultural context.

I would like to commend the Chairman of the Great Barrier Reef Marine Park Authority, Graeme Kelleher for pointing out the relevance of considering the cultural factors among inhabitants of the Torres Strait in the Baseline Study; and I am honored to be invited to speak about Western Torres Strait Island culture.

Maza: A Legend about Culture and the Sea

Cultural themes endure even in a changing economic and political world. The historical context of culture exists in folk legends; these mythical stories from the past help to understand better the present and explain people's ideals, symbolic representations. At the same time these myths provide insights into the pragmatic side of life, that is the hows and whys of actual behavior. The retelling of a legend or myth reinforces cultural values for the listener just as it communicates knowledge about the real world. I want to use part of a legend from Western Torres Strait[1] to illustrate the historical context of the contemporary connection between culture and the sea, social links between people in the vast marine-based environment, and the symbolic and economic value of the seascape for the inhabitants of the Torres Strait region. Extensive trading networks in the past connected the Eastern and Western islands which were distinguished through differences in ecological setting and the resulting subsistence base of the human populations. A distinct linguistic identity has also differentiated the two locales. Today however all Torres Strait Islanders speak "broken", a creole which provides a lingua franca for the political region (Shnukal 1988). The next speaker, Jeremy Beckett, who has published widely on the Torres Strait (Beckett 1965, 1977a, 1977b, 1987), will provide an overview of the local economic and political history.

The focus of my presentation is a legend about Aukum – a woman who fishes on the reef every day and shares the plentiful catch with her brothers. Common in many local myths, the theme of sharing is a strong one, but the folktale goes on to also provide glimpses of greedy, self-serving behavior. Thus, in the end disclosing the universal contradiction of sharing and selfishness; of altruism and economic gain. Aukum's lazy brother repeatedly takes many more fish from her than he can possibly eat while another brother, feeling cheated by what his sister gives to him, kills his nephew, Tiai, Aukum's baby son. This act, as others throughout the legend, reflect cultural contradictions[2] (many I cannot discuss more fully in this paper). Instead the focus is on those themes specifically related to Islander interaction with the sea.

Among Islanders the sharing ethic particularly associated with kinship, remains strong even within the contemporary competitive and escalating entrepeneurial setting of the Torres Strait region. Often through extended kinship ties and friendships more and more outsiders are allowed to fish on local home reef shared fishing grounds. This altruistic behaviour could in the future undermine the viability of the marine habitat. The current dilemna over access in the cray fishing industry is a poignant example which I will return to later; and one which needs to be addressed in any discussion of the international protected zone.

In the myth that I have been relating to you, the story transforms into a tale about the supernatural after Aukum's brother kills his baby nephew. This transition is appropriate for there are two worlds within which people operate in Torres Strait. In the story the fishing woman Aukum moves into the supernatural world and embarks upon a long journey in search of her dead son. Her journey may be traced on the of the Torres Strait Region (Figure 1); she starts at her home on the west side of Moa progressing to Mabuiag, Dauan, Saibai and finally Boigu[3].

In between the islands Aukum travels along the sea bottom encountering a myraid of reefs along her way. At each *maza*, or reef, she distributes baskets of various species of fish. Thus, in both worlds Aukum personifies fertility and reflects abundance – she provides food for her kin and she stocks the reef with a plentiful supply of fish. This motif of plenty with regard to the reef is a prevalent cultural theme. Abundance in the sea territories must be mediated, or needs to be negotiated, in the natural world through knowledge about the ecological setting: the seasons; the winds; the tides; and specific local conditions and species behaviour, and acknowledgement of the spirit world. Today's discussion about the reef, about *maza* in the Western Torres Strait environment, focusses on the telling of Aukum's trip in order to emphasize the significance of a cultural perspective in understanding the traditional inhabitants view of their marine environment.

We can look upon mythical Aukum's travel as an underwater topographic narrative map for the case of Mabuiag Island home reefs (Figure 2). Each home reef for Mabuiag Island is explicitely described by name and number of baskets of fish distributed. Before going further north on her search, Aukum's last distribution stop is at Buru, or Turnagain Island, still a sacred place today for Mabuiag Islanders.

Each island in Western Torres Strait – Badu, Moa, Duan, Boigu and Saibai – has a range of marine habitats which are defined within the framework of home island sea territories. Legends and myths passed on from generation to generation and now written down, provide history of use and ownership. The narratives inform about the location, names and uses of home island reefs and sea territory.

I first heard the story of Aukum in 1976 from Gib and Kauwi Gaulai on Mabuiag Island where I lived for over one year. The first documentation in print of the legend was by Haddon (1890a; 1890b; 1904, v:56-62) who in 1888 recorded it from Tom and Gizu of Mabuiag and Kirer of Badu (and another version from the Eastern Islanders). Papi during the same time period drew the sketch map shown in Figure 3 to accompany the written form of the tale (Haddon 1904, v:60). As pointed out by another researcher in Western Torres Strait, we need to keep in mind that people conceptually produce the environment they use, delimit and defend (Nietschmann 1988:60).

Haddon, a marine zoologist turned ethnographer, twice visited Mabuiag Island in 1888 and 1898 studying and documenting Western Island culture and society (1890c; 1901-1935). He and his multidisciplinary team from England were fearful the culture would disappear as more and more European ways predominated. This paradigm, underlying what is now referred to as "salvage" ethnography, assumes the inert nature of culture. Historically, cultures have been depicted as static and viewed in terms of traditional pasts, rather than "as negotiated, present processes" (Clifford 1988:273).

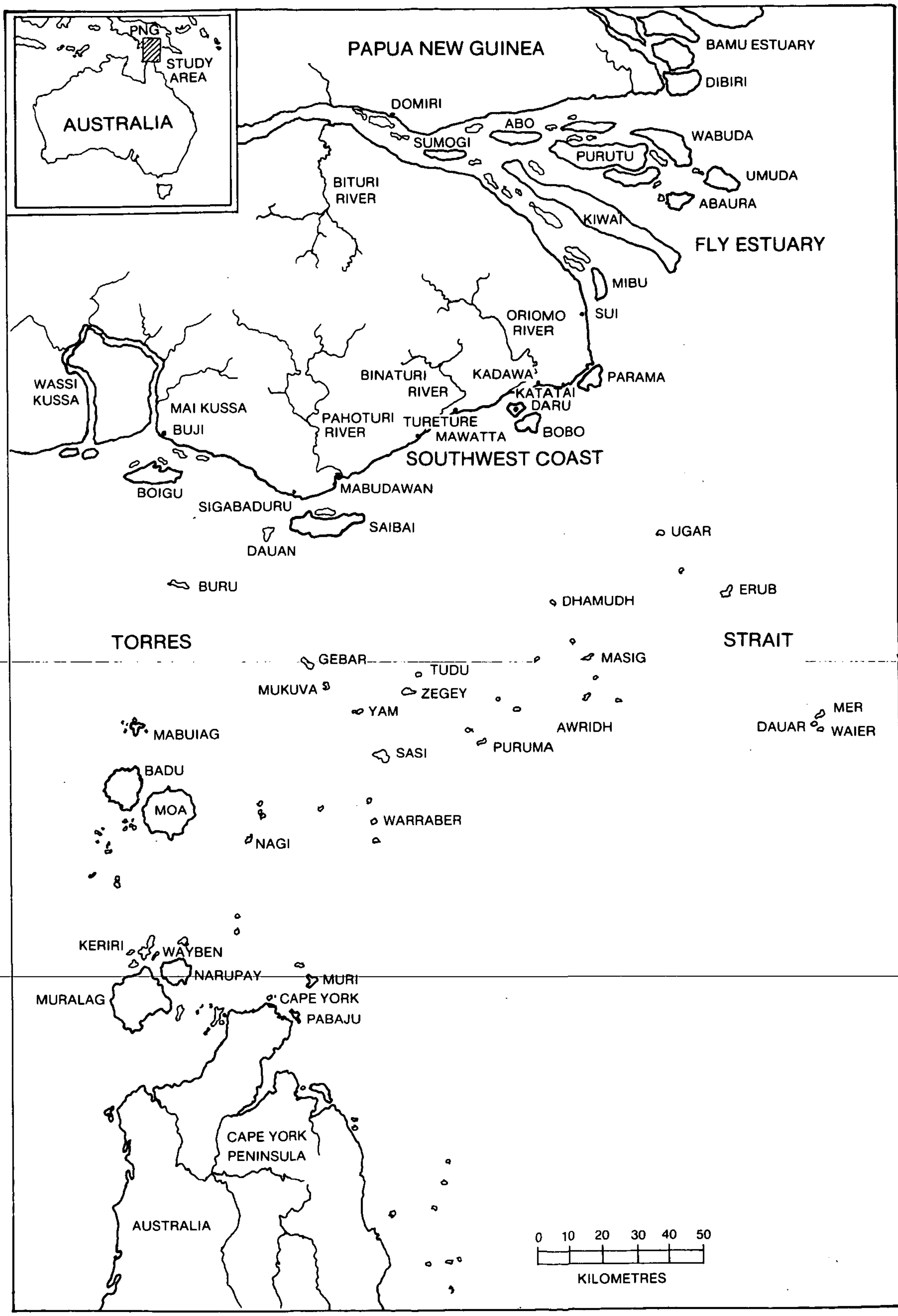


Figure 1. Map of the Torres Strait Region

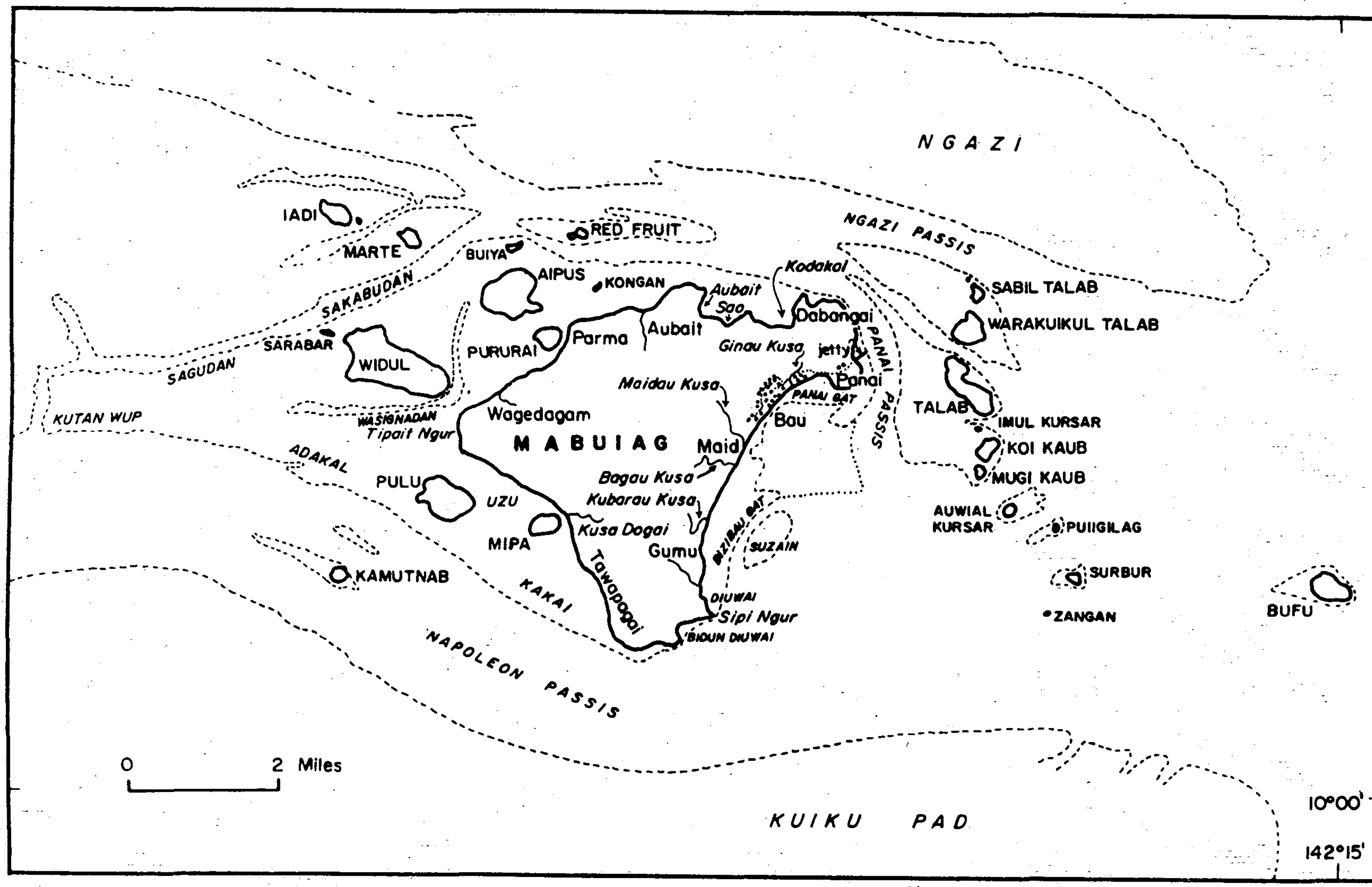


Figure 2. Map of Mabuiag Island home reefs

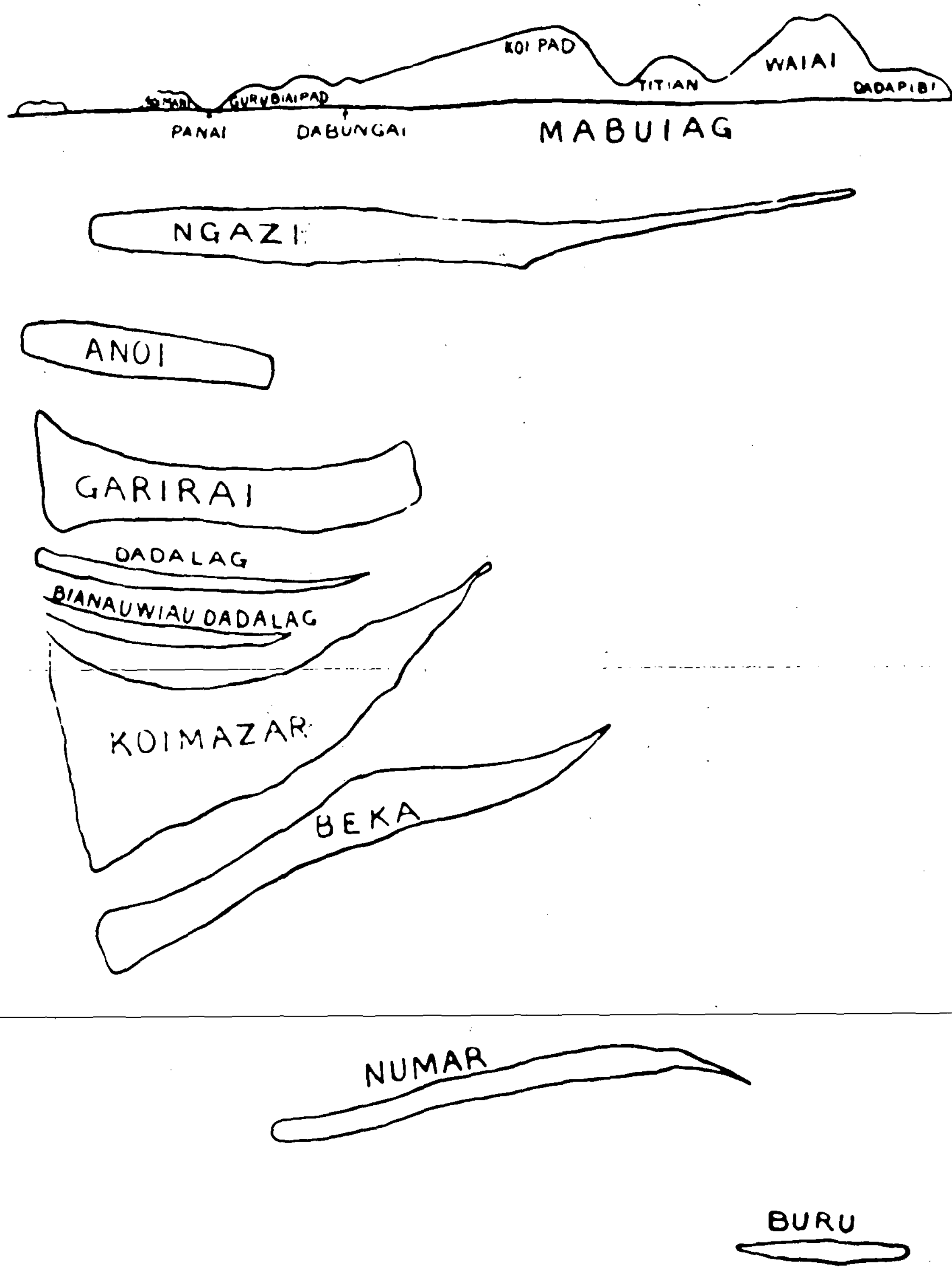


Figure 3. Sketch map of the coral reefs between Mabuiag and Buru (Drawn by Papi).

Now, almost 100 years later, Torres Strait Islanders from the Western Islands talk about cultural revival. Young, educated Islanders are returning home to marry, to live and to create a present day culture on their home islands.

Within anthropology it is commonly accepted that cultures grow, expand, contract, create and re-invent (Keesing 1989). This process of change is universal and inevitable. Much research, inspired by the rapid emergence of so many nation states in the island Pacific since World War II, focuses specifically on the topic of culture as a constantly negotiated and dynamic entity (cf. Keesing and Tonkinson 1982).

The struggle for a separate cultural identity vis-a-vis other black Australians by Torres Strait Islanders is a major concern as pointed out by Güitano Lui Jnr. earlier in the conference. This is part of a larger, pan-Pacific movement and like culture, cultural identity must be understood as creative, dynamic, and processual. We must keep in mind then that a symbolic concept of culture as proposed by Linnekin (1990:252) is necessary.

In addition to rock paintings and sacred sites, myths and legends are one way to perpetuate moral and cultural knowledge and guidelines. Connection to and knowledge about specific places on the land and the sea provides symbols of identity. It should seem obvious then that recognition of local traditions and knowledge is a high priority in any policy and management plans in Torres Strait.

Those threads of what we might consider traditional may disappear but very often identifiable cultural motifs do remain and are discernable as may be evidenced in narrative literature and may be observed in ritual performances today.

As I have documented elsewhere (Fitzpatrick-Nietschmann 1980; 1991; Nietschmann and Nietschmann (Fitzpatrick) 1981; and Cordell and Fitzpatrick 1987) cultural themes on Mabuiag Island predominate most social activity, including subsistence and economic endeavors especially within the marine environment. The threads of the story about Aukum's trip and the *maza* provide a symbolic representation of Islander concepts regarding the use, the access and characteristics of the reef.

People in Western Torres Strait today still know the story of Aukum. In Mabuiag sea territory all of the reefs named in the legend are still being used. Some however are being exploited in different ways. In particular, the rock lobster fisheries are creating new patterns of exploitation on the northern reefs, referred to generally as the Orman Reef complex.

As we heard earlier this week there are two types of harvesting in the rock lobster fishery: free diving and hooka rig. The study by Arthur and McGrath (1989) shows that Mabuiag Island has no freezer or large vessel with a hooka diving setup. Most rock lobster fishing is conducted from dinghies in areas fairly close to the island except in cases when non-Islander entrepeneurs with large vessels provide towing of dinghies to outer reefs and freezer facilities on board for the catch. In monitoring exploitation, an important distinction should be made with regard to type of vessel and technology used. We heard yesterday that during 1989 in the rock lobster industry Islanders used 200 vessels while non-Islanders used 30 vessels. We did not hear a definition of the various types of vessels or their capabilities. These types of comparisons without adequate definitions with regard to quality of gear and availability of facilities misprepresents the actual situation and contributes to misunderstandings.

Islanders have expressed their concerns about possible pollution from the north, the use of Turnagain Island, or Buru, which has always been a place of historical spiritual importance, and the anticipated over-exploitation of the nearby reefs by non-Islanders.

Whether or not current harvesting of these reefs fits within the 'Free Movement' clause contained in Article 22 of the Treaty for the Protected Zone is not clear. What is clear is that Western Torres Strait Islanders are culturally restricted from landing or visiting at Buru while non-Islanders freely utilize the space for camping and as a depot for catches of crayfish. Even though this is recognized as sea territory of Mabuiag Island, subsistence use of the space is not an issue. As Helene Marsh noted Boigu hunters obtain 10% of their dugong take on the sea grass flats south of Buru (this volume). Western Islanders continue to share marine hunting and fishing zones; the concern that has been voiced to me is the commercial use of the area by non-Torres Strait Islanders.

On Mabuiag Island, the western most of the inhabited islands in the Torres Strait, men, women, and children all utilize their local marine habitat and sea territory for food. Bob Johannes (this volume) reports in detail on the consumption patterns of Torres Strait Islanders. Historically, evidence suggests that the marine environment was of much greater importance to Mabuiag and Badu than for the Eastern Islanders who were intensive horticulturalists. Today, on Mabuiag very few year-round gardens are kept; although kitchen gardens exist, coconut and fruit trees are harvested, and a variety of terrestrial gathered foods are still sought after. The primary subsistence focus however is the marine environment. As a result social activities are dominated by the sea.

Much has been written about the marine herbivores, *dangal* (dugong) and *waru*, (turtle) which as I have noted elsewhere are the most prestigious sources of protein for Western Islanders (Fitzpatrick 1980; Nietschmann and Nietschmann (Fitzpatrick) 1981). In the past, both species were totems for the dominant clan groupings[4].

Today, men hunt for these subsistence foods on sea grass beds on Kuiku Pad and in the back of the island. They utilize many generations of accumulated knowledge and skill about the local territory. Especially important are the tides: *kulis* (current with wind, smooth and rolling) in contrast to *gutat* (current against wind with a choppy surface). These wind-current relationships define access and availability of species in the seascape of Mabuiag sea territory. Much time, labor and cash output are involved in marine hunting yet the meat is still shared and not sold (and not just because of outside laws) within the community through kin-based distribution networks. The symbolic and social significance of these species for Western Torres Strait Islanders is unrefutable.

Less prestigious but more common and critical to nutritional needs, is daily fishing in the local seascape. Availability of store-bought foods has improved significantly on the outer islands in the last five years yet fresh fish is a highly sought after food.

Generally, someone from every household on Mabuiag Island is involved daily in a subsistence fishing activity which provides fresh seafood for the group. Some men, but primarily women and older children utilize a range of the reef zones to catch a variety of marine species. Fishing is also determined by the tides and young and old women watch the four daily tides in order to select the appropriate time to go fishing. Often they are after a particular species or a favorite type of fish; or the season and tide may signal the abundance of a particular species and individuals will embark on trips to known sites of past successful takes. Technology is simple: hand line with hook and weight with either flour ball or *kiar* head bait and a bucket. Young girls and boys also do hand line fishing with their mothers, aunties or grandmothers. Sometimes a seine is used, particularly at creek mouths during the wet season. Fishing in groups provides not only security in returning with some food but is a highly desired social activity. This is the time stories are told; information passed on about good fishing spots, tidal ranges and species availability; and skills shared and learned by the young.

Boys and adolescents, as well as men, use a three prong spear, to fish along the shore or on the shallow reef. Squid, a favorite species is available according to the specific tide and season. Younger boys spear squid and gar fish. These favorites are readily caught in shallow water. Older men walk on the reef and spear any edible species.

Everyone has a favorite fish to eat. Women often go off fishing with this in mind. If a deeper water reef fish is desired the options available for women include: taking a dinghy out to a nearby special spot, waiting for a very low tide (*koi gat*) and walking out to the edge of the *maza* and fishing off the reef ledge, or fishing off the jetty constructed at Panai on the northeast corner of the island.

Even though people fish for favorite species, much of the fishing is determined by season and the timing of the tides, similar to strategies used in turtle and dugong hunting. Thus, at a specific time of year there is a specific fish available. Fishing is not a random activity. It is based upon known sets of information. Environmental signs – wind, season, tide, phase of the moon – trigger people's knowledge about what is available to obtain at any specific time of the year. People's knowledge about local fisheries often extends beyond their specific capabilities, defined by gender, age, skill, technology, and time. Much of this information is stored and recalled in songs, dances, stories and legends.

Like Aukum, people who fish share with their relatives. The amounts may be small and prestige is minimal when compared with dugong and turtle distribution, but everyone wants fresh fish. It is not spoken of in the same way as *dangal* or *waru* but it is critical for a good meal.

Fishing for commercial purposes has had a boom and bust history in the Western Torres Strait. The major problem for a viable rock lobster industry on some of the Western Islands at present is the lack of an adequate economic infrastructure. Individual fishermen just do not have the capital to purchase new technology or large vessels to improve the fishery. Any future development of the industry needs to look at local requirements, local knowledge, and must take into account cultural beliefs about the use of different zones within the proposed harvesting area.

Knowledge about the sea territories is extensive. This information could be tapped prior to the development of more elaborate research designs or policy plans. Local people's information, based upon years of accummulated experience in an ecosystem, often provides unknown and useful data about species feeding behaviour and seasonally defined geographic location. Local people can, as well, assist in monitoring programs. Besides the telling of legends and myths, specific information about particular family resource zones is passed from uncles to nephews; this tradition persists. Young people are learning about both systems: they hear about the natural and supernatural in their local environment through such stories as Aukum's underwater topographic narrative map; through exploration on their home island and reef; and through formal education in the State-run school where they also learn about the commercial aspects of the larger political regional system of Torres Strait.

I have told you about the *Maza* and Aukum, a folktale about the fertility of the reef and the social obligations of sharing in order to illustrate how origins, ownership and knowledge of a cultural group and its environment may be embedded within oral traditions. We need to always keep in mind that Torres Strait Western Island sea territories are social and cultural space as much as they are an economic resource or a subsistence space. Torres Strait Islander knowledge and connection to the sea territories are an asset and one we need to not only consider in the Baseline Study but respect, utilize and incorporate into any sustainable development plan in the region.

Notes

[1] The folktale has a version in the Eastern Islands and is recounted in Haddon (Volume 6) 1901-1935.

[2] Numerous cultural themes dominate myths in Western Torres Strait legends. The *wadwam* or *audi* relationship between a child and their mother's brother (maternal uncle) is one such theme (eg. the myth of Kwiom, the culture hero). Today *audi*, that is individuals who refer to each other by the term continues to be a crucial social relationship. A maternal uncle is the teacher of cultural knowledge generally and specifically about environmental information needed for fishing, hunting and gathering. Mother's brothers also are helpful during family disputes, especially those between parents and children.

[3] On each island she encounters groups of men performing rituals. She inquires if they have seen her son, Tiai. She apparently is not aware that she is in the spirit world and that her son is dead; or conversely, it may be that she does know she has moved into the spirit world in search of her dead son. Much of the belief system in Western Torres Strait cosmology was built upon belief in a Land of the Dead. An elaborate secondary mortuary ritual was a key event representing an intricate, obligatory exchange system among living relatives. Their prescribed actions guarantee the transference of the deceased to the proper world of the dead (cf. Fitzpatrick 1981). This cultural theme is yet another focus in the myth being discussed in the paper.

[4] People on Mabuiag today know their totem identity and their ancestral land and sea areas. However, the clan system of organization is not operative on a daily functioning basis.

Bibliography

Arthur, W.S. and McGrath, V. (1989), *Torres Strait Development Study*, Australian Institute of Aboriginal Studies, Canberra.

Beckett, J.R. (1977a), 'Mission, church and sect: Three types of religious commitment in the Torres Strait Islands', In, J.A. Boutelier, D. Hughes, and S.W. Tiffany (eds.), *Mission, Church and Sect in Oceania*, University of Michigan Press, Ann Arbor, 209-229.

Beckett, J.R. (1977b), 'The Torres Strait Islanders and the pearling industry: a case of internal colonialism', *Aboriginal History*, 1(1), 77-104.

Beckett, J.R. (1987), *The Torres Strait Islanders: custom and colonialism*, Cambridge University Press, Cambridge.

Clifford, J. (1988), *The Predicament of Culture*, Cambridge, MA: Harvard University Press.

Cordell, J. and Fitzpatrick, J.M. (1987), 'Torres Strait: cultural identity and the sea, *CS Quarterly*, 11(2), 15-17.

Fitzpatrick, J.M. (1981), 'Tombstone Openings: Cultural Change and Death Ceremonies in Torres Strait, Australia', *Kabar Seberang* No. 8/9, 1-15.

Fitzpatrick-Nietschmann, J.M. (1980), Another way of dying: the Social and Cultural Context of Death in a Melanesian Commuity: Torres Strait. PhD diss. University Microfilms, Ann Arbor.

Haddon, A.C. (1890a), 'Legends from Torres Strait', *Folk-Lore* 1(2), 46-81.

Haddon, A.C. (1890b), 'Legends from Torres Strait II', *Folk-Lore* 1 (2), 172-196.

Haddon, A.C. (1890c), 'The Ethnography of the Western Tribe of Torres Strait', *Journal of Anthropological Institute*, 10 (Feb), 297-440.

Keesing, R.M. (1989), 'Creating the Past: Custom and Identity in the Contemporary Pacific', *The Contemporary Pacific*, 1 (1/2), 19-42.

Keesing, R.M. and Tonking, T. (eds.) (1982), Reinventing Traditional Culture: The Politics of Kastom in Island Melanesia, *Mankind* Special Issue, 13(4).

Linnekin, J. (1990), 'The Politics of Culture in the Pacific', In J. Linnekin and L. Poyer, (eds.), *Cultural Identity and Ethnicity in the Pacific*, University of Hawaii Press, Honolulu. 149-173.

Nietschmann, B. (1988), 'Traditional sea territories, resources and rights in Torres Strait', In J. Cordell (ed.), *A Sea of Small Boats*, Cultural Survival, Cambridge, Mass., 60-93.

Nietschmann, B. and Nietschmann (Fitzpatrick), J. (1981), 'Good dugong, bad dugong: bad turtle, good turtle', *Natural History*, 90(5), 54-63, 86-87.

Shnukal, A. (1988), *Broken: an introduction to the creole language of Torres Strait*, Australian National University, Research School of Pacific Studies, Department of Linguistics, Canberra.

The Eastern Islands of Torres Strait

Jeremy Beckett, Department of Anthropology
University of Sydney

The Eastern Islands of Torres Strait include Erub or Darnley, Ugar or Stephen Island, and the three islands, Mer, Dauar and Waier, collectively known as Murray Island. There is also Nepean, which was inhabited within living memory, and other small islands and cays which, while never inhabited, have been regularly used over many years. The most important of these is Bramble Cay, near Erub.

The Eastern Islands lie within sight of one another, and together they constitute a distinct section of the Torres Strait Islands. This is not just because of their proximity, but also because of their physical character and the culture of their inhabitants.

Unlike the other islands in the strait, they are of recent volcanic origin, each set within coral reefs and surrounded by beaches, from which they rise steeply, in the case of the highest, Mer, to some 250 metres. Originally they were densely forested. This is still the case with Ugar and Dauar, and also with a large part of Mer. Grassy slopes situated at the west end of Mer have increased in area after repeated burning in historic times, and the same is true for a much larger area of interior Erub.

The inhabited islands are small, compared with the western group, but they are very fertile, being covered with rich volcanic soil, and since agriculture was traditionally practised, they could support relatively dense populations. Thus the Murray group, with an area of around six square kilometres, may have supported as many as 800 people in the first half of last century. Erub has an area of about 4.5 square kilometres

, but we have no estimates of population at contact. Ugar is much smaller and its inhabitants seem to have been fewer than 100.

All the Eastern Islanders spoke variants of the same language, known as Meriam, which is related to certain languages on neighbouring Papua New Guinea. The culture was also generally similar to that of the neighbouring mainland, particularly in the practice of agriculture. Using swidden techniques, with the land left fallow for several years after cultivation, they grew yams and a variety of other root crops, as well as bananas. These staple foods were supplemented by coconuts, which have always grown in profusion, and other fruit and nut bearing trees.

It seems that pigs were not kept until historic times. Protein came from the sea. Although the waters were too deep for dugong, there were turtles in profusion. The people hunted them in long sailing canoes, imported from Papua New Guinea. But around November and December they could be captured on sandbanks as they climbed up to lay their eggs. They also used the beaches of the Murray group for this purpose, when the people could catch them without even getting their feet wet, simply by rolling them on their backs.

Canoes were also used for deep water fishing, but at certain seasons shoals of small fish lay just off the beaches, where they could be caught with scoops or spears. These 'sardines' also attracted larger fish which could be caught with spear or line. During the north-west monsoon, when vegetable foods were short and other kinds of fishing were difficult, the people resorted to their large stone fish traps. High tide carried fish over the walls, and low tide left them stranded.

Although there were seasons of scarcity and occasional years of famine, the environment was sufficiently rich, and the exploitation of it efficient enough to enable the development of a rich ceremonial culture, involving use of song, dance and paraphernalia such as masks. Singing and dancing also figured largely in recreational activities enjoyed during harvest time and when turtle was plentiful.

The Eastern Islanders derived their identities from their kinsfolk, from the land and seascape, and from particular relationships with various spiritual beings. One identified oneself with a named section of the foreshore, around which the houses were situated; also with particular tracts of land in the interior, sea frontages, fish traps and reefs. Notionally also, one was identified with particular natural species, stars and winds, though the right was to use these things symbolically rather than economically. Further one was identified with certain religious cults and the spiritual beings and sacred objects – particularly masks – associated with them.

Underlying this was the kinship system, which organized the membership of territorial and cult groups, and the inheritance of rights over land, sea, sky and other things.

The Eastern Islanders maintained regular contact among themselves, for trade and religious purposes, and there was some inter-marriage. There were also similar contacts with islands to the west, particularly Masig (Yorke), and with coastal Papua and Australia. The myths and legends suggest an openness to new things, as one would expect of a society that depended crucially on the importation of canoes from

Fly River. European accounts from the first half of the nineteenth century describe the Islanders' eagerness to barter for iron and their readiness to engage in friendly exchanges with the strangers. Unfortunately, the foreigners were not always caring of local interests and sensitivities, giving rise to violent exchanges in which the Islanders finally came off worse.

Contact and Colonization

From the end of the eighteenth century to the 1850s, Europeans used the Strait simply as a seaway, and – apart from a few castaways – their contacts with the Islanders were fleeting. From the 1860s, however, they established a permanent presence. This was partly to provide government protection for passing vessels and a means of monitoring the ships of foreign powers, and it was presently followed by annexation of the islands. However, this decade also saw the emergence of a marine industry, exploiting the plentiful supplies of pearl shell and trepang (beche-de-mer). Finally the London Missionary Society came from Lifu and on July 1st 1871, landed missionaries on Erub to begin the work of evangelization.

These events were not the catastrophe for the Islanders that they were for the Aborigines. As elsewhere in the colonized world, while there was a drastic population decline, probably by more than half, no community was actually extinguished. And although some small communities were displaced or persuaded to move, the majority remained in occupation of their islands. The result was nevertheless a profound transformation.

Firstly, the Eastern Islanders had to accommodate considerable numbers of foreigners, including missionaries, pearlers and trepangers. Only a few Europeans were resident and none settled permanently, but considerable number of Pacific Islanders and Asians married local women and stayed, founding families. The government evicted most of the foreigners from Murray in the 1890s, but allowed them to remain on the other islands, whose indigenous populations were smaller. In recent times, Ugar has been dominated by the descendants of a local woman and a Filipino. In Erub too, most families trace their ancestry back to Loyalty Islanders, Solomon Islanders, Rotumans, Niueans or Jamaicans.

The most striking result of this settlement has been that, while Meriam language persists on Mer – and until recently the first language – it has been replaced on the other islands by a pidgin English which has become the vernacular. However, although this creole, known locally as Broken, is more developed on these islands, it has been the second language of Islanders throughout the Strait for more than a century.

This linguistic change is indicative of the complex process of cultural change that was taking place throughout the Strait. Although there were conflicts between foreigners and local people, there was also a degree of integration. Most of the foreigners came from cultures and environments that were broadly similar to those in the Strait, and just as they could be assimilated into the communities through marriage, so the communities could comfortable absorb the innovations they introduced, for example to house styles, cuisine, music and dance. The foreigners also introduced new varieties of the plans already cultivated in the Eastern Islands, and new crops such as corn and sweet potato, which could be readily absorbed into local agriculture and brought a greater diversity to subsistence system.

No more foreigners were allowed to settle after the turn of the century, so that the communities were allowed to stabilize. At the same time they were all undergoing change and increasing control under the impact of the mission, the marine industry and the Queensland Government, which took over administration of the islands towards the end of last century.

The missionaries broke up or drove underground the old cults and within a generation created sabbatarian communities, which were regulated by a strict code of Christian morality. What was remarkable was that this regime secured the active collaboration of the local population. At the turn of the century, the Queensland government added local government councils which complemented the congregational system of church government. Although these communities were regulated from outside, they gradually assumed a significant degree of local self-management.

From the beginning, Islanders had provided labour for the marine industry, mainly as skin divers and deckhands. For the next hundred years, almost every able-bodied male experienced periods of boat work, particularly during his younger years, and some went on to become renowned skippers. They quickly became adept in sailing the luggers through the complex system of reefs, even by night and in rough seas. These all-male groups, might be seen as replacing the all-male war or trading parties and initiations. Certainly they provided a new context in which boys received discipline and instruction from their elders. However, the absences were much more extended, running into weeks and months, and they were much more disruptive of the island economy.

The marine industry was volatile, and even in the best of times wages were insufficient to support the communities. Thus a section of the population, usually the women, children and older men, continued to garden and fish. During times of unemployment, the younger men joined them.

Life was not easy in the Eastern Islands during these years, but at certain seasons there was time for festivities. The old missionaries had been puritanical. The Church of England which replaced them in 1915 was less repressive, and it gave rise to a calendar of religious holidays which were to be celebrated. In addition, personal events such as weddings and the 'tombstone opening' which marked the end of a period of mourning, provided further occasion for celebration. The Islander communities developed out of their tradition and from what they had adopted from foreigners, a distinctive feasting complex, involving dancing and the consumption of special foods. Significantly, these are mainly local foods, including banana and cassava puddings, cooked in coconut cream, fish and turtle meat.

The Queensland Government strictly segregated the Islanders up to the outbreak of war in the Pacific, and under conditions of considerable stability, the communities had the opportunity to reach a new internal equilibrium, and to work out their relations with those who controlled their lives. The war created an interregnum, during which the bulk of able bodied men were drafted into the Torres Strait Infantry, based alongside white troops, in and around Thursday Island. During this period, those left behind on the islands had to look after themselves as best they could.

The Eastern Islands and Australia

The wartime experience left the Torres Strait Islanders eager for advancement towards the freedoms and economic well-being enjoyed by white Australians. The authorities attempted to restore the status quo with only slight modifications. Among these modifications, however, was permission for work parties to go to the mainland for the cane cutting season. And when some stayed on, finding work on the railways, the government made no attempt to repatriate them. The Eastern Islanders, who for various reasons found work in the marine industry unattractive, pioneered the move south. When in the early 1960s, the pearl shell market collapsed while the mainland demand for Islander labour boomed, the trickle became a flood. Whereas during the 1950s the emigrants had been males, many of them single, by 1970 whole families were moving to North Queensland, notably Townsville, Ayr and Mackay. Within a decade, the eastern island populations had fallen by more than 50%.

A study conducted for the Federal and Queensland governments by an Australian National University team in 1972 presented a gloomy forecast for the Torres Strait Islands, particularly the eastern group. Given the continuing economic stagnation at home, they anticipated a continuing flow of population to the mainland, and a minimal return back. Moreover, they presented the urban population as both atomized and disconnected from the home communities. The prognosis for the home islands was as a place for parents, wives and children, abandoned or not yet rescued by their kin on the mainland. Though not explicitly suggested, the eclipse of whole communities seemed to be on the horizon.

There are reasons to believe that this picture was overdrawn. However, to the extent that it was true, the factors that contributed to it changed again over the next twenty years. In particular, employment prospects for Islanders on the mainland deteriorated steadily through the 1960s; at the same time, some emigrants found that their high hopes for themselves and their children were disappointed. Simultaneously, as the island leaders took advantage of Federal intervention in indigenous affairs, living conditions in the Strait improved markedly. And while employment opportunities have scarcely improved in the Eastern Islands, it is now possible to live from a combination of welfare payments, including the dole. Increasing numbers of emigrants are returning home, even after living twenty and more years down South. The demographic profile of these communities is no longer distorted by migration as it used to be, but broadly what one would expect of a community reproducing itself in a fairly stable fashion.

Young people continue to go out of the communities, but the decision is no longer so irrevocable as it used to be. Whereas during the 1970s, it was extremely difficult to return to the home islands, there are now regular air services. Likewise, whereas before there was no way other than letter of communicating between island and mainland, there are now telephone hookups. The two populations are now in regular contact, and intervisiting by young and old is frequent, particularly during the holiday season.

Eastern Islands in 1990

The communities have changed over the last thirty years. Although religion remains important, it has become a matter of individual or family choice. There is no longer the strict sabbatarianism and the councils no longer attempt to enforce morality with imprisonment and fines. People expect much the same individual freedom that they experience on the mainland. Politics is now about obtaining and administering government funds.

The communities are now more prosperous than they were twenty years ago. Most of the housing is from manufactured materials; some have electrical appliances such as washing machines and videos, and the generators to run them. Vehicles carry people around the village. Fishing and hunting are now from aluminium dinghies with outboard motors. There are stores with a range of foodstuffs, including frozen meat and fish, in place of the old flour, sugar and tinned beef.

This material well-being is due in part to remittances from the mainland and the wages of those few in government employment, but largely to the welfare economy. Attempts to engage in commercial fishing have failed, for a variety of reasons, and the recent attempt to profit from the reviving prices for trochus shell remain uncertain. Nevertheless, some kind of marine industry provides virtually the only possibility of economic independence.

Meanwhile, the appearance of prosperity is superficial, and any reduction in social service payments could be disastrous. Freedom from the need to pay urban rents is offset by the extraordinarily high prices of retail goods, due to freight costs and periodic profiteering from shortages. Alcohol prices are exorbitant. Gardening has been curtailed and is largely confined to bananas, but fishing and turtle catching remain important supplements to income, as well as providing fresh food. They also remain activities which are valued in themselves.

Traditional foods also remain at the heart of the festive complex, which flourishes unabated. Indeed, with the opening up of air transportation, these occasions, particularly tombstone openings, provide opportunities for kinsfolk to assemble, renewing their family ties, and introducing the younger generation to the world from which their parents came.

Despite so many changes and so much outside contact, the communities retain their old integrity. The inhabitants are almost exclusively birth members of the community, or rather of longstanding families associated with the community. They own and jealously guard residential and garden land, which they have inherited in the traditional way, and they regard themselves as entitled to gather the fruits of the sea, and to follow ancestral pursuits.

A deterioration in the supply of marine foods, such as might follow from pollution of the sea, would impoverish the Islanders' diet as well as placing further strains on their meagre cash income. It would also terminate activities which people value as part of their cultural heritage as well as for their own sake. Finally, a termination of the supply of marine foods, and particularly of turtle, would seriously undermine the feasting complex which is central to community life and provides a focus for Islander identity.

Bibliography

Beckett, J. (1987), *Torres Strait Islanders: Customs and Colonialism*, Cambridge University Press, Cambridge.

Duncan, H. (1974)), *Socio-Economic Conditions in the Torres Strait: a Survey of Four Reserve Islands*, Research School of Pacific Studies, Australian National University. Canberra. (The Torres Strait Islanders, Vol I)

Fisk, E., Duncan, H. & Kehl, A. (1974) *The Islander Population in the Cairns and Townsville Area*, Research School of Pacific Studies, Australian National University. Canberra. (The Torres Strait Islanders, Vol III)

Haddon, A.C. (ed.) (1901-1935), *Reports of the Cambridge Anthropological Expedition to Torres Strait*, University Press, Cambridge.

Singe, J. (1989), *The Torres Strait Islanders*, University of Queensland Press, St Lucia. (2nd. ed.)

Wopkaimin Landowners, the Ok Tedi Project and the Creation of the Fly River Socio-ecological Region

David Hyndman, Department of Anthropology and Sociology
University of Queensland

Abstract

Following Godoy's (1985) approach to the anthropology of mining, this study of the Ok Tedi mining project and indigenous peoples is divided into an economic base and a derivative socio-ecological and ideological superstructure. The transnational Ok Tedi Mining Limited started their gold and copper mining of Wopkaimin's sacred Mt. Fubilan in 1981. Mining requirements for capital, labour and food for workers as well as the physical output of its operation integrated the surrounding indigenous peoples of the Fly River into a single ecological/economic region. From the beginning of production, the project has been nothing short of an environmental disaster. Wopkaimin protest has not only been confined to mine employment, and more broadly based ideological movements of social protest are spreading among indigenous peoples throughout the region.

Mineral Development of a Sacred Mountain

Following the anthropology of mining adopted by Godoy (1985), this study of the Ok Tedi mining project (Figure 1) and indigenous people is divided into an economic base and a derivative socio-political and ideological superstructure. The onslaught to Wopkaimin place and culture started with Kennecott test drilling on Mt Fubilan (Figure 2) in 1969, the location now commonly referred to as the "Pot of Gold" (Jackson 1982). To the Wopkaimin, Fubilan is a sacred mountain sitting on top of the land of the dead. Exploration determined that an extremely ambitious engineering project could convert Mt Fubilan into an 1200 metre deep mining pit.

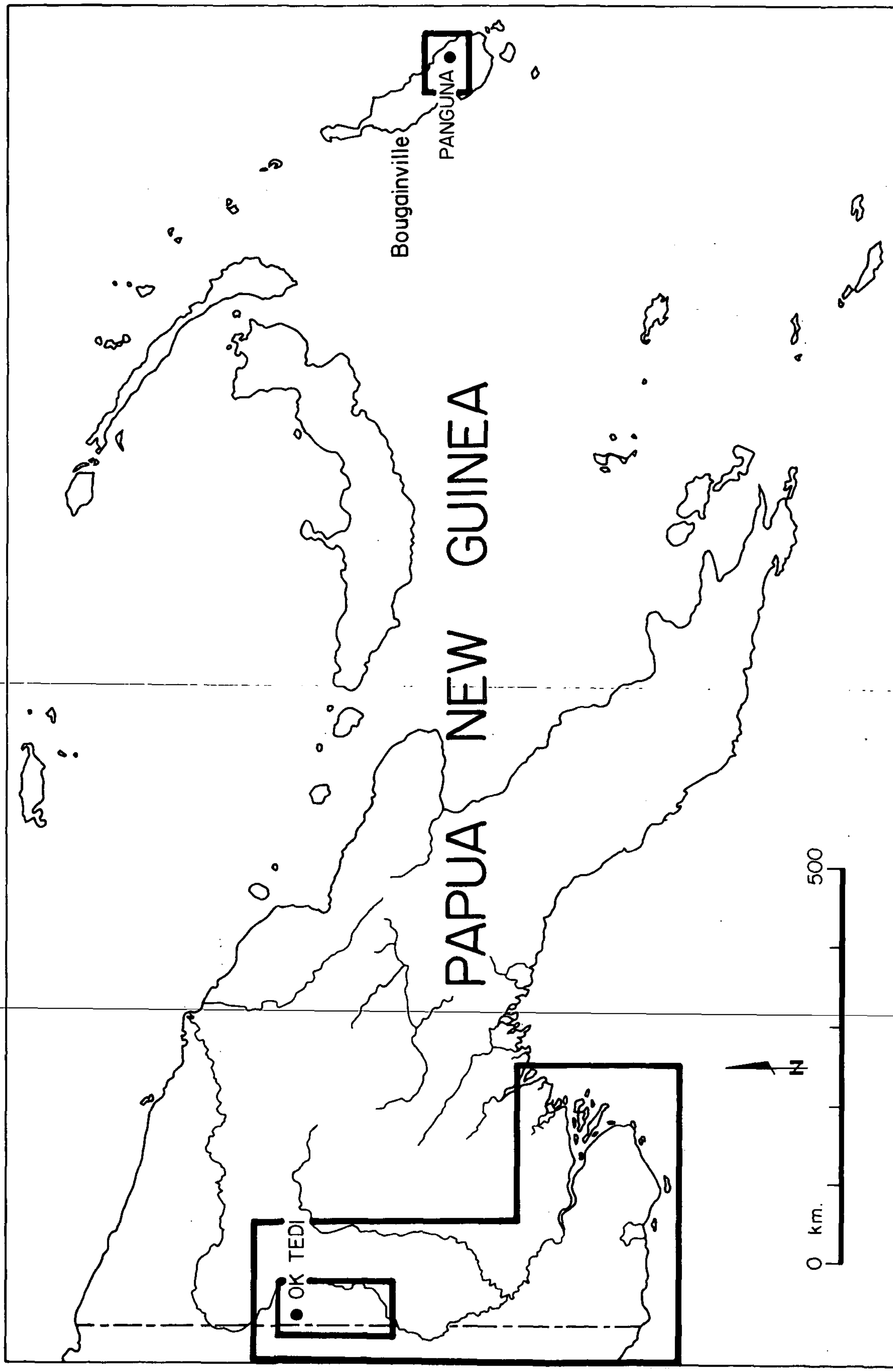


Figure 1.

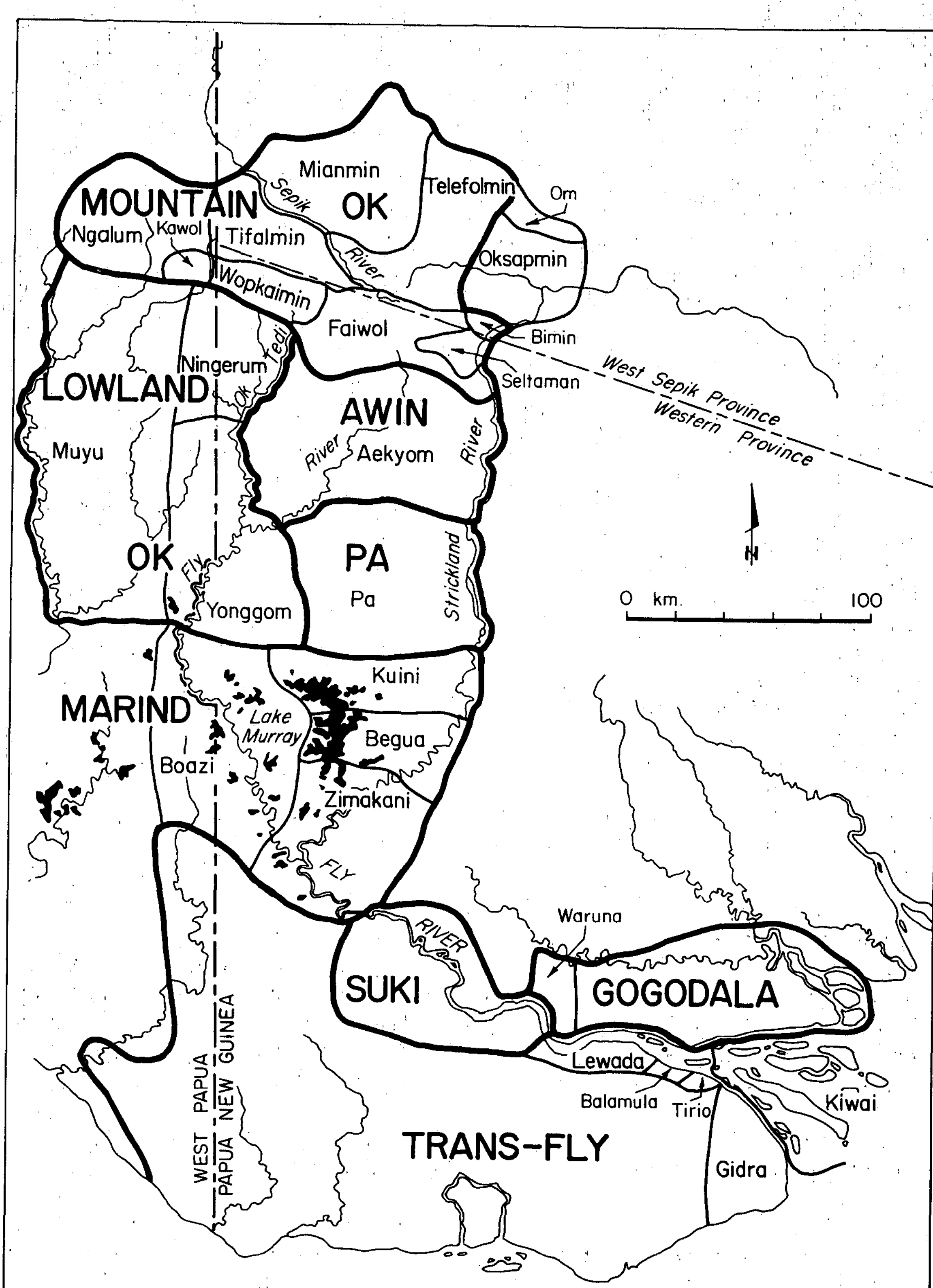

Mianmin
Telefolmin
Om
MOUNTAIN OK
Sepik River
Ngalum
Kawol
Tifalmin
Oksapmin
Wopkaimin
Faiwol
Bimin
Seltaman
Ningerum
LOWLAND OK
Ok Tedi
AWIN
River
Aekyom
River
West Sepik Province
Western Province
N
Muyu
PA
Pa
Strickland
Fly
Yonggom
0 km 100
Kuini
MARIND
Lake Murray
Begua
Boazi
Zimakani
FLY
Waruna
RIVER
SUKI
GOGODALA
Lewada
Balamula
Tirio
Kiwai
TRANS-FLY
Gidra
WEST PAPUA
PAPUA NEW GUINEA

Figure 2.

Kennecott never mined the pot of gold. Having their copper mines in Chile nationalized by the Allende government frightened Kennecott into abandoning the Ok Tedi project shortly before Papua New Guinea achieved independence in September 1975. From the beginning, tax and arbitration provisions (Jackson 1982:40-72; Pintz 1984:32-49), rather than environmental or land owner protection, were the National government's primary concern.

Following soaring gold prices, the transnational Ok Tedi Mining Limited (OTML) consortium was created in 1981 to develop the project. With the development of the Ok Tedi project, gold and copper mining became the major force in the economy of PNG; in 1982 PNG produced 18,000 kg of gold and 170,000 tonnes of copper, each were two percent of the world total.

A Regional Socio-Ecological System Under Threat

Mining requirements for capital, labour and food for workers as well as the physical output of its operation integrates surrounding regions into a single ecological/economic sphere (Godoy 1985:207). The PNG government decided for the Wopkaimin, and other indigenous peoples of the socio-ecological region, that their natural resources were to become national resources.

From the beginning of production the project has been nothing short of an environmental disaster. Weak environmental protection plans coupled with a long series of ecological disasters starting in 1984 have endangered natural resources sustaining over 40,000 indigenous peoples of the Ok Tedi and Fly Rivers (Figure 3). Within the socio-ecological region, the Upper Fly consists of 700 Wopkaimin Mountain Ok peoples, 3,000 Ningerum and 2,200 Yonggom Lowland Ok peoples and 6,000 Aikyom Awin-Pa peoples. Indigenous peoples of the Middle Fly speak Marind languages, including 2,000 Boazi and 1,500 Zimakani. South of the Strickland confluence are 1,000 Suki, 3,300 Waruna and 7,000 Gogodala peoples. On the Lower Fly are 200 Lewada, 170 Balamula, 280 Tirio and 23,000 Kiwai Trans Fly peoples.

By 1989 as outrage mounted from peoples throughout the Fly River socio-ecological region over increasing river pollution, the PNG government was forced to contract Applied Geology Associates of New Zealand to independently reassess the environmental impact of the Ok Tedi project. The National government bypassed 1 January and 1 April, 1989 deadlines for declaring Acceptable Particulate Levels (APL), but the new Prime Minister, Rabbie Namiliu, still stated emphatically that "we cannot and will not allow the wholesale destruction of aquatic life in the Fly River".

According to the Applied Geology Associates report the pollution from continued production with total discharge would be staggering, with an:

> 80% fish kill to the Middle Fly in the immediate term between 1990-1993 and a 60% fish kill for the life of the mine. The severe effect (60%) would continue down to the delta as well as into the Gulf of Papua and possibly the Torres Strait (*Post Courier*, 27 July, 1989).

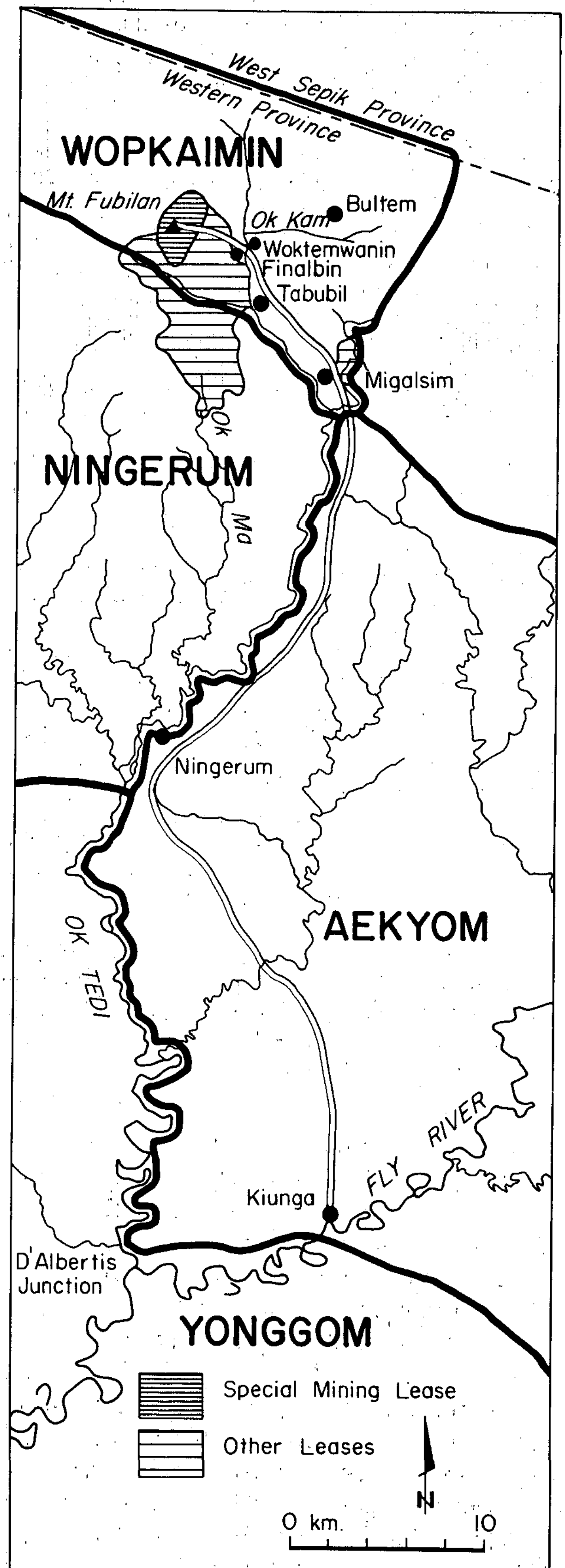

West Sepik Province
Western Province
WOPKAIMIN
Mt. Fubilan
Ok Kam
Bultem
Woktemwanin
Finalbin
Tabubil
Migalsim
Ok
NINGERUM
Ma
Ningerum
AEKYOM
OK TEDI
FLY RIVER
Kiunga
D'Albertis
Junction
YONGGOM
Special Mining Lease
Other Leases
N
0 km.
10

Figure 3.

Data presented from OTML to the National government (Table 1) on their predicted levels of fish loss due to continued mining without a tailings dam were even worse than than the Applied Geologt Associates report.

Table 1. Predicted Fish Catch Loss at Various Fly River Locations Under Current Ok Tedi Mining Limited Operations (source: Busse 1990)

	Fly River Locations														
	KIAMBIT				OBO				OGWA				DELTA	
	ss	pCu	FISH CATCH LOSS % ss	FISH CATCH LOSS % pCu	ss	pCu	FISH CATCH LOSS % ss	FISH CATCH LOSS % pCu	ss	pCu	FISH CATCH LOSS % ss	FISH CATCH LOSS % pCu	ss	pCu
BACKGROUND	110	45	0	0	103	45	0	0	430	45	0	0	430	42
CURRENT MINE PLAN 1990	758	1236	54	88	531	1150	17	88	665	524	22	57	665	149
1991	803	905	57	77	612	1202	18	78	681	401	23	46	681	174
1992	805	715	57	69	647	879	18	69	682	321	23	32	682	184
1993	803	875	57	77	649	693	18	77	681	388	23	44	681	201
1994	842	581	59	61	647	850	18	60	695	270	24	33	695	201
1995	842	581	59	61	677	564	18	60	695	270	24	33	695	200
1996	784	562	56	61	677	564	17	60	674	253	23	33	674	195

'ss' refers to the level of suspended sediment.
'pCu' refers to the level of particulate copper.
'fish catch loss' refers to the predicted percentage reduction in fish catch for the predicted levels of suspended sediment and particulate copper.

The National government had to make a choice between total discharge into the Ok Tedi or closure of the mine and by the end of July 1989 they were making an "environment or economy" decision for the peoples of the Fly River socio-ecological region. Finally on the 29th September, 1989 Jim Yer Waim, PNG Conservation Minister, announced "we decided in favour of the people". OTML was to avoid the estimated cost of K380 million for a permanent tailings dam and continue mining with total discharge of wastes in exchange for offering compensation money to the peoples of the Fly River socio-ecological region. An Ok Tedi Fly River Development Trust Fund of K2.5 million was to be created out of a levy paid to the National government for each tonne of ore processed and waste mined. According to Minister Waim, the State wanted to offset potential loss of fish with fish ponds, chicken farms and piggeries as alternative sources of protein. Underlying the National government's decision was the pragmatic view that, with the Bougainville mine closed, it was essential to secure K60 million from Ok Tedi in 1991. The decision "in favour of the people" was one of political expediency that jeopardised the welfare and health of 40,000 Fly River peoples.

Roadside Villages: A New Socio-economic Order

For Wopkaimin landowners far more than than the loss of hunting, fishing and gardening has been at stake with the intrusion of the Ok Tedi project. Traditionally, Wopkaimin culture was centred on male reciprocity. The Wopkaimin believed their way of life was founded by the 'great mother' ancestress Afek who built their most sacred cult house, the Futmanam, after she built the Telefolip. The Futmanam, permanently located in Bultem, integrates the Wopkaimin into a male initiatory cult. It is a permanent sacred site where youths are housed and transformed into men. Great Mother Afek nurtures her Wopkaimin children, in return for their maintenance of the sacred relics and performance of rituals and animal sacrifices to the ancestors inside the Futmanam. Reciprocity among initiated men ensures prosperity for all. The Futmanam excludes women. Indeed gender distinctions pervade Wopkaimin culture; men and women reside separately in women's houses and the men's house, instead of in family units, and elaborate prohibitions specify food acquisition and consumption by gender. Reciprocity between different hamlets is mediated through the Afek cult complex.

Total land leases by OTML amount to 16,530 hectares. The Wopkaimin alone lose 7,000 hectares to the Ok Tedi project (Figure 2). Monetary compensation for losing over seven percent of their land has been a cash payment of around K1 per person per day with an equivalent sum placed in a trust account for social inconvenience.

Simultaneously with the expansion of the Ok Tedi project, Bombakan, at the confluence of the Ok Tedi and Ok Kam Rivers, and Woktenwanin and Finalbin, south along the Ok Tedi, places traditionally used as temporary base camps for sago processing and hunting and fishing expeditions, were expanded into small hamlets (Figure 2). About a dozen Wopkaimin workers and their families lived for several years in Tabubil until 1981 when the entire surrounding plateau was converted into an instant township with over 5,000 outsiders. As white executives and their families moved into Tabubil, all Wopkaimin workers with their families were forced into Woktemwanin and Finalbin which grew into major roadside villages with over 350 residents by 1985.

By Wopkaimin standards these villages are extremely congested. Residents are predominantly Wopkaimin but include the Telefolmin and other Ok peoples from the Ifitaman Valley as well. Non-Wopkaimin are permitted to reside in the roadside villages but not to hunt or garden, so they are totally dependent on trade store commodities for subsistence. Villages use the term "corners" to refer to the aggregate of disparate neighbourhoods formed around previous Wopkaimin residential and descent group affiliation. Every "corner" has a trade store and commodities like rice and tinned meat and fish have not only become dietary staples but commodities to be sold rather than shared reciprocally, even among neighbourhood residents. From the 1970s, when they were entirely subsistence-oriented and dietarily self-sufficient, to the 1980s, the Wopkaimin have become increasingly dependent on a diet without many of their subsistence foods, especially *Colocasia* taro.

In the new roadside villages there is an ongoing breakdown of many aspects of traditional Wopkaimin culture. Established patterns of domesticity and social organisation are completely altered. Men no longer have a men's house in which to congregate at the expense of conjugal ties, but in the new family houses men take separate bedrooms from their wives and children. Food is no longer segregated by gender and all food prohibitions have been abandoned. Household sovereignty in consumption reverses the Afek culture complex pattern of inter-hamlet reciprocity. Jorgensen (1990) has observed this same process occurring among Telefolmin followers of *rebaibal*, an ideological movement described below.

A major social problem was spawned in the new roadside villages with the introduction of alcohol which was absent in the traditional Wopkaimin diet. During the construction period from 1981-1985 under the American transnational Bechtel, the Tabubil commissary was only open to higher paid workers residing in company houses. The Wopkaimin were relegated to using inferior stores where beer became the only new prestige commodity available to them. Gender restrictions excluded women from beer drinking. Aggressive drunken behaviour, black-marketing, fighting and adultery associated with heavy beer drinking now threatens family life. The Wopkaimin use the Melanesian Tok Pisin term *spakman* not only to refer to excessive beer drinkers but also to contrast those who move into the new roadside villages from those continuing to reside in established hamlets.

Once Bechtel departed in 1984, with the phasing out of construction and the phasing in of gold processing, the Ok Tedi project became known to the Wopkaimin as the "place without work". However, even before gold production started many Wopkaimin men became dissatisfied with the role of unskilled wage earner. Realisation that vast disparities in wealth and status separated them from the Europeans effectively removed the prestige and satisfaction initially associated with wage earning. Protest, however, was not confined to mine employment and more broadly based movements of social protest are spreading among the Wopkaimin and other Ok peoples throughout the region.

Rebaibal and Afek: Ideologies of Social Protest

Following the establishment of a Bible College by the Baptist mission in the Ifitaman Valley, a spectacular local evangelical movement emerged among the Telefolmin people. Many abandoned the Afek cult and replaced it with indigenous Christian revival movement commonly referred to as *rebaibal* in Melanesian Tok Pesin. Although the Baptists opened their first mission near the sacred Telefolip cult house in 1950, their threat to the Afek cult did not reach a crisis point until 1974 (Frankel 1976; Jorgensen 1981). Collective ecstatic outbreaks first occurred among the Telefolmin, especially the women. Later in 1977 a Telefolmin student of the Bible College experienced ecstatic seisures at Duranmin northeast of the Ifitaman Valley, triggering mass seisures, body shaking, crying, glossolalia, prophecy, healing, and exorcism and the rapid spread of *rebaibal* as the first popular indigenous acceptance of Christianity.

Rebaibal completely rejects established cultural patterns but it is much more than another transformation of a traditional cult system into a distinctly Melanesian Christinianity (cf. Guiart 1970). Cult houses and sacred objects are destroyed and secret knowledge is revealed. Gender roles are altered and women acquire more equal status. Food prohibitions and reciprocity of the Afek cult complex are abandoned in favour of nuclear families working, residing and consuming together (Barr and Trompf 1983).

By the time the Ok Tedi project started, *rebaibal*, with over 3,000 followers, represented the most popular indigenous acceptance of Christianity among the northern Ok peoples (Barr 1983). It has resulted in the destruction or desecration of men's cult houses in over a dozen Telefolmin villages and in Tifalmin, the closest northern neighbours of the Wopkaimin, the important cult house in Brolemabip was burned to the ground. *Rebaibal* has spelled the end of the traditional system of regionally organized initiations centred on the Telefolmin's supremely sacred Telefolip cult house. Rebaibalists argue there is nothing in the traditional Afek cult relevant to the problems posed by money, especially the development of the Ok Tedi project. An underlying theme of the *rebaibal* ideology is to legitimate household autonomy in opposition to community reciprocity in the use of cash. Rebaibal is an innovation and adjustment to culture change. Like the cargo cults of colonial and post-colonial Papua New Guinea, it is a major social protest and critique of an alien cultural system.

The Wopkaimin never experienced missionary proselytizing from whites but rebaibalists from the Telefolmin to the north and Catholic catechists from the Enkaiakmin to the east are now competing for converts in the new roadside villages near the mine. The scale of information flow is becoming intense and is also reflected in the competing interests and values between indigenous Christians and traditionalists as they manipulate for political influence. Wopkaimin culture is characterized by individual autonomy and sensitivity to the pressures of others and to negative sanctions imposed through public opinion and their leaders are primarily ritual specialists whose paramount concern is to the continuity of the Afek cult.

Gesock is the ritual leader of the Afek cult centred on the Futmanam, the focal symbol of Wopkaimin identity. He was appalled after the rebaibalists burned down the Tifalmin cult house and now crusades actively against the influence of the indigenous Christians. In the 1980s, as the Wopkaimin established their roadside villages near the mine, Gesock ensured that they continued their commitment to the Futmanam. He establishes interpersonal networks and manipulates the flow of secret/sacred information to reaffirm his people's traditional belief in the ritual legacy bequeathed to them from Afek. The Wopkaimin realise the Telefolip in Telefolmin has lost its pre-eminent position in the region because of the rebaibalists and it is Gesock who arranges and leads the ceremonies focussed on their Futmanam. Hosting a major refurbishing ceremony of their Futmanam in 1981 and starting a new sequence of male initiations in 1983 has provided the Wopkaimin with cultural identity as a people and legitimated their claim that the Futmanam is still a significant cult house in the regional system of male initiations.

In addition to ensuring continuity of ritual performance, Gesock has organised construction of the new traditional hamlet at Bombakan with residentially segregated women's houses and a men's house. By the beginning of 1986 a core of over 30 residents has decentralised from the roadside villages to live with Gesock in Bombaken and others circulated in for temporary residence, especially from Woktemwanin. The decentralisation process gained momentum and by 1989 most Wopkaimin had abandoned Woktemwanin for Bombakan or Ayanglim in the Kam

Basin (Chris Roberts personal communication). Previously the Wopkaimin only aggregated for short-term rituals but the new roadside communities have been maintained well beyond the time periods appropriate to short-term rituals and this is creating significant social stresses among those who live there. Through the more recent decentralisation, the Wopkaimin are constructing relationships with the transnational intruders into patterns comprehensible to them in terms of the established Afek cult complex obligations that underlie their own social relationships.

The Wopkaimin are reinstating old patterns of inter-hamlet reciprocity in Bombakan and the Kam Basin hamlets and are establishing extensive subsistence gardens. Many value decentralisation as a way of preventing loss of cultural knowledge and also of ensuring that boys are initiated. They are demonstrating their culture has a limited capacity for exercising social control, especially in the confines of the new roadside aggragate communities.

The future prospects for the two social protest movements among the Wopkaimin is uncertain. Currently the indigenous Christian movment started by the rebaibalists and the decentralisation movement associated with the Afek cult do not interact in common social protest over the intrusion of the Ok Tedi project, rather they are mutually exclusive. The rebaibalists started among peoples marginal to the Ok Tedi project and gained their support precisely because they rejected the social order of the past in favour of the supposed benefits of rapid economic change. By contrast the Wopkaimin are protesting against the consequences of rapid economic change through their continuation of the Afek cult. They find little appeal in the *rebaibal* movement because it jeopardises the status they exert as the indigenous landowners of the mine. Through decentralisation and continued commitment to the Futmanam, the Wopkaimin are carrying past traditions forward to retain a sense of cultural identity.

The Wopkaimin volunteered for work at the mine, but after the infrastructure phase it became the "place without work". The Ok Tedi project became an enclave of skilled workers without the bulk of the Wopkaimin undergoing a voluntary or coercive process of proletarianisation. Bombakan is like a safety valve from the new stress of life in the roadside villages, rather than an expression of worker solidarity. The Afek cult ideologically continues the Wopkaimin kinship mode of production while they are largely excluded from the capitalist mode of production that is the mine enclave.

Movements of social protest, like *rebaibal* and decentralisation, are part of the global move from autonomy by indigenous peoples at the mining frontier clash with kinship and capitalist modes of production. *Rebaibal* and decentralisation offer some prospect of increased self-determination. The Wopkaimin have retained enough autonomy for self-determined cultural policies and choices. Whether they can successfully withstand a full thirty year onslaught of the Ok Tedi project remains to be seen.

References

Barr, J. (1983), 'A Survey of Esctatic Pheonomena and 'Holy Spirit Movements' in Melanesia', *Oceania*, 54, 109-132

Barr, J. and Trompf, G. (1983), 'Independent Churches and Recent Ecstatic Movement in Melanesia: A Survey of Materials', *Oceania*, 54, 48-50.

Busse, M. (1991), 'Environment and Human Ecology in the Lake Murray-Middle Fly Area', In David Lawrence (ed.), *Sustainable Development for Traditional Inhabitants of the Torres Strait Region*, Great Barrier Reef Marine Park Authority, Townsville, (this volume).

Frankel, S. (1976), 'Mass Hysteria in the New Guinea Highlands', *Oceania* 48,106-133.

Godoy, R. (1985), 'Mining: An Anthropological Perspective', *Annual Review of Anthropology*, 14,199-217.

Guiart, J. (1970), 'The Millenarian Aspect of Conversion to Christianity in the South Pacific', In, S. Thrupp (ed.), *Millennial Dreams in Action*, New York, Schoken.

Jackson, R. (1982), *Ok Tedi: The Pot of Gold*, University of Papua New Guinea, Port Moresby.

Jorgensen, D. (1981), 'Life on the Fringe: History and Society in Telefolmin', In R. Gordon (ed.), *The Plight of Peripheral Peoples in Papua New Guinea*, Cultural Survival, Cambridge, Mass. (Occasional Paper No. 7), .59-79.

Jorgensen, D. (1990), 'Telefolip, Telefolmin: The Architecture of Ethnic Identity in the Sepik Headwaters', In B. Craig and D. Hyndman (eds.), *Childen of Afek: Tradition and Change Among the Mountain Ok of Central New Guinea*, University of Sydney, Sydney. 151-168.

Pintz, W. (1984), *Ok Tedi: Evolution of a Third World Mining Project*, London, Mining Journal Books.

The Subsistence Economy of the Kiwai-speaking People of the Southwest Coast of Papua New Guinea

David Lawrence, Torres Strait Baseline Study
Great Barrier Reef Marine Park Authority

Abstract

The Coastal Kiwai-speaking people of the southwest coast of Papua New Guinea live on a narrow strip of sandy foreshore between the sea and the coastal swamps and savannah lands of the coastal plain. The Kiwai have limited access to good gardening lands but have unrestricted access to the waters of the Torres Strait. For this reason they have remained predominantly subsistence fishermen.

Linguistic evidence indicates that the Kiwai may have migrated down the Fly River and settled in the Fly estuary region. Oral history states that the Kiwai originated from a central area on Kiwai Island and moved out from there. Villages were later established on the northern and eastern banks of the Fly estuary. Later people moved along the southwest coast as far as Mabudawan village. These movements follow the legendary travels of Sido, whose adventures form the principal origin myth of the Kiwai-speaking people.

Oral history, particularly the stories of Bidedu, Gamea and Kuke, also state that the Kiwai were taught fishing and hunting skills by the Torres Strait Islanders and that the methods for planking the sides of canoe hulls and for converting canoes into large double outrigger canoes were taught to them by the Saibai Islanders.

The coastal Kiwai established themselves as trading people who were able to exploit the customary exchange system which had been established by the Torres Strait Islanders and the people who lived inland from the coast. Ecological disadvantages have motivated them to adopt the outrigger canoe to their advantage and they have been able to manipulate exchange by their eventual dominance of maritime and fishing technology.

Dependence on subsistence, and limited commercial fishing activity, also means that the Kiwai are economically and culturally vulnerable to any adverse changes to the marine environment. With limited access to government support, and living in one of the least developed parts of Papua New Guinea their future depends on maintenance of the quality of both the fish they catch and the reefs upon which they fish.

Description

In contrast to the other parts of Papua New Guinea, most of the Western Province is a vast lowland region with mountains only in the north and north-west. The longest river in Papua New Guinea, the Fly River, and the largest lake, Lake Murray, are in this Province. The Fly River effectively divides the Province in two. South of the Fly River is the Oriomo Plateau, a generally featureless undulating ridge bordered in the north by the lower Fly River and in the south by a narrow coastal plain, the most prominant feature of which is the hill at Mabudawan which rises to a height of only 59 metres above sea level. This narrow plain is intersected by widely spaced, slow moving, muddy rivers such as the Oriomo, the Binaturi and the Pahoturi, as well as the Morehead and the Bensbach Rivers to the west. The coastal plain is subject to seasonal flooding and the shallow inshore waters are also muddy, with numerous reefs, mudbanks and shifting sandbars. The coastal region of the Western Province is a zone of low muddy shores, often mangrove-covered, and fringed with littoral woodlands interspersed with patches of coconut trees, gardens and small villages (Figures 1 and 2).

The coastal plain is, in places, only about three kilometres wide, and only three metres above sea level. Along the plain, from Parama Island to the tidal inlets of Mai Kussa and Wassi Kussa, are the villages of the Kiwai, Gidra, Bine, Gizra and Agob-speaking peoples. These peoples combine swidden horticulture with gathering bush foods, sago making, hunting and fishing. The soils of the Oriomo Plateau and the narrow coastal plain are mostly poorly drained clay soils. However, some good gardening soil exists behind the narrow beach ridges and inland from the coast along rivers and swamps.

Language

Dialects of the coastal Kiwai language are spoken in the villages of Mabudawan, Mawatta, Tureture, Kadawa, Katatai and Parama; Gidra is spoken in the coastal village of Dorogori; Bine is spoken at Masingara and Kunini; Gidra at Waidoro and Kulalai; and Agob at Buji, Ber and Sigabaduru. The most commonly spoken language on the island of Daru, the administrative centre of the Western Province, is also Kiwai as many of the people from coastal Kiwai villages have established communities, known as 'corners', on Daru.

The Kiwai family of languages consists of approximately seven distinct languages with 15 different dialects. The Kiwai-speaking people live on the coastal, near-coastal and insular areas of the Western Province extending from Mabudawan across the islands of the Fly estuary as far as the eastern bank of Era Bay. According to linguists (Wurm 1973:252 -255) the Kiwai languages show strong links with the languages located in the upper Fly River headwaters.

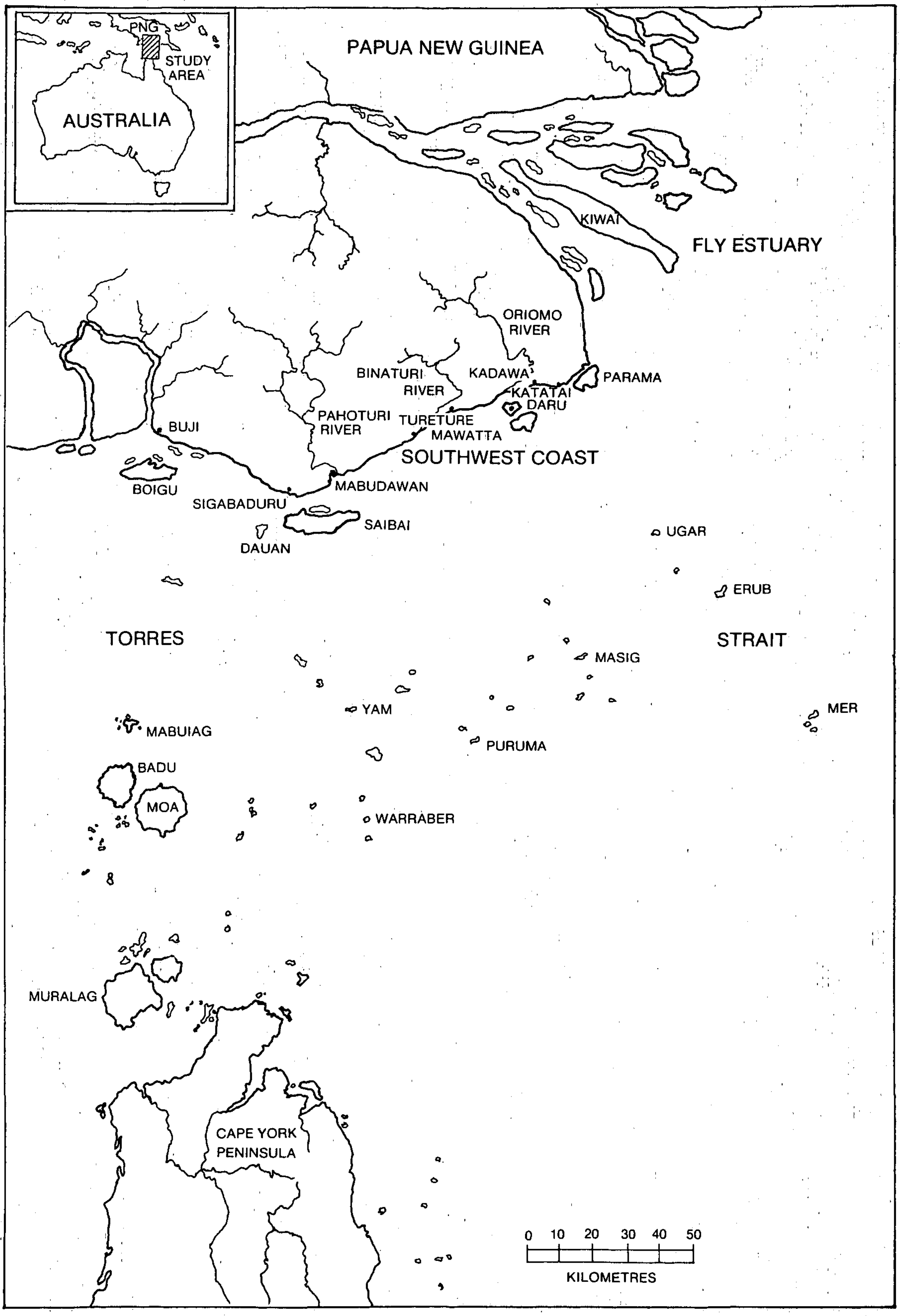


Figure 1. Torres Strait, Southwest Coast and Fly Estuary Region

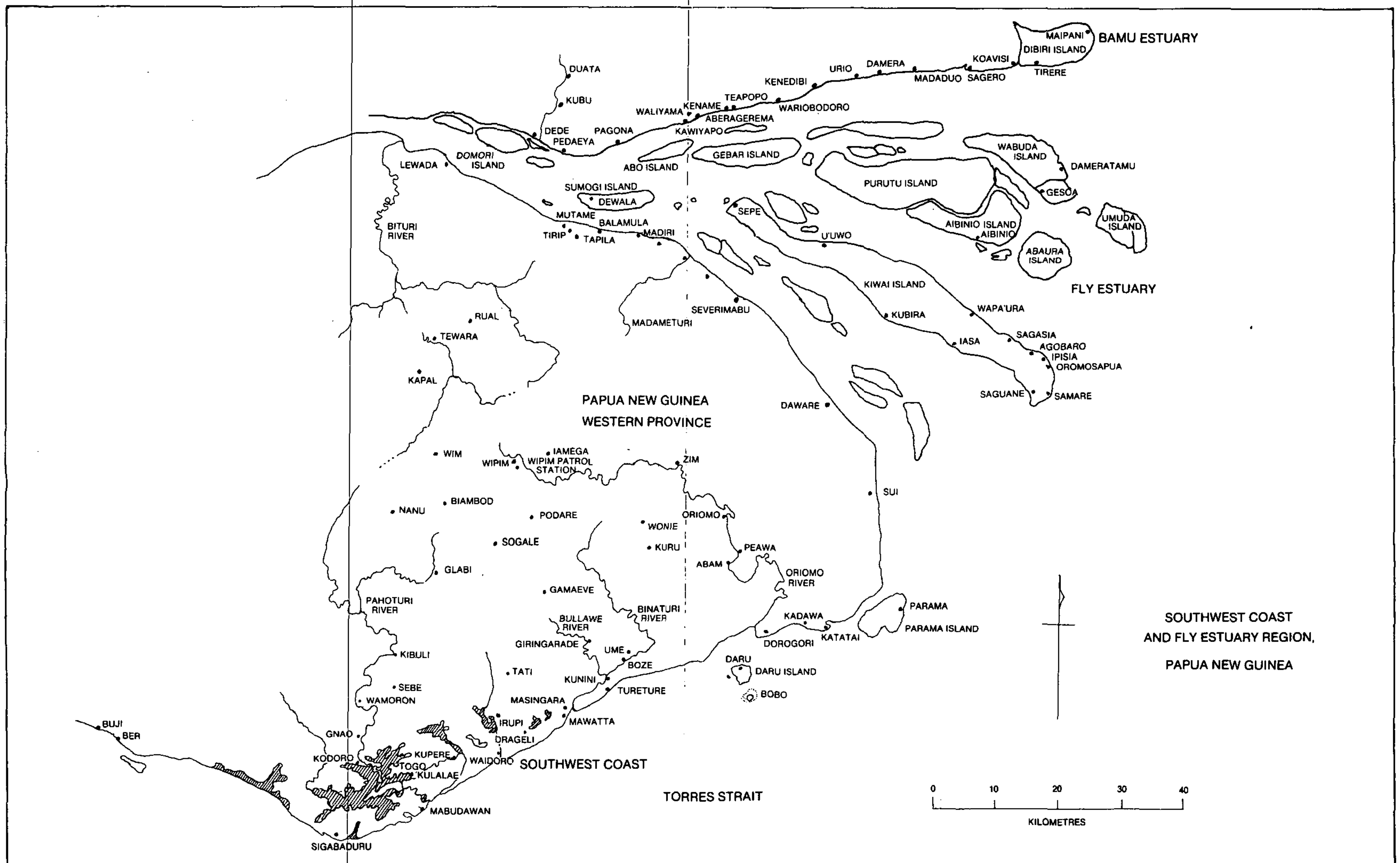


Figure 2. Southwest Coast and Fly Estuary Region, Papua New Guinea

This suggests that the original Kiwai speakers travelled down the Fly River in a series of migrations. They then moved from the estuary region east and north to the Bamu and south to the coastal lands bordering the Torres Strait. These coastal migrations have been tentatively dated to about 3000 to 4000 years ago (Wurm 1973: 255). This southward Papuan linguistic influence, supported by oral evidence for the movements of the Kiwai people along the coast and into the Torres Strait region, commenced with the journeys of the culture heroes and ancestors such as told in the legend of Sido, the principal origin myth of the Kiwai people, and continues with the travels and adventures of village leaders and the people themselves.

Oral History

In small-scale societies without a written history the traditions of migrations and village movements are important to people's heritage. This knowledge is transmitted throught the generations in legend, song and dance and constitutes the basis of legal, political, social and economic relations. On the basis of these myths and legends the rights and obligations of lineages are defined, and access to and the use of specific resources and territories are defended. To a people who are basically subsistence fishermen, these also include sea territories.

The oral accounts of the coastal Kiwai, particularly the stories of the adventures of important ancestor heroes such as Bidedu, Gamea and Kuke, document the movements of the Kiwai people from the Fly estuary along the southwest coast. As they went along the coast, the Kiwai obtained knowledge of gardening from the people of the bush and learnt the techniques for hunting dugong and turtle, fishing and adapting canoes from the Torres Strait Islanders. According to oral accounts, it was the Saibai Islanders who developed the first version of the double outrigger canoe. They in turn taught the coastal Kiwai the method for adapting the single outrigger into the large double outrigger form and it was the Kiwai who, in turn, taught the people living in the Oriomo, Binaturi and Pahoturi Rivers their methods of canoe making and sailing. Following the establishment of the coastal villages, and later the missions stations, such as at Mawatta and Mabudawan, the Kiwai began to explore the reefs and islands of the Torres Strait and established a complex network of trading and intermarriage connections between themselves, the Torres Strait Islanders and other Kiwai people of the Fly estuary (Lawrence 1989b).

Subsistence Economy

The people of the coastal Kiwai-speaking villages live on the narrow strip of sandy foreshore between the sea and the coastal swamps and savannah grasslands . The coastal swamplands contain nipa palm, mangroves and some sago palms bordered by dense woodlands. The people who live further inland from the coast such as the Bine and Gizra speaking people live along the rivers and the interconnecting streams. Access to the widely spaced villages can be effected by walking through the bush and swamps as well as by small canoes. The Kiwai, living in a region of variable wet and dry climate, with limited access to good gardening land but unrestricted access to the waters of the Torres Strait, have remained predominantly subsistence fishermen.

A broad range of subsistence patterns existed across the Torres Strait prior to sustained European contact. Within this broad spectrum of subsistence patterns, regional and local variation also occurred. In the Torres Strait, the Islanders exploited a wide variety of marine resources and this has been documented in some detail in the papers presented by Judith Fitzpatrick and Jeremy Beckett (this volume). Dugong and turtle, for example, played an important role in social and ceremonial life of the Islander people. This is also true for the Kiwai people of the southwest coast. The techniques used for hunting dugong were learned from the Islanders.

The first method was harpooning from a platform called a *narato* which was constructed over the seagrass beds on inshore reefs. The hunter waited on the platform with a harpoon (*wap*). A long eight-ply rope made from vines was used, as this rope was bouyant and easily recovered by canoe. This method of hunting was dangerous however, and there are many stories of hunters being drowned after becoming entangled in the rope and pulled along by the dugong. Use of the fixed platform declined after the Second World War. The second method, which is still used along the coast today, involved harpooning dugongs from the platform of a large canoe. The *motomoto* was ideal for this purpose as it could be sailed silently over reefs and shallow seagrass beds. It required a large crew of at least eight to ten men which meant that there was safety in numbers and assistance with manhandling the dugong or turtle, onto the canoe. The *motomoto* contained sufficient storage space for holding both dugongs and turtles captured on the one voyage.

Knowledge of dugong movements and the magic required to call dugongs was also handed down through the generations. Success at hunting was a sign of status in Kiwai communities and old hunters were well respected. The film 'The Kiwai: dugong hunters of Daru' showed some of the skills required by hunters. It was filmed along the southwest coast mostly in the village of Tureture. This film was also used to some effect in the educational programme designed to prohibit the sale of dugong meat in the Daru market (Hudson 1986:77-79).

Both the coastal Papuan and the Torres Strait Islander communities, in the period prior to European contact, were small-scale acephalous societies, often separated by water barriers. Such societies were characterized by the creation of interdependencies linked by rituals and customary exchange which drew groups into intermittent co-operation where otherwise only interrupted warfare and hostilities would have occurred. Trade, warfare and marital exchange provided the occasions for interaction (Beckett 1972:319-320).

Administrative control over the people of the Fly estuary and the southwest coast was extended from the permanent colonial administrative post established at Daru in 1895. The first government residency was in fact established near Mabudawan in 1891. This was later closed and Daru became the harbour, the fuel and stores depot and a base for trade and commercial exploitation of the Fly River and northern Torres Strait. Contact with police and colonial authority resulted in the suppression of warfare and raiding, and the eventual pacification of the peoples of the coastal area.

Commercial activity in the region was only partially successful. Plantations were established at Mibu Island in the estuary, at Madiri in the lower Fly and Dirimi on the Binaturi River. Commercially the region did not develop to any great extent.

Transportation and communications between villages has always been difficult in this region of the Western Province. The Western Province has remained economically depressed supporting only small villages with low population. Commercial agricultural developments continue to be unsuccessful, particularly along the southwest coast. It is not difficult to understand why mining developments, such as Ok Tedi, are seen as 'pots of gold' by the people of the Western Province. The economic spinoffs of mining developments have, however, had little impact in the south. Village development schemes such as that being developed by Ok Tedi Mining Limited for the middle Fly River, and now extended to the Fly estuary, will have little effect on the economic, social or health conditions of the villagers along the southwest coast. Because of this coastal villagers have continued to be involved in subsistence economic activities. The subsistence economy is supplemented by small scale cash cropping, seasonal commercial fishing and by remittances from kin, usually young males, working away from home, often on the commercial fishing boats operating in the Torres Strait and Gulf of Papua.

Largely for economic reasons, the people of the southwest coast still rely on sailing canoes for transportation of goods and people to and from Daru and out into the Torres Strait. It is not uncommon to see canoe hulls in various states of repair and construction on the beachfronts of coastal Kiwai villages. The complex skills required for planking the sides of canoe-hulls and adding the sailing platforms have not been totally discarded in favour of modern Western technology. Canoes are also seaworthy in the sometimes dangerous waters of the Torres Strait. The coastal villagers of Mabudawan, Tureture, Mawatta and Kadawa, in particular, still sail in large double outrigger canoes such as the two masted *motomoto* or the single masted *puputu* into the Torres Strait to hunt turtle and dugong, and to fish the Warrior, Wapa, and Gimini Reefs, as well as the Potomaza, Otamabu, Auwamaza, and Kokope reef complexes, and to travel to the islands of the Torres Strait on visiting and trading expeditions.

The position of Kiwai villages at the mouths of the Binaturi and Pahoturi Rivers enabled the Kiwai, over the past 100 years, to act as intermediaries in the customary exchange systems which had been established between the Torres Strait Islanders and the people living inland from the coast. The Kiwai were able to dominate the principal lines of interaction which went from the coast to the central islands of the Torres Strait, and from the coast to the nearby islands of Saibai, Dauan and Boigu, and then to the western Torres Strait Islands. The use of large, seaworthy canoes also facilitated access to the fertile eastern Torres Strait islands from the communities of Kadawa, Katatai and Parama, located near the Fly estuary (Lawrence 1989a).

The Kiwai established themselves as a 'trading' people who, for ecological and cultural reasons, formed a nexus between the insular dwelling Torres Strait Islanders and the inland 'bush' people. The Kiwai have been able to exploit the opportunities for 'trade' afforded to them by their position as littoral dwelling entrepreneurs while ecological disadvantages such as limited gardening land, have motivated them to adopt the outrigger canoe to their advantage (Lawrence 1989a).

The coastal Kiwai were able to exploit the fish-for-garden foods exchange system and they were able to manipulate exchange by their eventual dominance of maritime and fishing technology. European colonial settlments along the coast further strengthened the position of the coastal Kiwai. Kiwai men were often employed in the tradestores and police posts which were established at Mawatta, Mabudawan and Daru. With the growth of commercial activity in the Torres Strait, such as pearling, beche-de-mer fishing, trochus collecting and later commercial fishing, young men from the coastal Kiwai villages were in a favoured position to move into wage labour on the boats. The establishment of schools in coastal villages enabled Kiwai children to obtain an early understanding of basic English. Kiwai also became the language of the missions and remains the language commonly used in churches.

Contemporary Situation

In the latter part of the post-contact period, until the establishment of the independent state of Papua New Guinea in 1975, the dominance of European technology, the introduction of wage labour, the exchange of goods and services for cash rather than kind, and the introduction of European administration and law, were all instrumental in effecting permanent changes to the fabric of intersocietal exchange in the Torres Strait and Fly estuary region. The establishment of a border in the late 19th century between Australia and the territory of British New Guinea, which was renamed Papua in 1907, and the clarification of a formally established border between Australia and Papua New Guinea following independence in 1975, served to threaten and weaken the customary ties between the coastal Kiwai and the Torres Strait Islanders. The economic and social conditions of the Torres Strait Islanders were more profoundly changed by European and Pacific Islander, economic, social and cultural intervention than the peoples of the southwestern coast of Papua New Guinea.

The ratification of the Torres Strait Treaty in 1985, which recognized 'traditional' rights of free movement of both Torres Strait Islanders and Papuans within the Torres Strait Protected Zone has also served to acknowledge the importance of customary exchange at a time when it has ceased to be a mechanism for the distribution of scarce subsistence items across a region of different ecological zones. However, the survival of customary exchange into the present is indicative of the fundamental importance of inter-group contact in the face of colonial and inter-governmental intervention, though now it serves mainly as a linkage among people united by kinship and fictive kin ties. Maintenance of this linkage, largely through Papuan need for access to medical services, schools, casual employment and well stocked island stores, is still a question of survival to the Papuan people in the face of declining economic conditions in Papua New Guinea.

Islanders and Papuans operate within a range of multiple enterprise subsistence economies, similar to those described by Dr Chris Anderson for the Cape York Aboriginal communities (Anderson 1980). Wage labour on fishing and lobster boats is combined with tradestore purchases, fishing, hunting and gathering wild and semi-domesticated plants. However, on the Torres Strait Islands government income supplements provide a permanent income basis not available to coastal Papuans.

Sustainable Development for Traditional Inhabitants

Preservation of the marine environment in the Torres Strait and the Fly estuary is essential for the economic survival of the subsistence fishermen such as the coastal

Kiwai people. The coastal Kiwai are in a particularly vulnerable position. With little access to economic benefits from mining and other industrial developments, such as the Kutubu oil field development, they also live in an area of economic under-development. Unlike their Torres Strait neighbours, they have little access to government sponsored economic development schemes, nor do they have the infrastructure to develop marine industries to their advantage. The small-scale commercial barramundi fishing activities of the Kadawa and Katatai villages, and the villages of the Dudi coast in the Fly estuary, are seasonal and labour intensive. Environmental damage in the Fly River and the estuary region would ruin this enterprise. Ecologically sustainable development, as stated by Mr Kelleher in his keynote address (Kelleher, this volume), means using, conserving and enhancing community resources so that the ecological process, on which life depends, and the quality of life of the traditional inhabitants of the Torres Strait region, can be enhanced.

Mechanisms for the protection of customary practices and livelihood of the Torres Strait Islanders and coastal Papuan people have, to a large extent, been implemented with the establishment of the Torres Strait Protected Zone under the Torres Strait Treaty which was formally ratified in 1985.

In small scale societies such as those of the Torres Strait region, resource management practices have been developed by coastal and islander populations over long periods of time. They therefore formed part of the foundations of the social and economic stability of these societies. The establishment of resource strategies and management plans, such as those instituted by the Torres Strait Treaty and the proposed management plan for Western Papua and the Torres Strait, tend, by their very nature, to widen the gap between the 'traditional diverse resource utilization strategies and what becomes sectoral development designed to increase the economic well-being of a depressed region' (Burbridge 1982: 377). The difficulty has been the maintenance of the functional integrity of the customary, the so-called 'traditional', economic base while managing for broad-scale economic and social development.

The coastal Papuans remain in an economically disadvantaged position. Physical isolation in a difficult environment, poor land, limited access to education beyond basic primary levels, inadequate medical care and the lack of government supported income assistance continue to keep the standard of living of coastal Papuans below that of the Torres Strait Islanders. In recent years some Papuans have resettled on Torres Strait islands but, despite some economic advantages and better access to medical and educational facilities, their social and cultural status remains undefined.

Economic advantage, and possibly a relief from the boredom of village life, was the primary reason why young Papuan men left their villages and sought work in the Torres Strait fishing and pearling industries. To some extent the indentured work experience served as a new initiation process for young men and, like initiation, the enforced separation from women and the village, the struggle for status and the return, laden with valuables, appears to have been incorporated into another cultural experience. This experience still forms a large part of the stories recounted by older men in the coastal Papuan villages.

Conclusion

The full economic and social impact of the Torres Strait Treaty which sets out to protect the customary way of life of the Torres Strait Islander and coastal Papuan peoples has still to be fully appreciated. Under article 13 of the Treaty, both Australia and Papua New Guinea are required to take legislative and other measures to protect and preserve the marine environment in, and within the vicinity of, the Protected Zone. Both parties are also required to cooperate on measures for ensuring the long-term protection of the marine environment and to minimise, to the fullest practical extent, the release of any toxic, harmful or noxious substances from land-based sources.

The Torres Strait Baseline Study is another step towards the objective of maintaining the quality of the marine environment of the Torres Strait for the sustained use of the living resources of the sea, particularly by traditional inhabitants from both the Torres Strait Islands and from the villages of coastal Papua who together share access to this ecologically and culturally diverse region.

To date, village development schemes and resettlement programmes have been directed towards those peoples living in the vicinity of the mining operations and along the middle and upper Fly River areas. The needs of the people of the coastal region, and in the Fly estuary, have largely been overlooked. Yet, if environmental damage to the water of the Fly River does occur then the livelihood of the coastal Kiwai will be seriously affected. These people have no government sponsored support systems and only limited political power. It is the responsibility of environmental programmes, such as the Torres Strait Baseline Study, to ensure that the marine environment of this region is protected for present and future generations and that this protection is sustained.

Bibliography

Anderson, C. (1980), 'Multiple enterprise: contemporary Aboriginal subsistence strategy in southeast Cape York Peninsula', In N.C. Stevens and A, Bailey (eds.), *Contemporary Cape York Peninsula*, Royal Society of Queensland, Brisbane, pp77-81.

Beckett, Jeremy R. (1972), 'The Torres Strait Islanders', In D. Walker (ed.), *Bridge and Barrier*, A.N.U., Canberra, 307-326.

Bodley, John H (ed.) (1988), *Tribal Peoples and Development Issues*, Mayfield, Mountain View.

Burbridge, Peter R. (1982), 'Problems and issues of coastal zone management', In C.H. Soysa, Chia Lin Sien and W. Collier (eds.), *Man, Land and Sea*, Agricultural Development Council, Bangkok, 309-320.

Hudson, B.E.T. (1986), 'The hunting of dugong at Daru, Papua New Guinea, during 1978-1982: community management and education initiatives', In A.K.Haines, G.C. Williams and D. Coates (eds) *Torres Strait Fisheries Seminar (Proceedings, 1985)*, A.G.P.S., Canberra, 77-94.

Kelleher, Graeme (1990), 'Sustainable development for Traditional Inhabitants of the Torres Strait Region: keynote address', (this volume), Great Barrier Reef Marine Park Authority, Townsville.

Lawrence, David R. (1989a), The material culture of customary exchange in the Torres Strait and Fly estuary region. Unpublished PhD thesis, James Cook University of North Queensland, Townsville.

Lawrence, David R. (1989b), 'From the other side: recently collected oral evidence of contacts between the Torres Strait Islanders and the Papuan peoples of the south-western coast', *Aboriginal History*, 13(1/2), 95-123.

Lipset, David M. (1985), 'Seafaring Sepiks: ecology, warfare, and prestige in Murik trade', *Research in Economic Anthropology*, 7, 67-94.

Olewale, Ebia and Sedu, Duba (1982), 'Momoro (the dugong) in the Western Province', In L. Mourata, J. Pernetta and W. Heaney (eds.), *Traditional Conservation in Papua New Guinea: implications for today*, Institute of Applied Social and Economic Research, Boroko, 251-255.

Wurm, S.A. (1973), 'The Kiwaian language family', In K. Franklin (ed.), *The Linguistic Situation in the Gulf District and Adjacent Areas, Papua New Guinea*, A.N.U., Canberra, 216-260.

The Need for an Information Database of Resource Development Activities in the Torres Strait Region

Thomas Nen
National Research Institute

Abstract

Information is a tool for decision-making that effects community. People need information to understand the present or past situation of an issue or problem area. They need information to define a problem, measure the magnitude of a problem and to analyse the problem to find solutions to it.

Differing resource endowments and in some cases resource scarcity of groups concerned in the Torres Strait Region, as well as a greater degree of differentiation in development programmes within the region, will promote rather than dampen potential conflicts over social structures and the border. In such a situation, information gathering and its use in enhanced. Information on population, economic activity, education, social services and so on, should ideally be available to both countries concerned so that many obviously important rates of change for example, population growth and migration can be known to both parties.

Since major resource development inside the Papua New Guinea border will affect the people in one way or another, directly or indirectly, an information database should be established to identify their activities, the area and magnitude of their operations, and the area that these developments will affect the people, their environment, and their day-to-day activities.

Past information data on resource development activities such as mining, forestry and fisheries should be updated with the aim of educating the people of Australia and Papua New Guinea about the likely effects this will bring to the people in the region. Information should also be provided on the current resource development activities in the region.

Basically, what is needed is information provided for the people's basic needs for sustainable development in the region. Information collected for the region on any resource development should be disseminated to the people who are interested in understanding the problems and issues of sustainable resource development in the Torres Strait Region.

Introduction

The Torres Strait Baseline Study was instigated in response to concerns, expressed by Torres Strait Islanders as well as commercial fishermen and scientists, about possible effects on the Torres Strait marine environment from the current and future mining developments in the Fly River catchment area of Papua New Guinea.

These concerns gave rise to the following questions. What are the types of information required by possible user groups such as the Torres Strait Islanders, commercial fishermen and scientists or decision makers? How should the information collected be used and who should use it? How is the information collected going to be used by the decision makers and how are the decisions made on the information provided, going to affect the people in the region? Is information collection on resource development activities necessary to understand the present and future situation or practices of sustainable development in the region?

This paper will delve into some aspects of why both Australia and Papua New Guinea need to create an information data-base of resource development activities in the Torres Strait Region as well as in Papua New Guinea, that will directly or indirectly (in terms of planning and decision-making) affect the cultural, social, environmental and political stability of the people in the region.

It will briefly outline the strategies of government departments in Papua New Guinea involved in the renewable resources sector and some current issues of resource development in Papua New Guinea. It will also outline the primary objectives of the Department of Environment and Conservation in its rationalization of the development and exploitation of Papua New Guinea's natural resources. Lastly, it will point out some ideally important aspects of information needs and requirements for the region and attempt to mention the categories of specific information that are needed by various individuals, institutions, planners, policy makers and the people of the Torres Strait Region to understand the past and present resource development activities in the Torres Strait Region in which these resources can be planned to be sustained for the future generations.

The Definition and Concept of Sustainable Development

The concept of "sustainable development", pervades contemporary environmental discussion of management of the interactions of humans with their environment.

It urges development that meets the needs and aspirations of the present generations without compromising the ability of the future generations also to meet their needs.

Sustainability must refer not only to maintaining and/or improving environmental quality and the productive capacity of ecosystems, but also to maintaining and improving the well-being of people and enhancing their capacity to utilize available resources effectively and efficiently over the long run to meet the needs of the present and future generations.

Fairclough (1990:89) mentioned that:

> It is of great importance for developing countries that its approach to sustainable development and environmental protection are both essential and mutually dependent. The one cannot be achieved without the other. The concern for environment and natural resources must hence forward be an intergral part of every development project and program.

Since Papua New Guinea is a developing country, it is wise that its strategies towards sustainable development should be defined and understood by the interested individuals, multi-national corporations, planners and policy-makers both in Papua New Guinea and Australia. Common resources such as fish, wildlife, forests, suitable agricultural lands and water are all crucially important resources for sustainable development, but often suffer from over-exploitation. Important issues concerning resources development in the region should be identified and clarified on the government's present policies and strategies regarding sustainability of these resources in the country which might affect the people in the Torres Strait Region.

Strategies for Sustainable Development in Papua New Guinea

The renewable resources sector in Papua New Guinea consists of Agriculture and Livestock, Forestry, Fisheries and Marine Resources and Tourism. Each of these departments and the Tourism Development Corporation have developed their own strategies for sustainable development. Several strategies have been devised by each department and the corporation to increase economic development in the medium-term period from 1990 to 1994.

Department of Agriculture and Livestock

The Department of Agriculture and Livestock gives high priority to the following strategies: strengthen extension services; advance manpower development; increase food production; improve processing and marketing of agricultural produce; increase applied research activities; increase smallholder access credit; and to improve the quality of animal and plant health and quarantine services.

Department of Fisheries and Marine Resources

The Department places emphasis on the development of provincial fisheries plans: provisions for more effective support services to provincial extensions services; and the development and promotion of markets and incentives for private commercial investment in this sector.

Department of Forest

The Department gives priority attention to: long-term planning of forest resources to maintain an optimum balance between economic development and conservation of natural resources; afforestation and the acquisition of scientific and economic information about the different type of forest species in Papua New Guinea; local processing of forest products of which the walkabout (portable) sawmill is an example; and increased training for qualified Nationals.

The Tourism Development Corporation

The objectives of this newly formed corporation are to encourage the growth of tourism and to involve more Nationals directly in the industry while at the same time it will help to protect the indigenous cultures which make the country such a unique tourist attraction. This corporation will act as a Commercial Statutory Authority. The corporation's strategies will consider: investor's incentive packages to attract national and foreign investment in tourism; a new transport policy to encourage the operations of more international air services into the country to generate more tourism traffic and increased revenue from landing fees, tourist expenditures and so on; and linkages between tourism and other areas to maximize the use of local goods and services.

The Department of Environment and Conservation

The Department of Environment and Conservation is separated from the renewable resource sector because its primary objective is to rationalize the development and exploitation of Papua New Guinea's national resources – both renewable and non-renewable. The Department's strategies involve:

1. Application of a sustainable development policy, taking into account the social, economic, environmental and cultural aspirations of the population.

2. Providing revenue from the non-renewable resource development sector to develop, monitor and manage the renewable resources and related activities.

3. Adoption of a long-term perspective in planning because short-term gains will not be allowed to outweight the long-term viability of the resource or the long-term welfare of the people in the area to be developed.

4. Making data on economic, social, technical and scientific information available to all relevant parties.

5. Local participation in resource development and a programme of public and community education to develop awareness of issues involved in resource development.

6. Consideration of the effect of population growth and pressure on the resources.

Some Current Issues of Resource Development in Papua New Guinea

Papua New Guinea is endowed with many natural resources both renewable and non-renewable. However, great pressures have arisen recently for the exploitation of these resources by potential developers on the one hand and from the nation and people, for income, on the other. The desire to earn more foreign exchange seems to force the short-term exploitation of resources, sometimes in full recognition of the long-term costs involved. It must be realized that the people of Papua New Guinea live much closer to their natural environment than those in the industralized countries such as Australia. Consequently, they are much more directly affected by any change in their natural environment.

Fundamentally, a country's capability for managing its resouces and environmental affairs must be its own responsibility. The challenge for Papua New Guinea today is to properly manage these resources so that maximum benefits are derived from their exploitation (Polume 1988:204).

The only sure and effective way to achieve sound resource management and environmental protection in a developing country like Papua New Guinea is for those departments with responsibilities for resource development to have the information, skills, and financial support they need and the will to use them. They must coordinate their activities and cooperate with each other to obtain specific information required to develop a resource. They should not develop a resource independently. Otherwise, the purpose for one department to develop/exploit a resource will not be consistent with the other departments' priorities.

The general view of ordinary Papua New Guineans regarding resource development at present can be summarized in the following manner as reported in the Papua New Guinea Post Courier:

> Parts of Papua New Guinea will benefit immensely from the petroleum and mineral projects now coming on stream. Other areas will sadly miss out on such dramatic experiences and benefits. They will have to be content with their traditional low priced cash crops of coffee, cocoa, copra, palm oil and betelnut ... Massive monetary benefits will go to landowners of the sites where there will be oil wells extracting crude, where the oil pipeline passes through, and where mines and new townships are sited. Cash will flow to them through royalties and spin-off benefits.
>
> Those living on the outskirts of these huge projects will also benefit. These people will actually talk big money-amounts they have not handled before. They will walk around with bulky wallets and large cheque books while their countrymen in plantations will live much the same as they do today (Post Courier, 24 October 1990:23).

Information Needs and Requirements

People need information to understand the present or past situation of an issue or problem area. They need information to define a problem, measure the magnitude of a problem and to analyse the problem to find solutions to it. Information is a tool for decision making that might affect a community.

It is therefore necessary that careful planning for the use and exploitation of the natural resources must take into account the likely effects on the people of the Torres Strait Region from resource development in the Fly and the Purari River catchment areas of Papua New Guinea, as well as fisheries and oil exploration in the Gulf of Papua. This will require information on the type of resource development in these areas – information needed about the existing environment, the cultural, the local and provincial politics and socio-economic development of an area that will be exploited, as well as those islands and/or areas in the Torres Strait Region that will be affected from those development projects.

The information data-base needed must be adequate and comprehensive enough to suit the needs of researchers, decision makers and various people involved in the sustainable development of resources in the Torres Strait Region.

Additional research and development work is needed to improve the understanding of the various physical, biological, social, economic and political linkages involved in human exploitation of the natural environment in and around the Torres Strait Region. Past as well as present information on resource development activities such as mining, forestry and fisheries development should be updated with the aim of educating the people of Australia and Papua New Guinea about the likely effects this will bring to the people in the region.

Many Australians (away from the State of Queensland) do not know the status of the Islanders – who they are, their cultural and traditional beliefs, their relationship with the coastal people of Western Province of Papua New Guinea, and their ownership of the land or marine resources in the region.

The same can be mentioned of most Papua New Guineans. Do we as Melanesians know about the sharing of the marine resources between the Islanders and the Kiwais and other coastal villagers of Western Province of Papua New Guinea? How is this sharing of marine resources being determined? Who was or is responsible for this decision to share these marine resources?

Basically, what is needed is information provided for the people's basic needs for sustainable development in the region. Information collected for the region on resources development should be disseminated to people interested in understanding the problems and issues in this region.

Although, the information collected and disseminated to the public can effectively shape self-images, perceptions of reality, and indeed the interests of the people, one should also realize that information manipulation and distortion can have severe effects on a society or country's ability to define, understand, and deal with environmental problems. The denial and distortion of information is just acute in many developing countries, especially those anxious for foreign investment (Watt *et al*. 1977).

Categories of Information Needed for Sustainable Development

The categories of information needed to provide a database for sustainable development in the Torres Strait Region could be divided as follows:

(i) Land resources and utilization – the availability of land, the patterns of ownership/land tenure system, cultivation of food crops and dwellings. Classification of soils, land use, farming practices and techiques – traditional and modern.

(ii) Marine resources – species of fish, traditional and modern fishing practices, operations of fishing companies in the area, their annual catch and the destination of exports.

(iii) Other natural resources – potential areas for minerals and forestry development, the current developments and its likely effect on the local population.

(iv) Demographic – birth and death rates, population growth rate, age and sex distribution, dependency ratios, rates of migration within and outside the Torres Strait Region.

(v) Socio-economic – income distribution, employment levels, social activities, small business ventures involving landowners.

(vi) Cultural – innate skills and technology, religious and social taboos, beliefs, traditional leadership qualities to make and impose decisions in the community.

(vii) Educational – formal and non-formal, availability of schools, teacher/student ratios, adult education.

(viii) Health – hospital beds, family planning facilities, mobility patterns, child nutrition, and types of disease.

(ix) Transportation – types of transportation systems available, their linkages to major routes of services.

(x) Marketing and supply – disposal of produce including marine resources, distribution network and its efficiency.

(xi) Present environmental conditions – animal life, protection of fauna and flora, legislation concerning the protection of types of fauna and flora in the region.

Other relevant informations needed from other user groups can also be identified and included in this proposed database for the Torres Strait Region.

Conclusion and Recommendation

Past information on resource development activities, mining, forestry and fisheries in the south-west part of Papua New Guinea, should be updated with the aim of educating the people of Australia and Papua New Guinea about the likely effects these developments will have on the people in the region. There is an urgent need to carry out combine research in compiling information needs for policy makers involved in the sustainability of resources for the Torres Strait Region from both Papua New Guinea and Australia.

Research to collect information is almost limitless: on resources and their potentials; on historical, political and social change; demographic structure; education, and other areas that do not yet have the necessary data along the Papua New Guinea border. It is more important that an immediate and thorough inventory of present resources and their potential be undertaken, and that research and information networks be well-established. In Papua New Guinea, the National Research Institute and the University of Papua New Guinea in collaboration with relevant government departments should carryout a baseline survey to establish relevant information for the policy makers in Papua New Guinea which should also be easily accessible to other user groups who might be interested in the Torres Strait Border Issue.

Information disseminated to people on most subjects of interests would be beneficial, since correct and easily accessible information can decrease to a certain limit, the tensions in the region on the effects of resource development activities inside the Papua New Guinea border.

References

Department of Agriculture and Livestock, Fisheries and Marine Resources and Forests (1989), *The Medium Term Development Strategy for the Renewable Resources Sector*, Department of Agriculture and Livestock, Fisheries and Marine Resources and Forests, Port Moresby.

Department of Finance and Planning (1990), *Development Policies and Strategies on the Occasion of the 1990 Budget by the Hon. Paul Pora, Minister for Finance*, Department of Finance and Planning, Port Moresby.

Fisk, E., Tait, M., Holder, W.E., and Treadgold, M.L. (1975), *The Border and Associated Problems*, Australian National University, Research School of Pacific Studies, Canberra. (Torres Strait Islanders, Vol V).

Fairclough, T. (1989), 'The environmental reflex: policies, procedures and people', *The Courier No.118, African-Carribean-Pacific-European Community*, 88-91.

Gregersen, H.M. and Allen, L.L. (1990), *Forestry For Sustainable Development: Concepts and A Framework for Action*, Forestry for Sustainable Development Project, np. (Working Paper 1).

Kaputin J, (1976), 'A Papua New Guinea Perspective', In J. Griffins, (ed.), *Torres Strait Border Issue: Consolidation, Conflict or Compromise*, Townsville College of Advanced Education, Townsville, 47-52.

Polume, S. (1988), 'Mineral Resources and Ethics of Development', In P.J. Hughes and C. Thirwall, (eds.), *The Ethics of Development: Choices in Development Planning*, University of Papua New Guinea, Port Moresby, 204-221.

Redcliff, M. (1987), *Sustained Development*, Methuen, London.

The United Nations Centre on Transnational Corporations (1990), *The New Code Environment*, United Nations, New York. (UNCTC Current Studies no. 16).

Watt, K.E.F., Molloy, L.F., Varshney, C.K., Weeks, D. and Wirosardjono, S. (1977), *The Unsteady State: Environmental Problems, Growth, and Culture*, East-West Center, Honolulu.

Willekens, F. and Nair, P.S. (1982), *The data base for migration analysis in developing countries: with an emphasis on India*, Netherlands Interuniversity Demographic Institute, The Netherlands. (Working paper No. 28).

Torres Strait Traditional Fisheries Studies: Some Implications for Sustainable Development

Robert E. Johannes, CSIRO Division of Fisheries
Wallace MacFarlane, Queensland National Parks and Wildlife Service

Abstract

- *Average rates of consumption of seafood in the Torres Strait Island communities for which we have data are among the highest in the world.*
- *In these communities, green turtles, not finfish, are the most important seafood.*
- *There is no evidence for overfishing of any finfish stocks.*
- *Torres Strait could yield to Islanders at least an order of magnitude more seafood than it does today. We calculate, very conservatively, that Torres Strait could yield 30,000 tonnes of seafood per year.*
- *Islanders want to harvest these unused resources as a means of improving their material living standards, not simply as a means of satisfying subsistence needs. A major impediment, we believe, has been that the education provided in Torres Strait has not prepared Islanders to fully exploit the opportunities that their marine resources afford. This, fortunately, is changing. But it provides little consolation for Islanders today who have finished their formal education.*
- *There is little evidence for the existence of a cultural awareness among Islanders that the seas' resources are limited. Learning environmental awareness must therefore be part of the Islanders' formal education*

- *In framing management regimes for newly developing fisheries or sea ranching activities, the marine territorial sensitivities of the Islanders and coastal Papuans must be taken into account.*

Introduction

Results of CSIRO studies on the traditional fisheries of Torres Strait Islanders between 1983 and 1987 have important implications for sustainable development of marine resources in the Strait.

Seafood Consumption Among Islanders

CSIRO carried out detailed studies of seafood consumption in two Torres Strait Islanders communities, and more limited studies in several others. One of the detailed studies was at Yorke Island, where a large freezer supports a commercial export fishery (Poiner and Harris, in press). The other was at Boigu, where almost all fishing is for local consumption (Johannes and MacFarlane, in press). These two studies thus encompass opposite ends of the development spectrum within Island communities in the protected zone. In addition, Nietschmann (1982) documented seafood consumption in Badu in 1978.

Seafood consumption rates were high[1] in all three communities, even in comparison with consumption rates of traditional fishing cultures in Oceania (Table 1). The only fishing communities in Table 1 where per capita seafood consumption was as high as, or higher than, in Torres Strait were studied at times when both cash and store-bought foods were not nearly as available as they were in Torres Strait communities during the study periods there.

Torres Strait Islanders consume large amounts of two species that are looked upon in most other tropical regions as luxuries - where they are available at all. These are green turtles, and, in western Torres Straits, dugongs. Green turtles figure especially prominently in Islanders' diets today. Our data indicate an average annual per capita catch rate of about one sea turtle, implying an average consumption rate of about 125 grams of turtle meat per day (Johannes and MacFarlane, in press). Torres Strait Islanders thus consume, per capita, a greater quantity of turtle meat alone than the seafood-loving Japanese consume of all seafoods combined (Table l).

On none of the islands for which finfish, turtle and dugong catch statistics were gathered was finfish the most important seafood. During the CSIRO studies, turtle constituted about one-half of the seafood consumed on Yorke and Boigu respectively (Poiner and Harris, in press; Johannes and MacFarlane, in press). Similarly, in the late 1970s finfish accounted for only 9% of the total seafood consumed on Mabuiag, while dugong constituted 60%, and turtle 29% (Nietschmann, 1982).

In the late 1970s dugong was also consumed in greater quanties than turtle meat on Badu (where finfish consumption was not measured) (Nietschmann, 1985). Our more recent survey of dugong and turtle harvests at Mabuiag and Badu (as well as Kubin) indicated that turtle are now more important than dugong in these communities' diets.

Table 1. Per capita local seafood consumption on Boigu (1985-87), Yorke (1985-86), and Mabuiag (1976-78) Islands, with comparative data for other tropical islands and an Australian Aboriginal fishing community, as well as Australia, Japan, the U.S., and OECD countries.

	Total seafood consumed gm/cap/day	Turtle	Dugong	Fish	Other
		percentage of total			
	Seafood caught locally				
Boigu	238	49	14	38	n.d
Yorke	191-214[a]	49	3	44	4
Mabuiag	450[b]	29	60	9	2
W. New Britain	11[c]	73	3	23	3
Amer. Samoa	1.9 - 104[d]				
West. Samoa	27 - 69[e]				
Fiji	115 - 210[f]				
Ontong Java	250 - 380+[g]				
Lamotrek Atoll	313[h]				
Cook Islands	29 -122[i]				
N. Arnhem Land	560[j]				
Solomon Isl.	63 - 78[k]				
Tigak Is., PNG	24				
	Total seafood[m]				
Australia	22				
Japan	102				
United States	19				
OECD avg.	33 (range, 8 - 120)				

[a] Data for 1986-87 from Poiner and Harris (in press).
[b] Data for 1977 from Nietschmann (1982).
[c] Data for Garu Village in 1972 (Liem, 1977). Catch figures multiplied by 0.8 to estimate that portion of the catch actually eaten. The average fillet weight of commercial fishes is 20 - 40% (Osterhaug, et al, 1963). But traditional fishermen typically consume a much higher proportion than this of the fish they catch, almost never filleting them and often eating some of the internal organs as well as the especially tasty morsels of flesh in the head).
[d] Data from Wass (1982) for eleven American Samoan communities in 1977 - 80. The lowest figure was for the district center of Pago Pago. Catch figures multiplied by 0.8 to estimate that portion of the catch actually eaten.
[e] Data from Anon. 1978a for 48 villages in 1978, excluding the capital. Catch figures multiplied by 0.8 to estimate that portion of the catch actually eaten.
[f] Data from Bayliss-Smith (nd) for two outer island communities in 1973-74
[g] Data for main population centre and outer island community, 1970-71, from Bayliss-Smith (in press).
[h] Data from Bayliss-Smith (nd) for 1962-63
[i] Data from Anon. (1978b) for two communities. The smaller figure is for the urban center, Rarotonga. Catch figures multiplied by 0.8 to estimate that portion of the catch actually eaten.
[j]Data calculated from Meehan (1977) for the Anbara Aborigines of Northern Arnhem Land, 1972-73.
[k] Data for two urban and one traditional community in 1972, from Jansen and Wilmott (1973).
[l]Data for 1985 from Wright and Richards (1985) for adult villagers. Catch data multiplied by 0.8 to estimate that portion of the catch actually eaten.
[m]Data from Food Consumption Statistics, 1976-1985, Paris, Organization for Economic Cooperation and Development, 1988.

Here, during study periods lasting from four to ten months, daily mean per capita turtle meat consumption ranged from 90 to 280 mg. (No recent data are available for finfish consumption in these communities).

The Potential Yield of Seafood from Torres Strait

People living in Torres Strait Islands and along the adjacent coast of Papua New Guinea number about 15,000. There are about 30,000 km^2 of accessible shallow water in the Strait from which to obtain seafood. Sustained yields of reef and lagoon fisheries elsewhere in the tropics range from 0.4 to 23.7 t km^{-2} yr^{-1} (Russ, 1984). The lower figures within this range represent fisheries under low exploitation pressure. The higher figures represent heavily exploited coral reef communities. Figures in the middle of this range represent coral reef, seagrass, sand bottom complexes, such as those in Torres Strait – for which a mean yield of 3 - 5 tonnes km^{-2} can be expected in a moderately to heavily exploited fishery.

If we calculate, very conservatively, that Torres Strait could yield one tonne km^{-2} of seafood, this would amount to 30,000 tonnes of seafood per year, or about 5.5 kg day^{-1} *per capita* for Strait inhabitants. When the commercial catch of prawns, crayfish and finfishes exported from the Strait is subtracted from this figure, a potential per capita yield of about 5.2 kg day^{-1} remains. This is, of course, far in excess of local demand; Torres Strait could yield at least an order of magnitude more seafood than it does today[2]. Put another way, our conservative estimate of the unutilized potential yield of seafood from Torres Strait waters amounts to about 27,000 tonnes per year.

Fisheries Development

Not only are the marine resources in Torres Strait present in abundance, but also, most Australian seafood prices have been increasing much faster for a number of years than the rate of inflation, due to the devaluation of the Australian dollar and strong overseas demand[3]. And, Island leaders have stated, "it is the strong desire of our people to become economically independent, and to put ourselves thereby in a position of much greater control of our own lives and destinies. The only obvious resources we have at our disposal to exploit for economic purposes are those of our overwhelmingly marine environment, and we seek to play a major part in any initiatives in the area to generate economic development and employment," (Mye and Lui, 1986). These sentiments mirror those of many Islanders with whom we talked throughout the Strait.

The most difficult problems attending the exploitation of most marine stocks in Torres Strait lie at present not in their depletion[4], as is so often the case in other regions, but rather in the ability to exploit them effectively.[5] Because our study was focussed specifically on traditional fisheries, it was not our intention to explore in any detail the best specific means by which to expand the Islanders' commercial fisheries. But observations we made during the course of our work prompt us to mention certain relevant problems that we believe must be addressed.

To start with, there are a number of obvious problems characteristic of legions of isolated communities throughout the world; distant markets entailing high transport costs, vulnerability to external economic shocks, diseconomies of scale, and the inability to support the levels of specialization found in larger communities etc. Experience elsewhere shows they are not insurmountable. But they are seldom overcome simply by providing technological aid, fisheries training, loans and subsidies – the usual responses of development agencies and governments. Such approaches have generally failed miserably to lift the standards of living of artisanal fishermen (e.g. Smith, 1979; Alexander, 1975; Lawson, 1980; Ben-Yami, 1980).

To illuminate some of these problems it is instructive to compare the fisheries and relevant socioeconomic conditions in Torres Strait with those in the islands of Oceania. The environments, lifestyles and fisheries of the Islanders of the two areas have much in common. The failures of fisheries development programs in Oceania has often been due at least in part to certain impediments that are outside the purview of most fisheries development biologists. Are such problems relevant in Torres Strait?

One of the most pervasive of such impediments is the fact that social conditions in Oceania often constitute a fundamental barrier to the transition from non-capitalist to capitalist production. In much of the region, for example, there is strong traditional disapproval of deliberate striving to accumulate things beyond one's basic needs. This frustrates development efforts that depend upon entrepreneurial drive (e.g. Halapua, 1982; Johannes, 1989).

If this were ever true in Torres Strait, then a century of Islander involvement in the cash economy generated by maritime industries has brought about a change. For, as Beckett (1982, p. 103) puts it, Islanders have "bought into the whole materialist ethos." Similarly, Hendrickson (1972) commented: "The Melanesian people of this area (Torres Strait) are generally considered to be more motivated economically and to adapt more readily to a Western cash economy than many island peoples of the Pacific. If the Torres Straits and Solomon Islanders living on Darnley Island are any example of this, the consultant agrees that there is a marked difference from Micronesia and Polynesia which shows considerable promise for small, private venture here... Such people should be able to integrate rapidly and successfully into a western-styled economy, given a working base and market facilities."

Although high achievers are subject to a certain amount of gossip and envy (e.g. Beckett, 1971) this differs little from circumstances elsewhere in Australia and appears to constitute no unusual impediment to capitalist enterprise. Islanders have a reputation as hard and reliable workers; in the 1960s and 1970s they were in constant demand outside the Strait to work as miners, on pearl farms and in railroad construction.

In Torres Strait, however, there is another impediment to the expansion of commercial fishing by Islanders that also lies outside conventional categories of debate concerning fisheries development in Australia.

Education for Development

For reasons discussed in more detail elsewhere (Johannes and MacFarlane, in press) we believe that an important part of the problem is that Islanders' education has not prepared them to exploit adequately the opportunities their marine resources afford. It has, for example, not equipped them to come to terms with such essential subjects as marketing strategies, investment capital, quality control, gear design, resource management strategies etc., on the sophisticated plane that today's commercial fishing industry demands.

The Queensland government has in the past interposed itself between Islanders and the outside world in such a way that few had the opportunity to learn much about how it works. This is almost certainly part of the reason for Islanders not having been able to vertically integrate their existing commercial fishing operations (e.g. Anonymous, 1988), to expand the jobs available by serving as middlemen or by controlling the business of transporting the product between fishermen and southern retailer.

The standard of education in the Islands has been substantially lower than that on the Queensland mainland (e.g. Mollison, 1949; Beckett, 1963, 1987; Orr and Williamson, 1973; Duncan, 1974; Fisk, 1975; Anonymous, 1988). Islanders, themselves, have long recognized this (e.g. Douglas, 1899-1903; Gabey, 1949; Beckett, 1987; Agnew, 1989; see also Passi, 1986). In the mid 1970s one Island chairman was quoted as saying, "English is our big downfall in the Torres Strait today. You find that the people here know a lot but they just can't express what they think. Island people are ashamed of talking to Europeans because their English might be incorrect. The children who go to school down south have better knowledge and find things easier because they have English", and an Island deputy chairman said, "English is the main thing we want in the Torres Strait – that's the big problem," (Boxall and Duncan, 1979).

To be sure, Islanders can move to the mainland and get a better education. And many do. But, although this reduces population pressures in the Islands, it also selectively drains off the younger and the more productive and innovative members of the work force.

In 1975 Fisk argued: "The needs of a child who is to spend his life as a subsistence gardener, a subsistence fisherman, a crayfish lugger hand or even a pearl-shell diver are completely different from those of a child who wishes to become a skilled technician or a mechanic, and different again from one who is to enter business or a profession on the mainland. The reserve islands do not, and seem unlikely to offer, much opportunity for the latter two types of career," (Fisk, 1975, p. 55). Today Islanders living in the Strait do not want their children to remain subsistence fishermen or employees in marine industries run by non-Islanders. (It is doubtful if many did even in 1975, when Fisk wrote, in our opinion). If their ambitions are to be achieved, then the appropriate education must be made available in the islands.

In some Pacific Island countries a fundamental stumbling block for fisheries training programs, however, has been the lack of adequate basic skills on which to build (e.g. Meltzoff and Lipuma, 1983). It may seem unnecesary to point out that good education must start in the first grade if an economically competitive society is to be built and maintained. But this truism is generally overlooked by fisheries development personnel whose job is to get quick results with the existing work force. They are stuck with the thankless job of training ill-prepared students and observing the inevitably poor results. Anyone who would train adult Torres Strait Islanders in commercial fishing or any other profession today would face this same problem. Descriptions of proposed training programs for adult Islanders in the Strait's 1990-1995 regional development provide no indication, however, that planners are aware of it (Lea, Stanley and Phibbs, 1990).

Education for Resource Management

It is not enough to provide education that enables Islanders to exploit their marine resources more fully. With fuller exploitation comes the inevitable threat of over-exploitation. And with increasing development of a marine industry comes increasing problems of marine environmental degradation.

In order to combat such trends effectively, Islanders must possess a strong conservation ethic. We define the latter as an awareness of one's ability to deplete or otherwise damage natural resources, coupled with a commitment to reduce or eliminate the relevant deleterious practices.

Among the islanders of Oceania a widespread (although by no means universal) traditional marine conservation ethic evolved. All the basic marine conservation methods used in the west for the past 90 years were already in use in parts of Oceania centuries ago (Johannes, 1978b; Johannes and Ruddle, 1990). This is probably because traditional seafood stocks have been limited largely to narrow fringes of reef and lagoon around many of these islands. The finite nature of these resources must thus have become obvious, especially on smaller islands, only a few generations after human colonisation.

We searched among Torres Strait Islanders for evidence of such traditional awareness that the seas' resources are limited, but found none. Similarly, Carr and Main (1973, p. 20) noted, "it was clear from talking with (several Island leaders) that they had never conceived of fish stocks as exhaustible." (see also Passi, 1986, p. 92)[6].

There is no indication in the literature that the Islanders ever practiced marine conservation, nor that they ever needed to. Human populations in the Strait were kept low in the past by infanticide, abortion and warfare (e.g. Haddon, 1890). In recent decades the opening up of the mainland labour market has provided a new safety valve for Island populations; although the total number of Torres Strait Islanders is several times what it was during the early years of European contact, the number actually living in Torres Strait remains about the same (e.g. Beckett, 1987).

The issue of dwindling marine resources has arisen for the first time in Torres Strait only in the past century. And, for several generations, depletion affected only commercial species – bêche-de-mer, trochus and pearl shell. It is only within the past few years, as a consequence of the introduction of motorized fishing boats, that an important element in the traditional fishery, the dugong, has become noticeably less abundant. But nothing in Islanders' cultural experience has led them to consider that their own actions might be the cause. The most common explanation for the decline, when we began to interview Islanders on the subject in 1984, was that, "They've gone somewhere else right now. Sooner or later they'll be back."

Since such depletion is not part of the Islanders' past experience, it is not surprising that they do not possess a well-developed awareness of the vulnerability of their marine resources. This must change if they are to exploit these resources efficiently. And since this awareness cannot be expected to arise from traditional sources, it must be provided as part of their formal education.

Today in Oceania, marine environmental problems loom large. Depletion of shallow marine resources is the norm due to the pressures of expanding populations, outside cultural influences and the breakdown of traditional controls. One response has been to develop environmental education programs tailored specifically to tropical island settings. The impact of such education has taken effect quickly in Oceania because of the unusual speed with which young, western-educated people in these cultures achieve influential political positions (e.g. Johannes, 1981).

Relevant educational resources (readily available through the South Pacific Regional Environmental Programme at the South Pacific Commission in New Caledonia) are far more appropriate to conditions in Torres Strait than those produced for use in classrooms on the Australian mainland.[7] However, until the late 1980s this kind of educational material was not used in the Strait and there was minimal emphasis on environmental subjects.

In 1986 the responsibility for education in Torres Strait was removed from the Queensland Department of Community Services, an agency that has been long and bitterly criticized for exerting, until recently, what was widely perceived as rigid, paternalistic control over Islanders' lives. Education in Torres Strait is now in the hands of the Queensland Department of Education, a change long sought by Islanders (Beckett, 1987). English, science and locally appropriate environmental education[8] are now being given increasing emphasis in Island school curricula.

Future Islanders should therefore be better equipped to create and sustain a self-supporting economy based on their marine resources. This provides little consolation, however, for those Islanders today who have already completed their formal education.

Traditional Fishing Rights

Traditional fishing rights play an important role in contemporary marine resource management in a number of countries in Oceania (Ruddle and Johannes, 1990). Our findings and conclusions concerning traditional fishing rights in Torres Straits are discussed elsewhere (Johannes and MacFarlane, 1990 and in press). The issue is complicated and we will not deal with it in any detail here. Certain of our conclusions deserve brief mention, however.

One conclusion is that, if a new fishery or reef-ranching program (e.g. Crossland, this volume) were to develop in the Strait, marine resource management planners should consider carefully the territorial sensitivities of Islanders in framing the relevant management regime. For example, if support by any outside agency for some form of marine resource enhancement program were to be considered, it would be prudent to establish at the outset the principle that no area would be targetted for enhancement where Islanders disagreed over who, among them, would have the right of access to the contained resources.

We also conclude that, if it becomes necessary to further define local marine resource-use boundaries and resource-use rights within these boundaries, it would be much more practical in Torres Strait to make a fresh start rather than to try to resurrect a traditional sea rights system which our research shows is very poorly remembered. It might prove useful, for example, to devise for individual Island communities some form of exclusive use-rights (such as might be embodied, for example, in a leasing arrangement) to the resources in question in waters near their islands.

Notes

[1] Our results are in distinct contrast to those of Duncan (1974), which were based on two-week nutritional surveys on Badu, Yorke, Saibai and Murray Islands in 1973. She concluded that subsistence production of seafood was low and that Islanders' diets were strongly biased towards carbohydrates. It is not possible to compare our data with hers because she reported seafood consumption per household, without noting mean household size – although she did state that it ranged from one person to more than 11! She also ignored the turtle and dugong catches she recorded in calculating subsistence catches. Had she included them in her calculations they would have raised mean estimated local seafood consumption rates considerably – more than tripling them in the case of Badu households. It may be that carbohydrate intake is very high in the Islands, but certainly not at the expense of marine animal protein intake in the communities whose seafood consumption we studied.

[2] Not all of the excess potential yield has a broad market potential, however. European-Australians have conservative tastes in seafood. Some well-flavoured Torres Strait species would probably have little market value in mainland Australia other than in communities with significant populations of Islanders or tropical coastal Aborigines, such as Cairns, Townsville and Brisbane.

[3] The wholesale price of trochus shell, for example, almost doubled in Australia between 1986 and 1987. There is also an expanding and what appears to be recession-resistant demand for bêche-de-mer (van Eys, 1986).

[4] Among important marine species harvested traditionally in Torres Strait only five require, or may require, management, given current exploitation levels: dugong (Marsh, this volume; Johannes and MacFarlane, in press); green and hawksbill turtles (Limpus and Miller, this volume; Kwan, this volume; Johannes and MacFarlane, in press), rock lobster (Pitcher, this volume) and trochus (Coles, this volume). Only the last two of these species are (or are ever likely to be) of commercial significance in the Strait.

[5] This is a problem found across much of the rest of northern Australia and in Papua New Guinea as well. The region contains what is almost certainly the greatest area of underexploited shallow water marine seafood resources remaining in the tropics. Recently the Northern Territory government has expanded greatly its efforts to provide the infrastructure necessary to exploit seafood stocks similar to those in Torres Strait effectively. The results should be watched closely by those interested in developing reef fisheries in Torres Strait.

[6] Landtman (1927, p. 127,128) said, similarly, of the nearby Kiwai Papuans, who also fish and hunt in Torres Strait, "It is a firm conviction among the natives that the number of dugong, turtle and fish in the sea can never be exhausted, however unsparing their capture ... It is only 'things on land', particularly garden plants, which can be 'finished.' After a taro or yam garden has been cropped, nothing remains there. But with the animals in the sea it is different. 'Dugong he stop all time.'" See also Hudson (1986).

[7] It is ironic that developed countries such as Australia, which routinely contribute to the funding of special, locally relevant environmental education programs for third world countries, often overlook the need for similar programs in fourth world communities within their own borders.

[8] In addition, the Australian Fisheries Service, in collaboration with the Torres Strait Protected Zone Joint Authority, has prepared a dugong educational package for use in the primary grades in Island schools.

References

Agnew, R. Q. (1989), *Torres Strait in Australia's security: the weak link?* Australian Defense Studies Centre, Canberra.

Alexander, P. (1975), 'Do fisheries experts aid fisheries development?', *Marit. Stud. Mgmt*, 3, 5-11.

Anonymous (1978a), *Fishery catch assessment survey 1978,* Dept. of Statistics, Apia, Western Samoa.

Anonymous (1978b), *Fish catch assessment survey,* Cook Island Agriculture and Fisheries Department, Rarotonga.

Anonymous (1988), *Report of the Interdepartmental Committee on the Torres Strait Islands,* Department of Aboriginal Affairs, Canberra.

Bayliss-Smith, T. (in press), 'Atoll Production Systems: Fish and Fishing on Ontong Java Atoll, Solomon Islands', In, D.E. Yen. and J. Mummery (eds) *Pacific Production Systems,* Canberra, Department of Prehistory, Research School of Pacific Studies.

Bayliss-Smith, T. (n.d.), The price of protein: marine fisheries in Pacific subsistence, unpublished manuscript, np.

Beckett, J. (1963), Politics in the Torres Strait Islands. Ph.D. thesis, Australian National University, Canberra.

Beckett, J. (1971), 'Rivalry, competition and conflict among Christian Melanesians', In, C. Jaywardena and L.R. Hiatt (eds.), *Anthropology in Oceania: Essays Presented to Ian Hogbin,* Sydney, Angus and Roberston, 27-46.

Beckett, J. (1982), 'Torres Strait Islanders and the problem of custom' *Anthrop. News,* 19, 99-106.

Beckett, J. (1987), *Torres Strait Islanders. Custom and Colonialism,* Cambridge University Press, Cambridge.

Ben-Yami, M. (1980), 'Community fishery centers and the transfer of technology to small-scale fisheries', In, *Symposium on the Development and Management of Small-Scale Fisheries. Section III, Proc. 19th session Indo-Pacific Fishery Comm.*, Bangkok, FAO Regional Office for Asia and the Pacific, 936-945.

Boxall, R. and Duncan, W. (1979), *Education in Torres Strait (the mid-1970's),* Curriculum Branch, Queensland Dept. of Education, Brisbane.

Carr, A.F. and Main, A.R. (1973), *Report on an inquiry into ecological implications a turtle farming project in Northern Australia,* Commonwealth of Australia, Canberra.

Douglas, J. (1899-1900), 'The islands and inhabitants of Torres Strait, Queensland', *Geogr. J.*, n.s., 15, 25-40.

Duncan, H. (1974), *Socio-economic conditions in the Torres Strait,* Dept. of Economics, Research School of Pacific Studies, Australian National University, Canberra. (The Torres Strait Islanders, vol. 1)

Fisk, E.K. (1975), *Policy Options in the Torres Strait,* Dept of Economics, Research School of Pacific Studies, Australian National University, Canberra. (The Torres Strait Islanders, vol. 6)

Gabey, J. (1949), Notebook on Murray Islanders. Unpublished manuscript, Australian Institute of Aboriginal and Torres Strait Islander Studies Library, Canberra.

Haddon, A.C. (1890), 'The ethnography of the western tribe of Torres Straits', *J. Roy. Anthrop. Instit.* 19, 297-440.

Halapua, S. (1982), *The Tongan Fishermen,* Institute of Pacific Studies, Suva, Fiji.

Hendrickson, J.R. (1972), *South Pacific islands - marine turtle resources,* Rome, FAO. (Report prepared for South Pacific Islands Fisheries Development Agency)

Hudson, B.E.T. (1986), 'The hunting of dugong at Daru, Papua New Guinea, during 1978-1982: community management and education initiatives', In, A.K. Haines, G.C. Williams and D. Coates (eds), Torres Strait Fisheries Seminar, Port Moresby, 11-14 February, 1985, AGPS, Canberra, 77-94.

Jansen, A. A. and Wilmott, J. V. (1973), *Nutrition and dietary survey of urban and rural populations in British Solomon Islands Protectorate, part II: Solomon Islands special conditions,* Suva, South Pacific Health Services.

Johannes, R.E. (1978), 'Traditional marine conservation methods in Oceania and their demise', *Ann. Rev. Ecol. Syst.* 9, 349-364.

Johannes, R.E. (1981), *Words of the Lagoon: Fishing and Marine Lore in the Palau District of Micronesia,* University of California Press, Berkeley.

Johannes, R. E. (1989), 'Managing small-scale fisheries in Oceania: unusual constraints and opportunities', In, H. Campbell, K. Menz and G. Waugh (eds), *Economics of Fishery Management in the Pacific Islands Region*, Australian Centre for International Agricultural Research, Canberra, 85-93.

Johannes, R. E. and MacFarlane, W.J. (1990), 'Assessing traditional fishing rights systems in the context of marine resource management: a Torres Strait example', In, K. Ruddle and R.E. Johannes (eds.), *Traditional Marine Resource Management in the Pacific Basin: An Anthology*, Jakarta, UNESCO/ROSTSEA, 241-262.

Johannes, R. E. and MacFarlane, W.J. (in press), *Traditional Fishing in the Torres Strait Islands*, CSIRO Division of Fisheries, Hobart.

Landtman, G. (1927), *The Kiwai Papuans of British New Guinea*, London, MacMillan.

Lawson, R. M. (1980), 'Development and growth constraints in the artisanal fisheries sector in island states', In, R. T. Shand (ed.), *The Island States of the Pacific and Indian Oceans: Anatomy of Development*, Australian National University, Canberra. 61-85. (Development Studies Center Monograph No. 23)

Lea, J.P., Stanley, O.G. and Phibbs, P.J. (1990), *Torres Strait Regional Development Plan 1990-1995.*

Liem, D. S. (1977), ' Wildlife utilisation in the proposed Garu wildlife management area', In, J. Winslow (ed.), *The Melanesian Environment*, ANU Pres, Canberra, 285-292.

Meehan, B. (1977), 'The role of seafood in the economy of a contemporary Aboriginal society in coastal Arnhem Land', In, *Joint Select Committee on Aboriginal land rights in the Northern Territory (Hansard Rept.)*, Canberra, 1085-1095.

Mollison, P.J. (1949), 'The administration of the Torres Strait Islands. Pt. 2', *South Pacific*, 3, 217-220.

Mye, G. and Lui Jr., G. (1986), 'Address by Torres Strait Islander leaders to the Torres Strait Fisheries Seminar', In, A.K. Haines, G.C. Williams and D. Coates (eds), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985*, AGPS, Canberra, 25-30.

Nietschmann, B. (1984), 'Indigenous island people, living resources and protected areas', In, J. McNeeley and K. Miller (eds.), *National Parks, Conservation and Development*, Smithsonian Institution Press, Washington, 333-343.

Nietschmann. B. (1985), 'Hunting and ecology of dugong and green turtles Torres Strait, Australia', *National Geogr. Soc. Res. Repts*, 17, 625-652.

Orr, K. and Williamson A. (1973), *Education in the Torres Strait: perspectives for development*, Res. School of Pacific Studies, Australian National University, Canberra.

Osterhaug, K. L., Dassow, J, and Stansby, M. E. (1963), 'Nutritive value and quality of fish', In, M.E. Stansby (ed.), *Industrial Fishery Technology*, Reinhold, New York, 362-368.

Passi, G. (1986), Traditional resource knowledge, western education and self-management autonomy of Torres Strait. Masters thesis, University of Queensland, St Lucia.

Poiner, I.R. and Harris, A.N. (in press), In, R.E. Johannes and W.J. MacFarlane, *Traditional Fishing in the Torres Strait Islands*, CSIRO Division of Fisheries, Hobart.

Ruddle, K. and Johannes, R. E. (eds.) (1990), *Traditional Marine Resource Management in the Pacific Basin: An Anthology*, Jakarta, UNESCO/ROSTSEA.

Russ, G. (1984), 'A review of coral reef fisheries', *UNESCO Reports in Marine Science*, 27, 74-92.

Smith, I.R. (1979), 'A research framework for traditional fisheries', *ICLARM Stud. & Rev*, No. 2.

van Eys, S. (1986), ' The international market for sea cucumber', *Infofish Marketing Digest*, 5, 41-44.

Wass, R.C. (1982), 'The shoreline fishery of American Samoa - past and present', In, J. L. Munro (ed.), *Marine and Coastal Processes in the Pacific: Ecological Aspects of Coastal Zone Management*, UNESCO-ROSTSEA, Jakarta, 51-83.

Wright, A. and Richards, A. H. (1985), 'A multispecies fishery associated with coral reefs in the Tigak Islands, Papua New Guinea', *Asian Mar. Biol*, 2, 69-84.

Sustainable Development: Possibilities and Limitations to Indigenous Economic Development in the Torres Strait

Bill Arthur, Centre for Aboriginal Economic Policy Research
Australian National University

Abstract

The Torres Strait is an archipelago populated predominantly by Torres Strait Islanders (officially recognised as Australia's other indigenous minority). At the present time the Strait's economy is characterised by a significant public and private service sector, and by a productive sector based entirely on commercial fishing. There are pressures from Islander interests and from government policies, to decrease dependency on the public purse by increasing the opportunities for Islander employment. However, in the context of the region's fishing industry, these policies appear ambiguous. Furthermore, expansion is limited by the size and availability of fish stocks. It is also possible that as the level of services and employment in the Strait increase, it may become increasingly attractive, as a place to live or work, to both Islanders residing on the mainland and to Papua New Guinean nationals of Western Province. This may increase the local population and put further pressure on the natural resource base. A corollary of this is that in areas, such as the Torres Strait, government policies for indigenous people may have to accept that there are limits to the economic growth that can occur from primary production alone, and consideration should be given to broadening the economic base, and/or modifying policies which emphasise economic independence.

In this paper I will briefly look at the social and economic characteristics of the region, the possibilities for increased Islander involvement in the non-welfare economy, and some of the apparent constraints to increasing that involvement.

Introduction

The first comprehensive study of the socio-economic and political status of the Torres Strait was carried out in 1974 by a team, headed by E.K. Fisk, from the Research School of Pacific Studies, Australian National University (see Fisk 1974). Following calls from Torres Strait Islanders in early 1988 for political independence, the Federal Government set up an Interdepartmental Committee to examine Islander concerns regarding their disadvantaged status in Australian society. One of this Committee's recommendations was for further research into the contemporary economic situation in the Strait from an Islander perspective, and for a regional development plan to be prepared (O'Rourke 1988: 2). The primary economic research was carried out through the Australian Institute of Aboriginal Studies, and a baseline report prepared for the Island Coordinating Council (see Arthur 1990). A team from Sydney University began the regional planning process in late 1989 (see Lea *et al*, 1990).

Following the stated objectives of the Commonwealth Government's Aboriginal Employment Development Policy (AEDP), launched in 1986-1987, as well as those of the Island Coordinating Council, a goal of the research and planning during 1989 and 1990 has been to increase Islander incomes and reduce dependency on government funding.

There are several ways such goals could be attained, including: increasing Islander employment in current industries; expanding these industries, as well as increasing Islander employment in them; increasing subsistence income; and increasing Islander non-welfare incomes by other means, such as through a rent levied on other users of local resources (see O'Rourke 1988: 26-27; Lea *et al*, 1990: 62). Considering the data in Arthur (1990), and the recommendations of the subsequent regional development plan (Lea *et al*, 1990), it would appear that increased economic activity could occur in the following industries: public and private sector employment; tourism; artefact production and sale; commercial fishing; market gardening; and subsistence fishing and gardening. This suggests three broad strategies, namely: Islanderisation of waged employment; an expansion of the region's export sector; and import substitution.

With the possible exception of waged employment, which exists primarily in the region's service industries, these strategies are all subject to environmental constraints and considerations. This is particularly the case with commercial and subsistence fishing; given that a concern of this conference is sustainable development, I will focus on commercial fishing and subsistence here.

Sustainable development

Sustainable development is a somewhat imprecise and contentious concept, but following Pearce *et al* (1989), it would appear to include the requirement for an increase in income as well as in the quality of life:

> Sustainable development involves devising a social and economic system which ensures that these goals are sustained; ie that real incomes rise, that educational standards increase, the health of the nation improves, that the general quality of life is advanced (ibid: 1).

In addition sustainable development should strive for economic progress without impairing the welfare of future generations, which means paying due attention to the environment, as well as taking into account the contribution of unmarketed goods, like subsistence activities. But of possible equal importance is the notion that sustainable development embraces the goals of equity and of increasing peoples' sense of independence. A major problem for sustainable development is to achieve economic development without sacrificing an acceptable rate of economic growth (ibid: 30). This highlights the fact that concepts of sustainable development are value-based and culture-relative, for what may be considered an acceptable rate of economic growth for some would most likely be unacceptable to others. This suggests that sustainable development must involve a consideration of social, cultural and political, as well as purely economic, factors.

Some regional characteristics

There are an estimated 6,245 Islanders residing on sixteen of the Strait's some 150 islands (Table 1), as well as on two incorporated communities on the northern tip of Cape York (Arthur 1990: 3). Approximately 15,296 Islanders also live on the Australian mainland, 6,925 of these in other parts of Queensland (ABS 1987). Therefore, only around 30 per cent of those people who self-identify as Torres Strait Islanders live in the Strait.

There is however some variation in the socio-economic and political environments across the region, and it is useful for analytical purposes, to divide it into three inter-related zones (Map 1). Zone 1 includes what are referred to as the outer islands; Zone 2 consists of the two Islander communities on the tip of Cape York, and Zone 3 is the group of islands around and including the administrative and service centre of Thursday Island, and referred to as the south western group.

The outer islands (Zone 1) make up much of the Torres Strait Protected Zone (TSPZ)[1]. This area borders on Papua New Guinea (PNG) and contains the majority of the Strait's productive waters and reefs. In addition, it is the only area to which PNG people may legally make 'traditional visits' under the Treaty. Almost 52 per cent (3,240) of the Strait's Islander population and an estimated 175 people of Papuan descent live in this zone in incorporated communities which have their own elected Islander councils.

All of the outer islands, as well as Hammond Island (in Zone 3), and the two Islander Cape communities (Zone 2) hold their land under Deed of Grant in Trust (DOGIT) from the Queensland State Government. The size of each island and their population densities vary significantly (Table 1).

Thursday Island and the other islands in the south western group (Zone 3), with the exception of Hammond, are not DOGIT land but are administered by Torres Shire. Although there is a reserve (Tamwoy) on Thursday Island, there are no incorporated communities as such in this Zone. Thursday Island has a significant non-islander and Asian-Islander population and is more socially and racially heterogeneous than either the Cape or outer islands; it resembles a small, mixed-race, rural town, whereas the outer islands are small Islander communities.

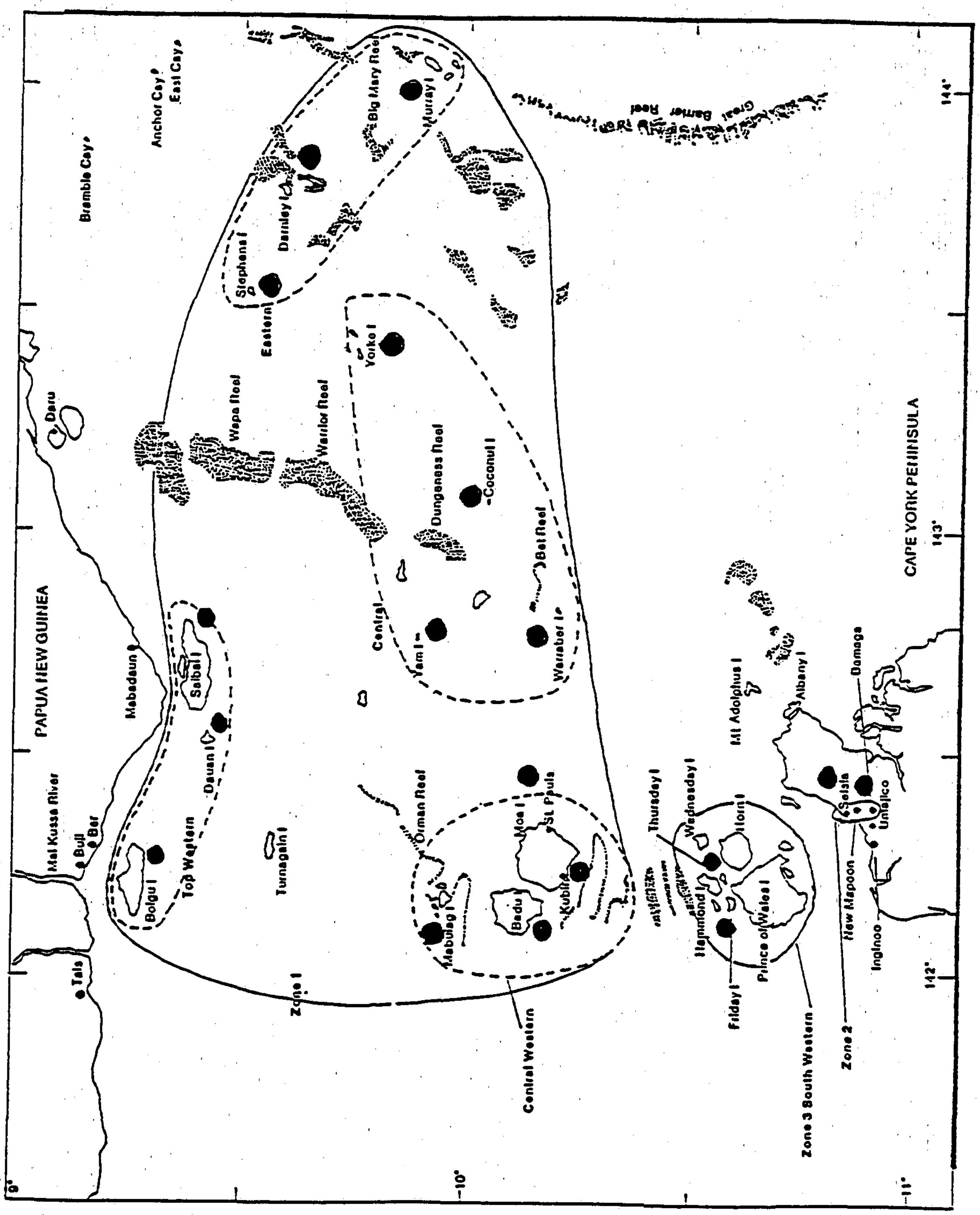
Table 1. Populations and land areas

Islands	Islander population	PNG population	Others (a)	Area DOGIT leases (ha.)	Population density (persons/ ha.)
Zone 1					
Boigu	340	13		6,630	0.051
Saibai	270	48		10,400	0.025
Dauan	135	0		355	0.380
Kubin	140	0		15,200	0.009
St Pauls	190	0		1,770	0.107
Badu	500	35		10,200	0.049
Mabuiag	180	0		626	0.287
Coconut	130	0		44	2.954
Warraber	165	0		93	1.774
Yorke	300	20		168	1.785
Yam	200	35		145	1.379
Stephen	40	0		36	1.111
Darnely	300	14		570	0.526
Murray	350	10		724	0.607
	3,240(b)	175	266(b)		
Zone 2					
Seisia	80	0		178	0.449
Bamaga	600	0	296(b)	6,660	0.090
Zone 3					
Hammond	170	0		1,660	0.102
Prince of Wales	45	0		20,500(c)	0.005(d)
Thursday Island	2,000	n d		260(c)	13.561(d)
Horn	110	n d		5,479(c)	0.036(d)
	2,325(b)		910(b)		
Total	6,245		1,472		

Notes (a) Those not Islanders or people of Papuan descent; ie principally Europeans.
(b) Total for this Zone.
(c) These islands are not DOGIT lease areas.
(d) Estimated.

Source: Arthur (1990)

The residents of Bamaga and Seisia on the Cape (Zone 2) are in a different environment from the other two zones. They identify as Torres Strait Islanders and are part of the Island Co-ordinating Council (ICC)[2], but their immediate neighbours are three Aboriginal communities which are members of the Aboriginal Co-ordinating Council (ACC), and the newly formed Cape York Land Council (CYLC). Being part of the mainland, these communities have much greater contact with tourist traffic to the tip of Cape York.



Map 1. Torres Strait Region divided into zones based on variations in socio-economic and political environments.

Because the Strait forms Australia's only border with another country, and has an indigenous population with special programs and servicing agencies, there is a significant bureaucratic presence in the region, and a distinct governmental flavour to its social, economic, and political environment[3]. The location of the Strait at the cultural and geographic crossroads between Aborigines, Islanders and Papua New Guineans adds to the complexity of this region.

Some features of the region's economy

The regional economy is characterised by a significant public and private service sector. There is virtually no manufacturing or secondary industry in the region, the majority of goods being imported from the mainland. The productive sector consists almost entirely of the fishing industry, with some small contribution from tourism and the production and sale of artefacts.

Public sector

There is a relatively high level of public sector employment in the Strait (Lea *et al,* 1990: 20; Arthur 1990). Much of this is focused on Thursday Island and the Cape where government offices, hospitals and secondary schools are located. However, there is also some full-time public sector employment on the outer islands, for example, in primary schools, medical posts, with the Island police, and in community management and maintenance.

The majority of the outer island communities (and those on the Cape) are also involved in part-time employment in the public sector as part of the Commonwealth's Community Development Employment Projects (CDEP) scheme. In this scheme, residents' unemployment benefit entitlements are paid as a lump sum to their community councils, along with a subsidy to cover administration costs and some project materials. The councils then organise work for their residents who are paid a weekly wage that approximates their unemployment benefit entitlements. At present, men usually work two to three days per week on community public works under the CDEP scheme, leaving them the remaining time to engage in other activities, such as commercial fishing (see below).

Retail sector

In 1988 there were a recorded forty-five retail establishments with a turnover of $20.35 million in the Strait (ABS 1988: 20). The retail sector is located primarily on Thursday Island, where a significant number of businesses are owned by residents of mixed Asian-Islander descent. The major player in the retail/wholesale sector is the State-owned Island Board of Industry and Service (IBIS).[4] Its central office is located on Thursday Island, but it also has a store on the Cape and one on each of the outer islands. There are also usually one or more small privately owned retail outlets on each of the outer islands. These small operations represent an aspiring Islander retail sector which must compete with the much larger Government-owned IBIS. Although the IBIS allegedly operates as a non-profit making company, it can be argued that it inhibits the development of an Islander retail sector. Consideration is being given to leasing outer island IBIS stores to residents. However it would also be worthwhile considering the transfer of the entire IBIS organisation to Islander ownership over a number of years (Arthur 1990).

Mining

The Commonwealth Department of Primary Industries and Energy (DPIE) considers the region to have high prospectiveness for gold. However, a mine which started production on Horn Island (in the south western group) in January 1988 had closed by early 1990 due to insufficient returns. The multiplier or spin-off to the regional economy from this mine was thought to be very limited, a feature also noted with regard to mining in other parts of remote Australia (O'Faircheallaigh 1985: 56). However Islanders held some 53 positions (or 33 per cent) out of a total mine-site and contracting workforce of 160[5], which is a high proportion compared to other parts of the country. For example, a survey of several mines across the country in the mid-1980s suggested that Aborigines and Islanders made up only approximately 2.6 per cent of the mining industry workforce (Cousins and Nieuwenhuysen 1984: 2), with this varying from 0.4 per cent to 7.8 per cent between different mines (see also Cousins 1985). On the other hand, the profile of the Horn Island workforce was similar to the national norm as far as occupations were concerned as Islanders tended to be employed as drivers and heavy plant operators and labourers, rather than as technical, process or managerial staff (Arthur 1990: 87).

Other minerals such as tin, copper, phosphate, mineral sands, and wolfram are all considered to have only low or low-to-moderate prospectiveness. There is a moratorium on sea bed exploration for oil until 1995, but with provision for this moratorium to be extended. Royalties from any mineral development would be subject to negotiation, but presently there is no provision for a royalty or tax to be paid to the region or to local people (DPIE 1988).

Tourism

There is a small tourism industry focussed mostly on Thursday Island and the Cape. It is estimated that in 1988-1989 20,000 people drove up to the tip of the Cape (Horwath and Horwath 1989), and that approximately 7,000 tourists visit Thursday Island per annum (Lea *et al*, 1990: 25). Presently no tourists visit the outer islands.

As indicated earlier, the outer islands vary in size (Table 1), and any social impact resulting from tourism development would probably be more noticeable on the very small islands, such as Yorke or Sue, than on the larger, such as Moa and Badu. Although Islanders are not overtly anti-tourism, many indicate that they would prefer development to take place either some distance from their community village, or on uninhabited islands. This suggests that it is unlikely that they envisage a great deal of 'direct' contact or involvement with the industry, a trend noted elsewhere in central and northern Australia (Altman 1988). An additional problem with developments on the outer islands would be the supply of potable water which is scarce on inhabited islands and usually non-existent on those that are uninhabited. Also the uninhabited islands are not held under DOGIT and so Islander control of any development would be very limited[6].

Island dancing and feasting (Kup Mari) are tourist attractions elsewhere, for example in Cairns, and these, together with the possible sale of artefacts, the natural beauty of the islands, and the warm winter season, are all possible draw-cards. However, these positives must be weighed against the negative aspects to tourism development in the Strait. For example, the winter tourist season is also the time of the south-east winds when the water becomes rough and dangerous and difficult for diving. As well as this the Strait is a more expensive destination than the Great Barrier Reef islands which have similar natural attractions (Babbage 1990: 20).

Artefacts

Currently, there is very small artefact industry in the region, with an estimated turnover in 1989 of only $8,000 (Arthur 1990: 28). This could be extended, especially if marketing was improved or regional tourism expanded, though it would probably remain fairly limited. Experience elsewhere has indicated that artefact production alone does not provide employment for very many people, nor does it usually signal a decrease in welfare dependency (Altman 1989); welfare payments are usually needed to subsidise the commercial activity of artists.

The fishing industry

There is virtually no manufacturing or secondary industry in the region (ABS 1988: 20), and in the current absence of any mining, the materially productive sector is based almost entirely on the exploitation of the marine resources. In 1989 the total value (to fishermen) of commercial fishing was approximately $21 million (Arthur 1990: 40) made up as shown on Table 2[7]. I will discuss this industry in some detail because it is linked in many respects to the Islander way of life, it is the major export industry of the region, it offers some scope for development, and it has implications for the environment.

Table 2. Value (turnover) of strait fisheries 1989

Fishery	Value $ million	Islander involvement (per cent)	Non-islander involvement (per cent)
Prawn	14.00	0	100
Cray	3.90	30	70
Trochus	1.20	100	0
Mackerel	1.10	3	97
Pearl Culture	1.20	0	100
Pearl Shell	0.05	n d	n d
Reef Fish	0.02	n d	n d

Source: Arthur (1990)

The organisation of commercial fishing varies across the Strait's fisheries[8]. Fishers are not all involved in the industry to the same extent or in the same way. It is likely that some of the differences in approach and technique relate to the degree to which fishers rely on the industry for their income, which in turn is influenced by their access to the fisheries. Those involved in commercial fishing and their sources of income can be conceptually categorised as in Table 3.

Table 3. Type of fishermen and sources of income

Category of fisher	Sources of income		
	Commercial fishing	*UB or CDEP*	*Subsistence*
Mainland non-islanders	yes	no	no
Local non-islanders	yes	no	no
Islanders (type A: full-time)	yes	no	no
Islanders (type B: part-time)	yes	yes	yes
PNG residents	yes	yes	yes
PNG traditional visitors	no	no	yes

This categorisation indicates two types of non-islander fishers, those from the mainland and those who are residents of the Strait. They are similar in that they largely rely on the industry for all of their income. However, the local fishers tend to be primarily involved in the cray fishery and employ local people, either Islanders or Papua New Guinean residents, and so contribute directly to the local economy.

On the other hand fishers from the mainland who are involved in the prawn, cray, and mackerel fisheries, generally do not employ local people and there are few spin-offs to the local economy. This is particularly noticeable with prawning which, with a turnover of $14 million per year, is the region's most valuable fishery. However, trawlers are provisioned and serviced by mother-ships from the mainland, and so generate little business for local traders. It is interesting to note that because mainland fishers hire almost all their employees and obtain most of their provisions from outside the region they probably contribute less, to the local economy than did the Horn Island gold mine when it was operating.

There are also two main types of Islander fishers, type A and type B. Type A islander fishers (and some PNG residents) rely on commercial fishing for all of their income[9].

However the majority of Islander fishers are in the category, type B, and for them commercial fishing is a part-time activity and is not their only, or even their primary, source of income. For those part-time fishers from the south western islands the balance of their income tends to come from unemployment benefit entitlements (UB) and other welfare payments. Those on outer islands involved in part-time fishing get the remainder of their income from employment on community public works carried out under the CDEP scheme as noted earlier, as well as from pension entitlements through the Department of Social Security and the Department of Veterans' Affairs, from subsistence fishing and gardening, and/or from selling small quantities of fish to other Islanders. The approximate break-up of outer island incomes is shown on Table 4, and indicates that CDEP wages are the largest component of outer island incomes.

We can say therefore, that the part-time section of Islander commercial fishing is indirectly subsidised by government transfers (CDEP, UB and other welfare payments). This arrangement has both positive and negative features. On the one hand, CDEP wages provide people with a base-income which largely protects them from fluctuations in the market, and which also allows them to be involved in commercial fishing when and if they wish. In this way CDEP wages could be viewed as a form of development subsidy (Arthur 1990). On the other hand, the primary use of the CDEP scheme is for construction of community public works, and so it can be argued that it competes with commercial fishing for people's time and labour. For example, in most cases CDEP regulations require workers to be available for work in their community for specific days and in some instances, because of tides or weather, these same days can be the best for fishing. Therefore, CDEP is not used directly to develop fishing, the only major regional export industry, and in some cases, it may actually hinder its development. This last point applies less to those part-time fishers on Thursday Island who are unemployed and receiving UB, because their movements are not restricted in the same way as are those on outer islands who participate in the CDEP scheme.

An additional feature of the CDEP scheme is that there is no mechanism to reduce an individual's CDEP wage in proportion to the amount they may earn in other areas, such as fishing. It can be argued therefore, that this system institutionalises and perpetuates the very dependency which government policy proposes to remove. On the other hand, as the CDEP scheme provides a substantial part of Islander income, it reduces the potential pressure on the marine resources.

It can be argued that a finite natural resource such as the Strait's fisheries can sustain a small number of full-time commercial fishers who are not dependent on government, or a larger number of part-time fishers who receive some other form of income support (such as CDEP wages). Present policies are ambiguous on this issue, that is, whether the aim is to sustain a smaller number of people without government support, or a larger number with government support.

Expansion of the fishing industry is limited by the natural stock of marine resources. Although this stock size has still to be accurately established for most fisheries it does seem that the present stocks are not fully utilised, either commercially or for subsistence, and that there may be room for limited increases. For example in the case of the mackerel fishery, the 1989 total allowable catch (TAC) stipulated under the Treaty,

Table 4 Source and amount of outer islanders' income (a)

Source of Income	Amount $ million	Per cent of total
CDEP wages	7.500	42
Social security payments (pensions etc)	4.170	23
Non-CDEP wages (b)	2.400	13
Commercial fishing	2.300	12
Subsistence (fishing and gardening)	1.800	10
Artefacts	0.008	0
Total	18.170	100

Notes (a) These data refer to outer islands only.
(b) For example, wages from employment in Island schools and medical aid posts.

Source: Arthur (1990)

was 500 tonnes, but the actual commercial catch was only 160 tonnes, that is, the fishery was apparently under-utilised by 340 tonnes. The fisheries authorities also considered that catch in the Islander cray fishery could be increased[10]. As well as this, in 1989 buyers from the mainland approached both the ICC and individual Islanders about starting a shark and shark-fin fishery and about the possibility of rejuvenating the former beche-de-mer fishery. Inquiries have also been made regarding the possibilities of expanding the scope of trochus, clam and barramundi fisheries through aquaculture.

At the present time there are insufficient data to estimate the commercial viability or potential of any of these ventures (Arthur 1990), but it cannot be assumed that because certain marine resources exist in the Strait then it is economically profitable to utilise them, a point noted for island-nations in the Pacific generally ('Pacific Dreams,' *The Economist*, November 24, 1990). The gold mine on Horn Island did not close down because the ore body was worked out, but because the low yields made the operation unprofitable. In a similar way it may not be commercially profitable to exploit some of the Strait's marine resources.

To date, Islanders have not entered the prawn fishery, although in 1989 a licence for one trawler was reserved for them. Islanders have no fully equipped cray boats, nor mackerel dories, although they are now operating several boats and old luggers to take trochus. The basic 'capital' equipment, for most Islander fishing is the aluminium dinghy. There is no accurate data on the efficiency of this unit, but it appears to vary. Although it may be suitable in some instances for cray, in many cases it will not be efficient for either trochus or mackerel and it provides only limited access to other than home reefs (Arthur 1990).

Islanders also have variable access to buyers and to processing plant (freezers). This is not a critical issue in the trochus fishery as the product is easy to manage. However, other produce such as cray, mackerel and reef fish all require careful handling and must be frozen soon after they are taken from the water. As freezing plants are not located on all islands this tends to hinder Islander participation. Access to various fisheries is also influenced by the fact that the species are not evenly distributed across the region. The data suggest a correlation between these features and the incomes generated from commercial fishing. For instance, the western islands (Badu, Moa and Mabuiag) which have the best access to equipment freezers and cray reefs, have the highest average per capita income from commercial fishing ($1166/head/year). The central islands (Yorke, Yam, Coconut and Warraber) with less access, have a lower income ($953/head/year) and the income in the eastern group (Stephen, Darnley and Murray) where there are no freezers is lower again at ($554/head/year). Most noticeably the northern Islands (Boigu, Saibai and Dauan) which are some distance from all the marketable species, appeared to derive no income from commercial fishing in 1989 (Arthur 1990).

Again, Islanders are hindered by their lack of expertise. They have no knowledge of prawn trawling and have limited expertise in fishing for, and handling, mackerel or reef fish on a commercial basis. Although beche-de-mer was a significant fishery until the Second World War, the local knowledge for processing this has largely been lost. There are also few tradesmen in the region, and little of the technical knowledge necessary to maintain boats and freezing plant.

Therefore, a key factor determining Islander involvement in commercial fisheries is access. This can take several forms such as access to capital or human resources, to appropriate equipment (trawlers, boats, dinghies, dories), to processing plant and buyers, and to specialised technical skills. The significance of this factor may be demonstrated by the fact that the only fishery fully exploited to its total allowable catch by Islanders in 1989-1990 was the trochus fishery. This is a fishery that Islanders have been involved in for most of this century (Beckett 1987) and so one in which they have expertise. Trochus fishers do not need access to freezing plant and unlike cray, beche-de-mer or fin-fish, trochus requires no careful handling and will not spoil; from the production perspective it is a relatively low risk fishery. Trochus can be fished from either boats or dinghies, and can be cleaned, bagged and stockpiled on the islands until picked up by the buyers. In general therefore, trochus is an accessible fishery, and this accounts for the fact that Islanders took up all of the total allowable catch for 1990.

It would seem that the issue of access needs to be addressed if Islander participation is to be increased, and both Arthur (1990) and Lea *et al*, (1990) proposed some form of development agency to facilitate this. In New Zealand the *Maori Fisheries Act 1989* approached similar problems by setting up a Maori Fisheries Commission which in turn established a commercial fishing company. The Commission is to receive 10 per cent of the total fish quota (or an agreed cash equivalent) over four years until 1992. Fifty per cent of this quota will go to the fishing company, with the remainder to be leased to Maori or non-Maori fishers. In addition the Government granted $10 million to establish the Commission and the company (Memon and Cullen 1990). It would seem that a similar concept may be appropriate for the Torres Strait. For instance, the government could consider granting all or part of the fisheries quota to Islanders who would then be required to lease this out to Islanders or non-Islanders.

A form of resource rent has also been considered as means of raising scarce development capital (Lea *et al*, 1990: 62). However, the concept of resource rentals generally applies to net profits and not to turnover (O'Rourke 1988: 26-27). While there are no accurate financial data for fisheries, it is unlikely that these are excessive (Arthur 1990: 118; Lea *et al*, 1990: 62). As shown above the total turnover of the Strait's fisheries is only in the order of $21 million, and therefore any resource rental based on profits is unlikely to be large, and could have a negative effect on industry participation.

However, even if access was improved, the employment potential of the industry is limited by the size of the sustainable stock. This has implications for policies which strive to decrease regional dependency on government funding, as for many Islanders their only option is to increase their fishing effort. Taking the present industry level plus some modest expansion, converting the catch in each fishery into a full-time income of $20,000, and assuming that Islanders take over all non-Islander sections, the industry may provide 250-300 full-time jobs [11] (Arthur 1990: 19). However, there was an average of 615 (male and female) recipients of CDEP wages and UB entitlements in the outer islands in 1989 and to achieve an unemployment level of 7.5 per cent (for parity with the mainland [12]) would require finding 570 jobs. Therefore, although the number of full-time jobs could be significantly increased, it is unlikely that dependency on government payments will completely disappear through full Islanderisation of the fishing industry. Further research is needed to more accurately determine how many people the region's fisheries could sustain.

The extreme volatility of markets for primary produce must also be considered. For example, in the early to mid-20th century the Strait's economy was based on pearl-shell, trochus-shell and beche-de-mer fisheries. This economy collapsed when plastic took over from shell in the fashion industry (Beckett 1987). The recent increase in the value of trochus is due to yet another change in the fashion industry, which may just as quickly change again. The cray fishery, although quite lucrative, is subject to sudden fluctuations in price. In 1988 cray sold for $25 to $30 per kilo, and in 1989 this price had fallen to $15 per kilo, a reduction of 40 per cent. These examples demonstrate the risk of concentrating the region's development on a few primary exports which have highly unstable markets.

Subsistence

Another component of income is subsistence fishing, and to a lesser extent gardening and dependency could also be reduced by increasing these, though again there are environmental limits. Also not all islands have the same gardening potential and because of the quarantine restrictions which are part of the management of the Torres Strait Protected Zone, the Queensland Quarantine Department discourages inter-island movement of local vegetables and fruit. This reduces the possibility for inter-island trade. However, at a purely subsistence level, that is, growing vegetables for household consumption, there would appear to be some room for expansion without any environmental degradation, and a survey of the area of land available for gardening on each island and the Cape would provide some useful data for measuring subsistence potential (Arthur 1990).

On the other hand, the level of gardening seems to have dropped dramatically in the islands, where it is now common for people to purchase rather than grow food (Arthur 1990). The residents of some islands, for example those on Boigu, and Murray, suggest that one reason that gardening effort has decreased is that the best or most accessible gardening land was used to build airstrips. However, others indicate that they now prefer the choice of foods that are available in the Island store. This is not a new phenomenon, and was noted as early as the turn of century, when some Islanders began to derive an income from the pearl-shell fishery (Beckett 1987: 48), and again in 1974 when a significant proportion of Islander income came from unemployment benefits and other social service allowances (Treadgold 1974: 17; Duncan 1975: 28). It is likely therefore that the current reluctance to garden or to increase subsistence fishing is due, at least in part, to the secure base-income which many Islanders derived from the CDEP scheme on outer Islands and Cape York, and from UB on Thursday Island (Arthur 1990: 53).

The Wider Economy and Possible Ramifications for Island Development

Since the 1950s there has been a steady movement of Islanders to the mainland in search of work, and improved economic status (Fisk 1974; Beckett 1987). There is now a small but noticeable (and as yet unmeasured) flow of Islanders returning to the islands. Some are people who returned for funerals or 'tombstone openings' and then remained. Others indicate that the reason they returned was that the differences in the quality of life between the islands and the mainland has decreased in recent years. They say that the standard of housing in the islands has improved, and that more jobs are now available in community management and fishing. Considering these improvements, together with the down-turn in the mainland economy and the associated increase in unemployment, the Strait has become a more attractive option for some Islanders [13].

In the past the Strait was a remittance economy (Treadgold 1974; Beckett 1987), but today residents are able to meet requests for money from relatives in the south from their cray earnings [14]. On the outer islands house rents and rates are reasonably low, and considering that people can supplement their incomes from CDEP wages or unemployment benefits with commercial and subsistence fishing, then their standard of living may be better than that which they would have as an unemployed person on the mainland, an observation made with respect to Aboriginal communities in other remote parts of Australia (see Altman 1987).

If this is the case, then as there are improvements in services, such as housing and electricity, as well as in levels of development infrastructure, such as freezers, the Strait may well prove increasingly attractive to both Papua New Guineans to the north and Islanders on the mainland to the south, and marine resources will come under increasing pressure to provide an income for these additional people. This may be of particular concern when there appears to be some degree of suspicion and distrust of fisheries authorities, especially with regard to total allowable catches, and a belief (amongst some locals) that there is little danger of over-fishing.

Conclusion

Fishing is the Strait's major productive export industry. The majority of Islanders who are involved with the industry are part-time fishers, who receive income support in the form of CDEP wages or unemployment benefits and other welfare payments such as pensions. The current structure of the income support system provides no incentive to decrease dependency on government transfers. On the other hand, as this system potentially reduces the need for Islanders to derive income from fishing, it also reduces the pressure on marine resources.

It is not possible to increase both the number of users of a primary resource, such as fishing, and their incomes, indefinitely. And, even by taking over those sections of the industry dominated by non-islanders, by improving access to fisheries, and by exploiting other species such as beche-de-mer and shark, the potential of the industry to generate sufficient export income to allow regional financial independence from government funding will be limited. Similar limitations apply to import substitution through subsistence activities. Therefore, in the longer term sustainable development in the Strait may be predicated on broadening the economic base by diversifying into other industries, rather than by simply expanding the local fisheries to unsustainable levels.

At the present time most research is focussed on measuring available fish stocks. Given the increased attractiveness of the Strait to Islanders as a place to live, it may be also be advisable to carry out further research into the level of population that the region can ecologically sustain. This would assist with the design of appropriate policies to facilitate sustainable development for the Strait.

Notes

1 The Torres Strait Protected Zone was established under the Torres Strait Treaty between Papua New Guinea and Australia, ratified in 1985. As a condition of this Treaty, Papua New Guineans are allowed to make 'traditional visits' to the islands inside the Protected Zone. In 1989 there were a total of 4,370 traditional visits to the Strait (Arthur 1990).

2 The ICC is a State body established under the *Queensland Community Services (Torres Strait) Act 1984-86*. As the name implies, its principal functions are the coordination of Strait-wide development, which to date has been primarily associated with services and elements of infrastructure, financed by both the State and Commonwealth Governments. The ICC draws its membership from the Outer Islands and the Cape Islander communities.

3 In some respects, the social and political atmosphere in the region remains colonial (see Beckett 1987).

4 Formerly the Island Industries Board (IIB).

5 The workforce was made up of those employed by the mine owners and by their contractors. Of the 79 people employed by the mine owners 27 (or 34 per cent) were Aboriginal or Islander people.

6 Ironically regulations under DOGIT also limit the possibilities for joint-ventures with tourism developers.

7 Babbage (1990: 20) gives the total value as $19-$23 million, made up of: coral trout $0.2 million; trochus $0.6 million; pearls $2-$3 million; pearl shell $0.7 million; mackerel $0.6 million; cray $4-$6 million; and prawns $13 million.

8 Under the Treaty and management of the Protected Zone there are specific categories of fishing, such as Community Fishing which provide Islanders with dispensation from normal licensing requirements. These are not detailed here (see AFS 1985).

9 In 1989, in the cray, trochus, and mackerel fisheries, there were approximately 18 type A full-time fishers from the south western islands, and 17 from the Outer Islands, and there were 177 type B part-time fishers across the entire Strait (Arthur 1990). In reality, the type B fishers can be further sub-divided into: those who fish regularly and who are also on CDEP; those who fish irregularly when the weather conditions are good and are also on CDEP; and those who may only fish several times per year, possibly when they require some extra income (this category includes students who fish during school holidays).

10 Any expansion in the cray fishery is reserved for Islanders. Scientific data are not yet available to indicate how large this expansion could be, without depleting the stock.

11 These calculations are based on preliminary data and further research is required on the efficiency of the various fishing units in the Torres Strait.

[12] The national unemployment level has varied between 7 and 8 per cent for some years. In discussing parity in employment levels for Aborigines and Islanders, government policy does not address the question of the specific level of unemployment to be aimed at in each region of the country.

[13] This movement could also indicate an increase in circular migration. As the air transport services have improved, the towns of Queensland's east coast and the Strait may have come to represent one socio-economic realm for Islanders.

[14] PNG cray workers also send money from Thursday Island to their relatives on the northern islands.

References

Australian Bureau of Statistics (1987), *Census of Population and Housing: Aboriginals and Torres Strait Islanders: Australia, States and Territories*. Cat. No. 2499, Australian Government Publishing Service, Canberra.

Australian Bureau of Statistics (1988), *Local Government Areas Statistical Summary, Queensland*. Cat. No. 1306.3, Australian Government Publishing Service, Brisbane.

Australian Fisheries Service (1985), *The Management of Fisheries in the Torres Strait Protected Zone*. Australian Fisheries Service, Canberra. (Fisheries Paper No 85-9)

Altman, J.C. (1987), *The Economic Impact of Tourism on the Warmun (Turkey Creek) Community East Kimberley*, CRES, Australian National University, Canberra. (Working Paper No. 19, East Kimberley Impact Assessment Project)

Altman, J.C. (1988), *Aborigines Tourism and Development: The Northern Territory Experience*, Australian National University, Northern Australia Research Unit, Darwin.

Altman, J.C. (Chairman) (1989), *Review of the Aboriginal Arts and Crafts Industry: Report of the Review Committee*, Australian Government Publishing Service, Canberra.

Arthur, W.S. (with assistance from Victor McGrath) (1990), *Torres Strait Development Study, 1989*, Australian Institute of Aboriginal Studies, Canberra.

Babbage, R. (1990), *The Strategic Significance of Torres Strait*, Strategic and Defence Studies Centre, Research School of Pacific Studies, Australian National University, Canberra.

Beckett, J. (1987), *The Torres Strait Islanders: Custom and Colonialism,*. Cambridge University Press, Melbourne.

Cousins, D. and Nieuwenhuysen, J.P. (1984), *Aboriginals and the Mining Industry: Case Studies in North Australian Experience*, George Allen and Unwin, Sydney.

Cousins, D. (1985), Aboriginal employment in the mining industry, In P Loveday and D Wade-Marshall, (eds), *Economy and People in the North*, Australian National University, North Australian Research Unit, Darwin, 178-193.

Department of Primary Industry and Energy (1988), Unpublished information from the Commonwealth Department of Primary Industries and Energy, Canberra.

Duncan, H. (1974), *Socio-Economic Conditions in the Torres Strait: A Survey of Four Reserve Islands*. Department of Economics, Research School of Pacific Studies, Australian National University, Canberra. (Torres Strait Islanders, Vol. 1)

Duncan, H. (1975), 'Life in the Torres Strait: food? you buy it in a store...', *New Guinea and Australia, the Pacific and South-East Asia*, January, 22-32.

Fisk, E.K. (1974), *Policy Options for the Torres Strait*. Department of Economics, Research School of Pacific Studies, Australian National University, Canberra. (Torres Strait Islanders, Vol. VI)

Horwath and Horwath Services (1989), *Tourism Development Opportunities Study for the Torres Strait Islands*, Horwath and Horwath Services, Brisbane.

Lea, J., Stanley, O., and Phibbs, P.J. (1990), *Torres Strait Regional Development Plan 1990-95*, Department of Urban and Regional Planning, University of Sydney, Sydney.

Memon, P.A. and Cullen, R. (1990), New Zealand fishery policies and Maori. unpublished paper presented at the New Zealand Association of Economists 1990 Sesquicentennial Conference, Auckland, August 1990.

O'Faircheallaigh, C. (1985), 'Mining as a source of employment in the Northern Territory', In D Wade-Marshall and P Loveday, (eds.), *Employment and Unemployment*, Australian National University, North Australia Research Unit, Darwin, 50-65.

O'Rourke, D. (Chairman) (1988), *Report Of the Interdepartmental Committee on the Torres Strait Islands*, Department of Aboriginal Affairs, Canberra.

Pearce, D., Markandya, A., and Barbier E.B. (1989), *Blueprint for a Green Economy*, Earthscan Publications, London.

Treadgold, ML, (1974), *The Economy of the Torres Strait Area: a social accounting study*. Department of Economics, Research School of Pacific Studies, Australian National University, Canberra. (Torres Strait Islanders, Vol. II)

Self-Management and the Bureaucracy: The Example of Thursday Island

Sandra J Kehoe-Forutan
Gutteridge Haskins & Davey

Abstract

Self-management has brought enormous change to the Torres Strait, including somewhat paradoxically, an influx or expansion of Government agencies. New departments are replacing old structures and other are paying attention to the region for the first time. Thursday Island, the main administrative centre in the Torres Strait Islands, not only hosts these departments but others as well that are not the norm within self-managed indigenous communities in Queensland. This is because Thursday Island, and the Torres Strait Islands as a whole are in the unique position of being located near Australia's only international border. Consequently, Thursday Island hosts Commonwealth departments such as Immigration, Customs and the only outpost of Foreign Affairs located within Australia's territory.

The increase in the bureaucracy on Thursday Island complicates an already extraordinary administrative set-up. It also exacerbates many of the severe problems found on the Island such as housing and water shortages. The growth in the bureaucracy on Thursday Island is not lessening as more Government presence is required to deal with the evolving issues and conflicts arising in the Torres Strait, many at an international level. This, combined with a refusal by State and Commonwealth Governments to recognise the need to locate on Horn Island and thus decrease their impact on an overcrowded Thursday Island, frustrates the residents of this Island, leads to anti-public servant sentiments, which in turn, modifies any successful articulation between the two societies, Islander and European.

A large amount of the research that has occurred in the Torres Strait has concentrated on what is termed the Outer Islands – those islands that were traditionally inhabited (permanently or semi-permanently) and continue to be so and today are administered under the *Community Services (Torres Strait) Act*. In addition to the Outer Islands there is another group of islands in the Torres Strait referred to as the Prince of Wales group. These islands, Thursday, Horn, Hammond, Friday, Goode and Wednesday, amongst others, are found in close proximity to Prince of Wales Island. However, while Hammond Island is located only one kilometre from Thursday Island, its historical circumstances and administrative and economic status require that it be classified as an Outer Island.

Previously indigenous reserves tightly administered by the Queensland Government, the Outer Islands have achieved a measure of self-management with the land being transferred to indigenous communal control by Deeds of Grant in Trust (DOGIT). The inhabited islands in the Prince of Wales group, namely Thursday Island, Horn and Prince of Wales Islands, fall under the administration of the Torres Shire in which the conventional Australian land system prevails and there is an absence of traditional indigenous custom and decision-making, albeit this may be changing as Islanders reassert their identity over these islands. Originally inhabited by Torres Strait Islanders before European contact, Islanders were either forcibly removed from islands such as Prince of Wales Island and/or had to modify their usage of such islands as Horn and Friday due to the proximity of Europeans. Thursday Island known as T.I., was established in 1876 as the main administrative centre for the region. It continues in this role.

Local government processes in the Outer Islands are co-ordinated by the Island Co-ordinating Council (or ICC) which is based on Thursday Island. The Torres Strait is also administered from this Island. Even though the Torres Strait encompasses a large area (the entire Torres Strait region south to 11 degrees latitude), in actuality it is responsible for a relatively small jurisdiction: only a small area of Cape York as the Cape York communities are all former indigenous reserves that have acquired a self-managed status; the previously named inhabited islands in the Prince of Wales group; and, other uninhabited islands that are not the responsibility of the Federal or State Governments or the individual self-managed indigenous councils.

Located on Thursday Island is the community of Tamwoy which, in actuality, is a combination of four suburb areas. The community of Tamwoy has an anomalous status. It is one of the few remaining indigenous reserves in Queensland and therefore is administered by the State department responsible for indigenous affairs, currently known as the Department of Family Services and Aboriginal and Islander Affairs, but its local government functions are performed by the Torres Strait Council. Tamwoy is represented on the ICC statutorily and on the Torres Shire Council by arrangement. In fact, it did not become a member of the ICC until two years after self-management was initiated and its Council was not legalised until its incorporation in 1988. This Council, the Tamwoy Development Association, primarily administers housing that is being transferred to its control by the State.

Out of a population of approximately 2 600 (1986 Census) on Thursday Island, 70% are classified as Torres Strait Islanders. The number of Torres Strait Islanders residing on T.I. comprises the largest Islander community in the Torres Strait. However, Islanders have only been permitted to live there since World War II. The centre for a marine boom in the last century which eventually became the base for Government administration, Thursday Island represents all that Islanders despise after a lifetime of paternalistic control. In addition to such adverse feelings towards this urban centre, T.I. has been perceived to contain an elastic community of temporary residents serving as a staging post for the urbanisation of Islanders before they enter the outside world. These perceptions, combined with economic decline, welfare dependency and the existence of numerous unco-ordinated Government agencies at all levels on T.I. has resulted in the inefficient administration and neglect of this Island from all sectors. Compounded with the problems of distance, isolation and physical constraints, T.I. was considered a stagnant urban centre with no stable identifiable community due to a huge migration outflow.

T.I. is the "melting pot" of the various Islander communities and of the diverse external cultures introduced since colonisation – Europeans, South Pacific Islanders, Papua New Guineans and Asians being the most prevalent. Factionalism is perpetuated here between the various groups. Severe problems exist on the Island such as water, land and housing shortages, overcrowding, high unemployment, a lack of infrastructure, a high cost of living and overall poor service delivery.

The changes associated with self-management have had notable multiplier effects upon Thursday Island because it is the administrative centre. Self-management has created renewed interest in the Torres Strait from all sectors, private and public, and somewhat paradoxically, but consistent with experience elsewhere, has led to the expansion of some government agencies and the arrival of others. More public servants are required to reside on T.I. and an upgrading of services such as education is increasing the number of European teachers. Officials travel in and out for various lengths of time and tourism is the new trend, increasing the demand for hotel rooms and related facilities. Consequently, private interests are rapidly expanding to meet increased or new demands, generating a further round of income and employment multipliers. Unfortunately few employment opportunities are trickling down to, or being taken advantage of, by the Torres Strait Islanders.

The Torres Strait is a polyglot of agencies at all levels of Government, all with a multitude of functions and responsibilities. Thursday Island hosts those departments that are the norm within self-managed indigenous communities in Queensland, and local government authorities or organisations such as the Torres Shire Council, the ICC, the Tamwoy Development Association and the Port Kennedy Association formed to protect the interests of those residing outside the Tamwoy area on Thursday Island. In addition, Thursday Island is in the unique position of being located near Australia's only international border. Consequently it hosts Commonwealth departments such as Immigration, Customs and the only outpost of Foreign Affairs located within Australia's territory.

In 1987 fifteen Commonwealth departments and agencies were operating on Thursday Island. In addition the State maintained eleven departments. This is in contrast to the eight Commonwealth departments and one State department located there in 1979. There are also many other Government departments not physically located on Thursday Island whose personnel visit for varying lengths of time.

To complicate matters, numerous formal and informal organisations have been formed adding to an already long list of public and private agencies involved in Torres Strait affairs. As a result, the roles of most of these organisations either overlap or lack focus and infringe upon each other's ability to achieve concessions and goals.

Since 1987 the government presence has continued to increase, the most notable being the Federal Department of Defence. This is due to the re-emergence of the Torres Strait strategic importance. In addition, one of the results of the 1988 independence movement was a concerted government effort to direct resources to the region in an attempt to alleviate the severity of many of the problems focussed upon by the Islanders as grievances promoting the need for political action. This has consisted of, amongst other things, the placement of more staff in departments based on T.I., secondments of staff to the ICC, and funding for private consultants.

The results of a heavy bureaucracy on T.I. have been duplication; a lack of co-ordination between many agencies, some within the same level of Government; competition; and the creation of inaccessibility and confusion for the Islanders. For example, education initiatives come from the State Department of Education, the Commonwealth Department of Education and the Commonwealth Employment Service. Many could not comprehend how the State and Commonwealth Departments of Education could be abundantly staffed whereas the Department of Social Security had two overworked officers and the Commonwealth Employment Service was in a similar predicament, both unable to meet the prevalent social needs of the Islander population. Torres Strait Islanders are the first to recognise the value of education but the majority felt that the State Department of Education was doing an excellent job whereas an agency like the Commonwealth Employment Service was not being provided with the necessary resources needed for the chronic unemployment in the region and the large geographical area under its jurisdiction encompassing the Torres Strait Islands and the Northern Peninsula Area.

It has been suggested that an increase in the public service increases the dependency upon welfare services. It has yet to be seen as to whether this is the case on Thursday Island and within the Torres Strait.

While a large bureaucratic sector on T.I. has created difficulties, to the clients such an increase in agencies, even if poorly endowed with resources, is a great improvement on the former State system which presented them with only one agency to contend with, but which inadequately provided services in some sectors, and in others, none at all. Torres Strait Islanders viewed the entire process as the first step towards achieving the same level of services available to the rest of Australia.

The bureaucracy in the Torres Strait urgently requires some type of localised co-ordination and/or management structure. This problem is not exclusive to the Torres Strait region. An attempt at the local level at liaison and co-ordination between agencies is occurring, although somewhat modestly. The Commonwealth and the State Government Departments responsible for indigenous affairs, attempting to overcome previous rivalries, started to communicate and co-operate for the first time. The ICC and the Torres Shire Council are now at least aware of each others responsibilities, not necessarily an assumption that could have been made only a few years ago and the communication lines are open between the two entities. Although these two organisations have many interests in common there is no formal or informal representation on each other's Councils nor are there any day-to-day administrative links between the two.

Tamwoy since its inception in the 1950s has not been considered worthy of attention by either Government agencies nor Islanders themselves. The Outer Islanders saw Tamwoy as being better off because it had the amenities and services of Thursday Island. Government saw Tamwoy as an unidentifiable, unstable community structure. It was associated with being non-Islander due to its location on Thursday Island. The mix of population on this Island reduces a sense of Islander identity and promotes factionalism even amongst Islanders themselves. Tamwoy's lack of political experience and its continued dominance by administrators, even in local matters, decreased its competitiveness with the Outer Island Councils for funds, services and resources.

Research by this author suggests the existence of a strong Islander community structure on Thursday Island. The refusal to acknowledge that a legitimate Islander community existed on T.I. was most inappropriate for the substantial number who had been born and raised on this Island without ever residing on an Outer Island. The neglect of Tamwoy, caught in a policy vacuum, continues into the self-management period. It is not undergoing the changes associated with DOGIT or self-management. Its leaders have had to struggle to gain the responsibility of landlord over a small portion of Tamwoy's housing stock.

Self-management has lead to a change in a perceptions regarding T.I., as its value as a point of articulation between the two societies, European and Islander, is recognised. The Islander community, many identifying with Thursday Island as "home", is slowly asserting its presence and consequently negotiations are occurring with the State in an attempt to normalise Tamwoy's status.

Only 315 hectares in area Thursday Island can be described as a small island. T.I. labours under severe physical as well as economic constraints in developing services and infrastructure. This is aggravated by the fact that approximately 89% of the Island is reserved for Commonwealth purposes (primarily defence), for local government water supply purposes, ecclesiastical purposes and for Queensland administrative, educational, residential and indigenous reserves.

While tourism and the increase of public servants injects new life into T.I.'s economy resulting in new investment and a face lift to the town's facade, the competition for land uses is also increasing.

The critical accommodation shortage on Thursday Island is not a new problem. Since the welfare system was introduced in the region in the 1970s, government departments have either been buying homes or land for homes or offices. Consequently, previous tenants have been displaced, less homes and land are available for local residents and the high prices paid by the public sector have escalated land and housing values on the Island. This trend has increased since the self-management process began.

A prevalence of sub-standard housing severe overcrowding, high density rates, high rental charges, and the related social problems resulting from the poor housing conditions has manifested itself into a genuine resentment of the public sector which continues to build "good" housing and buy more land.

This paper cannot adequately describe the conditions many Torres Strait Islanders were and continue to live under – many of a primitive nature and not of their own making. Slum landlords are common and Tamwoy's housing stock has been neglected for the past thirty-five years. While the Shire Council is trying to regulate sub-standard housing and the State Government is attempting to rectify the housing problems in Tamwoy, elsewhere on T.I., landlords prefer to knock down dwellings and sell off the land at a high price, usually to a government department. Reliable housing stock for Torres Strait Islanders on Thursday Island, as a whole, is decreasing.

Aggravating the situation is a failure of government to recognise its contribution to the critical housing problem on the Island and its refusal to utilise Horn Island as an alternative. Horn Island is accepted by all sectors as a potential suburb to Thursday Island easing the numerous pressures on this main administrative centre. When the Department of Defence decided to locate housing and a depot on T.I., another Commonwealth Department, the Department of Aboriginal Affairs (now ATSIC), strongly advised against it. The Defence Department's position was that military facilities needed to be located on T.I. to be close to administrative services and that personnel would "settle better" on the Island (*Torres News*, 01/12/1987:40). Residents of Horn and Thursday Islands criticised the Defence Department for displacing tenants with a depot that could have been located on vacant Commonwealth land: for building on T.I. where there is a water supply problem; for ignoring the feelings of the locals; for insensitivity by not assisting with problems on T.I. by locating on Horn Island; and, for locating military facilities in the centre of town (*Torres News*, 01/12/1987, (letters to the Editor), 05/02/1988, 10-16/11/1989).

Residents of Thursday Island question why they should have to move to Horn Island which lacks infrastructure and facilities when new public servants are easily able to live on Thursday Island. The Torres Shire, with a limited rateable base, does not have the resources to provide the necessary services on Horn Island. It was hoped that the State and Federal Governments would initiate the basic infrastructural requirements by locating there. Their refusal to do so, combined with the increase in the public sector in the Torres Strait which will continue as issues become more complex, many at an international level, and more officials, consultants and scientists are required, will only exacerbate the smouldering anti-European sentiments developing on Thursday Island. This in turn, will modify any successful articulation between the two societies, Islander and European, negating the original purpose of a public sector presence.

Internationalism, Indigenous Peoples and Sustainable Development

Peter Jull, North Australia Research Unit
Australian National University

Abstract

The issue of sustainable development and related cultural, social and polictical aspiration for indigenous people has had a tremendous impact on national governments and international politics in some parts of the world. The indigenous peoples of the north circumpolar world such as Inuit, whose lifestyles, marine orientation and socio-political circumstances are like the peoples of Torres Strait, have been particularly successful in leading a wave of reform. There may be valuable lessons in this experience for Torres Strait Islanders, and it may be desirable to begin active "networking" internationally in order to obtain greater local and regional benefits here at home.

Introduction

The purpose of this paper is to consider some of the practicalities of politics, especially minority politics, in the new age of global environmental awareness. Although it is evident that the structure of politics has changed in recent decades and now provides new possibilities for groups hitherto powerless, nobody should assume as a corollary that the political power concentrated in the governments of national states is diminishing. Nevertheless, there are substantial opportunities for even small and remote groups like the Torres Strait Islanders.

Soon after this conference ends another begins in Perth, Australia, bringing together the world's governments and major non-government organisations (NGOs) concerned with the environment. This is the IUCN general assembly – the International Union for the Conservation of Nature and Natural Resources. Many of their discussions will have particular importance for indigenous peoples like the Torres Strait Islanders. Some of the indigenous representatives from abroad will be particularly eager to talk with Islanders and Aboriginals in Australia about their experience in coping with European settlement and economic development. For instance, Inuit (the Eskimos) will be represented at Perth by their internal organisation, the Inuit Circumpolar Conference. They hope to hear from Islanders about shipping in an important navigation passage and about the struggle to establish greater local control over economic, social and political decisions in their islands. The reason for this interest is the fact that Inuit have problems very much like those of Torres Strait Islanders.

In the Northwest Passage along the coasts of Labrador, Quebec, Greenland, the Northwest Territories and Alaska, Inuit have learned that international cooperation to discuss similar problems and to share the benefits of each other's experience is an essential part of progress with problems at home. International cooperation requires particular initiative because governments and NGOs often forget to include indigenous peoples. For instance, unless there is a last-minute change of plans, Islanders will not be involved in the Perth IUCN conference.

It may not seem obvious that remote communities with many problems and little status in the laws and political frameworks of their home countries should start travelling the world. But the resolution of many problems, especially ones of minority rights and environmental quality, have become essentially international. A reflection of this fact was the recent work of the Constitutional Commission: no issue was more controversial or time-consuming than the resistance by the States to the Federal Government's role in human rights and environment as per the External Affairs Power in the Constitution (Constitution Commission 1988). In earlier times, (eg., when the Constitution was written), it may have been inconceivable that the trees one chopped down locally or the way one's public bodies treated non-European labour and indigenous people would be the business of other countries or association of countries. Yet the campaign against slavery in the 19th Century and the concern by British governments about treatment in Australia of indigenous peoples showed even then that times were changing (Reynolds 1988). Those public figures who play to xenophobic and isolationist sentiment in Australia today and deny the relevance of the world community are out of step and out of date.

International linkages are changing and developing very quickly. The recent collapse of the governments in the eastern half of Europe was caused as much by their human rights records as economic and environmental failures. In the renewed 'Helsinki process' (the Conference on Security and Cooperation in Europe) it is now planned that Europe plus Canada, the USA and USSR establish new standards for human rights, especially minority rights, and new standards for investigation of violations in each other's countries. Another source of new ideas is the publicity surrounding the 500th anniversary of the first voyage of Columbus to the New World in 1492. This is now turning into a world-wide scrutiny of European treatment of non-European peoples. Australia will be as much under scrutiny as the Americas themselves. That means that both State and Federal Government policies in Australia will be under examination. As an advanced European-peopled country, Australia will be judged by the same standards as any other.

Positive Possibilities: the Northern Hemisphere Case

If negative sanctions await non-performance by Australia in its policies towards Torres Strait Islanders and Aboriginals, internationalism is much more than a negative story. Used creatively, it can be helpful for indigenous peoples, governments, researchers and research institutions alike. Inuit regions of North America provide a case study especially useful for comparison with the Torres Strait. (For more detail relevant here on contemporary Inuit and their background see Usher *et al.*1987, Jull 1987, and Damas 1984).

Today's Inuit are descendants of a whale-hunting society which spread across the arctic from the Bering Sea around 800 AD. There were earlier Inuit cultures in the same regions, but they were now superseded by the new migrants. Archeologists suggest that a dramatic change of population took place, while anthropologists suggest continuity and an intermingling of peoples. This new wave of so-called Thule Eskimos moved quickly to occupy the coasts of the Chukotka Peninsula of what is now the USSR, and west and north coasts of Alaska, the coasts and islands of northern and north-eastern Canada, and the vast ice-covered island of Greensland.

In Greenland these Inuit first met Europeans – the famous Vikings, those strong and brave heroes of the White Man's history who continue to fascinate generations of school-children, movie-makers and publishers of coffee-table books. Archeology has shown that when the two peoples met in Greenland, the Inuit picked up all the ideas they could from the Vikings, but the Vikings seem to have learned little or nothing, except perhaps the striking designs seen today on the sweaters of those Viking descendants in Iceland. The Vikings could have learned much, however, because Inuit had many skills and much knowledge for coping with food needs, shelter and warmth, all of these being problems which eventually overwhelmed the Vikings in Greenland. The exact mix of causes for the Viking demise is still a subject of interest in north-western Europe, but it has become clear that the Viking refusal to adapt was a root cause. Inuit, on the other hand, soon had to abandon their whale-hunting life in the face of drastic changes in climate, the so-called Little Ice Age. They had to develop new ways of coping with local circumstances and opportunities, and they produced the various regional variations which modern anthropologists study as if they were separate cultures. They were, however, one widespread culture forced back on local ingenuity to survive.

In the modern age Inuit live, for the most part, in small isolated villages. They have been brought together from their scattered hunting camps by trading posts, schools, medical stations and other facilities – and by enforced government resettlement policies. Until the post-war era they were treated like unfortunate and rather simple people, with white people making decisions for them. In time they revolted. This revolt was not in the form of riot or insurrection, but rather in peaceful demands and protest. The real violence was revealed in the statistics of family and community breakdown. As late as 1970 it was possible say that while Inuit had access to a variety of unevenly spread conveniences of modern life, the rapid pace of social change, the destruction of traditional society by relocation, and concentration in confusing new villages with other Inuit they did not know, with a new language and way of life imposed by young whites, more than compensated for any benefits of modern technology.

The push by young Inuit in Greenland for more independence from Danish administration and in Alaska for land rights marked a new era from 1970. Canadian Inuit by this time were reacting to the enforced resettlement policies of the government. This was followed by crews looking for minerals, oil and gas, and planning the transportation of these (eg., by drilling and shipping in dangerous ice-filled waters). These activities were damaging to habitat and disruptive of wildlife essential to Inuit diet. Now a better picture of the post-1917 changes in Soviet policy for northern indigenous peoples, including Inuit, is also available. In 1990, these 26 Soviet indigenous peoples formed an association to press for autonomy, urgent environmental protection and rehabilitation, and self-government (Dahl *et al.*, 1990).

In 1973 in Copenhagen's Christiansborg Palace the Greenland Inuit held a meeting with Sami (the Lapps) from Norway, Sweden and Finland, and with Inuit, Indians and Metis (mixed-blood descendants of Indians) from northern Canada. For several days the participants shared the frustrations and comic episodes of their respective struggles for more control of their lives – lives then dominated by Europeans. Until that moment most of these people had felt themselves isolated and overwhelmed by the great power of the southern capital cities which decided their futures. They now discovered that they had counterparts fighting virtually the same battles for the same reasons abroad. The meeting led more or less directly to two more at which important new movements were formed.

In 1975 on a rainy autumn hillside of Vancouver Island off Canada's Pacific coast, a Nootka Indian reserve saw indigenous peoples from many continents, including Australia, meet to form the World Council of Indigenous Peoples (WCIP). There were many problems at that meeting. Some Indians from Latin America feared for their lives if their governments at home found out their names. There were translation problems and other misunderstandings. But the week-long meeting was a tremendous success. The theme which emerged quickly was the absolute dependence on traditional lands and waters of these people – on the bounty of wildlife, fish and birds. This close identification with the living environment made them different from the conquering and governing European cultures, and made them all very similar to each other in their needs. Since that time the WCIP has held many meetings around the world and has been effective in working through international political forums like the United Nations to promote indigenous rights to lands and seas, sea creatures and land creatures, and the traditional livelihoods based on these. It is likely that this work will culminate in a major international agreement on indigenous rights; it has already led to the limited but useful new International Labour Organisation (ILO) convention 169 which replaces an earlier convention on indigenous peoples.

In 1977 another idea developed from the Copenhagen meeting was taken up by the Inuit leader of the Alaskan North Slope at Barrow on the shore of the Beaufort Sea. There the world's great oil companies were developing Prudhoe Bay. Eben Hopson, the Inuit leaders in question, had invited the Inuit from Greenland and Canada to meet to discuss the future. He welcomed them with a few brief words, saying that their two purposes must be to develop strong Inuit-controlled governments in their different regions and to protect an environment essential for Inuit life, especially the marine environment. He was certainly right: it was oil from that Inuit shore which was poured out into the North Pacific in 1989 when an Exxon tanker ran aground, devastating wildlife and habitat on a hitherto unimagined scale.

Eben Hopson had already created the North Slope Borough. This is a government for a huge region of 88,000 square miles. By skilful use of the legal system and sheer determination the Inuit created a strong government which built good houses for all, schools and community centres, and retrained the whole population. The formerly poor and neglected North Slope was brought the best modern facilities of all kinds. The few thousand Inuit living in this region experienced a total change in their lives, as well as creation of many jobs and better kinds of jobs. They had already been faced with a pace of social change which was alarming and they were making the best of it with the revenues they were able to raise from the oil industry. They have also used their growing experience and confidence to impose on State, national and international authorities their own management plan for the coastal zone on-shore and off-shore, their own management schemes for the sea mammals most important to them – whales and walrus – and a variety of other measures supportive of their continuing dependence on the living environment of land and sea.

In 1980, meeting in Nuuk (formerly Godthab), the capital of the new 'home rule' Greenland, the Inuit Circumpolar Conference adopted a charter and established a secretariat. The feeling of pride among the Inuit Greenlanders in their new independence was tremendous, with the cabinet ministers and premier attending most sessions. In 1983 further general assesmblies were held in Canada and Alaska. Returning to Greenland in July 1989 for their assembly in Sisimiut (formerly Holsteinborg), the organisation had come a long way. For one thing, this meeting welcomed the first Soviet participation, a goal which all the member Inuit and the national governments (USA, Canada, Denmark) had worked hard to achieve. But much else was changing.

In the early years the organisation had the enthusiastic support of many individuals and leaders across the Inuit north. But by 1989 they were in positions of power – not only older and wiser, but more likely to draft a tactically subtle resolution than a merely angry or enthusiastic one. No longer merely demanding to have Inuit views heard, they were now directing important offices themselves or were engaged in serious negotiations to achieve major economic and political ends. Perhaps most striking was the fact that senior government representatives from the USSR, USA, Canada and Denmark spoke at Sisimiut in a sort of international 'accountability session', as did the heads of government in the Chukotka Autonomous Region, a representative of the Govenor of Alaska, and the premiers of the Northwest Territories and of Greenland. All these men and women explained how they were implementing the resolutions and policies advocated by the Inuit.

Two of those policy initiatives deserve mention. One was a comprehensive 'arctic policy', nothing less than a 150-page compendium of policy guidelines for development, conservation, social and cultural programs, and political affairs. Inuit, who had suffered so much from governments which were insensitive or uncomprehending, wanted to sit down with them and explain what their policies should be, with this document as a starting-point. (Canada has already accepted the principle of consultation with Inuit on most policy matters, and in Greenland the Inuit government has replaced the former Danish Ministry for Greenland.)

Of course, the most important aim remained the creation or taking charge of governments in their regions by Inuit themselves. This is being achieved. Any day now the Government of Canada is expected to announce a timetable for creation of Nunavut, a new territorial government covering one-sixth of Canada with most of the powers of an Australian State in an area where about 85% of the population are Inuit. On October 19, 1990, the Northwest Territories 'premier' and head of the Inuit land claims office sent a joint letter to the Prime Minister of Canada laying out their mutually agreed plan for bringing the new Territory into being - that is, carving out the eastern half of the existing NWT and reconstituting it as Nunavut. The Inuit language will be a language of teaching and official use in Nunavut alongside English, while the Nunavut land claims settlement, now agreed in principle, will give Inuit wide new powers and statutory bodies to determine future development and economic planning and environmental management on-shore and off-shore. Issues of sea mammals, protection of the seas from vessel traffic, especially tankers, and the hazards of navigation in ice-strewn waters (like the famous reefs of Torres Strait) have been major elements in all the Inuit land claims and policitical development work (Jull 1987). In October, 1979, for instance, the Canadian Prime Minister responded to Inuit protests about extending the powers of Provinces into arctic seas by promising in a press statement that indigenous peoples interests would not be forgotten (but in the event the provincial role was refused by the next Prime Minister in any case). Torres Strait Islanders preparing proposals for their regional future may well find the Canadian Inuit experience of interest because Canada is so similar in law and politics to Australia, and the Inuit situation and recent political experience is so similar to that of Islanders.

Inuit in the Province of Quebec have also developed proposals for a strong new regional government for their 15 communities totalling about 6000 people scattered along the shores of Ungava Bay, Hudson Strait and Hudson Bay. Their 1975 land claims settlement included a regional government as well as affiliated local governments in each community. Numerous special authorities were also established. But now Inuit have found that too many separate bodies have been set up under the claims settlement, and that this wastes time and spreads the leadership too thinly. Today they are seeking agreement with Quebec on the details of a streamlined and unified politico-administrative system for the region, while preserving local community governments as well. It seems likely that they will achieve this. They have also secured many benefits over and above the 1975 claims settlement from both the Canadian and Quebec governments because although those governments signed the thick agreement, bureaucracies were not adequately adjusted or organised to cope. As a result, Inuit have found themselves spending their claims compensation fund interest on high-powered teams negotiating fulfilment of the matters agreed in 1975 rather than on economic development projects as intended.

The second Inuit Circumpolar Conference initiative of interest is the Inuit Regional Conservation Strategy (IRCS). The 'region' in question is not a small one; it is the entire north of North America from the Bering Strait to the Greenland Sea. Following proclamation of the World Conservation Strategy in 1980, an IUCN document and the origin of the 'sustainable development' ethic which has been further elaborated in the Brundtland Report, the Inuit developed a research program to design community-based ecologically sustainable economic development. This work has been progressing under a multi-national team with headquarters in Ottawa. Marine species and marine management are the central issues in this work. As well, the Inuit team are represented on a special working group with Canadian federal departments and the Yukon and Northwest Territories governments, exchanging information and coordinating work to prevent overlap in achieving 'sustainable development' plans for the northern 40% of Canada's land area. That is the area where indigenous wildlife harvesting is the main land and water use.

It may be useful to note two other initiatives of Inuit in international matters. For many years Canada has been pained by the refusal of the USA and other countries to accept that the straits making up the Northwest Passage are internal Canadian waters. This issue has been a major irritant in Canada-US relations, as well as a source of anger to most Canadians. When the Americans sent an oil supertanker through the Passage in 1970, the Canadian government passed the Arctic Waters Pollution Prevention Act as a demonstration of its determined control of arctic seas. Then in 1985 the Americans sent through a Coast Guard icebreaker, the *Polar Sea*, without seeking Canadian permission. The Canadian government had difficulty responding to public outrage at first but later made strong statements of sovereign control. Inuit leaders loudly supported the Canadian government because they wanted the strongest possible anti-pollution standards enforced. Whereas Canadian officials had earlier been mistrustful of Inuit claims as quasi-separatist (which they never were), they now came to see the Inuit occupation of the arctic as the basis of national claims to the arctic seas in international law. After all, Inuit use the sea-ice for much of the year for camping, travel and hunting. The Nunavut 'land' claims settlement initialled recently between Inuit and the Federal Government applies to these marine areas as much as to the land (Indian and Northern Affairs Canada 1990).

Another major case of cooperation involved a Canadian project to liquify natural gas in the high arctic and ship it south to markets in special tankers. This Arctic Pilot Project (APP) was seen by Inuit as an attempt to 'pilot' a project not so much through ice-filled waters as past the objections of Inuit and environmentalists. The Inuit Circumpolar Conference set up an Ottawa office to fight the project, paid for in part by the Alaskan Inuit, and with the active participation of Greenland Inuit in the Canadian hearings. Inuit changed the nature of the whole exercise with their demonstration of the social and environmental aspects of the project. What had begun as a major threat to Inuit became a publicity exercise whereby Inuit achieved great publicity for their environmental knowledge vis-a-vis the supposed experts of the White Man's world. Ultimately the sponsors had to back down for a variety of reasons and the project was abandoned. However, few Inuit doubt that Canada will seek to ship oil sooner or later from the arctic. It was not suprising that at the Inuit international assembly in Sisimiut in 1989 the talk in the corridors was about the devastating lessons of the Exxon Alaska oil spill.

Within the Inuit region, then, scattered and isolated villages and camps are working together through regional and national organisations, as well as through the inter-national Inuit Circumpolar Conference, to achieve sound development and protect the environment. But the Inuit have taken their message farther afield. They have appeared before international forums like the United Nations to promote their environmental concerns and also to urge national governments and the world political community to adopt better, safer policies in respect of the arctic. For instance, Inuit have been extremely concerned about the military buildup, especially involving nuclear weapons, in their region. There may be a thaw in Cold War politics, but Cold War military machines are intact and continuing their cat and mouse manoeuvres above and below the ice of the arctic seas (although some very recent easing of tensions is significant (see Cox, 1990)). This month the Soviets tested a nuclear weapon in the arctic. Other issues like arctic haze and the buildup of dangerous elements in the Arctic Ocean from the Soviet rivers and the Gulf Stream which bring the industrial world's pollution right into the heart of the arctic ecosystem are no less important.

In May 1987 the Inuit international president, Mary Simon of Kuujjuaq, Quebec, visited the Polar Inuit in their communities at the north end of Greenland. The local people hunt polar bears for food and for the best warm clothing, and they wished to regain access to their ancient hunting grounds on the Canadian side of the Greenland-Canada border. That border was made without any reference to indigenous peoples' use. Also, the Polar Inuit had been moved from their ancient village site to make way for an American airbase in the 1950s, and have suffered many problems as a result, so they seek compensation. There were other issues, such as the disturbance to humans and wildlife of low-flying American military aircraft and the potential danagers of the airbase becoming a principal target for nuclear attack in war between the Superpowers. These problems well illustrate how even remote and supposedly humble communities may be enmeshed in matters which require resolution at the highest levels of national and international power politics. Canada is very touchy about its arctic sovereignty claims and, thus, accommodating Greensland Inuit hunters could become lost in a war of words among international lawyers. The American military with their highest-tech units engaged in preparing electronic defence or war had no grasp, we learned on that trip, of the views, feeling or needs of the Inuit.

But the Inuit have led an amazing breakthrough in this arctic zone of Cold War fears. Circumpolar cooperation was only a phrase, or a memory for those scientists involved in earlier international projects like the IGY, the International Geophysical Year of 1957-1959. Cooperation had never amounted to very much, although a sort of neutral sense of shared challenge accompanied the various explorations of the north polar region at the turn of the century. For Inuit, however, the term meant much more. Inuit had been arbitrarily divided by lines drawn on the map by white governments. In the Bering Strait the Alaskans had suddenly lost touch with their friends and kin on the Soviet side; the Alaskan Inuit who had moved into the Beaufort Sea coast of Canada after the Mackenzie Inuit had all but died out were cut off from relatives back home; and the Polar Inuit of Greenland were cut off from their traditional hunting areas in uninhabited Ellesmere Island in far northern Canada. For Inuit the emptiness of the White Man's national rhetoric was especially obvious. In recent years their attempts to meet together have often been met with suspicion by white governments. Canadian parliamentary committees inquire pointedly if Inuit internationalism is really an attempt at 'separatism', Canada's favourite fear fed by the French-Canadian nationalist movement in Quebec. Inuit reply that, No, they are only trying to join Canada as full citizens. (They could also point out that although Canada belongs to the British Commonwealth of Nations and to the Francophonie, the French-language commonwealth, nobody suggests that such historical and cultural ties are subversive).

An example of the achievement of goals is exemplified by the Inuit pressure on Canadian foreign policy. In 1985 a special committee of Parliament was set up to recommend foreign policy directions for Canada. The committee quickly found that the public had much to say and had much idealism about the need for an activist foreign policy rather than the careful cautious approach by the External Affairs department (Simard and Hockin 1986). Inuit and their advisers bombarded the committee with briefs and proposals in support of arctic cooperation, especially a cooperation based on social, economic and environmental realities rather than on speculative fears and fantasies relating to war and transportation technologies, sovereignty theories, macro-economic futures, etc. When the committee finally issued its report, there was a chapter on the north, and while the old hypothetical stuff of 'northern policy' was still there, it was preceded by strong recommendations for a people-centred approach, with many direct quotations from the Inuit briefs. This landmark report set off a chain reaction of conferences, discussions, publications, etc., and finally a report prepared by a special working group of the Canadian Institute of International Affairs responded to the committee's call with a full study of Canada's domestic and foreign northern policies with Inuit at the centre of the recommedations (Robertson 1988). This working group was made up of national authorities on many northern subjects and on constitutional, foreign and defence policy. The several parties in Parliament took the report to heart and the government even recommended it, in speeches by the foreign minister, as the document for the times on northern issues.

The Inuit had no end of trouble with funding their international work. The Greenland government and the Alaska North Slope Borough gave generously year after year, but the Canadians could not find money. The Canadian office and staff lived hand to mouth just to keep the office open, and yet managed a vigorous, high-profile campaign to pursue their main interests – regional Inuit self-government and environmental policy. By ingenuity and sheer doggedness the Canadian office kept things going, and has since become the headquarters with the election in 1986 of Mary Simon as international Inuit president. I have been told in the last few days (November, 1990) that senior United Nations officials have divulged that the Inuit Circumpolar Conference will be recommended for the Nobel Peace Prize.

Of course, influence in political affairs is very much a matter of images. Inuit with few dollars and much ingenuity have been successful both in their Canadian, Alaskan and Greenlandic work and in their international work. They certainly have not solved all their problems. After the world toasted Mary Simon as president at the Sisimiut 1989 assembly, her luggage full of gifts was impounded by the Canadian authorities on the grounds that traditional Inuit resources of walrus ivory and other materials were illegal. Taking traditional foods across international frontiers among arctic regions is a three-yearly headache for the assembly organisers; it seems that no matter how much prior special approval is gained, some dull uniformed agent of the state wrecks it all at the last moment when the planes land with the delegates, cultural performers, gifts and food.

In 1889 and 1990, Mary Simon and the Inuit Circumpolar Conference have arranged meetings among the world's circumpolar peoples and governments to address arctic environmental issues. Ms Simon has been appointed to various advisory bodies on defence and environment because of her high profile. In 1989 she won a United Nations award for leadership on environmental issues. She will also head the Inuit delegation at Perth for the IUCN meetings. In the northern hemisphere the Inuit have put the issue of ocean management, and their social and cultural dependence on the ocean, at the centre of national and international politics. They have also forced the pace in circumpolar cooperation among reluctant governments, only one of which – Norway, thanks to foreign minister Stoltenberg – was really very interested. To some extent the national governments felt forced to keep an eye on the Inuit and so they became involved. In Scandinavia, the Nordic Sami Council uniting Sami groups in Norway, Sweden and Finland has the support of the Nordic Council of governments itself, and has observer status at their meetings.

To conclude the Inuit story here, Inuit, through ingenuity more than any politial power, have rewritten the north circumpolar agenda from one of war and wariness to socio-economic and environmental cooperation. This development would have been unlikely had the usual officials in various governments been left to their own devices. Inuit talked up many important issues, not only their own narrow self-centred agenda, so that it was easier to win wide support for their approach. They also tailored their work to the realistic political facts of the region and of its member governments, playing to governmental enthusiams and taking advantage of any public forum possible to push their case. The presidents of the USA and USSR were improbably early in embracing this approach, and that made the dour Canadians and circumspect Nordics join the bandwagon with more enthusiam. And the newest body, Northern Forum, currently borrowing a desk in the Alaska governor's office, is made up of sub-national governments in the circumpolar area (eg, Greenland, Alaska, Norwegian northern counties, Chukotka Autonomous Region), in a direct result of Inuit prodding and example.

Australian Practicalities

In Copenhagen's National Museum there is a fine collection of Stone Age and Bronze Age artifacts. The last stone axes are beautiful, graceful, polished and most artistically designed. They were made under the threat of incoming bronze weapons and tools which might be homely but which were taking over the market. It has seemed to me sometimes listening to debates and reading papers by 'experts' on indigenous policy that some Australian thinking is similarly stuck in the late Stone Age. Much debate revolves around existing programs and bureaucratic habits, but the need is for a move from administrative to political solutions. The Torres Strait Islanders are not a community of welfare cases needing better service delivery; they are a people whose culture, society, bonds to a unique marine ecosystem and right to make decisions for themselves as a distinct community crying out for recognition and accommodation.

Today the Torres Strait Islanders are seeking to protect their reefs, islands and seas and the rich resources of living creatures within these. They are trying to find forms of economic development which can be managed locally and within the region, rather than be dependent on faraway decisions. They are seeking to obtain legal recognition of their ownership and related rights in their islands. And they are searching for a workable regional government which can manage their affairs and negotiate with senior governments and outside interests effectively. These are the same issues which occupy the minds of indigenous peoples all over the world. Furthermore, the Torres Strait Islanders are offering a moderate agenda and peaceful means for resolving these issues, unlike some liberation movements elsewhere. It should be easy for governments in Australia to accommodate them.

Meanwhile, other governments of the 'club' of wealthy industrial countries – the OECD (Organisation for Economic Cooperation and Development) – have accepted the autonomy within existing national states and elected decision-making bodies are necessary for the progress of indigenous peoples. Those countries have adopted such policies not because they are nice people but because they found that only such a policy could solve the problems experienced by the indigenous peoples. Lack of power has been identified through trial and error as the root of those problems.

It would be useful for Torres Strait Islanders to know more about the experience of other indigenous peoples with marine issues and with regional self-government. Governments always find it easier to discuss proposals which have precedents. The groups most relevant for Islander negotiating may be those who, like Islanders, live within an advanced industrial country. North Norway, the Faroe Islands, Shetland, Greenland, the Inuit north in Canada and Alaska, and the Indian coast of Canada's Pacific region are all good examples. The best way to learn from such cases is to send delegations for first-hand contact (and to include someone with research skills to obtain documentation and write a report). Such trips should be well-planned in advance. Australia has various grants for Islander and Aboriginal people to help with such foreign studies. There is also much background material available in Australia on comparable experience elsewhere, notably in the libraries and publications of the Australian Institute of Aboriginal and Torres Strait Islander Studies in Canberra, the North Australian Research Unit in Darwin, and James Cook University of North Queensland in Townsville.

International contact is also important for gaining interest and support in struggles at home. Inuit and Torres Strait Islanders are often forgotten because their countries have other larger groups of indigenous peoples who gain most of the public and official attention, (ie., the North American Indians and Australian Aboriginals). International attention can be a powerful weapon in aid of indigenous peoples. As outlined at the beginning of this paper, the situation is very promising now for world encouragement of Australian initiatives to accommodate indigenous peoples. It is unlikely that Canada would have moved so quickly to provide services to Inuit if it had not been for the criticism of Canadian neglect during the Second World War by Americans serving in Northern Canada. Fear of United Nations criticism of Danish 'colonialism' in Greenland was an important factor prompting the impressive material benefits in new housing, schools, hospitals and social community services which Denmark poured in to Greenland from the 1950s. In recent years it has sometimes seemed that Australian policy-makers were more often moved by international criticism than domestic moral purpose (Oakes, 1987). Of course, Australians resist and resent foreign comment, but if it helps make them act, what does that matter?

> *We frankly acknowledge that Australia's own past is not without blemish in regard to human rights, in particular concerning the treatment of Aboriginal and Torres Strait Islander people. However, we have progressed along the path of rectifying those injustices, we welcome international scrutiny of our efforts, and are prepared to engage in dialogue with any interested country at any time on such issues. We take the view that the question of conformity to international human rights standards is not each country's own internal business, but the world's business. (Evans 1990, pp 12-13).*

The question of how to combine indigenous self-government, environmental protection and sustainable development is now a serious subject of world discussion. In June 1989, the special global telecast for World Environment Day featured the chairman of the Brundtland Commission, Prime Minister Brundtland herself, with different indigenous people and performers from around the world stressing the relationship between indigenous survival and environmental survival. The report of the Brundtland Commission specifically recommends that Australia 'empower' indigenous peoples to manage their traditional resources and maintain their distinct societies (Brundtland 1987, pp 114-116). However isolated Islanders may sometimes feel, they are actually in the forefront of a world movement. They have much to gain from international contact in relation to both their regional self-government goals and 'sustainable development'.

Note

The source of much of this paper is the author's personal experience as an assistant to successive presidents of the Inuit Circumpolar Conference. Academic literature has not caught up with the rapid pace of Inuit political and social change in recent years. I would also like to acknowledge the researchers on my behalf by Ann Webb of the North Australian Research Unit, the first fruits of which are contained in this paper.

References

Brundtland G.H. (1987), *Our Common Future: The Report of the World Commission on Environment and Development*, Oxford University Press, Oxford.

Constitutional Commission (1988), *Final Report of the Australian Constitutional Commission*,, Commonwealth of Australia, Canberra, 2 volumes.

Cox David (1990), 'Grounded Looking Glass' in 'Defence Notes', *Peace and Security*, 5,3. (Canadian Institute for International Peace and Security, Ottawa, Autumn, 1990, 17)

Dahl J. (*et al.*) (1990), *Indigenous Peoples of the Soviet North*, International Working Group on Indigenous Affairs, Copenhagen, (IWGIA Document No. 67).

Damas D. (*et al.*) (1984), *The Arctic*, Smithsionian Institution, Washington, DC. (The Handbook of North American Indians, Volume 5)

Evans Senator G. (1990), *The United Nations: A New Era*, News Release, Minister for Foreign Affairs and Trade, Commonwealth of Australia, October 3.

Indian and Northern Affairs Canada (1990), *Agreement-in-Principle between the Inuit of the Nunavut Settlement Area and Her Majesty in Right of Canada*, Published under the joint authority of the Tungavik Federation of Nunavut and the Hon Tom Siddon, Minister for Indian Affairs and Northern Development, Ottawa.

Jull P. (1987), 'Inuit Politics and the Arctic Seas', In Franklyn Griffiths (ed), *Politics of the Northwest Passage*, McGill-Queen's University Press, Montreal, 46-63.

Oakes L. (1987),Untitled article, *The Bulletin*, Sydney, September 15, 1987.

Reynolds H. (1988), *The Law of the Land*, Penguin, Melbourne.

Robertson R.G. (1988), *The North and Canada's International Relations: The Report of a Working Group of the National Capital Branch of the Canadian Institute of International Affairs*, Canadian Arctic Resources Committee, Ottawa, and Canadian Institute of International Affairs, Toronto.

Simard J-M., and Hockin T. (1986), 'A Northern Dimension for Canada's Foreign Policy', In *Independence and Internationalism: Report of the Special Joint Committee of the Senate and of the House of Commons on Canada's International Relations*, Queen's Printer for Canada, Ottawa.

Usher P., Wenczel G., and Jull P., (*et al.*) (1987), *The Inuit of Canada*, Department of External Affairs, Ottawa.

Environment and Human Ecology in the Lake Murray-Middle Fly Area

Mark Busse
Papua New Guinea National Museum

Abstract

The Lake Murray-Middle Fly area lies in the centre of the vast lowland alluvial plain which constitutes much of the Western Province of Papua New Guinea. The dominant geographical features in the area are Lake Murray – the largest lake in Papua New Guinea – and the Fly and Strickland Rivers with their broad flood plains which in places are fifteen kilometers wide. In the midst of these flood plains are numerous lakes and extensive areas of swamp and marsh. Along the rivers and around the edges of the lakes, including Lake Murray, are large tracts of grassland and savannah which are periodically inundated when the Fly and Strickland Rivers flood their low banks. These grasslands and swamps are home to an extraordinary variety of wildlife, including large numbers of fish, turtles, crocodiles, and migratory birds, many species of which have not been adequately documented .

The Lake Murray-Middle Fly area is also home to some 3,500 people who speak the closely related Boazi and Zimakani languages. These two languages are closely related to the Marind language spoken to the west and southwest in Irian Jaya, and the culture of Boazi and Zimakani speakers is similar to that of the Marind-arnim and Bian Marind described by van Baal in his book Dema. Like the Bian Marind to the west the people of the Lake Murray-Middle Fly area live in small villages and isolated homesteads along the flood plains of the rivers and have a riverine adaption, relying on naturally occurring sago as well as fish and game for their food. Virtually all travelling is by dugout canoe. Because of the riverine adaption of Boazi and Zimakani, the negative effects of mining in the headwaters of the Fly and Strickland Rivers on those two rivers would have particularly serious consequences for the people of the Lake Murray-Middle Fly area.

This paper provides an introduction to human ecology in the Lake Murray-Middle Fly area, an area in which I conducted two and a half years of anthropological research between 1982 and 1985.[1]

I want to preface this paper by noting that I am a social anthropologist and my research in the Lake Murray-Middle Fly area focused primarily on kinship and marriage (see Busse 1987), not human ecology. Nonetheless, like most anthropologists who live among people who derive their daily living directly from their natural environment, I found that during the course of my research I had to learn a great deal about the physical environment in which I was living and about the ways in which the people among whom I was living thought about and used that environment. Not surprisingly, I discovered that much of the symbolic life of the people of the Lake Murray-Middle Fly area was and is closely connected to the physical world in which they live and that their view of that world differs in important ways from the view that an urban American such as myself might have of such an environment.

During the two and a half years that my wife and I lived in the Lake Murray-Middle Fly area, we came to appreciate the stunning beauty of the area and to understand, at least to some degree, the ways in which the people of the Lake Murray-Middle Fly area make a living from their environment and the rich social, cultural and emotional meanings which that environment has for them.

In this paper, I particularly want to emphasize that both the grasslands and *Melaleuca* swamp savannahs of the Lake Murray-Middle Fly area on the one hand and the hunting, fishing, and sago-making adaptation of its inhabitants on the other hand are unusual in New Guinea. Indeed, the physical environment of the Lake Murray-Middle Fly area is, in many ways, more reminiscent of parts of northern Australia than New Guinea.

The Lake Murray and Middle Fly Census Divisions comprise some 12,500 square kilometers in the midst of the vast lowland alluvial plain which constitutes much of the Western Province of Papua New Guinea and which stretches across the international border into south-eastern Irian Jaya. The dominant geographical features of the Lake Murray-Middle Fly area are Lake Murray – the largest lake in Papua New Guinea – and the Fly and Strickland Rivers with their broad floodplains which in places are fifteen kilometers wide. Along the rivers and around the edges of the lakes, including Lake Murray, are large tracts of grassland and *Melaleuca* swamp savannah which are periodically inundated when the Fly and Strickland Rivers overflow their low banks. This area is home to a variety of water birds, including ducks, geese, herons, ibises, storks, and pelicans. Away from the rivers are somewhat higher areas consisting of low ridges covered with open forest or closed canopy rainforest. In the marginally lower areas between the ridges are the vast sago swamps from which the people of the area get an important part of their food. Despite these somewhat higher areas away from the rivers and their floodplains, the overwhelming impression that one gets travelling through the area is of extensive flatness and swamp.

The Lake Murray and Middle Fly Census Divisions are home to approximately 4,500 people or fewer than 0.5 persons per square kilometer. The reasons for this low population density appear to be malaria and the limiting effects of particularly dry years rather than an absence of natural resources.[2] The cycle of particularly dry years warrants particular comment here in light of the activities of Ok Tedi Mining Limited upstream from the Middle Fly.

In an average year, the Lake Murray-Middle Fly area receives about 2.5 meters of rain, over half of which falls during the northwest monsoon season from late December to mid-April. Annual rainfall figures at Bosset in the Middle Fly between 1974 and 1984, however, ranged from 1.5 meters in 1979 to over 3.5 meters in 1975. The water level in the Fly River and its floodplain, however, depends primarily on rainfall in the headwaters of the Fly and Ok Tedi Rivers, and the water level in the Middle Fly appears to rise and fall independently of rainfall in the Middle Fly itself.

In the twenty five years prior to my research, particularly severe dry seasons occurred in 1958, 1965, 1972, 1979, and 1982, so severe dry seasons are not unusual events. During extreme dry seasons, such as the one that was in progress when I arrived in the Lake Murray-Middle Fly area in 1982, food and water are serious problems. During the second half of 1982, Bosset Lagoon[3] which is usually three to four meters deep, was completely dry and covered with high grass. During this time, the people of the Middle Fly abandoned their villages which are near the edge of the flood plain and moved to the banks of the Fly River because the river channel was the only source of drinking water. During October and November 1982, it was impossible to make sago – the main food in the area – because there was no water with which to wash the starch from the sago pith, even though people dug two-meter deep holes in the dry floors of their sago swamps. As a result of the lack of water with which to make sago, people were forced to rely on bananas and fish.

In addition to the difficult food and water conditions, the exposed lake beds are quickly covered with grass. When the river rises and the lakes are inundated – and Bosset Lagoon filled with water before it rained in the Middle Fly – the grass remains, at least temporarily. This grass removes the oxygen from the water which means that there are few or no fish in the lakes. Not only does this make it more difficult for people to obtain fish to eat, but it also means more mosquitoes, since the fish eat the mosquito larvae, and more mosquitoes means more malaria.[4] Thus, it appears that the cycle of extreme dry seasons may be an important limiting factor on human population in the Lake Murray-Middle Fly area.

Of the 4,500 people who live in the Lake Murray-Middle Fly area, approximately 3,500 speak the Boazi and Zimakani languages. There are approximately 2,000 Boazi speakers and about 1,500 Zimakani speakers. Zimakani is spoken by people living around Everill Junction (i.e., the confluence of the Fly and Strickland Rivers) and the southern part of Lake Murray, and Boazi is spoken by people living along the shores of the northern and central parts of Lake Murray and along the Fly River from the Binge River in the north to just above Everill Junction in the south.

Together, these two languages make up the Boazi Language Family, and Boazi and Zimakani speakers are social and culturally very similar to one another. The Boazi Language Family, in turn, is the easternmost of the three language families in the Marind Language Stock (Voorhoeve 1970, 1975:355-362). The other languages of the Marind Stock are spoken in Irian Jaya, and Boazi and Zimakani speakers are culturally similar to the Marind-anim and Bian Marind of Irian Jaya who have been described by van Baal (1966).[5]

The Boazi and Zimakani are riverine people who get most of their food by hunting, fishing and processing the pith of wild sago palms. Gardens are unimportant both culturally and in terms of day-to-day subsistence. The people of the Lake Murray-Middle Fly area live within and along the edges of the floodplain in semi-permanent villages and camps near their sago swamps and hunting grounds. Travelling is done primarily by dugout canoes which are made from a variety of trees in the forest. The forest also provides wood for paddles and drums, and the marshes and forests provide reeds, bark, and palm spathe for making baskets and water containers.

Boazi and Zimakani speakers see themselves as living in a rich environment, and, in many regards, they are right. The Lake Murray-Middle Fly area has vast tracts of naturally-occurring sago (*Metroxylon sagu*).[6] Under optimum conditions such as those found in the Lake Murray-Middle Fly area, sago palms grow to heights of fifty feet and take ten to fifteen years to mature. During its growth, the palm stores carbohydrates in its stem. At full maturation, these carbohydrates are converted to sugar to sustain seed production.[7] Therefore, the best time to harvest a sago palm is just before it flowers when its pith contains the maximum amount of starch.[8]

Sago-making is women's work, and sago is an important feminine symbol. A complicated process is used to extract the starch from the palm pith. A woman first selects a mature palm, fells it with an axe, and removes a section of bark. She then chops, or shaves, the pith with a tool made of two sticks, the ends of which are tied together at a right angle with cane rope. The sticks are then pulled to about a 60° angle and held in that position by a cord, also made of cane, tied to the other ends of the sticks (i.e., the ends that were not tied together initially). The cutting edge of the tool is a bamboo node, or sometimes a piece of metal pipe, fitted over the end of one of the sticks. The other stick then serves as the handle of the tool. When the woman has chopped the pith, she places it in a large basket made of bark or grass. She then pours water into the basket and squeezes the basket with her feet on a small platform at one end of a trough made of palm spathes tied together with grass. As she squeezes the basket full of pith, the water, with the sago starch in suspension, runs out of the basket and into the trough where the sago starch comes out of suspension and settles to the bottom of the trough. At the end of the day, the woman carefully pours off the water and loads the wet sago starch into her basket.[9]

Hunting is men's work and men's passion. The Lake Murray-Middle Fly area is rich in game. Cassowaries, wild pigs, two types of wallabies, and deer abound.[10] It should also be pointed out that the Lake Murray-Middle Fly area is home to one of the largest monitor lizards in the world, *Varanus salvadori* which can reach four meters in length (Cogger 1972). These are also hunted, and their skins are used for the heads of drums.

Almost all hunting is done with large bamboo bows and cane arrows. A variety of hunting techniques are used including the construction of blinds in the bush for hunting birds, the construction of traps for pigs, stalking (with or without the help of dogs), and drives in which game is driven toward a line of hunters waiting at the base of a peninsula. Hunting is almost always successful, and most people eat red meat at least twice a week.

The most dramatic hunts are the fire drives which take place during the dry season in the grasslands and savannahs of the river floodplains. These hunts, which may involve as many as sixty or seventy men, are the most important contemporary public expressions of masculinity.[11] In one fire drive in which I participated, over 300 hectares of grassland were burned, and seven deer, three pigs, and eight large grass wallabies (*Wallabia agilis*) were killed.

While ideologically and symbolically less important than hunting, fishing is more important as a source of food. People often eat fish more than once a day. Hooks, traps, spears, and commercial fishing nets are used, and, when the water is low, poison squeezed from the root of a vine is used to kill the fish in small creeks and streams. Boazi speakers recognize more than thirty five different types of fish, many of which are eaten. The most important species are barramundi (*Lates calcarifer*), saratoga (*Scleropages jardini*), various types of catfish (including *Arius augustus* and *Arius leptaspis*), tandans (*Neosilurus ater*), mudfish (*Oxyeleotris fimbriata*), and black bass (*Lutjanus goldiei*). Crocodiles are also hunted, and the sale of crocodile skins is still the main source of cash in the Lake Murray-Middle Fly area.

Finally, Boazi and Zimakani speakers gather a variety of foods from the forests and marshlands including bush fowl eggs (both *Megapodius* and *Tallegalla* are found in the Lake Murray-Middle Fly area) and turtles.

In sum, the Lake Murray-Middle Fly region, with its vast areas of grassland, *Melaleuca* swamp savannah, and freshwater swamp is an unusual ecosystem for New Guinea and is, in many ways, reminiscent of northern Australia. It is a rich environment about which natural scientists know very little. The periodic severe dry seasons appear to play an important role in limiting the human population of the area by causing shortages of food and water. They are also important in light of the dumping of mining wastes by Ok Tedi Mining Limited both because during severe dry seasons the fish and human populations are concentrated in and along the main channel of the Fly River and because immediately after a severe dry season the back swamps of the floodplain are refilled by the rising waters of the Fly River.

The adaptation of Boazi and Zimakani speakers is also an unusual adaptation for New Guinea inasmuch as it is based on hunting, fishing, and sago making, while gardening plays a very minor role.

I want to close this paper with a quotation and my concern. Volume I of the 1982 Ok Tedi Environmental Study (Maunsell and Partners 1982) predicted that there was,

> *little likelihood* of mine-derived effects on the aquatic resources that are of *major dietary importance* to the peoples of the Fly River, and there will be no terrestrial impact. A possible exception, but difficult to predict, is the effect of barge wash on turtle breeding grounds on sand bars of the Middle Fly. [Maunsell and Partners 1982:1:87; emphasis added]

Recently, however, Ok Tedi Mining Limited has predicted high levels of sediment and particulate copper in the Fly River as far downstream as the Middle Fly. The long-term impact of these waste materials on the fish in the river and on the human population which lives along the river is hard to predict, but Ok Tedi has predicted high "fish catch loss" percentages in the main channel of the Fly River in the Middle Fly area during 1990.[12]

Inasmuch as "aquatic resources ... are of major dietary importance to the peoples of the Fly River," the continued dumping of mining wastes by Ok Tedi Mining Limited into the Ok Tedi River (and hence into the Fly River) and the failure of Ok Tedi Mining Limited to construct a tailings dam thus poses a potentially serious threat to the environment of the Middle Fly and to the way of life of its people. This threat comes despite Ok Tedi Mining Limited's previous assurance that there would be little or no effect on the aquatic resources of the Middle Fly.

Notes

[1] My research in the Lake Murray-Middle Fly area was funded by a U.S. Department of Education Fulbright-Hays Doctoral Dissertation Fellowship. Subsequent analysis of field data has been supported by a Kenneth Hill Fellowship for Pacific Studies (administered by the Office of Graduate Studies at the University of California, San Diego), the Revelle College Humanities Program (University of California, San Diego), and a Postdoctoral Fellowship in the National Institute of Mental Health Clinical Training Program in Adolescence (Committee on Human Development, University of Chicago). I am also grateful to the Institute of Papua New Guinea Studies and the government of Papua New Guinea for permission to conduct the research on which this paper is based, and to the Papua New Guinea National Museum which has supported my research since February 1990. My greatest debt, however, is to the people of the Lake Murray-Middle Fly area, and particularly to the people of Bosset Village in the Middle Fly, for their patience and generosity to me and my wife during our fieldwork.

[2] Riley (1983) has argued that the present population distribution in New Guinea may be the result of population regulation by malaria. In support of his argument, Riley points to the efficient transmission of malaria through mosquitoes, the short incubation period of malaria, the high but selective mortality of malaria (causing death mainly in individuals between six months and five years of age), depressed fertility due to malaria (which may cause abortion or premature labor), and the reduction of the body's immune response to other infections due to malaria. In the Lake Murray-Middle Fly area, the deleterious effects of malaria appear to be made worse by the cycle of particularly dry years.

[3] Bosset Lagoon, like many of the other open bodies of water in the floodplains of the Fly and Strickland Rivers (including Lake Murray), is called a "blocked-valley lake" by geographers. In the context of the Southern Lowlands of New Guinea, this term is somewhat misleading since the terrain is so flat that the difference in elevation between a valley floor and the surrounding higher ground is often a matter of only five to ten meters. "Blocked-tributary lake" is probably a more accurate description. Such lakes are sometimes referred to as "lagoons" on maps of the Lake Murray-Middle Fly area, and in using the name "Bosset Lagoon", I am following an established usage.

[4] I am grateful to Kent Hortle, Senior Biologist with Ok Tedi Mining Limited, for these observations concerning the effects of extreme dry seasons on the aquatic environment of the Lake Murray-Middle Fly area.

[5] In addition to the cultural similarities between the people of the Lake Murray-Middle Fly area on the one hand and the Marind-anim and Bian Marind on the other, Boazi and Zimakani speakers see themselves as culturally related to the Bian Marind (van Baal 1940, 1966) and Yei-nan (van Baal 1982) to the west and the Suki (van Nieuwenhuijsen 1979) and Trans-Fly peoples (Ayres 1983; Williams 1936) to the south.

[6] Unlike most food plants in New Guinea, sago palms appear to be indigenous and sago was probably the staple food of the first inhabitants of the island (Rhoads 1982; Townsend 1982: 2). Sago palms grow best in shallow freshwater where there is a regular influx of fresh water (Paijmans 1971, 1976:43). The Lake Murray-Middle Fly area, with its large areas of frequently inundated swamp, is thus an excellent environment for sago palms.

[7] Sago palms also reproduce by sending out suckers during the later stages of their life cycle.

[8] Barrau (1959) reports that a sago palm harvested just before it flowers may yield 175 pounds of dry sago which may contain as much as 250,000 calories.

[9] According to Rhoads (1981:51), squeezing (or "trampling" as he terms it) sago pith with the feet has only been reported for the Kongara of Bougainville, the Suki, two groups in the Trans-Fly, and the Kairi and Pepike people of the Papuan Gulf. It is also used by the Foi people who live along the lower reaches of the Mubi and Digimu (or Soro) Rivers and by the Fasu people who live just to the northwest in the villages of Tamadigi and Manu.

[10] Deer were introduced at Merauke in Irian Jaya around 1920 and have thrived in the South Central Lowlands. According to Ayres (1983:8-9), an estimated 30,000 deer now live in the Trans-Fly region. The first deer was killed in the Bosset area in the early 1960s.

[11] Prior to pacification, head hunting and warfare were the exemplars of male power.

[12] This prediction is based on computer modelling of data gathered in 1989 and has a high potential level of error.

References

Ayres, M.C. (1983), This Side, That Side: Locality and Exogamous Group Definition in Morehead Area, Southwestern Papua. Ph.D. Dissertation, Department of Anthropology, University of Chicago.

Baal, J. van (1940), 'Een en ander over de bevolking van het Boven-Bian-gebied', *Tijdschrift voor Indische Taal-, Land- en Volkenkunde*, 80,568-584.

Baal, J. van (1966), *Dema Description and Analysis of Marind-anim Culture (South New Guinea)*, The Hague, Martinus Nijhoff. (Koninklijk Instituut voor Taal-, Land- en Volkenkunde, Translation Series, Number 9).

Ball, J. van (1982), *Jan Verschueren's Description of Yei-nan Culture: Extracted from the Posthumous Papers*, (Verhandelingen van het Koninklijk Instituut voor Taal-, Land- en Volkenkunde, Number 99). The Hague, Martinus Nijhoff.

Barrau, J. (1959), 'The sago palm and other food plants of marsh dwellers in the South Pacific islands', *Economic Botany*, 13,151 - 162.

Busse, M. (1987), Sister Exchange among the Wamek of the Middle Fly. Ph.D. Dissertation, Department of Anthropology, University of California, San Diego.

Cogger, H.G. (1972), 'Lizards'. In *Encyclopaedia of Papua and New Guinea*, Volume 2, Melbourne, Melbourne University Press, 651-657.

Maunsell and Partners, Pty. Ltd. (1982), *Ok Tedi Environmental Study*, Port Moresby, Ok Tedi Mining Limited.

Nieuwenhuijsen, C.H. van (1979), Een Zuster voor een Vrouw: uwelijk en Verwantschap bij de Suki, Papua New Guinea Uitgave 15, Afdeling Culturele Antropologie, Antropologisch-Sociologisch Centrum, Universiteit van Amsterdam.

Paijmans, K. (1971), 'Vegetation, forest resources, and ecology of the Morehead-Kiunga area', In *Land Resources of the Morehead-Kiunga Area, Papua New Guinea*, Commonwealth Scientific and Industrial Research Organization, Melbourne, CSIRO, 88-113. (Land Research Series, Number 29).

Paijmans, K. (1976), 'Vegetation', In *New Guinea Vegetation*, K. Paijmans ed), Commonwealth Scientific and Industrial Research Organization and The Australian National University, Canberra, 23-105.

Riley, I.D. (1983), 'Population change and distribution in Papua New Guinea: An epidemiological approach', *Journal of Human Evolution*, 12,125-132.

Rhoads, J.W. (1981), 'Variation in land-use strategies among Melanesian sago eaters', *Canberra Anthropology*, 4(2),45-73.

Rhoads, J.W. (1982), 'Sagopalm management in Melanesia: An alternative perspective', *Archaeology in Oceania*, 17(1),20-27.

Townsend, P. (1982), Sago in Papua New Guinea A review of recent and needed research. Unpublished manuscript.

Voorhoeve, C.L. (1970), *The languages of the Lake Murray area*, The Australian National University, Research School of Pacific Studies, Canberra. (Pacific Linguistics, Series A: Occasional Papers, Number 25), 1-18.

Voorhoeve, C.L. (1975), 'Central and western Trans-New Guinea Phylum languages', In *New Guinea Area Languages and Language Study, Volume 1: Papuan Languages and the New Guinea Linguistic Scene*, S.A. Wurm (ed), The Australian National University, Research School of Pacific Studies, Canberra, 345-459. (Pacific Linguistics, Series C: Books, Number 38).

Williams, F. E. (1936), *Papuans of the Trans-Fly*, Oxford, The Clarendon Press.

The Torres Strait Treaty and the Environment

Judith M. Laffan, Papua New Guinea Section
Department of Foreign Affairs and Trade

The Torres Strait Treaty was negotiated between the governments of Australia and Papua New Guinea in order to clearly establish the border of sovereignty and jurisdiction between the two countries in the region of the Torres Strait. The two basic boundaries were established: the Seabed Jurisdiction and the Fisheries Jurisdiction Line. The Seabed Jurisdiction Line is also the boundary of sovereignty with the exception of fifteen islands or cays north of that line (including the inhabited islands of Boigu, Saibai and Dauan), over which Papua New Guinea recognized Australian sovereignty. The Treaty also explicitly acknowledged and sought to preserve the traditional way of life and livelihood of the traditional inhabitants of the Torres Strait region, and established for this purpose the Torres Strait Protected Zone.

The environment provisions of the Treaty are important for the well-being of the traditional inhabitants, for the preservation of the traditional and commercial fisheries, and for general recognition of the fragility of the Torres Strait environment. Though many of you here will be very familiar with the text of the Treaty, I would like to point out here the parts of the Treaty which specifically deal with protection of the environment.

In the Preamble to the Treaty, it clearly states:

> 'RECOGNISING ALSO the importance of protecting the marine environment ... in the Torres Strait area;'

Under Article 7 pertaining to navigation and overflight, Clause 2(a) states that each Party is to ensure that:

> 'those vessels observe generally accepted international regulations, procedures, and practices for safety at sea and for the prevention, reduction and control of pollution from ships'.

Article 10 Clause 4 states:

> 'A further purpose of the Parties in establishing the Protected Zone is to protect and preserve the marine environment and indigenous fauna and flora in and in the vicinity of the Protected Zone.'

Article 13 specifies the obligations incumbent upon both Parties in order to ensure the protection and preservation of the marine environment, through legislative or other measures, to prevent or control 'pollution or other damage to the marine environment from all sources and activities under its jurisdiction or control'. Clause 1 requires the taking into account of 'internationally agreed rules, standards and recommended practices ... adopted by diplomatic conferences or by relevant international organisations'. Clause 3 specifies that the measures taken by each Party 'shall be consistent with its obligations under international law'; and Clause 4, that the Parties shall consult each other about any concerns relating to the environment.

Article 14 states the obligations of both Parties to protect and preserve indigenous fauna and flora through:

- identification of endangered species;
- protective measures;
- prevention of introduction of harmful foreign species;
- control of noxious species of fauna and flora;
- exchange of information and consultation between the Parties.

Article 19 states that the Torres Strait Joint Advisory Council (JAC) should advise the two governments on

> 'any matters relevant to the effective implementation of this Treaty including the provisions relating to the protection and preservation of the marine environment, and fauna and flora, in and in the vicinity of the Protection Zone.'

The Treaty also recognises the importance of properly managing the commercial fisheries resource of the Torres Strait region in a sustainable way. The Preamble states:

> 'DESIRING ALSO to cooperate with one another in that area in the conservation, management and sharing of fisheries resources ...'

Articles 21 through to 28 address the management of the Protected Zone commercial fisheries, with provision to apply conservation measures and management arrangements with respect to a species; and provisions for licensing, inspection and enforcement to control who does how much fishing of which species, including fishing by third states.

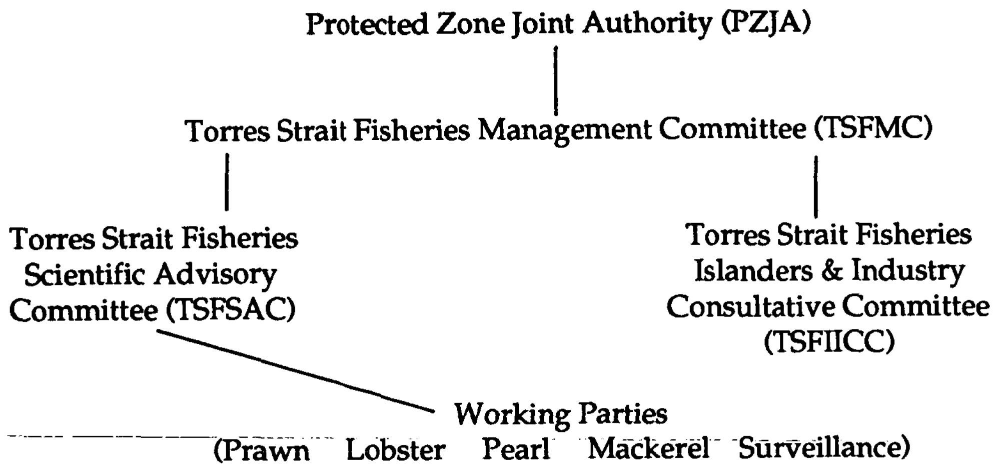
The Treaty thus has a major environmental protection dimension. Although originally primarily conceived to delimit the boundary of sovereignty and jurisdiction in the Torres Strait region between Australia and Papua New Guinea, the drafters of the Treaty were conscious of the importance of this environmental dimension. In assessing the comprehensiveness and usefulness of the environmental coverage of the Torres Strait Treaty, we should bear in mind that any treaty is inevitably a reflection of the understanding and concepts of the times in which it was conceived, negotiated, and signed. However the Torres Strait Treaty bears up very well in this regard. It was signed by Australia and Papua New Guinea in December 1978, and came into force in February 1985 upon its ratification by both Parties. Its period of formation was between about 1972 and 1978, a time when general awareness of the importance for man's well-being of his relationship to his natural environment was beginning to take shape, an awareness brought about largely by the recognition of the damage wrought by mainly developed countries on the environment, local and global. The first United Nations environment conference (UN Conference on the Human Environment) had been held in Stockholm in 1972, which adopted a 'Declaration on the Human Environment' recognising the need for development to be sustainable, and which agreed on an Action Plan which the United Nations Environment Programme (UNEP) was created to implement and promote. We are all now preparing for the 1992 United Nations Conference on Environment and Development (UNCED) to be held in Brazil, which is intended to address the central issues of:

- strengthening international environmental cooperation to contain, reduce and eliminate global environmental damage;
- promoting sustainable and environmentally sound development in all countries;
- finding ways to provide additional financial resources for measures directed at solving major global environmental problems;
- promoting environmental education.

(See UNGA Resolutions 43/196 of December 1988 and 44/228 of March 1990).

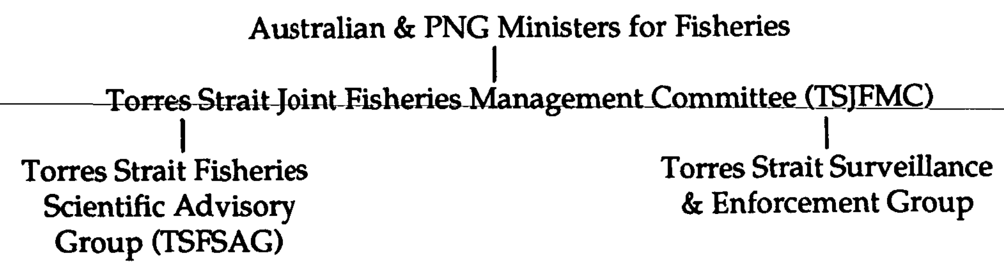
Looked at in this light, the Torres Strait Treaty with its considerable environmental protection content, and many of its environmental provisions already being implemented, seems to have been rather ahead of its time. Earlier international treaties with major or sustainable environmental content were not numerous, although the environmental problems were already there; and many of the early treaties addressed only a single environmental issue. For example, the Antarctic Treaty, signed in 1959 and entered into force in 1961 (to which both Australia and Papua New Guinea are parties), is nowadays regarded as a major early environmental treaty, but does not mention the word 'environment' anywhere in the text of the treaty itself, and makes only one reference to 'preservation and conservation of living resources' (Article IX 1.f). It was only in the 1970s and 1980s that substantial Conservation Measures, and the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Convention for the Conservation of Antarctic Seals (CCAS) were added to the Antarctic Treaty system. Australia along with France, Italy and Belgium, are currently leading an effort to incorporate complete and comprehensive environmental protection provisions into the Antarctic Treaty system. By contrast, the Torres Strait Treaty included provisions for sustainable management of commercial fisheries, protection of traditional fisheries, protection of fauna and flora, prevention of pollution and environmental damage from all sources and activities, and exchange of information and research cooperation, in the original text of the Treaty in the 1970s, and it is still a good tool for achieving environmental protection of the Torres Strait region, quite apart from its several other purposes.

Earlier papers have outlined the consultative and decision-making mechanisms on the Australian side for its share of the fisheries management under the Treaty:



Islander organisations, government agencies, and fishing industry organisations are represented on these committees.

No specific bilateral fisheries bodies are mentioned in the Treaty; but some informal bodies have been established:



The establishment of the Environmental Management Committee (EMC) by the JAC in 1988, as a consultative body for detailed consideration of Torres Strait environmental issues at annual meetings, has further strengthened the environmental protection capacity of the Treaty.

We are all aware of the main environmental issues preoccupying us in the Torres Strait region at present.

One of the most prominent issues is obviously the potential impact and long-term effects of mining and oil development projects in Papua New Guinea and Australia: these currently comprise Ok Tedi and Porgera in the Fly River system catchment area; the Kutubu oil project due to commence production in about mid-1992; and the Horn Island gold mine. Separate papers in these proceedings have given some account of the environmental situation of the Ok Tedi and Porgera projects (see Ross, this volume; Eagle and Higgins, this volume).

The Australian government maintains a regular exchange of information with the Papuan New Guinea government on the environmental aspects of oil and mineral development projects adjacent to the Torres Strait:

- through Prime Ministerial and Ministerial contacts;
- through the Joint Advisory Council Meetings;
- through official contact in Canberra and Port Moresby.

The Australian government also maintains regular contact with Australian and other companies involved in PNG oil and mineral development projects, about their environmental programmes, including through detailed briefings and as necessary, obtaining of specific information. We welcome the contact and cooperation we receive from the PNG government and companies, and attach importance to its continuation. We are all aware that the majority of the data we must rely on at present in assessing the impact of PNG projects on the Torres Strait is that from the environmental monitoring and research programmes of the Ok Tedi and Porgera projects, and formerly from the Horn Island project. It is highly desirable that there should be independent monitoring and research of the Torres Strait environment to complement the monitoring and research programmes of the companies involved in the mining and oil development projects, excellent as some of these programmes are. Thus the Torres Strait Baseline Study will be an important and major element in assessing the current Torres Strait environmental situation and providing a datum against which future change can be compared.

As a sovereign and independent country, Papua New Guinea of course has a responsibility under the Treaty to ensure that mining projects on its territory do not harm the environment of Torres Strait. But the Australian government has made clear it is prepared to help with technical and other assistance on environmental issues. The previous Australian Minister for Resources, Senator Cook, offered such assistance at the Australia-PNG Ministerial Forum in January 1990. In the case of the Kutubu oil development project:

- Prime Minister Hawke agreed during his recent visit to PNG, to a PNG government request for assistance with preparing legislation and regulations for the oil pipeline, and legislation and contingency plans for possible oil spillage from the off-shore oil terminal and tanker traffic;

- Australian government officials have begun to provide this assistance (a team of experts from DOTAC and DPIE visited PNG in early November and had preliminary discussions with PNG officials of DEC and DME);

- Papua New Guinea is a member of the International Maritime Organization (IMO), and is already party to several important international conventions directed at protecting the seas from pollution;

    - International Convention for the Prevention of Pollution of the sea by Oil (OILPOL (1954),
    - Convention relating to Intervention on the High Seas in the case of Oil Pollution Casualties (1969),
    - International Convention on Civil Liability for Oil Pollution Damage (CLC) (1969),
    - Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention) (1972).

- Australia also understands that PNG is considering acceding to MARPOL (International Convention for the Prevention of Pollution from Ships 1973/78) which is the most stringent international convention to date for the protection of the seas from ship-sourced operational pollution;

- Also relevant is the SPREP Convention Protocol concerning cooperation in combatting pollution emergencies in the South Pacific region which requires parties to "within their respective capabilities, cooperate in taking all necessary measures for the protection of the South Pacific region from the threat and effects of pollution incidents" (Article 3.1);

- The PNG government is aware of the recent USA legislation requiring double-hulling of oil tankers entering USA waters, and is looking into this idea. Australia is also considering the effectiveness of this and other measures;

- Australia has now had it accepted in the IMO that governments should instruct ships to comply with Australia's compulsory pilotage scheme for all merchant vessels over 70 metres in length and all loaded oil tankers, chemical carriers and gas carriers, irrespective of size, transmitting the inner route of the Great Barrier Reef between the northern tip of Cape York Peninsula (10° 41'S) and 16° 40'S, as well as through Hydrographers Passage off Mackay. Since most major maritime traffic using the Great Barrier Reef inner route, is coming from or going through the Torres Strait, except for those ships going through the Great North East Channel, this new regulation of compulsory pilotage for the GBR inner route should mean in effect that virtually all of this traffic would have pilots aboard in their passage through Torres Strait as well. The level of compliance with the voluntary pilotage scheme is presently about 90% for vessels using the Great Barrier Reef inner route; under the compulsory pilotage scheme, non-compliance should become minimal. The PNG government also has the option of making compulsory pilotage part of its port entry requirements for tankers loading at Kikori terminal.

These mining and oil development projects are important for Papua New Guinea. Some may fear the economic imperative might override environmental considerations. However one lesson of Bougainville has been the need to achieve a perception of balance with environmental considerations. The Papua New Guinea government has taken steps to ensure that mining projects are governed by stricter environmental regimes, and companies have also recognised that it is in their interests to ensure that local landowners are not driven by perceptions of environmental damage to demand expensive compensation or to resort to subsequent action against a project. This whole process of course is part of the endeavour to define 'sustainable development', an endeavour in which both Australia and Papua New Guinea are engaged in our respective territories.

In the case of the Horn Island gold mine, the Queensland government has been investigating the possibly anomalous data provided in the monitoring report of the company which was operating it before its closure at the end of 1989 (Torres Strait Gold Pty Ltd). The Queensland government will report on this matter at the coming EMC III Meeting.

Besides the question of the impact and long-term effects of mining and oil development projects adjacent to the Torres Strait, other current and future environmental issues include:

- other land-sourced marine pollution (eg agricultural chemicals, industrial and domestic detergents);
- the effects of seabed mining exploration and development;
- coastal and wetland management;
- preservation of biological diversity, including species identification;
- illegal fishing, illegal and unsustainable fishing practices, and catch underreporting;
- the effects on marine resources of increases in commercial fishing;
- the impacts of global climate change and sea-level rise.

Most of these issues are able to be addressed under the provisions of the Torres Strait Treaty, and several are in the process of being, or are soon to be, so addressed.

In addition to the Treaty, however, the Australian government also attaches importance to other regional and international fora, organizations, and conventions, as part of the means to protect the Torres Strait environment.

The first South Pacific regional environmental instrument, the Convention on the Conservation of Nature in the South Pacific (Apia Convention), was signed in Apia, Western Samoa, in 1976, and came into force in March 1990.

In 1980, the South Pacific Regional Environmental Programme (SPREP) was launched with the objective of:

> 'helping the countries of the South Pacific to maintain and improve their shared environment and to enhance their capacity to provide a present and future resource base to support the needs and maintain the quality of life of the people'.

With the support of ESCAP, the Conference on the Human Environment in the South Pacific was held in Rarotonga in 1982, and produced the South Pacific Declaration on Natural Resources and the Environment, and agreed on an Action Plan for Managing the Natural Resources of the South Pacific (the SPREP Action Plan). This Plan was intended to:

> 'provide a framework for environmentally sound planning and management, suited to the needs and conditions of the countries and the people in the region and to enhance their own environmental capacities'

and has four specific objectives:

- further assessment of the environment of the region and the impacts of human activities on it;
- development of environmental management methods suited to the region;
- the improvement of national environmental legislation and development of regional agreements; and
- the strengthening of national and regional capabilities, institutional arrangements and financial support.

The Plan also led to the development of the Convention on the Protection of Natural resources and Environment of the South Pacific Region (SPREP Convention) and its two Protocols, which were signed in 1986 and came into force in July 1990. The Plan is currently being reviewed and it is expected that a revised Plan will be agreed at a Ministerial-level Meeting in mid-1991.

The Apia Convention and the SPREP Convention both apply to the Torres Strait region, and are relevant and useful for the protection of the Torres Strait environment. The SPREP Convention is particularly broad and comprehensive. As an example of the work done under SPREP, the 1988 SPREP Intergovernmental Meeting resulted in a recommendation for a project focussing on the development of arrangements for regional marine turtle conservation and management, which is now proceeding under the guidance of the SPREP Secretariat with funding from AIDAB and the Canadian International Centre for Ocean Development (ICOD).

The SPREP Secretariat, which provides the main environmental advice to the SPC and the South Pacific Forum, will also service and promote the regional sea-level rise question is clearly important for the Torres Strait environment. Several other South Pacific regional organisations have some responsibility for and some expertise in environmentally related fields: the Forum Fisheries Agency (FFA); the South Pacific Commission (SPC); and the South Pacific Forum Secretariat. For example, the Forum Secretariat is investigating the need for a Code of Environmental Conduct for extra-regional countries, to cover the activities of their nationals and agencies within the region. It is interesting that a similar proposal with global application is being considered in the preparations for UNCED 1992.

The Convention for the Prohibition of Fishing with Long Driftnets in the South Pacific (Wellington Convention) is aimed at preventing the use of driftnets within the South Pacific because of their adverse effect on the marine environment, particularly on non-target species such as dolphins; the Convention is administered by the Forum Fisheries Agency.

The South Pacific Nuclear Free Zone Treaty (Rarotonga Treaty/SPNFZ) was adopted by the South Pacific Forum in 1985, and aims to limit activities in the region involving the use of nuclear energy, and completely preventing activities involving nuclear weapons. It arose from concerns over the environmental and health risks posed by radioactive contamination from weapon testing and dumping of wastes. The decisions of the USA, the UK, and particularly France not to become involved obviously limit its effectiveness, although China and the USSR have signed the relevant Protocols.

There are a number of major international environmental conventions, which the Australian government is active in the negotiations for, or a signatory or party to, which are relevant and useful for the protection of the Torres Strait environment. These include:

- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES);

- Convention on the Conservation of Migratory Species of Wild Fauna (Bonn Convention);

- Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention);

- Vienna Convention for the Protection of the Ozone Layer (1985) – the first international agreement responding to concerns over ozone depletion; and its Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol 1987);

- United Nations Convention on the Law of the Sea (UNCLOS);

    - Part IX contains a Deep Seabed Mining Regime,
    - Article 192 describes the general obligation of all states to protect and preserve the marine environment,
    - Article 194 places an obligation upon states to act individually or jointly in order to prevent, reduce, and control pollution of the marine environment from any source,

- Basel Convention on Control of Transboundary Movements of Hazardous Wastes and their Disposal;

- Climate Change Convention – the Second World Climate Conference recently agreed to proceed with the negotiation of a Climate Change Convention, which we hope will be achieved by the time of UNCED 1992.

Our understanding of the workings of the global environment, and of local ecological systems, is still at a very early stage. As our knowledge and understanding increases, so our ability to protect and preserve the environment, and manage the effects of human activities on it, should improve; but the growing international commitment to the 'precautionary principle' (a cautious approach to the risk of irreversible or serious environmental degradation), requires that action be taken based on assessments of the risk of degradation using available knowledge. This principle is a component of what is emerging as the key environmental concept, 'sustainable development'. Efforts so far to define 'sustainable development' have yet to find final concensus but have produced broad agreement on several principles, in addition to the precautionary principle:

- the integration of economic and environmental goals;
- the appropriate valuation of environmental assets;
- a cautious approach to the risk of irreversible or serious environmental degradation (the precautionary principle);
- public participation in decision making;
- the acceptance of responsibility for environmental damage (the polluter pays principle).

It will be the task of all authorities and bodies, companies and corporations, responsible for any share of environmental management to tackle the practical implementation of these principles, and to further develop the definition of 'sustainable development'. The Australian government has formed a system of nine special working groups to look at this question as it applies to different sectors of our economy. The Working Groups have commenced their work and will report in October 1991.

To conclude, the Australian government takes the view that the Torres Strait Treaty is a valuable and central instrument through which Australia and Papua New Guinea, and particularly the people of the Torres Strait region, can work cooperatively to protect and preserve the Torres Strait environment. The effectiveness of the Treaty for this purpose clearly depends more upon its good use and implementation than upon its content and provisions, comprehensive and flexible as these are. The requirements of Article 13 Clause 1 to take into account 'internationally' agreed rules, standards and recommended practices adopted by diplomatic conferences or by relevant international organisations', provides the scope for further improvement of the means and measures we apply to protection of the Torres Strait environment under the Treaty, both in the letter and the spirit, to be party to, and support negotiations for, regional and international conventions and agreements which cover regional and global environmental issues which are relevant to the Torres Strait.

The Maza Wildlife Management Area, Western Province, Papua New Guinea: The Resources and Its Management

William Asigau, Nature Conservation Division,
Papua New Guinea Department of Environment and Conservation

Introduction

The Maza Wildlife Management Area (WMA) is one of few marine conservation areas in Papua New Guinea. The area was declared under the Fauna (Protection and Control) Act, chapter 154, for Marine Conservation especially for dugongs and marine turtles on the 7th day of December 1978.

The declaration of the area was the result of a three year study on the marine mammal *dugong dugon* sponsored both by the Food and Agriculture Organization (F.A.O.), and the Papua New Guinea Government Department of Environment and Conservation.

A research biologist, Mrs B. Hudson, was engaged to study the dugong's biology, ecology and ethnobiology and to make recommendations to the Government of Papua New Guinea for its protection and management. Her studies revealed that without proper management, these slow breeding mammals were threatened with extinction as the populations were decreasing due to increased catches from use of new techniques and better fishing methods.

A thorough survey of the animals feeding range and migration patterns revealed that the animal was covering a large area for feeding and breeding hence a large area was necessary for the effective conservation of the species.

The Maza Wildlife Management Area is located in the Western Province of Papua New Guinea. The boundaries of the management area starts from the Binaturi river on the West, to Moon Passage in Warrior Reef complex in the south then East on Parama island. The management area covers a total of 184,230 hectares.

No specific studies have been done to report on the marine resources of the Maza Wildlife Management Area, since the dugong studies. Studies independent of the Department of Environment and Conservation have been done by other Government Departments on specific species in and around the Maza Wildlife Management Area.

The Department of Fisheries and Marine Resources in particular has done extensive studies on the prawn, lobster and barramundi fisheries in the area. Catch statistics on turtles, trochus, mother-of-pearl oysters and beche-de-mer have also been kept while turtle biology is an area of interest by previous fisheries research officers and some overseas researchers.

The Department of Fisheries and Marine Resources currently have personnel in Daru who continue to collect data on the above Fisheries.

The Resources of the Maza Wildlife Management Area

Maza Wildlife Management Area is a marine conservation area with extensive seagrass beds, coral reefs and mangroves. The area is rich in marine resources especially those associated with coral reefs, seagrass beds and mangroves. The list of marine resources is inconclusive as the area is very extensive and much time, effort and money will be required to do a thorough list of the resources of the area. The spiny lobster fisheries, prawn fisheries and the barramundi fisheries are some commercial operations within the area. Trochus shells, beche-der-mer and the mother-of-pearl shells are also common in the area. Fish, turtles, dugongs and many invertebrates are of subsistence importance in the area.

Coral Reefs

The Maza Wildlife Management Area has within it several large coral reefs. The largest of these is Wapa reef, an extension of the Warrior Reef. The Auomaza Reef from which the management area got its name is also quite large. Other notable reefs in the area are the Gemini Reefs, Silver Reefs, Kokopi Reefs, Parakivori Reefs, Kumusi Reefs, Otamabu Reefs and the home reefs of Tureture and Parama villages.

Seagrass beds

Most of the large reefs in the area have seagrass communities. The seagrass beds are among the most extensive in the world. These beds provide nursery grounds for prawns, trochus, pearl oysters, lobsters, fish and many invertebrates. The seagrass beds are especially important for the survival of dugongs, turtles and many fish as these are the major feeding grounds for these animals.

Mangroves

Mangroves are known for their importance in marine productivity and energy transfers to the nearby coral reefs. Besides this important function they are also important as nursery grounds especially for the barramundi and the banana prawns.

Mangroves also have important roles in land stabilization and accretion. Their roles in providing energy (firewood), building materials and other subsistence needs are widely appreciated facts.

Within the mangroves, other marine resources include the mud crabs *Scylla serratta*. However, smaller and smaller sizes are brought into the Daru market meaning the collecting of crabs is putting pressure on populations on Daru Island and the adjacent Bistrow Island.

Mangroves provide shelter and nesting places for many birds. Flocks of sandpipers, cormorants and other sea birds are seen nesting in the mangroves especially on Bistrow Island. An exciting site for mangroves and sea birds is the Otomabu Reef; where single stands of several mangrove species are found spread over a large area creating resting places for many different species of sea birds. Large numbers of pelicans, common sandpipers, cormorants, egrets perch on these trees at high tide and may be seen wading in the shallow pools at lowtide. An added attraction is the large sand bar on Potomaza, which is used commonly by seabirds.

Islands and sand spits

There exists within the management area several islands and sand spits. These islands (Daru and Bristow) and the sand spits provide shelter and protection for many seabirds. Many sea birds are also seen wading in the shallows at lowtide in the management area along the coast and near the islands. Migratory birds are often seen on the islands during migrations north from Australia.

Wildlife utilizations

Marine resources provide an important source of protein for the Kiwai people. The herbivorous fishes (garfish and rabbit fishes) seem to be the most important as great numbers are common in the fish market. The white fish (trevelleys) and barramundi are also very common. However, coral reef fish are not common in the market. Invertebrates including crabs, various gastropods and bivalves, especially from the mangroves can also be seen in the Daru Market. Birds sold in the market include wild ducks and cassowary.

The Management of the Maza Wildlife Management Area

The Maza Wildlife Management Area is managed by a management committee representing local villages and communities. The Committee has an executive chairman who oversees the operation of the committee. The committee's responsibility is to enforce the management rules and collect fees as outlined in the rules (See Attachment).

The Concept

The Maza Wildlife Management area is managed especially for the protection of dugongs and turtles. The WMA concept is to create conservation areas without loss of land by village people and to engage the local people in the managment of their own resources. The Maza WMA is a conservation area created under the WMA concept.

The management of the area is the responsibility of the elected committee therefore its success depends on the will, the ability and the eagerness of the committee. The Department of Environment and Conservation has tow roles. Firstly it assists in the identifying of the boundaries, the committee and in drawing up the regulations. Secondly, the department provides advice and assistance where necessary from time to time to the Management Committee.

The Management Concerns in the Maza Wildlife Management Area.

The management committee is currently concerned that the village people are starting to break the management rules by taking turtles and dugongs illegally. Dugongs are sold on the black markets to avoid detection by committee members while turtles are taken to the markets and sold without the notice of the committee members.

The committe is aware of the illegal activities but is unable to enforce the rules because it lacks knowledge of offenders, and taking them through the legal system for successful prosecution is time-consuming and difficult. Also, the committee is disintergrated and disorganized due to lack of regular meetings to discuss their strategies for enforcing the rules. The non-attendance of members for meetings is due to the inability of the committee to meet travel expenses of committee members. The committee lacks basic facilities needed for the management of the area. For example, the lack of a dinghy and an outboard motor to track down offenders is a major concern.

The inability to manage the area can also be attributed to the lack of support and guidance from National Government agencies. The Government has failed to teach basic skills of management to members of the committee, most of whom have very little education, and therefore, the committee lacks the managerial skills needed to control the management areas.

The committee expressed concern over the indiscriminate cutting of mangroves for firewood, and for building materials in the settlements, especially on Daru, where people from the Kiwai islands are moving in to settle. The management of mangrove resources is not covered by the management regulations, therefore, the committee is concerned the mangrove resoures will be seriously depleted.

Common problems experienced by the committee in the Wildlife Management Area are:

- The difficulties of apprehending offenders and the lack of knowledge in the prosecution of offenders makes it difficult to enforce the management rules.
- The lack of revenue and funds to meet member expenses and management costs has led to the failure of members to attend meetings to review management strategies.
- The lack of basic management facilities such as dinghies and outboard motors has resulted in the non-management of the area.
- The lack of support and assistance from government departments has resulted in the committee ignoring their responsibility to manage the area.

Some suggestions to solve the above problems

The management concerns expressed by the committee suggest that the major problems are a of lack of finance, basic management knowledge and facilities. It is obvious that the committee needs financial support to be able to carry out its management functions. Therefore a revenue generating mechanism is necessary for the committee to meet the costs of their management functions. While royalty fees can be collected from the sale of turtles and dugongs the revenue generated is so small it is inadequate to meet the management costs. Other means of generating revenue must be provided. The committee believes that commercial operators in the management area should be levied a management levy payable to the committee. It should be possible to negotiate a mechanism with Fisheries and Marine Resoures for the management levy to be collected and paid to the management committee.

The Western Provincial Government and the Department of Environment and Conservation should help the committee to seek assistance from organisation such as the Office of International Development Assistance (OIDA) and foreign embassies for management facilities or in the establishment of guest houses for tourists as income generating options. Maza Wildlife Management Area has some tourist attractions in the coral reefs and the mangroves. The Otamabu Reefs are used by many seabirds as nesting places and the sand bars on Potomaza provides good B.B.Q. sites while birdwatching in the nearby Otamabu Reefs. Daru has become the centre of activity for all the different ethnic groups of the Western Province. Engaging the committee in providing facilities and services for tourism could bring in good revenue for the management committee.

As the committee lacks resource management skills the Department of Environment and Conservation could provide training programs to educate the committee on resource management. The Department could also assist by providing copies of the Maza Wildlife Management Area rules and the copies of the Fauna (Protection and Control) Acts to the Department of Western Province who could then assist the committee to enforce the rules.

The current rules of the management area should be reviewed and amended where necessary to include new rules to improve the management of the area. The committee should be allowed to carry out activities which are consistent and not contrary to conservation ethics. The change of rules should provide for better management regulations suitable to the changing situation in the Western Province. Other Government authorities (eg. the Police and Magistrates office, the Department of Western Province), should be made aware of the existences of the Maza Wildlife Management Area and asked to assist the committee in their own ways to help manage the area.

Other researchers (overseas or local) should be encouraged to collect data on the Maza Wildlife Management Area as the information can be used for making management decisions about the area.

Concluding Statement

Maza Wildlife Management Area provides one of the most important Marine Conservation Areas (WMA) in Papua New Guinea, therefore the successful management of the area is important. It is clear that continuous dialogue and consultation between the Government and the people is necessary to enable the people to maintain the area successfully and provide a basis for the effective management of marine resources such as dugongs and turtles.

Attachment

THE INDEPENDENT STATE OF PAPUA NEW GUINEA

STATUTORY INSTRUMENT.

No. 4 of 1981

Fauna (Protection and Control) Maza Wildlife Management area rules 1981.

Being by the Minister after consultation with the Maza Wildlife Management Committee under the Fauna (Protection and Control) Act 1966.

1 - INTERPRETATION.

In these Rules, unless the contrary intention appears-

"the Area" means the Maza Wildlife Managment Area;
"the Committee" means the Maza Wildlife Management Committee.

2 - RESTRICTION OF TAKING, ETC., OF DUGONG.

(l) Subject to Subsection (2), a person may at any time take catch or kill a dugong within the area by the traditional hand-harpoon method from a canoe, whether powered by out-board engine or otherwise.

(2) A person shall not take, catch or kill -

(a) a mother dugong or a baby dugong within the area; or
(b) a dugong, other than a mother or a baby dugong, except in accordance with Subsection (1)

3 - RESTRICTION ON USE OF NETS IN THE AREA.

(l) A person may use a net to take or catch Barramundi within the area and for that purpose shall only use a net the mesh size of which is 15.2 centimetres.

(2) Notwithstanding Subsection (1), a person shall not use, in the reef areas around Bobo and Daru Islands, a net the mesh size of which is over 5.1 centimetres.

4 - SELLING OF DUGONG AND TURTLE.

(l) A dugong or turtle taken or caught within the Area may only be sold in the market at Daru and in the case of a dugong-

(a) only one dugong may be brought in for sale at any one time; and

(b) the dugong shall be of 2.4 metres or above in length.

(2) Where a person intends to sell a dugong or a turtle in the market at Daru he shall, before offering it for sale-

(a) in the case of a dugong, bring it, in whole, to the Daru Wildlife Division Dugong Project Office for inspection by -

(i) a Wildlife Officer; or
(ii) a member of the Committee; or
(iii) a person authorized by a Wildlife Officer or member of the Committee; and

(b) pay to a member of the Committee or a person authorized by him, the total amount of royalty payable on a turtle or a dugong, as the case may be; and

(c) on payment of the royalty under Paragraph (b), be issued a receipt which shall be endorsed with -

(i) the name and village of the owner of the turtle or dugong; and
(ii) the amount of the royalty; and
(iii) the signature of the member of the Committee or the person authorized by him.

5 - ROYALTY.
A person who intends to sell a dugong or turtle in the market at Daru shall pay a royalty of K5.00 for each dugong and K1.00 for each turtle.

6 - PENALTY.
A person who, without reasonable cause (the burden of proof of which is on him, contravenes or fails to comply with a provision of these rules is liable to the appropriate penalties set out in the Act.

7 - REPEALED RULES.
The Fauna (Protection and Control) (Maza Wildlife Management Area) Rules 1979 are repealed.

DATED this day of , 1981.

MINISTER FOR ENVIRONMENT AND CONSERVATION.

THE INDEPENDENT STATE OF PAPUA NEW GUINEA

STATUTORY INSTRUMENT

No. of 1979

Fauna (Protecton and Control) (Maza Wildlife Management Area) Rules 1979.

MADE by the Minister after consultation with the Maza Wildlife Management Committee under the Fauna (Protection and Control) Act 1966.

1 - INTERPRETATION.
In these Rules, unless the contrary intention appears -

"the Area" means the Maza Wildlife Management Area.

2 - TRADITIONAL HAND-HARPOON METHOD MAY BE USED,
A person may at any time take or catch a dugong within the Area by the traditional hand-harpoon method from a canoe, whether powered by out-board engine or otherwise.

3 - RESTRICTION ON NETTING DUGONGS.

(l) A person shall not take or catch a dugong within the Area by means of a net except-

(a) during the months of May, June and July, and
(b) in the immediate area of Daru Island.

(2) Where a net is used to take or catch a dugong the mesh size shall not exceed ten inches.

4 - BEST ENDEAVOURS NOT TO TAKE, ETC., MOTHER OR BABY.

A person shall use his best endeavour not to take, catch or kill within the Area a mother dugong or a baby dugong.

5 - SELLING OF DUGONGS.

(l) A dugong taken or caught within the area may only be sold in the market at Daru.

(2) Where a person intends to sell a dugong in the market at Daru he shall, prior to offering it for sale, bring it to the Daru Wildlife Division Dugong Project Office for inspection by -

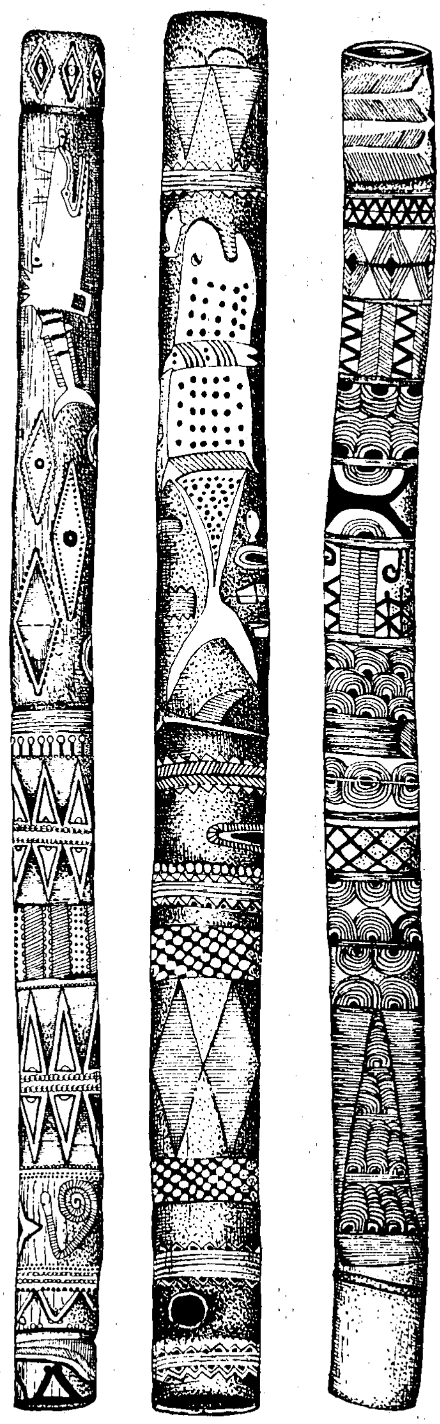
(a) a Wildlife Officer; or
(b) a member of the Maza Wildlife Management Committee; or
(c) any person authorised by a Wildlife Officer or member of the Maza Management Committee.

6 - PENALTY.
A person who, without reasonable cause, (the burden or proof of which is on him), contravenes or fails to comply with a provision of these Rules is liable to the appropriate penalties set out in the Act.

DATED the 13 day of 1/79. 1979.

MINISTER FOR THE ENVIRONMENT AND CONSERVATION.

TORRES STRAIT BASELINE STUDY



Bamboo smoking pipes

The Policy Context of the Torres Strait Environmental Baseline Study

Allan K. Haines, Marine and Coastal Section
Department of Arts, Sport, the Environment, Tourism and Territories

Introduction

The marine environment is a continuous medium, interconnecting all maritime countries. Ocean currents carry sediments, pollutants, and living organisms and many marine species move great distances. For these reasons it is not possible for any country acting in isolation to protect its marine resources or to conserve its marine biological diversity. It is increasingly being recognized that management of the marine environment must be carried out by countries working together in global, regional and bilateral contexts. The co-operation between Australia and Papua New Guinea to manage the Torres Strait marine environment is a bilateral arrangement which also has regional significance, and is indeed fulfilling a regional role in the South Pacific.

In the context of regional co-operation, my Department also welcomes the presence here of Professor Koewadji from Indonesia. We have close connections with Papua New Guinea and our South Pacific neighbours and we consider it important to build up similar connections with Indonesia.

SPREP Convention

Torres Strait falls within the area of the Convention for the Protection of the Natural Resources and Environment of the South Pacific Region (commonly known as the SPREP – South Pacific Regional Environment Programme – Convention). Australia and Papua New Guinea are partners, along with our South Pacific neighbours, in the development and implementation of this Convention.

In particular, the following Articles of the SPREP Convention are relevant to the environmental issues which our countries are dealing with in Torres Strait. In fact, our joint activities can be regarded as partial fulfilment of our obligations under that Convention.

ARTICLE 7
"POLLUTION FROM LAND-BASED SOURCES

The Parties shall take all appropriate measures to prevent, reduce and control pollution in the Convention Area caused by coastal disposal or by discharges emanating from rivers, estuaries, coastal establishments, outfall structures, or any other sources in their territory."

ARTICLE 13
"MINING AND COASTAL EROSION

The Parties shall take all appropriate measures to prevent, reduce and control environmental damage in the Convention Area, in particular coastal erosion caused by coastal engineering, mining activities, sand removal, land reclamation and dredging."

ARTICLE 14
"SPECIALLY PROTECTED AREAS AND PROTECTION OF WILD FLORA AND FAUNA

The Parties shall, individually or jointly, take all appropriate measures to protect and preserve rare or fragile ecosystems and depleted, threatened or endangered flora and fauna as well as their habitat in the Convention Area. To this end, the Parties shall, as appropriate, establish protected areas, such as parks and reserves, and prohibit or regulate any activity likely to have adverse effects on the species, ecosystems or biological processes that such areas are designed to protect. The establishment of such areas shall not affect the rights of other Parties or third States under international law. In addition, the Parties shall exchange information concerning the administration and management of such areas."

ARTICLE 16
"ENVIRONMENTAL IMPACT ASSESSMENT

1. The Parties agree to develop and maintain, with the assistance of competent global, regional and sub-regional organisations as requested, technical guidelines and legislation giving adequate emphasis to environmental and social factors to facilitate balanced development of their natural resources and planning of their major projects which might affect the marine environment in such a way as to prevent or minimise harmful impacts on the Convention Area.

2. Each Party shall, within its capabilities, assess the potential effects of such projects on the marine environment, so that appropriate measures can be taken to prevent any substantial pollution of, or significant and harmful changes within, the Convention Area.

3. With respect to the assessment referred to in paragraph 2, each Party shall, where appropriate, invite:

(a) public comment according to its national procedures;
(b) other Parties that may be affected to consult with it and submit comments.

The results of these assessment shall be communicated to the Organisation, which shall make them available to interested Parties."

ARTICLE 17
"SCIENTIFIC AND TECHNICAL COOPERATION

1. The Parties shall co-operate, either directly or with the assistance of competent global, regional and sub-regional organisations, in scientific research, environment monitoring, and the exchange of data and other scientific and technical information related to the purposes of the Convention.

2. In addition, the Parties shall, for the purposes of this Convention, develop and co-ordinate research and monitoring programmes relating to the Convention Area and co-operate, as far as practicable, in the establishment and implementation of regional, sub-regional and international research programmes."

ARTICLE 18
"TECHNICAL AND OTHER ASSISTANCE

The Parties undertaken to co-operate, directly and when appropriate through the competent global, regional and sub-regional organisations, in the provision to other Parties of technical and other assistance in fields relating to pollution and sound environmental management of the Convention Area, taking into account the special needs of the island developing countries and territories."

Torres Strait Treaty

While the SPREP Convention applies to the Torres Strait area, the primary basis for ordering affairs between Australia and Papua New Guinea in Torres Strait is the Torres Strait Treaty.

Under Article 10 of the Treaty establishes the Protected Zone, the principal purpose of which is to acknowledge and protect the traditional way of life and livelihood of the traditional inhabitants. A further purpose is to protect and preserve the marine environment and indigenous fauna and flora.

Article 13 deals with the protection of the marine environment, establishing the intent, the obligations on parties to protect the marine environment and procedures for consultation on the harmonization and implementation of measures.

Article 14 deals with the protection of flora and fauna and Article 15 prohibits the mining of the seabed or the drilling for exploration or exploitation of petroleum for ten years after the entry into force of the Treaty, with an option for parties to extend that period.

Article 19 establishes the Torres Strait Joint Advisory Council (JAC), which is comprised of representatives of the Australian, PNG, Queensland and Western Provincial Governments and of the Australian and PNG traditional inhabitants. The JAC's role is to seek solutions to problems and to review and make recommendations to the Australian and PNG governments on matters relating to the Treaty, including its environmental provisions. It has no responsibility for management or administration, which remains with relevant authorities.

Environmental Management Committees

There are two key requirements which form the basis of good management of a natural resource – communication and information. Management arrangements need to pay adequate attention to establishing appropriate mechanisms to ensure these two aspects. With respect to the environmental management of Torres Strait, the mechanism for communication is the Environmental Management Committee (EMC), and for information, the Baseline Study in Australia and relevant studies in PNG, particularly the Ok Tedi Mining Ltd (OTML) programme.

At its second meeting, in August 1988, the JAC noted that there was no mechanism for Australia and PNG to discuss policy and technical matters relating to the protection of the Torres Strait environment. It recommended that Australia and PNG establish such a mechanism.

In response to this recommendation the Australian and PNG Departments responsible for the environment jointly convened the EMC. The first meeting was held in February 1989 and the second in December 1989. It was agreed that membership of the EMC be open to all relevant agencies of the four governments plus the representatives of the traditional inhabitants. In addition, other interested parties can attend all or part of meetings with the agreement of both convening parties.

An open membership of agencies is considered to be important for a committee of this nature as environmental issues can change and develop quite rapidly. For example, the environmental implications of petroleum developments adjacent to the Torres Strait area is an issue which has arisen quite rapidly since the EMC was established.

The deliberations of the EMC are reported by the convening agencies to their respective Ministers. In addition, the EMC reports on its proceedings to the JAC, which in turn reports to the respective Ministers responsible for foreign affairs in each country. On the Australian side, the activities of the EMC have also been reported to the Torres Strait Fisheries Consultative Committee.

The traditional inhabitants participate in the EMC and the JAC and, on the Australian side, also in the fisheries consultative arrangements.

In developing this mechanism, the precedent of the fisheries arrangements under the Treaty which had been developed earlier by the respective fisheries authorities was followed as far as possible.

Development of the Baseline Study

The environmental implications of the Ok Tedi development have been given detailed attention in PNG since the initial conception of the project. A number of studies have resulted, the principal one being the monitoring programme being carried out by OTML.

The question of possible effects of Ok Tedi on Torres Strait was raised as long ago as 1980 during discussions at the seminar on "Traditional Conservation in Papua New Guinea". Participants at the "Torres Strait Fisheries Seminar" in 1985 expressed concern over the possible implications of Ok Tedi for Torres Strait traditional and commercial fisheries. Since then, the Torres Strait Island Co-ordinating Council, commercial fishermen, the scientific community and more recently some conservation groups have all expressed the view that an Australian environmental study was needed.

The then Department of Arts, Heritage and Environment commissioned a consultancy to design a study in 1987. The results of this consultancy have been incorporated into the design of the present study. Following representations by Islanders and commercial fishermen, the Prime Minister's Environment Statement of July 1989 announced the establishment of a four year environmental study of Torres Strait. The study, to be conducted in close consultation with the PNG Government, will collect data which will determine the background levels of metals and sediments in the Strait and assist in determining whether there is evidence of contamination from mining operations. It is intended to provide options for managing and protecting the Torres Strait environment.

Policy Objectives of Study

The study is not intended to be a monitoring programme, although the question of the need for and nature of a monitoring programme will be addressed by the study. The technical objective is to provide scientifically valid baseline information on the Torres Strait environment, against which any future changes can be measured. Since the study has taken some time to commence, clearly the baseline to be measured against will be the baseline as it presently exists, not the baseline as it may have been before mining began.

It is intended that the results of the study be used as a basis for decision making to manage the Torres Strait marine environment. DASETT wished to make the most efficient use of all available resources in the study, and therefore decided to endeavour to bring to bear all relevant agencies and sources of expertise onto the study.

The Great Barrier Reef Marine Park Authority is carrying out the study on DASETT's behalf because of its technical and management expertise in co-ordinating research projects of this nature.

It should be pointed out that at the time of the study was being developed only the Ok Tedi project was a reality and Porgera was being planned. Since then there have been:

- the decision to dump Porgera tailings into the Strickland watershed;
- the Horn Island mine has begun and finished;
- there is the likelihood of an oil terminal near Kikori with a consequent increase in tanker traffic;
- the possibility of off-shore petroleum developments near the Protected Zone has arisen;
- a chlorine bleach pulp mill in Irian Jaya, near Torres Strait, is reported to be under consideration;
- some preliminary studies have indicated that there may be natural high levels of heavy metals in the Torres Strait environment, and;
- a CSIRO study has shown that Torres Strait Islanders are among the highest consumers of seafood in the world.

In addition, PNG is developing a proposal for environmental management of the coastal Western Province and there is increasing interest in the long-term effects of climate change and possible sea level rise.

The study as designed has quite limited and narrow objectives developed with one particular project in mind. The question of whether the study should be broadened to take account of the increasing pace of developments has not yet been addressed by governments.

Reporting and Consultation

The progress of the study is being reported to DASETT and to the EMC. As well, relevant aspects are being reported by GBRMPA to the Great Barrier Reef Ministerial Council, which consists of the Commonwealth and Queensland Ministers responsible for environment and primary industries. This Council co-ordinates policy with respect to the management of the Great Barrier Reef.

Steps are being taken to ensure close consultation between the study and the traditional inhabitants, and with the relevant industries. These steps will be described by Dr Lawrence.

What happens if the study finds an environmental problem?

The simple and correct answer is that the problem would be addressed by the relevant governments of the day in the manner they judged appropriate, and in the context of overall Australia-PNG relations.

In a procedural sense, if researchers uncovered a particular environmental problem, then in the first instance the problem would be reported to DASETT. DASETT would brief its Minister and raise the problem at the EMC or through the EMC Convenor Department in PNG if out-of-session consideration was necessary. If the problem was relevant to the Great Barrier Reef then the GBR Ministerial Council would also be briefed. In due course, the EMC would also report to the JAC on the issue and the JAC may decide to make recommendations through the Australian and PNG Ministers responsible for foreign affairs. The traditional inhabitants would have input to deliberations in both the EMC and JAC. They would of course also be able to take up the issue through established political structures outside of the Treaty context, if they considered it in their interests to do so. Queensland and Western Provincial officials are also involved in the EMC and JAC, and would ensure appropriate involvement of their governments.

Affected industry groups would almost certainly have the opportunity to take part in EMC deliberations, although they are not represented on the JAC. They would also of course have access to existing political structures outside the Treaty context.

How the problem can be dealt with would depend very much on the nature of the problem, how important Governments judged the problem to be environmentally, socially and economically, the likely time-scale of the problem, possible mitigation or control measures, and the attitudes of the various interest groups. Australia and PNG have agreed that they share the same environmental concerns and that any problem that arose would be of common concern to both countries. While the problem may be dealt with to some extent through official and diplomatic channels, the decisions on action would rest with the relevant Governments of the day.

Sustainable Development for Traditional Inhabitants of the Torres Strait Region

David Lawrence, Coordinator
Torres Strait Baseline Study
Great Barrier Reef Marine Park Authority

Abstract

This paper will be an introduction to the background, administration and progress of the Torres Strait Baseline Study which is currently being undertaken by the Great Barrier Reef Marine Park Authority. This paper, therefore, follows on from the previous one in which Allan Haines outlined Commonwealth Government policy relating to environmental protection in the Torres Strait. It also serves as an introduction to the next paper in which Ian Dight will outline the nature and extent of the revised scientific programme due to commence in the Torres Strait in 1991.

The Torres Strait Region

The Torres Strait, which contains over 100 islands, islets, coral reefs and coral cays lying between longitudes 141°15'E and 144°20'E, and latitudes 9°20'S and 10°45'S, consists of approximately 30,000 square kilometres of shallow water. As was stated in the keynote address (see Kelleher, this volume), the Torres Strait is a complex mosiac of different environments. Extensive seagrass beds occur in the western and northern areas. In this region of muddy and turbid waters large numbers of dugongs (*Dugong dugon*) are found (see Marsh and Saalfeld, this volume). Along the coast of Papua New Guinea and adjacent islands mullet, barramundi, prawns and crabs are common. In the clear waters and coral reefs of the east near the most northerly section of the Great Barrier Reef, are the rich commercial fishing grounds for rock lobster, prawns, reef fish and for pelagic fish such as mackerel (see Phillips and Crossland, and

Pitcher, this volume). Six species of sea turtles, including the green turtle (*Chelonia mydas*), are also found in the Torres Strait (Heinsohn and Wolanski 1985)(see Kwan, and Miller and Limpus, this volume).

Geographically the islands in the Torres Strait can be divided into four main groups: an eastern group of fertile islands; a central group of low sandy cays; a western group of high, mostly granitic, islands of limited fertility; and a 'top' western group of low swampy islands composed of mangrove muds and peats (Lawrence 1989a). The Torres Strait is the 'traditional' home of the Torres Strait Islanders, Australia's only Melanesian minority group. To some extent, the Islander people may also be divided into eastern, central, 'top' western and western groups with language, social and cultural differences whose subtleties are often unnoticed by the wider Australian community (see Fitzpatrick, and Beckett, this volume). In former times, subsistence strategies varied across the region. In the eastern islands, and to some extent the 'top' western islands, horticulture was combined with occasional fishing. Horticultural practices were similar to those adopted by the Papuan people to the north. The eastern Islanders also built large rock-walled fishtraps which filled with the rising tide and left fish and turtles stranded in the shallows on the falling tide. In the less fertile central and western islands the populations were more mobile, particularly during the long dry period from about May to November, and subsistence strategies emphasised fishing, marine hunting for dugongs and turtles, reef foraging and opportunistic horticulture (Nietschmann, 1984)(see Johannes and MacFarlane, this volume). Subsistence strategies in the lower western islands were similar to those of the mainland Aboriginal people.

Population groups in the Torres Strait, prior to sustained contact with Europeans after the 1840s, were small and dependent upon the seasonality of horticulture, and upon established hunting and fishing practices which varied according to access to resources.

External contacts with the Papuan people to the north and the Australian Aboriginal people to the south were maintained. The creation of artificial dependencies through patterns of customary exchange, ritual, and marriage bound the people of the Torres Strait into small self-contained groups. The patterns of customary exchange which linked Islanders to Papuans and Aboriginal groups provided a means for the circulation of scarce resources, valued exchange objects and foodstuffs such as garden-foods and fresh and dried seafoods. This exchange enabled the small, acephalous groups to survive during periods of drought and famine and permitted reciprocal exchange and distribution of surplus during periods of plenty (Lawrence 1989a).

The principal valued exchange items were cone shells (*Conus litteratus* and *Conus leopardus*) which were exchanged for canoe hulls from the Fly estuary, weapons, such as bows and arrows, stone-headed clubs, and even women. Papuan cultural influences are therefore strong in the eastern and northern parts of the Torres Strait islands. Torres Strait cultural influences also extended down the Queensland coast to as far as Princess Charlotte Bay (Chase 1980, Thomson 1933, 1934). Marine resources remain important to Islander and Papuan people (see Johannes and MacFarlane, this volume). In the Torres Strait region dugongs and turtles are important culturally for they are valued seafoods in customary exchange and feastings, particularly those associated with 'tombstone openings' which signal the end of the mourning period. The myths and legends of the Islander people are rich in reference to fish, turtles, dugong, shellfish and other sea creatures (Lawrie 1970 and Lawrence 1989b).

Southwest Coast of Papua New Guinea

In contrast to the reefs and islands of the Torres Strait the southwest coast of Papua New Guinea is generally flat and featureless. The only high point along the entire southwest coast is the 59 metre hill at Mabudawan at the mouth of the Pahoturi River. The narrow coastal plain, backed by the low Oriomo Plateau, is flooded during the wet season from December to April and dessicated during the dry. The few large rivers which all enter into the northern Torres Strait such as the Oriomo, Binaturi, Pahoturi, Morehead and Bensbach are slow moving, muddy and widely spaced. The coastal mangrove swamps are extensive while the shallow coastal waters are dangerous with many hidden shoals, old reefs and mudbanks. To the north the Fly River, the largest river in Papua New Guinea, bisects the Western Province. North of the Fly is a vast, and spectacular, wetland. In the Fly estuary there are numerous islands and sandbanks separated by wide channels which are subject to rapid change from flood waters and tidal flows.

A number of indigenous groups live along the narrow coastal plain and these people are mostly horticulturalists. However, the most dominant cultural group in the southwest region is the Kiwai-speaking people who live in widely spaced villages from Parama Island in the east to Mabudawan in the west. These coastal villages are built on narrow sandridges backing onto the mangrove swamps and tidal inlets. The Kiwai are predominantly subsistence fishermen, with little access to garden lands, who supplement their diet with sago starch obtained from the many sago palms which grow in the large palm swamps on the estuarine islands. The coastal Kiwai moved out of their traditional home villages in the Fly estuary and moved south eventually settling on the southern coast towards the end of the last century. They have also settled on the inhabited islands in the Torres Strait where they live in small squatter settlements near the Islander villages. Their lifestyle and status as second class citizens can be seen in contrast to the relative prosperity of the Islanders. The Kiwai have, since the later 1890s, been recruited as cheap labour on the commercial fishing boats in the Torres Strait. Remitted monies, and end of season payments, have been important sources of cash money to the coastal Papuan people who live in the most economically depressed and underdeveloped part of Papua New Guinea (see Lawrence, this volume).

The commercial fishery continues to be the major industry in the Torres Strait region (see Elmer, this volume). As has been stated, this industry is economically unpredictable, dependent on national and international tastes and market-place decisions beyond the control of local fishermen. The Torres Strait region has a long history of boom and bust commercial marine industries. Protection of the commercial fisheries is important for Islander and Papuan livelihoods as it remain one of the only sections of the Australian economy open to Islanders who wish to continue living on their home islands (see Arthur, this volume). In Islander, and Papuan, communities where cultural patterns emphasise the importance of marine resources, and where economic opportunities revolve around the exploitation of those marine resources, protection of the marine environment assumes a high profile.

It is apparent from papers presented at this conference that the Torres Strait region, including the Fly estuary and southwest coast constitutes a vast area of considerable geographical, ecological and cultural diversity. All these factors must be taken account of in policies relating to ecological sustainable development, conservation of the natural environment, protection of endangered species and social, cultural and economic rights of the indigenous people of Torres Strait.

The constant supply of marine resources, in contrast to the fluctuating supply of garden and bush foods, has meant that both Torres Strait Islanders and Papuans depend on marine resources for their continued survival. Protection of the marine environment is also important to the wider Australian community, particularly to the valuable commercial fishing industry, as well as to local indigenous groups.

Mining Developments in the Fly River Catchment Area

There has been considerable public and scientific concern both in Australia and Papua New Guinea about the possible environmental problems associated with mining operations in the Fly River catchment area. Of principal concern is mining pollution from the Ok Tedi mine the large copper, and formerly gold, mine at Mt Fubilan in the Star Mountains region (see Eagle, and Smith, this volume). However, in recent years, other mining developments have been approved which also have an impact on the Fly river ecosystem. The gold mining development at Porgera (Mt Waruwari) in Enga Province commenced production in 1990 (see Ross, this volume) and the Mt Kare alluvial gold field, also in Enga Province, is expected to begin production soon.

Gold production commenced at Ok Tedi in 1984 but ceased in 1988 after the gold cap had been worked out. Copper concentrate production commenced in 1987 and is expected to peak between 1989 and 1992 (ANZ McCaughan 1990). The original plan for Ok Tedi included the construction of a tailings dam prior to the commencement of ore production. However massive landslips in 1983 and 1984 made the completion of the Ok Ma tailings dam impossible. The company sought, and obtained, an agreement from the PNG Government to dispose of tailing fines and overburden into the river systems via direct discharge or by use of failing dumps. It has been estimated that the natural sediment load of the Fly River, measured below the confluence of the Strickland River, was in the order of 74 million tonnes per annum (mta). Of this, 66 mta can be attributed to the natural sediment load of the Strickland River. Present mining operations at Ok Tedi add a further 62 mta of ore residue and overburden into the river system by way of naturally eroding slips and direct input. Of this approximately 42 mta of material under 100um is expected to reach the estuary (Lawrence and Dight in press). Maximum production levels at Porgera will release perhaps 4.4 mta into the Strickland. Both Ok Tedi and Porgera companies conduct extensive environmental monitoring programmes in the river systems, and OTML is currently funding considerable oceanographic research into current and sediment movements in the Fly River, Fly estuary and the Gulf of Papua (Wolanski, Pickhard and Jupp 1984 and Wolanski, Ridd and Inoue 1988)(see Wolanski, this volume).

A number of concerns have arisen about the possible effects of sediment and particulate copper contamination in the Fly River, the estuary region (see Baker, and

Harris, this volume) and also in the Strickland River into which Porgera discharges fines and overburden. The marine ecological implication of the disposal of large volumes of mine tailings and overburden into tropical river systems are still largely unknown (see Furnas, Robertson, and Waite, this volume). Possible effects on the environment include increased particulate loading of the Fly River system which may cause significant loss of productivity and increased sediment in rivers may also eliminate bottom dwelling species. However, a more serious problem may be the translocation and incorporation of residual metals from tailings waste into marine sediments, and the subsequent uptake by marine organisms of the Torres Strait. The processes of bio-accumulation are also presently unknown. Therefore the accumulation of trace metals in important commercial and community fisheries, particularly the mackerel, prawn and rock lobster fisheries, have become issues of considerable concern to the northern commercial fisheries industry. Damage to corals in the Great Barrier Reef region, detrimental effects on endangered species such as dugong and turtle, and the possibility of potential human health problems from increased metal content in seafoods, particularly among Torres Strait Islanders who have one of the highest per capita consumption rates of seafoods in the world, have also become concerns. Damage to the backswamps, lagoon and creeks which provide fish and drinking water for the villages in the upper and middle Fly River and Ok Tedi region have not been investigated nor have the long-term cultural effects of environmental damage on subsistence livelihoods of the indigenous peoples of these regions been considered (see Busse and Hyndman, this volume).

Torres Strait Baseline Study

In 1989 the Australian Prime Minister announced, as part of his Statement on the Environment, that the Commonwealth Government would fund a four year environmental programme of the Torres Strait marine environment. This funding was in response to concerns expressed by both Islanders and scientists at the Torres Strait Fisheries Seminar held in Port Moresby in 1985 (Haines et al 1986). At this meeting the following statement was endorsed:

> Because the Fly River is the largest and most important freshwater input into the Torres Strait region, the participants of the Torres Strait Fisheries Seminar wish to express serious concern over the possible effects that dumping of Ok Tedi mining wastes in the Fly River may have, directly or indirectly, on Torres Strait fisheries.

The seminar recommended that a scientific environmental monitoring programme be established as soon as possible to investigate the problem of possible mining pollution in the Gulf of Papua and adjacent Australian waters.Funds for the Torres Strait Baseline Study have been provided for the periods 1989/90 ($150 000), 1990/91 ($200 000), 1991/92 ($200 000) and for 1992/93 ($200 000) (Hawke 1989). It has become apparent however that in order for the study to assess the levels of heavy metals in the Torres Strait the funding provided will need to be increased. The expectations of the Torres Strait Islander people, who are demanding a long-term monitoring programme, may not be met. Regrettably no comprehensive marine management plan exists for the Torres Strait region. Notwithstanding these problems the study has been given positive support by Islander people and will provide important baseline data on the present state of the Torres Strait marine environment.

The Great Barrier Reef Marine Park Authority has been charged with the management of the study because of expertise, and experience, in managing marine environmental research in northeastern Australia. However, the most northerly section of the barrier reef, which forms the eastern boundary of the Torres Strait, is not within the jurisdiction of the Marine Park Authority.

The baseline study will acquire data which will assist in determining the extent of influence of Fly River discharge and whether there is evidence of contamination in the sediments and in the biota of the Torres Strait from mining operations in the Fly River catchment area and provide options for management of the marine environment. The objectives of the baseline study programme are: to establish existing levels of trace metals within the sediments and biota; to identify the important transport, geo-chemical and trophic pathways of trace metals in the Torres Strait marine environment; to determine the potential effects of trace metal concentrations on selected marine organisms; to access the potential effects of present and future mining operations on sediment loads and trace metal concentrations, and, to provide a basis for an ongoing monitoring programme in the Torres Strait.

The original programme proposal entitled *Programme for Torres Strait Baseline Pollution Study*, was prepared by Marine and Freshwater Research for the then Commonwealth Department of Arts, Heritage and Environment, in 1987. This programme formed the basis for earlier costings of the study and have, naturally, become outdated in the light of recent industrial developments in Papua New Guinea particularly the recent opening of the Porgera gold mine in Enga Province, and the Kutubu Petroleum Development Project planned for the Kikori region of the Gulf Province. Therefore the scientific programme proposal has been rewritten and has been submitted for approval to the Advisory Committee. The objectives, and the operation of the scientific programme will be examined in detail in the following paper. Briefly, they are to:

- establish existing levels of trace metals within the water, sediments and selected marine organisms of the Torres Strait;
- identify the important transport, geochemical and trophic pathways of trace metals within the Torres Strait;
- determine the potential effects of trace metal concentrations on selected marine organisms in the Torres Strait;
- assess the potential effects of present and future mining operations in the Fly River catchment area on the levels of sediment and trace metals in the Torres Strait; and
- provide the basis for an ongoing monitoring programme for trace metal levels and their effects within the Torres Strait.

The Coordinator is responsible for the effective management of the study and, through the Assistant Executive Officer - Research and Monitoring, reports to the Great Barrier Reef Marine Park Authority and to the Department of Arts, Sport, the

Environment, Tourism and Territories. The Coordinator also acts a secretary to the Advisory Committee and will be responsible for the management of contracted research projects, the coordination of the scientific programme and liaison with other departments, governments and mining companies. The proceedures for the management of research projects and coordination of contracted reseach are well established within the Research and Monitoring Section of the Great Barrier Reef Marine Park Authority.

In addition to the Coordinator's position, two other positions, a part-time Scientific Adviser and an Assistant Coordinator, have been established to provide support to the Coordinator and facilitate the efficient operation of the study.

The Great Barrier Reef Marine Park Authority has appointed Mr Ian Dight as Scientific Adviser to the study. Mr Dight will provide advise on the operation of the scientific research programme and will identify the needs and priorities of the scientific research and monitoring programme. The first task of the Scientific Adviser was to revise the original baseline programme (see Dight, this volume). The Scientific Adviser will also obtain written reviews of research proposals in a variety of scientific fields including marine engineering, and biological studies.

An Assistant Coordinator, Mr Vic McGrath, now attached to the Island Coordinating Council on Thursday Island, commenced duties in January 1991. His appointment was be made in consultation with the Aboriginal and Torres Strait Islander Commission (ATSIC) and his role will be to carry out fieldwork on the community and commercial fishery collection project in the Torres Strait. In addition the Assistant Coordinator will ensure that the nature and the progress of the Baseline Study is explained to the communities of the Torres Strait and that the activities of the scientific programme, paticularly the field work components, are fully understood by the Torres Strait Islander people.

The Assistant Coordinator will be based on Thursday Island so that contact can be maintained with Islander communities and Islander organizations such as the Island Coordinating Council and the newly formed Regional Council which will advise ATSIC on Torres Strait Islander affairs. This will also mean that Islander people can articulate their needs and concerns directly with an officer on Thursday Island who is familiar with the politics and culture of Torres Strait Islander people.

An Advisory Committee, which will advise the Great Barrier Reef Marine Park Authority, has been formed and the Committee has held regular meetings. The Advisory Committee is comprised of representatives from the Australian, Queensland and Papua New Guinea Governments as well as scientists and academics. The Advisory Committee will meet to review existing research data, such as that presented at this conference, to review applications for funding for research to be conducted for the Baseline Study and to approve the nature, direction and financial allocations for scientific research. The Committee will also review the progress of the scientific programme, recommend research priorities, and the release of public information.

The Minister for Arts, Sport, the Environment, Tourism and Territories will be informed of the progress of the Baseline Study through normal departmental channels via the appointment of a nominee in the Department.

It is apparent that the Torres Strait marine environment is perceived, particularly by Islanders, to be at a crucial point in its history. Torres Strait Islanders see their home reefs and the rich marine environment as being under threat from mining developments from which they receive no benefits, and from developments which are beyond the direct jurisdiction of the Australian Government despite the environmental and cultural provisions of the Torres Strait Treaty between Australia and Papua New Guinea.

Torres Strait Treaty

Following the Independence of Papua New Guinea in 1975 a treaty was drawn up which establishes the maritime and international boundaries between Australia and PNG (Australia. Treaties 1978). The treaty, which was signed in December 1978 and ratified in February 1985, also serves to protect the importance of the traditional way of life and livelihood of the Islanders and Papuans who share common access to the natural resources of the Torres Strait region. The Torres Strait Treaty also permits free movement in and out of the region by traditional inhabitants of both the Torres Strait islands and the adjacent areas of Papua New Guinea and provides for mechanisms for the protection of the marine environment while allowing for freedom of access for vessels and aircraft from both countries (see Laffan, this volume). Under the treaty commercial catch-sharing arrangements for fisheries resources and certain seabed mineral rights are specified.

Significant features include the creation of the separate Seabed Jurisdiction Line which is also the boundary of sovereignty with the exception of fifteen islands or cays north of that line, including the important inhabited islands of Boigu, Dauan and Saibai, over which PNG recognized Australian sovereignty. As well as this a Fisheries Jurisdiction Line was established and a complex system of commercial fisheries catch sharing arrangements established between the two countries. The central element in the operation of the provisions of the Treaty has been the creation of the Torres Strait Protected Zone which was established north of $10^{o}50$ S. The treaty also specifically acknowledged that the protection of the traditional way of life and livelihood of the people of the Torres Strait region was an essential element in the treaty. The Protected Zone comprises all the land, sea and airspace, seabed and subsoil in the defined area which can generally be described as the whole of the central Torres Strait but excludes the regional administrative centre of Thursday Island and the provincial administrative centre of Daru.

Papua New Guinea has also enshrined environmental management and protection in its Constitution. The fourth national goal states that conservation of natural resources shall be for the collective benefit of the people as a whole. Replenishment of natural resources for future generations is also incorporated in this stated goal (Pernetta 1988).

In 1988 the Joint Advisory Council, the principal advisory body formed under the treaty, recommended the formation of the Torres Strait Environmental Management Committee (EMC) as a consultative body for detailed consideration of environmental issues. The EMC has, to date, met three times and has discussed a wide range of environmental matters of concern to both countries. Membership of the committee is open to relevant agencies of the four Governments (National and State or Provincial) together with membership from the traditional inhabitants. Other parties can attend all or part of the meetings with agreement from convening parties which are usually the Australian Government Department of Arts, Sport, the Environment, Tourism and Territories and the PNG Government Department of Environment and Conservation. The deliberations of the EMC are reported, by the Departments, to their respective Ministers. The EMC also reports to the JAC and to the other fisheries management bodies responsible for management of the commercial fisheries resources. Islander representatives are members of all Torres Strait treaty committee and working groups. The EMC has facilitated detailed bilateral discussions about the effects of mining operations, communicated the needs for oil contingency plans in the Gulf of Papua, examined seagrass resource information and has enabled bilateral discussion between Australia and Indonesia to take place. The Great Barrier Reef Marine Park Authority reports on the operation and research activities of the baseline study to the JAC and the deliberations of the EMC are reported to the Great Barrier Reef Ministerial Council which consists of the two Australian Commonwealth Ministers and the two Queensland State Ministers of the departments responsible for the administration of the environment, primary industries and fisheries resource management.

The most important aim of the study is that it will provide background information for options for managing and protecting the Torres Strait environment as required under Article 13 of the Torres Strait Treaty which requires that both Australia and Papua New Guinea shall take legislative and other measures to protect and preserve the marine environment in, and in the vicinity of, the Torres Strait Protected Zone. Each party is required to take measures for the prevention and control of pollution, or other damage, to the marine environment from all sources and activities, in particular, to minimise the extent of the release of toxic, harmful, or noxious substances from land-based sources.

Mechanisms for the preservation of the livelihood of traditional inhabitants and the protection of the environment have, to a large extent, been implemented with the establishment of the Torres Strait Protected Zone under the treaty. The treaty has enabled Islanders and Papuans to have more direct input into issues of concern to them and given indigenous inhabitants a greater involvement in the decision-making process at a senior Government level. The full economic and social impact of the treaty has still to be fully appreciated. Discussions over complex issues such as control of pollution from mining operations have been open and frank.

Conclusion

Preservation of the marine environment in the Torres Strait and the Fly River is essential to the long-term security and survival of the Torres Strait Islander and coastal Papuan peoples. The coastal Kiwai people are in a particularly vulnerable position for they have limited access to the economic benefits of mining development while, as subsistence fishermen, they will be directly disadvantaged by high sediment loads and trace metal contamination in the rivers and seas. Unlike their Torres Strait Islander neighbours they have no access to government sponsored social security benefits or to government economic development schemes, nor do they have the economic infrastructure and political unity needed to develop regional marine industries to their own advantage.

The Torres Strait Treaty is an effective bilateral arrangement for the open and frank discussion of environmental matters of concern to both countries. It is fortunate that the mechanisms for discussion and debate are in place and that all meetings relevant to the management and long-term protection of the marine environment of this culturally, ecologically and biologically diverse area contain representatives from traditional inhabitant groups from both countries. However, while the treaty recognizes the importance of the customary way of life and livelihood of the traditional inhabitants of the region, and provides a means for the open discussion of issues of concern between the two countries, the difficult question of maintaining the functional integrity of the 'traditional' economic base while managing resources for broad scale economic and social development of marginal areas still remains unresolved.

Cooperation and consultation between diverse groups with different cultural patterns, languages and issues of fundamental concern, particularly over the complex issue of balancing the demands for economic development with sustainable use of renewable and non-renewable resources, will always be a problem in the Torres Strait region. However, cooperation and consultation also the keys to the success of the Torres Strait Baseline Study.

Much research has already been conducted in the Torres Strait region. One of the aims of this conference was to bring together researchers from different areas in order to give focus and direction to the Torres Strait Baseline Study. The baseline study remains restricted by financial and time constraints. It is important that full use is made of the research already undertaken in the Torres Strait. Much of that research is presented in these proceedings. The funding allocated to the study is not sufficient to answer all questions of concerns regarding environmental protection of the Torres Strait region. Mining commenced in 1981 and it is obvious the the term 'baseline', as applied to the study, is misleading. However the study is a significent step towards the environmental protection of the region.

The Torres Strait Baseline Study is designed to ensure that the quality of the marine environment of the Torres Strait will be maintained for the sustained use of its living resources, particularly be traditional inhabitants, and that the indigenous marine species and genetic diversity of this region is protected for present and future generations.

Bibliography

ANZ McCaughan (1990), *Papua New Guinea: resource development*, ANZ McCaughan Securities Ltd, Melbourne.

Australia. Treaties (1978), *Treaty between the Independent State of Papua New Guinea and Australia*, Department of Foreign Affairs and Trade, Port Moresby.

Burmester, H. (1982), 'The Torres Strait Treaty: ocean boundary delimitation by agreement', *American Journal of International Law*, 76, 321-349.

Chase, A.K. (1980), Which way now?: tradition, continuity and change in a North Queensland Aboriginal community. PhD thesis, University of Queensland, St Lucia.

Haines, A.K., Williams, G.C. and Coates, D. (ed) (1986), *Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985*, Australian Government Publishing Service, Canberra.

Hawke, R.J.L. (1989), *Our Country, Our Future*, Australian Government Publishing Service, Canberra.

Heinsohn, G.E. and Wolanski, E. (1985), 'The Torres Strait', *Habitat*, 13(6), 12-18.

Lawrence, D. (1989a), The material culture of customary exchange in the Torres Strait and Fly estuary region, PhD thesis, James Cook University of North Queensland, Townsville.

Lawrence, D. (1989b), ' From the Other Side: recently collected oral evidence of cross-cultural contacts between Torres Strait Islanders and the Papuan peoples of the southwestern coast', *Aboriginal History*, 13(1-2), 95-123.

Lawrence, D. and Dight, I. (in press), 'The Torres Strait Baseline Study: environmental protection of a tropical marine environment in northern Australia', paper to be presented at the Coastal Zone '91 conference, Los Angeles.

Lawrie, M. (1970), *Myths and Legends of Torres Strait*, University of Queensland Press, St Lucia.

Nietschmann, B. (1984), 'Indigenous island people, living resources and protected areas', In Jeffrey McNeely and K. Miller (eds), *National Parks, Conservation and Development*, Smithsonian Institution Press, Washington, 333-343.

Pernetta, J.C. (1988), 'The Ok Tedi mine: environment, development and pollution problems', In J.C. Pernetta (ed), *Potential Impacts of Mining on the Fly River*, UNEP, Nairobi, 1-8.

Thomson, D.F. (1933), 'The hero cult, initiation and totemism on Cape York', *Journal of the Royal Anthropological Institute of Great Britain and Ireland*, 63, 453-537.

Thomson, D.F. (1934), 'The dugong hunters of Cape York', *Journal of the Royal Anthropological Institute of Great Britain and Ireland*, 64, 237-262.

Wolanski, E., Pickard, G.L. and Jupp, D.L.B. (1984), 'River plumes, coral reefs and mixing in the Gulf of Papua and the Northern Great Barrier Reef', *Estuarine, Coastal and Shelf Science,* 18, 291-314.

Wolanski, R., Ridd, P. and Inoue, M. (1988), 'Currents through Torres Strait', *Journal of Physical Oceanography,* 18, 1535-1545.

The Torres Strait Baseline Study Scientific Programme: Assessing the Impacts of Heavy Metals in a Physically Complex and Biologically Diverse Tropical Marine System

Ian J. Dight, Scientific Adviser
Torres Strait Baseline Study
Great Barrier Reef Marine Park Authority and
James Cook University of North Queensland

Abstract

The Torres Strait Baseline Study is concerned with the identification of impacts from heavy metals on human health and the resources of the Torres Strait. The study was instigated in response to concerns about the possible effects of mining developments, particularly those within the Fly River catchment of Papua New Guinea. Its purpose is to acquire data that will assist in determining the extent of influence of Fly River discharge and whether there is evidence of contamination from mining operations.

This paper outlines the Torres Strait Baseline Study scientific programme objectives, the conceptual design of the scientific programme, and provides details of the pilot study which is to commence in 1991. An initial aim of the programme is to establish the spatial and temporal variation in trace metal concentrations within the Torres Strait. The study design seeks to correlate change in the concentration of trace metals along a series of transects away from the mouth of the Fly River with physical and chemical parameters related to river discharge and material of terrigenous origin. The programme is exploratory in design as our present understanding of trace metal distribution and bio-availability within the Torres Strait is limited. Three basic methods will be used to quantify trace metal concentrations: analysis of water, sediments and biota. The sampling of biota is an important focus of the programme and will include species of relevance to the community and commercial fisheries, as well as the identification of suitable indicator organisms of trace metal bio-availability.

Introduction

The Torres Strait Baseline Study scientific programme was instigated in response to concerns about the possible effects of mining developments, particularly those within the Fly River catchment of Papua New Guinea. The purpose of the scientific programme, therefore, is to acquire data that will assist in determining the extent of influence of Fly River discharge and whether there is evidence of contamination from mining operations. In order to be able to determine the impacts of metals associated with discharge from coastal river systems on the resources of the Torres Strait, now and in the future, it will be necessary to, firstly, describe the spatial and temporal distribution of trace metals and then develop an understanding of the physical, chemical and biological processes associated with trace metal impacts.

The evaluation of trace metal impacts on the resources of the Torres Strait will not be a simple task, as the region is physically complex, biologically diverse and poorly understood. Furthermore, there are few data which correspond to pre-mining conditions from within the Torres Strait. Thus, such an evaluation will require some consideration and understanding of:

- present concentrations of trace metals within the Torres Strait, for, amongst other reasons, a datum against which to compare concentrations measured within the region in the future;
- the frequency and extent of trace metal inputs from the Fly River system;
- chemical speciation, or change from one chemical form to another;
- partitioning of trace metals between the different fractions, including free metal ions, colloids, inorganic and organic particulate forms;
- bioavailability of trace metals, including transfer up the food chain; and
- the remobilization of trace metals from temporary sinks, such as bottom sediments, by both physical and biological mechanisms.

The Torres Strait Baseline Study will complement the monitoring programme currently being conducted in the Fly River, Fly estuary and Gulf of Papua by Ok Tedi Mining Limited and its consultants, and will be conducted in close cooperation with the Papua New Guinea Government. The results of the scientific programme should provide options for appropriate management of the resources of the Torres Strait in relation to trace metals. The Torres Strait Baseline Study aims to provide background information and options for managing and protecting the Torres Strait marine environment as required under Section 13 of the Torres Strait Treaty. The treaty requires that both Papua New Guinea and Australia take legislative and other measures to protect and preserve the marine environment, not only within the Torres Strait Protected Zone but also in its vicinity.

The Baseline Study Objectives

The baseline study scientific programme objectives are to:

- establish existing levels of trace metals within the water, sediments and selected marine organisms of the Torres Strait;
- identify the important transport, geo-chemical and trophic pathways of trace metals within the Torres Strait;
- determine the potential effects of trace metal concentrations on selected marine organisms in the Torres Strait;
- assess the potential effects of present and future mining operations in the Fly River catchment on sediment loads and trace metal concentrations in the Torres Strait;
- provide the basis for an ongoing monitoring programme for trace metal levels and their effects within the Torres Strait.

An aim of the Torres Strait Baseline Study scientific programme is to establish the spatial extent and temporal variation of trace metal inputs to the Torres Strait from the Fly River. It is necessary to remember that metals occur naturally in the marine ecosystem and that background concentrations of various metals are a result of inputs from a variety of sources. Rivers draining highly mineralised areas, such as the Fly River system, are a natural source of metals to the marine environment. This poses particular problems with respect to the identification of increased levels due to mining operations.

It is not anticipated that the Baseline Study scientific programme will necessarily be able to differentiate between the possible causes, natural or otherwise, of elevated trace metal concentrations should they be shown to exist. This would require further research. The aim, at this stage, is to establish present levels and to determine whether or not a potential problem exists, either to human health or ecologically sustainable development, which can be attributed to Fly River discharge. The Torres Strait Baseline Study is designed to ensure that the quality of the marine environment of the Torres Strait is maintained for the sustained use of its living resources, particularly by indigenous inhabitants of the region, and that the marine species and genetic diversity of this region is protected for present and future generations.

Conceptual Design of the Programme

Three basic methods will be used to quantify trace metal concentrations in the Torres Strait: analysis of water, sediments and biota. The sampling of biota will be an important focus of the baseline study. It is intended to sample community and commercial fishery species, indicator organisms, and to investigate seasonal variation in trace metal bio-availability.

The Fly River catchment is considered as a point source of impact of trace metals on Torres Strait resources. As such, the study design will seek to identify a gradient of change in a number of parameters away from the mouth of the Fly River. The programme will seek to correlate change in the concentration of trace metals with physical and chemical parameters related to river discharge and material of terrigenous origin. The programme needs to be exploratory as our present understanding of trace metal distribution and impacts within the Torres Strait is limited.

The sampling program will be carried out along five transects; all lie within important habitats and/or along the most likely transport pathways into the Torres Strait (Figure 1). A series of sampling stations has been identified along each transect. The sampling stations are not spaced equally along the transects as the available data suggest that there is likely to be a steep gradient adjacent to the coast of Papua New Guinea, beyond which the influence of the Fly River may be substantially reduced.

There will be a series of replicate sites per station and replicate samples will be collected per site. The sampling station is the basic unit against which spatial and temporal trends will be assessed. The final design of the programme, including the number of stations and their spacing, could be modified in light of results from the pilot study that will commence in 1991.

Due to the magnitude of discharge from the Fly River into the Gulf of Papua and its close proximity to the Torres Strait, all five transects are situated within areas which, at this stage, must be assumed to be influenced by Fly River discharge. Therefore, no areas within the Torres Strait can be identified as suitable 'control' or unaffected sites. However, control sites are required if spatial and temporal trends in metal concentrations are to be identified and attributed to Fly River discharge. Control sites are therefore located in areas adjacent to the Torres Strait which are representative of the different physical and biological environments covered by the five transects.

It is anticipated that there will be two main sampling periods for sediments and biota: one near the end of the monsoon season (March) and the other towards the end of the dry season (October-November). Chemical analysis will be carried out for a range of potentially toxic metals, including As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Se, Sn and Zn, as well as metals such as Al, Ca, Fe, Mn and Si which may provide insight into the reactivity of metals and be used as indicators of the source.

Sampling of Water Quality

Phillips (1980) identifies several disadvantages associated with the use of water analysis as an indicator of trace metal availability. In particular, he draws our attention of the difficulty of producing a time-integrated value of pollutant bio-availability at any specific location. Trace metal concentrations present in the water at any location can show extreme temporal variation. Accurate estimates of time-integrated concentrations therefore requires relatively frequent sampling. Other disadvantages include the low concentrations of many metals, which give rise to problems of analytical sensitivity and sample contamination.

Trace metal inputs to the Torres Strait may be pulsed, with episodic events coinciding with particular combinations of meteorological conditions resulting in most input. The water quality programme is process oriented, and a principal focus will be to determine the frequency of discharge from the Fly River into the Torres Strait, the

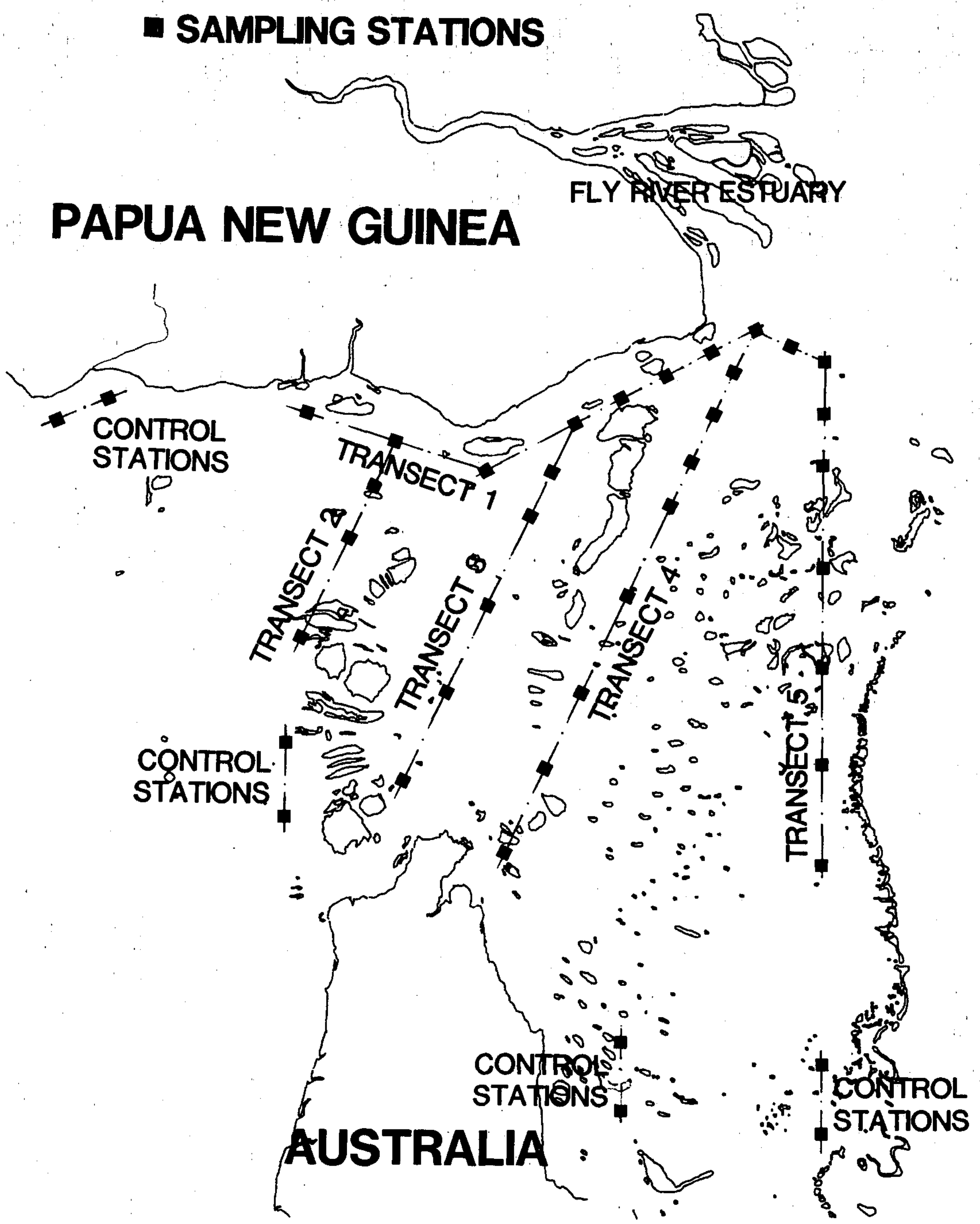


Figure 1. Map of the Torres Strait showing the location of sampling stations for sediments. The conceptual design of the scientific programme is illustrated by the five transects.

extent of penetration, the prevailing oceanographic conditions and trace metal concentrations. Meteorological data extending over the period of the study will be obtained and analyzed.

Water quality sampling will ideally be carried out as frequently as possible at a sub-set of stations for physical characteristics (temperature, salinity, silicate concentrations, turbidity, etc.) as well as for dissolved, particulate and total metal concentrations. This component will aim to sample water quality over a range of different meteorological conditions, including wind direction and discharge rates from the Fly River.

Sampling of Sediments

Metals associated with inorganic particulate material are generally considered to have low availability. However, metals may become mobilized from the sediments through ingestion and absorption within the gut of deposit-feeding invertebrates such as holothurians, or adsorbed to organic material and ingested by more selective feeders. The metals may then become available to other organisms at higher levels in the food chain.

Sediment samples will be collected at all stations during each of the two sampling periods and will be analysed for:

- sediment type (including grain size distribution, carbonate content and particle characteristics);
- metal concentrations associated with the organic and inorganic particulate fractions; and
- 'biomarkers' of terrigenous carbon.

Sampling of Biota

Many, if not most, organisms regulate the concentration of trace metals by physiological processes, and expel or accumulate metals in small concentrations according to their requirements. Thus, different organisms have different tolerances and accumulation characteristics for different metals. Also, different species respond to different portions of the total trace metal load. Thus, trace metal profiles in one species do not necessarily match those of another in the same location at the same time. It is therefore necessary to select a variety of indicator organisms which will be representative of the different habitats and uptake routes for trace metals. This approach will provide a greater understanding of trace metal mobility and partitioning within the ecosystem.

This component of the baseline study will comprise three discrete studies:

- community and commercial fisheries;
- indicator organisms; and
- seasonal variation in trace metal bio-availability.

Community and Commercial Fisheries

The study of community and commercial fisheries will include a wide range of species of relevance to the Torres Strait Islander community and commercial fishing operations.

This study will, in particular, address concerns about human health. Special consideration will be given to the dietary intake of seafood by the Torres Strait Islanders. Also, tissue selection and preparation of samples will consider the way foods are prepared and eaten by Torres Strait Islanders.

Indicator Organisms

Trace metals have been shown to accumulate in certain marine organisms to levels substantially higher than the surrounding environment – water and sediment. The principal advantages of using indicator, or sentinel, organisms to quantify trace metals are the direct measurement and the time-integration of trace metal bio-availability. Filter feeding organisms are commonly used as indicator species as they are sessile, filter relatively high volumes of seawater each day, and are known to accumulate metals from seawater. Tridacnid clams have been identified as suitable filter feeding organisms for establishing baseline metal concentrations in the Torres Strait (Denton, 1986).

Phillips (1980) notes, however, that different species respond to different portions of the total trace metal load. Tridacnid clams, for example, possess algal symbionts in their tissues from which they derive a significant portion of their nutritional requirements. This group of animals may, therefore, only reflect the dissolved metal portion. In the absence of any understanding of the relative availability of the different portions to biotic resources within the Torres Strait, it is therefore necessary to select a variety of indicator organisms which will be representative of the different uptake routes for trace metals.

Seasonal Variation in Trace Metal Bio-availability

The use of indicator organisms is not, however, without problems. Phillips (1980) identifies the most serious of these problems to be associated with the possible interference of extraneous parameters with the uptake of trace metals. Most important of these parameters is the organism itself: within and between-species differences in uptake of different trace metals, and age, size and sex differences between individuals within a species. Also, spikes of heightened exposure may be retained within tissues well after the incident and metal concentrations have returned to normal. Variation in trace metal concentrations due to any or all of these factors can make detection of seasonal variation and impacts more difficult.

Seasonal variation in trace metal bio-availability will be addressed through experimental transplants. The suitability of Tridacnid clams for this specific purpose has also been identified by Denton (1986). However, Tridacnid clams may reflect only one fraction of the total metal load. Their use should therefore be supplemented with a species which derives its nutrition from other sources. Together, both species will better reflect the total metal load.

Juvenile Tridacnid clams, probably *Tridacna gigas*, and black-lip oysters are presently being raised successfully in mariculture by researchers at James Cook University of North Queensland and private centres. Individuals raised by mariculture techniques have the advantage of all being approximately the same size and of known age. A pre-reproductive age class can be selected which will eliminate problems associated with reproductive state. Also, individuals raised by mariculture techniques will display far less genetic variation than those within 'wild' populations.

It is intended to place juvenile clams and black-lip oysters within cages on reefs for three month periods covering at least a year in order to determine more accurately present levels and temporal variation in trace metal availability.

The Pilot Study

The pilot study has been designed with five considerations in mind. These are as follows:

- the Torres Strait is a physically very complex environment and trace metals from the Fly River are unlikely to be distributed and deposited uniformly throughout the region;
- there is presently no understanding of temporal variation in trace metals;
- the extent and nature of chemical speciation within the Fly River estuary and coastal region is poorly understood and, therefore, also the relative importance of the different geo-chemical forms that may be present;
- it is, therefore, unclear which trophic groups will be most important in the transfer of metals through the food chain; and
- the distribution and abundance of suitable indicator organisms is largely unknown.

The pilot study has five specific objectives:

- to determine the most effective and cost-efficient sampling strategy for trace metals in sediment and biota;
- to identify the research organizations and laboratories which are best able to perform the analyses of trace metals that are required;
- to provide a preliminary assessment of the impacts of current levels of trace metals in marine biota on the health of Torres Strait Islanders and Papuans;
- to identify suitable indicator organisms and locate sampling sites where they can be found in appropriate abundances; and
- to provide a preliminary assessment of the spatial and temporal variation in trace metals within sediments and biota of the Torres Strait.

These objectives will be achieved by completing the following tasks:

- collect sediment samples from selected sampling stations for analysis of sediment type, trace metal concentrations and organic carbon content;
- collect and prepare biota samples for community and commercial species for analysis of trace metal concentrations;
- collect and prepare biota samples for indicator species from selected sampling stations for analysis of trace metal concentrations;

- analyse sediment and biota samples for trace metal concentrations under established protocol and quality control procedures, and assess the accuracy of results by inter-laboratory comparison; and

- report on the results of the Pilot Study with respect to future directions.

Pilot Study Programme Design

Two basic methods will be used within the Pilot Study to quantify trace metal concentrations in the Torres Strait: analysis of sediments and biota. The analysis of water samples requires more complex and expensive sampling procedures, primarily due to problems of contamination. It will be considered when a better understanding of spatial and temporal trends in metal concentrations has been established. The conceptual design of the programme has already been outlined above. The selection of pilot study sampling stations are indicated in Figure 2, and will be located by latitude and longitude. There are seven sampling stations for sediments (S1 to S7) and nine for biota (B1 to B9). The sampling stations all lie within distinctive physical environments and represent important biological habitats. They are spread across most of the Torres Strait, and are positioned to identify gradients over a number of spatial scales. Sampling stations will be located in the field using Global Positioning System (GPS) Navigation.

The sampling programme will be conducted over two sampling periods for sediments and biota (indicator species only): the first near the end of the trade wind season (September-October, 1991) and a second towards the end of the monsoon season (March, 1992). The selection of these two periods is based on the following considerations:

- analysis of 40 years of Bureau of Meteorology wind records from Thursday Island which indicates two distinct regimes, one corresponding to the monsoon period (December to March) and the other to the trade wind period (April to November);

- the difficulty of working within the Torres Strait during the period June to September because of strong southeasterly winds (particularly in relation to the sampling of biota); and

- better integration and interpretation of results from sediment and biota analyses if they are collected at approximately the same time.

Sampling of Sediments

Sediment samples will be collected using a number of techniques. These will include hand and gravity corers, and a Smith-McIntyre grab. The aim is to determine the most effective means of sampling sediments and ensuring that the fine surface material is not lost. The surface 3-5 cm of sediment samples will be analysed for:

- sediment type, including grain size distribution, carbonate content and particle characteristics;

- total metal concentrations; and

- organic carbon content.

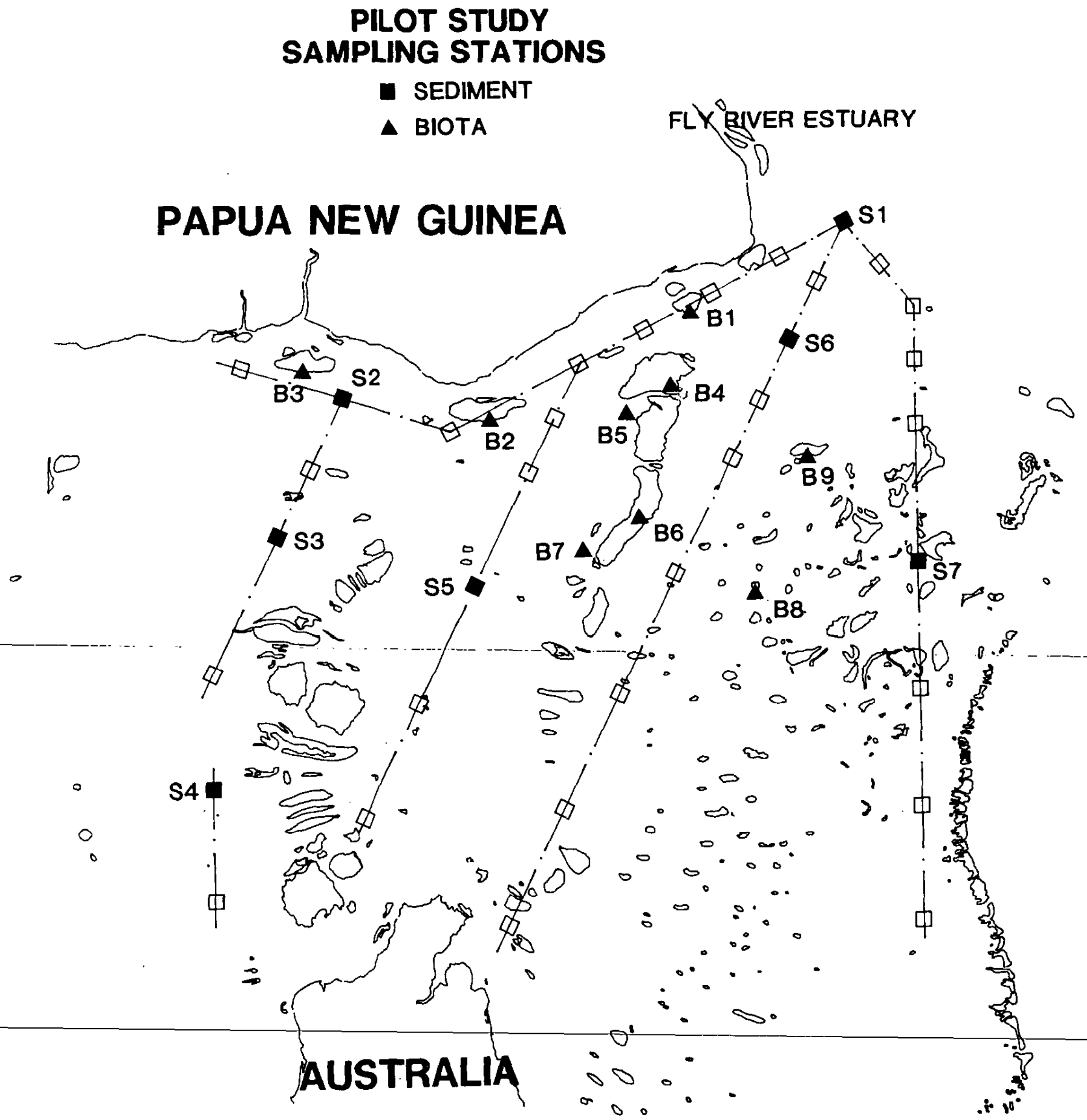


Figure 2. Map of the Torres Strait showing the location of the pilot study sampling stations.

Each sampling station is to be represented by an area which is defined by a rectangle placed centrally over the station coordinates. Each side of the rectangle shall have a length of 200 metres. Three sampling sites will be randomly selected within each station, and three replicate samples will be collected from each site. In all, nine samples will be collected from each station. This sampling design is hierarchical and will provide measures of variability at two spatial scales. The purpose of the hierarchical design is to determine the most statistically powerful sampling regime for the detection of spatial and temporal change in the mean and variance of metal concentrations, given the natural variability in trace metal concentrations and financial constraints. At two sites (one at each of stations S1 and S3), three replicate samples will be collected at three different stages of the tidal cycle (peak flood, slack water and peak ebb). The intent here is to determine the degree to which results may be influenced by such short term variation in the tidal cycle.

Sampling of Biota
The sampling of biota will comprise two discrete studies: community and commercial fisheries; and indicator organisms.

Community and Commercial Fisheries
This component of the pilot study will commence in mid 1991. Sample collection for community and commercial species need not coincide with the two principle sampling periods. The community and commercial species will include:

(1) *Dugong dugon* (Dugong/*Deger*/*Dangal*)#
(2) *Chelonia mydas* (Green turtle/*Nam*/ *Waru*)#
(3) Reef fish (e.g. *Siganus lineatus*, *Siganus spinus* (Black trevally/*Bodo*/*Kebim*), *Lisa vaigiensis* (blue-tailed mullet/ *Weeree*/*Maker*), *Mugil cephalus*, *Valamugil sehili*, small serranids)#
(4) *Scomberomorus commerson* (Spanish mackerel/*Dobor*/*Dubui*/ *Dubu*)#+
(5) *Lates calcarifer* (Barramundi/*Bata*)#+
(6) *Strombus luhuanus* (Red lipped stromb/*Keret*)#*
(7) *Lambis lambis* (Common spider shell/*Etai*)#*
(8) *Tridacna maxima* (Clam/*Me*)#*
(9) Prawns (*Penaeus esculentus*, *Metapenaeus endeavouri*)+
(10) *Panulirus ornatus* (Painted crayfish/*Kaiar*)+

Species of particular relevance to the community fishery are indicated #, while commercial species are indicated +. The tissues of *T. maxima*, *S. luhuanus* and *L. lambis* (indicated *) may also be suitable as indicators of changing trace metal bio-availability.

The collection of samples from community and commercial species will need to be carried out in an opportunistic manner. Certain animals, such as dugong and turtle are not always available and are reserved for special occasions. The programme will aim to collect at least two samples of each of a wide range of community species, and ten from each of the commercial species. Samples will be collected either from the communities directly or from commercial fishing operations. Communities of particular interest include Yorke (*Masig*), Stephen (*Ugar*), Darnley (*Erub*), Mabuiag , Boigu, Saibai, Daru and Parama Islands.

Every effort will be made to determine the specific location from where each sample was collected. Details such as body length, wet weight, sex, etc. will also be recorded for all animals.

The tissues which are to be sampled will vary between species, but will be of relevance to human consumption. For *Dugong dugon* and *Chelonia mydas*, muscle tissue, kidney and liver will be collected and analysed. All fish will be gutted and separate samples for muscle and head will be required from *Scomberomorus commerson*, *Lates calcarifer* and all reef fish. Where whole animals are not collected as samples, representative cross-sections of the body, rather than smaller tissue parts, will be required. Only the abdomen of prawns and crayfish will be sampled and analysed. The whole body (excluding the shell) will constitute the sample for *Strombus luhuanus*, *Lambis lambis* and *Trochus niloticus*, while separate analyses for the adductor muscle and whole body of *Tridacna maxima* are required for this component of the programme.

Indicator Organisms

A particular problem that we are faced with in the Torres Strait is the diversity of habitats and paucity of data on abundance and distribution of all but commercial species. Communities adjacent to the Papua New Guinea coast are different to those within the central region, which in turn differ to those in the west and east. Species found in one region will probably not be present in all other regions. The distribution and abundance of appropriate indicator organisms and the ease with which they can be found is unclear at present. An objective of the pilot study is to identify and locate sampling sites where indicator species can be found in appropriate abundances.

The indicator species which are being considered include:

(1) *Halophila ovalis* or *H. spinulosa* (inter-reef seagrass) [S2,S3]
(2) *Thalassia hemprichii* (reef seagrass) [B1,B2,B3,B4,B6,B8,B9]
(3) A Tridacnid clam (*Tridacna maxima* or *T. crocea*) [B4,B6,B8,B9]
(4) *Pinctata margaritifera* [B4,B6] and *P. maxima* (pearl oysters) [B5,B7]
(5) *Polymesoda erosa* (cockle) [B1,B2,B3]
(6) *Strombus luhuanus* (Red lipped stromb) [B8,B9]
(7) *Trochus niloticus* (Trochus) [B4,B6,B8,B9]
(8) *Lutjanus carponotatus* (stripy - reef fish) [B4,B6,B8,B9]

The sampling stations from which it is anticipated that the indicator species be collected (Figure 2) are indicated above in square brackets.

The sampling design for all indicator organisms will be essentially the same as for sediments. That is, each station will be represented by an area which is defined by a rectangle placed centrally about the station coordinates. The size of the sampling station may vary depending on the abundance of the organism that is being sampled, and may be substantially smaller than that for sediments. Three sampling sites will be randomly selected within each station, and five replicate samples will be collected from each site. In all, fifteen samples will be collected from each station. This sampling design is, again, hierarchical and will provide measures of variability at two spatial scales. In the case of reef species which are distributed over a wide range of depths, attention will be paid to restrict the station to a single depth interval. Also, organisms of approximately the same size will be collected to minimize age effects. Indicator organisms will be collected and stored in treated plastic bags on ice and transported to the Horn Island Research Station for dissection and sample preparation.

It is anticipated that *H. spinulosa* or *H. ovalis*, both inter-reef seagrasses, can be collected from stations S2 and S3. If insufficient material is available from the grab/core sediment samples, then a dredge will be used to collect material. The sampling design will be the same as described for sediment sampling. The reef-associated seagrass *T. hemprichii*, on the other hand, is expected to be found at stations B4, B6, B8 and B9. Only the leaves of the seagrasses will be collected and analysed routinely. It is intended to collect and analyse the root and rhizome material of *Syringodium isoetifolium* separately from the leaves at two stations (B4 and B6). This is because root and rhizome material is known to accumulate trace metals and, presumably, reflects a different uptake route and metal fraction to that of the leaves.

It is anticipated that Tridacnid clams can be collected from stations B4, B6, B8 and B9. Only the kidney of clams will be dissected and analysed routinely. At two stations (B4 and B6), the kidney, adductor muscle and visceral mass should be dissected and analysed separately from the remainder of the body (excluding shell). The remaining molluscs, *P. margaritifera*, *P. maxima*, *Anadara sp.*, *S. luhuanus* and *T. niloticus* will be analysed for whole body (excluding shell) metal concentrations. The liver and muscle tissues of *L. carponotatus* will be analysed separately for trace metal concentrations.

Quality Control

The pilot study programme design should provide a good estimate of station homogeneity and the variation or 'error' in metal concentrations for sediments and selected sedentary biota, both among replicate samples and sites. However, a second source of variation or 'error' can result from the analytical techniques. All sediment and biota samples for trace metal analysis will be sub-sampled, freeze-dried and stored in sealed acid-washed bottles for distribution to different laboratories for quality control by inter-laboratory comparison, also by comparison with analytical standards and spiked samples. All interested laboratories with a demonstrated capability to analyse metals will be invited to participate. The aim is to ensure that the metal concentration analyses are accurate and repeatable. The final sampling strategy will consider the relative magnitudes of the two different sources of 'error'.

Acknowlegements

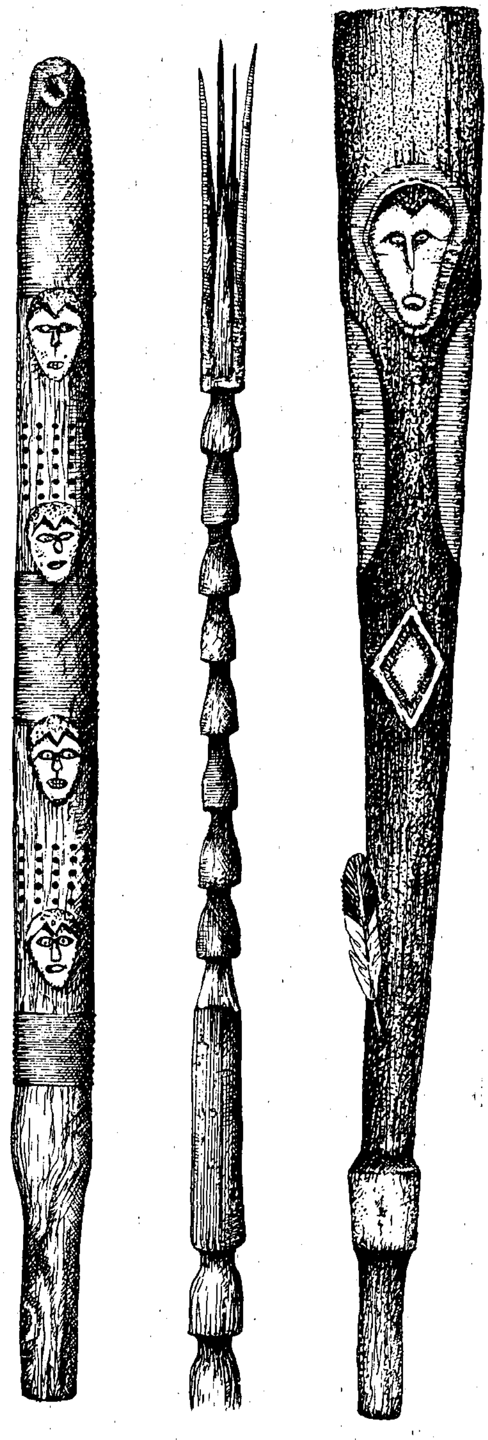
The design of the Torres Strait Baseline Study scientific programme and Pilot Study has been developed under review by the Torres Strait Baseline Study Advisory Committee, and their recommendations incorporated into the programme.

Bibliography

Denton, G.R.W. (1986), 'Guidelines for trace metal surveillance studies in Torres Strait and adjacent waters', In A.K. Haines, G.C. Williams and D. Coates (eds), *Torres Strait Fisheries Seminar, Post Moresby, 11-14 February 1985*, Canberra, Australian Government Publishing Service, pp. 299-307.

Phillips, D.J.H. (1980), *Quantitative aquatic biological indicators*, Applied Science Publishers Ltd., London.

CONCLUDING REMARKS



Dance staves

Lines in the Water: Sea Tenure as "Custom Today" in Western Oceania

John Cordell
Cultural Survival Inc.

Introduction

I work with Cultural Survival, a support center for indigenous peoples, with offices in the U.S. in Cambridge, Massachusetts. We are a non-profit, membership organization, founded in 1970. Our primary goal is to help indigenous peoples gain control over decisions affecting their resources, lives, and future. To this end, we carry out projects to support communities own self-development efforts and we have a complementary program of case studies, research, and publications. Our activities include a wide range of advocacy work on behalf of indigenous organizations, like some of the groups represented here, as well as assisting local communities in the quest to secure territorial rights and social justice, in legal and environmental defense, in economic development and acquisition of new technologies, and in solving resource management problems.

It's a privilege to be invited to address this gathering and offer some parting thoughts, meant to be shared more as "food for thought" than a summation of the findings of your many excellent papers. As I am a relative stranger to these kinds of proceedings in Australia, there was in fact no way to do justice to the diverse cross-section of papers and issues raised here. I would like to have incorporated more of your comments.

I have to say that I am deeply moved by the statements of indigenous leaders from Torres Strait and Papua New Guinea. I share their sense of frustration in trying to get conference speakers to more directly engage their social and environmental concerns, and provide answers they can take home. I hope to make my discussion more meaningful to Islanders by returning to the questions they themselves and various papers have raised concerning the relationship of the sea to culture identity. This fundamental theme is found throughout the Torres Straits and in the surrounding region as well. I hope to also show how it has critical implications for devising future sustainable development plans.

Let me preface my discussion with a word about the conference agenda. Along with ecological concerns, the organizers, whether intentionally or inadvertently, have pushed a range of ethical and indigenous rights concerns to the forefront of what is ostensibly an environmental monitoring, baseline study, project. Judging from the program outline, they are not only hitching their plow to a more ecologically sane version of development but to a more socially aware and enlightened management program that would involve local people as more genuine partners. This is a very ambitious plan. It sounds fine on paper. It raises the stakes. But can the planners deliver? How far are they prepared to go?

I sense here a welcome inclination to try harder to accommodate the perspectives and needs of the traditional inhabitants of Torres Strait and their Papua New Guinea neighbors. Otherwise this might have been billed as another "technical workshop." The worthy aim of making it more comprehensive and opening it up, directly or indirectly, to the concerns of indigenous communities, paints some of the larger picture of the inter-connectedness of the region's peoples, landscapes, seascapes, and governments. Because both development and the processes of nature display a notorious disregard for geopolitical boundaries, both management authorities and indigenous peoples for once find themselves in the same boat: what good is creating protected zones or promoting local rights and self-reliance, if your neighbors are uncontrollably polluting, or overfishing?

Torres Strait has the "transboundary blues." The nature of marine management problems which have arisen in Torres Straits are relatively unique in that they involve issues of both sustainable development and social justice and equity among indigenous inhabitants of a maritime frontier. This is an elusive combination. There is the immediate task of figuring out how to proceed with the baseline study. At the same time there are the long-range, far more cumbersome socio-political issues and legalities of integrating Papuans and Islanders in a shared marine management framework which they can mutually uphold as legitimate and which works in their best interests.

These conditions present many difficulties in setting up an unambiguous agenda. Obviously some items are complementary and overlap, yet they tend to gallop off in different directions. Quite admirably, the organizers, have tried to address these incongruities and bring the human and physcial environmental sides closer together. The danger I see is that you wind up "sort of" addressing the indigenous rights and welfare angle and sort of dealing with the environmental management end of the business, without fully doing justice toeither. Finally, an even more encompassing, far-reaching agenda seems to be emerging: how to coordinate work on abroad multicultural and environmental front, dealing with everything from shipping, oil spill contingencies, marine mammal protection, food standards, to human migration, to figuring out how to link major conservation initiatives around the whole Torres Strait region.

So, where are we? I think in search of a common ground, some new, unifying conceptual framework, perhaps eventually tagged to a political program to help coordinate work on transboundary problems. This is a very tall order. No one seems to know quite how to proceed, though the potential exists for governments and environmental groups to develop a much better working relationship with indigenous peoples on issues of shared resource management. The extensive, time-series environmental monitoring that the baseline plan may require is a window of opportunity for cooperation, as is planning sustainable development.

There are some impediments in the search for more participatory, co-management approaches to resource management, but two especially stand out: at this stage consultative mechanisms to vitally involve local communities in the multiple levels and phases of resource management are practically non-existent. Moreover, there are few NGOs, grassroots or voluntary organizations to facilitate empowerment in this area, compared to the scope of activities elsewhere in the Tropics. Secondly, very few mechanisms exist to link indigenous management practices with official policies and scientific strategies.

Let me briefly run through some crucial aspects of property formation in the sea which have not been introduced in our discussions. Why bring up property rights in the sea? Aren't fishery and coastal zone management measures, and international treaties and the Law of the Sea conventions enough? It is often difficult to visualize how populations interact with their environments, but technology and economics aren't the only means. What mediates these systems are different kinds of property institutions that determine the values people assign to resources, along with actual physical access to resource zones including laws and regulations governing ownership and use rights. So I want to focus for a moment on the class of property variables which intervene between the physical environment and culture systems in question here. It is important to bear in mind that states have the option to manipulate property institutions to some extent for purposes of environmental management or to simultaneously improve the welfare of indigenous peoples. Or, I might add, to further marginalize rural communities through ill-conceived conservation programs.

The significance of customary territorial rights and arrangements for managing coastal seas was foreshadowed in Judith Fitzpatrick's and Jeremey Beckett's presentations yesterday which explored the relationship of culture and the sea among Eastern and Western Islanders. Marine property customary laws, use rights, etc. applied to the inshore sea are seldom part of the sustainable development discourse. In this connection, and in contrast with our extensive knowledge of tenure in land economies, the rights and ownership customs of maritime peoples have not been widely documented until recently.

I'm inclined to join the ranks of some fishery economists who argue that the lack of well-defined property rights in the sea, can contribute to its degradation and vulnerability to pollution and a host of other development excesses. Although, "tragedy of the commons" arguments about the perils of leaving valuable resources propertyless are open to numerous criticisms, there may be a lesson for us here. Open access is supposedly a reckless, dangerous state for a renewable resource, in that it gives individuals the incentive to shirk responsibility to the wider community and the environment. It presumes people act out of narrow self interest and have no reason to conserve resources. The image of coastal seas as ownerless and in principle free access coupled with the view that sea life and resources are inexhaustible is truly a recipe for ecological disaster. On the other hand, instituting property rights which limit access, thereby internalizing the costs of over exploitation, should act as an incentive for conservation. Or so the argument goes.

Unfortunately, arguments to remove the destructive condition of open access by instituting property rights tell us very little about management choices in the monday morning world if some classes of property systems might work better than others for certain management purposes. I am less pessimistic than some about our ability to develop effective property arrangements to strengthen marine resource management. I think exclusive home reef tenure systems in the Pacific have many strengths to recommend them. I also think, under certain conditions, Western economic models, so-called limited entry systems, protected area and biological reserve concepts have much to recommend them. The point is, they don't have to be mutually exclusive. Some hybridization might be possible. I will come back to this idea.

Exactly what is traditional marine tenure or sea tenure? Let me locate this question within the discourse about the meaning of "tradition" now taking place in Pacific societies.

Newcomers to Melanesia and Pacific studies in general are bound to hear and read a lot about, the Melanesian way, "custom ways," "kastom", or "island custom." In Pacific studies this is a household word almost as popular as "sustainable development" is among politicians. Islanders all around the Pacific are reported to invoke ancestral ways as political symbols to distance themselves from the colonial experience and reaffirm their unique identities. In doing so, sometimes they resort to the mythical past to reaffirm their relationship to territory. When Torres Strait islanders (or Solomon Islanders) speak about "home islands" and "homereefs" this can be taken to represent another variation on the pan-Pacific theme of "custom today." What is significant about this is the elevation of ancestral seas, not just land, to symbolize unity with group territory. To my knowledge, this aspect of reconstructing the past has seldom been discussed as a strategy to carve out new cultural identities in the present.

Yesterday Bob Johannes noted it is unlikely that the extent of group identification with inshore waters and associated ownership customs was considered in any detail when the TSPZ (Torres Strait Protected Zone), the Australia-PNG Sea Boundary Treaty, DOGIT (deed of grant in trust) legislation, and fisheries regulations were drawn up for Torres Strait. Yet these underlying customs could have a critical bearing on future marine management proposals. I don't think there is any question that notions of home islands, reefs, and seas, represent historically authentic connections of communities with their marine environments. What is very difficult to convey is that Islanders compacts with the sea are qualitatively different, something like a quantum jump removed from Western common property conventions and laws presently governing coastal waters, including those in Australia.

The kind of overriding sense of belonging to the environment is something Australians might associate more with Aboriginal mythology and land use than Islanders custom. However, there is strong evidence that a similar bonding occurs in maritime settings among Torres Strait Islanders and that this is a pattern perhaps many coastal groups in PNG share as well. Whether or not this union can be traced to origin myths, supported by lengthy unbroken residence in a homelands place, or whether it expresses some new found "custom today" political ideology is not the issue. The point is this domain of custom retains the power to influence a wide range of cultural behavior in relation to the use of marine resources from who controls access to subsistence fisheries, to home reef fishing effort, catch sharing, to rituals of fishing and marine hunting, to food preferences, to sacred seaspace associated with burial rituals and the supernatural. Without exaggeration, we could say the sea connection is pretty basic to cultural survival.

Most folks have heard about the Law of the Sea Convention. But what about the "other law of the sea" that makes home reef economies endure in places like Torres Strait? Property domains, partioned like land, in the sea? That sounds peculiar maybe something fishy. I remember in the late '60's when I started to do research on small boatfishing. I had a friend who went to work in the Santa Cruz Islands in the Solomons. I said: when you're out there, how 'bout checking out the question of property rights in fishing. (I'd come across some strange reports on this topic from Melanesia). Six months later I got a card saying, "so help me, I haven't turned up anything interesting for you on fishing rights. It's just like everywhere else: common property." Then a few weeks later a card came: "funny thing, a guy took me fishing the other day and we went around to all these octopus holes which he claims belong to him."

Time does not permit me to review the wealth of material on this topic for Torres Strait. Suffice it to say that sea tenure finds perhaps its greatest elaboration and most durable expression in Melanesia where "custom owners" still exert control over large stretches of rural land and sea territory.

Sea tenure is closely bound up with kinship, sharing, traditional law and authority, and other structures which shape cultural identity, so it encompasses far more than Western bioeconomic usages of fisheries or fishing "rights." Sea tenure is documented by named story places, as the underwater narrative of "Aukum's trip to Maza recounted by Judith Fitzpatrick aptly illustrates. Sea tenure systems often designate portions of land and associated underwater features as off-limits, like Turn-Again Island, a place of awesome power, is for people of Maubiag. Finally, it is important to stress local sea tenure is not just an ancestral realm but part of living culture and peoples lives today. It is a knowledge system, enmeshed in social relations, constantly being updated and adapting to changing conditions.

I would like to try now to shed some further light on the signifiance of traditional sea tenure by considering what its relationship might be to sustainable development, and to relay some of my concerns about what the uncritical acceptance of sustainable development policies could mean for indigenous peoples.

In an article on the sustainable development crusade, a recent issue of *The Economist* notes: "never have so many politicians seized so quickly on one idea." To be against sustainable development is like being against "mom and applepie." (or mums, meat pies, and sausage rolls) or trees and clean air. And this is partly why groups from such opposite ends of the political spectrum as oil companies and "deep ecologists" are willing to jump on the bandwagon together in the name of sustainable development. I'm as pro-biosphere as anyone else. And in calling attention to what is sometimes a non-critical acceptance of this attractive concept, I'm not debunking environmental concerns. Yet can we look to the sustainable developers to give us a program of social change? To help eliminate poverty? To enhance social justice, and promote cultural as well as biological diversity? From the indigenous perspective, I think these are legitimate questions.

Among the five criteria for sustainable development outlined in the opening address by the Chairman of the Great Barrier Reef Marine Park Authority, I would emphasize the third one on the list: social equity. Sustainable development fits very neatly with today's prevailing utilitarian ethic; sometimes it would seem to imply little more than simply learning how to manage natural resources more efficiently and cost-effectively. But this tells us very little about paramount questions of distribution who gets what? Who profits? From this consideration, perhaps a sixth principle akin to Australia's brand of multiculturalism could be derived: preserving cultural diversity, especially the ethnic identity and integrity of indigenous peoples.

Sooner or later, environmentally-sound development in Torres Strait and PNG, places still largely inhabited by indigenous groups, comes down to three important principles: firstly, biodiversity support programs cannot overlook local customs, economic needs and aspirations. Secondly, conservation programs cannot afford to ignore the property claims and institutions of local residents. Thirdly, there is mounting evidence that what local residents need foremost to sustainably manage their territories be they on land or sea is security of tenure. Recognition of community based and communal sea rights where tenure holders are encouraged to work out their own management practices is one way to ensure relatively equitable rights of access to marine resources at the local level. This approach will not work for all situations, but there are definitely precedents for it in the customary sea tenure systems of island Melanesia. My view is that sustainable development policy for Torres Strait waters cannot fail at least to consider whether patterns of indigenous sea tenure might work to help stabilize home reef economies, perhaps serving as a model for extended fisheries management, and protected area design as well. Whatever the form sustainable development takes for Torres Strait, the point is, it should not be something handed down. Islanders can and should formulate their own strategies, in their own voices and meanings.

Conclusion

Patterns of old lines and zones in the sea in Torres Strait, not just straight ones but wavy ones, too, may be tangled and blurred (and are still mostly transparent to outsiders). In fact, all the different kinds of imposed boundaries on maps I've seen makes the place look like spaghetti. But in some places, pockets or vestiges of what were perhaps long ago full-blown customary tenure systems persist. So what? Well, we might ask what would have already happened to fragile reef-associated habitats and valuable fisheries if territorial systems like this were not operating in places like the Solomons, Vanuatu, PNG, and Torres Straits. If sea tenure didn't exist it would probably have to be invented. In fact it is being reinvented as "custom" today in parts of Oceania, and in the form of "limited entry"restrictions in fisheries worldwide. I've presented the somewhat special case for community custody and territorial regulation of home reef economies, like those now developing in Torres Strait and PNG. I've emphasized the drawbacks of pursuing free access policies for managing tropical inshore waters, to which indigenous groups lay claim, formally or informally. I've suggested the concept of sea tenure may have some bearing on untangling complex issues of transboundary responsibility for the environment in Torres Strait. Where does this perspective lead.

Let me turn to some final reflections on the meeting in terms of the home reef tenure perspective I've been developing with a short selection of questions and answers where I ask the questions and give the answers.

1. First, where does this leave Islanders in terms of the status of their sea rights? We have heard impressions and that's what I think they are basically anecdotes that customary sea tenure is in a kind of limbo or residual state in Torres Strait, that traditional boundaries have broken down (groups in Western Province, PNG, also supposedly fall in the "lapsed boundary" category). I'm very wary about over-generalizing and oversimplifying about this. I think it should be left to the groups in question to consider what future uses might be made of sea tenure. But as pressures increase on resources, and they inevitably will even on home reefs, I think Islanders are going to need more security of tenure, perhaps some kind of formally recognized exclusive control over their home reef systems. I feel it is absolutely critical for management not to do anything to undermine or interfere with longstanding home island/home seas customs. I think management should figure out ways to work around these systems, possibly using them as a foundation for more extended marine protection. Let's not be too disappointed about whether these systems were explicitly designed to enhance conservation. In some ways, making sea tenure practices run modern "management" tests is taking them out of context. Why not, instead, honor them in the arena where they belong in terms of our fundamental obligations to treat indigenous rights and aspirations for self-management with respect.

2. Second, where does this analysis leave management in with regard to its agendas, especially in terms of advancing the baseline study? In terms of implementing new, socially responsive programs, management's tasks and responsibilities are becoming increasingly complicated and I can only touch on a few ideas. Could Islander and Papuan customary sea tenure be strengthened or revived (if indeed it does turn out to be broken down) to enhance self-development and help control the kinds of management problems that exist today?

This question has been posed before and I'm not really prepared to go farther than raise it again here, perhaps as a proposal for a future study. In the meantime, it might be something worthwhile to bring up and get a reading on through the councils. There are now a number of anthropologists, biologists, geographers, and others who have expertise in this area who would be willing to help. From my experience with small-scale fishing elsewhere in the tropics, the worse-case scenario is trying to design management programs which are costly and impossible to enforce, where there are no indigenous claims, and no local commitment to sea territory. From a cross-cultural standpoint, this is why I feel Australia and other governments in the region could begin to entertain the idea that the customary systems within their borders are management assets in the long-term, not liabilities. To be sure, the disposition of property rights in the sea, concentrated in traditional enclaves like Torres Strait, and surrounded by all-citizen fisheries and inimical common property conditions presents state management with a major dilemma. You can ignore local sea rights issues, but they tend not to go away.

On the other hand, we know what a common fallacy it is to regard the sea as a safe dumping ground. The nature of the marine environment a liquid medium, where it is often hard to observe what goes on is in a sense conducive to environmental irresponsibility and lack of accountability. Which is maybe why managing marine resources requires extra precautions. Yet what if it were common knowledge and accepted that the sea, like the land and islands on the PNG coast and in Torres Strait was blanketed with customary property rights which had the force of law? Would governments and companies think twice about the transboundary repercussions of development projects? Maybe; maybe not. But it's a proposition to keep in mind in seeking strategies to improve marine conservation.

Just as Islanders may have to reappraise their custom of granting requests for visitors who want to fish on their homereefs, Australia may have to take another look at its declared policy of free access in its coastal seas. Like island custom, national fisheries statutes, founded in another time on notions of resource abundance and the idea that anyone should be able to have a "fair go," making a living from the sea, may be luxuries neither Islanders nor the country can afford in light of global expansion of maritime and adjacent land economies.

3. Third, do we have a take home message for Islanders or anyone else as to how to interpret the threats to people and the environment in Torres Straits and coastal PNG from mining in the PNG highlands? What the situation with the Ok Tedi mine has done is destroy the illusion of our separateness and make us contemplate the scale of regional interaction and development impacts. Perhaps like others here, I am struck by disquieting indications of environmental disruption caused by mining in PNG. However, I do not dectect a concensus among the scientists in our midst of an environmental crisis of massive proportions building from Ok Tedi alone. Apparently, the numbers are still not in on Ok Tedi. Rather than alleviate my anxiety, though, this inconclusiveness is ominous. Also, it is not this project alone but the desperate overall "can't live with it, can't live without it" development dilemma that Ok Tedi has come to symbolize for PNG, that is most unsettling.

4. Finally, continuing the sea tenure as custom today theme of my talk, for the indigenous leaders here, I would like to close with a maritime metaphor: I say get your lines in the water if they are not there already; old ones and new ones. In terms of international conservation initiatives, conditions have never been more favorable than they are now for recognizing sea tenure principles as a basis for managing home reefs and future seafood economies. The alternative, as an Islander recently put it an edition of *Torres News*, is becoming strangers on your own shores and reefs, sharecroppers on someone else's fishing boats.

I suggest the baseline study organizers take a hard look at the terms of reference for sustainable development as this is being defined. Sometimes the concept seems a bit unwieldy and a far cry from the spirit in which indigenous peoples relate to and "manage" the natural world. Perhaps what is indicated is a little less of the Western management mentality, a different attitude towards the Earth, and a more compassionate understanding of the problems of indigenous peoples who are the traditional owners and residents of some of the world's most threatened habitats.

DRAFT SUMMARIES OF PAPERS PRESENTED

Draft Summaries of Papers Presented

Note

During the conference some concern was expressed by participants that the information presented during the physical and biological environment sessions was overly complex and technical. It was decided that the five most central points of each paper would be summarised in lay terms and presented to the participants. This was done to ensure that the essential messages from each paper were understood by the conference participants. This is the final copy of those draft summaries.

Introduction

Why are we concerned about the Torres Strait and the possible effects of heavy metals?

We need to understand and address the concerns of the people who use and depend on the Torres Strait about the possible effects of heavy metals from the Fly River on them and their livelihood.

To address these concerns we need more scientific and other information about the Torres Strait, its people and its ecosystems, to interpret that information for management and to give advice to the people who live in and depend on the Torres Strait.

We need to deal with the information in an objective and clear way to improve understanding and to reduce misunderstanding.

Why is the Torres Strait important?

- People live there and depend on its resources for their livelihood and culture.
- There are important fisheries in the Torres Strait, both commercial and traditional.
- It is important biologically and ecologically.

What are Heavy Metals?

- They are naturally occuring elements which can be found in rocks, attached to sediments, dissolved in water, attached to rotting vegetation.
- They are found naturally in marine plants and animals.
- The amounts of heavy metals found in marine plants and animals can vary significantly between individuals of the same species of plants and animals, between different groups of plants and animals, between different places and different times. There can also be significant differences between levels of heavy metals in different parts of a single plant or animal.
- It is usually difficult to measure accurately the amount of heavy metals in the plant or animal.
- Some metals are important in low concentrations for growth in plants and animals (e.g. copper and zinc). The same metals are poisonous to the same plants and animals if they are absorbed at levels which are too high for the animal or plant to tolerate. Mercury, lead and cadmium have no known use for plants or animals and can also be poisonous.
- People have always eaten food containing heavy metals. When levels are raised above 'normal levels' then we need to find out whether this will affect the health of the people, plants and animals which are absorbing the heavy metals.

What do we know already and what do we need to find out?

- Ok Tedi Mining Ltd. and Porgera Joint Venture are discharging wastes from mining operations into tributaries of the Fly River. These wastes consist of large amounts of sediments and contain heavy metals, particularly copper from Ok Tedi Mine. The wastes are washed down the Fly River to the delta at the mouth.
- Most of the sediment and the heavy metals probably settle at the mouth of the Fly River.

- The water that discharges from the mouth of the Fly River moves in a number of directions. Most of the water flows eastward to the Gulf of Papua. Some of the water flows westward along the coast of Papua around Daru and Saibai Islands and into the Torres Strait via the Great Northeast Channel. The water contains some sediments and heavy metals.

- We do not know how much sediment and heavy metal is transported into the Torres Strait, how they are transported, where they end up or which plants and animals absorb them.

Keynote Address

Sustainable Development for Traditonal Inhabitants of the Torres Strait Region, *Graeme Kelleher* (page 15)

- Term *Baseline Study* is misleading because the study will commence after discharge of mine sediments into the Fly River has begun.

- The main industry for the Torres Strait for both Islanders and Papuans is fishing, which is an unpredictable industry.

- Development of the Region must be sustainable ecologically, socially and economically.

- Baseline Study is a Commonwealth funded project for 3-4 years, commissioned in response to concerns by Torres Strait Islanders, commercial fishermen and scientists.

- TSBS is consistent with current world trend towards ecologically sustainable development.

Reply from Chairman of the Island Coordinating Council, Chairman of Yam Island Community Council, *Getano Lui, Jnr.*

- Torres Strait Islanders form part of the environment and have historical and cultural ties to the marine environment.

- Survival of the Torres Strait Islanders as a race of people is dependent on maintaining a traditional lifestyle.

- Torres Strait Baseline Study is seen as recognition of the need to protect a separate race of people.

- Sustainable economic development for Torres Strait Islanders is essential.

- Torres Strait Islanders recognise the need for PNG development but also need protection and development of their own resources.

Reply from the President of the Kiwai Local Government Council,
Clement Hesaboda

- Concerned about impacts from Ok Tedi, Porgera and Kutubu. Matters of importance to Torres Strait Islanders are also of importance to Kiwai people.
- Kiwai people believe that changes have occured to fish and crocodiles since Ok Tedi Mine commenced.
- PNG also needs to make a commitment to environmental protection.
- Kiwai people do not understand why a tailings dam was not built for Ok Tedi Mine.

Physical Environment of the Torres Strait Region

Planning & Management of the Great Barrier Reef Marine Park,
Wendy Craik (page 25)

- Great Barrier Reef Marine Park is managed through a zoning system which relies heavily on public input in the preparation of plans.
- Compulsory pilotage of all ships calling at Australian ports will be made law soon under the Great Barrier Reef Marine Park Act.
- Great Barrier Reef Marine Park is a multi-use marine park which provides for a range of uses in different areas.

The Impacts of Projected Climate Change on Coastal Land Use in Papua New Guinea, ***Marjorie Sullivan*** (page 33)

- Climate changes from global warming will affect PNG.
- Estimates of sea level rises range from 30cm to 1.5m, possibly over the next 40 to 50 years.
- Greatest effect likely on those people least likely to be able to afford to deal with it (e.g. traditional inhabitants of the coastal strip). The loss of land from sea level rising will be catastrophic because all other other land is already owned.
- There will be effects on water supplies, coral reefs, increased humidity and flooding. Some small islands will be lost.
- The highlands will be able to grow crops higher up; this may mean the loss of montane forest.

Sedimentation at the Juncture of the Fly River Delta and Northern Great Barrier Reef, *Peter Harris* (page 59)

- Eighty-five million tonnes of sediment enters the Fly delta each year. Two percent goes into the Torres Strait. Fifty percent goes into the delta. The remainder either goes into the Gulf of Papua or along the southern PNG coast to the west.

- Westward flow of water via Missionary Passage is important from April to November. This includes the time when the flow of water from the Fly River is at its highest.

- The central Torres Strait basin is scoured clean of fine sediments leaving a gravel surface with undersea dunes which move.

- The main area where fine sediments are known to be deposited is around Yorke Island.

Copper and Zinc Distribution in the Sediments of the Fly River Delta and Torres Strait, *Elaine Baker* (page 87)

- High levels of zinc and copper were found in sediments associated with runoff from the Fly River. Zinc is found with sediments which come from the land so it should be a good indicator of sediment transport pathways from the Fly River.

- Levels of metals declined with distance from the mouth of the river.

- Higher metal levels are found in samples with higher levels of fine particles.

- Layers from sediment cores may represent periodic, possibly yearly deposition and hence form an historic record which could be tested for changes in metal levels with time. Initial tests showed no obvious connection with the beginning of mining.

- Copper appears to be transported more easily. More work is needed to find out how it moves with sediments and water.

Environmental Investigations on the Effects of the Ok Tedi Copper Mine in the Fly River System, *Murray Eagle* (page 97)
Biological Investigations into the Impacts of the Ok Tedi Copper Mine, *Ross Smith* (page 261)

- OTML has conducted environmental investigations programs since 1981, investigating the chemistry, biology and hydrology of the Fly River system.

- In 1989, OTML implemented programs of investigation and research in the Fly estuary, Gulf of Papua and the Torres Strait.

- The Government of PNG established environmental management criteria for the mining project in April 1990.
- OTML is complying with these criteria and will continue monitoring and investigations over the life of the mine.
- Programs can be changed to meet different perceptions and impacts.
- Predictions have been developed which predict that fish catches will improve at the impacted sites during the life of the mine and that fisheries resources of the Fly River will decrease but remain viable during the life of the mine.
- Metal concentrations in fish flesh in the Ok Tedi, where natural concentrations are much higher than those in the Torres Strait or in the Fly River are less than human health standards.

Staged Development and Environmental Management of the Porgera Gold Mine in Papua New Guinea, *Charlie Ross* (page 119)

- Porgera gold mine started production in 1990 and has an expected life of 18 years.
- Environmental investigations began in 1980 and an environmental plan was approved by the Papua New Guinea Government in 1989.
- Potential impacts from mine operations come from sediments, cyanide and mercury. Cyanide is destroyed at the plant using calcium hypochlorite.
- Increased suspended sediment loads are high in the Porgera river and part of the Lagaip River and will suppress fish populations in these places. Tailing from the mine is predicted to have no significant impact on the Strickland and Fly Rivers or the Torres Strait.
- Most mercury is either removed or immobilised before discharge. Mercury discharged is estimated to add 1% to background levels. Background levels are already high.

Oil Shipments, Controls and Contingency Planning in the Torres Strait, *John Douglas*

- The development of the Kutubu oilfields and shipment of oil through the Torres Strait is of concern.
- Expected shipments will be around 150 tonnes per day.
- Resource mapping of the Torres Strait for risk management purposes should be continued.
- Present capability to handle an oil spill is poor.

The Water Circulation in the Torres Strait, *Eric Wolanski* (page 133)

- The movement of water and the shape of the sea bed in the Torres Strait is very complex. This makes it difficult to understand how sediment and heavy metals move into and around the Torres Strait.

- Currents in the Torres Strait are mainly driven by tides. Most of the movement is back and forth with little movement through the Straits.

- Freshwater from the Gulf of Papua enters the Torres Strait.

- Water flows around islands and reefs may be different from the overall waterflow in the general area.

- There is a lot of information which could be used to predict where the water is likely to flow in the Torres Strait.

South Pacific Regional Environmental Program Marine Coastal Pollution Study (STREP-POL), *Nicholas Currey and Walter Benko* (page 143)

- The National Analysis Laboratory is equipped to handle all the analyses needed for the TSBS.

Australian and Some International Food Standards for Heavy Metals, *George Rayment* (page 155)

- The maximum permitted concentration of heavy metals in foods are set by some countries, including Australia, to protect people from food which might injure their health.

- Cadmium, lead and mercury are the metals of most concern but agreement has not been reached on internationally applicable standards for these environmental contaminants.

- Selling food with higher than the maximum permitted concentrations of heavy metals is illegal but not necessarily unsafe because people eat different amounts and react differently to the levels of metals in the food.

Processes Influencing the Fate of Trace Metals in Torres Strait: A Review of Current Data and Concepts, *T. David Waite and Ron Szymczak* (page 165)

- If we want to understand how metals move into the Torres Strait and how to predict where they might end up we need to understand what controls the processes of transport.

- heavy metals from rivers may enter the sea in different ways by being released from sediments in dissolved form and attaching to other metals (e.g iron). Is this an important process for transporting metals into the Torres Strait? If so, how long does it take? Are these metals able to be absorbed by plants and animals?

- We need to know a lot more about how much heavy metals are concentrated in the sea at different depths, especially at the surface, and in what forms the metal exists there (i.e. is it dissolved, in particles or joined together with other metals).

- We need to know if metals attached to sediments are able to be taken in by plants and animals.

Biological Environment of the Torres Strait Region

The Status of the Dugong in Torres Strait, *Helene Marsh and Keith Saafeld* (page 187)

- The Torres Strait is one of the most important dugong habitats in the world. There are at least 12,000 dugong in the Torres Strait.

- Because dugongs live a long time and breed slowly they can suffer from over-exploitation.

- We will not know whether the present level of exploitation is too high for some years yet, because it takes about ten years to notice any effect.

- Management options include public education, additional sanctuaries and managed areas (e.g. Buru Island).

- Further surveys to check numbers and the geographic limits of the Torres Strait stock are planned.

- We need to know how many dugong are being caught by traditional fishermen (Horace Nona program).

A Review of Queensland Department of Primary Industries' Research on Commercial Prawn Species in Torres Strait, *Clive Turnbull* (page 195)

- The basic life history and the migration pathways of the brown tiger prawn are now known.

- This knowledge helps fisheries managers in deciding which areas to close to protect small prawns and when to close areas to increase catch.

- The seasonal closure now seems to be too late. This information was determined from following tagged prawns.

- Future research will assess the effectiveness of closures and provide similar information on other important prawn species.

Biological Oceanographic Measurements in the Torres Strait and Far Northern Great Barrier Reef, *Miles Furnas* (page 197)

- Very little is known about the biological and chemical processes in the water column in the Northern GBR and the Torres Strait.
- Dissolved nutrient levels in the Torres Strait and the Northern GBR are slightly higher than elsewhere in the Coral Sea, possibly due to intense mixing of nutrients by water movement and by biological activity.
- Marine plants (e.g. algae and seagrasses) may contribute to productivity in the water column.
- Silicate may be a useful indicator of freshwater penetrating into the Torres Strait.

Torres Strait Marine Turtle Resources, *Jeff Miller and Col Limpus* (page 213)

- Three species of turtle live in the Torres Strait (Hawksbill, Flatback and Green). Green turtles are most important to people of the Torres Strait Region. We have most information about Green Turtles.
- These turtles use many areas for feeding but only a few areas for nesting.
- Like dugongs, turtles are long-lived and can suffer from overfishing. The number of green turtles available to be caught can be influenced by weather.
- Recent research has suggested that there are separate stocks of turtles from the Southern GBR, Northern GBR and Western Australia. Turtles nesting in the eastern Torres Strait are part of the breeding stock from the Northern GBR.
- Green turtles which breed in the Torres Strait feed in many places including Indonesia. People from Indonesia, Papua New Guinea and the Torres Strait catch turtles from the northern GBR breeding stock.
- Conservation of turtles is an international conservation issue involving at least Australia, Papua New Guinea and Indonesia.

Ciguatoxin in the Marine Biota as a Model for the Movement of Metals, *Michael Capra, Andrew Flowers and Scott Hahn* (page 227)

- Ciguatera poisoning occurs in humans after eating certain tropical fish.
- The poisoning is due to poisons produced by single-cell organisms (epiphytic dinoflagellates)
- Ciguatera poisoning occurs at different times at at different places in tropical waters.
- Ciguatera poisoning could occur in the Torres Strait and become a significant problem.

- By studying the movement of ciguatera poisons in marine animals we might be able to also follow the movement of heavy metals through those animals in the Torres Stait.

Australia's Fisheries Research in the Torres Strait Protected Zone, ***Geoff Williams and Derek Staples*** (page 229)

- Fisheries research is coordinated through the Torres Strait Fisheries Scientific Advisory Committee.

- Fishermen, Torres Strait Islanders and researchers can suggest research needs to the Committee.

- Research is funded by Commonwealth (DPIE and CSIRO) and Queensland (DPI) agencies.

- Current research covers Tropical Rock Lobster, prawns, traditional fishing, seagrass habitat monitoring, catch statistics, turtles and dugong.

- Future research will be on the above and also heavy metals and oil spills.

The Artisanal Turtle Fishery in Daru, Papua New Guinea, ***Donna Kwan*** (page 239)

- Turtles are important for Kiwai people for income and dugongs are important for food and cultural needs.

- There is an increase in the proportion of turtles sold for non-traditional purposes.

- Flatback, green, loggerhead and hawksbill turtles are all caught. Between 900-1300 turtles are caught each year.

- Daru seems to be a turtle 'hotspot'.

- Indonesian take of turtles is very high. Turtles come from the same stock as those taken at Daru.

Benthic and Pelagic Processes in the Fly River Delta and the Nearshore Gulf of Papua, ***Alistar Robertson and Dan Alongi*** (page 241)

- Because the Fly River discharges very large amounts of freshwater and sediments, this is likely to have a big effect on the food chains in the Gulf of Papua and maybe in the Torres Strait.

- The Fly river has extensive and highly productive mangrove forests which produce large amounts of carbon which is transported into the Gulf of Papua. Carbon is essential for the growth of plants and animals.

- Unvegetated intertidal mudbanks do not generally have high numbers of animals living in the mud, but do have hi~h levels of bacteria which use the carbon at a high rate. There is little transport of dissolved nutrients from the mudbanks.

- Subtidal sediments in the Fly delta and the nearshore Gulf of Papua generally have low levels of copper in particle form, although the levels in the southern channel are slightly higher. There is little measurable release of dissolved copper from the sediments to the water.

- Carbon in particle form is rapidly used in the water column and in the sediments of the Fly Delta and in the nearshore Gulf of Papua.

Research for Sustainable Development of the Tropical Rock Lobster Fishery in Torres Strait, *Roland Pitcher* (page 253)

- Tropical rock lobsters migrate across the Gulf of Papua and into the northern GBR to breed.

- There could be potential for increased yields from the Torres Strait rock lobster fishery.

- Restrictions on minimum size and closed seasons will not increase the size of the total catch.

- Young lobsters are collected to estimate the expected size of next year's catch when they will be adults. This can also give an early warning of problems.

- Further research is needed on the size and extent of the breeding lobsters, where they go when breeding has finished, the size of the catch and the behaviour of young lobsters.

Torres Strait Fisheries Management, *Mark Elmer* (page 283)

- Commercial fisheries in the Torres Strait is worth about $25 million p.a.

- Tropical rock lobster, prawns, mackeral, pearl shell, turtles, and dugong are managed under the Protected Zone Joint Authority (PZJA).

- The Torres Strait Fisheries Management Committee which reports to the PZJA receives advice from the Torrres Strait Fisheries Industry and Islander Consultative Committee (TSFIICC) and the Torres Strait Fisheries Scientific Advisory Committee (TSFSAC).

- A range of management measures are used for the fisheries, including licence limitations, closures for prawns, gear limitations, and minimum legal size for lobsters.

- Other fisheries including trochus, reef fish and recreational fishing are managed by the Queensland Fish Management Authority (QFMA).

- Future work includes monitoring fishing effort and education/extension.

Rock Lobster Fisheries: Enhanced commercial yeilds by artificial shelters?
Bruce Phillips and Chris Crossland (page 295)

- Artificial shelters similar to those used in Cuba and Mexico could increase lobster catches in the Torres Strait.
- Shelters are easy to construct and use.
- However because they might only be aggregating lobsters rather than increasing their numbers, they may lead to over-exploitation.
- Shelters may also damage seagrass beds.
- More research should be carried out before they are used in the Torres Strait.

Trace Element Profiles of Clams (*Tridacna crocea*) gathered from various sites in Torres Strait, ***Gerry Murphy, Clive Turnbull, Robert Manning and Robert Pearson*** (page 303)

- Burrowing clams collected from eight sites in the Torres Strait showed levels of the metals cadmium, copper, lead, zinc and mercury of less than 1/10 the Maximum Permitted Concentrations for food for human consumption.
- The levels found were also found to be environmentally low and not biologically significant.
- In general levels were lowest in the clam muscle and highest in the visceral mass (for example, the kidney, stomach and liver) with the mantle tissue in between.
- There was not much variability in the levels measured.

Tridacna: **Sentinels of Heavy Metal Pollution in Torres Strait Waters – a Critical Evaluation,** ***Gary Denton and Leroy Heitz*** (page 311)

- An organism, to be suitable to be used as an indicator of water pollution, must have a well defined set of properties.
- The clams *T.crocea* (the burrowing clam) and *T. maxima* have these properties, especially the kidney.
- *T.crocea* accumulates mercury better than lead or cadmium but all show a linear rate of accumulation with time but a slow loss rate.
- Because of this we can use this clam to roughly predict future metal levels in the clam kidney when there is known metal levels in the water and vice versa.
- This can help us decide how often to sample the clams.
- For good results we need clams which are the same size and age and not too old. Clams grown on a farm may be useful to put out on the reef for a fixed time to then be collected and tested.

Human Environment of the Torres Strait Region

Maza: A Legend about Culture and the Sea, *Judith Fitzpatrick* (page 335)

- Strong connection exists between sea territories and culture in Western Torres Strait Islands.
- A myth about Aukum who symbolizes fertility in the reef exemplifies this relationship with the sea.
- People's lives are dependent upon the vitality of the reef (maza).
- Cultural identity is based on historical, symbolic and social association with the sea and use of marine resources.

The Eastern Islands of the Torres Strait, *Jeremy Beckett* (page 347)

- Eastern islanders of the Torres Strait have strong sense of place.
- Cultural knowledge still important.
- Eastern islanders still practice subsistance horticulture and have strong identity with their land.

Wopkaimin Landowners, the Ok Tedi Project and the Creation of the Fly River Socio-ecological Region, *David Hyndman* (page 355)

- Mt Fubilan is the sacred mountain of the Wopkaimin people.
- Mining requirements for capital, labour and food for workers integrated the surrounding indigenous peoples into a single ecological/economic region.
- There have been few benefits to the Wopkaimin and the mine has been an ecological disaster.
- Mine employment has been limited and social protest is spreading around the indigenous people of the region.

The Subsistence Economy of the Kiwai-speaking People of the Southwest Coast of Papua New Guinea, *David Lawrence* (page 367)

- Coastal Kiwai people live on the sandy foreshore between the sea and coastal swamps.
- Limited gardening land but access to Torres Strait has meant that they remain subsistence fisherman.
- Associations with Torres Strait Islander people has been long and Torres Strait Islanders taught the Kiwai fishing and hunting skills.

- Kiwai are economically and culturally vulnerable to adverse changes to marine environment.

The Need for an Information Database of Resource Development Activities for the Torres Strait Region, *Thomas Nen* (page 379)

- Information of population, economic activity, education, social services etc. need to be available so that both Australia and PNG can understand processes of change in the Torres Strait region.
- A database on major resource developments in PNG is needed.
- Information on other resource development projects needs to be updated.
- Information needs to be disseminated.

Torres Strait Traditional Fisheries Studies: Some Implications for Sustainable Development, *Bob Johannes and Wallace MacFarlane* (page 389)

- Average rates of seafood consumption in the Torres Strait Islanders communities is among the highest in the world and comprise approximately 238 gm per capita per day (Boigu) to 450 gm per capita per day (Mabuiag).
- Green turtle accounts for approx 70% of this seafood consumption. The average comsuption rate being 125g/day.
- Torres Strait could yield about 30,000 tonnes of seafood per year.
- Educational programmes about exploitation of marine resources and improved environmental education are needed.

Sustainable Development: Possibilities and Limitations to Indigenous Economic Development in the Torres Strait, *Bill Arthur* (page 403)

- Fishing provides the only available means for economic development in the Torres Strait region.
- Islander cultures, climate, geography, politics and access to resources has created a complex mixture of problems in the Torres Strait.
- High failure rate of local business receives undue attention, as it is common in all sections of the Australian economy but need for management support.
- Island Coordinating Council should become a regional development agency.

Self-management and the Bureaucracy: the Example of Thursday Island, *Sandra Kehoe-Forutan* (page 421)

- Expansion of bureaucratic organizations on Thursday Island as a result of self-management policies.

- There are problems with the high cost of housing and water shortages.
- Problems exist between Islander and European communities over the presence of many public servants on Thursday Island.
- The bureaucracy refuses to recognise the need to relocate offices and housing to Horn Island.

Internationalism, Indigenous Peoples and Sustainable Development,
Peter Jull (page 427)

- Concepts such as sustainable development and the new age of global environmental awareness have had considerable impact on international politics.
- The indigenous people of the world have been able to utilize these movements to their advantage.
- Heading the move have been the north circumpolar peoples, such as the Inuit in Canada and Greenland.
- There are important lessons to be learnt by Torres Strait Islanders from these movements.
- International linkages are also developing quickly.

Environment and Human Ecology in the Lake Murray-Middle Fly Area,
Mark Busse (page 441)

- The Lake Murray and Middle Fly area comprises vast lowlands with large tracts of grassland and savannah which are innundated when the Fly and Strickland rivers flood.
- A wide variety of wildlife inhabits this region.
- It is home to the Boazi and Zimakam speaking people who have cultural links with Irian Jaya people.
- The people rely on sago, fish and game, and travel by canoe.
- Negative effects of mining would have serious consequences for the middle Fly peoples.

The Torres Strait Treaty and the Environment, ***Judith Laffan*** (page 451)

- Torres Strait Treaty clearly established the border of sovereignty and jurisdiction between Australia and Papua New Guinea.
- The Treaty preserves the traditional way of life and livelihood of the traditional inhabitants.

- It seeks to strengthen environmental protection of Torres Strait region.
- The Treaty is a valuable instrument for cooperation between Australia and PNG.

The MAZA Wildlife Management Area, Western Province, Papua New Guinea: The Resources and its Management, ***William Asigau*** (page 461)

- Maza Wildlife Management Area was established to protect marine resources.
- Operational problems and need for infrastructure development are critical to its success.

Torres Strait Baseline Study

The Policy Context of the Torres Strait Environmental Baseline Study, ***Allan Haines*** (page 473)

- Torres Strait falls within the area of the SPREP convention.
- The Torres Strait Treaty is the primary basis for ordering affairs between Australia and PNG.
- The Joint Advisory Committee and the Environmental Management Committee important bodies of review and recommendation.
- Development of the baseline study was instigated from the recommendations of the Torres Strait Fisheries Seminar.

Sustainable Development for Traditional Inhabitants of the Torres Strait Region: The Torres Strait Baseline Study, ***David Lawrence*** (page 481)

- Baseline study was developed from recommendation at the Torres Strait Fisheries Seminar and was funded by Commonwealth Government in 1989.
- Roles of Coordinator, Assistant Coordinator, Scientific Adviser and Advisory Committee are outlined.
- Program to be conducted in close cooperation with PNG Government.
- Scientific study will collect information on trace metal concentrations in water, sediments and selected biota; identify transport, geochemical and trophic pathways; determine the potential effects of mining operations in the Torres Strait marine environment, and provide a basis for an ongoing monitoring programme in the Torres Strait.

The Tores Strait Baseline Study Scientific Programme: Assessing the Impacts of Heavy Metals in a Physically Complex and Biologically Diverse Tropical Marine System, *Ian Dight* (page 493)

- Programme objectives are outlines.
- Aim of scientific programme will be to establish spatial and temporal extent of trace metal inputs to the Torres Strait.
- Study design will seek to identify a gradient of change in a number of parameters along a series of transects away from the Fly estuary.
- Three basic methods will be used to quantify trace metal concentrations: analysis of water; of sediments; and of biota.

Concluding Remarks

Lines in the Water: Sea Tenure as "Custom Today" in Western Oceania, *John Cordell,* (page 509)

- The Baseline Study have shown that ethical and indigenous rights issues are at the forefront of environmental concerns.
- Torres Strait is an extremely complex area with regard to socio-political, social justice and equity issues
- The significance of sea tenure and 'island custom', with regard to concepts such as sustainable development is important and needs to be considered.
- Traditional inhabitants of the Torres Strait region can and should formulate their own development strategies.
- It is important to strengthen and incorporate customary tenure with management strategies.