EFFECTS OF FISHING IN THE GREAT BARRIER REEF REGION

PROCEEDINGS OF A WORKSHOP HELD UNDER THE AUSPICES OF THE ADVISORY COMMITTEE ON RESEARCH ON FISHING IN THE GREAT BARRIER REEF REGION

SUMMARY REPORT

FEBRUARY 19-24, 1989

MAGNETIC ISLAND, TOWNSVILLE, QLD.

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This report represents the opinions of those at the workshop. It does not neccessarily represent the opinions of the agencies represented or the Advisory Committee on Research on the Effects of Fishing in the Great Barrier Reef Region.

EXECUTIVE SUMMARY

A scientific workshop was held from 19 - 24 February 1989 at Magnetic Island under the auspices of the Advisory Committee on Research on Fishing in the Great Barrier Reef Region* to discuss and recommend a research program on the effects of fishing, particularly trawling, in the Great Barrier Reef Region.

The specific objectives of the workshop were:

1. Bring together information on fisheries in the Great Barrier Reef Region (GBRR)
2. Bring together information on near reef and inter reef biota
3. Identify ways in which fishing could affect the GBRR
4. Recommend and prioritise future research which is required to answer issues raised in 3.

Presentations of research findings related to the effects of fishing in the Great Barrier Reef Region were made and existing knowledge and information gaps identified were summarised for each subject area.

On the basis of current information, significant conclusions drawn by the workshop include:

- the effects of fishing are major issues for the agencies concerned with management of the GBR Marine Park
- the effects of trawling and line fishing on the GBR Marine Park are not well understood because there have been few studies
- from studies of prawn fisheries of Torres Strait and central Queensland, no direct interactions between trawling and reef communities have been identified
- coral reef fish species occur rarely in the bycatch of trawlers (but all bycatch studies have been undertaken in established trawl grounds: Torres Strait and central Queensland prawn fisheries)
- discards from trawlers result in significant changes to energy transfers; in Torres Strait most of the discards are dead when returned and are consumed by birds, sharks, dolphins and bottom fish,

* The Advisory Committee on Research on the Effects of Fishing comprises of Queensland Department of Primary Industries, Queensland Fish Management Authority, Queensland National Parks and Wildlife Service, Great Barrier Reef Marine Park Authority, Australian Institute of Marine Science, Commonwealth Scientific Industrial Research Organisation, Queensland Commercial Fishernmans Organisation, Queensland Sport and Recreational Fishing Council.and all organisations with research and management interests in the Great Barrier Reef Region. The general purpose is to coordinate and review research on the effects of fishing.

- studies of trawling on the North West Shelf, Southeastern Gulf of Carpentaria and Torres Strait show semipelagic and predatory fish species increase in abundance, while demersal fish species decrease in abundance

- comparisons of benthic communities of areas open and closed to trawling in Torres strait and central Queensland suggest prawn trawling has a significant effect on benthic communities by decreasing the biomass of epibenthic animals and plants on the trawl grounds

- apart from studies of the distribution of the benthic communities of portions of central Queensland little is known about the inter-reef benthic animal and plant communities of the GBR, the effect(s) on the system of their removal, or the recovery rate of these communities if trawling ceased

- apart from some reproductive, dietary, age and growth data for seven species, little is known about the biology of fish species of commercial and recreational importance

- little is known about the impact of line fishing on reef species although one studty of the impact of line fishing after a 3 year closure on one reef (Boult Reef) in the southern GBR suggested an increase in mean fish size and stock size and, after reopening, rapid declines in CPUE and stock size of coral trout

- seasonal closures in prawn fisheries (similar to Northern Prawn Fishery management regimes) can be seen to economically and biologically enhance the fishery, reduce the ecological impact of prawn trawling and minimise conflicts with groups outside the processing industry

- management objectives require clear specification and should encompass biological, social and economic data/information

- an empirical management approach to modelling rather than traditional 'take it or leave it' models allows uncertainties to be identified, more promise in the outcome and interaction with industry

Recommendations

Given that

- the Workshop considers that the best available information and expertise has been used in determining the following program outlined above and
- the workshop considers that the program is vital to achieving stated objectives in terms of on-going monitoring and maintaining the resources of the GBR Region, the Workshop recommends that:

- **a high priority should be given to studies of the effects of fishing on the GBR**
- **a study of the effects of trawling, similar to that carried out in Torres Strait, should be repeated in the area closed to trawling (Marine National Park B Zone) in the Far Northern Section of the Great Barrier Reef Marine Park**
- **a multi-agency study should be undertaken to investigate the effects of fishing (line and trawl) using the rezoning process to manipulate fishing activities at selected sites within three Marine Park sections in such a way to minimise disruptions to commercial and recreational fishing activities**

- **the Advisory Committee on Research on the Effects of Fishing in the Great Barrier Reef Region should approach the Federal Government with a proposal and recommendation for funding for this program in its entirety**

Recommended research program

After considerable discussion on potential fishing effects, available data, existing closures, and scales of interaction, it was considered unlikely that reductionist research would provide useful answers to effects of fishing questions at the scales with which we are dealing. The workshop decided that a large scale experimental approach to the question was more appropriate and highly likely to produce a useful outcome. The workshop concluded that, at present, no realistic or useful experiment to investigate trawling effects in existing nearshore trawl grounds could be identified because of lack of obvious connections with reef communities, the difficulty of closing the substantial areas required for adequate investigation and the uncertainty of what is being investigated. The workshop concluded that the focus of the experiment should be on recreational and commercial handline fisheries and the redspot king prawn fishery. The workshop concluded that interactions between the trawl fishery and reef communities, if they are significant, are likely to be most significant in the red spot king prawn fishery, in which juveniles are found on reefs and for which trawling occurs near and between reefs. The workshop also concluded that line fishing effects appears to be significant and should be experimentally investigated. The workshop focussed on two areas of research:

i) Replicate of Torres Strait investigation

- Subject to adequate surveillance and enforcement of the Marine National Park B (MNPB) Zone in the Far Northern Section of the Great Barrier Reef Marine Park, it is recommended that the CSIRO Torres Strait study of the impact of trawling and the fate of discards be repeated north, south and inside the MNPB transect. This three year study would provide a replicate of the Torres Strait results to assess their generality and provide a GBR study of trawled and 'recovering' areas. The three year study would focus on the impact of trawling on benthic systems, recovery of the benthic communities in MNPB and the fate of discards from the fishery.

ii) GBR line fishing-trawling study

- It is recommended that a study of the effects of fishing (line and resdspot trawl) be undertaken using the rezoning process of the Great Barrier Reef Marine Park, to minimise disruptions to commercial and recreational fisheries. This would be achieved by establishing an experiment in which, in three Marine Park sections, two 'complexes' of at least 5 reefs (2.5 open and 2.5 closed to line fishing) and in which the area surrounding one complex is open to trawling and the other closed to trawling with the closure extending out 5 km into the GBR lagoon. After 3-5 years under this regime, all closed areas are opened to fishing and all open areas closed to fishing. Such a design accommodates the necessary replication, crossover effect, north-south gradient, and staircase design required in large scale natural resource experiments.

During the experiment a coordinated multi-agency program of research and monitoring would be undertaken to evaluate the closures. and measure the significance of any interactions between fishing and the reef community. Such a study in three Marine Park sections would take a minimum of 10 years (with 3 year crossovers).

efw execsumm

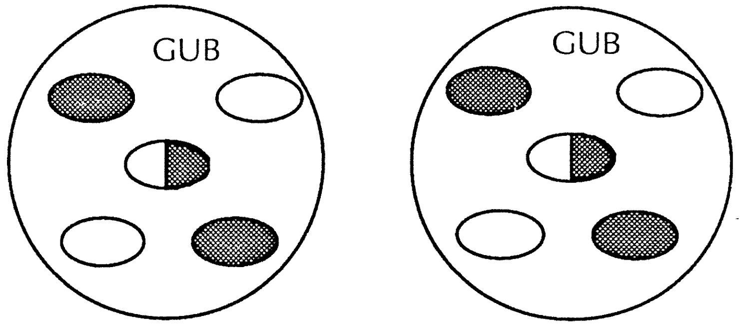
Figure 1: GBR Line Fishing-Trawling Study

(i) Cairns Section

Swap line fished and unfished areas after 3-5 years.

Line fished

Unfished



GUB = General Use B Zone (closed to trawling)

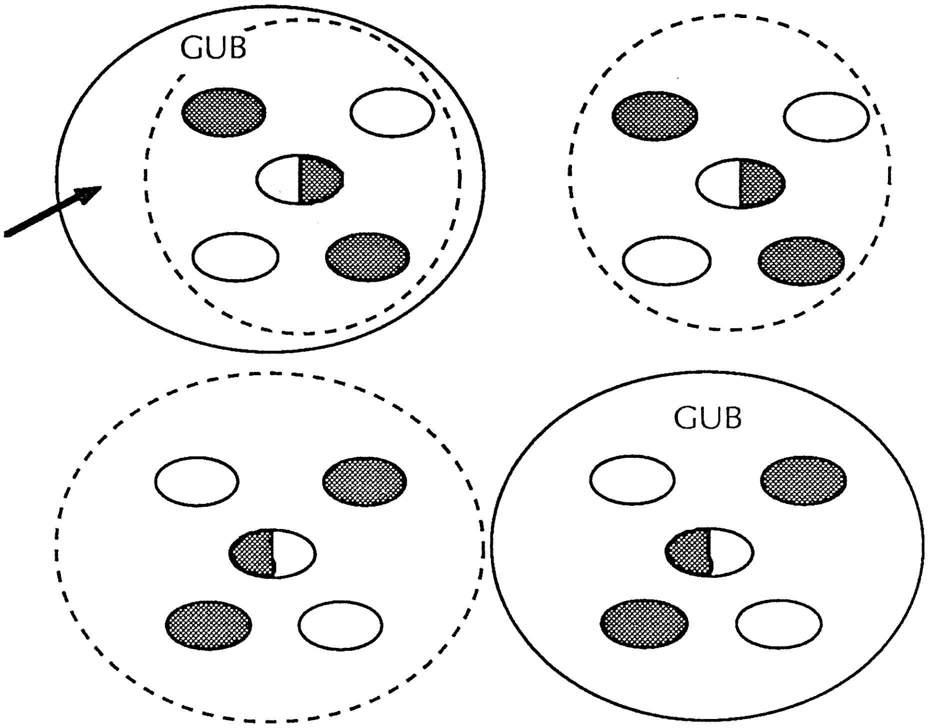
(ii) Townsville

5km Extension into GBR Lagoon

Swap line fished and unfished areas after 3-5 years.

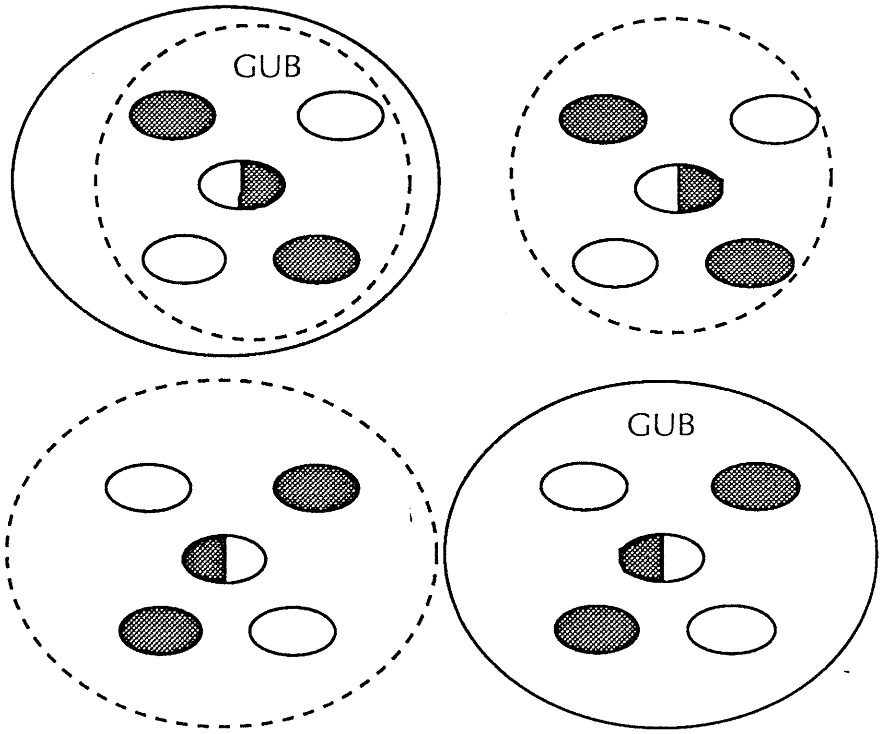
Previous GUB

Current GUB



(iii) Mackay/Capricorn-Bunker

Swap line fished and unfished areas after 3-5 years.



INITIATE EACH OF (i) TO (iii) AT SUCCESSIVE TIMES

PROPOSED RESEARCH PROGRAM

Workshop Discussion of Research Directions

Background

The workshop met to consider the development of a monitoring program that was both sensible and affordable. The discussion was led by Professor Carl Walters (CW).

To put the discussion in context CW suggested there were a number of approaches to prediction of impacts. These included:

* Religious
  - appeal to ethics, risk aversion, common sense to rationalise what feels correct
  - 90% of decisions seem to be based on this

* Reductionist in which the whole system is inferred from its past
  - generally a failure wherever used

* Empiricist where historical experience with similar policies and ecologies is considered important

* Experimentalist where one seeks to define the spatial and temporal structures of impacted and control sites

The GBR Region offers great opportunities to achieve the last of these. The group focussed upon this approach.

It was agreed that the main policy and management problems within the Region with regard to this workshop were linefishing and the red spot prawn trawl fishery.

Objectives

The objectives were further refined as:

* to develop a plan for research with allocated priorities
* to consider this on a large scale of fished and unfished areas
* to plan collaboration among agencies
* to examine experimental designs
* to crudely estimate the cost of such a program.

Design

A matrix of processes affecting the GBR was constructed using spatial scales from 10m to 1000km+ and temporal scales from 1 day to centuries. Within that framework, the group determined that a large number of significant observable and testable events occurred within the spatial scale of 100's meters to 1000s of km and temporal scales of lunar days to 50years and decided to concentrate on this area of the matrix.

It was suggested that perhaps the best way to approach the monitoring on these scales was to set up a factorial sampling design incorporating the following elements:

* areas open to trawling
* areas open to line fishing
* areas open to both
* closed areas.

Because of spatial heterogeneity, it was agreed there were benefits of having such a design replicated along the north and south gradient in the GBR.

The workshop then considered experimental design and agreed that the following principles of design should:

* generate strong contrasts
* measure transients which requires a cross-over design (ie swap treatments)
* allow replication as opposed to "identical" control sites
* consider interspersion of sites throughout the area bearing in mind known gradients
* consider what indices to measure
* consider the opportunities for cooperative monitoring.

To achieve this a range of designs could be considered ranging from the simple to the very complex, but four design types were considered:

* a large number of small experiments on small reefs and soft bottom patches
* to work with a small number of units (8-10) with a size of about 30x30km; each area being relatively homogenous
* very large cross-shelf bands with widths of about 100km (the width determined by biological processes such as migration and dispersal).
* use of modification of existing seasonal closure of areas.

The first and last of these options were discarded as being either reductionist or impractical.

Line fishing and trawling study

It was decided that a suitable method of implementing the design was to select two or three pairs of reef clusters along the length of the reef for study. One of the clusters in each pair would have any restrictions on prawn trawling lifted, while the other member of the pair would have the protected zone around it extended by about 5 km into the lagoon. Within the clusters there would be two reefs closed to fishing; two open to fishing and the fifth with half of the reef open to fishing and the other half closed. After three to five years, the closure treatments would be reversed. Each pair of clusters would be initiated in successive rezoning processes.

This design would allow assessment of:

* the effects of line fishing on individual reefs
* the effects of near-reef trawling on the interreef area and reefs
* indirect effects - interactions between trawling and line fishing
* replenishment areas from closed parts of reefs.

See Figure 1

Agencies

The group considered the specific areas of investigation, approximate annual costs and potential agencies involved. These were:

	Agencies
Age structures of key recreational targets and indicator species (coral trout, sweetlip emperors, small sharks, damselfish, parrotfish, butterflyfish	QDPI/JCU/AIMS
Fishing catch and effort	GBRMPA/QDPI/QNPWS
Density index monitoring (visual censuses)	GBRMPA/AIMS/JCU
Larval recruitment (light traps and census)	AIMS
Tagging and trapping	QDPI/JCU/AIMS
Crown of thorns starfish and benthic survey	GBRMPA/AIMS
Benthos (on and off the reef)	JCU/AIMS/Q.MUS
Selected oceanographic parameters	
Modelling	JCU/AIMS/CSIRO/VIMS
Coordiantion	
Bycatch (in trawling expt. areas)[1]	QDPI
Red spot king prawn juveniles[1]	QDPI

[1] in Townsville and Mackay-Capricorn Bunker areas only.

The workshop considered that it would be absolutely essential to the program to employ a full-time coordinator and support staff.

Far North Transect

Replicate of Torres Strait investigation

A further study was recommended for the Far Northern Section cross shelf transect (MNP B Zone) Subject to adequate surveillance and enforcement of the MNP B zone, it is recommended that the CSIRO Torres Strait study of the impact of prawn trawling and the fate of discards be repeated north, south and inside the MNPB. As well as providing specific information for the GBR Region in trawled and recovering areas, this would be valuable as a replicate for the Torres Strait investigation. The three year study would focus on the impact of trawling on fish communities, the impact of trawling on benthic systems, recovery of the benthic communities in MNPB and the fate of discards from the fishery.

Conclusion

The workshop considered that the program was vital to achieving stated objectives in terms of on-going monitoring and maintaining the resources of the GBR Region.

The best available information and expertise has been used in determining the program outlined above.

The workshop strongly recommended that the Advisory Committee on the Effects of Fishing in the great Barrier Reef Region should approach the Federal Government with a proposal and recommendation for funding for this program in its entirety.

SUMMARIES OF EXISTING INFORMATION AND GAPS IDENTIFIED

Inshore fishery

Aquarium fishery

Reef fishing

Trawling - scallops

- prawns

- fish

- bycatch

Benthos

Seagrasses

Turtles

Sea snakes

Seabirds

Dolphins

Management

Modelling

Methods - trawling

- logbook

summ.exis.info

INSHORE FISHERY: POLLOCK

What has been done

- commercial (net) element and recreation (line) elements
- catch whiting, barramundi, threadfin, queenfish, trevally, other inshore (non-reef fish); whiting 74% of catch
- the net fishery is limited entry, and suject to other restrictions.
- there is a compulsory logbook system.
- coastal angling clubs have detailed catch and effort information some back to 1950's
- Mackay club data analysed; slight changes in CPUE to date; effort changes need to be taken account of. The modal size of fish has remained constant.
- late 1979/80 limited data from boat ramp surveys.

Gaps identified in information.

- need to analyse other club data.
- need to analyse aerial survey data from coastal surveillance for this fishery to provide information on numbers etc.

doc name inshore fish info

AQUARIUM FISHES: POLLOCK

What Has Been Done

- 500 species of fishes collected and many invertebrates
- 20 collectors in 1985; 120 in 1989
- Cairns is the most heavily collected area
- compulsory logbook monitoring
- catches and effort (fishing days) recorded by broad species groups for 14 groups with12 months data so far collected
- -- targetting of effort for particular species and gear differences make the use of CPUE data difficult.
- operators in some areas are moving offshore.
- currently fishing intensity not great but there may be localised problems eg Amphiprion species (clown fish) at Arlington reef species
- Amphiprion may be used as indicator species.

. chaetodonts	19,000 reported	collected	in Queensland	in 1988
. damsels	27,000 "	"	"	
. anemones	7,000 "	"	"	
. wrasses	12,000 "	"	"	

Gaps Identified

- more detailed study on most collected species at most collected reef: eg.Amphiprion (clown fish) at Arlington Reef.
- validation of catch and effort data

doc name aq.fishes

REEF FISHING - BEINSSEN, BROWN, CRAIK

What Has Been Done

- age and growth: data for 7 species of reef fish available
- diet: *Plectropomus leopardus* (teleosts (98%) ; *Lethrinus chrysostomus* (crustaceans, crabs, molluscs)
- reproduction data available for approximately 7 species: size at maturity , spawning times; may be protogynous hermaphrodites, form spawning aggregations
- migration and movement: tagging studies on coral trout and assorted lutjanids, lethrinids and serranids and some work on spawning aggregations; most fish are resident on certain reefs, may move up to 30 kilometres
- catch and catch per unit effort: 1979/1980 catch by "region" data exists; commercial catch approx 2700 tons, speedboat catch approx 6600 tons, charter boat catch 600 tons (includes some pelagic species); broad catch groupings such as lutjanids, lethrinids and serranids
- some regional data for catch and landings exist; some distributional surveys made in specific areas e.g. the Whitsundays; only comprehensive data set is coral trout from visual surveys
- effort: almost no usable data available for commercial vessels; logbook brought into operation in January 1988; recreational fishing: some effort data for charter vessels and speedboats; dated and patchy. Recent aerial surveillance data useful
- estimates in the early 80's suggest a doubling of fishing effort by 1990. Many of the new charter boats not primarily used for fishing; speedboats more numerous and a lot bigger and can more effectively target areas and species
- overseas studies have shown some cycling of target species; not clear whether this is actually happening in the GBR
- Pre and post visual censuses of closed reefs in Capricornia shows increases in numbers and sizes
- FMA/QDPI compulsory fisheries logbook system, established in 1988, will provide far wider coverage of the GBR line fisheries (in terms of both the fleet and the fishing grounds) than could be achieved by previous voluntary logbook, boat-ramp or creel censuses/surveys.
- This will overcome the major biases inherent in previous landings estimates eg. partial reporting (Qld Fish Board records) and inaccurate conversion from estimated monetary values.

- To ensure the development and maintenance of confidence between the fishing industry and research and management agencies, a cautious approach is being taken with regard to accessibility and use of the fishery statistics.

- Boult Reef experiment to assess reef closure and reopening depletion showed

  - increase in standing stock while closed
    -rapid decline in CPUE (90% in just two weeks for coral trout) once reopened
  - 25% stock decline in 2 weeks of coral trout.

- Fishing (line and trawl) could affect the line fishing target species in the following ways

  - Direct

    . short term exploitation

  - Indirect

    . chronic heavy exploitation leads to changes in recruitment processes and changes in community structure
    . reproductive
    . juvenile habitat (seagrasses, lagoons)
    . discard survival
    . dispersal (recruitment vs immigration)

Gaps identified

- some standardised, validated, distribution and abundance data at various stages of the fishes life history

- long term information on movement and growth studies should be obtained in different areas

- information that has been gathered from fishing clubs is to be re-analysed and updated, however a need still exists for a systematic catch and composition data set to be gathered over standard areas for a long time period

- re-survey of speedboats catch effort is essential

- more work on reef fish diets required

- size at sexual maturity in different areas for different species and to examine which species are protogynous hermaphrodites and to examine the relative advantages versus gonochoristic strategy

- need for more consideration of experimental design in reef closures

- replication of Boult Reef experiments required
- consideration needs to be given to encourage participation by user groups in management of these resources
- management objectives need clear definition particularly questions of allocation
- a management plan needs to be formulated by QFMA in consultation with QDPI and GBRMPA as a priority
- need to ensure the data are validated
- possible need to consider finer-scale geographical resolution, particularly in the vicinity of experimental zones
- need for common data-base for recreational fishery statistics.

TRAWLING: SCALLOPS - DREDGE

What has been done

- GBR scallop fishery history relatively well documented from start to decline (fishery, gear efficiency, catch, effort, areas)
- recruitment overfishing is suggested as being responsible for the decline in catch
- heavy exploitation resulted in current very low CPUE maintained only by high market price
- recent management measures include area closure to maintain broodstock
- suggestions that the fishery is expanding into new areas.

Gaps Identified

- effectiveness of permanent closures of broodstock for longterm recruitment
- lack of oceanographic data
- role of refuge populations in recruitment to the fishery

TRAWLING : PRAWNS - DREDGE

What Has Been Done

- history of redspot king prawn (Penaeus longistylus) multi-species fishing is relatively well documented
- peak catch rate (May-June) has become progressively earlier
- voluntary logbook and research survey using 2 cross shelf transects provide information base for fishery
- fishing season duration depends on bycatch (bugs, scallops)
- suggestion that prawn trawling may enhance populations of red spot king prawns
- fishery is evolving and may increase
- juveniles found on reef tops
- suggestion that bycatch may have reduced since trawling began

Gaps Identified

- impact of a developing prawn trawl fishery on prawn populations
- impact of a developing prawn trawl fishery on bycatch composition and biomass.

TRAWLING: FISH - POINER, SAINSBURY

What Has Been Done

- Studies of the Torres Strait and Gulf of Carpentaria prawn trawl fisheries, and the North West Shelf fish trawl fishery showed trawling has altered the composition of fish communities on the trawl ground

- on the NW shelf the abundance of lethrinids, lutjanids and serranids all declined significantly, whilst the abundance of nemipterids and sauridae increased significantly. The total abundance of fish showed no significant change.

- an adaptive management program in the NW shelf appears to be reversing many of the trends and demonstrates the advantages of combining research and management

- in the Torres Strait the abundance of bottom fish have declined whilst the abundance of small predators (Carangidae, Charcharinidae) and midwater species (Engraulidae) have increased in abundance

- in the Torres Strait the biomass of fish in the bycatch correlates with the effort patterns of the fishery with an increase of fish biomass durng the summer closure of the fishery.

Gaps Identified

- mechanism(s) of change need to be identified

- relative importance of habitat modification, fishing mortality, and changes in trophic relationships needs to be elucidated.

TRAWLING : BYCATCH - HILL, POINER, WATSON

What Has Been Done

- bycatch studies have been done in Gulf of Carpentaria, Torres Strait, PNG, and GBRR and fate of discard studies in Torres Strait and Moreton Bay
- coral reef species are a rare event in the bycatch; that was a speculation
- 4-5 families of fish (of no fishing interest) are predominant component of bycatch
- central GBRR: distinct nearshore zone; mid shelf and reef sites show greater affinity to each other
- central GBRR: spatial component of variability more significant than temporal component
- Torres Strait and central GBRR: very similar in bycatch composition.
- Torres Strait is different to Moreton Bay re the fate of discards; in Moreton Bay crabs are a major beneficiary but in both areas a significant proportion of discards are consumed by pelagic species (dolphins, sharks) and seabirds.

Gaps Identified

- bycatch studies all undertaken in well established (prawn) trawl fishery
- need for bycatch and discard studies in remaining sections of GBRR and in newly developing trawl grounds
- level of mid water scavenging needs investigation
- dedicated bycatch studies with proper experimental design and replication required
- sorting of bycatch from Q.DPI Swains trip required.

BENTHOS - ARNOLD, BIRTLES, HUTCHINGS, POINER

What Has Been Done

- GBRMPA commissioned a comprehensive review of epibenthic communities of the GBRR
- apart from central GBR and Torres Strait there is limited information available
- available data are inadequate to suggest a North-South gradation in soft sediment fauna
- two studies (Moreton Bay (infaunal) and N W Shelf) suggested rapid recovery of benthic communities following large scale disturbance
- a comprehensive cross shelf study in the central GBR is underway; distinct zones have been identified; the middle and outer shelf supports rich epibenthic communities.
- Torres Strait areas closed to fishing support a significantly higher biomass of epibenthic species compared to fished areas
- major environmental pertubations (eg. cyclones) can be major forcing factors in these communities
- near reef gutters are transition zones
- patches of Turbinaria with lethrinids have been removed by trawling in some areas; some still exist in Swains

Gaps Identified

- existing unanalysed, unreported samples for the Central GBRR would provide valuable pre and post trawling information
- recovery of benthos studies required
- role of infauna needs investigation
- life history studies required for much of benthic fauna
- information gaps in species distribution in Southern GBRR (N-S transect along GBRR required)

SEAGRASSES - DERBYSHIRE, POINER

What Has Been Done

- diver surveys of seagrasses of Queensland coast have been undertaken
- 14 species found in coastal waters less than 15 m; deeper grasses may exist; some may also occur between reefs.
- seagrasses are significant nursery areas for prawns (23 species and 9 as juveniles found especially important for (P. esculentus).
- some fish found mostly (non commercial) are found in seabeds; juvenile lethrinids occur in seagrass beds.
- coastal seagrass beds are not trawled (mostly protected);

Gaps Identified

- temporal variation in seagrass beds
- location, composition of seagrass beds in reef areas and deepwater seagrass
- investigation of patchiness and its role in analyses
- effects of increased nutrient loading on seagrass beds needs documenting

TURTLES - MILLER, POINER

What Has Been Done

- world distribution and breeding biology of turtles well understood, mainly from nesting grounds

- nesting distribution within the Great Barrier Reef has been extensively surveyed. Most nesting is restricted to a few small beaches within two sections:
  - Far Northern Section
    - outer barrier cays, including Raine Island - green turtles
    - inner shelf cays - hawksbill turtles

  - Southern Section, including Capricornia
    - Capricorn - Bunker Groups - green turtles
    - Capricorn - Bunker Groups, adjacent mainland, Swain Reef says - loggerhead turtles
    - inshore continental islands, including Peak and Wild Duck Islands
    - flatback turtles

- Great Barrier Reef feeding areas are more widely distributed with intra specific differences:
  - green turtles - sea grass pastures, coral reefs, rocky reefs
  - loggerhead turtles - coral reefs and rocky reefs
  - flatback turtles - soft bottom habitats of Great Barrier Reef lagoon
  - olive ridley turtles - soft bottom habitats of Great Barrier Reef lagoon
  - leatherback turtle - near surface waters, avoiding reefs.

- research on the population dynamics of green and loggerhead turtles within Great Barrier Reef feeding areas in progress

- best overseas models suggest that marine turtles populations can withstand only very low mortality among adult and large immature age classes

- human induced mortality (including trawling) is a significant problem

- while data from Gulf of Carpentaria suggests rate of capture is low (<0.05 turtles/shot), trawling can be a problem in specific areas, eg. Mon Repos.

Gaps identified

- detailed information on population dynamics of all species of marine turtles

- turtle bycatch in trawls in Great Barrier Reef: species composition, mortality by species and region.

- seasonal closures or use of TEDS in localised areas need consideration

SEASNAKES - WARD

What Has Been Done

- seasnakes occur in trawls and an industry is developing for skins for the domestic market
- mortality has been estimated at up to 40% of snakes trawled

Gaps Identified

- population dynamics of seasnakes

SEABIRDS - BLABER, HULSMAN, WALKER

What Has Been Done

- information exists on distribution and breeding colonies of GBR seabirds
- pelagic fish such as engraulids, clupeids, scombrids and exocoetids are the main prey of the seabirds
- silver gulls could be a factor in the population structures of birds in the Region based on their ability to take chicks and raid nests; a colony in northern NSW grew from 2,000 to 1940 to around 100,000 in 1978
- fish from trawling discards are important in the maintenance of some seabird populations.
- changes in seabird populations in response to fishing have been observed elsewhere eg North Sea

Gaps identified

- data on bird abundance in the GBR Region.
- are increases in populations of silver gulls (with increasing availability of refuse) like to affect other bird species?
- effects of fishing on different species of seabird population dynamics
- which species interact with commercial and recreational fishing?
- data on diet and seasonal changes for seabirds breeding in the GBR
- relationships between seabirds and their fish prey

DOLPHINS - CORKERON, HILL

What Has Been Done

- three studies of dolphins show they are major consumers of trawled discards

- it is possible that shark ecology is also affected by trawling (attacks on dolphins)

Gap identified

- funding required to work up Helene Marsh's data on dolphins in the GBRR and Torres Strait

- need to test level of dependence of dolphins on trawl discards in diet

MANAGEMENT - GLAISTER, SOMERS

What Has Been Done

- management of prawn trawl fishery has been largely on economic considerations not biological with the exception of biological concern re tiger prawns
- clear objectives need to be set for management, objectives should be economic/biological not just economic
- seasonal closures are seen as a principal management tool and can be shown to economically and biologically enhance the fishery
- timing and duration of closures are critical to meeting specific objectives
- environmental factors are important in recruit dynamics
- fishery effort can be responsible for long term declines

Gaps Identified

- multispecies problem
- timing and duration of closures
- clearly defined management objectives
- effects of changes in predator prey relations on prawn population
- effects of substrate changes on prawn populations

MODELLING - SAINSBURY

What Has Been Done

- traditional "take it or leave it" models are inappropriate for management goals for effects of fishing questions
- an alternative empirical management approach which identifies uncertainty and its consequences offers more promise in the management context and allows interaction with industry
- components include industry response, the observation process and feedback to the management decision process
- this process will lead to understanding of uncertainty in time and space of the GBRR
- considerable modelling has occurred in the GBRR including fish recruitment, coral interactions, physical oceanographic models and cots; but little work re observation process
- preliminary model for the GBR is currently being developed

METHODS: TRAWLING - PENN

What Has Been Done

- demonstrated effectiveness of microwave transmitter device in locational accuracy in prawn and scallop depletion experiments (±m)

Gaps Identified

- number of sweeps of trawl necessary for effective depletion needs investigation

doc no abst2

WORKSHOP : EFFECTS OF FISHING IN THE GREAT BARRIER REEF REGION

Sunday 19 to Friday 24 February 1989
Latitude 19, Magnetic Island

Objectives

1. Bring together information on fisheries in the Great Barrier Reef Region (GBRR)
2. Bring together information on near reef and inter reef biota.
3. Identify ways in which fishing could affect the GBRR.
4. Recommend and prioritise future research which is required to answer issues raised in 3.

Outputs

1. Finalised report to Advisory Committee at end of workshop covering objectives 1 to 4.
2. Publication of about 12 papers on effects on trawling in AJFMR about January 1990.

Chairperson

Dr Ron Davies

PROGRAM

Sunday 19 February: Participants arrive

Monday 20 February: Introduction and review of existing data sets

Introduction

Don Kinsey	Welcome and outline of workshop objectives	
Wendy Craik	Housekeeping details Introduction of rapporteurs	 Steve Hillman Brian Lassig Beryl Dennis Rhonda Lane

Review of existing GBR data sets

Review existing data sets of biological and fisheries data. Data should be from the GBRR or from other areas in Australia relevant to the GBR. This is not meant to be a detailed presentation of the results of the work; rather it is intended to be a statement of the scope of the project, assumptions, reasons for doing it, techniques, type of results, general interpretations and conclusions. Participants should bring along lists of publications and promised papers, show examples of data to bring out resolution of area and time; identify gaps; describe work in progress on form to be provided. It is intended merely to set the scene so that we know what has been done and what information is readily available or will become available in the near future.

15 minutes is a general guide to the length of presentations desired.

<u>Line fishing</u>

Wendy Craik	Information on distribution of effort, species and size composition, longterm trends in CPUE, methods of collecting information for reef fishes
Barry Pollock	Information on catch trends, species , size composition, methods of collecting information etc for inshore fishes
Ian Brown	Information on mackerel, effects of trolling

<u>Trawling</u>

Mike Dredge	Distribution of effort, trawler behaviour, logbook systems Brief description of trawl gear
John Glaister	Management and its effects on trawling - limitations, closures, switching of effort

Reg Watson	Overview of bycatch composition on the East coast (redspot, Low Isles work)
Ian Poiner	Bycatch composition - Torres Strait
Ian Poiner Peter Arnold Alistair Birtles	Epibenthos and seagrasses
Lester Cannon	Sponges and other epibenthics; areas surveyed etc
Kurt Derbyshire	Seagrasses
Col Limpus Ian Poiner	Turtles
Terry Walker	Seabirds - survey information
Tim Ward	Seasnakes
Ian Brown	QDPI study
Dave Williams	AIMS study
Peter Corkeron	Dolphins

Open session for all participants to identify data not already covered.

Tuesday 21 February: Mechanisms

More formal seminars (invited presentations only) than on Day 1; these presentations will probably form the basis of papers to be published in AJFMR, though it is not essential for presenters to have a written paper for the workshop (although it would be nice) or to write up for later publication. Other papers or notes for publication may be identified during the course of the workshop. Papers to focus on mechanisms for impact e.g work already carried out into effects of fishing in other areas (eg NW Shelf, Torres Strait, SE Gulf). Data need not be from the GBR, but may be from other relevant areas. The papers may in some cases be speculative eg. from available literature on epibenthos, what is the likely impact of one off trawling, repeated trawling; what is the likely regeneration time of sponges, other epibenthos; is it better to trawl in blocks or strips from the point of view of epibenthos?

Approximately 25 minutes presentation, 10-20 minutes discussion time per paper.

<u>Trawling</u>

Pat Hutchings	Regeneration of epibenthic faunas - commissioned review
Alistair Birtles Peter Arnold	Detrital feeders and the role of disturbance
Ian Somers	Effects of trawling on prawn populations (theoretical)
Mike Dredge	Effects of trawling on prawn populations (E coast examples)
Mike Dredge	Effects of trawling on scallop populations
Jim Penn	Techniques for direct measurement of the impact of trawling on benthic populations, particularly prawns and scallops in WA
Ian Poiner	Effects of prawn trawling on fish populations (G of C and TS)
Reg Watson) Mike Dredge)	Bycatch from redspot project
Col Limpus	Effects of trawling on turtles - population dynamics
Burke Hill	Fate of discards in Torres Strait
Kees Hulsman	Feeding by seabirds
Steve Blaber	Birds as beneficiaries
Keith Sainsbury	Effects of trawling on NW Shelf, focus on modelling, interpretation and management

Wednesday 22 February: Unstructured

Each modeller to present his comments identifying principal mechanisms , choosing appropriate models, discussion of ways in which the system probably operates etc. from previous 2 days talks. Approximately 15 minutes each.

John Parslow

Keith Sainsbury

Chairperson leads discussion of mechanisms for impact (direct and indirect); critique of approach to date. Synthesis; does the information really identify the mechanisms? Agenda to be sorted out in advance. Everyone involved.

Thursday 23 February: Synthesis and future research program

Attempt to synthesise the information and identify gaps in knowledge. Discussion of appropriate techniques for obtaining this information. Chairperson to structure the day so that there is a clear objective with discrete topics. Chairperson should guide discussion towards either resolving or identifying unresolved areas and making recommendations on how these could be resolved and by whom.

Friday 24 February: Report finalisation

Review reports from rapporteurs and prepare final document. This is not a session to reargue issues but to agree on coverage, content of report etc. Most participants should be able to leave after lunch.Editors (Ian Poiner, John Glaister, Wendy Craik, Ron Davies finalise report in afternoon and evening for Advisory Committee.

16 February 1989

Line fishing

Konrad Beinssen	Boult Reef experiment
Howard Choat	
Peter Doherty	
Gary Russ	
Dave Williams	Possible mechanisms for effects of line and trawl fishing on reef fish (possible cots connection)
Ian Brown	Effects of line fishing

Organisation
Each day there will be rapporteurs to work up the days information overnight.
Word processor and venue rooms will be available at night and day.
Drafts will be circulated each day to enable participants to comment.
Usual conference facilities (OHP, slide projector, PC) will be available.
A VHS video recorder and tv will be available.
Attendance is by invitation only.
Attendees meet own travel, accommodation, meal costs; GBRMPA to meet costs of Chair.

Publication of papers
It is hoped that papers presented on Day 2 would form the basis of a publication of around 12 papers and possibly a few notes in an isue of AJFMR in January 1990 (so pagination starts at 1). This would cost nothing except editorial input. Papers would need to be submitted by June/July 1989, papers refereed by around September/ October, typesetting and printing November/ December, publication January 1990.

16 February 1989

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EFFECTS OF FISHING IN THE GREAT BARRIER REEF REGION

PROCEEDINGS OF A WORKSHOP HELD UNDER THE AUSPICES OF THE ADVISORY COMMITTEE ON RESEARCH ON FISHING IN THE GREAT BARRIER REEF REGION

ABSTRACTS AND BACKGROUND PAPERS

FEBRUARY 19-24, 1989

MAGNETIC ISLAND, TOWNSVILLE, QLD.

Editors : Wendy Craik
John Glaister
Ian Poiner

ABSTRACTS AND BACKGROUND PAPERS

Non-trawl fisheries

Barry Pollock. Non Trawl Fisheries in the GBR Region.

Reef fishing

I W Brown. An Overview of Some Mechanisms of Possible Significance to the Exploitation of Tropical Reef Fish by Handline Fisheries.

J H Choat, G R Russ, D McB Williams. Towards a Tropical Fisheries Biology.

W Craik. Reef Fish in the Great Barrier Reef Region: Summary of Research.

K Beinssen. Impact of Fishing in Coral Trout Population in Capricornia.

Trawling - scallops

M C L Dredge. Effects of Trawling on Scallop Populations. Recruitment Overfishing in a Tropical Scallop Fishery?

Trawling - prawns

M C L Dredge. Brief Description of Trawl Gear.

M C L Dredge. A Trawl Fishery for King Prawns.

Ian Poiner. Effects of Prawn Trawling on Fish Populations.

Trawling - fish

Keith Sainsbury. Effects of Trawling on the Northwest Shelf and its Management.

The ecological basis of multispecies fisheries in tropical Australis (extract).

Trawling - bycatch

Ian Poiner. Bycatch in Torres Strait

R A Watson. Bycatch Studies in the Great Barrier Reef

R A Watson, M C L Dredge. Spatial and Seasonal Effects on Demersal Fauna Associated with a Prawn Fishery on the Great Barrier Reef

B J Hill, T J Wassenberg. The Fate of Discards from Trawlers in a Tropical Prawn fishery in the Torres Strait Between Australia and Papua New Guinea

Benthos

Ian Poiner. Epibenthos

P W Arnold, R A Birtles. Soft Sediment Epibenthos of the Central GBR Shelf

R A Birtles and P W Arnold. Temporal Patterns in Shelf Echinoderms and Some Thoughts on the Role of Disturbance in Structuring Shelf Communities

Distribution of trophic Groups of Epifaunal Echinoderms and Molluscs in the Soft Sediment Area of the Central Great Barrier Reef Shelf.

Pat Hutchings and Ian Baxter. A Speculative Review of the Effects of Trawling and Potential for Recovery on Inter-reefal Communities

A Speculative Review of the Effects of Trawling and Potential for Recovery on Interreefal Macro benthic Epifaunal communities.

Seagrass

Kurt Derbyshire. Seagrasses

Turtles

Ian Poiner. Turtles

C J Limpus, J D Miller. Turtles

C J Limpus, J D Miller. Effects of Trawling on Turtles - Population Dynamics

Sea snakes

Tim Ward. Seasnakes

Seabirds

Kees Hulsman. The Effects of Trawling on Pelagic fFish Populations and Seabird Populations

Terry Walker. Seabirds

S J M Blaber and T J Wassenberg. Feeding Ecology of the Piscivorous Birds *Phalacrocorax Varius, P. melanoleucos and Sterna bergii* in Moreton Bay, Australia: Diets and Dependence on Trawler Discards

Dolphins

Peter Corkeron. Dolphins

Dolphins

Peter Corkeron. Dolphins

Management

J P Glaister. Management of the East Coast Penaeid Prawn Fishery

Ian Somers. Theoretical Effects of Trawling on Prawn Populations

Modelling

Keith Sainsbury, John Parslow. The Uses of Modelling in the Management Process

Methods

L M Joll, J W Penn. Techniques for the Direct Measurement of the Impact of Trawling on Scallop and Prawn Populations

Ian W Brown. Establishment of a Commercial Fisheries Database in Queensland

Research proposals

I W Brown. Proposed QDPI Study on Inter-Reef Epibenthos and Associated Fish Fauna

Alistar Robertson and Dan Alongi. FIRDTF Proposal Food Chains and Nutrient Cycles - Supporting Adult Prawn Stocks (Central GBR)

backgroundpapers

ABSTRACT

NON-TRAWL FISHERIES IN THE GBR REGION

BARRY POLLOCK
Queensland Department of Primary Industries

The first stated objective of this Workshop is "to bring together information on fisheries of the GBR region". Trawl fishing and line fishing for reef fish will be covered in detail by other participants. Other fisheries in the GBR region include:

- aquarium fish collecting
- inshore fin-fish fishery
- tuna fishery
- coral collecting
- pearl shell trochus collecting
- beche de mer
- shell collecting
- spear fishing
- traditional fisheries (by aboriginals and islanders)
- crab fisheries
- oystering

This paper provides a brief overview of aquarium fish collecting and the inshore fin-fish fishery.

Aquarium fish collecting involves about 500 species of fishes and many species of invertebrates. Collectors (120) operate along the coastline from Port Douglas to the Gold Coast. Cairns region is the heaviest collecting area in the Marine Park. Management of this fishery includes gear restrictions, prohibition on collection of certain species, restruction to general use zones in the Park, a maximum of two assistants for each collection and a compulsory log book return. Log details are held by QDPI and provide details of fishing effort on all reefs and islands, and catch of the fourteen major groups of animals.

The inshore fin-fishing has a commercial net fishing element and a recreational (line) fishing element. A variety of species are targetted including barramundi, threadfin salmon, jardine fish, shark, bream, whiting, flathead, queenfish and trevally. The net fishery is a limited entry fishing subject to gear restrictions, time and over closures, minimum sizes, and a compulsory logbook.

The recreational fishing is not well documented but information on long term catch and effort is held by angling clubs at Bundaberg, Gladstone, Rockhampton, Mackay and Townsville. QDPI has carried out an analysis of the Mackay data which show slight changes in CPUE over the past 30 years apparently due to improved fishing techniques and increasing total effort. The model size of fish taken by anglers has remained remarkably stable.

nontrawl

ABSTRACT

AN OVERVIEW OF MECHANISMS OF POSSIBLE SIGNIFICANCE TO THE EXPLOITATION OF TROPICAL REEF FISH BY HANDLINE FISHERIES

I.W. BROWN
Queensland Department of Primary Industries

A number of mechanisms or features which may affect the way tropical marine reef fish stocks respond to fishing pressure is examined. They include the multi-species nature of typical reef fisheries; the patchy distribution of both resource and fishing effort along the length of the GBR; differences in reproductive strategy, chronology and behaviour; and environmental control of larval dispersal and post-settlement survival. Some comments are also made on factors which influence the survival of non-target species and undersized individuals of desirable species.

Documented examples of the effects of exploitation in the short term (direct) and longer term (indirect) are discussed. While indirect links between community structure and exploitation pressure have been reported, the mechanisms involved are unclear.

All reef fish species of direct commercial and recreational value have pelagic eggs and larvae. Patterns of larval dispersal (and ultimately recruitment) depend on various mechanisms including spawning chonology, aggregative behaviour, water movement along and across the shelf, and larval/juvenile behaviour. Some species such as coral trout which form spawning aggregations at certain times of the year may become much more vulnerable to fishing mortality during those periods.

Many of the most valuable species (eg serranids and lethrinids) are characterised by a protogynous hermaphroditic reproductive strategy. Simulation modelling has indicated that, despite previous fears to the contrary, this factor alone does not make fish such as serranids more susceptible to overexploitation, at least over a moderate range of mortality rates.

docno ab.IW Brown

WORKSHOP ON EFFECTS OF FISHING IN THE GREAT BARRIER REEF REGION
MAGNETIC ISLAND, 20-24 FEBRUARY 1989

Background Paper

AN OVERVIEW OF SOME MECHANISMS OF POTENTIAL SIGNIFICANCE TO THE EXPLOITATION OF TROPICAL REEF FISH BY HANDLINE FISHERIES

I.W. BROWN

Southern Fisheries Research Centre
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INTRODUCTION

Many of the characteristics which distinguish tropical reef fisheries from temperate water fisheries in general have been identified by Bannerot *et al.* (1987) as creating obstacles to stock assessment and hence to effective management of the systems. These features include

1. The multispecific nature of the fishery, with many diverse taxa having diverse biological and population characteristics.

2. Diffuse nature of fishing effort, with a variety of gears in use and uneven spatial distribution of effort.

3. Non-centralised landings, with catches often landed at numerous ports.

With the possible exception of gear variety, these features apply equally to the demersal fisheries of the GBR region. The sorts of problems they produce in terms of data acquisition and interpretation include incompleteness of catch and effort data (by area particularly), difficulty in collecting and quantifying effort data by gear type, and the incidence of "product lumping", where several species are reported in single categories.

A number of reviews, papers and workshop proceedings published over the last decade (e.g. Pauly 1979, Saila and Roedel 1980, Huntsman, Nicholson and Fox 1982, Pauly and Murphy 1982, Polovina and Ralston 1987) deal specifically with assessing, modelling and/or managing tropical multi-species stocks in various parts of the world, and estimating their population parameters.

However much of the recent research on fish on the GBR has been of a theoretical ecological nature, directed towards small, site-specific species of little direct economic value apart perhaps from their aquarium market potential. These studies have revealed important new insights into recruitment dynamics and mechanisms influencing community stability, but there has not yet been much attempt to to apply the theory to the species targetted by the commercial and recreational line fisheries of the GBRR.

There are no simple answers to the question of the effects of fishing activities on GBR fish stocks. What we're really concerned with is identifying features of the tropical reef fisheries which are likely to cause the system to react in a way we might not immediately anticipate.

One of the main characteristics is the first "obstacle to stock assessment" of Bannerot *et al.* - i.e. the multispecific nature of the fishery, and the inherent fact that its component parts do not exist in isolation from each other. Trophic inter-relationships, possible competition for limited space, and the tendency for fisheries to target the top end of the trophic web all conspire to produce what might not be entirely predictable effects within the reef fish community.

The highly non-uniform distribution of fishing effort along the length of the GBR must also have some effect on the way the resource as a whole responds to exploitation. It immediately begs the question as to the geographical limits to the individual populations or sub-populations that make up the resource. Not only is fishing effort distributed in a highly non-uniform manner, as a result of the location of the major coastal centres of human population, but the resource itself is very patchily distributed, because of its intimate association with patchy coral reef habitats.

Close scrutiny of the biological and behavioural characteristics of key demersal reef fish species should be helpful in understanding and identifying the mechanisms which influence their spatial distribution and population limits. Reproductive strategies and associated spawning behaviour of target species have been identified as important to our knowledge of how the system responds to varying levels of fishing pressure. The timing of reproductive events, in relation to local environmental conditions, can have a significant bearing on the dispersal of eggs and larvae, and consequently affect patterns of recruitment of juveniles. The requirement of juveniles (and perhaps postlarvae) for specific "intermediate" nursery habitats may further influence the way in which the reef habitats of the adult fish are colonised. Spawning behaviour is potentially of great significance to the direct effects of fishing pressure on the stock - the regular occurrence of spawning aggregations of some species at specific locations at a predictable time of the year could lead to extreme temporal changes in their vulnerability.

The reproductive strategies of various groups of exploited reef fishes are known to differ, and this may well result in populations of one species reacting in quite a different way from populations of another species in the same fishery, subject to the same level of exploitation. A clear understanding of the relative direction and magnitude of these effects is of great importance to the development and fine-tuning of specific management strategies.

The following discussion examines some of these mechanisms in greater detail, to determine how relevant they may be to interpreting the effects of fishing (line-fishing in particular) on the fish resources of the GBR.

1. DIRECT PERTURBATION

Possibly the most conceptually simple mechanism comprises the direct modification of a fish community by fishing. Various studies (e.g. Craik 1979, Ayling and Ayling 1986, Goeden 1986) have demonstrated differences between localities on the GBR in the density and/or size structure of populations of large target species (coral trout in particular), which have been attributed to differing levels of fishing pressure.

In a controlled experimental situation at Boult Reef (Bunker Group), Beinssen (1988) provided an indication of the size and speed at which changes can occur when a more or less previously unfished community is subjected to intense fishing pressure over a short time period. There is some evidence that the observed decline in coral trout catch rate was not entirely due to the diminishing numerical size of the stock; there may have been an element of "hook-shyness" tending to overestimate the depletion rate in short time spans. Such behavioural changes have often been suspected, but there is little documented evidence of their importance in stock assessment through depletion experiments.

While Ayling and Ayling (1986) found between-reef differences in coral trout population density consistent with differences in the supposed levels of past fishing pressure, they also noted anomalies in the size distribution of trout populations in the Capricorn-Bunker group, and cautioned that different genetic stocks may be involved.

2. INDIRECT PERTURBATION

Of greater long term significance is the change in fish community composition and structure resulting from the partial or total removal of a few usually upper-trophic level predator species. In contrast to artisanal marine reef-based fisheries which are characterised by diverse fishing methods including netting (Lock 1986) and trapping (Munro 1983), GBR fish are exploited principally by hook and line.

This gear tends to be more selective than nets and traps, and the catch consists predominately of active predators with relative large mouths (serranids, lutjanids, carangids, and lethrinids), rather than herbivores (e.g. scarids and siganids) or small-mouthed species such as angelfishes and chaetodonts. Thus the species mix in a heavily exploited artisanal or subsistence fishery may be quite different from that in a heavily exploited but essentially single-gear commercial/recreational fishery.

Ferry and Kohler (1987) compared two reefs in Haiti which had been subject to substantially different levels of exploitation by trap fisheries. They found that although the modal sizes of two of the most abundant groups (scarids and chaetodonts) were significantly lower on the more heavily exploited reef, there was little difference in either species composition, total abundance or numerical CPUE between the sites. In contrast, Russ and Alcala (1988) observed marked shifts in the species composition of the coral reef fish assemblage in the Philippines following resumption of intensive fishing after an extended closure.

Goeden (1982) documented differences in species composition between reefs which were believed to have had different exploitation histories, and related this to population changes in a "keystone predator" (coral trout). Such observed variation in community structure between sites might have been due as much to stochastic recruitment effects (Sale 1977, 1980; Talbot and Gilbert 1984) as to unpredictable changes resulting from fishing mortality on the large predatory serranids, as postulated by Goeden (1982). However it does seem intuitively reasonable that relieving the predation pressure on an assemblage of lower trophic-level species might increase the magnitude of periodic changes in the composition of the assemblage, particularly amongst the shorter-lived, more rapidly growing species (Munro and Williams 1985).

The change of perspective in our understanding of the stability (or lack thereof) in reef fish community structure has developed to a large extent from the ecological work of Sale, on small non-commercial fishes. It remains to be seen how appropriate Sale's hypotheses are with respect to communities of larger species characterised by a much lower numerical abundance. Despite the lack of certainty about recruitment and ultimately community structure, on a broader geographical scale consistent patterns of abundance have been observed in broadly similar habitats (Williams 1982). However, as Saila (1980) has pointed out, it is essential to incorporate the stochastic element of recruitment and species replacement in management considerations.

3. DISPERSAL MECHANISMS

It is impossible to totally segregate discussion of the processes of dispersal, recruitment and community or population structure, and in the preceding section reference has already been made to the uncertainty and unpredictability of the mechanisms which ultimately determine the composition of reef fish communities.

Virtually all of the reef fish species exploited from the GBRR are characterised by a pelagic egg and larval phase in their life histories (Thresher 1984, Leis 1987). Recent attempts to explain the evolution of such a strategy in the coral reef environment have resulted in two general hypotheses - (i) Dispersion, and (ii) Diminished Predation (McFarland 1982). The Dispersion hypothesis states essentially that the pelagic larval stage is designed to ensure larvae dispersal to, and colonisation of, patchily distributed reef habitats (e.g. Barlow, 1981). Diminished Predation, on the other hand, views the pelagic phase as a mechanism to reduce mortality by temporarily isolating a particularly vulnerable part of the life cycle from areas of high predator density, viz. the reef habitat (Johannes 1978).

The latter hypothesis is generally favoured, but the value of a pelagic larval phase in enhancing dispersal to other reefs and reef systems obviously cannot be denied. Both functions are undoubtedly significant; their relative importance may vary from species to species. As a mechanism to minimise natural mortality during a non-exploited phase of the life cycle, the pelagic larval "propagule" has little relevance in discussions about the effects of fishing. One might argue that heavy exploitation of high-trophic level pelagic predators (e.g. scombrids) by, for example, mackerel fishermen, might conceivably result in an increase in populations of scombrid prey (e.g. pelagic planktivores). This might in turn cause increased predation pressure on the ichthyoplankton. While several studies have concluded that predation is the major cause of mortality amongst fish larvae, it would be very difficult to conclusively demonstrate such a cause-effect relationship, given the high level of noise in the system.

In terms of dispersal, however, the "propagule" assumes immense importance in the context of the effects of fishing since the mechanisms which direct and control its movement are ultimately responsible for the geographic distribution of the adult stock. This mechanism is obviously of greater significance to species whose adults are highly site-associated than to those (such as the scombrids and carangids) characterised by a high degree of mobility. Factors which influence the effectiveness of larval dispersal include the individual species' capacity to prolong larval life, the direction and strength of water currents and the timing of egg release (McFarland, 1982). The capacity of a larva to recognise the proximity of suitable settlement sites and make the necessary behavioural responses must also be of some considerable importance.

Little is known about the larval ecology of fish species that are exploited in the GBRR, because of difficulties in specific identification, and particularly the apparent relative scarcity of those species in the ichthyoplankton (Leis, 1987). However, information from related species in other areas can provide a useful indication of the probable situation on the GBR. Of greatest interest are the lutjanids, serranids, lethrinids and carangids. The following summary is from Leis (1987):

Lutjanid ("snapper") eggs are spherical generally slightly less than 1 mm in diameter, and take about 17 to 36 hr to incubate, depending on species and temperature. Larval yolk reserves are exhausted 3-4 days after hatching, and total larval life ranges from 25-47 days. With the exception of the etelines (which occur in deeper outer reef slope habitats), larvae are more abundant in continental shelf waters than oceanic waters. They avoid surface waters by day, but are evenly distributed through the water column at night. Abundance varies seasonally according to species, but most are more abundant during summer than winter. Size at settlement (10 - 50 mm) varies between species, but is reasonably consistent within species. Leis and Goldman (1984) found that lutjanids comprised 3.5-8% of all larvae from the large GBR lagoon, but only 0.3-4.0% in the immediate vicinity of coral reefs, and concluded that the open waters of the main lagoon constitute the primary nursery area for lutjanid larvae. No significant differences in larval abundance across the lagoon itself were evident.

Epinepheline serranids also have small (~1 mm) pelagic eggs, with incubation periods between 20 and 45 hr (Leis, 1987). Epinepheline larvae are even more scarce than lutjanids, but Leis maintains that this may merely reflect the relatively small size of the spawning population. On the North West Shelf Young *et al.* (1986) found *Epinephelus* larvae mainly on the mid-shelf (50-100 m), *Cephalopholis* only on inner- and mid-shelf, and *Plectropomus* mostly on the inner shelf (40-58 m). As with the lethrinids, Leis and Goldman (1984) found epinephelid larvae were much more abundant in the open waters of the greater GBR lagoon than close by the coral reefs. Vertical distribution patterns also paralleled those of the lutjanids.

Size at settlement is about 25 mm for *Epinephelus* species; laboratory studies indicate that this equates to an age of between 35 and 50 days. *Plectropomus* larvae apparently settle out at around 20 mm; *Cephalopholis* at ~18 mm.

The absence of Lethrinids from the tropical west Atlantic means that there is comparatively little data available on their larvae. However they do produce planktonic eggs and larvae, whose characteristics are probably not dissimilar to those of the lutjanids.

Thus the species of greatest interest to the commercial and recreational fishermen of the GBR may spend anything up to seven or eight weeks as larvae, with relatively limited mobility, drifting at the mercy of local oceanic currents. The observed diel vertical migratory behaviour is probably related more to diurnal predator avoidance than to a directed utilisation of currents, although Williams *et al.* (1984) suggest that larvae may have some control over cross-shelf movement by vertical migration. This capability appears not to have received much attention, at least in tropical reef species (Richards and

Lindeman, 1987).

With a lifespan in excess of six weeks, a larva could travel a substantial distance if the current remained in one direction. However water movement around the GBR is complex, with wind-driven and semi-diurnal tidal currents superimposed on a persistent seasonal flow (Sammarco and Andrews, 1988). Other hydrological features influencing larval dispersal can include surface-layer mixing; Langmuir cell convergence or upwelling; temperature, salinity or nutrient discontinuities associated with frontal zones; gyres, eddies and internal waves; and bottom boundary-layer dynamics (Richards and Lindeman, 1987). These can result in a variable and unpredictable net water flow (Griffin *et al.*, 1987). Williams *et al.* (1984) assembled data from previous studies of large and small-scale water circulation patterns in the central section of the GBR lagoon off Townsville, and concluded that neither retention of larvae in natal reef waters nor their entrapment in gyres behind reefs is likely. The data suggested that summer-spawned larvae in outer shelf waters will be transported in a generally southerly direction, while those closer inshore will not move so far because of periodic current flow reversals.

In addition to studies such as this, the oceanographic work being undertaken in relation to coral spawning will be of interest to ichthyoplankton ecologists, and should lead to a better appreciation of stock-recruitment relationships and the likelihood that genetically distinct stocks of particular species may have developed on different parts of the GBR system. The existence of distinct stocks may be indicated by differences in population parameters such as growth rates and size at reproductive maturity. There is some evidence that coral trout, for example, exhibit differences in reproductive chronology between Capricorn and Cairns area stocks (G. McPherson, pers. comm.), and possibly in growth characteristics (Ayling and Ayling 1986).

Another important consideration relating to the geographic scale of propagule dispersal is the question of the likely rate at which a locally depleted reef population might recover if fishing pressure were removed. How large a stock within what geographical radius would be required (given the stochastic nature of settlement success) to re-populate the reef with, for example, coral trout? Questions such as this are likely to be of increasing importance to the management of the GBR and its fish fauna, particularly with regard to the designation of reefs as replenishment areas.

4. REPRODUCTIVE STRATEGIES

a) Behaviour

While a number of reef-associated species produce demersal eggs (Richards and Lindeman, 1987), almost all have pelagic larvae (Talbot and Gilbert, 1984). Various specialised behavioural patterns have evolved to facilitate the dispersal of the eggs and their transport away from the reef (Robertson and Choat, 1974). Some species of parrotfish, wrasse and grouper undertake short spawning migrations, resulting in a group of fish aggregating in a preferred spawning site often near the edge of a drop-off (Smith, 1982) or channels through the reef (Johannes, 1980). Frequently the fish make brief upward dashes in the water column, which presumably aids in mixing the gametes and maximising fertilisation success. Thompson and Munro (1983b) did not observe spawning aggregations of lutjanids in the Caribbean although other studies indicate that they spawn in "groups".

Epinephelid mating behaviours range from pairing to group aggregation, depending on species (Thompson and Munro 1983a). Such aggregative spawning behaviour probably results in a very strong spawning pulse occurring once or twice per year, perhaps at a particular stage of the tide or moon (Brock, 1960) to maximise dispersal or survival. In many species these pulses tend to be superimposed over a longer term low level of reproductive activity which may extend throughout most of the year. This may be a bet-hedging strategy, with the maximum reproductive effort being generated when environmental conditions should be optimal. In case of unusual adverse oceanographic or atmospheric conditions at that time, some spawning nevertheless occurs during other periods.

The use of spawning aggregations as a convenient estimate of population sizes has been suggested by Johannes (1980, 1983), but widespread knowledge amongst fishermen of the times and places at which such events occur could cause management problems if the concentrated and highly vulnerable spawning stock were subjected to intense fishing mortality.

b) Sex Reversal

A feature of tropical coral reef fish communities is the large number of species which have evolved a sex reversal strategy. Many serranids (including the coral trout) are known to be protogynous hermaphrodites (PH-strategists) (Thompson and Munro, 1983a; Loubens, 1980; Smith, 1982). This strategy of sequential hermaphroditism has also been found to be typical of the Lethrinids (Loubens, 1980; Young and Martin, 1982), scarids and labrids (Robertson and Warner, 1978), some sparids (Smith, 1982) and various other groups. On the other hand the lutjanids appear to be exclusively gonochoristic (G-strategists) (Thompson and Munro, 1983b; Grimes, 1987) with the sexes after differentiation remaining fixed throughout life. The other major group of interest, the carangids, is evidently also exclusively gonochoristic (Thompson and Munro, 1983c).

In most sequential protogynous hermaphrodite species there is an overlap in size frequency distributions of the two sexes, indicating that sexual transition is not necessarily tied to a particular size or age. There is considerable evidence that sex transition in a number of species is triggered by social interaction with other members of the same species, and that the removal of a large male from the social group will result in the transformation of one of the larger females into a male (Smith, 1982). Liem (1963) and Harrington (1967) have shown that environmental factors such as crowding, temperature and starvation can also influence sexual succession.

Whatever the precise nature of the regulating mechanism involved, the effect of removing (via fishing mortality) larger fish from the population is not straightforward. In a protogynous species (few tropical reef hermaphrodites appear to show protandry), the larger fish will tend to be males. Exploitation will thus selectively remove males from the population. If the social stimulus to replace the lost males by transformation of females occurs very rapidly, the net effect will actually be to increase (rather than decrease) the M:F sex ratio. This is because removal of a male essentially equates to the "death" of a female. On the other hand, if the process of compensation is slow (or non-critical over a broad range of M:F) the sex ratio will decrease. A complicating factor may be a tendency for heavy fishing pressure to reduce the size or age at which sex reversal occurs in the population, although Thompson and Munro (1983a) found that this was not the case for epinephelids in a comparison between a very heavily fished area and a lightly fished reef in the Bahamas.

The processes involved in exploitation of a hermaphroditic population lend themselves to simulation modelling, and attempts have been made to predict what might happen to the reproductive capacity and sex ratio of an hermaphroditic fish population stressed by fishing. Goeden (1978) examined the effects of differential mortality rates on hermaphroditic and otherwise equivalent gonochoristic populations by way of a simple fecundity model related to an age-specific mortality schedule. He found that the fecundity of the protogynous population was greater than that of the gonochorist population during times of "increased" mortality, and vice versa, and interpreted this as a buffering mechanism. However of greater significance was the fact that, on average, females in the (simulated) protogynous population produced fewer eggs than did their gonochorist counterparts (representing a small energy saving), and that small alterations in the age at which sex reversal occurred resulted in a marked change in the sex ratio.

Smith (1982) also explored the effects of exploiting protogynous species with a model comparing the reproductive "value" of simulated gonochorist and hermaphroditic populations with a specified age at first maturity, longevity, annual survivorship and age-fecundity relationship. The model predicted that the younger hermaphroditic females had a high reproductive value, which tapered off rapidly because of their limited lifespan as females, whereas the gonochoristic females' reproductive value was sustained for a longer period, but at relatively lower levels. These models do not take into account the regulation of "desirable" sex ratios through social control of sex reversal.

In a very comprehensive treatise, Bannerot (1984) used both static and dynamic models to compare population resiliency in PH and G populations, and possible effects of reproductive strategy on predictions from standard age-structured (Fox) yield models.

The latter included detailed response-sensitivity analyses of yields given various combinations of density dependent and independent mortality, growth, maturation and sex allocation, random or non-random mating strategies, and recruitment, with age-specific fecundity schedules. The model first computed fertilised egg production, and from this a yield based either on the Beverton and Holt or Ricker stock-recruitment relationships. Growth, mortality and maturation data were obtained from the literature for representative grouper species.

The effects of using density dependent growth and sex allocation functions were of interest because rapid facultative sex reversal is known to occur in several reef fishes, and if the population is food- or space-limited, declining density may result in enhanced individual growth rates.

The model predictions led to the conclusion that the PH reproductive strategy (as measured by the "mated female ratio", i.e. the number of PH females mated/number of G females mated) is superior over a range of Z, depending on rate of M-F contact, length of spawning season and effective time spent as a female. PH populations would be predicted to be superior to G populations with intermediate levels of contact and a broad range of Z in situations where the spawning season was protracted and the time spent as a female was brief (i.e. low age at reversal). Generally, PH populations should be superior provided there is not a problem with availability of males (i.e. sperm is not limiting), but as increasing mortality reduces contact time between males and females, the relative reproductive success of PH populations declines. When sperm becomes limiting at high mortality levels, G-strategists obviously gain reproductive superiority. Interestingly, these conclusions are inconsistent with the hypothesis that groupers (serranids) in the Gulf of Mexico and Caribbean, and presumably elsewhere, may be more vulnerable to overexploitation than snappers (lutjanids) simply as a result of their protogyny (Bannerot *et al.*, 1987). As Munro and Williams (1985) pointed out, there is still insufficient data on mechanisms controlling sex reversal to make reliable general assessment of the significance of changes in sex ratio on particular exploited stocks.

5. JUVENILE HABITAT REQUIREMENTS

It is now generally accepted that there is only a remote probability that larval fish will recruit to the same reef as that on which they were spawned. Dispersal ranges in the order of tens to hundreds of kilometres appear to be more likely. The behavioural and physiological events surrounding the transition of reef fish larvae from the pelagic to the demersal environment are essentially unknown, and we have little definitive knowledge of the juvenile habitat requirements of even the major commercially important species.

The nature of the substrate upon which a species can successfully settle out will have a direct bearing on postlarval mortality. If successful settlement can occur, for example, on flat inter-reef expanses of sand and coral rubble, the larva would stand a much better chance of surviving than if it required a high-relief hermatypic coral reef habitat, simply because of the differences in total area of the two habitat types. If the use of intermediate or juvenile nursery habitats is a widespread phenomenon amongst reef fishes, it will increase the difficulty of establishing stock-recruitment relationships and identifying geographic links between spawning and recruitment localities.

Juvenile lutjanid species which as adults inhabit reefs are known to occur on shallow seagrass flats and/or in mangrove stands (Thompson and Munro, 1983b; Starck, 1971), and may not recruit to the reef until they reach a length of 12-20 cm. Juvenile west Atlantic serranids have been found in shallow reefs, seagrass beds and mangrove swamps. Carangid juveniles and pre-adults of reef-associated species have been recorded from various habitats, including reef, harbours and in association with flotsam. Beam trawl samples from seagrass areas near Warrior Reef and Green Island by Fisheries Research Branch staff have contained numbers of juvenile *Epinephelus tauvina* and *Lethrinus ramak*, and *L. nebulosus* and *L. mahsena* respectively (K. Derbyshire, pers. comm.).

The emphasis often placed on findings such as these might well be due to lack of sampling in alternative habitats or areas, and consequently there is very little information available on whether occupation of habitats such as grass-beds is obligate of facultative. The adaptive advantage of occupying intermediate habitats (whether it be primarily food or mortality-related), and the processes involved in secondary dispersal of juveniles from these areas to the adult reef-associated population are very unclear at the present time. Questions such as these need to be addressed in the context of both environmental and fishery management in the GBRR.

6. DISCARD MORTALITY

A frequently-used tool in the management of fish stocks is the minimum legal size. The length at which fish species can be taken is designated to ensure that a proportion of the stock will have an opportunity to reproduce. With certain types of fishing gear (e.g. traps, pots, nets) it is customary to minimise the capture of undersize fish by placing minimum limits on mesh size, requiring escapement panels etc. In line fisheries, however, it is impossible to legislate gear restrictions to prevent the capture of small fish. Although most fishermen would organise their fishing strategy in the hope of catching the largest fish, the typical catch would normally include a proportion of undersize individuals.

The assumptions underlying the use of minimum size regulations are (1) that the fisherman will return undersized fish to the water, and (2) that once returned, the fish will survive. If either of these assumptions fails to any great extent, fishing mortality will be underestimated, an important consideration for stock assessment and management (Pawson and Lockwood, 1980; Matheson and Huntsman, 1984).

Probably the main cause of post-release mortality of undersized fish, particularly those line-fished or trawled from deeper waters, is barotrauma; disease resulting from changes in pressure (Rogers *et al.*, 1986; Garratt, 1987). Barotrauma results from swimbladder expansion and rupture, with consequent displacement and eversion of parts of the alimentary system through the mouth and cloaca. Specific barotrauma symptoms recorded by Rogers *et al.* (1986) in fish trawled and handlined from depths of around 37 m varied between species, and it was considered that most would have caused high rates of mortality in subsequently-released fish.

A second source of mortality amongst undersized target species or generally among non-sought-after species results from the use of such individuals as bait, particularly if they were physically damaged and considered unlikely to survive return to the water. The incidence of this practice is not known, as fishes used as bait are not likely to be recorded on creel censuses or logbooks. While probably not a major cause of mortality of non-target, lower trophic-level species, it may conceivably contribute to mortality amongst more valuable species captured from deeper water.

In some fisheries the effect of imperfect survival of released undersized fish is considered sufficiently important to have been incorporated in regional management plans (Huntsman and Waters 1987).

CONCLUSIONS

The effect of exploitation upon a tropical reef fish stock is likely to be detected initially as a change in density and size structure of populations of the most important target species. Some direct and much inferential evidence is available for changes of this type in demersal reef fish stocks of the GBR. However long-term changes in the species mix resulting from modification of the trophic web by selective removal of upper-level predators are not so well documented.

Various of the target species' biological and behavioural characteristics, including their reproductive and larval dispersal strategies, and the habitat requirements of their post-settlement juvenile stages, will almost certainly prove to be important factors in modulating the way the stock responds to fishing pressure. A good deal more effort must be applied to understanding these characteristics of at least a few of the more important serranid, lutjanid and lethrinid species on the GBR. This will greatly assist in interpreting changes and explaining why they occur. It is clear, however, that attention must equally be focussed upon identifying what those changes are - i.e. addressing the need for reliable quantitative data derived preferably from well controlled, large-scale experiments.

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TOWARDS A TROPICAL FISHERIES BIOLOGY

Working Paper: Effects of Fishing Workshop

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The accessible information base on the effects of fishing on GBR reef fishes is small. What is available has already been summarized and what remains is open to speculation. However, additional speculation on the effects of fishing is probably the last thing the scientific, management or commercial sectors need.

Our main brief will be to identify and prioritise the type of research that needs to be done. This complements the objectives listed by Dr. Kinsey at the start of this workshop. In association with the setting of a research agenda we are in the process of collating and synthesizing information on GBR fisheries. Dr. Garry Russ will be discussing this aspect.

Sainsbury & Poiner (Trawling) have summarized the obvious effects of trawling on reef and reef-associated species. Effects of line fishing are more difficult to evaluate although the limited information available suggests a typical growth overfishing response with a reduction in mean size. The major potential effects can be summarized as follows:

1) Direct effects

a) Removal of juveniles, especially of lutjanids (trawling)

b) Removal of adults (line fishing): modification of size structure and abundance patterns (see examples from Craik)

2) Indirect effects

a) Habitat modifications - removal of biogenic between-reef assemblages by trawling which are possible settlement and recruitment sites (juveniles)

b) Habitat modifications - possible removal of "stepping stones" used in migration of adults of reef species between reefs, e.g. coral trout in Capricorn Bunker

c) Modification of trophic links by removing food organisms or disruption of habitat (juveniles and adults)

d) Modification of regimes of species interaction - Removal of predators, as an example

It is of interest to note that a range of management agencies: QCFO, QFMA, QDPI all identify effects of trawling on reef fishes as a research priority.

We agree with the summary of probable effects. The most important questions are not those which speculate on the magnitude of these effects but on the form of program designed to address the questions posed.

Assessment of the direct and indirect effects listed requires information on the demography, life cycles and numerical trends in target species. This must be set in the framework of a broader methodological and biological research program. It is our belief that while higher order interactions among tropical fish assemblages are important we see the assemblage of a data base reflecting demographic and life history phenomena of individual species as the main priority of such a program.

Ecologists working on reef fishes have been active in the development of demographic models which explore settlement and recruitment events. However, in terms of tropical fisheries biology, we proceed in ignorance of the basic considerations of population biology once fishes have settled and commenced to grow to fishable size. No one would dispute the need for general explanations accounting for the variability in fish stocks. We maintain however that the most appropriate investigative pathway for fisheries biologists must commence with an analysis of the life cycles of commercially important species. A scientific program which is responsive to the needs of management must establish the ontogeny of habitat occupation, trophic interactions and the age specific schedules of growth, reproduction and mortality in target species. It must also be integrated with a program which provides better estimates of abundance, in both juveniles and adults. Moreover such a program must be capable of long-term maintenance of sampling, for a period greater than the generation time of the target species.

Although trawling on the GBR may not specifically target reef species, juveniles may be taken as a by-catch. Preliminary work suggests that these may represent the juveniles of large species targeted by line fisheries which are important commercially and recreationally, e.g. L. sebae and L. malabaricus. A further important feature of trawling operations in GBR waters is that the by-catch comprises species of commercial importance in other tropical regions such as Southeast Asia. These include leiognathids, scianids, engraulids and loligonid squids. Estimates of the effects of trawling the GBR waters can serve as models for Asian and Pacific nations.

A program investigating the life histories and demography of commercially important species which might occupy or interact with reef environments would have the following framework:

Taxonomic Identities

Lutjanidae: Lutjanus sebae, L. malabaricus, L. erythropterus, L. johnii

Lethrinidae: Lethrinus chrysostomus, L. nebulosus, L. miniatus

Serranidae: Plectropomus leopardus, P. maculatus, P. laevis

Various work has been carried out on these species in the GBR, but much basic biological information relevant to the management of their stocks is not yet available. We identify the following requirements for a study aimed at closing the life-cycles of these species.

1) The identification of juvenile habitats

Preliminary information indicates the likely significance of interreefal and nearshore waters, including seagrasses, for a number of lutjanids and lethrinids in particular. Plectropomus spp. occurs as newly settled individuals in small numbers adjacent to and on the sedimentary aprons of reefs. A more comprehensive examination of deeper water settlement and recruitment habitat is required for these species.

2) The estimation of adult abundances.

For many species this is problematical. For reefal species L. nebulosus, L. chrysostomus and P. leopardus, visual censuses are still the most appropriate method although the development of comparative approaches through analysis of catch records is urgently required. For deeper water species and those in interreefal habitats combinations of catch records (preferably from controlled fishing experiments), long-line surveys, trawl surveys (for juveniles) and the development of a mark-recapture program based on trap collection must be developed. The primary concerns would be to a) establish sampling programs that avoid the biases inherent in most catch-record data, b) incorporate them into long-term programs and c) develop sampling programs which combine a variety of different methods to allow comparisons and validation. The need to obtain better estimates of fishing effort is also a major concern.

3) Demographic processes.

Although the long-term pattern of numerical change in fish populations is a primary focus for fisheries research most managers must deal with the day-to-day pragmatics of how fast the fish grow, where and when they spawn and the interaction of growth, reproduction and death for particular groups. Most marine ecologists and ichthyologists have ignored the requirement of gathering the data on growth and age structure necessary to establish age and size specific schedules of growth, reproduction and mortality on recruiting and adult fish.

4) We are aware of other sources of information, including ageing studies and catch records, especially for the commercially important lutjanids. The most realistic basis for synthesizing such information and developing collaborative programs would be to make a comprehensive description of the life cycle of selected commercial species a primary research goal. This would provide the most appropriate information base for management as well as an agenda for research programs.

Future Directions

Our goal is to provide, through an analysis of life-cycles, a scientific basis for an explicitly tropical fisheries biology. This would build on the infrastructure provided by Longhurst & Pauly (1987).

Management has already provided valuable contributions but the discipline world-wide has yet to achieve the same degree of coherence and focus as its temperate counterpart. It is our belief that four elements are critical to the development of such a discipline.

1) A group of fisheries-oriented scientists committed to the study of the life cycles and demography of tropical species in collaboration with a multi-disciplinary group of scientists concerned with tropical marine environments, together with the logistic support necessary to carry out studies in a wide range of habitats.

2) Institutional support and a funding scheme which provides for the establishment of long term studies with the aim of tracking numerical changes in selected species.

3) Access to and collaboration with management agencies and commercial and recreational fishing sectors.

4) The opportunity to present and evaluate the main ideas of fisheries biology in the context of an undergraduate and graduate teaching program, leading to a recognized qualification in the discipline.

Our program will be based on two approaches:

1) An application to Commonwealth funding agencies to establish a program of research whose objectives are to:

(a) develop a collecting methodology and sampling designs for commercially and recreationally important reef and interreefal species. This would incorporate trawl programs, long-lining and the development of an experimental trap fishery.

(b) establish the habitat requirements and growth and mortality schedules of juveniles of lutjanids and lethrinids.

(c) maintain collections of adults for analysis of age structures, reproductive schedules and feeding biology.

2) A consolidation and analysis of the existing information base on commercially important reef and reef-associated fishes, firstly on the GBR but also in other tropical regions.

ABSTRACT

REEF FISH IN THE GREAT BARRIER REEF REGION: SUMMARY OF RESEARCH

WENDY CRAIK
Great Barrier Reef Marine Park Authority

This paper summarised the research work that had been done to date on reef fish within the region and identified further work that was required. A summary of research areas, the work done and future needs are outlined below.

* Abundance and distribution.

There is some regional data for catch and landing of reef fish and some for specific areas such as the Whitsundays. The only comprehensive data set that exists is for coral trout from visual surveys. There is a need for some standardised distribution and abundance data at various stages of the fish's life history.

* Migration and Movement

There have been a number of tagging studies undertaken on coral trout and assorted Lutjanids, Lethrinids and Serranids and some work has been done on spawning aggregations of coral trout. It has been found that most fish are resident on certain reefs although there may be seasonal movement of up to 30 kilometres. The need exists for some longterm information on movement and studies should be made in different areas.

* Catch and Catch Per Unit Effort

Catch of reef fish by region was collected during 1979 and 1980 and estimates suggested that the commercial catch was approximately 2700 tons, the speedboat catch approximately 6600 tons and the charter boat catch 600 tons. This includes some pelagic species. The composition of catch was broken down by broad groupings such as Lutjanids, Lethrinids and Serranids. Some more specific data was collected from recreational fishing clubs. Overall however, the collection of catch data from the region has been very patchy. With regard to effort there is almost no usable data available for commercial vessels although this has been addressed by the logbook that was brought into operation in January 1988.

For recreational fishing there is some effort data for vessels but this is now dated and a bit patchy. Effort data for speedboats is broad and dated but usable. The information that has been gathered from fishing clubs is to be reanalysed and updated, however a need still exists for a systematic catch and composition data set to be gathered over standard areas for a long time period.

It is essential that some consistent measure of effort is incorporated into this data set.

* Age and Growth.

There is data for 7 species of reef fish available at present. However, samples have come from a number of areas and from a number of sources. It appears from preliminary work that there is fast growth of the animal in year one, then a slow increase in size. There is a need for broader spatial coverage, a better sampling strategy to be developed, and consideration of fished versus unfished areas.

* Diet

Work has been carried out on Plectropomus leopardus and it has been found that 98% of its diet are teleosts and the rest squid and shrimp. For Lethrinus chrysostomus the diet appears to be crustaceans, crabs, molluscs, and perhaps crown of thorns starfish. There is a considerable amount of work to be done in the area of reef fish diet.

* Reproduction

Data is available for approximately 7 species and provide size at maturity, specific spawning times; may be protogynous hermaphrodites and some form spawning aggregations. There is a need to look at size at sexual maturity in different areas for different species and to examine which species are protogynous hermaphrodites .

* Experimental Work

There have been some pre and post visual censuses of closed reefs in the Capricornia region and some work done on an area of Boult Reef that was closed to fishing and then reopened. There is a need for more consideration of experimental design in reef closures.

WORKSHOP DISCUSSION OF PAPER

Consideration was given to increase in the number of boats primarily used for fishing within the GBR. Estimates made in the early 80's suggested that there would be a doubling of effort by 1990 and that this could grossly affect the populations of reef fish. However it was noted that many of the charter boats were not primarily used for fishing. Speedboats that are not only more numerous but a lot are bigger and can more effectively target areas and species. Damage caused by boats such as anchor damage was discussed and monitoring at high usage sites such as pontoons was mentioned.

Overseas studies have shown that there is some cycling of target species but is not clear whether this is actually happening in the GBR. Aerial surveillance has been used in the past to try and determine the level of effort within the reef , however there are problems with the statistical reliability of the Coastwatch data. This problem has been addressed by the new aerial surveillance flight patterns.

REEF FISH IN THE GREAT BARRIER REEF REGION

SUMMARY OF RESEARCH

Wendy Craik

GREAT BARRIER REEF MARINE PARK AUTHORITY
1989

INTRODUCTION

Ten years ago I wrote a paper on research on GBR fishes (of interest to fishermen) with a view to recommending future research particularly from GBRMPA's view. At that time there was work on Plectropomus leopardus, Lethrinus chrysostomus, and visual census work at a number reefs, some landing data from the QFB and not much more. Then, I recommended studies of:

- population estimation (verification of visual census)
- age and population structure of fished and unfished population
- reproductive biology of recreational and commercial fishes
- migration and movement of recreational and commercial fishes
- larval dispersal
- oceanographic research.

Since then, oceanographic research in the GBR has made great advances and we know much more about general water movements, small scale water movements and something about connectivity of reefs. In the fish area, a perusal of references shows that by far the majority of effort has gone into visual censusing. While that has produced a valuable data base of relative distribution and abundance of coral trout at over 200 reefs in the GBR and some time series data, it is unfortunate that investigations have not emcompassed other topics with the same enthusiasm.

Some advances have been made. We know a little more about

- migration and movement
- age and growth in some species
- spawning aggregations
- catches and effort, especially in the recreational sector.

Now in 1989, I would say the major knowledge requirements are:

- CPUE data -
  Catch: species, numbers, kg
  Effort: reefs, hours
- migration and movement data in long term
- repetition of broad scale surveys of coral trout every 5 years
- investigation of reproductive data
  hermaphroditism, spawning aggregations, age at maturity in fished and unfished areas.

No less important, as the evidence of Beinssen's Boult Reef experiment and visual census here, the Philippines and Florida have shown the beneficial effect of reef closures, further experimental investigation of their effect (both immediate and long term) is required.

The following data is in three sections:

1. Summary of knowledge on each topic (e.g. age, growth etc.)
2. Synopsis of GBR studies
3. Bibliography.

ABUNDANCE AND DISTRIBUTION

- Selective data is from catches and landings
- Some data for specific areas e.g. Whitsundays.
- Some data on larval occurrences in some areas.
- Other data of interest is trawl bycatch data showing presence or absence of reef fish.
- Most distribution and abundance data available for reef fish of non-recreational and commercial importance but it is not unreasonable to believe that the sorts of NS, EW reef zone variability also exists for larger fish.
- Only comprehensive data exists for coral trout from visual census

Inter alia, the surveys have shown the following:

- each species of trout has a different cross-shelf distribution
- *P.leopardus* in the most abundant species of trout, with highest population levels on mid shelf reefs, and with higher numbers on central and southern Great Barrier Reef than northern and far northern GBR reefs.
- Relative density indices for *P.leopardus* lie generally in the order of less than 50 per ha for fished reefs, except for the Swains, where trout densities appear higher.
- unfished reefs (grouped) have higher densities than fished reefs and few smaller trout.

Comment

- Need for standardised information on abundance and distribution at major life history stages of fish of recreational and commercial importance.

ESTIMATED ANNUAL REEF FISH CATCH FOR GBRR (KG) (1979/80)

Home Port	[1]Commercial	[2]Speedboat	Av. wt/fish	[2]Charter boat	Total Rec
Cairns	746,370	2,309,830	2.7	?	2,308,830
Townsville	807,210	1,881,338	2.3	94,300	1,975,683
Mackay	794,630	1,103,655	2.2	340,400	1,444,055
Rockhampton	380,400	1,277,889	1.3	144,500	1,422,389
TOTAL	2,728,610	6,571,757	2.1	579,200	7,150,957

1 Includes pelagic and non reef spp.

2 Includes pelagic.

Comment

. Landing data available by port for commercial catch, no indication of area caught (old QFB etc.)
. Total catch (commercial) should be available through the logbook program by area (30′ grid) from January 88
. Recreational catch needs resurveying; if rates here continue by 1990 recreational catch will be 12,000 tonnes.. Black market catch unknown.

CATCH COMPOSITION   Queensland Fish Board figures on landings of reef fish 1973/74 to 1980/81

Year	Lutjanids/Lethrinids (Tonnes)	Serranids (Tonnes)	% Trout
1973/74	278.7	186.5	85
74/75	297.5	160.9	79
75/76	198.1	181.2	75
76/77	251.5	165.1	75
77/78	177.7	90.3	74
78/79	219.4	163.7	86
79/80	240.5	210.7	85
80/81	202.7	205.0	86

(From Geoff McPherson, Qld DPI)

CATCH COMPOSITION: Species as % total catch (various sources)

	[1]Port Douglas	[2]Cairns	[3]Townsville	[3]Mackay	[3,4]Rockhampton
Coral trout	20	37	34	36-40	/
Red sweetlip	27	9	54	50-52	/
Red emperor	11	17	/		
Cod	2	7	/		/
Spangled emperor			/	/	
Nannygai	13	3			
Snapper		9			
Parrotfish					/

/ recorded regularly in catches.

Comments

. Little systematic data collector figures incomplete
. Species groupings dont help (coral trout: 7 species; sweetlip 2 + species)
. Catch composition varies between nearby reef (coral trout 11-70% of catch at individual reefs off Cairns and Port Douglas)
. New logbook data for commercial fishermen should help but species groupings problems will still exist.

Effort: Charter Boats (1979/80)

Home Port	No. vessels	Mean boat length (m)	Mean no. anglers/boat	No. trip for fishing primarily	Mean trip length	No. angler days p.a. (primary purpose)
Cairns[1]	39	10-15	15			
Townsville	10		14	210	2	5780
Mackay	60	30	10	1118	2.5	2800
Rockhampton	10	10	8	350	4.5	1600

[1] relates only to game boats

In 1984/85, there were 275 charter vessels of which 52 have line fishing as principal activity and 40 as significant activity.

Effort for speedboats (1979/80

Area	No. Boats Fishing at Sea	Average No. Fishing Trips to Sea/Boat/yr	Total No. Fishing Trips to Sea/yr	Average Boat Length	Average No. Fishermen/ Boat	Average Time Lines in Water/ Trip	Average Effort/ km^2/yr
				m		hrs	fishing hrs/km^2
Cairns	3530	14	49,400	5.1	2.6	7.1 (max. 30)	16
Townsville	4320	14.4	62,708	5.2	2.6	5.7 (max. 40)	11
Mackay	2597	10.5	27,269	4.8	2.6	6.4 (max. 48)	4
Rockhampton	4440	13	57,720	4.5	2.6	5.2 (max. 24)	8
GBRR	14887	13.2	196,597	4.9	2.6	6.0	9

DISTRIBUTION OF EFFORT

Overall: Broad picture of reefs fished and some ranking of their importance (GBRMPA PPP's)

Commercial: late 1970 - early 1980's

- nos. of reef fishermen by home port e.g. 100 primary reef fishermen in GBRR 1979/80
- approx 1000 persons employed in non otter trawl commercial fisheries 79/80.

Recreational

Speedboats - see attached table

Charter vessels - see attached table.

Comment

Commercial

- effort data pre log book introduction (1988) almost useless for CPUE studies
- since Jan 88 log book data should show person days effort by 30' grids

Recreational

- effort data for charter vessels used by clubs ok but dated and a bit patchy
- data for 1980 to present about to be analysed.
- effort data for speedboats broad and dated but usable.
- need for updated survey of recreational fishing effort by speedboats.

Effort. GBR Commercial Fisheries (1979/80)

Home Port	No. otter trawlers	No. other fishing vessels	% sample reef fishing	% sample in two or fisheries	Mean No. employees	Total no. employees
Cairns	196	157	43	80	2	314
Townsville	129	149	40	84	1.6	238
Mackay	36	89	58	70	2	178
Rockhampton	129	140	-	-	4	581
Total	490	535				1311

Current estimate is 150-200 full time commercial primary reef fishermen and 100 commercial reef fishermen for whom reef fishing is a secondary occupant.

REPRODUCTION

Species	L at Maturity	Reprod. Period	Protogynous Hermaphrodite	Spawning Aggregations	Other
Plectropomus leopardus	F22 cm SL M35-40 cm SL	Sept-Jan (varies)	Yes	Yes	
P.laevis		Nov-Feb. (varies)		Yes	
Cherlinus undulatus		Dec-Feb.		Yes	
Lethrinus chrysostomus	age at mat. known	July-Aug	No evidence		Sex ratio 1:1
L. nebulosus		May-Oct	No evidence		Sex ratio 1:1
Lutjanus sebae		Sept-Jan	No evidence		
L.maculatus		Sept-Jan			

Comment

Only Plectropomus leopardus and Lethrinus chrysostomus investigated in any detail. There is a need for similar investigations for other major species in catch, esp age/size at maturity, spawning aggregation, hermaphroditism.

GROWTH

Species	Sample	Technique	Length at age at age (CMSL) 1	2	Largest aged this study	Largest this study
Lutjanus malabaricus	commercial fishery Cns 1981-84 N = 856	Otoliths			67 cm SL 7 yrs	70 c 8.2 kg
L. ethrythopteus	commercial fishery Cns 1981-84 N = 369	Otoliths			51 cm 7 yrs	51 cm 3.5 kg
L. sebae	commercial fishery Cns 1981-84 N = 607	Otoliths	20 FL		66 cm SL 8 yrs	69 cm 9.11 kg
L. maculatus	commercial fishery	Otoliths	19 FL		54 cm FL 7 yrs	
Lethrinus chrysostomus	Fishing from charter vessels N = 463	Scales	25	30	(mean c.47 cm 7 yrs	
L. nebulosus	commercial fishery Cns N = 150	Otoliths	17		54 cm SL 12 yrs	54 cm 3.8 kg
Plectropomus leopardus	commercial fishery Cns 1981-84 N = 135	Otoliths	16		50 cm SL 7 yrs	54 cm 4 kg
	commercial fishery S. GBR	length frequency			46 + cm SL 5 + years	

CPUE

Commercial: No data to my knowledge
. log book data should give future results

Recreational: 1979/80

	Fish/angler/ day C Boat	Fish/angler/ day Speed	Kg fish/ angler day C Boat	Kg fish/ angler day Speed	$fish/km^2/pa$
Cairns	1	6	5	15	n/d. /21
Innisfail	2		5.5		
Townsville	5	n.d.	9	n.d.	
Mackay	6.5	17	9	26	
Rockhampton	17	11-15	16	11-15	7.5/25

Other data:

Data from deep sea fishing clubs on catch per unit effort has shown inter alia:

. considerable variability in no. fish/man/day over time but no obvious declines in Capricornia, and reefs off Townsville and Mackay to 1979.

. an increase in no fish/angler/day with increasing distance from shore off Cairns and Innisfail.

. a gradual decrease from 1967 to 1984 in the mean size of reef fish caught off Townsville from 2.5kg/ per fish to 1.4kg per fish while mean no/fish/man/day remained stable

. a decrease in the mean size of fish from the northern to southern GBR (3kg to 1kg) and an increase in the mean number of fish caught per man per day from one to 16 fish from the north GBR to the southern GBR.

The catch is distributed unevenly between fishermen. The top 10% of fishermen take approximately 30% of the catch and the bottom 50% of fishermen take only 20% of the catch. At reefs off Cairns this translates into 2.5 fish or fewer per person/day for the bottom 50% of fishermen, to 13 fish/person per day for the top 10% of fishermen. Similar situations have been found for other areas in the Great Barrier Reef.

Comment

. need for recent data analysis of deep sea fishing club data to present will give current situation as will logbook data
. need for speed boat CPUE data.

Diet

Species	Diet Composition	Comment
Plectropomus leopardus	Adults: Teleosts 98% (eg atherinds) Squid, Shrimps	0-1 yr bottom feeders
L. chrysostomus	Adults: crustaceans, crabs, molluscs (reported (crown of thorns eater)	Selective individualistic

Comment

Little systematic work done on diet of major species.

Need for a lot more work in this area.

Comment

Length frequency analysis and ageing techniques seem to suggest rapid growth in 1st year, then considerable slowing. There is a need for investigation of these species in different areas e.g. N-S. A great deal of l-f data remains to be analysed from tagged fish.

Movement and migration

Species	Evidence	Movement
P. laevis	Spawning aggregation	Seasonal movement
P. leopardus	Spawning aggregation Tagging Observation	Seasonal movement? Generally resident Some inter reef movement recorded (30) km Increase home area with size
Cheilinus undulatus	Spawning aggreg.	Seasonal movement?
Lethrinus chrysostomus	Tagging	Generally resident little movement recorded (to 5 km)
Assorted Serranids Lutjanids Lethrinids	Tagging	Resident

Comment

Most species examined demonstrate generally little movement over short term, except for some apparent seasonal movement. Obviously some species (eg coral trout) can move considerable estimates i.e. variable in home ranging.

More tagging studies in different areas are required; especially for long term information.

Please return this completed book to the Marine Park rangers or if this is not possible, post to:

Queensland National Parks and Wildlife Service
194 Quay Street,
Rockhampton, 4700.
Telephone: (079) 27 6511

Thank you for your Co-operation.

About you and your fishing gear.

1. Were you spearfishing, line fishing or both?

2. If line fishing, what bait(s) did you use?

Pilchards	%
Fresh Cut	%
Other	%
Wogs/lures	%
Hook size used mainly?	
Did you use mainly ganged hooks?	
Weight of line used mainly?	

3. Are you a member of a fishing club?

4. How experienced at reef fishing are you?

Never reef fished	
Reef fish once per year or less	
Reef fish 2 - 5 times per year	
Reef fish 6 or more times per year	

5. Are you licenced as a commercial fisherman?

6. Any Comments?

6 p.m. to 12 midnight

If you fished at Boult Reef between the above times, please fill out this page

A Please record your fishing locations, fishing time and catch.

FISHING BLOCK (see map)	EXACT TIME SPENT FISHING Hrs : Mins	NUMBER OF FISH CAUGHT AND KEPT									FISH THROWN BACK	
		Coral Trout	Coronation Trout	Lippers	Footballer Cod	All other Cod species	Hussars	Red Emperor	All Mackeral Species	All Others Combined	Coral Trout	All Others
1	:											
2	:											
3	:											
4	:											
5	:											
6	:											

B Please record the length in centimetres of each Coral Trout caught, from the tip of the snout to the fork in the tail. Use the tape measure provided.

C Please record any tagged fish caught (or fish with tag scars).

SERIAL TAG NUMBER	SPECIES	LENGTH	BLOCK

Please indicate on the map, exactly where each tagged fish was caught.

3 p.m. to 6 p.m.

If you fished at Boult Reef between the above times, please fill out this page

A Please record your fishing locations, fishing time and catch.

FISHING BLOCK (see map)	EXACT TIME SPENT FISHING Hrs : Mins	NUMBER OF FISH CAUGHT AND KEPT									FISH THROWN BACK	
		Coral Trout	Coronation Trout	Lippers	Footballer Cod	All other Cod species	Hussars	Red Emperor	All Mackeral Species	All Others Combined	Coral Trout	All Others
1	:											
2	:											
3	:											
4	:											
5	:											
6	:											

B Please record the length in centimetres of each Coral Trout caught, from the tip of the snout to the fork in the tail. Use the tape measure provided.

C Please record any tagged fish caught (or fish with tag scars).

SERIAL TAG NUMBER	SPECIES	LENGTH	BLOCK

Please indicate on the map, exactly where each tagged fish was caught.

12 noon to 3 p.m.

If you fished at Boult Reef between the above times, please fill out this page

A Please record your fishing locations, fishing time and catch.

FISHING BLOCK (see map)	EXACT TIME SPENT FISHING Hrs : Mins	NUMBER OF FISH CAUGHT AND KEPT									FISH THROWN BACK	
		Coral Trout	Coronation Trout	Lippers	Footballer Cod	All other Cod species	Hussars	Red Emperor	All Mackeral Species	All Others Combined	Coral Trout	All Others
1	:											
2	:											
3	:											
4	:											
5	:											
6	:											

B Please record the length in centimetres of each Coral Trout caught, from the tip of the snout to the fork in the tail. Use the tape measure provided.

C Please record any tagged fish caught (or fish with tag scars).

SERIAL TAG NUMBER	SPECIES	LENGTH	BLOCK

Please indicate on the map, exactly where each tagged fish was caught.

9 a.m. to 12 noon

If you fished at Boult Reef between the above times, please fill out this page

A Please record your fishing locations, fishing time and catch.

FISHING BLOCK (see map)	EXACT TIME SPENT FISHING Hrs : Mins	NUMBER OF FISH CAUGHT AND KEPT									FISH THROWN BACK	
		Coral Trout	Coronation Trout	Lippers	Footballer Cod	All other Cod species	Hussars	Red Emperor	All Mackeral Species	All Others Combined	Coral Trout	All Others
1	:											
2	:											
3	:											
4	:											
5	:											
6	:											

B Please record the length in centimetres of each Coral Trout caught, from the tip of the snout to the fork in the tail. Use the tape measure provided.

C Please record any tagged fish caught (or fish with tag scars).

SERIAL TAG NUMBER	SPECIES	LENGTH	BLOCK	
				Please indicate on the map, exactly where each tagged fish was caught.

6 a.m. to 9 a.m.

If you fished at Boult Reef between the above times, please fill out this page

A Please record your fishing locations, fishing time and catch.

FISHING BLOCK (see map)	EXACT TIME SPENT FISHING Hrs : Mins	NUMBER OF FISH CAUGHT AND KEPT									FISH THROWN BACK	
		Coral Trout	Coronation Trout	Lippers	Footballer Cod	All other Cod species	Hussars	Red Emperor	All Mackeral Species	All Others Combined	Coral Trout	All Others
1	:											
2	:											
3	:											
4	:											
5	:											
6	:											

B Please record the length in centimetres of each Coral Trout caught, from the tip of the snout to the fork in the tail. Use the tape measure provided.

C Please record any tagged fish caught (or fish with tag scars).

SERIAL TAG NUMBER	SPECIES	LENGTH	BLOCK	
				Please indicate on the map, exactly where each tagged fish was caught.

12 midnight to 6 a.m.

If you fished at Boult Reef between the above times, please fill out this page

A Please record your fishing locations, fishing time and catch.

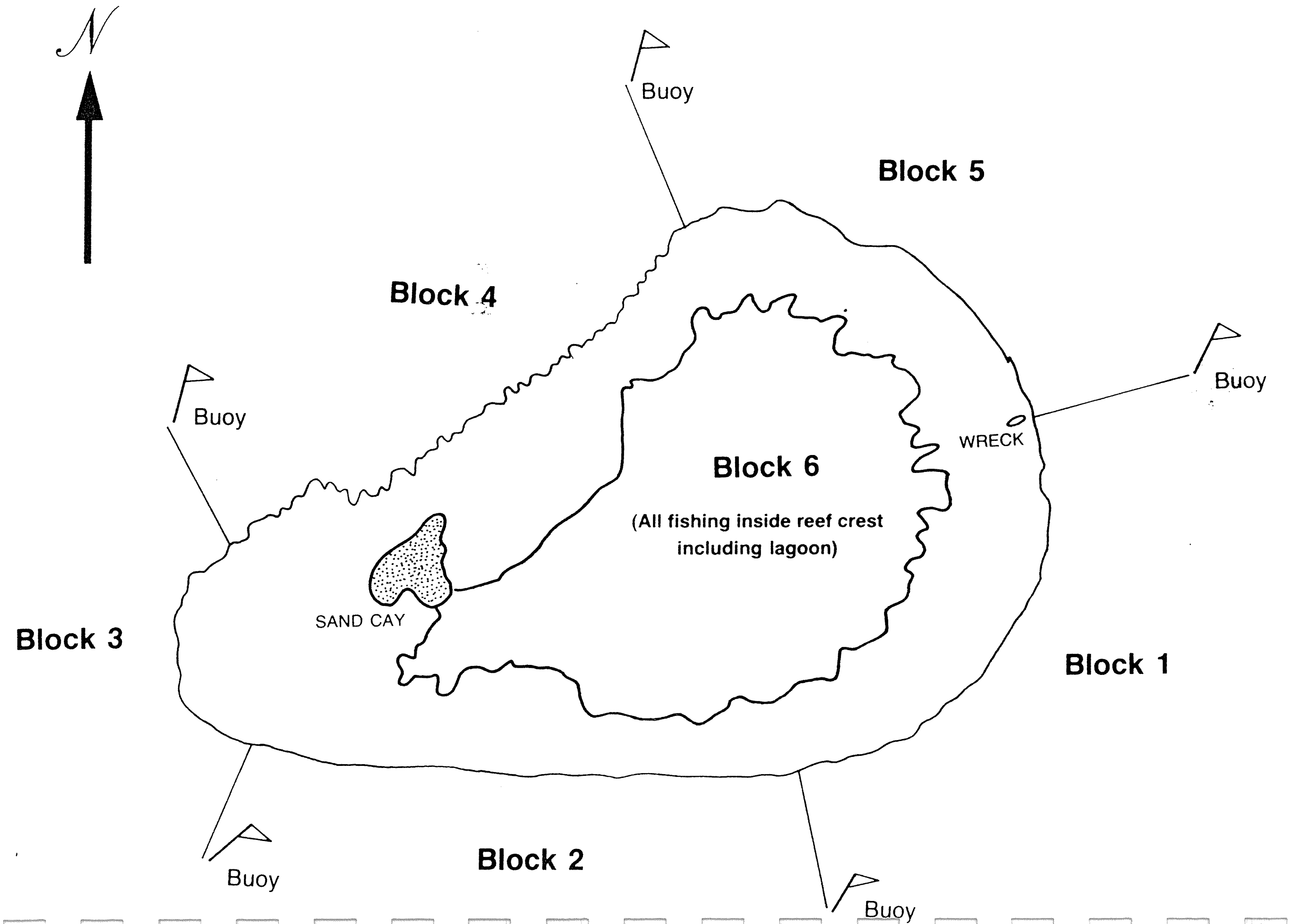
FISHING BLOCK (see map)	EXACT TIME SPENT FISHING Hrs : Mins	NUMBER OF FISH CAUGHT AND KEPT									FISH THROWN BACK	
		Coral Trout	Coronation Trout	Lippers	Footballer Cod	All other Cod species	Hussars	Red Emperor	All Mackeral Species	All Others Combined	Coral Trout	All Others
1	:											
2	:											
3	:											
4	:											
5	:											
6	:											

B Please record the length in centimetres of each Coral Trout caught, from the tip of the snout to the fork in the tail. Use the tape measure provided.

C Please record any tagged fish caught (or fish with tag scars).

SERIAL TAG NUMBER	SPECIES	LENGTH	BLOCK	
				Please indicate on the map, exactly where each tagged fish was caught.

Boult Reef Fishing Blocks



Date	: :	Time	:
Serial No.			

DAILY FISHING LOG
Boult Reef
Queensland National Parks and Wildlife Service.

Please take a few minutes to record your catch and fishing times. Record this information each time you move your boat to a new fishing block and at the following times each day.

6 a.m.
9 a.m.
12 noon
3 p.m.
6 p.m.
12 midnight

Please hand this completed log back at the end of each fishing day, before leaving Boult Reef.

To become eligible to win the prizes being offered, please fill out the space below.

Name:..

Address:..

....

Telephone Number:....................................

Catchability of fish changed dramatically over the first 14 days. A figure of 0.05 is used for extrapolating from the experiment at Bout.

* F for Capricornia is estimated at .33 (28% of available stock taken annually). This would give an average standing stock of 86000 fish in the study area.

Final Points

* The fishing industry should be encouraged to participate fully in all aspects of management; self-management to the greatest possible extent should be a government goal.

* It is critical that debate be started with users of the resource, on management objectives.

* At this point, a management plan for the fishery should be prepared. This would place the industry on a sound footing and would provide a focus for debate on management objectives and policy directions (including research priorities).

docname-Beinssen-coraltrout

ABSTRACT

IMPACT OF FISHING ON CORAL TROUT POPULATION IN CAPRICORNIA

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Q.NPWS is conducting four projects in Capricornia with the general goal assessing fishing mortality (F) for the coral trout population.

- Total fishing effort was derived from aerial surveillance information. In 1987, 92999 hrs ± 7000 were spent fishing in Capricornia between Douglas Shoal and Lady Musgrave Reef

- Total reef area occupied by the stock is being estimated from aerial photographs and colour sounder traces yet to be conducted. An initial estimate of 14000 hectareas is estimated and an area of 343 h for Boult Reef is estimated.

- CPUE levels were estimated from creel census information. A value of 0.26 trout per daylight fishing hour is calculated. Creel census information also provides insight into the requirements and opinions of anglers which will be useful in setting management objectives.

- The catchability (q) of coral trout was estimated in an experiment conducted at Boult Reef at the time of its reopening to fishing after a 3 1/2 year closure. Information on species composition, size composition (for coral trout), movement, tagging techniques and other matters was also gained.

The following calculations and conclusions can be made:

* Using the above effort and CPUE figures, a total annual catch of 24000 coral trout (value at $M0.5) is taken.

* At Boult Reef, 2136 coral trout were taken in 1994 fishing hours in the first 14 days following re-opening.

  Of the 375 double tagged trout, 93 (corrected for tag loss) were returned. This gave an estimated population of 8613 ±873 at opening.

  The catch rate for coral trout dropped from 4.63 trout/hour on day one to 0.37 on day 14.

  Visual surveys conducted at one area on the reef prior to and after fishing showed a relative density decline of 30%, from 4.63 fish per 5 minute count to 3.24.

  Size frequency data taken at the reef at opening and again 18 months afterwards, indicates growth overfishing.

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Objectives:	Analysis of landings of Queensland Fish Board data 1967-1978
Methods:	Landing rate from QFB analysed
Results:	. Reef fish higher proportion of landings in Cairns and Innisfail than Townsville or Bowen . September/November peak in sweetlip landings in Bowen, Townsville and Cairns, but not Innisfail . October/November peak in coral trout landings at all 4 ports . Cairns and Townsville landed more finned fish than other ports . Coral trout and sweetlip and emperor most important reef fish . 1972/73 low landings cf 67/68.
Limitations:	No effort data Generalised description
Usefulness:	Catch omposition, differences between port
Reference:	64

Objective:	Description of demersal fishing effort in GBRR
Methods:	Research information, Govt information, representations, fishermen info, aerial surveillance info.
Results:	1988: Cairns - general distribution of line fishing effort 1987: Capricorn and Capricornia - recreational and commercial demersal fishing areas shown 1988: Central - recreational and commercial demersal fishing areas shown 1984's FNS - recreational and commercial demersal fishing areas shown Maps (generalised) plus ratings of reefs from fishermen etc.
Limitations:	Precise figures on effort for individual reefs not known esp. for commercial fishermen.
Usefulness:	Generalised indication of effort.
Reference/s:	55. 56, 57, 58

Objectives:	Description of economic characteristics and significance of reef fishing (i.a.) both recreational and commercial.
Methods:	Mail questionnaires Interviews Govt data - for 1979-80. Analysis of numbers $'s etc boat ramp surveys, other anlaysis.
Results:	Nos. 79/80 : 69 primary reef fishermen 1980 : 15000 small boats used for reef fishing - i.e. 30 - 45000 people Fishery: description of spp, gear, mobility, vessels, catch, value and gross volume, some CPUE info (recreational).
Limitations:	One years data Broad figures by region
Usefulness:	First comprehensive summary of catch and effort data (afap) for GBRR fisheries.
Reference/s:	49, 50, 51, 52, 53, 54

Objectives:	Distribution, abundance of coral trout in GBRR and temporal changes to determine effects of management.
Methods:	Aylings visual surveys of 228 reefs distributed throughout GBRR (some more than once) QNPWS: visual surveys of 13 reefs in Capricornia (some more than once) GBRMPA: visual surveys of reefs in Capricornia (some more than once).
Results:	Ayling: l-f and distributional info on 5 spp coral trout NS and EW in GBRR . groupings of fished vs unfished reefs show differences in l-f and densities. . some suggestion of greater numbers of smaller trout in fished vs unfished reefs QNPWS: groupings of fished vs unfished reefs show differences in densities.
Limitations:	See limitations for techniques Repetition using same or calibrated technique.
Usefulness:	Valuable data base appears to be able to indicate broadly distributions and zoning effects.
Reference/s:	37, 39, 44, 46, 47, 48, 59, 60, 61, 62, 63

Objective: To produce a statistically acceptable visual survey method for evaluating reef fish of commercial and recreational importance; within constraints of time and cost.

Methods: Four workshops (3 in field), application of 3 survey methods, analysis by researchers and other interested parties of survey results. Much discussion.

Results:

. A visual survey technical of straightline transects on reef slopes can be used to give broad evaluation of status of coral trout populations,
. variance is high
. significant density changes (eg 50%) hard to demonstrate statistically in low density areas
. investigation of biases and stratification in technique required.

Limitations: See results above.
Broad scale technique.

Usefulness: Everybody has counted coral trout
Valuable data base of numbers and l-f of coral trout obtained. Pluses and minuses of technique well aired.

Reference/s: 34, 35, 36, 37, 38, 39, 42, 43, 44, 45

Objective:	Survey of trends in Queensland fisheries.
Methods:	Number of Queensland fishermen, areas fished, gear, time spent fishing etc. gathered from survey.
Results:	Reef fishing: 1979-1980 nos. of primary reef fishermen 156 (6%) - 112 (4%) of primary fishermen Greatest changes in area 1 (S Qld), area 2 Rockhampton -Bundaberg and area 3 (Mackay), no. of reef fishermen Port Douglas to Bowen remained same.
Limitations:	No information on areas fished, effort.
Usefulness:	Broad evaluation of numbers involved in commercial fishery.
Reference/s:	32, 33

Objective: Catch, effort, economic and attitudinal data for speedboats fishing from Tully to Port Douglas (Cairns Section)

Methods: Personal interviews at 7 boat ramps for 23 days in August September 1980.

Results:
. 300 questionnaires completed
. 60% went to reef
. wind and weekday effects on numbers fishing
. main reefs fished from each ramp
. length of trip, numbers fishing, distance travelled
. CPUE 0.7 fish/angler hr; (4/angler day) of Capricornia 11 fish/ angler day
. Top 10% fishermen take 40% of catch and .... 50% 84% of catch
. Sweetlip, coral trout, red emperor, cod main spp.
. main reasons for fishing: enjoyment of the sea, providing food, sport of fishing, getting away from work.

Limitations: length of survey

Usefulness: Verifiable estimates of CPUE

Reference/s: 31

Objective:	To establish the importance of recreational fishing from speedboats in Capricornia.
Methods:	Personal interviews at 5 boat ramps for 20 days in July/August 1979 for catch and effort, economic and attitudinal information.
Results:	. relationship between fishing activity and week day and wind . Most people fishing inshore . large boats travelled greater distances . coral trout, sweetlip, parrot fish main reef fish caught at reef . "fishing" and "an outing" most important reason for trip.
Limitations:	Few people surveyed fished at reef Numbers too small.
Usefulness:	Limited, general description of small boat fishing activity in the area.
Reference/s	30

Objective:	To determine whether there have been changes in reef fish catches over time, if particular reefs or particular species show changes in catch.
Methods:	Analysis of deep sea fishing club and charter vessel catches and effort.
Results:	Catches increase further offshore - off Townsville, mean fish size decreased 1961-1976 and early 1980's. - Capricornia catches and mean fish size similar for 20 years - more smaller fish caught as go from Cairns to Capricornia.
Limitations:	Effort measure a bit vague No accounting for gear changes Patchy data
Usefulness:	The only historical catch and effort data for reef fish around Will be useful for comparison with updated information (being done now).
Reference/s	29, 40

Objective: To determine movements of reef fish, particularly coral trout.

Methods: 7 week long trips to Capricornia
Fish caught at many reefs by hook and line and tagged with spaghetti tags. Reward offered for recaptures.
Trips between Dec 80 and October 83.

Results: 5652 fish tagged, over 100 recaptured.
Most recaptures where fish tagged, except for 25% of trout returns moved reefs (30km) - one L.chrystostomus moved 5 km,
Max time between recaps - 12 months, most very short term.
Main species coral trout. L.nebulosus, yellowtail emperor, stripeys.
Lots of l.f data.

Limitations: High tag loss
Length measurements
Mostly not written up.

Usefulness: Indicated generally little movement of most recreational and commercial reef fish, but some coral trout moved substantially.
(inter reef) distances

Reference/s 27, 28

Objective: To review GBR fish studies to see what needed to be done for recreational and commercial species (inter alia).

Methods: Literature review

Results: Distribution: nothing much on large fish except Goeden and Walkers work.
Home range: only Goeden's work and home area corresponding to size of fish and Domm and Domm on diurnal/nocturnal movements.
Recruitment: generalised OTI study showing temporal variability and adult presence no guarantee of juveniles or vice versa
Reproduction: protogynous hermaphroditism established for Serranids; Goeden on coral trout; Walkers work on Lethrinids
Some breeding seasons established (Walker and Goeden)
Research needed - population estimation eg mark recapture (validity of visual census)

. age and population structure of fished and unfished
. reproductive biology of recreational and commercial fishes
. migrations and movement of recreational and commecial fishes
. larval dispersal of recreational and commercial
. oceanographic research.

Limitations: Written without much GBR field experience and particularly before 10 years experience with visual census techniques.

Usefulness: Survey for that time of what was known. Interesting comparison with current knowledge.

Reference: 26

Objective:	Establish populations of selected commercial and recreational fish stocks at Wheeler Reef in 1977.
Methods:	Scuba manta tow around perimeter recording species, numbers and sites. "Indicator" species of Serranids, Plectorhynchids, Lethrinids selected.
Results:	. Population "density indexes" calculated and % of sample . P. leopardus 44%, Lethrinids 23%, Plectorhynchids 13% . Wheeler regarded as moderately fished because of low numbers of 3-5 yr fish of unfished controls. . increased survival of younger fish.
Limitations:	. No effort data . survey method.
Usefulness:	Description of main recreational and commercial fish at Wheeler Reef.
Reference/s	25

Objectives:	Description and analysis of bycatch from red spot king prawn (*P. longstylus*) fishery between 18° and 21°S.
Methods:	Log book program for prawns and monthly sampling and monitoring program at cross shelf sites in GBR trawled using typical gear plus small net for nearly 2 years.
Results:	. Crustacea and bony fish dominated bycatch in weight and numbers. . Main groups of fish caught not those of recreational and commercial fishing interest (Apogonids, Scorpaenids) . Distinct coastal fauna from open reef and near/ inter reefal faunas.
Limitations:	No pre trawl data on faunal composition of GBR between 18° and 21°S. No check list of reef fish for this area.
Usefulness:	Spatial and temporal description of bycatch in important trawl fishery. Numbers of recreational and commercial fish of interest.
Reference/s	24.

Objective:	Taxonomy and biology (growth, age, sex ratio, length, wt., reproduction, feeding, parasites) of GBR Lethrinids, mostly L. chrysostomus.
Methods:	Taxonomic investigation, samples from local charter and amateur fishing clubs from Townsville.
Results:	. Sex ratios L.nebulosus, L. reticulatus), L. chrysostomus about 1:1 . L. chrysostomus 25 cm 1 yr, 30 cm 2 yrs. . L.c. catch mostly 3, 4, 5 year class . l- weight relationship described . L.c. diet info crustaceans, crabs, molluscs . Lethrinids carnivorous, selective, individualistic. . Spawning times identified for main lethrinids: L.c. July-Aug; L.n. June-July . age at maturity determined . parasites investigated.
Limitations:	Only Townsville fish from opportunistic fishing trips.
Usefulness:	Basic biological parameteres of one of the main species in catch described.
Reference/s	23

Objective: To measure the impact of fishing on stocks and rate at which fish can be removed from a population (Boult Reef).

Methods: Tagging 1700 fish of 33 species (567 coral trout) before reopening.
Publicity campaign, tag rewards, for 14 days getting all people fishing to fill in log book.

Results:

- . First 14 days after reopening ~~1200~~ 2000 hrs fishing and 2000 coral trout caught
- . 25% of trout at reef caught
- . 96% of captured and tagged trout were caught at release site
- . hussar and sweetlip similar to trout
- . catch rates at Boult greater than nearby open reefs.

Limitations: Intensive recording of catch for only 2 weeks.

Usefulness:

- . 3 1/2 year closure of Boult reef showed significant replenishment of stock
- . fish stock can be very rapidly depleted.

Reference/s 22.

Objective:	Survey of charter boat industry in GBRR including numbers and locations of vessels, fishing effort and catches for 84/85
Methods:	Questionnaires and interviews.
Results:	278 charter vessels in GBRR, 52 have fishing as principal activity, a further 40 as a significant activity - total catch reef fish 263,000 kg (43 boats) pa - total catch reef fish extrapolated to all boats 450,000 kg pa - data for each vessel on major species, areas fished and estimates of catch.
Usefulness:	Detailed investigation of charter vessel activity - including fishing.
Reference/s	19

Objective: Calculate age, growth, reproduction parameters for 4 species *Lutjanus sebae*, *L. maculatus* *Lethrinus nebulosus* and *Plectropomus leopardus*.

Methods: Otoliths reading and general examination from commercial fishery, handlining and spearing.

Results: Description of fishery

. Age length

Age length	Ls	Lm	Ln	Pl
SL at 1	20.1 FL	18.6 FL	16.7	15.5
SL max	79.1 FL	82.7 FL	54.0	50
Age at max SL	8	7	12	7

. *Ls* and *Lm* - September to January reprod.
Plectopomus September to November reprod.
Ln May to October reprod.

. differential growth rates for males and females *L. sebae*, *L. maculatus* males faster than females)
, no sex change evident for Ls and Ln.

Limitations: Validation required for *P leopardus* and *L nebulosus*
Possible gear selectivity
Insufficient material.

Usefulness: First age/length/reprod. information for three of these fish.

Objective: To establish frequency of redfish juveniles in prawn trawl bycatch.

Methods: Bycatch from commercial trawlers from Hinchinbrook to Torres Strait
Trawl survey in Cairns area.

Results: Only 3 spp in bycatch of recreational and commercial line fishing significance:

. abundant <u>Lutjanus</u> <u>sebae</u>, <u>L</u>. <u>malabaricus</u> and <u>L erythropterus</u> - all juvenile
. <u>L.s.</u> 4 - 16cm; <u>L.m.</u> 4 - 18 cm; <u>L.e.</u> 6 - 22 cm (TL)i.e. mostly below size caught by line fishermen
. generally not caught in large numbers in by catch.

Limitations: pilot study small, few $ study, therefore few data.

Usefulness: General outline of whats caught, frequency etc.

Reference/s 17

Objectives: Measure dimensions of demersal reef fishery in Capricornia, size and species composition, effort, fishing mortality, to establish optimal annual catch.

Methods:
. aerial surveillance for effort since 1981
. Boult Reef reopening experiment
. creel census
. estimation of demersal reef fisheries habitat in Capricornia.

Results:
. 1986 ca 90,000 hrs fishing effort between Douglas Shoal and Lady Musgrave Island
. Boult reopen population 8000 trout
  - in 2 weeks 2000 trout caught in 1200 hrs
  - reduction in catchability of trout
  - little movement of fish around reef
. creel census shows 4.26 fish/hr and ~~0.23~~ 1 trout/hr
. demersal habitat 350 ha Boult rreef and 12,000 ha study area.

Limitations:
. Creel census incomplete
. One page report to hand.

Usefulness: Experimental examination of fishing effort and catch for previously closed reef.

Reference/s: 16

Objectives: Basic biological information on coral trout *Plectropomus leopardus*.

Methods:

- . l-w analysis
- . visual census
- . underwater observations
- . gonad examination.

Results:

- . length weight relationship provided: age 1-5+: 25mm - 500mm SL
- . Population density approx 68 per ha unfished to 35 per ha fished (down to 3 per ha)
- . 0,1 yr bottom feeders, 2-3 yr mid water feeders, opportunistic
- . home range increases with weight: age 1 - 70 m^2 to age 5: 1100 m^2
- . protogynous hermaphrodites (females mature at 22 cm SL 2 yrs female till about 4 yrs 35-40 cm SL)
- . 83,000 eggs pa 2 yrs, 450,000 @ 4 yrs.

Limitations:

- . GBR coral trout
- . l-f data based on fish from a variety of locations

Usefulness: comprehensive study of biology of major GBR species.

Reference/s 15, 21

Objectives:	Diet and distribution of Plectropomus maculatus (leopardus?) at Heron Island.
Methods:	Visual transects and stomach content analyses.
Results:	. Most on outer slope, occasionally on crest and flat . main diet: teleosts 98%, squid 1.5%, shrimps .5% . atheronids esp numerous . opportunistic feeder.
Limitations:	small study, opportunistic.
Usefulness:	diet and generalised distribution of P.Leopardus.
Reference/s	14

Objectives: Review coral reef fisheries production and characteristics of coral reef fish life histories.

Methods: Literature review.

Results: Life history characteristics:
site attached; great range of growth, natural mortality, max. length, longevity, reproduction strategies
Standing crops in GBR relatively high
Yields of coral fishes (0.5 - 5mt/km^2/pa) comparable with temperate demersal yields
GBR yields "unexploited" reefs may be 8-12 m tons/km^2/pa.
Difficulty in applying trad. stock assessment models.
Experimental assessment of fishing effects by closed vs open reefs. (Philippines)

Limitations:
. little comparable fisheries data in GBR
. data patchy, different bases etc.

Usefulness:
. Compilation of coral reef fishery info for world.

Reference/s 13

Objectives: To determine the distribution and abundancy herbivorous fishes in the Central GBR.

Methods: 30 min. visual census x 5 m (scuba transects) recording number (log 3 scale) of Acanthurids, Scarids and Siganids in the early 1980's at 5 zones within each of 3 reefs in each of inner, mid shelf and outer Central GBR caging experiments.

Results:

. Inshore assemblages different from mid and outer shelf (fewer scarids and acanthurids)
. Within reef (mostly depth) variability greater than between mid (reefs) and outer (reef) and reef groupings
. distinctive zone assemblages of herbivorous on fishes across mid and outer shelf/reefs
. broad correlation between turf algae availability and abundance of herbivorous fishes.

Limitations:

. Central GBR only.
. no inshore fringing reefs studied.

Usefulness: Basic description of distribution and abundance of significant herbivorous groups in GBR.

Reference/s 10, 11, 12.

Objectives:	Location and timing of spawning aggregations in GBR for *Plectropomus* spp and *Cheilinus undulatus*
Methods:	Discussions with fishermen.
Results:	Location, timing and description of spawning aggregations in GBR of these species.
Limitations:	Limited number of observers.
Usefulness:	. Information in reproduction timing, possible movement of these fishes . relevance to fish census information . importance for fishing.
Reference/s:	8 and 5.

Objectives:	Description of reef fish larvae, vertical and horizontal distribution, seasonality and maintenance of patterns.
Methods:	Review of studies, plankton tows, taxonomic work, circulation data.
Results:	. Two main periods of spawning and low reproductive effort in winter period . Distinct cross shelf vertical and age patterns in larval distributions . Few larvae remain close to natal reef; many within 1 km of reef
Limitations:	Most larvae cannot be identified to species, circulation data poorly known.
Usefulness:	GBR not a well mixed bath Distinct larval patterns varying between species and age with implications for adults.
Reference/s	7.

Objectives:	Review of recruitment survey data in relation to recruitment limitation hypothesis.
Methods:	. assessment of survey data . larvae fish plankton tows, night lighting artificial recruitment habitats.
Results:	Larvae extremely patchy Replenishment of a year class not certain. Spatial and temporal variability in recruitment occurs.
Limitations:	Amount of data on reef fish of commercial and recreational fishing importance.
Usefulness:	Mechanism in population dynamics, partial explanation of variability in adult populations.
Reference/s	6

Objectives:	Description of *Lethrinus chrysostomus* fishing of Norfolk Island (90% of catch)
Methods:	5 days observation and participation in fishery.
Results:	. Description of fisheries (vessels), fishing grounds, facilities, other species caught, fishing gear, seasonality. . *L. chrysostomus* 90-95% of catch . Limited CPUE data, but catch rates still very high though, 30% decline 1959-1981 suggested.
Limitations:	Short observation period and therefore limited data base.
Usefulness:	Comparison with GBR *Lethrinus chrysostomus*
Reference/s	5

Objectives:	To assess condition of demersal fish stocks and effects of fishing on large predator community in GBR.
Methods:	Scuba manta towing (356 samples) in 3-15 m water around 76 reefs from Melville Passage to Heron recording numbers of 4 families of Plectorhynchids, Lethrinids, Plectropomids, Serranids 1976-1980.
Results:	Population density indices of plectropomids for 8 general areas suggesting fishing has significantly reduced plectropomid populations esp *P. leopardus*. *P. leopardus* regarded as "keystone" species and significant differences between large predator communities show effects of fishing.
Limitations:	Survey technique No effort data.
Usefulness:	. intersting historical comparison . proposed mechanism of effect of fishing.
Reference/s	4, 20, 41

Objectives: Description of reef fish resources, fishery, legislation management, attitudes in Capricorn/Bunkers (late 1970's) (inter alia)

Methods: Interviews and discussions with fishermen and OBP submissions, QFS and CDPI records

Rationale: Background for zoning of Capricornia Section of GBRMP (late 1970's)

Results:
- . Estimates of landings and composition for the area (1970-76), description of fishery, main areas fished
- . suggestions that some fish showing smaller average size eg. coral trout
- . 1976 est. 550,000 kgs (whole wt) or 27% total demersal reef fish landed in Queensland
- . coral trout and sweetlip 35% and 34% of landings.

Limitations: No effort data
Landing data only, area of catch not specified.

Usefulness: Historical descriptive information on areas, landings, composition, attitudes.

Reference/s: 3

Objectives:	Distribution of fish assemblages (inter alia) at 10 high islands in Whitsundays.
Methods:	Scuba transects permanently marked. 30 x 5 m for large vagile species (10 x 2.5 m within large transect for small spp Record numbers (log 5 abundance) all species.
Rationale:	minimal ecological information on high islands Part of benthic and fish survey of islands.
Results:	Tables of abundance by species for each site at each reef Some analyses comparing diversity at different sites
Limitations:	Small sample sites Few replicates
Usefulness:	Qualitative description of fauna
Reference/s:	1 and 2.

EFFECTS OF TRAWLING ON SCALLOP POPULATIONS

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This fishery has been relatively well documented since 1976 however, before that date there was almost no knowledge of the scallop fishery. The initial work carried out was on standard biological parameters such as growth, reproduction, movement and with the objective of trying to develop a yield model.

The areas fished are generally in the area between the coast and the GBR in the Hervey Bay to Swains Reefs area and sometimes around the area between Lucinda and Bowen - typically 30-50m.

The animals are winter spawners, spawning between May and October, have an extended (2 to 3 weeks) larval cycle, a very short stage during which they are attached to the substrate which is not surprising since they live in open sandy areas and have a fast rate of growth reaching about 80 to 90 mm in 6 months range. 90 mm is in fact the legal size at which these animals can be taken. Once settled the animals move very little which makes research relatively easy because growth and experimental determination of mortality rates can be carried out on sedentary populations.

As part of the research on this fishery, a voluntary logbook was developed and landings and process statistics were monitored. The processors data showed very low levels of catch between 1960 and 1968. This had reached 500 tons by 1969/71 and was right up to 1000 tons in the seasons of 72 and 73. These very low catches in 1974 and 1976 may be due to redirected effort into the prawn fishery. By 1977/78 the fishery was back to approximately 1000 tons per annum and this continue through to 1980.

The research program virtually stopped in the year of 1980. It is known though that there was a change to more specialised gear in the period 1978-80. By using sleds , twin trawl nets. were replaced by triple and quad sets. This effectively doubled the gear breadth towed compared with the earlier years.

Another factor in the equation was that in 1980 and 1981, prawn fishermen were doing quite poorly and scallopers seem to be making quite a good living. At this point some dedicated vessels were built for the scallop fishery. The fishery peaked in 1982 and has been dropping every since. The average catch rate in 1978 for example was an average of about 40 kg per boat per hour (up to 400 kg per boat per hour) but had dropped to 2 kg per boat per 2hr by 1988.

At the same time the price of scallop meat, largely determined by overseas markets escalated quickly in 1985 so fishing was still a profitable enterprise even though the catch rate were extremely low. Work has shown that the density is now down to as little as 1 individual for every 150 sq metres of ocean floor in fished areas. This may have significant implications for spawning in sedentary, gonothertstic animal.

Effort in the fishery increased quite substantially from 1976 at which time there were about 10,000 tow hours to 120,000 hours in 1986. This is considered to be highly likely to be responsible for the decline in the stocks. In an attempt to conserve the resource areas those which are likely to have received high spatfall fall have been closed off from trawling. These areas are about 100 miles square and are in three locations in the reef region.

New areas for scallop fishing have been discovered and worked out near Hydrographers Passage and indeed 400 tonnes have been taken from this area in the last four months. At this stage it is not clear what this patch means in relation to the rest of the fishery.

WORKSHOP DISCUSSION OF PAPER

The design of the year was described. Essentially the net has a 3 inch mesh, is made of 150 ply twine, has a 3/8 1/2 inch ground chain which is used to disturb the scallops that are caught whilst swimming and there is a gap between the chain and the net to minimise capture of rubbish. This arrangement means compared with, for example, the prawn fishery there is very little bycatch. The description of the gear raised the question about damage to the ocean floor and it was made clear that most of small animals would remain on the ocean floor but large hard animals would be retained by the net, but that the damage to the floor was not as great as one might immediately imagine.

Further discussion occurred regarding movement of scallops and it was stated that the largest movement seen for a tagged individual was 12 kilometres but that generally there is very little movement and in fact a single mode of the animal had been followed from a size of 40 mm for 12 months while recording no significant movement at all.

Further consideration of bycatch suggested that at times the fish bycatch could by as much as 50% of the total catch but recent work has not been carried out and the new method of using 3 hour shots may have changed this.

The previous paper suggested that the effect of trawling on redspot king prawns may have had a positive effect on their population due to the fact that more suitable environments were available for their existence. It was asked whether that was a possibility in the case of the scallop fishery whereby prawns would finds more suitable areas for development. It was noted that the areas for scallops and prawns are largely separate in a spatial sense in the Yeppoon Hervey Bay area. Numbers of boats were briefly discussed and it was stated in the inital period of the fishery there were 30 or 40 boats but by 1980 there were 100 with 20 relying almost entirely on scallops. The number of boats involved in the fishery was now dropping and those that remained were achieving the majority of their catch earlier and earlier in the season. In fact it was noted that many sublegal size animals were caught several times before being finally taken.

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RECRUITMENT OVERFISHING IN A TROPICAL SCALLOP FISHERY?

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ABSTRACT The fishery for saucer scallops *Amusium japonicum balloti* is an important component of a multi-species trawl fishery for shellfish on Queensland's east coast. Effective effort directed at the scallop stock has increased by a factor of fourteen in the period between 1977 and 1987. During this period, total annual catch increased from a base of 380 tonnes of meat to a peak of 1220 tonnes in 1982, then declined to 450 tonnes in 1987. Catch rates have fallen steadily between 1977 and 1987. Recruitment overfishing has been considered as a possible cause in the fishery's decline. Selective protection of broodstock may be an effective means of managing the scallop stock, as an alternative to restricting effort or actively enhancing the stock.

Key Words: Scallops, *Amusium japonicum balloti*, catch statistics, multi-species fishery, recruitment overfishing, broodstock protection

INTRODUCTION

A fishery for the scallop *Amusium japonicum balloti* Bernardi developed off the coast of southern and central Queensland (Australia) in the mid 1950s. The fishery is based in waters of the Great Barrier Reef Lagoon between 22°S and 26°S, in grounds which cover some 16000 km^2. Intermittent catches of scallops are made between 18°S and 21°S (Figure 1), and the species also supports a fishery in waters off Western Australia, between 25°S and 30°S (Heald and Caputi 1980). Scallops are normally trawled from depths of between 25 and 55 m, but have been recorded in depths between 10 and 75 m. A smaller sympatric species, *Amusium pleuronectes* L. occurs in shallow waters (<20 m) throughout the Indo-Pacific region and is fished with varying intensity by Australian and Asian fishermen.

The Queensland scallop fishery is one component of a complex multi-species otter trawl fishery which is largely managed as an entity. The status of the scallop stock will be examined in the light of this management regime.

The Trawler Fleet

Some 1140 otter trawlers are licensed to operate along the 2400 km of Queensland's eastern seaboard (Anon 1987). They fish for a range of shellfish stocks, including penaeid prawns (*Penaeidea*), slipper lobsters (*Scyllaridae*), portunid crabs (*Portunidae*), and scallops. In northern coastal waters, there is a mixed species fishery for tiger and endeavour prawn (*Penaeus esculentus*, *P. semisulcatus* and *Metapenaeus endeavouri*, *M. ensis*) and an irregular day time fishery for banana prawns (*P. merguiensis*). Waters of the Great Barrier Reef Lagoon support fisheries for king prawns (*P. longistylus* and *P. latisulcatus*) in addition to scallops. In southern waters, stocks of *P. esculentus*, a third species of king prawn (*P. plebejus*) and two *Metapenaeus* species also support fisheries. Slipper lobsters (*Thenus spp.*) and portunid crabs (*Portunus spp.*) are taken as marketable bycatch in all of these fisheries.

Most licensed trawlers have access to all of these stocks. Vessel design has been based on the need to evolve a small to medium size general purpose coastal trawler, equipped to handle a relatively low volume, high value catch, and have an extended range. Most vessels are between 10 and 20 m long (average 16 m), powered by diesel engines between 50 and 300 kw, and carry a comprehensive range of electronics, including 50 and 200 kz echo sounders, radar and multi range radio. Sonar is becoming widely accepted. A large proportion of the fleet operates in remote northern waters and may be at sea for periods of three months or more. Trawlers which fish in this area are equipped with snap freezing facilities which have the capacity to freeze one to two tons of wet product per day down to −40°C.

A major development in the fleet occurred between 1976 and 1978, at which time all boats towed two trawl nets spread by four otter boards. By substituting the inner boards for passive skids, fishermen were able to fit a third trawl net between the skids. The reduction in drag induced through the reduction to two boards outweighed the increase due to the extra net, and there was a rapid increase in the size of nets used in the fishery. A variant of this system, whereby four or six nets separated by skids and spread by four trawl boards, was utilized by many trawlers. In 1976, a trawler of average size and power typically towed two trawls with a combined head rope length of between 25 and 30 m. The same boat presently trawls with a combined headrope length of about 50 to 55 m.

In 1979, the previous open entry policy was reversed, and trawler numbers in the fleet were restricted to a total of 1270 vessels (Hill and Pashen 1985). There has been a slight reduction in numbers since that time. A number of regulatory measures including restrictions on net sizes, seasonal and area closures, designed to restrict growth of effective fishing power, have also been introduced since 1979. But improved gear technology and willingness by fishermen to spend more time at sea have negated these attempts to restrict the growth of effective fishing effort.

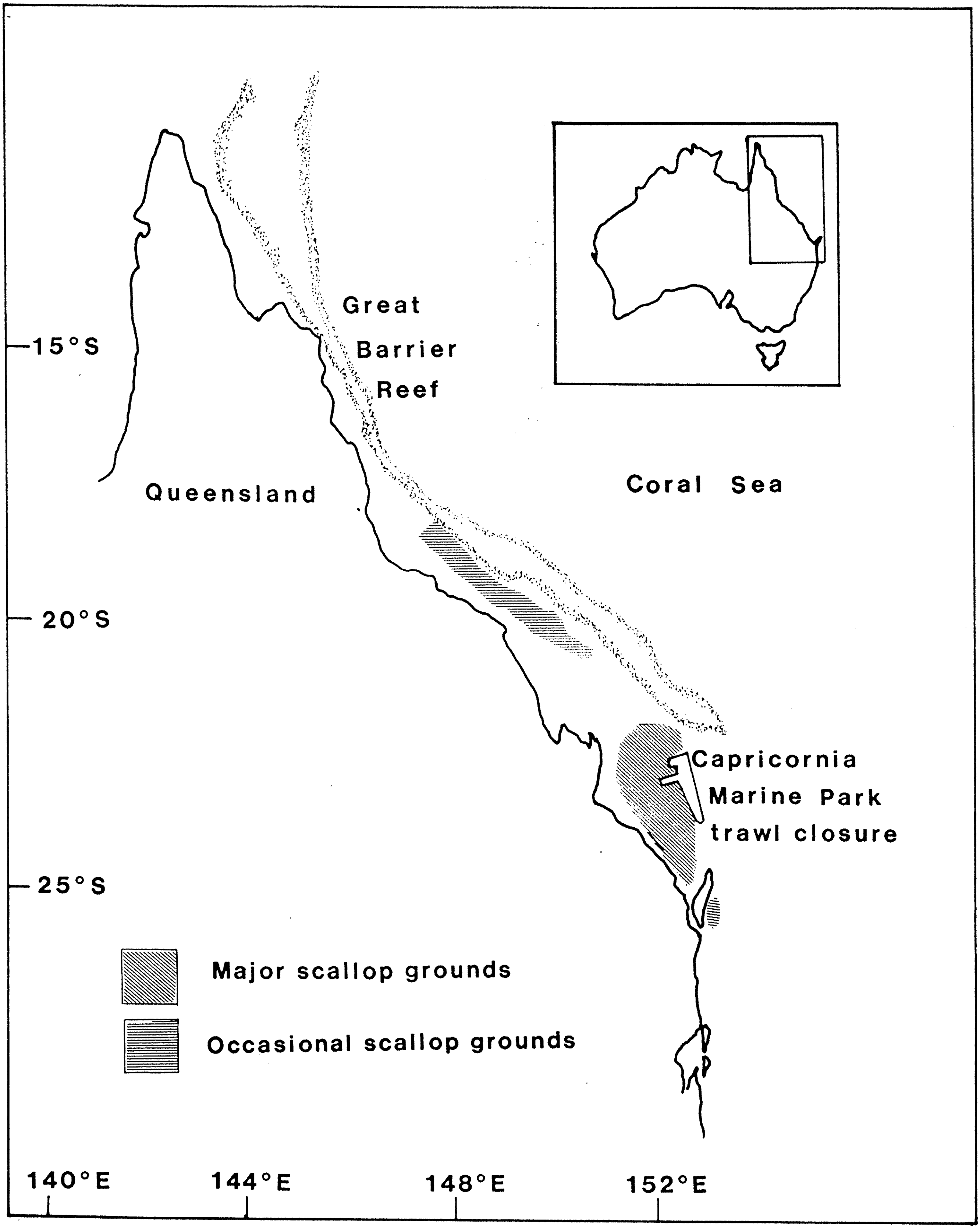

Figure 1. Location of scallop grounds off the Queensland coast.

The Scallop Fishery

Scallops occur in beds with maximum density of about one per m^2. Beds are separated by areas of low or zero scallop abundance. Fishermen working for scallops spend a certain amount of time searching for suitable concentrations if other vessels are not already working a bed. Once fishing has begun, trawlers will work continuously for periods of up to twelve days before returning to port. Trawlers fishing for scallops normally tow three nets at a speed of 3.6 to 4.4 km $hour^{-1}$. Trawl shots are of 1 to 3 hours duration. Scallops are held as whole animals on board, either frozen or refrigerated in a recirculated chill brine spray. Shucking takes place in onshore factories or moored processing barges, where the roe-off meat is frozen into block form or packed for the retail trade. Approximately 80% of Queensland's scallop production is exported, most going to Asia.

Scallop fisheries are characterized by irregular landings (Serchuk et al. 1979), but the extent of variability from the Queensland stock has been exceptional (Figure 2). Following an extended developmental phase between 1955 and 1968, landings followed an upward trend for some five years. Then followed a period of irregular highs and lows over a period of some 10 years, up to 1983. Between 1983 and 1986, total landings were reasonably stable. The appreciable decline recorded in 1987 may be significant.

There are no administrative or logistic barriers which restrict the entry of licensed Queensland trawlers into the scallop fishery. In 1980 only 20 trawler operators considered scallops to be their primary source of income, although more than 100 participated in the fishery, treating scallops as a secondary source of income after prawns (Williams 1980). Dredge (1985b) suggested that there was more than adequate fishing capacity to harvest the scallop stock. The availability of alternative stocks for trawlers to work should dampen earnings fluctuations in an environment where most fished species were short lived and showed irregular recruitment.

Excessive fishing effort has induced measurable reduction of recruitment in short lived tropical shellfish species. Multi-species fisheries are more at risk than those which are mono-specific (Penn and Caputi 1986). When there is appreciable environmentally induced variation in recruitment strength, the relationship between spawning stock size and recruitment may be extremely difficult to identify (Garcia and Le Reste 1981). But in heavily exploited stocks, the significance of stock depletion cannot be overlooked. In this paper, a description of the biology, fishery and known population parameters of *A. japonicum balloti* are given. The status of the stock is reviewed against a background of increased available fishing effort which can target on the species.

MATERIALS AND METHODS

Scallop Biology

An investigation aimed at describing the natural history of *A. japonicum balloti* and identifying sources of landing

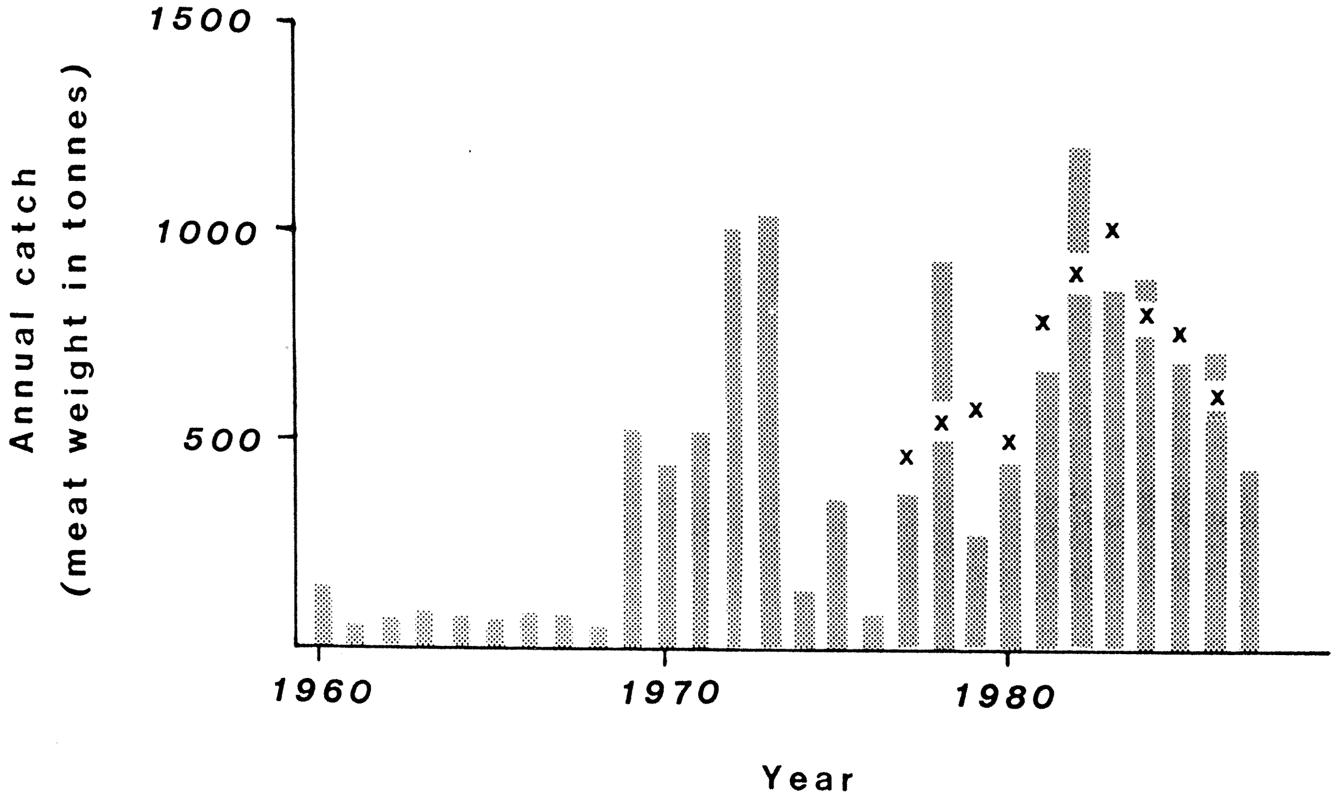

Figure 2. Annual landings of scallop from the Queensland fishery. Crosses indicate 3 year running averages of landings between 1976 and 1987.

variability was carried out in the period between 1976 and 1982.

Biological information was collected during a two year long monthly sampling programme on fished beds of *A. japonicum balloti*. In this programme, abundance, size composition, condition of the adductor muscle and reproductive status of scallops were monitored. An extensive tagging programme was undertaken to monitor growth, mortality and movement in the species. The growth and natural mortality parameters of scallops from an isolated bed were monitored in a second monthly sampling programme. Details of these programmes are given in Dredge (1981), Williams and Dredge (1981) and Dredge (1985a).

Catch and Effort Data

Information on the fishery was obtained by collecting both processor's landing figures, and detailed catch and effort data from fishermen. Processor's landing figures were summarized as total monthly landings. As all scallop processing works were monitored between 1976 and 1981, these figures are believed to be reliable estimates of total catch. Fishermen kept detailed (trawl by trawl) records of scallop and other catch on a voluntary basis. Data collected included catch weight by species, fishing location in 10 by 10 minute grids, time trawled, and depth. A separate file on each trawler's hull, engine and gear characteristics was maintained. Between 1976 and 1980, an average of 56% of total annual scallop landings were covered in this programme. The proportion of detailed catch and effort records declined to approximately 5% of total catch between 1981 and 1986 as the programme was wound down. Both the logbook and processors monitoring programmes were re-established in 1987 in response to reports of declining catch rates. Detailed catch rate and effort distribution statistics are available for approximately 14% of scallop catches taken since January 1987.

RESULTS

Scallop Biology

Amusium japonicum balloti spawned in winter and spring. Spawning coincided with temperature changing through the range of 18°C to 23°C. Mature females carried between 5×10^5 and 2×10^6 mature oocytes, and possibly spawned more than once in a single season (Dredge 1981). In laboratory conditions, a larval period of 18 to 22 days preceded settlement. There is some doubt as to the occurrence of a byssal phase (Rose and Campbell in press, Kettle 1984). Both tagging data and size frequency analysis showed that growth of juveniles was rapid. In 6 to 8 months, most scallops had attained a shell height of 85 mm, recruiting into the fishery at this size (Williams and Dredge 1981, Dredge 1985a). Sexual maturity was first reached at an age of one year or less and the natural mortality rate of adults ($M = 0.020-0.025$ week^{-1}) suggested that few animals survived longer than three years. A yield per recruit analysis indicated that yield would be maximized over a wide range of fishing mortality if the size of scallops at first capture was between 85 and 90 mm (Dredge 1985c).

Catch and Effort Data

Estimated annual landings and annual abundance indices based on catch rates but corrected to allow for increases in gear size are given in Table 1. The observed changes in catch rates covers the period 1976–1978, when unfished grounds south of 22°S were first being fished. By 1980 all grounds between 22°S and 26°S were searched comprehensively each year (Figure 3). New grounds north of 22°S are still being identified. In previously unfished areas, beds of scallops containing animals from more than one year class were found. Such beds were highly productive.

Total effort directed at the scallop stock has been estimated by dividing estimates of total catch by average catch rate (Table 1). In the period between 1976 and 1987, trawlers doubled their effective fishing power on the basis of increase in net size alone. The sharp increase in boat hours trawled is amplified by this increase in net size. The decline in catch rate between 1978 and 1980 corresponds to the period when grounds were considered to be fully exploited, with beds being dominated by single age classes. The second decline in catch rates (1984–5) coincided with an substantial shift in scallop meat price (Table 2), which encouraged fishermen to keep trawling at extremely low scallop densities.

Stock and Recruitment

With the exception of unfished scallops in the Capricornia section of the Great Barrier Reef Marine Park (Figure 1), survivors from one year class (the late 0+ and

TABLE 1.

Annual catch, standardised catch rate, estimated effort expenditure and average net size for the scallop fishery.

Year	Total catch (tonnes of adductor meat)	Mean catch rate per m head rope (kgs/hour)	Boat hours trawled	Average trawl headrope length (m)
1976	70	0.85	3000	25
1977	380	1.44	11000	25
1978	950	1.28	25000	30
1979	250	0.62	14000	30
1980	530	0.34	43000	36
1981	660	0.33	53000	36
1982	1220	0.38	86000	36
1983	880	0.66	38000	36
1984	900	0.30	81000	36
1985	660	0.13	107000	46
1986	700	0.13	116000	51
1987	450	0.11	77000	51

3a,b

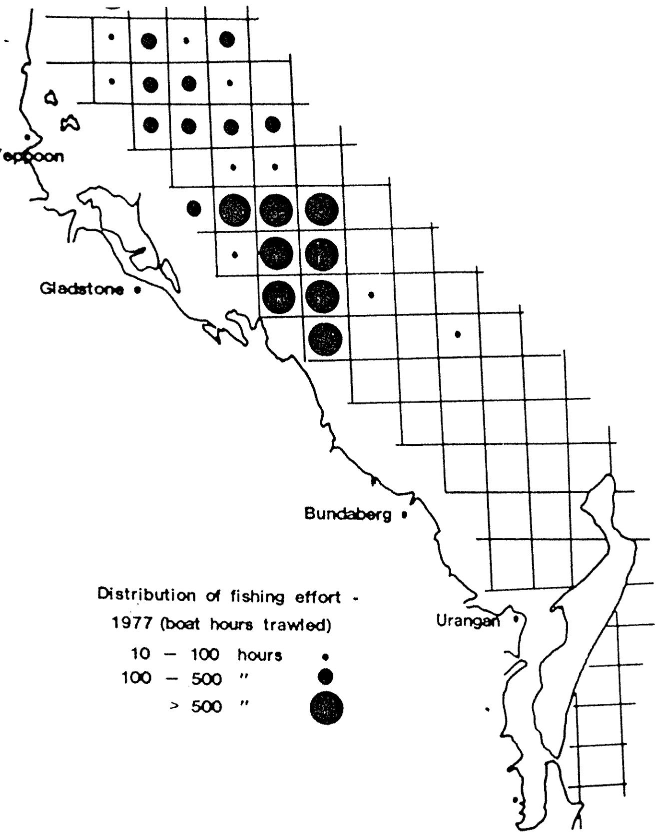

Figure 3a. Location of fishing effort-1977.

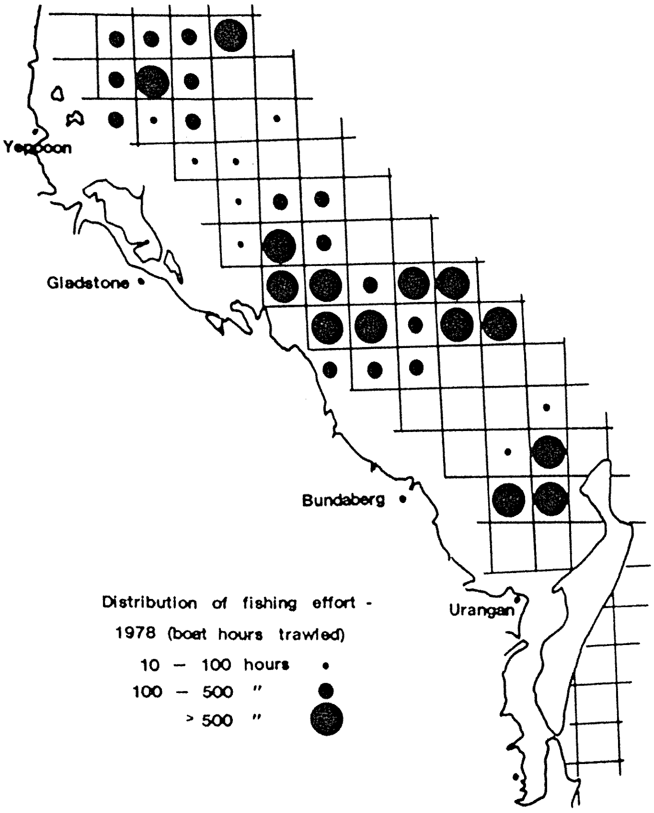

Figure 3b. Location of fishing effort-1978.

3c,d

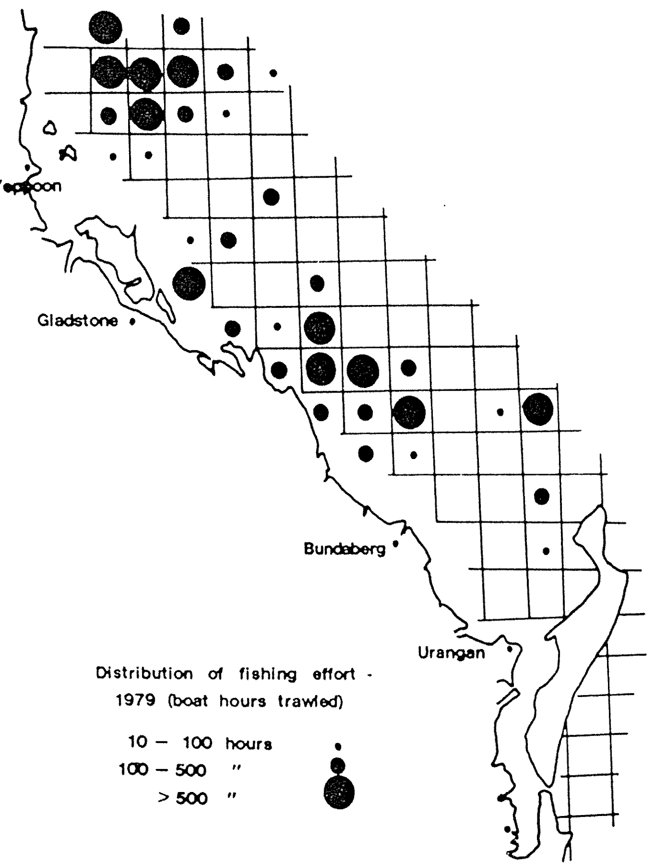

Figure 3c. Location of fishing effort-1979.

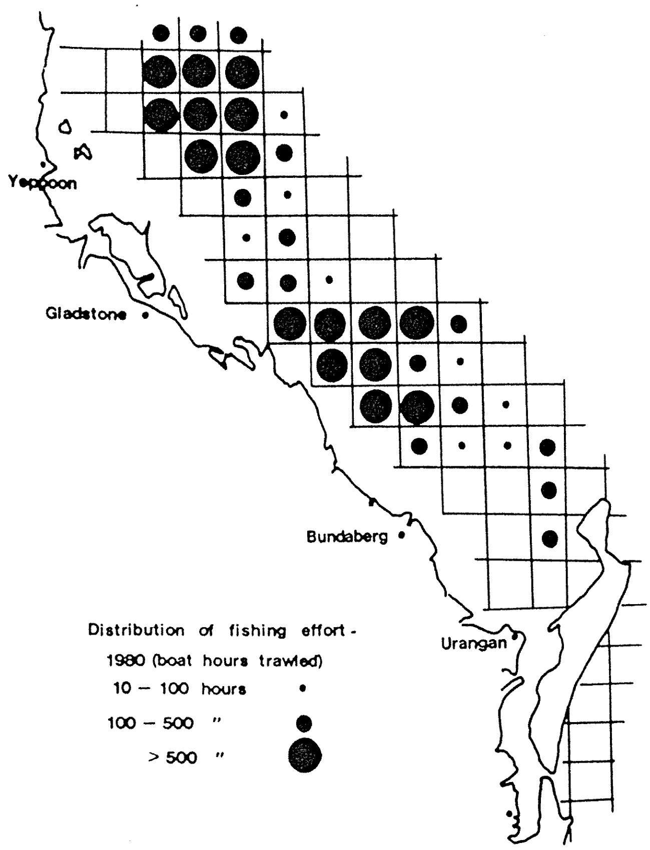

Figure 3d. Location of fishing effort-1980.

TABLE 2.

Average price paid to fishermen for scallop meat (110 meats/kg)*

Year	Price in $A/kg	Price indexed to 1980 $A	Price in $US
1980	5.87	5.87	6.81
1981	5.00	4.58	5.80
1982	6.00	4.99	6.61
1983	5.32	4.50	4.99
1984	7.87	5.59	7.13
1985	11.25	7.54	8.72
1986	16.30	8.41	11.22
1987	18.00	8.56	12.78

* Base source: Seito Ocean Products, Bundaberg, Queensland.

early 1+ group) are thought to make up the bulk of the catch and of spawners each year. The fishery is therefore dependent upon the success of this single year class for its continuity. There are insufficient data available to develop an accurate stock-recruitment relationship at this time.

DISCUSSION

The Queensland scallop fishery has developed rapidly in the period between 1976 and 1987. Between 1977 and 1982 an eight fold increase in boat hours trawled was accompanied by a doubling of annual landings. Effective effort continued to increase between 1982 and 1986, while annual landings declined from an unexplained high point in 1982.

In the three years between 1983 and 1986, there was sufficient available trawling effort directed at scallops to cover the total grounds between 22°S and 26°S between one and one and a half times each year. There is sufficient searching power in the fishery to locate virtually all scallop beds during the course of a year's trawling. Once a bed is discovered, it is ultimately reduced to a density at which fishing is no longer profitable. In 1986 and early 1987, the cut off point corresponded to a real scallop density of about one animal per 120 to 150 m^{-1}. This high level of efficiency means that the fishery is largely based upon late 0+ or early 1+ animals, depending on time of year. Few animals survive much longer than 18 months to 2 years. A yield per recruit analysis indicated that maximum yield would be obtained by first harvesting scallops at an age of 6–8 months (Dredge 1985c), which is the present situation in the fishery. But scallops from the single year class which now dominates the stock comprise the majority of spawners. As they are subject to heavy fishing pressure prior to spawning, as 0+ animals, the stability of future recruitment strength must be questioned.

The propensity of scallop stocks to vary greatly in numbers as functions of either undescribed or subtle causes is well known (Serchuck et al. 1979, Caddy 1979). But the massive increase in effort aimed at the Queensland stock of *A. japonicum balloti*, associated decline in catch rates and recent decline in total catch indicates that there may be a decline in recruitment as a consequence of excessive fishing pressure. Evidence that recruitment overfishing can occur in short lived tropical species has encouraged managers of Queensland's fisheries to adopt conservative management policies which include acceptance that recruitment overfishing may occur in scallop stocks, even though such overfishing may not have been conclusively proved.

No alteration to the present regime of open access to the scallop fishery has been considered. Previous consideration or implementation of limited entry in other Queensland fisheries has lead to an increase in fishing effort in the short term. This apparent contradiction has occurred because access to the limited fishery has been only available to those with a history of participation in the fishery. In the period between discussing limited entry and actual implementation, a great many fishermen manage to acquire some historic rights to the stock.

An alternative strategy to enforced effort restriction currently under consideration involves recruitment enhancement by selectively protecting broodstock. If a model of larval transport can be formulated, tested and verified, areas from which spat originate can be delineated. If adults in these areas were protected, reproductive potential of the stock should be enhanced.

Information on water transport in the Barrier Reef Lagoon between 22°S and 26°S is limited (Woodhead 1970, Griffin et al. 1987, Campbell unpub). Available data indicate that a gyre in Hervey Bay may act as a trap to larvae

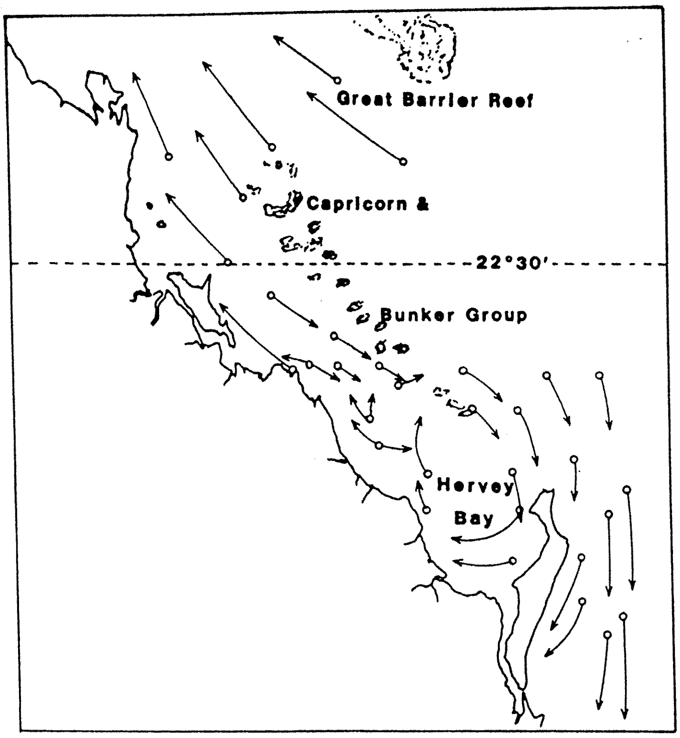

Figure 4. Summary of known surface water transport in the major scallop grounds.

spawned to the west of the Bunker and Capricorn groups of islands, whilst larvae produced near and to the east of these islands may be dispersed southward (Figure 4) to areas which do not normally support scallop fisheries. The only water transport model which can be used to model larval advection in the northern part of the stock's distribution suggests there may be net northwest transport (Griffin et al. 1987).

Knowledge of the early life history of *A. japonicum balloti* is limited. Before serious consideration could be given to managing the scallop stock by selective protection of broodstock, additional information on larval behavior and mortality is needed. Given that larval transport may not be entirely passive, the relationship between water transport and larval dispersion needs elucidation. Further information on fine scale timing of spawning is also essential for effective modelling of the system.

Stock enhancement by seeding out spat caught in conventional mesh bags for growout has also been considered. Pilot studies failed to demonstrate the validity of this technique (Sumpton pers. com.). The rearing of scallop seed in hatcheries has also been suggested as a means of stock enhancement, but could only be regarded as a long term option.

Taking steps to protect a stock before recruitment overfishing has been clearly demonstrated could be interpreted as an indication of panic or an imposition of unnecessary costs on the industry. But recent experiences in Australian peneaid prawn fisheries have clearly shown that the costs and social trauma associated with rehabilitating overfished and overcapitalized fisheries (Kailis 1985) far outweigh the small benefit gained by allowing a stock to be exploited to a point where recruitment overfishing can be clearly recognised.

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BRIEF DESCRIPTION OF TRAWL GEAR

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Distribution of Effort, Trawler Behaviour, Logbook Systems

On the east coast of Queensland there are approximately 1000 trawlers operating, actual number 1034. These vessels range in size from 10 to 20 metres and generally tow two, three or four nets. They are constrained by legislation to less than 20 metres, less than 400 hp and less than 88 metres total head and foot rope length.

They trawl for 9 species of prawns as well as scallops Bugs and Crabs take as bycatch. Attached maps show the areas fished for the major species.

The general philosophy in Queensland is that all trawlers have access to all fisheries, thus it is difficult to monitor stock per unit effort work difficult.

There is now a compulsory logbook system in place for the vessels in which they provide catch statistics, a measure of effort based on days fished and a location with a resolution of a 30 x 30 minute grid. In the past voluntary systems have been set up for this fishery. Table 1 is a summary of data sets that in the past have been collected. This data however is quite patchy and does not give a reasonable historic record of the fishery in terms of catch effort. It is hoped that the compulsory logbook will fill this data requirement.

WORKSHOP DISCUSSION OF PAPER

During discussion it became clear that these vessels are very nomadic due to weather conditions, catch rates and so on, so it becomes difficult to resolve what the "fleet" is actually doing. As a method of validating the compulsory logbook returns, it was suggested that the voluntary system be continued. Furthermore it was noted that some of the voluntary logbook systems are collecting data at a higher temporal and spatial resolution than the compulsory system.

Mention was made of the possibility of vessels transgressing into areas where fishing was not allowed (eg the far north transect) and it was asked whether it was likely that these vessels would maintain logbooks for these fishing activities. This proved impossible to answer.

CATCH AND EFFORT DATA COLLECTED FROM LOG BOOKS ON THE QUEENSLAND EAST COAST

AREA	DATE	PRINCIPAL	No. REC	RESOLUTION	AVAIL
Moreton Bay	1965-9	Qld. Fish Haysom	?	?	Lost
East Coast (scattered)	1972-4?	CSIRO Hynd	?	6*6 min Shot to daily	Cleveland
Moreton Bay & Tincan Bay	1970-7	CSIRO Lucas/ Somers	?	6*6 min Shot to daily	Cleveland
East Coast (scattered)	1977-	Com. Fisheries	?	6*6 min Shot to daily	Canberra, via Cleveland
East Coast (patchy)	1977-89	Qld Fish Dredge	30K	10*10 min 6*6 min Shot to daily	Burnett Heads
East Coast (compulsory)	1988-	Qld Fish Williams	?	30*30 min Daily	Brisbane (restricted)

ABSTRACT

A TRAWL FISHERY FOR KING PRAWNS

M.C.L. DREDGE

The fishery is of recent origin. Landings increased from approximately 250 tonnes 1981-2 to about 1800 tonnes in 1987, largely through increase in effort. The fishery occurs in waters to the west of the Great Barrier Reef, in depths of 40-50 m between 19° S and 21° S, and is predominantly an autumn - winter event. Catch rates in the fishery have peaked earlier each year in the period 1985-88.

Penaeus latisculentus recruits into the fishery earlier and over a shorter time frame than P. longistylus. There was significant variation in the proportion of P. latisculentus : P. longistylus between 1985-6.

Inter annual catch rate variation cannot be explained at this time, and there is insufficient data to consider long term trends in the stock.

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ABSTRACT

EFFECTS OF PRAWN TRAWLING ON FISH POPULATIONS

IAN POINER
CSIRO

This study was carried out in the Torres Strait and the south east area of the Gulf of Carpentaria. It began in 1984 largely because of the Torres Strait Protective Zone and Torres Strait treaty and the management arrangements that were necessary because of international commitments and Torres Strait Islanders.

This fishery targets one species of tiger prawn but many animals are caught in bycatch. The bycatch is largely fish and they are dominated by small individuals of a large number of species. Samples were taken from areas close to and far from reefs and in all cases it was found that very few reef species were caught although there was a marginal increase close by.

The main components of the bycatch were small non commercial inter reefal fishes. At times large numbers of tropical lobsters were taken. These used to be targetted during their migration but this is no longer allowed.

The objective of the study was to look at what has happened to inter reefal fish based on the data collected by Ian Munro pre the northern prawn fishery. This has been used as a base data set and was collected in the early 1960s and compared with the new data that had been sampled some 20 years later.

Standardisation of the collected data was made on the basis of sites, months, times, net design, speeds of trawl and taxonomy. Essentially changes in the abundance and diversity were looked at. Results showed that for pooled day and night shots there was a significant decrease in abundance per site, particularly in night sights. However there was an increase in the number of species, again, particularly in night time trawls.

In the context of this study, species were divided into essentially three groups. (Benthetic dwellers, those that lived in holes and cravasses - demersal species that lived close to the bottom and semi pelagic species that live between the bottom and the surface.) The species that have increased in abundance they were mainly semi pelagic and the benthic and semi demersal species have essentially decreased.

Because of difficulties in comparison of data collected other parameters such as sediment and run off have provided little information in the context of this study. In the Torres Strait work took place in both the closed area to the east and the normally fished area to the west of the Warrier Reefs and a series of trawl surveys was carried out each three months over several years. All surveys used prawn nets. It appears that fish catch in the closed area does not change much on a temporal scale, however in the open area, the catch of fish seems to be correlated with fishing effort associated with the prawn fleet.

Species that had changed in Torres Strait in terms of abundance were significantly the same as in the South East Gulf in that seven out of eleven

pelagic species had increased and thirteen out of nineteen dimersal and benthic species had decreased.

In summary one could say that the long term affects of trawling were significant decreases in abundance, significant increases in the number of species, and changes in relative abundance.

In the short term there were significant cyclical changes correlated with effort expended by the prawn fleet. The mechanisms involved in these changes are suggested to be habitat modifications, direct fishing pressure, and other as yet undetermined factors.

Future work will include focussing on the catch taken by prawn trawlers as opposed to that taken using fish trawls. There will be some work on mackeral species and further consideration of habitat modifications.

WORKSHOP DISCUSSION OF PAPER

Discussion largely revolved around the ability of the researchers to effectively compare the work done by Ian Munro in the early 60's with the work that was done about twenty years later.

It was pointed out that particular years could grossly affect factors such as sediment composition and catch.

ABSTRACT

EFFECTS OF TRAWLING ON THE NORTHWEST SHELF AND ITS MANAGEMENT

KEITH SAINSBURY
CSIRO

The northwest shelf has been fished by a Taiwanese pair trawl fleet since 1972, and has supported a small Australian trap fishery since 1983. The trawl fishery targets a large number of species, while the trap fishery targets a small number of Serranid, Lethrinid and Lutjanid species. Data from research surveys dating back to 1960 show that the species composition changed following development of the trawl fishery, with serranids, lethrinids and lutjanids decreasing in abundance and nemipterids and saurids increasing. Other changes are also know to have occurred at the same time. In particular the changes in the fish community are correlated with the strength of the southern oscillation, suggesting the possibility of environmental forcing of the change in the fish community, and the abundance of sponges decreased following fishing, suggesting that habitat modification could have played a role in the changes in the fish community. This latter possibility was supported by an examination of the usage of the epi-bethic habitats by fish which showed that lethrinids and lutjanids are strongly associated with open habitats

Three other possible mechanisms for the changes in community composition involving intra specific and interspecific interactions among the fish species groups, were also identified as being biologically reasonable and consistent with the available data leading overall to consideration of 5 general classes of mechanism for the changes. These mechanisms have different management implications, and particularly management of the competing trap and trawl fisheries. Some imply that a valuable trap fishery could be obtained in the absence of trawling, while others imply that a trawl fishery would provide the greatest value from the resource.

A number of different management policies involving the target trawl species were examined for each of the possible mechanisms. Specifically this examination included the costs (including monitoring) and revenues from following the policy, the observation obtained from monitoring the resource under that policy, and the effectiveness of those observations is leading to future management decisions which are most appropriate to the resource dynamics mechanism in question. This allows identification of short term management policies that cost-efficiently lead to application of correct long term management policy no matter which of the mechanisms is actually true.

This analysis suggested that there was considerable value in closing part of the North West Shelf to trawling for 5-10 years, followed by encouragement of trapping in the closed area for a further 5-10 years. For this and other reasons, the federal and state managers of the fisheries closed an area of the North West Shelf to foreign fishing in 1985, and a further area in 1987. The annual monitoring of the fish community and epibenthic habitats in these areas and in the area still open to trawling has shown that

- the population sizes and recruitment of all lethrinids and most lutjanids has rapidly increased.

- the population sizes and recruitment of all <u>Nemipterus</u> and Sauridae species has trended downwards, in a pattern suggestive of a damped oscillation, and

- there have so far been no changes in the abundance of the epibenthic habitats.

Overall, the use of the closures on the North West Shelf has already provided very useful management information, and appears to be succeeding in its objective of empirically leading to an informed management of the trawl and trap fisheries in a much shorter time than would be possible if reductionist scientific research were relied upon to distinguish the various possible ecological mechanisms.

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forces and resource dynamics. Rather, it places importance on consideration of alternative ecological interpretations of the available data and examination of the consequences of proposed management measures under these alternative models to provide a 'reasoned empiricism'. This involves use of ecological knowledge to formulate alternative models, consideration of the value of model discrimination, and consideration of the implications of present management actions for model discrimination in the future. Management actions can then be evaluated from the risks, costs and benefits across the alternative models. A methodology for these evaluations is provided by Walters (1986).

An empirical and manipulative approach to questions of community dynamics has been suggested by a number of authors (e.g. Holling, 1978; Sainsbury, 1982, 1987; Sugihara *et al.*, 1984), and the unexpectedly high value of a large manipulation was recently shown by Garcia and Demetropoulos (1986). Intuitively, an empirical and manipulative approach would provide a more reliable means of guiding community structure to a desired state than basing management decisions solely on the predictions of a single model somehow deemed best from knowledge that must be acknowledged as being very incomplete.

MANAGEMENT OF THE FISHERY ON THE NORTHWEST SHELF OF AUSTRALIA

The environment, fish community and fisheries

The continental shelf of northwestern Australia (Figure 14.1) supports a diverse and productive demersal fish community, provides a large proportion of the Australian continental shelf area, and has been fished mostly by foreign distant-water fleets (Sainsbury, 1987). The histories of the fisheries on the Northwest Shelf are described in Sainsbury (1987), but briefly, they are;

– A Japanese trawl fishery from 1959 to 1963 targeted on fish of the genus *Lethrinus* between 116°E and 117° 30'E and depths between 30 and 120 m. *Lethrinus* comprised about half the catch, and catch rates did not decline during the period of the fishery.

– A Taiwanese pair trawl fishery from 1972 to the present takes a wide range of species between depths of about 30 and 120 m. The retained catch mostly comprises the genera *Nemipterus* (21%), *Saurida* (12%), *Lutjanus* (9%) and *Lethrinus* (8%). The fishery began in international waters and came under Australian jurisdiction in 1979. Since then a licensing and access fee has been charged by Australia.

– A domestic Australian trap fishery began in 1984, targeted on *Lethrinus*, *Lutjanus* and *Epinephelus*. There is interest in expanding this fishery, but to date fishing effort has been low. Traps are operated to about 80 m depth and in areas subjected to little trawling.

Research survey data on the composition of the fish community are available

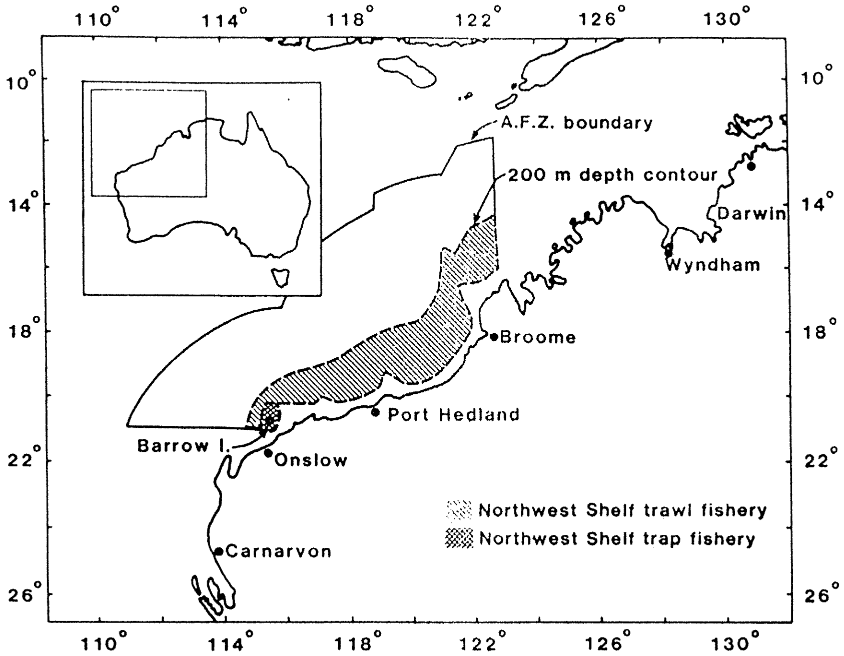

Figure 14.1 **The 200 nmi Australian Fishing Zone (AFZ) and 200 m depth contour in the faunistic region of the Northwest Shelf. This region was identified from cluster analysis of the fish species composition data from research vessel catches. The area exploited by trawl and trap fisheries on the Northwest Shelf is also shown**

for some years since 1960 (Sainsbury, 1987). Total fish catch rate showed no significant correlation with year of survey (Sainsbury, 1987), and so absolute abundance of each fish taxon is proportional to its percentage of the total catch (Figure 14.2). There is a significant negative correlation between year of observa-

Table 14.1 **The frequency of main features of the four demersal habitats on the Northwest Shelf. Habitats were defined from cluster analysis of 44 binary attributes recorded from each of 8566 photographs of the sea floor in the path of 108 trawls. 'Large benthos' is all benthic organisms larger than about 25 cm, and density categories are the numbers of organisms seen in the photograph**

Habitat	Total no. photos	Number of photographs containing large benthos density					small benthos density			
		0	1	2	3	>3	0	1–4	5–7	>7
1	5364	5095	196	37	12	24	5364	0	0	0
2	2234	2234	0	0	0	0	0	1760	162	56
3	475	0	270	97	46	63	0	475	0	60
4	493	0	153	83	79	178	0	260	233	194

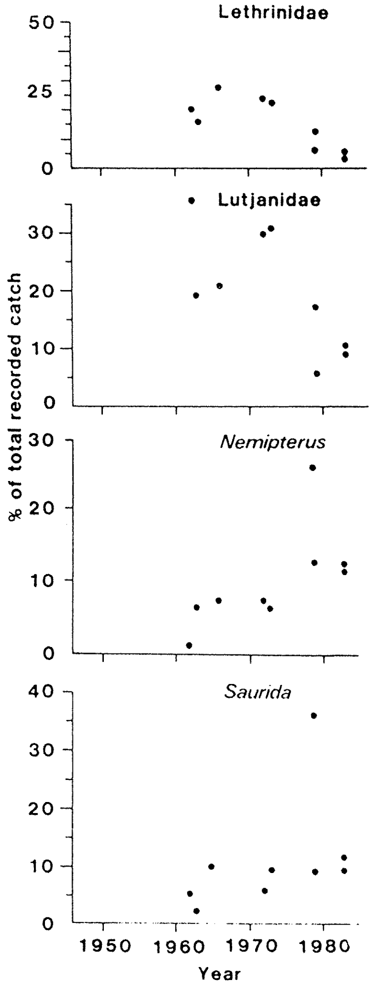

Figure 14.2 The percentage of total catch comprised of Lethrinidae, Lutjanidae, Nemipteridae and Saurida in research catches from the Northwest Shelf (data from Sainsbury, 1987). Total research catch rates are not significantly correlated with year (mean catch rate 219 kg/h)

Table 14.2 The relative abundance of different fish genera in each of the main demersal habitats on the Northwest Shelf. Estimates can be interpreted as the expected catch of a research vessel trawl if the whole of the trawl path is of the same habitat type. Standard errors are given in parentheses

	Habitat			
	1	2	3	4
Lethrinus	1.8 (0.35)	0	0	416.5 (14.94)
Lutjanus	13.9 (1.46)	0.8 (2.54)	0	40.1 (6.67)
Nemipterus	108.0 (2.30)	0	0	2.3 (2.12)
Saurida	250.7 (4.96)	30.2 (6.8)	0	0

tion and the abundance of both Lethrinidae and Lutjanidae, and a significant positive correlation for both Nemipteridae and *Saurida*. More detailed data on *Saurida* since 1978 shows both this increase in absolute abundance and changes of species composition within the genus (Thresher *et al.*, 1986). Overall, the fish community has maintained the same biomass but its composition has altered from 40–60% by weight of *Lethrinus* and *Lutjanus* and 10% *Nemipterus* and *Saurida* prior to development of the pair trawl fishery, to about 10% *Lethrinus* and *Lutjanus* and about 25% *Nemipterus* and *Saurida* at present.

The demersal environment of the Northwest Shelf is also known to have altered during this period, because the quantity of epibenthic fauna (mostly sponges, alcyonarians and gorgonians) caught in trawls is now considerably lower than it was prior to and during early development of the pair trawl fishery (Sainsbury, 1987). During CSIRO research surveys, the sea bed in the path of trawls was photographed by a camera on the trawl headline. Four major habitat types were defined by cluster analysis of the presence and approximate size of the epibenthic fauna in each photograph (Table 14.1). The photographs were used to estimate the proportion of the trawl path occupied by each habitat type (h_{ij} for habitat i in trawl j). The catches from photographed trawl paths were then used to calculate the catch per unit area of *Lethrinus, Lutjanus, Nemipterus* and *Saurida* for each habitat type. For each genus the catch per unit area of the ith habitat (λ_i) was estimated by considering the catch in numbers of the jth trawl to be a Poisson variable with parameter $\Sigma h_{ij}\lambda_i$ (Table 14.2). These estimates show that *Lethrinus* and *Lutjanus* occur almost exclusively in the habitat containing large epibenthos, while *Nemipterus* and *Saurida* occur mostly in the open sand habitat. If this habitat usage remains constant, then alteration of the area of each habitat would alter community composition.

Management of the pair trawl fishery since 1979 has been by total catch quota and minimum mesh size, both calculated from multiple single-species models (Sainsbury, 1984, 1987). Changes in relative abundance of *Lutjanus, Lethrinus* and *Nemipterus* are of little consequence to the pair trawl fishery, as all have similar commercial values. Although decrease in the combined abundance of these groups and increase in the abundance of low-valued *Saurida* may require some 'fine tuning' of the present management regime, a more fundamental management issue is posed by development of the trap fishery. The trap fishery has no market for *Nemipterus* and *Saurida*, and relies heavily on *Lethrinus* and *Lutjanus*. Expansion of this fishery would require return of something like the historical community composition. Cessation of trawling might allow a future attempt to expand the trap fishery if the community composition recovers. However, even if the fish community recovers, it is not certain that expansion of the trap fishery is economically or socially possible in this remote part of Australia. Two management questions arising from this situation are: do the long-term rewards to Australia warrant efforts to alter the fish community structure and type of fishing employed, and if so which of the many possible management regimes involving continued trawling, trawl closures and trap fishing is considered best? Calculation of the possible outcomes and the value of different management regimes, upon which a resource manager might base a decision, requires specification of resource dynamics and a method of evaluating the value of a management action when resource dynamics and the capability for fishery expansion are uncertain.

Models of the Northwest Shelf fish community

Four models of the four main species groups were examined, each reflecting a different interpretation of the available data. Each model is very simple because the data do not permit estimation of many parameters.

1. All species groups are controlled by 'intraspecific' processes (i.e. the 'multiple single-species' approach).

Lethrinus and *Lutjanus* follow the difference equation for logistic population growth:

$$B_{t+1} = B_t\,[1+r-(rB_t/K)-qE_t]$$

where B_t is the relative abundance (research vessel catch rate) at time t, r is the intrinsic population growth rate, K is the carrying capacity in units of relative abundance, q is the catchability coefficient for pair trawlers and E_t is the trawling effort between t and $t+1$. K, r and q were determined from inspection of the likelihood surface of the model fitted to the observed time series of abundance (Figure 14.2) and fishing effort (Sainsbury, 1987). Where a ridge in the likelihood surface indicated indeterminacy in this or any of the other models used, a range of parameter sets were selected from along the ridge to give model–parameter set combinations which were treated as separate models during evaluation of management options. Multiplicative log-normal measurement errors were assumed throughout.

Nemipterus and *Saurida* increased in abundance with fishing, which, assuming only intraspecific population processes, suggests that the population growth rate depends upon population age structure. This might be due to high levels of cannibalism by old individuals which are subsequently removed by the fishery, or a highly domed relation between population egg production and recruitment combined with strongly age-dependent individual fecundities. A simple model of this is

$$B_{t+1} = B_t\{1+r-(a_t rB_t/K)-[(1-a_t)rB_t/\delta K]-qE_t\}$$

where a_t is the proportion of the population biomass at time t made up of animals younger than some critical age from which they strongly retard population growth and δ is a measure of the strength of this retardation. Values of a_t were obtained from age structure submodels using the population parameters given in Sainsbury (1984), then r, q, K and δ were again determined from examination of the likelihood surface of the model fitted to the time series of abundance and fishing effort.

2. *Lethrinus* and *Lutjanus* have intraspecifically controlled population growth, while the population growth of *Nemipterus* and *Saurida* is also negatively influenced by the combined biomass of *Lethrinus* and *Lutjanus*. Population growth for *Lethrinus* and *Lutjanus* is as in model 1, and for *Nemipterus* and *Saurida* is

$$B_{t+1} = B_t[1+r-(rB_t/K)-(\alpha rW_t/K)-qE_t]$$

where α is an interaction coefficient and W_t is the combined abundance of *Lethrinus* and *Lutjanus* at time t.

3. *Nemipterus* and *Saurida* have intraspecifically controlled population growth, while the population growth of *Lethrinus* and *Lutjanus* is also negatively influenced by the combined biomass of *Nemipterus* and *Saurida*. Population growth for *Nemipterus* and *Saurida* is as in model 1, and for *Lethrinus* and *Lutjanus* is

$$B_{t+1} = B_t[1+r-(rB_t/K)-(\alpha rW_t/K)-qE_t]$$

where W_t is the combined abundance of *Nemipterus* and *Saurida*.

4. Carrying capacity of all groups is determined by the amount of suitable habitat and habitat abundance is altered by the physical effects of trawling. For all groups population growth is

$$B_{t+1} = B_t[1+r-(rB_t/(\Delta\sum^{i} h_{t,i}\lambda_i)-qE_t]$$

where $h_{t,i}$ is the proportion of the area of habitat i at time t, λ_i is the relative density of the species group in habitat i, and Δ is a constant. Since the fish community mainly reflects the presence or absence of large benthos (Table 14.2) only these two habitats were considered. Estimates of $h_{t,i}$ were obtained from a simple model of the benthos in which the sea floor is considered to comprise a number of small, independent patches, each the size of the area covered by a survey photograph (about 4 m^2). Each patch has a fixed probability (s) of receiving a recruit each year and each benthic organism has a fixed probability (*d*) of dying each year. If it takes T_{25} years for the organisms to grow to 25 cm then the proportion of patches with one or more individuals of large benthos is

$$1 - \prod_{\phi=T_{25}}^{\phi=\infty}[1-se^{-\phi d}]$$

If each trawl sweeps a proportion *p* of the fished area, there are *E* trawls in year *T*, and an individual aged ϕ is removed with probability r_{ϕ} on encounter, then the probability of an individual not being removed by trawling that year is approximately $\exp(-pr_{\phi}E_T)$. Assuming r_{ϕ} can be written as

$$r_{\phi} = r_{max}(1-e^{-c\phi})$$

but restricting $r_{T_{25}}$ to be 0.95 r_{max} so that *c* can be expressed solely in terms of T_{25} and r_{max}, gives the proportion of patches with one or more individuals of large benthos at time *t* (i.e. $h_{t,1}$ in the difference equation for model 4) as approximately

$$1 - \prod_{\phi=T_{25}}^{\phi=\infty}[1 - s\,e^{-D_{\phi}}]$$

where $D_{\phi} = \phi d + p\sum_{k=1}^{k=\phi} r_{\phi-k}\, E_{T-k}$

A similar equation can be obtained for the proportion of patches with small benthos, and since both proportions were measured in 1983 this gives two equations in four unknowns, *s*, *d*, T_{25} and r_{max}. A value of $r_{max} = 0.75$ was considered reasonable from observations of trawls in progress, and a literature (Harrison and Cowden, 1976) value of $T_{25} = 10$ years was used to allow calculation of *s* and *d*.

These models have different implications to the yield available from a trap fishery. Models 1 and 2 imply a low yield because the historical decline of *Lethrinus* and *Lutjanus* is interpreted as being due to low productivity. Models 3 and 4 give a high yield to the trap fishery since trapping removes no benthos (which under model 4 allows return of high carrying capacities for *Lethrinus* and *Lutjanus*) and catches few *Nemipterus* and *Saurida* (which under model 3 allows the *Nemipterus* and *Saurida* populations to decrease to their unfished levels, with consequent reduction in the negative influence they exert on *Lethrinus* and *Lutjanus* population growth).

Evaluation of management options under alternative models

If a number of possible long-term management regimes (U_k, $k=1$ to m) and resource models (m_j, $j=1$ to n) have been identified from examination of historical data, then the expected revenue from applying each U_k can be influenced by the probability placed on the alternative models. Sometimes it might be desirable to delay application of any of the U_k and apply a different regime, W, until model discrimination is improved. This approach to management raises the question of how to identify W and the learning period durations which lead to selection of the most appropriate U_k at the end of the learning period, and which maintain a high expected economic return from the resource. The magnitude of the expected value from the resource is the result of 'trade-offs' between the revenue generated during the learning period, the model discrimination provided by observations made during the learning period, and the economic value of that discrimination in leading to application of an appropriate U_k. An approach similar to that of Walters and Hilborn (1976, 1978) and Walters (1986) is used here to determine model discrimination during a learning period and to calculate the expected value of management policies across the alternate models. All of the policies examined here comprise one cycle of a closed loop policy (Walters, 1986). In this cycle alternative resource models and long-term management regimes are identified at present time T, a trial management regime W is applied during a learning period of duration t, and at time $T+t$ observations made during the learning period are used to update the credibility of the alternative models and select the management regime to be applied henceforth. The object is to determine the effect of different W and t in leading to the greatest long-term value from the resource (including the revenue during t).

The first step is to determine the present relative probability placed on the proposed models of resource dynamics. At time T all alternative models are regarded as being consistent with historical observations, and can be reasonably parameterized with the historical data set (O) of observations made during time $T-h$ to T. All models are given equal probability at time $T-h$ (i.e. $P_{T-h}(m_j) = 1/n$), and the probability placed on each model at time T can be calculated from Bayes' Theorem as

$$P_T(m_j) = \frac{P_{T-h}(m_j)\, L(O/m_j)}{\sum_{i=1}^{i=n} P_{T-h}(m_i)\, L(O/m_i)}$$

where $L(O/m_i)$ is the likelihood of the existing data set if model i is true. Usually the $P_T(m_j)$ will be approximately equal.

The next step is to determine the relative probabilities placed on each model after application of each trial policy for a period. In this policy W is followed during a learning period of duration t, and observations made during this period are used to update the probabilities placed on each model. Data sets $O_{j,W}$ which might be available at time $T+t$ can be generated by simulation of the observation process (i.e. sampling) and the behaviour of model j under policy W. For each data set the likelihood that it was generated by each of the models is calculated, $L(O_{j,W}/m_i)$, and the probability placed at the end of the learning period on model i when W is applied to true model j is

$$P_{T+t}(m_i/W,m_j) = \frac{P_T(m_i)\ L(O_{j,W}/m_i)}{\sum_{k=1}^{k=n} P_T(m_k)\ L(O_{j,W}/m_k)}$$

If W is perfectly informative $P_{T+t}(m_i/W, m_j)=1$ if $i=j$ and zero otherwise, while if W is totally uninformative $P_{T+t}(m_i/W, m_j)=P_T(m_i)$.

It is then possible, for each model, to compute the present value from the resource under each combination of learning period policy and subsequent long-term policy. For model j the present value of applying policy W during $(T, T+t)$ and then applying policy U_k is

$$V(U_k/W,t,m_j) = \sum_{v=0}^{v=t} A_{T+v}(W/m_j)\ \Phi^v + \sum_{v=t+1}^{v=\infty} A_{T+v}(U_k/m_j)\ \Phi^v$$

where $A_{T+v}(W/m_j)$ is the annual net value from policy W applied to model j in year $T+v$ and Φ is a discount rate. If model process error or stochastic environmental perturbations are included in the resource models then $A_{T+v}(W/m_j)$ will also be stochastic because of its dependence on the resource state at time $T+v$.

At time $T+t$, when the decision to follow a particular U_k is made, the data available from true model j will be interpreted as being due to model i with relative probability $P_{T+t}(m_i/W,m_j)$, and this will be erroneously associated with the annual value from the resource when model i is true. At $T+t$, perceptions of the value of the resource under different management regimes will be influenced by such errors, and management decisions at $T+t$ will be based on this 'apparent value'. Here it is assumed that the resource manager is risk neutral (see Walters, 1986) and will choose the U_k with the greatest expected value. For model j true and assuming constant equilibrium annual returns from each model ($A^*(U_k/m_i)$) for simplicity, the chosen U_k will maximize the 'apparent value'

$$AV_{T+t}(U_k/W,m_j) = \Sigma\ P_{T+t}(m_i/W,m_j)\ A^*(U_k/m_i)$$

The $P_{T+t}(m_i/W,m_j)$ are random variables because $O_{j,W}$ is influenced by random processes such as sampling. Furthermore, if the $A_{T+v}(U_k/m_j)$ are also stochastic then calculation of the expected value from the resource for particular W and t usually involves a large number of simulations of the $O_{j,W}$, the decision process, and the revenue flow from T onward until $A_{T+v}(U_k/m_j)\ \Phi^v$ is negligible. Here the $A_{T+v}(U_k/m_j)$ are regarded as being deterministic, so that the expected value of W

for period t can be obtained more simply by calculating $Q_{T+t}(U_k/W,m_j)$, the probability that each U_k is selected at time $T+t$ when model j is true and W is applied during $(T,T+t)$. $Q_{T+t}(U_k/W,m_j)$ is calculated from the frequency of selection of each U_k during repeated simulations of the $O_{j,W}$, calculation of $AV_{T+t}(U_k/W,m_j)$ and simulation of the decision process.

The expected value from the policy with regime W for period t is then

$$E[V(W,t)] = \sum_{j=1}^{j=n} P_T(m_j) \sum_{k=1}^{k=m} Q_{T+t}(U_k/W,m_j)\ V(U_k/W,t,m_j)$$

The bounds of $E[V(W,t)]$, corresponding to W being perfectly informative (i.e. $P_{T+t}(W,m_j)=1$ for $i=j$ and zero otherwise) and totally uninformative (i.e. $P_{T+t}(m_i/W,m_j)=1/n$ for all i,j) in time t, are readily obtained from this relation because $Q_{T+t}(U_k/W,m_j)$ is easily calculated analytically at each bound.

Additional considerations are necessary if achievement of $V(U_k/W,m_j)$ is dependent on development of the fishery's ability to apply W or U_k. For example, a policy may be selected which requires expansion in a fishery, but since fishery development is also influenced by the decisions of commercial industry, it does not follow that expansion will in fact occur. Examination of learning period regimes which reduce revenue from one style of exploitation to allow development of another style must include consideration of how observations of the success or failure of the new style to develop will alter perceptions of the possibility that it will ever develop. These altered perceptions affect the 'apparent value' of each U_k, and will influence how long the opportunity to expand continues to be made available to a fishery which shows no sign of expansion. While this could be examined from a detailed economic model of fishery development, *ad hoc* examination of the effects of this uncertainty can be achieved by including in the calculations the values of successful and failed development, an estimate of the probability presently placed on successful development, and modelling the way this probability alters as attempted development is observed. The values are represented by introduction of a subscript for success and failure of the regimes attempted, so that a failed attempt at application of U_k after a failed W gives value $V({}_fU_k/{}_fW,m_j)$ while successful development of U_k and W gives $V({}_sU_k/{}_sW,m_j)$. The perception that any regime (W or any of the U_k) will be successful is represented here by a single probability, which is assessed as being s_T at time T and alters during the learning period according to whether W is observed to develop successfully or not. It is assumed that s_T alters to $s_{T+t}=s_T\psi^t$ after t years of observed unsuccessful attempted development and to $s_{T+t}=1-\psi^t(1-s_T)$ after t years of observed successful development, where ψ is an arbitrary constant $(0<\psi<1)$ reflecting how quickly s changes with years of observation of attempted fishery development. As indicated, alteration of s_T when success is observed need not follow the same model as when failure is observed. With these additional considerations, the 'apparent value' maximized by the manager in the selection of a U_k at time $T+t$ is

Table 14.3 The annual net value (millions of dollars) to Australia implied by one parameterization of each model under three fishing regimes (U). Models are described in the text. The value obtained if the trap fishery fails to expand is taken to be the value of the present annual catch of 300 tonnes

True model	U_1 Trap fishery (F = 0.1)		U_2 Trap fishery (F = 0.2)		U_3 Pair trawl fishery
	succeeds	fails	succeeds	fails	
1	1.3	0.3	0.1	0.3	0.5
2	1.3	0.3	0.1	0.3	0.5
3	1.7	0.3	3.4	0.3	0.5
4	2.0	0.3	4.0	0.3	0.5

$$AV_{T+t}(U_k/_sW,m_j) = \sum_{i=1}^{i=n} P_{T+t}(m_i/_sW,m_j)[(1-\psi'(1-s_T))A^*(_sU_k/m_i)+\psi'(1-s_T)A^*(_fU_k/m_i)$$

for calculation of $Q_{T+t}(U_k/_sW,m_j)$ after observation of successful development of W during the learning period, and

$$AV_{T+t}(U_k/_fW,m_j) = \Sigma P_{T+T}(m_i/_fW,m_j)[\psi' s_T A^*(_sU_k/m_i)+(1-\psi' s_T)A^*(_fU_k/m_i)]$$

for calculation of $Q_{T+t}(U_k/_fW,m_j)$ after observation of unsuccessful development of W. Consequently the expected value of employing regime W for time t is

$$E[V(W,t)] = \sum_{j=1}^{j=n} P_t(m_j)$$

$$\{s_T \sum_{k=1}^{k=m} Q_{T+t}(U_k/_fW,m_j)[(1-\psi'(1-s_T))V(_sU_k/_sW,m_j)+\psi'(1-s_T)V(_fU_k/_2W,m_j)]$$

$$+ (1-s_T) \sum_{k=1}^{k=m} Q_{T+t}(U_k/_fW,m_j)[\psi' s_T V(_sU_k/_fW,m_j)+(1-\psi' s_T)V(_fU_k/W,m_j)]\}$$

Application to the Northwest Shelf fisheries

Possible management actions during learning periods of up to 20 years were examined across a number of parameterizations of each resource model, giving model/parameterization combinations which were treated as separate models. For brevity, only one parameterization of each model is discussed here.

Three long-term fishing regimes are considered for possible implementation after the learning period: U_1, a trap fishery for *Lethrinus* and *Lutjanus* with a fishing mortality of 0.1 (close to maximum sustainability yield for models 1 and 2; U_2, a trap fishery with fishing mortality of 0.2 (close to maximum sustainable yield for models 3 and 4); and U_3, continuation of trawling at the present trawling effort (and no development of the trap fishery into area presently trawled). The yield to the pair trawl fishery remains about the same under all models and so the annual return from this fishery is taken to be the present annual licensing and access fee of $\$0.5\times10^6$. Vessels in the trap fishery obtain an after-costs value of about $1142 per tonne of retained catch (M. Moran, Western Australian Department of Fisheries, personal communication), and this was used to calculate the annual equilibrium value from the resource under each model and fishing regime (Table 14.3). No consideration was given to 'flow on' effects from U_1 or U_2 in the domestic economy, or to future changes in capture costs and product value. Successful development of the trap fishery provides greatest return under all models (although different levels of fishing mortality are needed), but provides lower returns than the trawl fishery if the trap fishery fails to expand. Consequently revenue from the resource is greatly influenced by successful expansion of the trap fishery. The probability of successful expansion of the trap fishery at present (i.e. s_T) is taken to be 0.5, and empirical modification of this probability is assumed to occur as described above with $\psi=0.8$.

The expected values of four possible management policies involving the various U_k and possible regimes during a learning period were examined. These policies are: W_A, indefinite continuation of U_3 (i.e. no learning period, so $t=0$, and continuation of the *status quo*); W_B, immediate application of the U_k giving greatest expected value, in this case U_1 (i.e. $t=0$ and application of the regime presently considered best); W_C, continued trawling during a learning period of t years, then applying the U_k giving greatest expected value (i.e. learning does not disrupt revenue flow or empirically explore trap fishery expansion); and W_D, a learning period with $t/2$ years of trawl closure followed by $t/2$ years of attempted trap fishing, then applying the U_k giving greatest expected value (i.e. learning disrupts revenue flow but empirically explores trap fishery expansion). W_A and W_{BV} are degenerate cases ($t=0$) and do not involve consideration of further learning, while for W_C and W_D the learning period duration giving the greatest economic benefit is of management interest.

The expected values from the different regimes are given in Table 14.4. Attempting immediate expansion of a low-intensity trap fishery (W_B) with $s_T=0.5$ provides an expected value which is 1.4 times the value of the present trawl fishery (W_A). The expected value of this trap fishery remains greater than that of the trawl fishery for probabilities of successful trap fishery expansion (s_T) greater than 0.14, i.e. the expected revenue from the trawl fishery exceeds that from the trap fishery only if the trap fishery is assessed to have a very low chance (less than 0.14) of successful expansion. The upper and lower bounds to the expected values of W_C and W_D show the range in expected value from the resource possible for different levels of model discrimination obtained during the learning period. The lower bound occurs if no model discrimination occurs as a result of the observations made during the learning period, and in this case W_C and W_D provide lower expected values than W_B for all $t>0$ so that delay in the introduction of W_B is not economically justified. However, if perfect model discrimination results from observations made during the learning period of W_C and W_D, then these policies provide higher expected values than W_B for learning periods

Table 14.4 Bounds for the expected present value (M$) of four management policies involving fishing regimes U_k described in Table 14.3. The bounds arise from observations during a learning period of duration t which is either totally uninformative or perfectly informative in discriminating models of resource dynamics. The policies are: W_A, indefinite continuation of trawling (i.e. U_3); W_B, immediately apply the U_k giving greatest expected value (in this case the U_1); W_C continued trawling during the learning period of t years then apply the U_k giving greatest expected value; and W_D, a learning period with $t/2$ years of trawl closure followed by $t/2$ years of attempted trap fishing, then apply the U_k giving greatest expected value. No revenue is generated during the trawl closure, and a 0.95 discount rate was used throughout

Policy		Expected value	
W_A		10.0	
W_B		14.1	
W_C	t	W_C uninformative	W_C informative
	0	14.1	19.9
	5	12.7	17.1
	10	11.5	14.9
	15	10.7	13.3
	20	10.1	12.0
W_D	t	W_D uninformative	W_D informative
	0	14.1	19.9
	5	13.5	18.6
	10	12.6	18.1
	15	10.9	14.5
	20	9.2	12.1

of up to about 15 years. Since W_C and W_D could provide higher expected returns than W_A or W_B, depending on the model discrimination provided by observations made during the learning period, the model discrimination to be expected from W_C and W_D must be examined in more detail.

The actual discrimination provided by W_C and W_D was determined by simulation of the learning period and the observation process. Examples of the predicted trajectories of one model during a 10-year learning period of policy W_D are shown in Figure 14.3. Simulated time series of research vessel observations (the $O_{W,t}$) were obtained by 'annually' sampling the trajectories, assuming multiplicative log-normal measurement errors such that ±2 standard deviations encompassed the interval 0.67–1.5 times the predicted value. For each management regime the simulated time series were used to estimate the $P_{T+t}(m_i/m_j)$, and from these the U_k giving greatest expected value was selected and used, as before, to obtain $Q_{T+t}(U_k/W,m_j)$. Typical $P_{T+t}(m/m_j)$ resulting from a single simulation of each regime are given in Table 14.5. Observations of continued trawling do not provide good discrimination between models, and with the sampling errors and learning periods examined they frequently lead to an

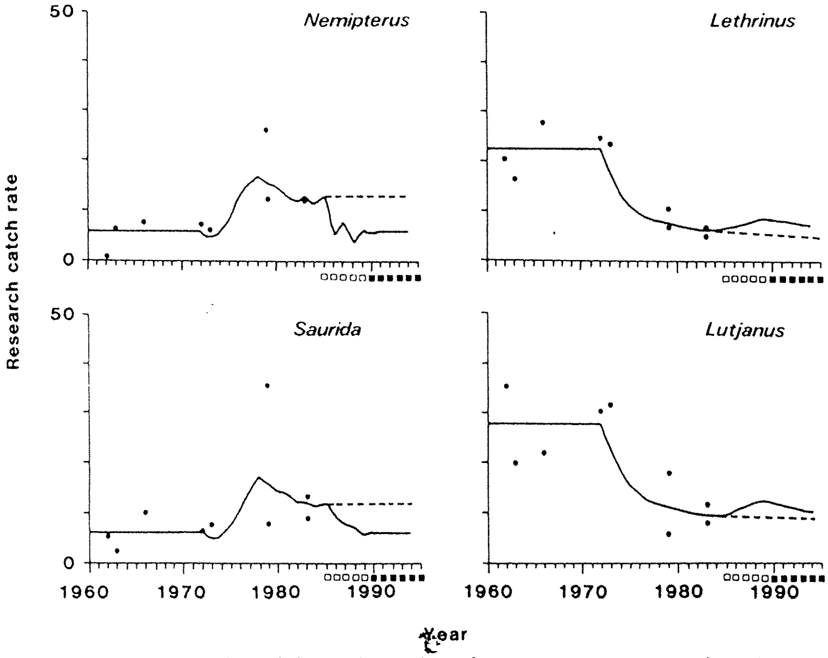

Figure 14.3 Examples of the trajectories of a parameterization of model 1 for each species group under a particular management policy. The observations of actual abundance prior to 1985, to which the model is fitted, are plotted, and the predicted trajectory during a 10-year learning period (marked with squares) is shown. The regime examined divides the Northwest Shelf into two areas, with continued trawling in one area (dotted line) and a 5-year trawl closure (open squares below time axis) followed 5 years of light trap fishing ($F=0.1$, closed squares below time axis) in the other (solid line)

incorrect model being assigned highest probability at time $T+t$. Conversely, observations of a trawl closure followed by a trial trap fishery provide a high probability of detecting each model when true. From many such simulations it was found that the expected value of W_C remains close to the lower bound given in Table 14.4, and so is less than that of W_B for all learning period durations. However, the expected value of W_D is greater than that of W_B for learning periods of between about 7 and 12 years, and a learning period of about 10 years provided the greatest expected value of the regimes examined. W_D with a 10-year learning period has a high chance of leading to U_1 if models 1 or 2 are true and expansion of the trap fishery is possible, to U_2 if models 3 or 4 are true and expansion of the trap fishery is possible, and to U_3 if expansion of the trap fishery is not possible. For learning periods less than about 7 years the limited observations available do not lead to greatly improved management decisions at

Table 14.5 The conditional probabilities placed on model *i* when model *j* is true at the end of the learning period, calculated from one simulated time series under each of two management regimes: (a) continued trawling for 10 years and (b) trawl closure for 5 years followed by a low-intensity ($F = 0.1$) trap fishery for 5 years

(a)	*i*	*j*			
		1	2	3	4
	1	0.49	0.01	0.81	10^{-10}
	2	10^{-3}	0.13	10^{-16}	0.02
	3	0.51	0.59	0.19	10^{-9}
	4	10^{-12}	0.25	10^{-19}	0.98

(b)	*i*	*j*			
		1	2	3	4
	1	0.99	10^{-24}	0.06	0
	2	10^{-19}	1.0	10^{-26}	10^{-8}
	3	0.01	0	0.94	0
	4	0	10^{-4}	0	1.0

the end of the period, and so the revenue foregone during the learning period exceeds the economic value of the model discrimination obtained. Learning periods longer than about 12 years provide good model discrimination and usually lead to selection of the most appropriate management choice at the end of the period, but the revenue foregone during the learning period exceeds the economic gain from making the correct choice.

The implications of a number of possible management regimes during the learning period were examined in this way. Partly on the basis of this the management agencies for the Northwest Shelf (the Western Australian Department of Fisheries and the Commonwealth Department of Primary Industry) have introduced a management regime based on dividing the Northwest Shelf into three zones (Figure 14.4). The western zone was closed to pair trawling in October 1985, the middle zone was closed to pair trawling in October 1987, and the eastern zone will remain open to pair trawling. It is anticipated that trap fishery expansion will be attempted in the two western areas after they have been closed to trawling for about 5 years.

DISCUSSION

Ecological theory provides a number of concepts which may be used to interpret a given set of observations. Many of these interpretations imply very different longer-term dynamics, none is universally accepted (indeed many authors

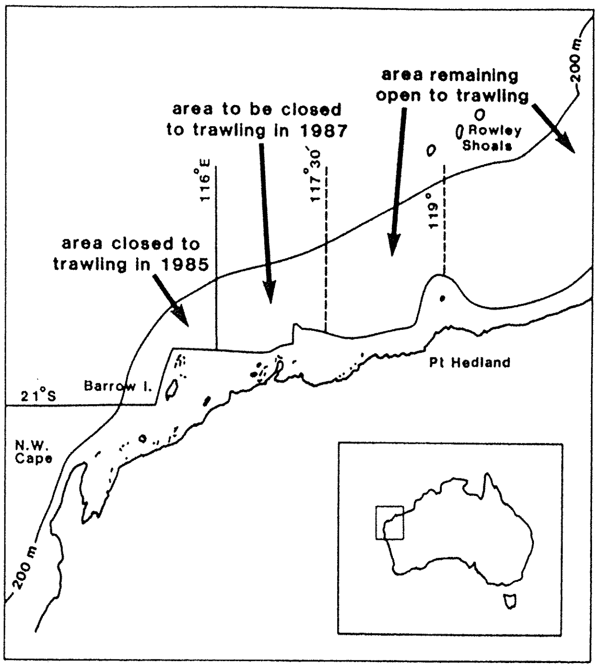

Figure 14.4 The fishery management zones being used in the present alteration of the fishing regime on the Northwest Shelf

emphasize the different mechanisms may dominate the behaviour of different communities), and parameterization even of simple models of part of a community is often prohibitively difficult. Consequently fisheries management of communities is conducted with considerable uncertainty about resource dynamics, and is largely empirical (even if this is not explicitly recognized). Under these circumstances it is highly desirable to evaluate the implications of recognized uncertainties to proposed management actions, and to introduce new management measures in such a way as to provide information which will be of management value in future. The extent to which short-term revenue should be compromised to gain information about resource dynamics will depend on both social acceptability and the value of the information in leading to higher revenue in the long term.

The methodology described by Walters and Hilborn (1976, 1978), Hilborn (1979) and Walters (1986) for management of resources with poorly known dynamics arose from consideration of environmental management problems (Holling, 1978), and is well suited to some of the problems of multispecies fishery management. The approach leads naturally to formulation of resource models reflecting different ecological interpretations and assumptions, to examination of the value of distinguishing these hypotheses, and to the search for management policies that are both economically acceptable and robust across the resource dynamics implied by the hypotheses.

The analysis of the Northwest Shelf fishery used very simple economics, ecologically highly simplified resource models, and a very abbreviated method of relating these to a management decision. There is a clear need to improve the treatment of each of these elements as additional information becomes available. An obvious limitation is the small number of models examined, and the assumption that the actual dynamics of the community might be approximately described by one of them. In particular, all of the models examined imply that the resource recovers smoothly after perturbation, whereas some ecological and fisheries observations suggest that community structure may persist in the perturbed state for a time and recover in a series of abrupt changes. To some extent this limitation could be reduced by consideration of more models, but it cannot be eliminated. The implications to management of some uncertainties about resource dynamics and simple forms of learning (i.e. discrimination between previously identified alternatives) can be examined, but the overall approach remains firmly empirical and the analysis is to help guide empirical exploration of the resource dynamics. However, this analysis provided a very useful framework for examination of different management actions for the Northwest Shelf fisheries.

The Northwest Shelf analysis led to the introduction of area closures in the fishery. Although closure of large areas may not be possible in all fisheries, they have proved useful in management of resource recovery, resource usage conflicts and age at first capture in a number of fisheries (e.g. Garcia and Demetropoulos, 1986; Seager, 1981). Where closures are possible, analyses of the sort applied to the Northwest Shelf fisheries could help determine the values of different closure policies, particularly if uncertainty about resource dynamics is an important consideration. The methodology is not limited to examination of closures, of course. When any change in management regime is proposed it may be quite rewarding to examine the implications of different ways of introducing the change across alternative resource models (or alternative parameterizations of the same model). Small differences in the method of implementation can sometimes provide surprisingly different economic returns and insights into resource dynamics.

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ABSTRACT

BYCATCH IN TORRES STRAIT

IAN POINER
Commonwealth Scientific & Industrial Research Organisation

Data for this study has come from research into the possible effects of trawling on traditional fisheries in the Torres Strait.

Bycatch composition from surveys has been related to that caught by commercial trawling prawn operations using log books to extrapolate for efficiency of trawl operations.

Little annual variation (between 1985 and 1986) in the overall composition (in terms of average weight of taxa per trawl) was noted (see Tables 1 and 2).

The ratio of bycatch to target species was about 6-7:1. Bycatch was dominated by teleosts, which accounted for over 50% of the total by weight. For the teleosts, around 8 families accounted for over 60% of the total (see Table 3).

Large animals eg sharkes are underestimated in the bycatch.

Currently work is in progress comparing prawn trawling with fish trawling.

Torres Strait Penaeid Prawn Fishery
(Commercial catch composition)

Percentage composition (wt) of the main (>1% of the bycatch in 1985 or 1986) fish Families (Teleost and Elasmobranch).

Taxa	1985 %	1986 %
DASYATIDAE	0.77	3.38
LEIOGNATHIDAE	0.99	1.78
GOBIIDAE	1.31	2.94
PLOTOSIDAE	1.53	0.40
SCORPAENIDAE	1.83	0.82
SERRANIDAE	1.85	1.15
APOGONIDAE	2.32	4.78
DACTYLOPTERIDAE	2.34	1.00
CARANGIDAE	2.45	2.79
LABRIDAE	2.87	3.85
MULLIDAE	3.50	3.36
CALLIONIMIDAE	3.75	2.49
TETRAODONTIDAE	4.20	3.24
NEMIPTERIDAE/SCOLOPSIDAE	4.66	5.41
PLATYCEPHALIDAE	5.24	3.71
BOTHIDAE	5.39	5.75
PRIACANTHIDAE	6.27	10.08
BALISTIDAE/MONACANTHIDAE	11.63	3.43
SYNODONTIDAE	13.33	12.60
NEMIPTERIDAE	14.03	16.14

Torres Strait Penaeid Prawn Fishery
(Commercial catch composition)

Taxa	1985 %	1986 %
SPONGE	- *	0.04
SQUID	0.10	0.17
OCTOPUS	0.29	0.23
SNAKE	0.05	0.24
TURTLES	2.34	0.28
SHARKS	0.39	0.50
SEPIA	0.93	1.35
BUGS	0.63 *	1.66
RAYS	0.92	2.02
SCALLOPS	0.04 *	2.99
NON COMM.PRAWNS	0.98 *	3.72
LOBSTERS	0.09	4.75
TRASH	10.71	4.97
CRABS	0.09 *	7.73
PRAWNS COMM.	13.64	16.70
TELEOSTS	68.79	52.26
avg wt (/30 min trawl)	75.89 kg	65.21 kg
no of trawls	43x4	34x3
Total prawn catch **	1100-1200t	900-1000t
Total bycatch	8798t	5988t
Teleost portion	6052t	3129t

(* underestimated 1985)
(** estimated from transfer certificates, TS catch reporting and NPF logbooks)

Torres Strait Penaeid Prawn Fishery
(Survey catch composition)

Taxa	1985 %	1986 %
SQUID	0.11	0.15
OCTOPUS	0.30	0.20
SNAKE	0.11	0.37
SPONGE	-	0.40
SHARKS	1.27	0.44
SEPIA	1.38	1.35
BUGS	1.78	1.87
TURTLES	1.33	2.06
RAYS	2.28	2.14
NON COMM.PRAWNS	2.59	3.30
SCALLOPS	0.80	3.46
LOBSTERS	0.11	4.17
TRASH	9.92 *	4.81
CRABS	0.11	7.30
PRAWNS COMM.	12.67	13.30
TELEOSTS	64.71	54.71
avg wt (/30 min trawl)	59.85 kg	66.65 kg
no of trawls	43X4	34X3

(* includes the sponge catch)

ABSTRACT

BYCATCH STUDIES IN THE GREAT BARRIER REEF

R. A. WATSON
Queensland Department of Primary Industries

Presented a summary of five bycatch studies in the GBR Region and P.N.G. Table 1 compares and summarises these studies. More detail is provided in Table 2.

Conclusions that could be drawn from these studies included:

* Knowledge of bycatch is imperfect with very few temporal or spatial replicates being considered;

* There are a number of taxonomic problems;

* Generally, large fish and benthos (corals and sponges) were excluded;

* The studies were often not the primary purpose of the research;

* Sampling is selective, and is of dubious value in considering community structures;

* The experimental design and analytical techniques could be considered largely qualitative.

The question was raised as to whether alternative gear types had been used. Some had, but usually using alternative net or mesh sizes in prawn trawls. Gear designed for fish trawling had not been used.

The question of sampling was raised with regard to the randomness of sites chosen to be trawled. A good deal of the work had in fact taken place in known trawl areas.

WORKSHOP DISCUSSION OF PAPER

Ensuing discussion focussed on bycatch composition changes as a result of distance from reefs. Generally it had been found that reefal communities have very distinct boundaries to their habitat and these were found to be close to the reef edge.

Deepwater patches of corals and sponges (flowerpots) with reefal communities occur in untrawled ground ie Swains. Trawling may have significant effects on these phenomena. It was noted that many such areas had been destroyed in areas of heavy trawling. Such areas have communities of lethrinid fishes.

The comment was more than even some previously untrawled areas eg in Swains lookedl like heavily trawled areas.

Other comments made included the availability of data from logbooks. Various reasons were given, and it was felt that it was of paramount importance to maintain the fishermen's confidence in the program.

watson

TITLE:
Trawl fishes of the Gulf of Papua

WHERE:
Central Gulf of Papua, PNG

WHO:
Kailola, P.J. Then P.N.G. D.P.I
Wilson, M.A.

WHEN:
1960 - 1969

SAMPLING STRATEGY:
Surveys since 1955 (Rapson) 1,932 trawls and subsequent commercial trawling to 1969
Tagula and Climacs (later 311 trawls) voyages 1960-68
Most trawls included were Dec-April
Daytime and night-time (?) trawls

SUBSAMPLING STRATEGY:
Unreported, probably variable

SAMPLE PROCESSING:
Likely some samples assessed in field, specimens returned to laboratory for identification

TYPE OF ANALYSIS:
Percentage occurrence
Simple dominance and ranking

GENERAL RESULTS:
Percentage occurrence of fish Families in trawls
Dominance of Families (weight) by depth zone and area
Indicator species (species correlated with good and poor prawn catches)
Checklist and Taxonomic keys
Data on currents and water temperature

PROBLEMS & ASSUMPTIONS:
Varied methodology (?)
Only fish included
Few winter samples

PUBLICATIONS:
Kailola, P.J. and Wilson, M.A. 1978. The trawl fishes of the Gulf of Papua. Dept Primary Indust. P.N.G. Research Bulletin No. 20. 85pp.

PRESENT STATUS OF DATA:
Unknown - maybe with P.N.G. or Kailola
Museum specimens

TITLE:
Trawl fish composition and harvest estimates for the Gulf of Papua

WHERE:
Central Gulf of Papua, PNG

WHO:
Watson, R.A. then P.N.G. D.P.I.

WHEN:
June and September, 1983

SAMPLING STRATEGY:
Two two-week cruises on commercial prawn trawlers
Mostly daytime trawls
75 Trawls sampled

SUBSAMPLING STRATEGY:
Random two shovelfuls from combined twin net catch
Subsample about 2-3 kg
Some species studied by collecting all specimens from trawl

SAMPLE PROCESSING:
On board identification, weights and lengths
Some sexed, no aging done
No stomach contents done

TYPE OF ANALYSIS:
Ratio of prawn catch in subsample to total prawn catch used to estimate total weights of other groups
Simple proportions, percentage occurrence, ranking, t-tests

GENERAL RESULTS:
Occurrence in trawl by Family
Ranking by number of individuals by Family
Fish to prawn ratio
Families by weight in sample
Families by CPUE
Total catch estimates
Spatial and seasonal differences

PROBLEMS & ASSUMPTIONS:
Only 2 cruises with relatively small samples
Extreme extrapolations necessary to estimate total weights
Only some work at species level
No work in summer when previous study done (Kailola and Wilson, 1978)
Narrow range of depths and distance off-shore
Environment different than Torres Strait or GBR

PUBLICATIONS:
Watson, R.A. 1984. Trawl fish composition and harvest estimates for the Gulf of Papua, PNG Fisheries Research & Surveys Branch, Dept Primary Indust. 84-01 25pp.

PRESENT STATUS OF DATA:
Most data somewhere in Kanudi, PNG
Some data with author
Generally not available

TITLE:
Community patterns revealed by trawling in the inter-reef regions of the GBR

WHERE:
Qld coast, a lot of samples in Cairns and Rockhampton area

WHO:
Cannon, L.R.G. - Queensland Museum
Goeden, G.B. - previously QDPI
Campbell, P. - Univ. Queensland

WHEN:
Sept 1979 - May 1982

SAMPLING STRATEGY:
Series of seven trawls with differing strategies
Mostly from resource exploration night-time trawls
229 sites

SUBSAMPLING STRATEGY:
Differing, not described

SAMPLE PROCESSING:
Frozen in bulk, transported to laboratory, thawed, preserved, sorted to Phylum, transported to Museum for identification

TYPE OF ANALYSIS:
Two trawl series analyzed, one only for presence/absence
the other for log transformed frequencies
Ordination and cluster analysis (Canberra metric / flexible sorting strategy) using TAXON (CSIRO)
Cramer measures

GENERAL RESULTS:
Site assemblages at Family and Genus levels
Fish also at species level
Related to carbonate levels in sediment

PROBLEMS & ASSUMPTIONS:
Large variety of methods and areas prevented use of whole data set

PUBLICATIONS:
Cannon, L.R.G., Goeden, G.B. and Campbell, P. 1987. Community patterns revealed by trawling in the inter-reef regions of the Great Barrier Reef. Mem. Qld Mus. 25(1): 45-70.

PRESENT STATUS OF DATA:
Original data presented in appendix, no longer on computer

TITLE:
Bycatch of the Central Queensland prawn fishery

WHERE:
Townsville area

WHO:
Dredge, M.C.L., QDPI
Watson, R.A., QDPI
Jones, C., QDPI
Derbyshire, K., QDPI
Goeden, G. formerly QDPI

WHEN:
Jan 85 - Dec 86

SAMPLING STRATEGY:
Monthly trawls at fixed sites: 8 sites for 24 months, 16 for 12 months either 1985 or 1986
Sites on trawling grounds in transects between coast and GBR or from near-reef to off-reef
one net with commercial-size mesh, one with smaller
Trawls at night, at or around the new moon

SUBSAMPLING STRATEGY:
Approx. 10kg random subsample from commercial mesh net
Extremely large taxa excluded
Sponges and corals not included
New taxa from smaller-meshed net also retained

SAMPLE PROCESSING:
Samples frozen, identified to species in laboratory or forwarded to Qld Museum etc
No sexing, aging or stomachs done

TYPE OF ANALYSIS:
Initial frequency analysis with SPSS
Species occurring in <5% of samples (in 1985) or with doubtful species identification were excluded from further analysis
Log transformed abundances of species used in first year's analysis to calculate
Bray-Curtis measures with were used in Cluster analysis (CLUSTAN) with Ward's method
Site assemblages were characterized by species using F-tests and Cramer indexes
Analysis of two years data used Bray-Curtis measures with flexible sorting (TAXON)
Runs test were done on weight and species richness for seasonal trends
2-way ANOVA of site and season affects

GENERAL RESULTS:
Species list by abundance and stations
Comparison with Russell's (1983) list of reef species
Correlation of site assemblages with sediment type (grain size and carbonate content), water depth and proximity to reefs
Effects of site and season
Annual species abundance variation
Site assemblages characterized by obviously missing species and unexpectedly abundant species

PROBLEMS & ASSUMPTIONS:
Lack of replication of samples at sites at time of sampling
Change of all but eight sites during second year of study
Limitation of sampling gear to reflect entire fauna
Inability to include sponges, coral and larger specimens of fish

PUBLICATIONS:

Reports:

Dredge, M.L.C. 1988. Bycatch from the Central Queensland prawn fisheries, Part 1: The prawn fisheries and their by-catch composition in terms of species and community assemblages. Qld Fisheries Research Branch Technical Report #4. (Report by QDPI to GBRMPA) 23+16pp.

Dredge, M.L.C. Bycatch from the Central Queensland prawn fisheries, Part 2: Changes in bycatch composition and community assemblages I. seasonal and year to year changes, II. as a function of proximity to coral reefs. Qld Fisheries Research Branch Technical Report (Report by QDPI to GBRMPA) (In Prep.)

Papers:

Jones, C.M. and K. Derbyshire. 1988. Sampling the demersal fauna from a commercial prawn fishery off the central Queensland coast. Mem. Qd Mus. 25(2): 403-415.

Watson, R. and G. Goeden. 1989. Spatial zonation of the demersal trawl fauna of the Great Barrier Reef. Mem. Qd. Mus. (In Press).

Watson, R. and Dredge, M.L.C. (second year of data) (In Prep)

PRESENT STATUS OF DATA:
Most still in use, maybe available later

TITLE:
Incidence of juvenile redfish in commercial prawn trawl bycatch

WHERE:
Cairns area

WHO:
Jones, C., QDPI
Goeden, G., formerly QDPI

WHEN:
1980-84

SAMPLING STRATEGY:
Night-time trawls
Catch data from 8 trawlers Hinchinbrook to Torres Strait, 1980-83
Four research surveys near Cairns, May-August 1984
Research data collected from commercial trawlers
Research survey, trawls 30min duration, twin 6-fathom nets, all reef species separated

SUBSAMPLING STRATEGY:
All "reef fish" removed from catch
2-3 kg subsample of catch taken

SAMPLE PROCESSING:
All individuals of "reef fish" or all animals in subsample from identified (to species), counted and weighted at laboratory

TYPE OF ANALYSIS:
Percentage, size-frequency, t-tests, CPUE

GENERAL RESULTS:
Main "reef fish" species identified and their abundance and significance estimated
Size-frequency of these species
Seasonality in catch of these
CPUE of these

PROBLEMS & ASSUMPTIONS:
Few samples to represent such a large time and space regime

PUBLICATIONS:
Jones, C. and G. Goeden. 1985. Report to the Great Barrier Reef Marine Park Authority on the incidence of juvenile Redfish species in commercial prawn trawl bycatch. Qld Dept Primary Indust. Mimeo. 8+pp

PRESENT STATUS OF DATA:
Data with C. Jones, possibly available

ABSTRACT

SPATIAL AND SEASONAL EFFECTS ON DEMERSAL FAUNA ASSOCIATED WITH A PRAWN FISHERY ON THE GREAT BARRIER REEF

R.A. WATSON M.C.L. DREDGE
Queensland Department of Primary Industries

The composition of demersal fauna trawled from fixed sites altered between samples taken in 1985 and those in 1986. The percentage of individuals in Crustacea increased in 1986 while the percentage in Osteichthyes and Echinoidea decreased.

Seasonal patterns were observed in the benthic community and these were greatly influenced by changes in the abundance of a few relatively abundant species such as *Maretia planulata*. Seasonal effects were much weaker than spacial effects. Fauna from coastal sites was consistently different than that from lagoonal and inter-reefal sites. Fauna from previously unfished sites immediately adjacent to reefs differed from that previously described on reefs but was not dissimilar to other inter-reef sites.

The use of indicator species chosen for their sensitivity, value or seasonal stability may overcome many difficulties associated with whole community studies.

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ABSTRACT

THE FATE OF DISCARDS FROM TRAWLERS IN A TROPICAL PRAWN FISHERY IN THE TORRES STRAIT

B.J. HILL and T.J. WASSENBERG
CSIRO Division of Fisheries, PO Box 120, Cleveland 4163

The fate of fish, crustaceans and cephalopods discarded from prawn trawlers in the Torres Strait between Australia and Papua New Guinea was investigated. These groups make up about 80% of the discards by weight, have a high mortality rate and are therefore the most likely animals to be eaten by scavengers. The remaining 20% of discards consists of animals like turtles, sharks, bivalves and sponges which are caught in low numbers and appear to have low mortality from trawling. Teleosts fish make up 78% of the discards, non-commercial crustaceans 18% and cephalopods 3%. Nearly all fish are dead when discarded and about half of these sink. About half the non-commercial crustaceans were alive when discarded and all sank. Only 2% of cephalopods are alive when discarded and around 75% sink. Altogether about 40% of the material floats when discarded. Most of the discards that floated were scavenged by sharks and dolphins. Birds (Common and Crested Terns, and Lesser and Greater Frigates) scavenged only during the day but about a quarter of discards are dumped in daylight. There was little scavenging in midwater but the fast rate at which animals sank (less than 5 min to reach 25 m), meant that discards spent little time in the water column. Nemipterids and sharks ate most of the material that reached the bottom, scavenging by intertebrates was negligible.

In an adjacent area that had not been trawled for 8 years, no dolphins and fewer birds were seen scavenging discards on the surface, but there were more sharks at night. On the bottom, fewer fish were attracted to discards. The cause of these differences is not known, while it may reflect learned behaviour by some scavengers such as birds and dolphins, there may also be intrinsic differences between the two areas unrelated to trawling.

Discarding from trawlers transfers large quantities of biological material from the bottom to the surface and makes food that would otherwise be inaccessible, available to surface scavengers.

ABSTRACT

EPIBENTHOS

IAN POINER
Commonwealth Scientific & Industrial Research Organisation

This paper presented a preliminary analysis of studies started in September 1988 in which a comparison was made of trawled and untrawled areas in Torres Strait (see Map 1). Sites were surveyed in an area that had never been heavily trawled and is now closed to trawling as well as sites that are, and have been, both lightly and heavily trawled for tiger and banana prawns. Sampling was done using dredges in combination with video techniques.

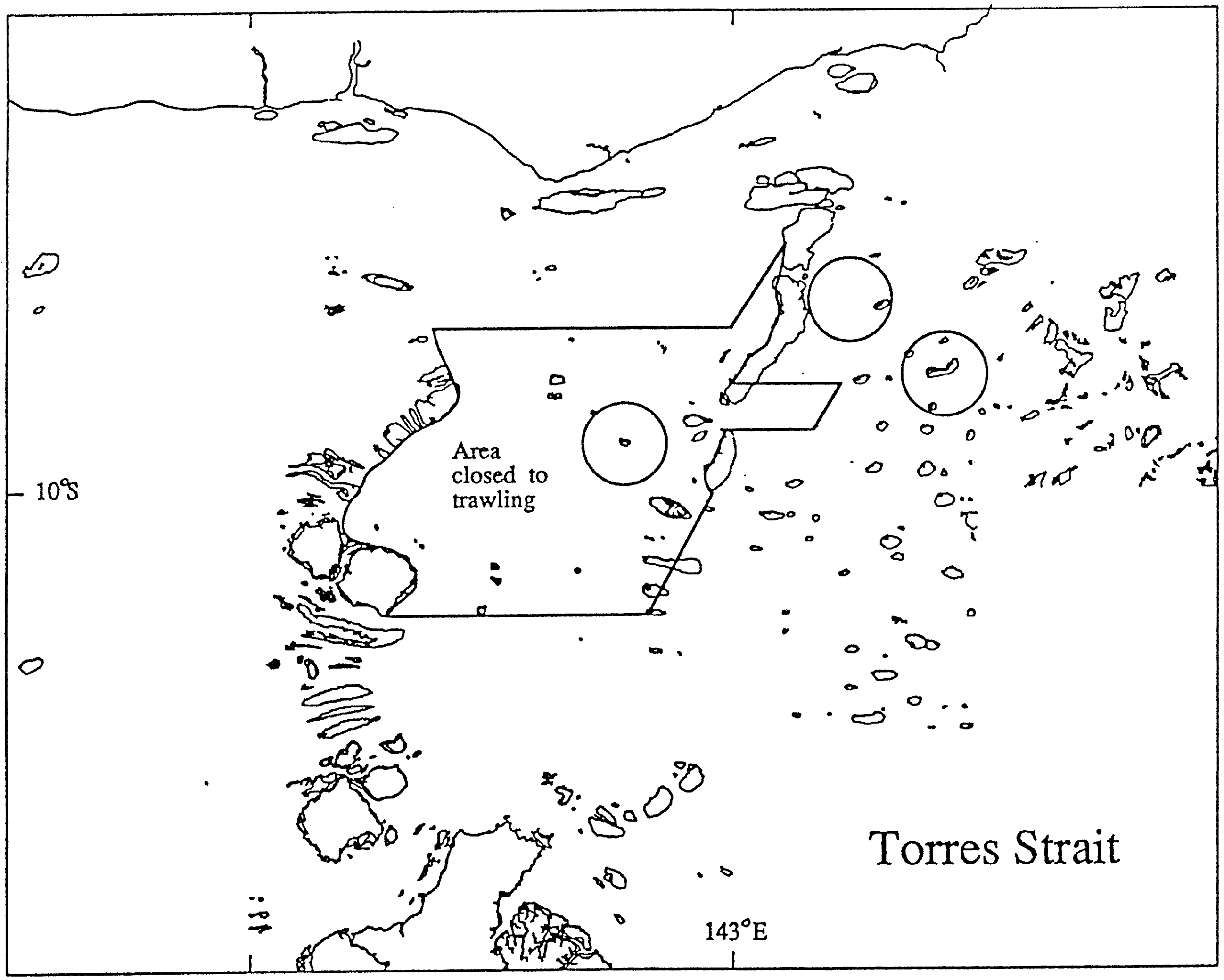
Marked qualitative and quantitative differences were apparent (see Figures 1 and 2).

Closed areas supported around five times the biomass of epibenthic organisms, and there was a significant difference in the taxonomic composition between closed and trawled areas. Trawled areas had sponges only, while untrawled areas supported much more diverse communities (Table 1).

It was noted that there existed a sharp demarcation between reefal and inter-reefal communities.

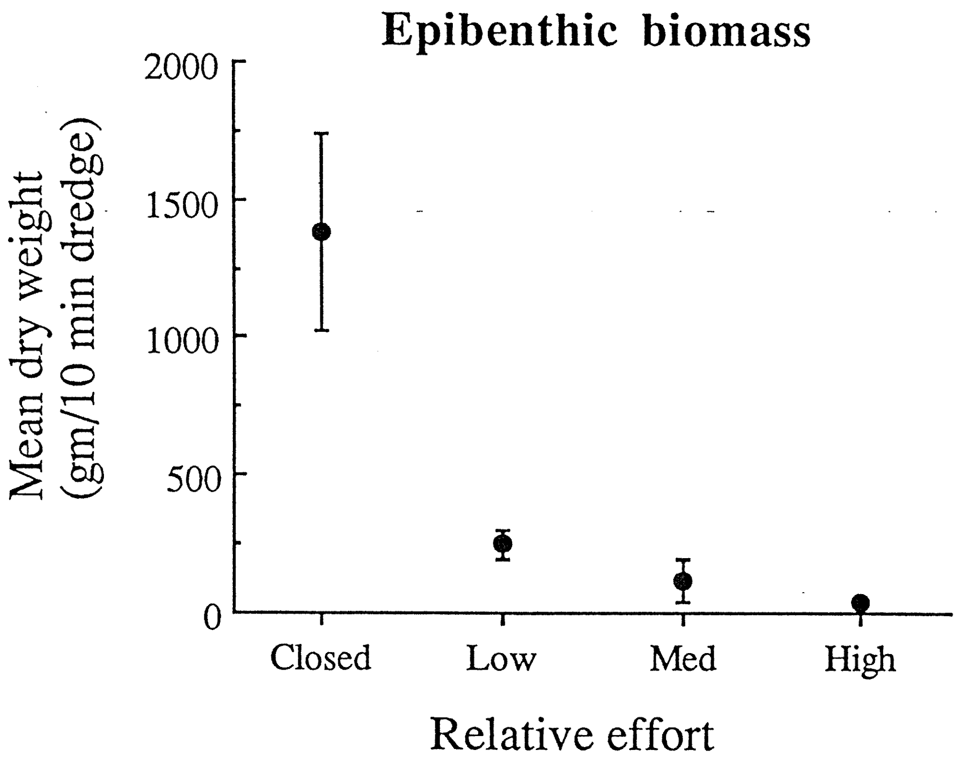
WORKSHOP DISCUSSION OF PAPER

Discussion revolved around the confidence in being able to ascribe the observed differences to trawling alone (as opposed to natural variation between locations on opposite sides of the Warrior Reefs). It was pointed out there was no difference in sediment patterns between east and west, however echinoderm studies have shown major geographic differences in the same region.



MAP 1

Figures 1



Epibenthic biomass
Mean dry weight
(gm/10 min dredge)
2000
1500
1000
500
0
Closed
Low
Med
High
Relative effort

Epibenthic biomass

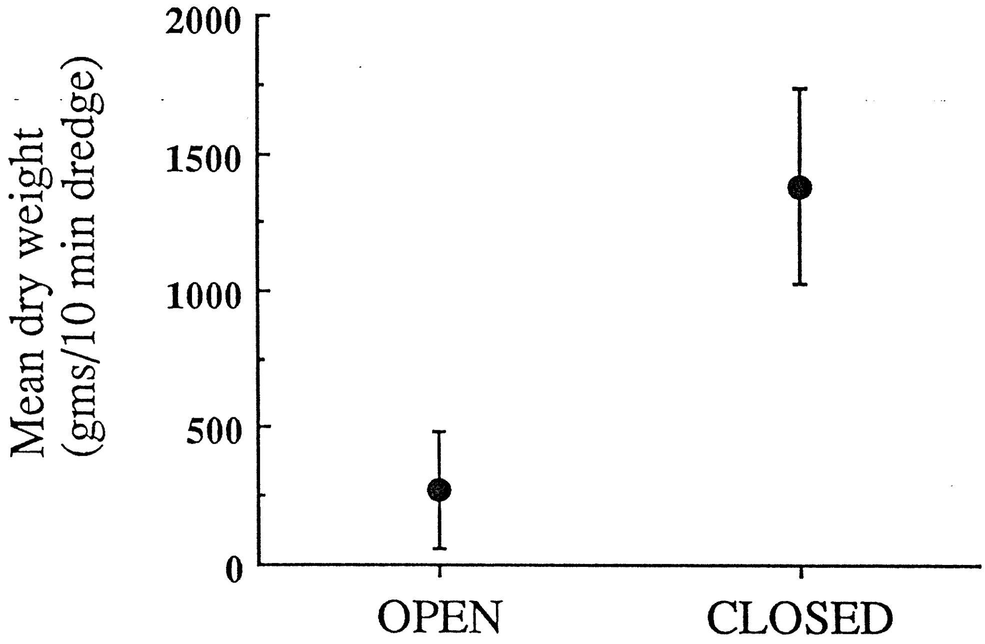


TABLE 1

Torres Strait Sedentary Epibenthos

Group	Closed	Open
Sponges	•	•
Seagrass	•	
Halophila ovalis		
Halophila spinulosa		
Halophila decipens		
Cymodocea serrulata		
Algae	•	
Caulerpa spp		
Halimeda spp		
Udotea spp		
Bryozoans	•	
Ascidians	•	
Pennatulacea	•	
sea pens		
Octocorallians	•	
sea whips		
sea fans		
gorgonians		
Hydroids	•	

ABSTRACT

SOFT SEDIMENT EPIBENTHOS OF THE CENTRAL GBR SHELF

P.W. ARNOLD AND R.A. BIRTLES
Queensland Museum and Private Consultant

An overview of a long term (10 year) study on soft sediment epibenthos on the central GBR shelf was given with a summary of some results on the sessile epibenthos.

For both sessile and mobile epibenthos, there was a sharp division at about 22m depth into inner and middle shelf zones. This was consistent for all phyla examined and stable throughout the sampling period. The inter-reef area, seaward of the middle shelf, appears to have a distinct fauna. Samples have not been fully analysed but the transition from middle shelf to inter-reef fauna does not appear to be as sharp as that between inner and middle shelf zones.

The inner shelf sites had fine sediment subject to regular but unpredictable resuspension by wave action. Sessile species characteristic of (but not necessarily restricted to) the inner shelf showed various morphological specializations for life on soft unstable sediment and an independence from settlement on hard substratum.

The middle shelf sites had mixed sediments, with an important carbonate component; the physical environment is more stable. Species characteristic of the middle shelf often stopped abruptly at the transition depth to the inner shelf zone. Biological attributes of this fauna included larger size range and, especially for sessile forms, carbonate production leading to formation of poly-specific biogenic rubble. Biogenic rubble was utilised by single species or groups of species forming multi-species clumps, building up natural isolates - stable substratum produced by living organisms. These acted as settlement surfaces for other organisms, especially acrophilic suspension feeders and browsers on sessile biota. Natural isolates were particularly characteristic of the shallow middle shelf.

The primary separation of fauna reflects differences in sediment type and degree of physical disturbance. Biological interactions may, however, be important (eg habitats provided by seagrass beds on inner shelf, natural isolates on middle shelf).

The occurrence of inner shelf and middle shelf faunas, in environments differing in the degree of physical disturbance, suggests that the component species may react differently to man - made disturbance, eg trawling.

Sessile epibenthos, lacking the option to move from suboptimal conditions, may better reflect environmental changes. They also are part of the habitat of mobile benthos and, especially on the middle shelf, may create important settlement surfaces and habitat.

The predominantly colonial taxa which form stable substrate on the shelf (algae, foraminiferans, sponges, cnidarians, bryozoans, solitary ascidians) may have quite distinct biological attributes in comparison with the mobile, solitary forms. For example, there is some evidence that larval life of colonial taxa may be significantly shorter than in the classic examples of of fishes, echinoderms, crustaceans, molluscs. This potential limit to dispersal is necessary to consider in assessing ability of sessile epibenthos to regenerate after disturbance.

abst-arnoldand birtles

TEMPORAL PATTERNS IN SHELF ECHINODERMS AND SOME THOUGHTS ON THE ROLE OF DISTURBANCE IN STRUCTURING SHELF COMMUNITIES

R.A. BIRTLES and P.W. ARNOLD

This presentation focussed on aspects of the biology and ecology (including distribution, abundance and size frequency distributions) of the echinoderms from three years of a ten year data set (1977-1986) of epibenthos from the central GBR shelf.

Echinoderms are a species rich component of the benthos demonstrating a wide range of morphologies, trophic groups and life histories and thus provide a good subset of the overall data. They were the most abundant group in the samples.

The 256 samples (from 1979-1981) contained 155 species and over 30,000 individuals which were numerically dominated by deposit feeders.

Although a few species were ubiquitous, distinct cross-shelf assemblages were apparent. The inner shelf was characterised by low diversity, low evenness and small size of echinoderms. The middle shelf region was separated into two areas - the shallow, coralligenous middle shelf and the deep middle shelf. The former was characterised by high diversity, high evenness and large organisms; the latter by lower diversity and lower evenness.

Key points of the study included:

* The overall spatial pattern (in terms of site classification and species richness as described above) persisted through time.

* There were substantial temporal changes in abundance of individual species and hence in certain community structure indices, e.g. diversity and evenness.

* Deposit feeders were numerically dominant in inner and deep middle-shelf areas where trawling is largely concentrated.

* The life history strategies of several deposit feeders show a variety of adaptations to disturbed/stressful environments (e.g. rapid growth, early maturity and short lifespan).

* The middle shelf coralligenous assemblage (natural isolates supporting a diverse community) included relatively long-lived organisms likely to be vulnerable to disturbance such as trawling.

* The patterns are generally consistent with the larval availability model, but restriction of many species to the coralligenous assemblage over the sampling period with several recruitment episodes raises the possibility of

larval adaptations favouring retention and/or heavy early post-settlement mortality.

Analysis of the full 10 years of data would provide information on natural variability with time.

Points were made about the levels of physical and biological disturbance across the shelf. It was high on the inner shelf (with the fauna showing many biological adaptations to this physically rigorous environment) and periodic (due to cyclones) on the middle shelf. The temporal scale of these was compared with that from trawling.

Other aspects of the benthic community were that:-

* Infauna appeared to show different cross shelf patterns to the epifauna, with no decrease in diversity inshore.

* The small size of macroinfauna and abundance of microbes and meiofauna are evidence of a pioneering benthic community in several shelf localities.

Discussion

Although mechanisms had been suggested for the observed distribution and abundance patterns, some of the size frequency data of species such as Laganum depressum was open to a variety of interpretations because of the plasticity of echinoderm growth and reproduction. Analysis of the material from other years was likely to lead to clarification of the recruitment patterns of several of the more abundant species.

Lower diversity on the deep middle shelf correlated with trawl grounds for king prawns. Analysis of the 1977 and 1978 samples (pre-dating expansion of the fishery) could clarify whether changes had occurred.

Extrapolation from particular types of small scale sampling gear (eg grabs) to broad scales was noted as a major problem.

The sledge data, collected on a grid system across the shelf, gave valuable information on spatial (as well as temporal) scale of recruitment episodes.

No data on the mortality of echinoderms caught as trawler bycatch was available, but it was thought to be high.

The potential effects of cyclones on epibenthic communities was raised. It was noted that the observed effects were largely unpredictable, with very little correlation between the strength of cyclones and their effects.

ab/pa

from Proc. 6th Int. Coral Reef Symp. (1989)

DISTRIBUTION OF TROPHIC GROUPS OF EPIFAUNAL ECHINODERMS AND MOLLUSCS IN THE SOFT SEDIMENT AREAS OF THE CENTRAL GREAT BARRIER REEF SHELF

R.A. BIRTLES[1] and P.W. ARNOLD[2]

[1]Dept. Marine Biology, James Cook University, Townsville Qd 4811
[2]Queensland Museum:North Queensland Branch, Townsville Qd 4810

ABSTRACT

Echinoderms (103 species, 2235 individuals) were the most abundant, and molluscs (196 species, 1992 individuals) the most diverse epifaunal taxa at four intensively sampled sites located on a transect across the soft sediment areas of the GBR shelf off Townsville. An inner site (depth 22 m) separated clearly from more offshore sites (depth 26-41 m) based on species of both molluscs and echinoderms. Community structure was similar with highest species richness and species diversity at offshore sites.

Proportional species richness and abundance in trophic categories showed substantial differences between sites for both echinoderms and molluscs, although the separation between inner and middle shelf sites was not always consistent between the two taxa. The same sharply defined pattern was evident for both taxa in a general browser category. High diversity and abundance were correlated with the abundance of coarse biogenic rubble and algae which provided the primary feeding focus of many browsers. This material, especially abundant on the inner middle shelf, also supported a suite of hard-substrate dependent, suspension feeding taxa (crinoids, dendrochirote holothurians, siliquariid gastropods and various bivalves) amongst whom acrophilic behaviour was common. Suspension feeders from both phyla were generally abundant on the middle shelf and dominated the echinoderms at the deepest site. The inner shelf molluscs were dominated by infaunal suspension feeding bivalves. Carnivorous echinoderms dominated the inner shelf due to the abundance of a single asteroid whereas highest numbers of carnivorous molluscs occurred on the middle shelf due to several, widely distributed gastropods. Deposit feeders of both groups were abundant at all sites. Differences between phyla at sites across the shelf may reflect patchiness in space and time of a few abundant deposit feeders.

INTRODUCTION

Knowledge of the trophic relationships of benthic organisms is important to an understanding of the processes which might structure communities and the functional role of trophic groups has been the focus of increasing interest (e.g. reviews by Woodin and Jackson 1979, Posey 1987). In this study, we examine the variation in trophic groups of two major epifaunal taxa, echinoderms and molluscs, across a broad tropical continental shelf, in relation to environmental variation.

METHODS

Four sites were sampled along transect C (figure 1). Each site was a square with sides of one nautical mile (1.9 km). The centres of adjacent sites were separated by eight nautical miles (14.9 km) in a north-south direction. Samples were collected with a modified Ockelmann sledge (Ockelmann 1964) and sieved to a 2 mm mesh sieve. Sampling and other field procedures were as given in Birtles and Arnold (1983), except that at sites on transect C, eight samples were taken in a north-south direction within the one nautical mile square in addition to the four samples taken along the sides of the square.

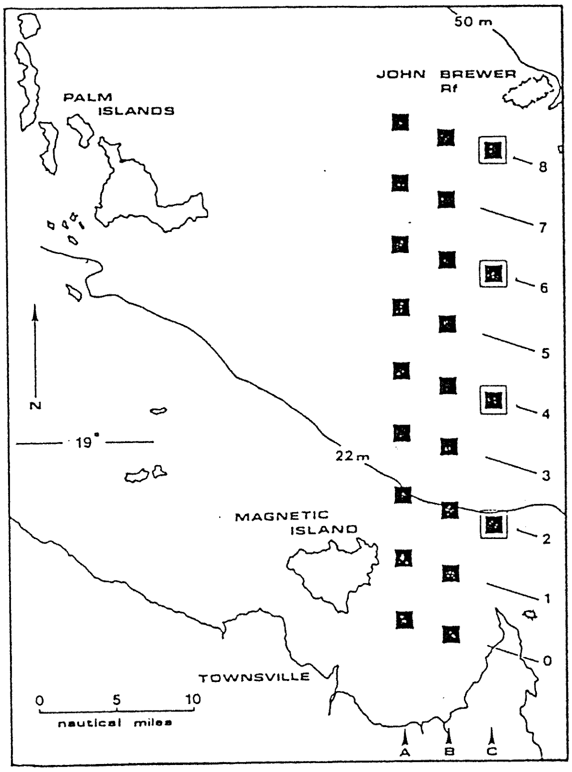


Figure 1. Map of the study area off Townsville.

Sediment was collected from the south-east corner of each site with an 0.06 m^2 Smith-McIntyre grab. Samples of about 150 g were wet sieved after disaggregation with sodium hexametaphosphate after the method outlined in Carver (1971). Major visual components of the sediment and their relative abundance on a three point scale (present, common and very common) were recorded during sorting, as were the more dominant seagrasses and algae.

The 103 species of echinoderms and 196 species of molluscs were classified as carnivores (C), deposit feeders (D), suspension feeders (S), browsers (B) and parasites (P). Species were assigned to particular trophic categories based on our diving observations and gut content analyses of the numerical dominants, extensively augmented by recent compilations (e.g. Taylor, Morris and Taylor 1980; Jangoux and Lawrence 1982). Although the term browser is most commonly applied to herbivores (Walker & Bambach 1974), many marine predators also browse upon their prey (Woodin 1982). Many of the asteroids, echinoids and gastropod molluscs in this study, could not be satisfactorily separated into either browsers on plant material or browsers on colonial encrusting animals (bryozoans, ascidians, cnidarians, sponges, etc.), due to their polytrophic and opportunistic feeding behaviour and the dearth of accurate, and especially quantitative dietary information. They were therefore all included in the same generalised "browser" category even though animals at either end of the dietary spectrum would be at quite different trophic levels.

Hierarchical cluster analysis, using the package CLUSTAN 1C, was based on log10(n+1) transformed values of species abundances at the sites. Dissimilarity was calculated using the Bray-Curtis index and the dendrogram constructed using the flexible sorting strategy, with B=-0.25.

RESULTS

Environment

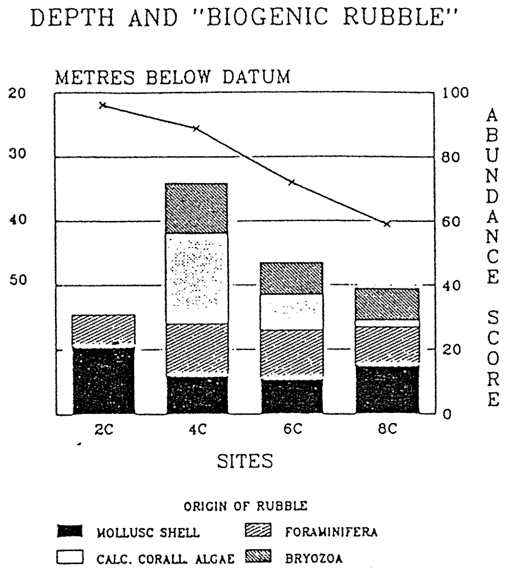
The depth gradient was least between the inner site 2C (mean depth below datum 21.9 m) and 4C (depth 25.6 m); the latter, and the two more offshore sites 6C and 8C (depths 34 m and 40.5 m), were more evenly spaced by depth (figure 2). The sediment at 2C was dominated by mud (28%) and medium to very fine sand (59%); fine gravel and pebble particles (>2.00 mm), collectively termed "rubble", comprised only 2.5%. Sites 4C, 6C and 8C had 10% or less mud and were dominated by coarse and very coarse sand (45%, 53% and 57%, respectively) and rubble (33%, 23% and 9%, respectively). The three offshore sites consistently varied from 2C in having a greater diversity and abundance of large rubble of biological origin (foraminifera, calcareous red algae, bryozoa, mollusc) as well as of seagrasses and algae (figure 2).

Faunal Patterns

The major separation of sites in the classification analysis, for both echinoderms and molluscs, occurred between the inner site 2C and the more offshore, middle shelf sites 4C-8C. Within the offshore site grouping, the outer two sites (6C, 8C) separated from the inner middle shelf site 4C for both echinoderms and molluscs (figure 3).

Echinoderm abundances at the offshore sites were 1.2-1.6 times that at site 2C, the number of species at each of the offshore sites was more than double (2.3-2.5) that at 2C (figure 3A). Low species richness combined with low evenness J, so that species diversity H' at 2C was about half to two-thirds that of offshore sites. Although abundances were lower at 4C than at the other offshore sites, species richness, species diversity and evenness were comparable (figure 3A).

At 6C and 8C, mollusc abundance and species richness were about double that at 2C and evenness was similar at these three sites. However, while abundances were similar at 2C and 4C, species richness was almost twice as high at the latter site, and species diversity and evenness were higher at 4C than at any other site (figure 3B).



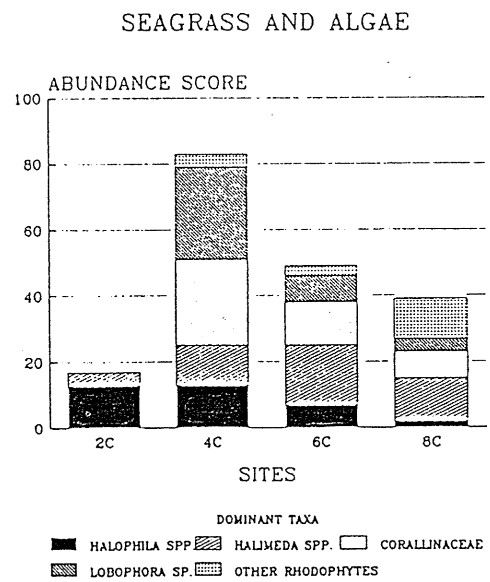
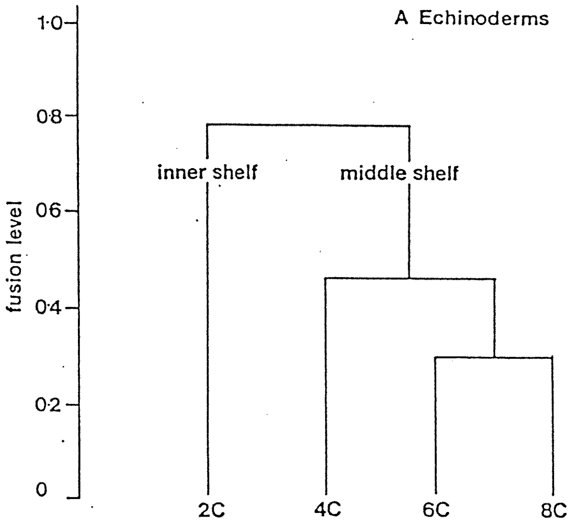


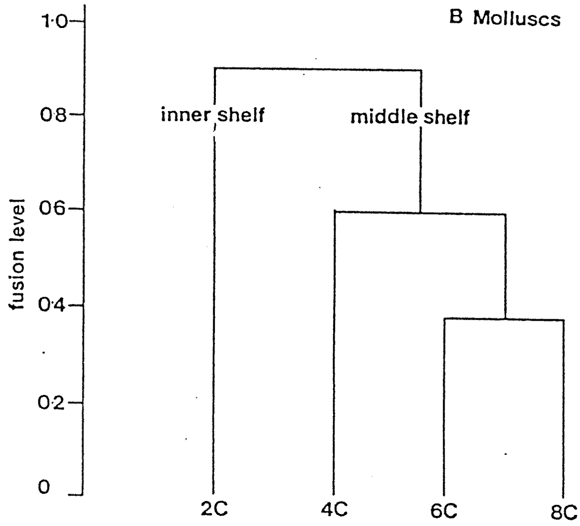
Figure 2. Environmental features of transect C. Abundance scores based on categories recorded in the field; present=1, common=2, and v. common=3. Scores are summed over all 12 sites to give site total.

Echinoderm trophic groups

A systematic breakdown of feeding types is given in Appendix I and a breakdown by class of species and abundance in the trophic groups is given in table 1. The overall proportion occupied by each of the trophic categories (summed over all sites) was similar whether species richness or total abundance was considered. Suspension feeders dominated (44.7% of species, 40.8% of individuals), followed by deposit feeders and browsers (table 1). The major discrepancy was with carnivores which accounted for only 8.7% of species but 19.4% of individuals.



SITE	TOTAL ABUND.	NO. OF SPP.	H'	J	H(MAX)
2C	424	28	0.8787	0.6072	1.4472
4C	497	69	1.5560	0.8462	1.8389
6C	628	65	1.4022	0.7734	1.8129
8C	686	67	1.5608	0.8547	1.8261



SITE	TOTAL ABUND.	NO. OF SPP.	H'	J	H(MAX)
2C	270	47	1.2512	0.7483	1.6721
4C	327	89	1.6837	0.8637	1.9494
6C	619	107	1.5724	0.7748	2.0294
8C	778	89	1.5280	0.7838	1.9494

Figure 3. Cluster analysis of sites, based on distribution and abundance of species. See text for details of transformations, similarity index and sorting strategy. Abundance, species richness, species diversity and evenness are given for each site. A. Echinoderms. B. Molluscs.

Table 1. Echinoderm trophic groups. Breakdown by class of the number of species and abundance (percentage species and abundance in parentheses) in five trophic categories.

TROPHIC GROUPS	CRINOIDS		ASTEROIDS		OPHIUROIDS		ECHINOIDS		HOLOTHURIAN		TOTALS	
	# SPP	ABUND	# SPP	ABUND	# SPP	ABUND	# SPP	ABUND	# SPP	ABUND	# SPP	ABUND
CARNIVORES			5 (29)	276 (42)	4 (15)	157 (40)					9 (9)	433 (19)
DEPOSIT			1 (6)	169 (26)	5 (19)	7 (2)	8 (47)	297 (74)	13 (45)	72 (20)	27 (26)	545 (24)
SUSPENSION	14 (100)	419 (100)			16 (62)	201 (51)			16 (55)	291 (80)	46 (45)	911 (41)
BROWSERS			11 (65)	215 (33)			9 (53)	105 (26)			20 (19)	320 (14)
PARASITES					1 (4)	26 (7)					1 (1)	26 (1)
TOTALS	14 (14)	419 (19)	17 (17)	660 (30)	26 (25)	391 (17)	17 (17)	402 (18)	29 (28)	363 (16)	103	2235

When the classes of echinoderms are treated separately, there were substantial differences in the representation of trophic groups, according to whether species richness or abundance was considered. The majority of asteroids (11) were browsers, but they represented only 33% of individuals. The five species of carnivorous asteroids contributed 42% of individuals, while the only deposit-feeding asteroid, Stellaster equestris, accounted for 26% (table 1). Within the ophiuroids, the majority of species and individuals were suspension feeders. Although 19% of species were deposit feeders, they represented only 2% of individuals. In contrast, four carnivorous species contributed 40% of the ophiuroid individuals. Ophiomaza cacaotica was the sole parasitic echinoderm. The echinoid species were about evenly divided between deposit feeders (eight species of sand dollars and heart urchins) and browsers (nine regular urchins), but the former category contained about three-quarters of echinoid individuals (table 1). The holothurian species were also about equally divided into two groups, with suspension feeders (order Dendrochirotida) slightly more diverse than deposit feeders (orders Aspidochirotida, Molpadida and Apodida). However, suspension feeders were about four times as abundant as deposit feeders.

The differences in the proportion of species in each of the five main trophic groups at the four sites were not great, with the three middle shelf sites in particular showing considerable similarity (figure 4). There were greater proportions of carnivores (18%) and especially deposit feeders (39%) and fewer of browsers (11%) and suspension feeders (32%) at 2C. In contrast, there were some very marked differences in the percentage abundance of each trophic group at the four sites (figure 4). The most striking difference was the very high abundance of carnivores at 2C in contrast to offshore, where they formed 10% or less of the site totals. The same site had a greatly reduced number of suspension feeders and browsers. At 4C, the proportion of browsers was almost double the total percentage for all sites, while at 6C the number of deposit feeders was raised to 42% of site total. The deepest site 8C, showed a marked increase in the number of suspension feeders totalling 63% of the individuals at the site.

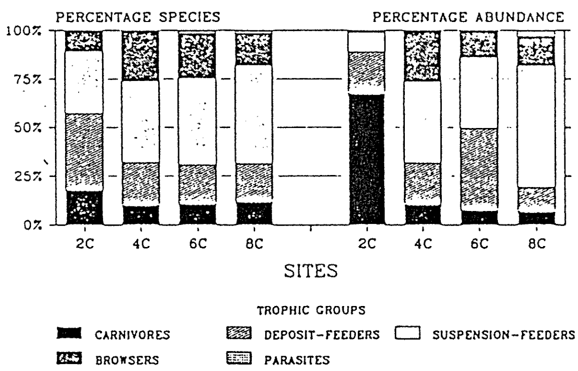


Figure 4. Proportions of echinoderm trophic groups at each site: nos. of species (l.), abundance (r.)

Figure 5 illustrates the inter-site differences in trophic group abundances in greater detail. Carnivores dominated site 2C, forming 68% of the site total (figure 5A). Asteroids comprised 50% of the echinoderms at the site, with Astropecten velitaris contributing 47.4% of the site total. The remaining 18% was contributed mostly by two ophiuroids Ophiopsammus yoldii and Ophiochasma stellatum. Deposit feeders formed 21.5% of the site total; over half of them consisted of the asteroid Stellaster equestris. Suspension feeders contributed less than 10% to the site total and the number of browsers was negligible.

Site 4C (figure 5B) was very different to 2C except for deposit feeders, which again formed just over 21% of the site total. At 26% of the site total, the browsers were abundant; 84% of this was asteroids. Ten of the total of 11 browsing asteroids occurred at 4C but over a third (35%) of all asteroids at this site were Pentaceraster regulus. Although browsing echinoids were not abundant, all but one of the nine species found on transect C were also obtained at this site. Apart from the raised browser numbers, the 4C abundance pattern was similar to that of the other middle shelf sites.

Carnivores (10%) were reduced to a typically low offshore value; suspension feeders had substantial contributions from three taxa although there were more holothurians than crinoids and ophiuroids combined. This was due, at least partly to the abundance of the dendrochirote Pentacta australis which was the most abundant echinoderm at the site (11% of site total).

The main contributors to the higher proportion of deposit feeders at 6C were echinoids, especially the sand dollar Peronella orbicularis which formed 19% of the site total (figure 5C). If this species were removed however, the proportion of deposit feeders was reduced to below that of the transect overall (22% cf. 24%).

Site 8C was dominated by high abundances of suspension feeders which formed 63% of the site total; 57% of this category were crinoids. Suspension feeders occupied seven of the first eight positions, when echinoderms at the site were ranked by abundance. Five of the top six were crinoids, four of these in the genus Comatula (figure 5D). Ophiactis luteomaculata, the second most abundant echinoderm at the site, formed 65% of the suspension-feeding ophiuroid total. The remaining 23% of the suspension feeders were dendrochirote holothurians. Both the browser and carnivore abundance were similar to that of 6C, and these were fairly evenly divided between asteroid and echinoids, in the former case, and between asteroids and ophiuroids in the latter. The ninth ranked echinoderm at the site was Ophiomaza cacaotica, the only echinoderm in the transect C samples regarded as parasitic (Clark 1976). Its abundance at 8C reflected the distribution of its crinoid hosts (Comatula cratera, C. rotalaria, C. solaris).

Mollusc feeding groups
For carnivorous and suspension feeding molluscs summed over all sites, there were generally similar patterns whether species richness or abundance were considered. The major discrepancies were with deposit feeders, with 9.7% of species but 26.4% of individuals, and the browsers, with 14.3% of species but only 4.9% of individuals (table 2). Molluscs were dominated both in numbers of species and individuals by carnivores (41.8% and 38.5% respectively).

Table 2. Mollusc trophic group totals.

TROPHIC GROUPS	SPECIES NO.	SPECIES PERC.	ABUNDANCE NO.	ABUNDANCE PERC.
CARNIVORES	83	42.3	769	38.6
DEPOSIT	19	9.7	519	26.0
SUSPENSION	63	32.1	597	30.0
BROWSERS	29	14.8	101	5.1
PARASITES	2	1.0	6	0.3
TOTALS	196		1992	

When classes of molluscs are treated separately, there were substantial differences in representation of trophic groups. Scaphopods and cephalopods were exclusively carnivorous, while chitons browse on both animal and plant material. None of these classes were abundant, although cephalopods were moderately diverse, with 10 species.

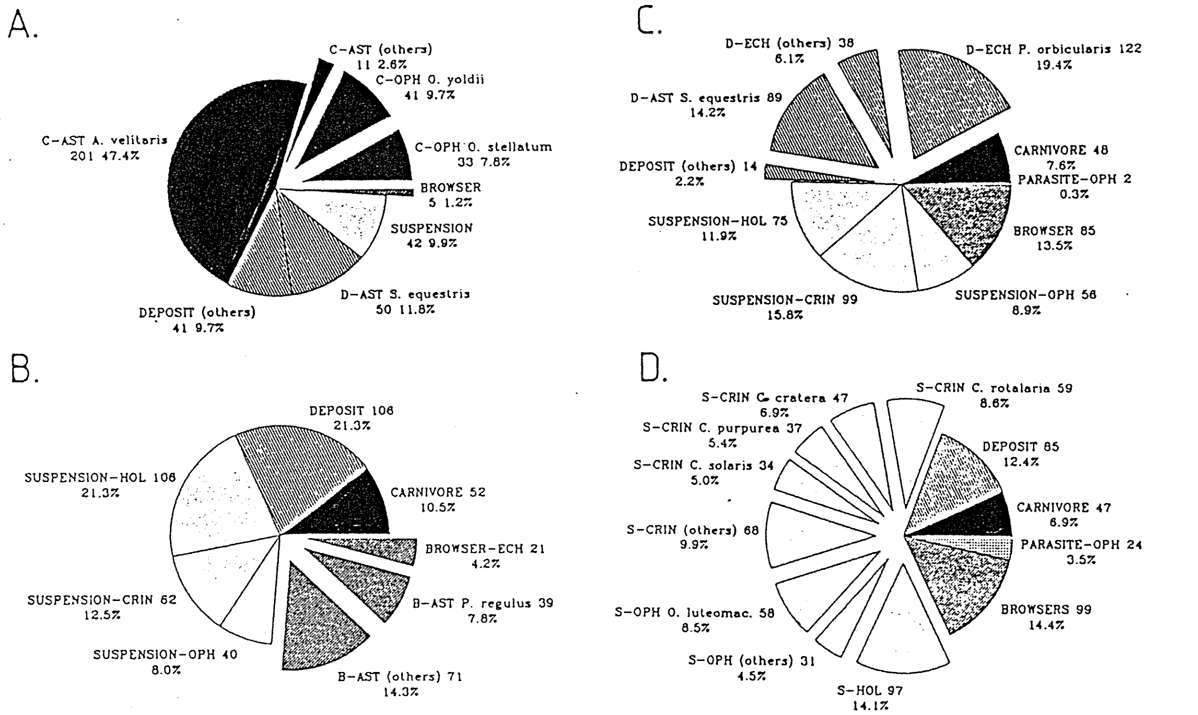


Figure 5. Proportional abundance of echinoderm trophic groups at each site. The five categories (see shading) are subdivided to show class contributions and those of numerically dominant species (abundance & percent. of site total). C=Carnivore, D=Deposit, S=Suspension, B=Browser. A. Site 2C B. 4C C. 6C D. 8C.

Bivalves were almost exclusively suspension feeders (57 species, 547 individuals). Only the tellinaceans (2 species, 2 individuals) were considered deposit feeders. Gastropods had the widest range of feeding types (Appendix I), but were dominated by carnivores (72 species, 744 individuals). Although there were only 17 species of deposit feeding gastropods, these included 517 individuals and represented the next most important feeding category in the class.

When sites are considered separately, there was a major distinction between abundances of the various trophic categories at site 2C and those at the middle shelf sites (figure 6). The degree of dominance within deposit feeders at site 2C was especially obvious, with only 13.6% of species but 45.6% of individuals. This was due to the abundance of three species: Strombus vittatus, Xenophora solarioides and Philine sp. The last is generally considered a carnivore, but the small specimens collected had guts full of foraminiferans and appeared to be selective deposit feeders (pers. obs.).

There was a general similarity in the proportions of individuals in each trophic category at the three middle shelf sites. Carnivores were especially abundant at the middle shelf sites (35.8-44.6%). Five species (Tudicula armigera, Chicoreus banksii, Fusinus colus, Phos senticosus and Latirus paetelianus) accounted for 55.5-61.4% of the numbers of carnivores at these middle shelf sites. Of these, only C. banksii was associated with patches of biogenic rubble, the others being sand-dwelling carnivores of infauna, especially polychaetes (pers. obs.).

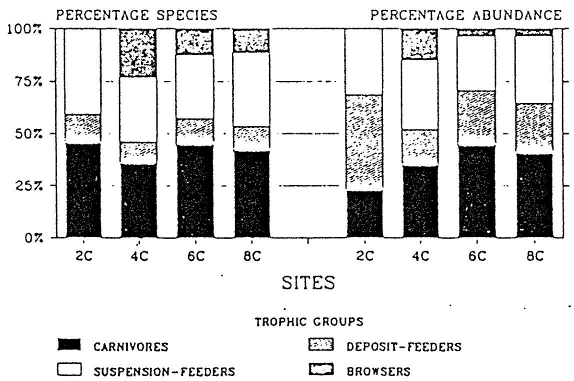


Figure 6. Proportions of mollusc trophic groups at each site: nos. of species (l.), abundance (r.).

Deposit feeders were especially abundant at the outer sites 6C and 8C (figure 6). Five species (in order of abundance: Strombus dilatatus, Xenophora solarioides, X. cerea, Monilea lentiginosa and S. vittatus) accounted for 89% of the individuals at these sites.

Suspension feeders were uniformly distributed along the transect but the species varied from site to site. At site 2C, the numerical dominants were the infaunal glycymeridid Melaxinea labryntha and an epifaunal pteriid. At site 4C, the numerical dominant was a siliquariid gastropod, associated with sponges. Sites 6C and 8C had a diverse fauna of suspension feeding bivalves, the most abundant being an unidentified ostreid, epizoic on Strombus species. Other families, both infaunal (glycymeridids, cardiids) and epifaunal (arcids, chamids and anomiids) were also well represented at these sites.

No browsers were recorded from the inner shelf site 2C, but they occurred at all middle shelf sites. However there were about twice as many species and about four times as many individuals at site 4C, compared with the outer sites 6C and 8C.

DISCUSSION

The major separation of sites in both echinoderms and molluscs occurred between 2C (21.9 m) and 4C (25.6 m) (figure 3). More extensive sampling along transects A and B (figure 1), as summarised in Birtles & Arnold (1983), indicated a clear separation of echinoderms, molluscs, crustaceans, bryozoans, demersal fishes, ascidians and algae at about 22-23 metres. This major faunal discontinuity corresponded closely to the separation of an inner shelf and middle shelf zone by Belperio (1983), based on sediment characteristics. We also indicated that these overall patterns of distribution and abundance had remained stable for the previous six years (1977-1982).

Relative to site 2C, the middle shelf sites had a higher diversity and greater abundance of large calcareous rubble elements, which were of biological origin (figure 2). Such biogenic rubble, often several centimetres across, acts as a settlement site for solitary and clonal organisms. Where these organisms themselves secrete calcareous skeletons, there is often a build-up of calcareous material to provide quite a large, stable surface, suitable for the settlement of numerous other organisms. This process can lead to the development of multi-species clumps (as defined by Fedra 1977). Other large settlement surfaces are provided by single taxa such as stolidobranch ascidians (Herdmania, Polycarpa) and sponges (Ircinia). We refer collectively to all these hard substrate elements (biogenic rubble, multi-species clumps and single taxa) as "natural isolates". Seagrasses and algae, which were a diverse and abundant feature of the middle shelf sites (figure 2), also act as settlement surfaces. Living corallinaceans were especially abundant at 4C and their dead skeletons were of particular importance in the development of the large biogenic rubble elements which were abundant at the site.

Within both the echinoderms and the molluscs, browser abundance corresponded closely with that of biogenic rubble. As outlined in Methods, this generalised browsing category included both herbivores and animals feeding primarily on clonal animals (sponges, cnidarians, bryozoans). The latter trophic group corresponds to the Group II carnivore category used to characterise feeding types of asteroids (Jangoux 1982). Browsers were absent (molluscs) or in greatly reduced numbers (echinoderms) at 2C, but occurred at all the middle shelf sites. However, it was at 4C, with the maximum concentration of biogenic rubble and algae (figure 2), that the browsers were most strongly represented. Proportional abundance of browsers at 4C was twice and four times that at other middle shelf sites for the echinoderms and molluscs respectively.

While the relative abundance of suspension feeding molluscs was similar across the shelf, suspension feeding echinoderms were clearly best represented on the middle shelf, and especially at site 8C. In situ observations while diving have shown that the dendrochirote holothurians and crinoids are rheophilic and acrophilic behaviour is frequent. Most species are largely restricted to the natural isolates (discussed above) which form islands of hard substrate in a "sea" of otherwise unstable soft-sediment. The elevation provided by such substrate can substantially increase the resources available to passive suspension feeders (Fedra 1977). However, this association with hard substrate clearly did not control crinoid abundance at 8C, which had the highest numbers of crinoids but the smallest amount of biogenic rubble of the middle shelf sites (figure 2). The explanation lay in the fact that the two most abundant crinoids at the site (Comatula rotalaria, C. cratera), at least as adults, do not require hard substrate, supporting themselves on their arms on the surface of the sediment. Why should the environment at 8C be favourable to large, epifaunal suspension feeding echinoderms? Several possibilities can be advanced, including increased bottom stability at the greater depths and hence also lower turbidity, greater availability of suspended food either through currents or because of the effects of pulses of upwelled, nutrient rich water, as suggested by Andrews and Gentien (1982).

The greater abundance of suspension feeding molluscs at 2C is partly explained by the numerical dominance of juvenile pteriid bivalves epizoic on plumulariid hydroids; this flexible substrate is not used by any echinoderm. The majority however, were infaunal suspension feeding bivalves which may be functionally different from the larger epifaunal echinoderms and are often put in a distinct trophic category (Walker & Bambach 1974).

The distribution of carnivorous molluscs was also different from that of carnivorous echinoderms, with the former dominant at middle shelf sites and the latter inshore. This may reflect the difficulty of placing a species unambiguously in a single trophic category. Many of the middle shelf asteroids in our generalised browser category have been classified as carnivores by Jangoux (1982). Philine, a numerically dominant mollusc at 2C, although usually carnivorous (Kohn 1983), was classified as a deposit feeder based on gut content analyses of specimens at that site.

All but one of the numerically dominant echinoderm and mollusc carnivores were infaunal feeders. The inner shelf site was dominated by Astropecten velitaris which feeds primarily on bivalve and gastropod molluscs and small crustaceans (Lemmens 1986). Its high numbers at 2C may be due to the ease of feeding in soft mud compared with the more compact sediment of the middle shelf, rather than simply prey availability; large specimens are confined to offshore sites. The middle shelf molluscan carnivores were dominated by gastropods feeding primarily on sedentary polychaetes. This also does not simply reflect availability of prey items as there is a rich polychaete fauna within the inner shelf zone (Arnold 1979).

The overall proportion of deposit feeders was similar for the echinoderms and molluscs (24% and 26% of total abundance, respectively) and they formed a substantial proportion at all sites. However, there was a condiderable discrepancy between numbers of deposit feeding echinoderms and molluscs, especially at 2C and 6C. This may largely reflect patchiness in space and/or time of numerically dominant deposit feeders such as Peronella orbicularis on the middle shelf (pers. obs.) and Laganum depressum which, while rare at 2C, could occur in large numbers at other sites on the inner shelf (Birtles & Arnold 1983).

The clearest pattern in the data was the separation of the inner site 2C from the outer sites. It differed not only in taxonomic composition, but in the proportional abundance of some of the feeding types represented. This is especially well shown by the browsers. In the middle shelf zone, sites with higher concentrations of biogenic rubble and natural isolates (e.g. site 4C) provided both food resources (as evident from distribution of browsers) as well as hard substrate for acrophilic and rheophilic suspension feeders, especially crinoids and dendrochirote holothurians. These suspension feeders and the predominantly suspension feeding species which comprise the isolates, may represent an important pathway along which energy is passed from the water column to the benthos (Fedra 1977). Especially where such natural isolates are formed from relatively long-lived organisms (e.g. large stolidobranch ascidians, sponges), they may be vulnerable to short-term but frequent disturbances such as trawling concentrated in particular areas. This is in contrast to the inner shelf zone where the bottom appears to be more unstable and there is less biogenic hard substrate.

Our demonstration of substantial variation in epibenthic taxa and functional groups over the scale of tens of kilometres, and at least partially linked to variability in substrate across the shelf, indicates that caution is necessary in making generalisations. It belies the recent attempt to include the whole central Great Barrier Reef shelf benthos into a single "super-community" (Goeden and Watson 1987). We suggest that an important implication of this is that the distinct zones across the shelf which we have demonstrated will probably require different management strategies. At a different level, such small-scale variability may confuse attempts to make broad-scale inter-regional comparisons. We thus question the validity of the attempt by Petersen and Curtis (1980) to contrast latitudinal patterns of energy flow, given that they used only a single location in Thailand to represent all tropical marine shelf soft sediment habitats.

ACKNOWLEDGEMENTS

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Appendix I. Trophic categories of echinoderms (103 species) and gastropod molluscs (124 species). Values are the number of species per family within the trophic category.

TROPHIC GROUP	ECHINODERMS				GASTROPOD MOLLUSCS			
CARNIVORES	Asterinidae	1			Acteonidae	1	Muricidae	14
	Astropectinidae	2			Atyidae	2	Nassariidae	3
	Luidiidae	2			Buccinidae	2	Naticidae	1
	Ophiodermatidae	3			Bursidae	2	Pleurobranchidae	1
	Ophiuridae	1			Conidae	8	Ranellidae	7
					Coralliophilidae	1	Terebridae	2
					Costellariidae	6	Turbinellidae	1
					Fasciolariidae	3	Turridae	13
					Melongenidae	1	Volutidae	3
					Mitridae	1		
DEPOSIT FEEDERS	Amphiuridae	3	Laganidae	5	Cerithiidae	3	Trochidae	2
	Brissidae	1	Lovenidae	1	Eulimidae	2	*Euchelus atra*	
	Caudinidae	1	Ophiotrichidae	2	Philinidae	1	*Monilia lentiginosa*	
	Clypeasteridae	1	Stichopodidae	2	Pyramidellidae	1	Xenophoridae	3
	Goniasteridae	1	Synaptidae	2	Strombidae	5		
	Holothuriidae	8						
SUSPENSION FEEDERS	Antedonidae	1	Ophiacanthidae	1	Siliquariidae	3		
	Colobometridae	1	Ophiactidae	2	Trochidae	2		
	Comasteridae	8	Ophiocomidae	1	*Umbonium* spp.			
	Cucumariidae	11	Ophionereidae	1	Vermetidae	1		
	Euryalidae	1	Ophiotrichidae	10				
	Himerometridae	1	Phyllophoridae	5				
	Mariametridae	1	Zygometridae	2				
BROWSERS	Cidaridae	1	Pterasteridae	1	Aplysiidae	1	Ovulidae	1
	Echinasteridae	1	Temnopleuridae	6	Architectonicidae	2	Polyceridae	1
	Goniasteridae	3	Toxopneustidae	2	Cypraeidae	2	Triphoridae	2
	Metrodiridae	1			Dorididae	7	Trochidae	3
	Ophidiasteridae	2			Fissurellidae	5	Turbinidae	2
	Oreasteridae	3			Lamellariidae	1		
PARASITES	Ophiotrichidae	1			Hipponycidae	2		

ABSTRACT

A SPECULATIVE REVIEW OF THE EFFECTS OF TRAWLING AND POTENTIAL FOR RECOVERY ON INTER-REEFAL MACRO BENTHIC EPIFAUNAL COMMUNITIES

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The composition and biogeographical affinities of natural undisturbed inter-reefal faunal communities of the Great Barrier region are discussed and compared with similar communities occurring on the North West Shelf and in the Gulf of Carpentaria. It appears that there is a distinct inter-reefal fauna with some species occurring in two or more of these biogeographical areas. This inter-reefal fauna does not appear to occur on nearby reefs and much of the inter-reefal fauna is adapted to living on fine sand and terrigenous muds. This fauna is rich and diverse although in many groups a large part of the fauna is undescribed.

The fauna exhibits marked zonation patterns related to depth and sediment type. Typically there is an inshore and an offshore community which may be further subdivided. We review the limited data available on the natural fluctuations which may occur in the composition and abundance of this community together with the reproduction and recruitment of this type of community. As there is such limited data available we attempt to summarise what is known about other species in the genera occurring in other coral reef inter-reefal areas, in the hope that this may shed some light on the biology of the species occurring in tropical Australia. Similarly, virtually nothing is known about the growth rates of any of the components of the Australian inter-reefal fauna and so information on related species is given as this may also be relevant.

The available information on the role of this community within the coral reef ecosystems is reviewed. These isolates provide a complexity and 3-dimensional structure to the inter-reefal areas and certain species of fish are characteristically associated with these isolates.

Trawling physically removes much of this community and it seems unlikely that much of the by-catch survives when it is returned to the sea. Associated with this removal of the epifaunal community there is an associated change in the species composition of the fish communities.

In conclusion we highlight areas where additional information is needed in order to be able to evaluate fully the impact of trawling on the reefal ecosystem and to be able to predict the rate of recovery of these communities after trawling has ceased.

abs_HutchingsBaxter

ABSTRACT

SEAGRASSES

KURT DERBYSHIRE
Queensland Department of Primary Industries

Seagrasses are angiosperms which possess several adaptations related to the marine environment in which they exist. There are 14 species in tropical Queensland waters. Most have been found in <15m depth, with the greatest biomass occurring in 2-6m depth, though this can vary with species and locations.

Almost the entire Queensland coast has been mapped for seagrasses. The mapping technique involves a diver determining the presence/absence of seagrass. If found, a $0.25m^2$ quadrat is cleared and returned to the laboratory for analysis. Beds are trawled for associated fauna. Finer scale work has been conducted in Moreton Bay and Cairns Harbour, and on Green and Mornington Islands.

Seagrass meadows stabilize bottom sediments, have complex nutrient cycles, are highly productive and are utilized as a food resource. They act as nursery/shelter areas for many organisms. Twenty-three species of penaeids have been found as juveniles in seagrass beds and 9 of these are of commercial importance. Juveniles of species such as the brown tiger prawn (Penaeus esculentus) are unlikely to survive unless seagrass beds are available. Many fish (mostly non-commercial) are found in seagrass beds (eg trumpters, gobies, ponyfish); some commercial fish are also found (eg garfish, silver jewfish, lethrinid juveniles). The sand crab (Portunus pelagicus) is common.

Development and reclamation activities threaten seagrass beds in some areas. Estimates for prawn production in Cairns Harbour seagrass beds were $3500/ha/yr, a value which would seem unlikely to restrict destructive development, through recreational and aesthetic considerations were not included in this figure. Trawler operators accept the need to protect seagrass beds from destructive trawling.

Further research into reef top and deeper water seagrass meadows is necessary.

ABSTRACT

TURTLES

IAN POINER
Commonwealth Scientific and Industrial Research Organisation

This paper looked at the incidence of turtle capture during trawling at a number of sites between Melville Island and Cape York from both research and commercial fishing (see Map 1).

Overall, the incidence of turtle capture was low, with a maximum of 0.048 catch/trawl of turtles. (just over 100 turtles in approx. 3000 trawls). There was no reported mortality of turtles caught in trawls of less than 90 minutes duration (Figure 1).

There was no significant trend in the catch rate for duration of trawl, but there was a tendency for lower catch rates to occur during shorter trawls (Table 1).

There was a consistent of lower catch rates with increasing depth (see Figures 2,3 and 4). Depth corrected figures are shown in Figure 5.SQ

For the Gulf of Carpentaria (Figure 6), average catch per year was in the order of 3,000 - 6,000 and mortality was between 150 - 350.

Flatback and loggerhead turtles were the most frequently caught (Table 2).

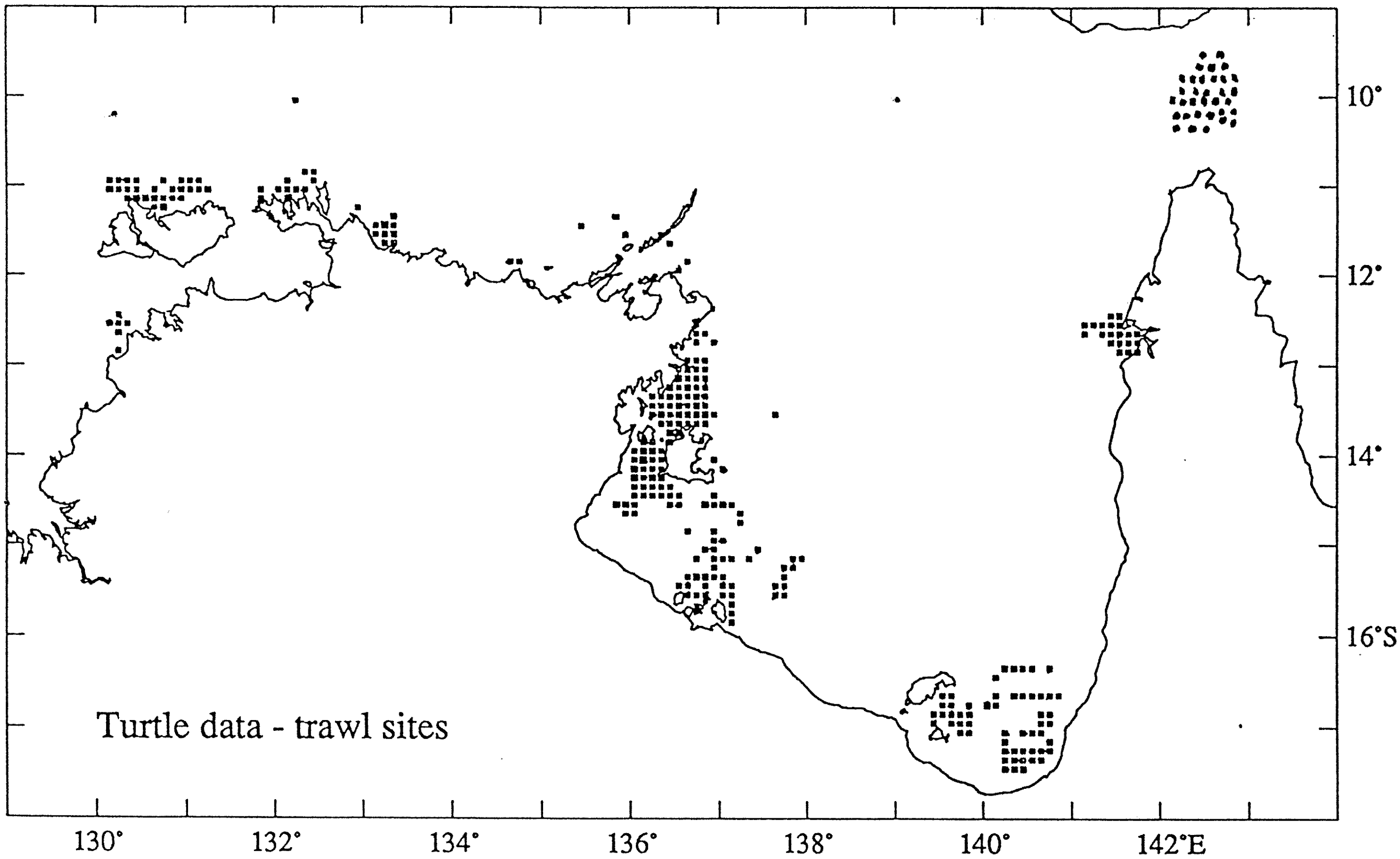
Catch rates seem higher in June in September.

Overall, it was concluded that trawling had a minimal impact on turtle populations in the Gulf of Carpentaria.

WORKSHOP DISCUSSION OF PAPER

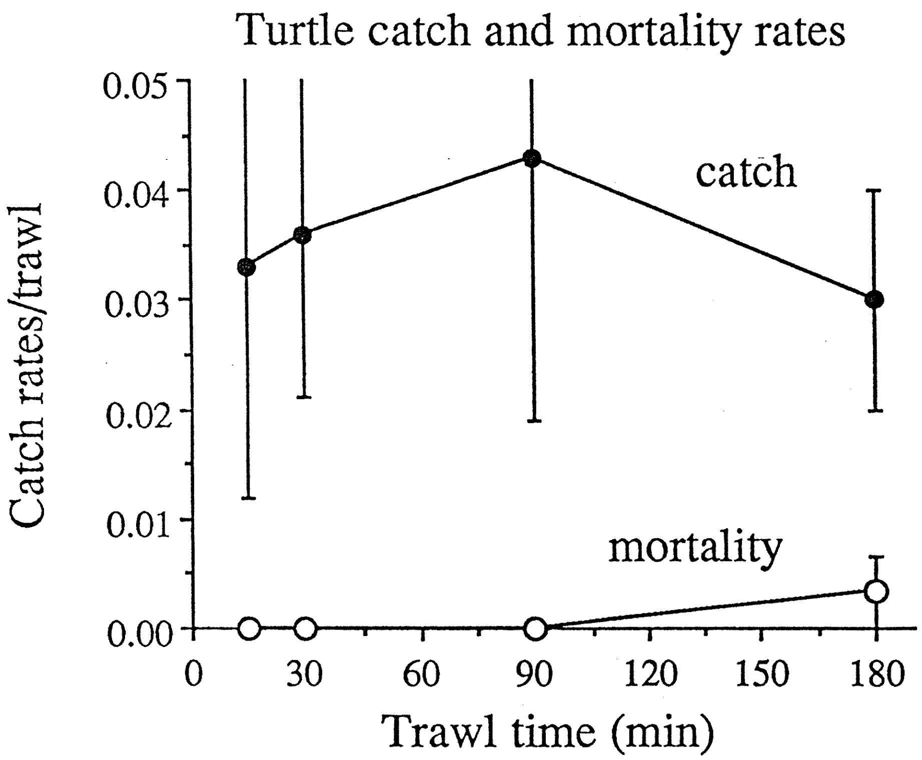
Discussion centered around comparisons with other geographic areas, depth variability and susceptibility to capture or mortality but because of low sample numbers it was noted that these are difficult to determine.

MAP 1



Turtle data - trawl sites
10°
12°
14°
16°S
130°
132°
134°
136°
138°
140°
142°E

FIGURE 1



Turtle catch and mortality rates
Catch rates/trawl
0.05
0.04
0.03
0.02
0.01
0.00
catch
mortality
0
30
60
90
120
150
180
Trawl time (min)

TABLE 1

Turtle catch rates and their 95% confidence intervals.

Period	Area	No. of trawls	Average duration	No. of turtles	Catch/ trawl	95% C.I.
1988-89	E. Gulf	276	15 min	9	0.033	±0.021
1963-65	S.E. Gulf	1249	34 min	11	0.009	±0.005
1983-86	S.E. Gulf	211	30 min	4	0.018	±0.018
1984-88	T. Strait	560	30 min	12	0.021	±0.012
1987	W. Gulf	328	40 min	5	0.015	±0.013
1982-83	W. Gulf	282	90 min	12	0.043	±0.024
1971-85	W. Gulf *	708	180 min	33	0.047	±0.016
1985-86	W. Gulf *	338	180 min	13	0.038	±0.021
1979-82	Melville *	416	180 min	20	0.048	±0.021

* Commercial catch monitoring.

Figure 2

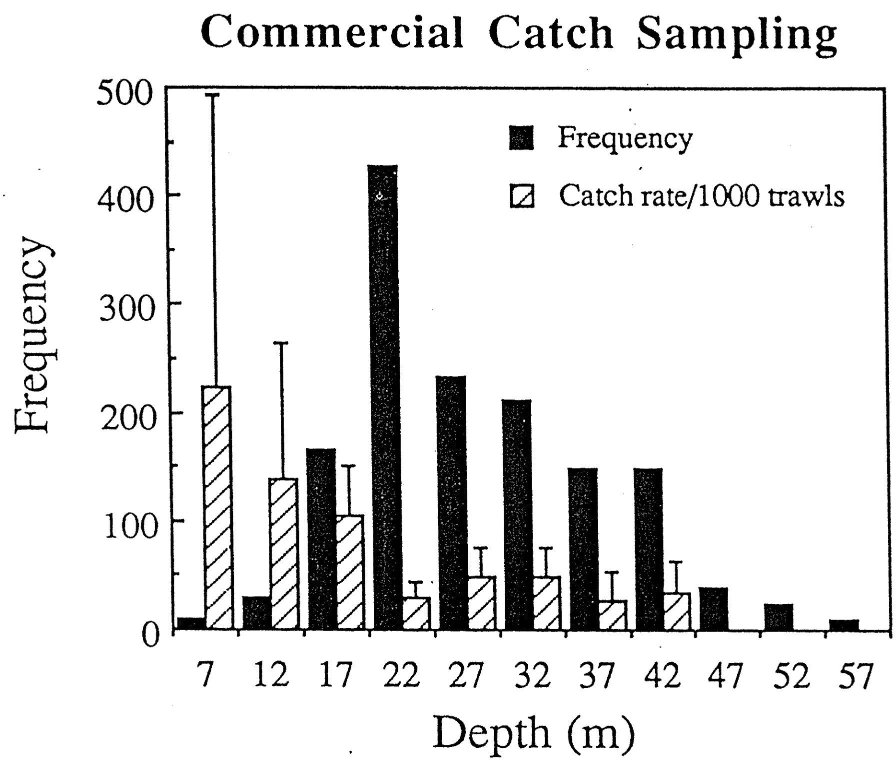

Commercial Catch Sampling
500
400
300
200
100
0
Frequency
Frequency
Catch rate/1000 trawls
7
12
17
22
27
32
37
42
47
52
57
Depth (m)

Figure 3

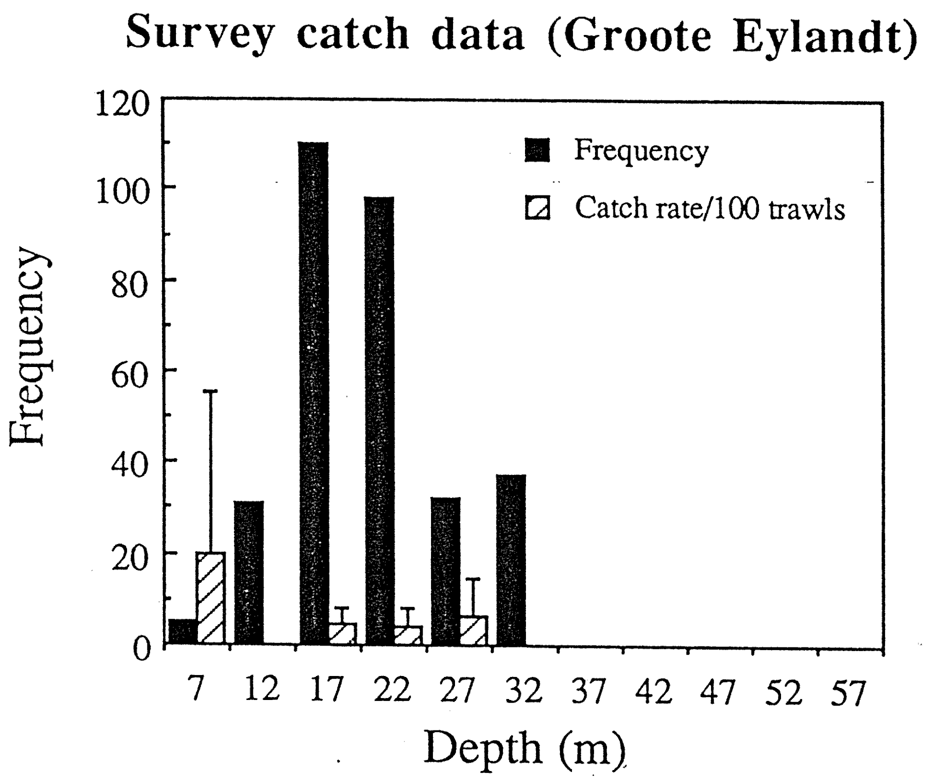

Survey catch data (Groote Eylandt)
Frequency
Catch rate/100 trawls
Frequency
120
100
80
60
40
20
0
7 12 17 22 27 32 37 42 47 52 57
Depth (m)

Figure 4

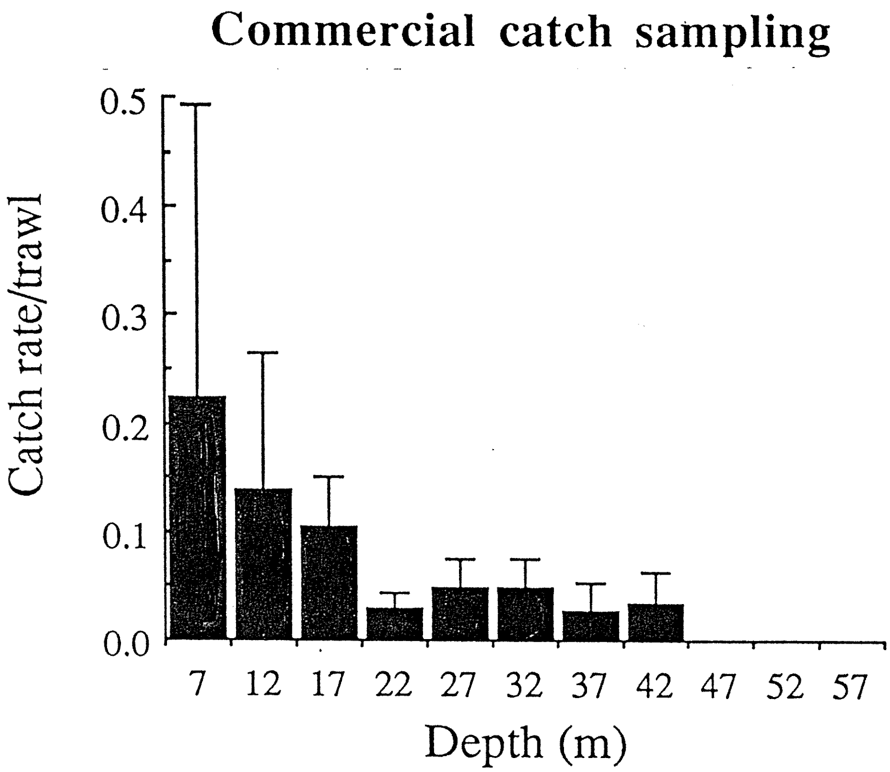
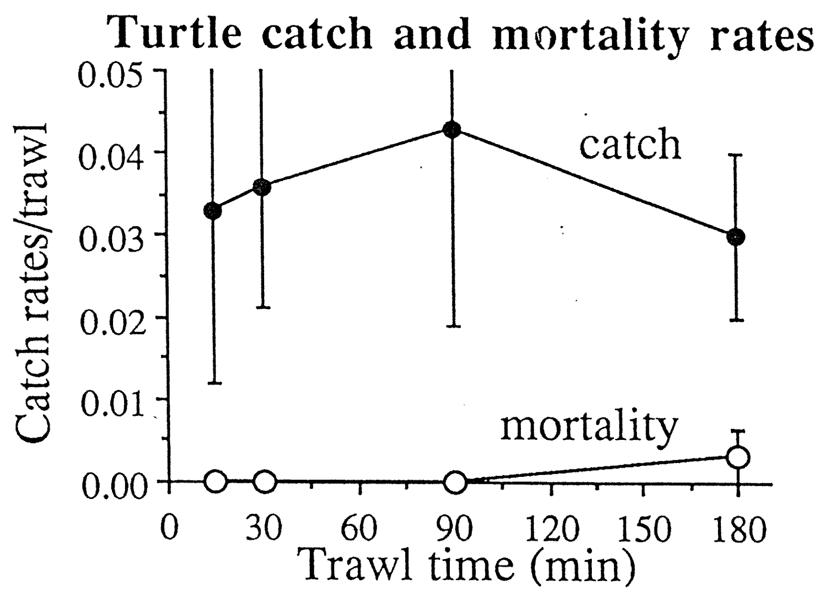
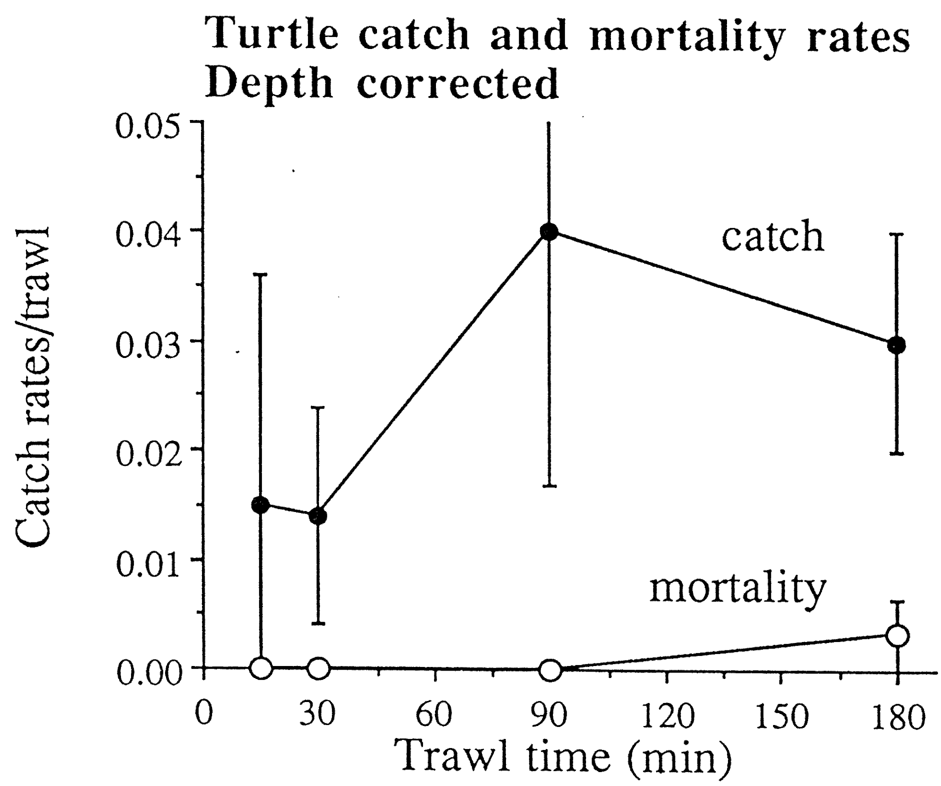

Commercial catch sampling
Catch rate/trawl
0.5
0.4
0.3
0.2
0.1
0.0
7
12
17
22
27
32
37
42
47
52
57
Depth (m)

Figure 5



Turtle catch and mortality rates
Catch rates/trawl
0.05
0.04
0.03
0.02
0.01
0.00
catch
mortality
0
30
60
90
120
150
180
Trawl time (min)



Turtle catch and mortality rates
Depth corrected
Catch rates/trawl
0.05
0.04
0.03
0.02
0.01
0.00
catch
mortality
0
30
60
90
120
150
180
Trawl time (min)

Figure 6

Commercial catch of turtles GofC

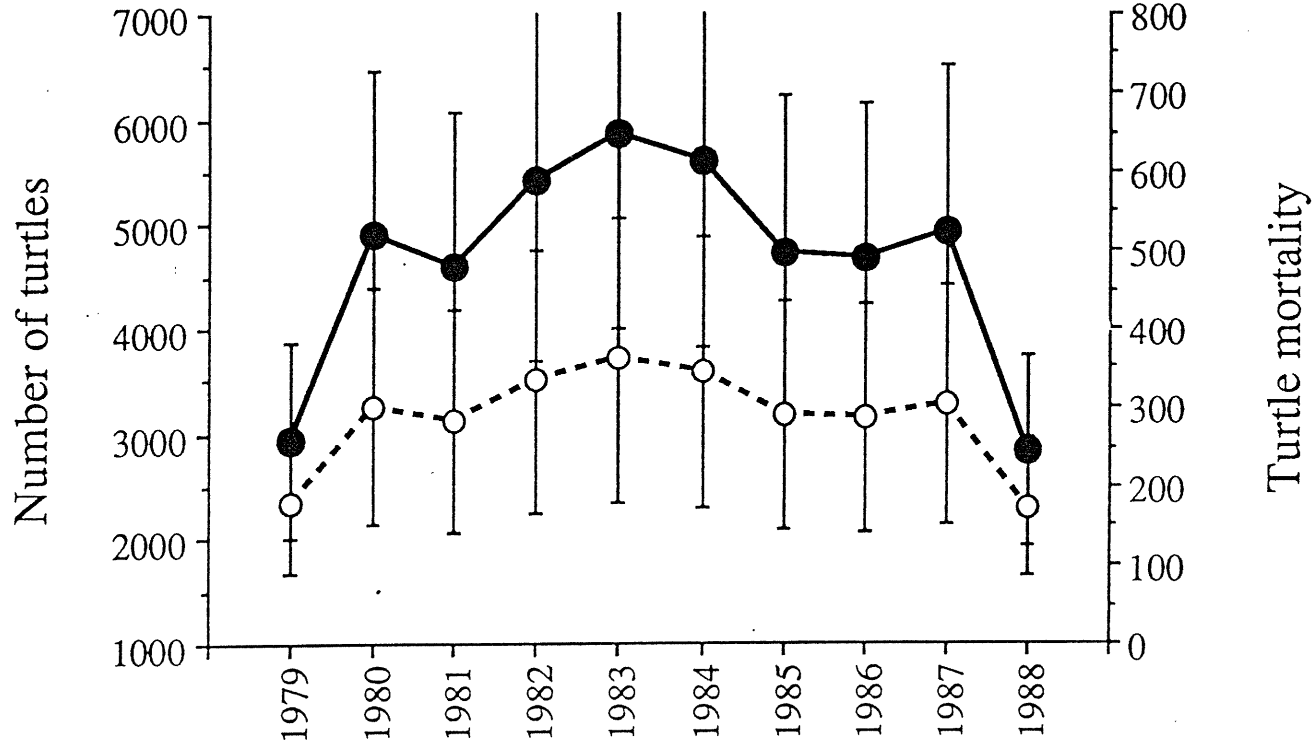


TABLE 2.

Species composition of the trawler caught turtle catch.

Species	South-eastern Gulf	Torres Strait	Albatross Bay	Western Gulf
Flatback (Natator depressa)	2	6	3	1
Loggerhead (Caretta caretta)	2	2	1	1
Olive Ridley (Lepidochelys olivacea)	-	1	2	
Green (Chelonia mydas)	-	-	1	4

TURTLES

C.J.LIMPUS and J.D. MILLER
Department of Conservation and Environment

On a world scale marine turtles are considered to be endangered but there are many in Australian waters. This makes Australia particularly important for the status of turtle stocks because they are harvested in other areas of their range. It has been noted that turtles do not restock nesting areas from which they have been eliminated.

Most available information has come from laying females. There is less known of other stages of their life cycle. It appears that hatchlings aggregate in oceanic convergences and could be considered to be "enormous planktonic animals". The basic characteristics of marine turtles are known to be:

* many (circa 50) years to sexual maturity
* long breeding life and long period between breeding years
* high mortality before adulthood
* highly fecund with several clutches per breeding year per female
* migratory with foraging far from nesting sites
* high fidelity to a limited number of nesting sites, inter nesting areas and to foraging areas
* determination of sex by nest temperature

Poorly known factors regarding turtles include:

* survivorship rates
* sex ratios
* population estimates and structure
* migratory patterns
* population genetics

Major studies that are being undertaken are involved with population genetics and structure. The techniques used for these include tagging, rodeo capture, laparoscopy, aerial surveys and mtDNA analysis.

Nesting distribution in Queensland: for green turtles the majority of nesting occurs at the north (Raine Island) and south (Capricorn - Bunker Groups) of the region with inconsequential amounts in between. Loggerhead turtles concentrate their nesting in the Capricorn-Bunker Group and the adjacent mainlang near Bundaberg. Hawksbill turtles nest mostly on the innershelf cays of the far northern Great Barrier Reef and eastern Torres Strait.

Threats to the stock include:

* egg harvest
* international trade
* development on beaches
* floating debris
* trawl, drift and stationary nets
* degradation of foraging areas

* harvest by indigeneous population

WORKSHOP DISCUSSION OF PAPER

Most discussion revolved around the population dynamics of turtles and it became clear that tag loss was a major factor in the lack of ability to determine population sizes and movements . Much historical data has been lost because of tag loss. The use of titanium tags is expected to address this problem.

EFFECTS OF TRAWLING ON TURTLES - POPULATION DYNAMICS

C.J. LIMPUS and J.D. MILLER
Department of Conservation and Environment

Of the six species of sea turtles that occur within the Great Barrier Reef, five are benthic feeding species. These latter species are not uniformly distributed because each species has different habitat requirements: green turtles are mostly found in sea grass bed and on reefs, hawksbill turtles occur mainly on reefs, loggerhead turtles, olive ridley turtles and flatback turtles feed mainly over soft bottom habitats.

General information on turtles and factors that are still unknown regarding these species were reiterated from the previous day's paper. It was also reiterated that consideration of population dynamics of turtles should consider two groups - the nesting group and the foraging group. It was noted that members of a single foraging group migrate to several nesting sites and a nesting site is utilized by turtles from several different foraging areas. Comparisons were made among a number of species but the emphasis was primarily on loggerhead turtles .

Immature loggerhead turtles settle onto the foraging area at a carapace length of approximately 70 cm (green turtles settle at about 40 cm and hawksbill turtles at about 35 cm) . Marine turtles show great fidelity to their foraging areas, nesting sites and internesting habitats . Annual recruitment for loggerhead turtles into the southern GBR feeding habitat is about 17 %. The sex ratio in this species at Heron Island is about 0.41 female to 1.0 male. Only about 24% of the sexually mature females breed in any one year; each female breeds on average once in four years. Loggerhead turtles produce 3 to 5 clutches of an average of 127 eggs in a breeding season. Sixty percent of the loggerhead nesting in the southern GBR region occurs on the islands. Hatchling sex ratios were found to differ between the islands and the mainland with 40% of hatchlings being female on islands and 75% on the mainland. Data from over seas suggests that survivorship of loggerheads is only about 25 for 10,000 eggs in a stationary population and in a declining population this number is reduced. Although often implied in the literature, there is no evidence to suggest that hatchlings return to the natal beach. Growth has been seen to be relatively fast in the initial years but slows dramatically as maturity is achieved. However it essentially follows the Von Bertalonffy curve fairly well.

Effects of Trawling

From throughout the Great Barrier Reef, large numbers of turtles are trawled annually. Three species account of most of the turtle bycatch: flatback turtles, loggerhead turtles and olive ridley turtles. Some of the turtles die as a result of being trawled but the resulting mortality has not been quantified from within the Great Barrier Reef waters. The trawling induced mortality of turtles from within the Great Barrier Reef is operating on the limited sized flatback and loggerhead turtles breeding units of the southern Great Barrier Reef. The breeding unit associated with the olive ridley turtles of the Great Barrier Reef has yet to be documented.

Current population models for sea turtles indicate that the populations are most sensitive to increased mortality of adult and large immature individuals; the same size classes that are usually trawled. In understanding the impact of trawling on turtle populations the catch per unit effort should not be seen to be as important as the actual number of turtles caught and the resulting mortality.

Three methods that could reduce trawler induced mortality were suggested: (1) trawlers could reduce soak times to less than 90 minutes; (2) specific areas could be closed unless TEDs are used; (3) seasons could be created during which TEDs must be used.

Evidence was presented that there is a correlation between the number of trawlers operating off Mon Reppos beach and the numbers of turtles found dead washed onto the beaches in the vicinity. This was largely a qualitative analysis; however, there is a documented decline in the number of nesting loggerhead turtles in the Mon Repos area between 1983 and 1988.

DISCUSSION OF PAPER

There was some dissension within the group as to the reliability of the correlation between trawling effort and turtle mortality. It was agreed that the data are circumstantial but that observations had shown that trawlers were operating at times when turtle mortality appeared to be the greatest. It seemed reasonable that it may be useful for the trawler fishermen to have a seasonal closure at the time of the nesting season for the turtles because this was also a recruitment phase for the prawn fishery. Given that a seasonal closure may be beneficially to both the fishermen and the turtles, it could be seen that a seasonal closure would be a win/win situation for both parties.

ABSTRACT

SEASNAKES

TIM WARD
James Cook University

The issue of a management plan for sea snakes needs to be addressed:

* Approximately 18 species are known to ocur in the GBRMP;
* Sea snakes are commonly caught in the nets of prawn trawlers;
* QDPI permits the collection of 20,000 sea snakes from between Bowen and Cape York;
* commercial tanneries use these sea snakes to produce leather for the domestic market.

Leather Industry

Commercial tanneries in Townsville and Cairns currently sell sea snake leather to manufacturers in Victoria, NSW and Queensland. Large and lucrative markets for sea snake leather goods exist in Europe and North America. However legislation in the Wildlife Protection Act prohibits the export of wildlife products (such as sea snakes) inthe absence of a management plan which ensures that exploitation is ecologically sustainable.

Size and composition of the by-catch

Dawson (1975) collected 108 sea snakes (8 species) from prawn trawlers off Townsville, Heatwole and Burns (1987, unpublished) collected 290 specimens (8 species) from between Cairns and Cape York. These data are insufficient to discern spatial and temporal patterns of distribution and abundance for even the most common species (eg Hydrophus degans, Lapemis hardwiekii).

Trawl mortality

Heatwole and Burns (1987) estimated trawl-induced mortality levels in the Gulf of Carpentaria of 42% when fishing for tiger prawn and 10% when fishing for banana prawns. No data are available for the GBRMP.

Population Sizes

Difficulties associated with relating by-catch to sea snake population size include the fact trawling only gives an estimate of snakes on the sea floor and misses those on the surface. This could be addressed by combining visual surveys with trawl by-catch analysis. Problems with this technique include species indentification, sightability and low density. Other methods of investigating sea snakes could be to attach sonar transmitters and/or depth recorders to scales to identify relative surface/bottom times.

Life history and reproduction

Heatwole and Burns (1987, unpublished) provided some information on the reproductive potential of sea snakes. Data from the east coast were combined with that from the Gulf of Carpentaria.

Age-determination

An age-determination technique does not exist for sea snakes. Sectioning bones to identify growth layers and using tetracycline to calibrate deposition rate would appear to be the method most likely to provide a reliable age-determination technique.

Some Management Options

1. Ban trade in rare species.
2. Impose quotas for commercially important species.
3. Monitoring population changes (using CPUE data)
4. Implementation of a numerical tagging system.

TWseasnakes

ABSTRACT

THE EFFECTS OF TRAWLING ON PELAGIC FISH POPULATIONS AND SEABIRD POPULATIONS

KEES HULSMAN
Griffith University

Introduction

In this paper, I propose to address the relationship between populations of seabirds and pelagic fish species. This relationship then sets the context in which one may consider the effects of trawling on seabird populations of the Great Barrier Reef (GBR).

There is a scarcity of information available about the bioenergetics of seabird communities of the GBR. Hulsman (unpublished data) has calculated that the 1.8 million seabirds in the Capricornia Region of the GBR Marine Park consume more than 15,000 tonnes of fish during the course of the birds' breeding season. Pelagic fish species constitute more than 99% of the dietary biomass of seabirds in the region. Pelagic fish such as engraulids, clupeids, scombrids and exocoetids are the main prey of these seabirds.

It is important to remember that most seabirds congregate at their breeding colonies for a small portion of the year. They spend most of the non-breeding season dispersed over a large area. The breeding season may vary from 3 to 9 months depending on the species. Therefore seabird predation on fish populations is not concentrated in a localised geographical region throughout the year. This may enable local fish stocks to recover. It is possible that the movement of pelagic fish species out of an area may cause seabirds to disperse from their breeding colonies.

Perusal of the literature reveals that seabird populations are capable of removing prey at rates that may have an impact on local fish stocks (Schneider et al 1987). For example, seabird communities in the northeastern Pacific and the North Sea utlise an estimated 22 to 29% of the annual fish production respectively (see Wien & Scott 1975, Furness 1978). The removal of such large quantities of pelagic fish may lead to competition between seabirds and commercial fishmen and affect the viability of one or both of the competitors: seabirds and man.

We are not sure of the exact number of seabirds on the GBR, but, for the sake of a discussion, let us suppose, that there are 14.4 million seabirds there. That is eight times the population in the Capricornia Section. Such a population would consume more than 118000 tonnes of pelagic fish per annum. This is a "ball park figure" to give you some appreciation of the quantity of fish that seabirds consume.

Need for management

One could conclude that it may be a good idea to decrease the seabird population on the GBR. Although that may decrease predation on fish slightly it would have serious repercussions on other parts of the coral reef system. For example the dispersal of seeds of vegetation which occurs on islands would be greatly decreased. The nutrients that the birds transfer from the sea to the land would be decreased and thus the vegetation would lose a major source of nutrient input. Thus because of the role that seabirds play in the coral reef environment, the managers of that environment must also protect and manage seabird populations. Such a task not only involves the protection and management of the nesting areas but also the food sources utilised by the birds.

Information required

Irrespective of the geographic area with which we are dealing, there are a number of questions that ought to be answered.

1. **What is the biomass of each size class of each pelagic fish species in the region?**

2. **What is the annual cycle of each pelagic fish species and how does its biomass in each size class change during the course of that cycle?**

3. **What is the biomass of each size class of each pelagic fish species eaten by seabirds?**

4. **What is the biomass of each size class of each pelagic fish species caught by commercial fishermen?**

5. **At what size does each pelagic fish species start to breed successfully?**

6. **What is the rate at which individuals are recruited to the breeding population?**

7. **What is the mortality rate of each size class?**

8. **What are the main causes of mortality of each size class of each pelagic species?**

At present we are unable to anser any of these questions fully but we are able to estimate the biomass of each size class of each pelagic fish species eaten by seabirds. These estimates can be improved by obtaining larger sample sizes to calculate the allometric equations needed more accurately.

Relationship between seabirds and fishery

From the answers to the eight questions above we need to be able to determine the impact that seabirds and commercial fishing each have on the fish stocks.

1. **Does predation by seabirds have a different effect on the fish populations than does commercial fishing?**

2. **How do seabirds and a commercial fishery affect one another?**

Let us deal with these two questions in sequence. Consider the following, predators select their prey from schools. In this context they tend to cull in so far as they capture individuals which are ill or slow in responding. Predators use some distinctive characteristic of the prey to single out the potential victims. It may be a colour difference or the manner of movement and so on. In contrast, commercial fishing seems to be less selective than other predators. Fish are entraped in nets of certain mesh size and any fish which is to large to pass through the mesh is caught. If indeed this brief sketch is correct then commercial fishing methods will have a different effect on fish stocks that piscivores and seabirds will have. Obviously these points need further consideration and investigation.

Commercial fishing may affect seabird populations by decreasing the numbers of predatory fish such as tuna and mackeral that the seabirds rely on to drive their prey to the surface. Were the decrease in the number of tuna to lead to decreased accessibility of food for the seabirds then the seabird populations could well decline. With such a decline in numbers one has also to consider the role of seabirds in the coral reef environs and what would the effect be of such a decline.

Let us now consider the effect seabirds may have on a commercial fishery. Were seabirds to consume large numbers of the size classes of pelagic fish species that are too small to be caught for commercial purposes, then it is possible that seabirds could affect the recruitment rate of some fish species to the size classes caught by fishermen. The question that remains, for such a situation, is do the seabirds significantly affect the sustainable catch for the fishery?

Epilogue

There is another aspect to this, namely, commercial fishermen may use seabird flocks to tell them what fish are present in the area and their exact location. In other words, seabirds indicate to fishermen where to fish for particular fish species. Fisheries and seabirds co-exist elsewhere in the world, it is a question of obtaining an appropriate balance between the two.

In this short presentation, I have attempted to raise a number of points that require consideration and I think require further investigation. Seabirds may be used to sample palagic fish populations to inform us about the annual cycle and abundance of particular species of pelagic fish. Such studies provide a different aspect to the more conventional methods of sampling fish populations to gain formation about their biology.

docname-trawl.eff.seabird

ABSTRACT

SEABIRDS

TERRY WALKER
Queensland National Parks and Wildlife Service

The days when Australian commercial fishermen depleted seabird colonies for bait and eggs or to reduce fishing competition are long gone. Today some seabirds appear to be benefitting from by-catch of the fishing industry in the GBR region. There is insufficient quantitative data historically to assess change in Reef seabird populations.

It is not possible at present to quantify feeding populations of seabirds on the GBR but preliminary maps illustrating breeding colony sizes and locations can be prepared. Four spatial patterns of breeding can be generalised for the major seabird species:-

1. Species that nest on islands along the length of Reef are the Crested Tern, Bridled Tern and Black-naped Tern although south of the Whitsunday Group the latter species seems to be present only on offshore cays. The Crested Tern feeds along the Reef year round but most Bridled Terns migrate or disperse overseas after the breeding season (3-4 months).

2. Species that nest solely or primarily at both the southern and sub-northern ends of the Reef are the Brown Boody, Masked Boody, Roseate Tern and Least Frigatebird.

3. Species that nest primarily along the northern half of the Reef are the Sooty Tern, Lesser Crested Tern and Common Noddy.

4. Species nesting primarily at the southern end of the Reef are the Wedge-tailed Shearwater and Black Noddy. The Shearwater population migrates or disperses from the GBR following breeding (5-6 months) as does most of the Black Noddy population from the southern islands. The largest colonies of Silver Gulls are also on southern cays but this species may be increasing in the north in association with increasing human activities.

Other seabird species are of minor importance numerically in Reef waters. These include cormorants, Caspian Terns, Little Terns, tropicbirds and pelicans. Cormorants have historical interactions with commercial fishing in temperate waters but are only common in a few small GBR areas. Pied Cormorants have breeding populations of a few hundred in the Whitsunday Islands, Shoalwater Bay and in Keppel Bay only (excluding mainland or estuarine populations). Little Pied Cormorants have a population of possibly 200 in the Capricorn Bunker islands where there is also a smaller population of Little Black Cormorants. Small groups of Little Pied Cormorants also occur on a couple of northern Peninsula islands.

Silver Gulls are a species for which there is some evidence of increasing numbers on the GBR as a result of human activities. Increases are attributed to availability of garbage at towns and islands combined with provision of fishing by-catch and

offal. The possibility of a 100-fold increase in gull populations such as has occurred in southern states and elsewhere in the world should be considered if numbers of people continue to increase in the Reef area. Higher numbers of gulls decrease the breeding success of other seabirds (sometimes to zero) due to gull predation on eggs, chicks and theft of food from chicks.

There are many gaps in information on GBR seabird feeding and breeding distribution. Conservation and management of the seabirds cannot be achieved until baseline surveys are carried out and ongoing monitoring is set in place to detect changes that occur.

ABSTRACT

FEEDING ECOLOGY OF THE PISCIVOROUS BIRDS *PHALACROCORAX VARIUS, P. MELANOLEUCOS AND STERNA BERGII* IN MORETON BAY, AUSTRALIA: DIETS AND DEPENDENCE ON TRAWLER DISCARDS

S.J.M. BLABER and T.J. WASSENBERG
CSIRO Division of Fisheries Research, PO Box 120, Cleveland 4163, Queensland, Australia

The diets of three piscivorous bird species from Moreton Bay, Queensland, Australia,were monitored for 14 months from April 1986 to September 1987. Regurgitated pellets from *Phalacrocorax varius* (pied cormorant) , *P. melanoleucos* (little pied cormorant) and *Sterna bergii* (crested tern) were collected monthly and prey items were identified from otoliths, spines and whole-fish remains. Otolith weight to fish length and weight relationships were used to aid in calculation of diet composition. *Sepia sp.* was the commonest prey of *P. varius* and *P. melanoleucos*; *Sterna bergii* took few *Sepia sp.* In order of decreasing importance, the teleosts ,and *Sillago maculata, Apogon fasciatus and Leiognathus moretoniensis* were the next most common prey in all diets. *P. melanoleucos* had previously been reported to eat primarily crustaceans. The size ranges of fish prey were 18 to 452 mm for *P. varius*; 25 to 246 mm for *P. melanoleucos*; and 33 to 226 mm for *Sterna bergii.* The three species had similarly narrow diets. There was a significant rank correlation between the diet of *P. varius* and the by-catch of the prawn trawlers. This, together with observations of feeding behaviour, the similarity of the diets and the benthic and benthopelagic nature of most prey species, suggests that in Moreton Bay the three bird species are primarily dependent on food from fishery discards. The population of about 350 *P. varius* possibly consume 13.7% of the total fish by-catch. The relationships between the fishery and the piscivorous birds is discussed in relation to size of bird popualtions and its possible dependence on the fishery.

docname-abst-blader-piscivorous

ABSTRACT

DOLPHINS

PETER CORKERON
University of Queensland

During a sociobiological study of dolphins in Moreton Bay, specifically for common species found around trawlers (humpback and bottlenose) the following results were obtained:

* Bottlenose dolphins are ubiquitous, but humpbacks generally only occur up to 3 miles offshore. It was attempted to determine where the groups of dolphins occur, but this was biased by the requirement for clear water which was found only in certain areas.

* However, the home range for groups could be assessed and this was as much as 250 square kilometers for some males. It was also found that animals outside the bay were different groups to those inside.

* Groups and individuals were identified by visual means.

* The density of bottlenose dolphins within the main study area was comparable with densities reported elsewhere. (People tend to gab numbers).

* Food studies showed that dominant males have first preference but it was also found that food value was not a determining factor, nor was the size of available food.

* In summer, when there are many trawlers working, the dolphins behaved in a manner inconsistent with food shortages. At this time dolphins may get most of their food from trawlers. But in winter, when there are fewer trawlers, they were much less selective of food offered to them.

* At least 36% of dolphins seen had wounds inflicted by sharks. However, these wounds healed quite quickly (circa 8 months for a major wound). Peak shark attack frequency was in summer when more trawlers and new calves were around. Males and females did not have any observable difference in attack frequency, except when females had calves.

* It is possible that shark ecology is also affected by trawling.

Some discussion occurred . No surveys had been done regarding the reliance of dolphin populations on trawlers and conclusions to this effect could not be drawn.

Some of the data collected by Helene Marsh during her dugong surveys could be applicable to studies of dolphin populations in the GBRR.

Marine Biology 101, 1–10 (1989)

Marine Biology

Feeding ecology of the piscivorous birds *Phalacrocorax varius*, *P. melanoleucos* and *Sterna bergii* in Moreton Bay, Australia: diets and dependence on trawler discards

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Abstract

The diets of three piscivorous bird species from Moreton Bay, Queensland, Australia, were monitored for 14 mo from April 1986 to September 1987. Regurgitated pellets from *Phalacrocorax varius* (pied cormorant), *P. melanoleucos* (little pied cormorant) and *Sterna bergii* (crested tern) were collected monthly and prey items were identified from otoliths, spines and whole-fish remains. Otolith weight to fish length and weight relationships were used to aid in calculation of diet composition. *Sepia* sp. was the commonest prey of *P. varius* and *P. melanoleucos; Sterna bergii* took few *Sepia* sp. In order of decreasing importance, the teleosts *Sillago maculata, Apogon fasciatus* and *Leiognathus moretoniensis* were the next most common prey in all diets. *P. melanoleucos* has previously been reported to eat primarily crustaceans. The size ranges of fish prey were 18 to 452 mm for *P. varius;* 25 to 246 mm for *P. melanoleucos;* and 33 to 226 mm for *Sterna bergii.* The three species had similarly narrow diets. There was a significant rank correlation between the diet of *P. varius* and the by-catch of the prawn trawlers. This, together with observations of feeding behaviour, the similarity of the diets and the benthic and benthopelagic nature of most prey species, suggests that in Moreton Bay the three bird species are primarily dependent on food from fishery discards. The population of about 350 *P. varius* possibly consumes 13.7% of the total fish by-catch. The relationships between the fishery and the piscivorous birds is discussed in relation to size of bird populations and its possible dependence on the fishery.

Introduction

Analyses of the relationships between commercial fisheries and piscivorous birds generally concentrate on the competition for a common resource, comparing the quantities of fish taken by birds and fishermen (Bailey and Hislop 1978, Furness 1982a, Furness and Cooper 1982). However, the effects of commercial fishing on piscivorous bird populations, mediated through such phenomena as altered fish abundances and fish discards, as described by Furness (1982b), has received less attention. The natural diets of piscivorous birds living in cool or temperate marine and oceanic waters have been closely examined (Wiens and Scott 1975, Furness 1982a, Croxall et al. 1984), while the diets of piscivorous birds of inshore marine and estuarine waters of the subtropics and tropics have been largely neglected (Serventy 1938, Whitfield and Blaber 1979).

Prawns have been trawled commercially in subtropical Moreton Bay, Queensland, for about 30 yr (Haysom 1985). The fate of the quantities of discarded fish by-catch has been studied by Wassenberg and Hill (1988, and in preparation), who reported that approximately 49% by weight is scavenged by piscivorous birds. The diets of three birds that feed on the by-catch in Moreton Bay – *Phalacrocorax varius* (pied cormorant), *P. melanoleucos* (little pied cormorant) and *Sterna bergii* (crested tern) – are described in the present study. The objectives of the work were to determine what proportions of the diets are derived from scavenging by-catch, whether this varies seasonally, whether the resource is partitioned among the bird species, and to what extent the birds may now be dependent on the commercial fishery.

Materials and methods

Bird diets

Regurgitated pellets and fish remains were collected once a month from April 1986 until May 1987 from seven navigation light platforms in Moreton Bay (Fig. 1). Platforms 2, 3, 4 and 5 were frequented by *Phalacrocorax varius* and Platforms 1, 6 and 7 by *P. melanoleucos.* In addition, pellets from *Sterna bergii* were collected from the old jetty at St. Helena Island in April, May and June 1986 and in March and April 1987.

All otoliths in pellets were individually weighed. Fish prey items in pellets were identified, and their length and weight calculated, mainly from otoliths (or in the case of

Table 1. Formulae used to calculate fish length (standard length, $SL = p + qx$, where x = otolith wt, mg) and weight (= ax, where x = otolith wt, mg) from otolith weights and fish weights (weight = rSL^k) from whole-fish lengths (standard length in mm; – = missing value)

Fish species	Fish length (mm) p+qx	Fish wt (g) ax	Fish wt (g) $10^{-6}\ rSL^k$
Apogon poecilopterus	39.3 + 0.9584x	0.51x	6.29 $SL^{3.44}$
Apogon fasciatus	33.0 + 1.0432x	0.30x	10.60 $SL^{3.28}$
Arius spp.	67.6 + 0.5227x	0.49x	0.16 $SL^{3.99}$
Atherinomorus lacunosus	60.6 + 1.6363x	0.62x	4.32 $SL^{3.27}$
Callionymus spp.	20.3 + 38.473x	4.89x	4.27 $SL^{3.24}$
Centropogon marmoratus	37.6 + 4.0999x	1.60x	708.00 $SL^{2.29}$
Euristhmus lepturus	61.9 + 12.588x	2.94x	98.30 $SL^{2.39}$
Gerres ovatus	60.4 + 3.7363x	3.56x	27.10 $SL^{3.03}$
Hyperlophus vittatus	–	2.37x	1.12 $SL^{3.44}$
Hyporhamphus regularis	84.0 + 5.7416x	1.67x	0.05 $SL^{3.82}$
Johnius australis	66.7 + 0.5048x	0.46x	24.90 $SL^{2.99}$
Leiognathus moretoniensis	30.5 + 7.8391x	1.49x	11.10 $SL^{3.22}$
Mugil georgii	56.0 + 2.6751x	2.04x	7.78 $SL^{3.21}$
Paramonacanthus otisensis[a]	4.96 + 0.00372x	0.89x	62.70 $SL^{2.87}$
Paraplagusia spp.	34.4 + 15.26x	3.27x	11.70 $SL^{2.99}$
Pelates quadrilineatus	49.4 + 10.468x	5.23x	16.20 $SL^{3.11}$
Platycephalus spp.	120.9 + 2.8364x	2.19x	0.61 $SL^{3.53}$
Plotosus anguillaris	94.5 + 5.3774x	3.44x	1.43 $SL^{3.36}$
Polydactylus heptadactylus	61.3 + 7.6586x	6.45x	27.30 $SL^{3.00}$
Priacanthus macracanthus	−47.1 + 131.923x	49.00x	120.00 $SL^{2.66}$
Pseudorhombus spp.	101.0 + 5.5493x	8.20x	0.22 $SL^{3.9}$
Saurida undosquamis	79.9 + 7.0005x	3.71x	2.85 $SL^{3.27}$
Siganus spp.	36.2 + 56.429x	13.10x	37.10 $SL^{2.90}$
Sillago ciliata	55.9 + 1.4419x	0.94x	12.30 $SL^{3.02}$
Sillago maculata	48.8 + 1.6062x	0.78x	31.40 $SL^{2.78}$
Siphamia roseigaster	24.6 + 3.565x	0.43x	47.90 $SL^{2.83}$
Sphyraena obtusata	139.8 + 2.2706x	2.47x	17.70 $SL^{2.85}$
Stolephorus carpentariae	34.9 + 10.243x	0.67x	3.38 $SL^{3.21}$
Suggrundus harrissi	75.4 + 4.3498x	2.33x	14.90 $SL^{2.94}$
Thryssa hamiltoni	64.3 + 2.6962x	1.17x	0.05 $SL^{4.22}$
Upeneus tragula	52.6 + 14.726x	8.13x	4.19 $SL^{3.38}$

[a] First dorsal spine length used in place of otolith weight

Paramonacanthus otisensis from first dorsal spine length). An otolith reference collection was compiled from fish collected from prawn trawl catches and by beach seining. This reference collection was used to construct otolith weight to fish weight conversion factors (a x, where x = otolith weight in mg) and otolith weight to fish length linear regressions [standard length (mm) = p + qx, where x = otolith weight in mg]. Hence, fish length and wet weight could be reconstructed. The fish collected from trawl catches and beach seines were also used to construct fish length (standard length, SL) to fish wet weight power-regressions [wt (g) = $r\,SL^k$: Table 1] to allow the wet weight of larger whole-fish remains to be estimated. Cephalopoda were identified as far as possible from beaks or shells. The mantle length and total weight of *Sepia* sp. were estimated from beak size and use of the formulae of Mattacola et al. (1984).

The diet of each bird species was analysed both in terms of the contribution by wet weight of each prey category and its numerical frequency. The diet of *Phalacrocorax varius* was analysed monthly over the complete sampling period, but the diets of *P. melanoleucos* and *Sterna bergii* were analysed overall for the 14 mo period, as sample sizes were small or sampling was incomplete.

Diet breadths (Bs) were calculated for each bird species using the formula of Levins (1968), $B = (\varepsilon p_i^2)^{-1}$ (where p_i is the proportion each prey category contributes to the diet by weight), standardised to fractions of maximum possible breadth (1) by the method of Hespenheide (1975), $[B_s = (B-1)/(n-1)]$.

The composition of the diet was compared with published data on rankings of species caught on fish trawls, using Spearman's rank correlation coefficients.

The use of otoliths for quantitative estimation of diets of marine piscivores has been criticised by Jobling and Breiby (1986). They argue that because otoliths are rapidly attacked by stomach acid solutions, otoliths taken from stomach contents or faeces may be misleading or give inaccurate results. Jobling and Breiby did not study otoliths from regurgitated pellets, although Duffy and Laurenson (1983) showed that otoliths in the pellets of *Phalacrocorax capensis* may be partially or entirely digested. However, otoliths can accurately determine the diets of piscivorous birds if they are not eroded or digested (Lumsden and Haddow 1946, Whitfield and Blaber 1979, Ainley et al. 1981, Doornbos 1984, Jackson 1984). In the present study, very few otoliths in pellets showed any sign of erosion.

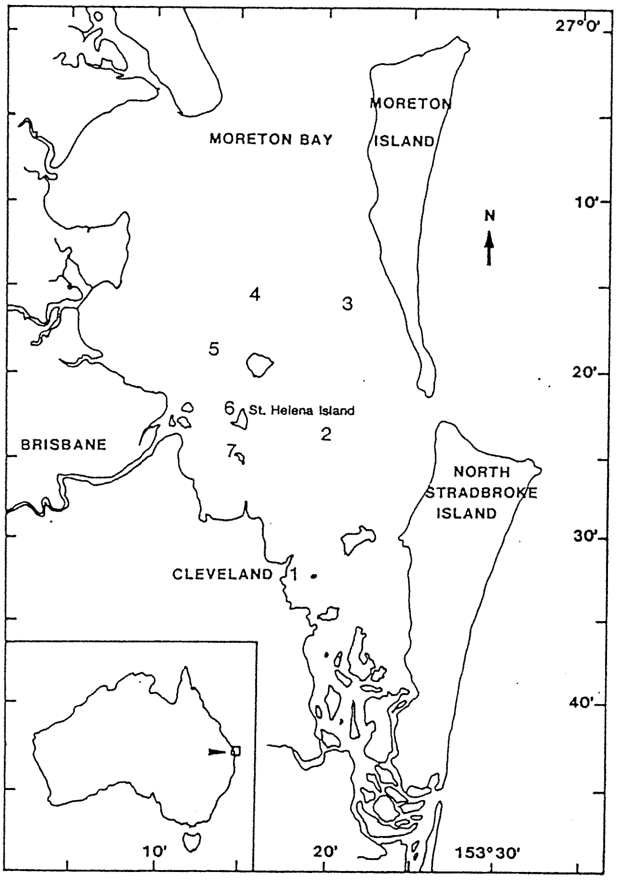

Fig. 1. Moreton Bay, Queensland, Australia, showing location of seven sampling stations and St. Helena Island

Table 2. *Phalacrocorax varius*. Diet in Moreton Bay from April 1986 to May 1987. Depth zone of prey fish shown for all taxa >0.1%; B: benthic; BP: benthopelagic; P: pelagic

Food items	% wt	% nos.	Depth zone
Acanthopagrus australis	<0.1	<0.1	
Alepes djedaba	<0.1	<0.1	
Ambassis spp.	<0.1	<0.1	BP
Anguillidae	0.4	<0.1	B
Antennarius sp.	<0.1	<0.1	
Apogon poecilopterus	0.4	0.5	BP
Apogon fasciatus	12.8	30.5	BP
Arius spp.	1.1	1.0	B
Arnoglossus sp.	<0.1	<0.1	
Aserragodes macleayanus	<0.1	<0.1	
Atherinomorus lacunosus	0.5	0.9	P
Callionymus spp.	0.9	2.3	B
Canthigaster maculatus	<0.1	<0.1	
Centropogon marmoratus	0.2	1.2	B
Cyclichthys jaculiferus	<0.1	0.2	B
Dasson variabilis	<0.1	<0.1	
Euristhmus lepturus	<0.1	0.1	B
Gerres ovatus	5.2	4.2	BP
Gobiidae	<0.1	<0.1	
Harengula sp.	0.2	0.1	P
Hippocampus planifrons	<0.1	<0.1	
Hippocampus whitei	<0.1	<0.1	
Hyperlophus vittatus	<0.1	<0.1	
Hyporhamphus regularis	0.8	0.8	P
Johnius australis	12.1	4.1	BP
Leiognathus moretoniensis	1.4	8.9	BP
Meuschenia trachylepis	<0.1	<0.1	
Mugil georgii	2.0	0.6	BP
Muraenesox cinereus	0.1	<0.1	B
Paramonacanthus otisensis	4.1	7.7	BP
Parapegasus natans	<0.1	<0.1	
Parapercis nebulosa	0.2	0.5	B
Paraplagusia spp.	1.3	0.7	B
Pelates quadrilineatus	5.1	6.7	BP
Pentapodus setosus	0.3	0.4	BP
Platycephalus spp.	1.0	0.3	B
Plotosus anguillaris	1.5	0.8	B
Polydactylus heptadactylus	1.8	0.4	B
Priacanthus macracanthus	<0.1	<0.1	
Pseudorhombus spp.	2.3	0.3	B
Rhabdosargus sarba	<0.1	<0.1	
Saurida undosquamis	0.5	0.5	B
Siganus spp.	<0.1	<0.1	
Sillago ciliata	1.6	0.9	B
Sillago maculata	16.4	5.5	B
Siphamia roseigaster	0.1	0.7	BP
Sphyraena obtusata	0.6	0.4	P
Stolephorus carpentariae	<0.1	0.1	P
Suggrundus harrissi	1.1	1.1	B
Syngnathidae	<0.1	0.2	BP
Thryssa hamiltoni	0.4	0.5	P
Upeneus tragula	<0.1	<0.1	
Non-fish items			
Sepia sp.	22.8	14.3	
Octopus sp.	0.3	0.5	
Total wt (g) + no.	65 398	4 361	

Bird numbers

The numbers of *Phalacrocorax varius*, *P. melanoleucos* and *Sterna bergii* on each of the platforms were counted monthly, prior to pellet collection, from June 1986 until August 1987. Overall counts of these species were undertaken throughout Moreton Bay in May, July, August and September 1987.

Trawler numbers

The number of trawlers working in the vicinity of the collecting platforms was noted from June 1986 until June 1987. In addition the number of trawlers working in Moreton Bay each month from October 1986 to June 1987 was recorded.

Results

Bird diets

Phalacrocorax varius (pied cormorant)

A total of 1121 pellets and 335 other remains (mainly fish) were examined, equivalent to a total weight of 65 398 g of prey.

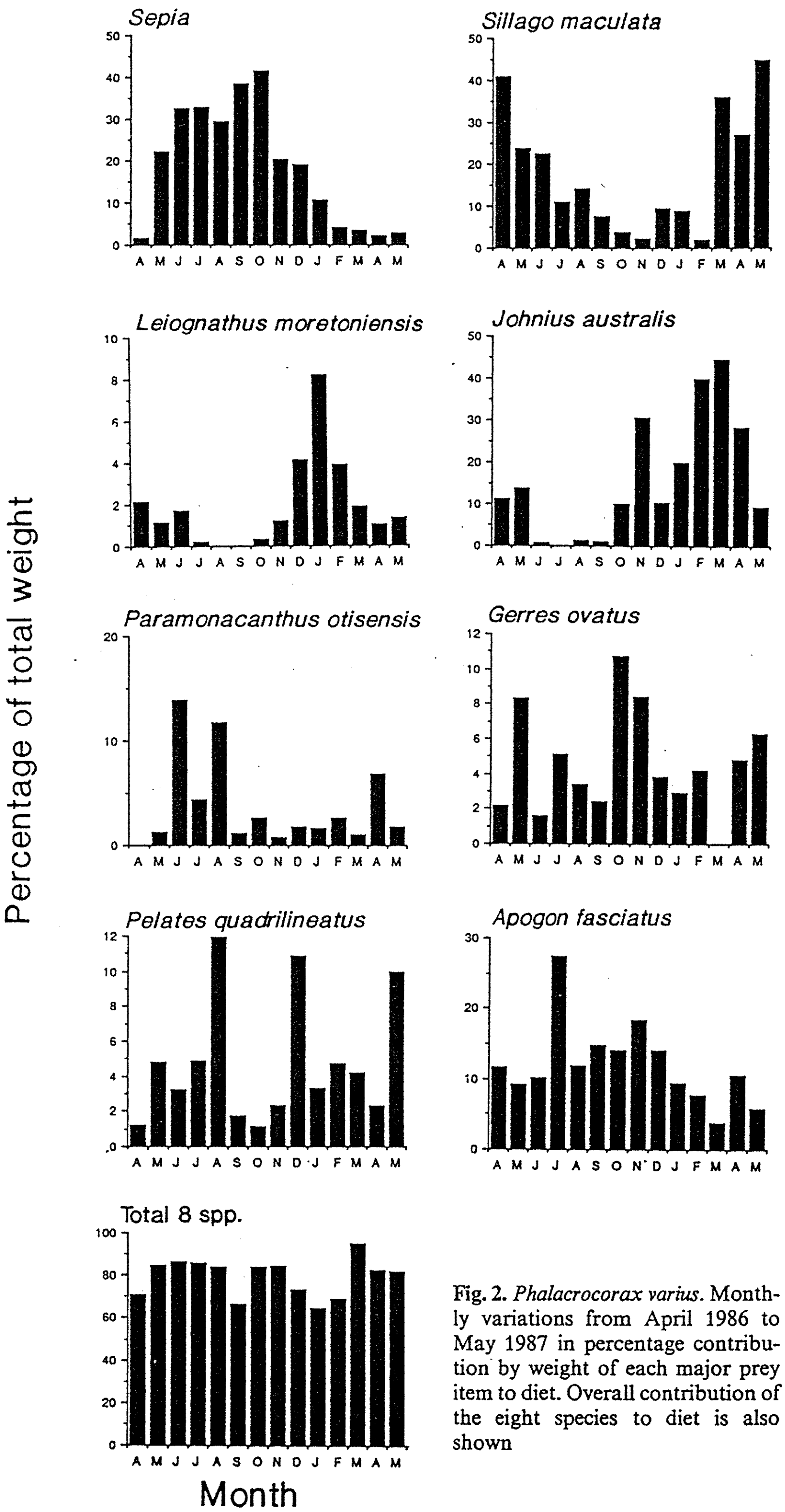

Fig. 2. *Phalacrocorax varius*. Monthly variations from April 1986 to May 1987 in percentage contribution by weight of each major prey item to diet. Overall contribution of the eight species to diet is also shown

Overall diet. The composition of the diet from April 1986 to May 1987, in terms of the percentage weight and numerical frequency of each food taxon, showed that although the birds ate representatives of 54 taxa, over 80% of the prey, both by weight and numbers, consisted of eight species (Table 2). In terms of weight, the cuttlefish *Sepia* sp. was the most important prey (22.8%), followed by *Sillago maculata* (16.4%) and *Apogon fasciatus* (12.8%). In contrast, *A. fasciatus* was numerically most important (30.5%), followed by *Sepia* sp. (14.3%) and *Leiognathus moretoniensis* (8.9%).

Monthly variations in diet. Monthly changes in the relative contributions of the eight dominant prey and the total percentage contribution of these eight prey (Figs. 2 and 3) indi-

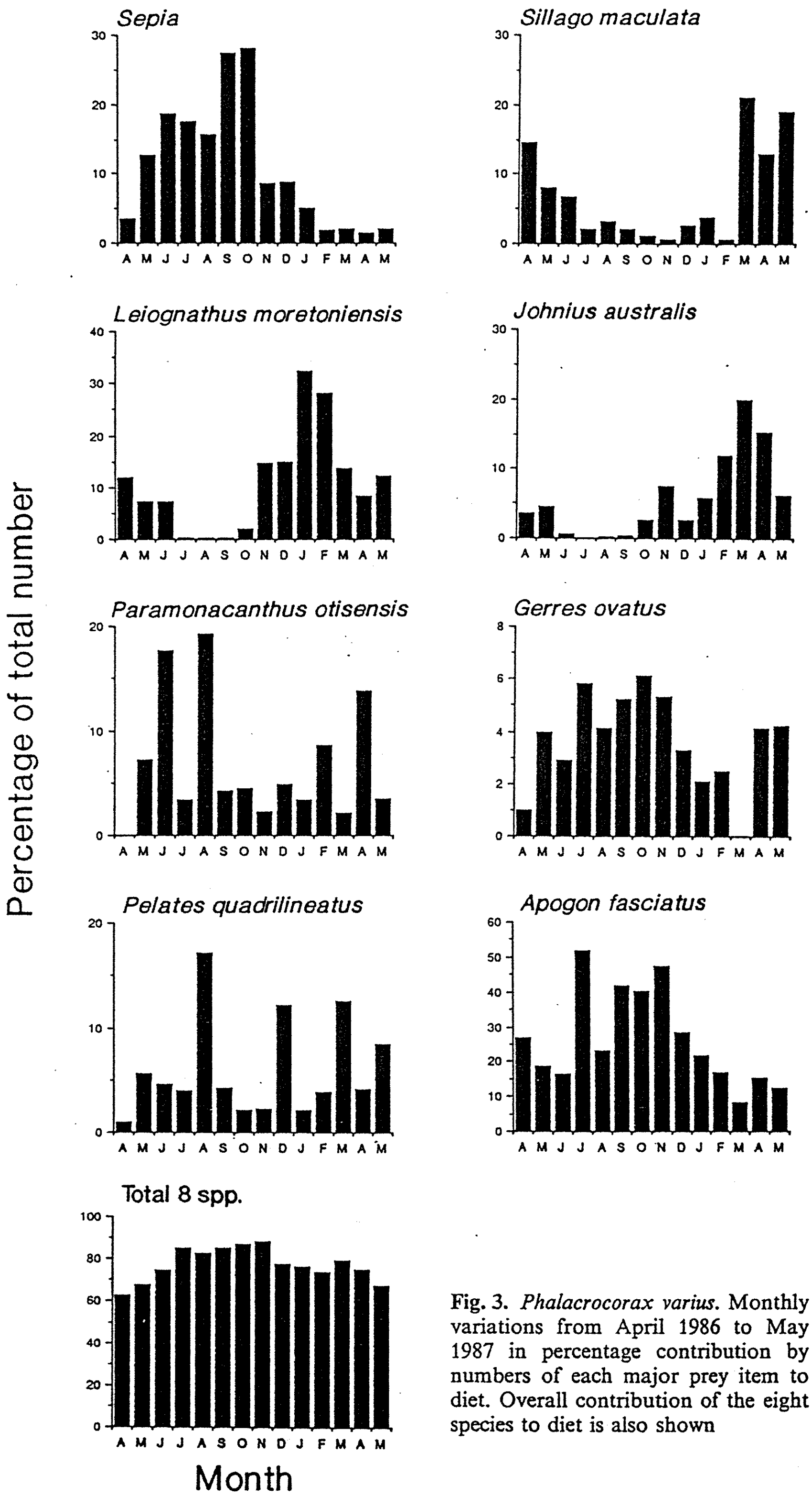

Fig. 3. *Phalacrocorax varius*. Monthly variations from April 1986 to May 1987 in percentage contribution by numbers of each major prey item to diet. Overall contribution of the eight species to diet is also shown

cate pronounced seasonal changes in diet. *Sepia* sp. was eaten in greatest quantity from May to December, with a peak in October; *Sillago maculata* from March to August, with a peak in May; *Apogon fasciatus* throughout the year, peaking from July to December; *Johnius australis* from October to May, with a peak in March; and *Leiognathus moretoniensis* from December to June, with a January peak. *Gerres ovatus, Pelates quadrilineatus* and *Paramonacanthus otisensis* were eaten throughout the year.

Length and weight of prey. The mean length and weight of fish prey-items, irrespective of species, together with minima and maxima, are shown in Table 3. Mean length varied from 66 to 93 mm with a grand mean of 76 mm. The size range

Table 3. Mean lengths (SL, mm) and weights (g) of fish prey of three piscivorous birds in Moreton Bay from April 1986 to May 1987. Standard deviations in parentheses. –: no data

Month	*Phalacrocorax varius*				*Phalacrocorax melanoleucos*				*Sterna bergii*			
	SL (mm)	wt (g)	range		SL (mm)	wt (g)	range		SL (mm)	wt (g)	range	
			SL	wt			SL	wt			SL	wt
Apr.	80 (51)	17 (21)	20–400	0.1–149.3	72 (42)	15 (17)	25–103	0.4–33.7	69 (28)	12 (14)	33–160	0.4–54.8
May	78 (42)	16 (20)	18–324	0.1–141.0	91 (35)	19 (18)	42–155	2.6–51.7	58 (8)	5 (5)	52– 63	1.1– 8.8
June	68 (31)	12 (13)	36–207	0.1– 77.0	–	–	–	–	95 (52)	23 (24)	38–226	1.4–84.6
July	66 (31)	9 (12)	34–278	0.3–117.3	–	–	–	–	–	–	–	–
Aug.	69 (31)	12 (19)	24–230	0.2–259.5	51 (18)	13 (18)	30– 94	3.0–67.8	–	–	–	–
Sep.	72 (33)	15 (41)	30–233	0.1–675.0	73 (43)	17 (26)	35–173	0.5–91.7	–	–	–	–
Oct.	70 (35)	14 (19)	30–197	0.2–118.2	–	–	–	–	–	–	–	–
Nov.	66 (32)	13 (18)	27–192	0.2–115.8	77 (24)	12 (8)	36–165	0.5–45.1	–	–	–	–
Dec.	72 (35)	11 (15)	34–228	0.6–148.6	70 (22)	12 (8)	39–139	1.6–28.9	–	–	–	–
Jan.	78 (45)	16 (30)	34–372	0.4–261.9	72 (33)	13 (14)	30–160	0.4–53.4	–	–	–	–
Feb.	71 (33)	12 (14)	34–200	0.7– 58.3	60 (25)	9 (11)	34–111	0.4–36.5	–	–	–	–
Mar.	93 (36)	19 (19)	37–178	0.2– 76.2	81 (30)	20 (15)	39–122	1.6–40.9	110 (28)	36 (16)	60–165	7.8–56.6
Apr.	87 (42)	19 (15)	31–341	0.9– 73.7	84 (56)	20 (27)	37–246	1.1–95.5	84 (43)	20 (20)	36–176	0.3–62.7
May	91 (46)	20 (21)	36–452	0.3–201.6	97 (65)	24 (30)	39–208	1.8–77.5	–	–	–	–
Overall	76 (9)	15 (3)	18–452	0.1–675.0	75 (13)	16 (5)	25–246	0.4–95.5	83 (21)	19 (12)	33–226	0.4–84.6

Table 4. *Phalacrocorax melanoleucos*. Diet in Moreton Bay from April 1986 to May 1987. Depth zone of prey fish shown for all taxa; B: benthic; BP: benthopelagic; P: pelagic

Food items	% wt	% nos.	Depth zone
Apogon poecilopterus	0.3	0.6	BP
Apogon fasciatus	10.2	23.5	BP
Arius spp.	1.8	0.6	B
Arrhamphus sclerolepis	0.2	0.3	P
Atherinomorus lacunosus	0.3	1.9	P
Centrogenys vaigiensis	0.2	0.3	B
Dasson variabilis	<0.1	0.3	B
Euristhmus lepturus	0.3	1.9	B
Gerres ovatus	3.1	4.3	BP
Johnius australis	9.1	3.4	BP
Leiognathus moretoniensis	0.6	3.7	BP
Meuschenia trachylepis	<0.1	0.3	BP
Paramonacanthus otisensis	1.7	4.3	BP
Parapercis nebulosa	<0.1	0.6	B
Pelates quadrilineatus	6.7	9.0	BP
Pentapodus setosus	7.7	10.8	BP
Platycephalus spp.	0.6	0.9	B
Plotosus anguillaris	3.0	2.8	B
Polydactylus heptadactylus	0.7	0.9	B
Pseudorhombus spp.	<0.1	0.3	B
Scorpaenidae	<0.1	0.3	B
Sillago maculata	26.6	11.1	B
Stolephorus carpentariae	<0.1	0.3	P
Suggrundus harrissi	0.2	0.6	B
Syngnathidae	<0.1	0.3	BP
Thryssa hamiltoni	0.2	0.9	P
Non-fish items			
Sepia sp.	26.7	12.4	BP
Total wt (g) + no.	6478	323	

Table 5. *Sterna bergii*. Diet in Moreton Bay during April, May and June 1986 and March and April 1987. Depth zone of prey fish shown for all taxa. B: benthic; BP: benthopelagic; P: pelagic

Food items	% wt	% nos.	Depth zone
Apogon poecilopterus	1.1	1.5	BP
Apogon fasciatus	15.0	34.6	BP
Arius spp.	1.1	1.5	B
Atherinomorus lacunosus	0.8	2.3	P
Callionymus spp.	0.1	0.8	B
Gerres ovatus	1.7	0.8	BP
Harengula sp.	1.4	0.8	P
Johnius australis	21.2	9.2	BP
Leiognathus moretoniensis	5.4	24.6	BP
Pelates quadrilineatus	0.4	2.3	BP
Plotosus anguillaris	4.4	0.8	B
Sillago maculata	46.5	16.1	B
Stolephorus carpentariae	0.1	1.5	P
Suggrundus harrissi	0.2	0.8	B
Non-fish items			
Sepia sp.	0.6	1.5	BP
Macrophytes	0.1	0.8	B
Total wt (g) + no.	2345	130	

was most commonly from about 30 to 250 mm, but the overall recorded range was from 18 to 452 mm. The largest prey item was a single specimen of the eel *Muraenesox cinereus*. Mean weight of fish prey varied from 9.3 to 19.5 g, with an overall range of 0.1 to 675.0 g. The mean weight of *Sepia* sp. prey was 0.3 g, with a mean mantle length of 55 mm and a range of 18 to 105 mm.

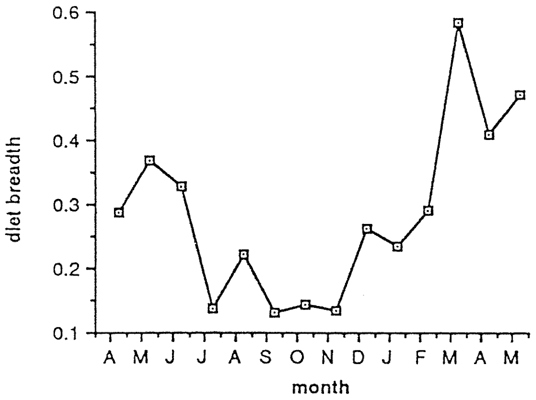

Fig. 4. *Phalacrocorax varius*. Diet breadth from April 1986 to May 1987

Phalacrocorax melanoleucos (little pied cormorant)

A total of 92 pellets and 33 other remains (mainly fish), equivalent to a total weight of 6 478 g, were analysed.

Overall diet. The contributions of each food type in terms of percentage weight and numerical frequency showed that 80% of the diet by weight was comprised of five species (Table 4): *Sepia* sp. (26.7%), *Sillago maculata* (26.6%), *Apogon fasciatus* (10.2%), *Johnius australis* (9.1%), and *Pentapodus setosus* (7.7%). In terms of numbers, however, *A. fasciatus* (23.5%), was the most important, followed by *Sepia* sp. (12.4%), *Sillago maculata* (11.1%), *P. setosus* (10.8%) and *Pelates quadrilineatus* (9.0%).

Length and weight of prey. The mean length of fish prey was from 51 to 97 mm, with a grand mean of 75 mm (Table 3). Length ranged from 25 to 246 mm. Mean weights ranged from 9.4 to 24.3 g with a grand mean of 15.9 g. Weights of fish prey ranged from 0.4 to 95.5 g. The mean weight of *Sepia* was 0.3 g, with a mean mantle length of 55 mm and a range from 50 to 148 mm.

Sterna bergii (crested tern)

The 68 pellets collected were equivalent to a total weight of 2 345 g of prey.

Overall diet. The percentages contributed by each food category in terms of weights and numbers showed that five species made up more than 90% of the diet by weight (Table 5): *Sillago maculata* (46.5%), *Johnius australis* (21.2%) and *Apogon fasciatus* (15.0%) were the most important. Numerically the most frequently consumed species were *A. fasciatus* (34.6%), *Leiognathus moretoniensis* (24.6%) and *S. maculata* (16.1%). Very few *Sepia* sp. were recorded in the pellets.

Length and weight of prey. The mean length of prey was from 58 to 110 mm with a grand mean of 83 mm (Table 3). Length ranged from 33 to 226 mm. Mean weights ranged from 4.5 to 35.8 g, with a grand mean of 19.1 g and a range from 0.4 to 84.6 g.

Variety in the diet

The diet of *Phalacrocorax varius* was least varied from July to November, (Fig. 4) when *Sepia* sp. and *Apogon fasciatus* contributed most to the diet (Fig. 2). It was most varied in autumn and early winter, when *Sillago maculata, Johnius australis* and *Leiognathus moretoniensis* made up much of the diet. Overall diet breadth, measured by the Levins' (1968) formula (scale of 0 to 1, where 1 is maximum breadth) for the 14 mo sampling period was 0.274. Overall diet breadths for *P. melanoleucos* and *Sterna bergii* were similar at 0.266 and 0.241, respectively.

Comparisons of items in diet with trawl by-catch

For the nine major species consumed by *Phalacrocorax varius*, there is a significant correlation between their numerical rankings in the diet and in the trawl catches recorded by Stephenson et al. (1982b) (Spearman's $R=0.176$; $P<0.05$). They did not record weights, but the weight rankings of species in the diet of *P. varius* correlate significantly with the weight rankings in the trawl catches of Maclean (1972) ($R=0.785$; $P<0.02$). Maclean did not record Cephalopoda, so these were omitted from weight rankings. The mullet *Mugil georgii* was the only species that appeared regularly in the diet of *P. varius* but was not listed in trawl records. This species made up 0.2% (July), 0.5% (September), 6.3% (October), 8.3% (November) and 6.6% (December) of diet by weight. There were no significant rank correlations between the diets of *P. melanoleucos* or *Sterna bergii* and the catch composition data of Maclean or Stephenson et al. (1982b), either in terms of weights or numbers.

Number of birds

The number of *Phalacrocorax varius* at the seven sampling stations at each monthly count averaged 127 (SE = 7.5), with a low of 75 in June 1986 and a high of 185 in September 1987 (Table 6). There were fewer *P. melanoleucos:* an average of 9 (SE = 1.8), with a low of 2 in May 1987 and a high of 26 in September 1986. *Sterna bergii* were not counted, as they did not roost consistently on the sampling platforms. Counts were also made of the cormorants in the whole of Moreton Bay. There were 373 *P. varius* in May 1987, 320 in July 1987, 323 in August 1987 and 383 in September 1987. The mean was 350 (SE = 19). Diet samples were therefore being taken from about a third of the total Moreton Bay population of *P. varius*. The number of *P. melanoleucos* varied considerably; many may have been roosting away from Moreton Bay or out of sight from the boat.

e 6. Numbers of cormorants on seven sampling stations in ·eton Bay from June 1986 to September 1987. –: no count made

nth	*Phalacrocorax varius*	*Phalacrocorax melanoleucos*
ıe	75	0
·y	136	4
ıgust	167	9
ptember	141	26
:tober	151	4
ovember	106	19
·ecember	143	6
ınuary	117	7
'ebruary	110	10
/Iarch	97	7
\pril	128	7
Vlay	136	2
June	–	–
July	112	8
August	100	10
September	185	20
$\bar{x}$ (SE)	127 (7.5)	9 (1.8)

Table 7. Number of trawlers recorded at night in Moreton Bay as a whole and during daylight in the vicinity of sampling platforms. –: no count made

Month	Night, Moreton Bay		Day, near platforms
	mean count of boats	no. of counts	total no. of boats
1986			
June	–	–	2
July	–	–	1
Aug.	–	–	6
Sep.	–	–	20
Oct.	23	4	0
Nov.	20	4	13
Dec.	3	5	0
1987			
Jan.	17	7	13
Feb.	26	13	11
Mar.	28	5	8
Apr.	17	3	16
May	22	6	11
June	7	3	–
Overall mean (SE)	20.5 (1.8)	$n=50$	mean = 8.4 (2.0)

Number of trawlers

The number of trawlers recorded fishing in Moreton Bay from October 1986 to June 1987 varied considerably (Table 7). The grand mean per day was 20.5 (SE = 1.8) boats. There were very few occasions when there was no fishing activity. From between 0 and 20 (mean 8.4; SE = 2.0) trawlers were working in the vicinity of the sampling stations at the time of pellet collection.

Discussion

The diets of the cormorants *Phalacrocorax varius* and *P. melanoleucos* in Moreton Bay were alike, with *Sepia* sp., *Sillago maculata*, *Apogon fasciatus* and *Johnius australis* constituting the most important prey (Tables 2 and 4). The three fish species also predominated in the diet of *Sterna bergii*, which consumed few cuttlefish. A small number of species made up most of the diets. The mean lengths and weights of the fish prey of the three bird species were nearly equal, but *P. varius* took a wider size range and is capable of catching much larger fish (Table 3).

Phalacrocorax varius in south-west Australia was reported to eat chiefly small fishes such as apogonids and gobiids (Serventy 1938). *P. carbo*, a similar-sized species to *P. varius* (about 2 kg), feeds in the subtropics on fish 20 to 226 mm long and 1 to 214 g in weight (Whitfield and Blaber 1979, Jackson 1984), results similar to those obtained here for *P. varius*.

Phalacrocorax melanoleucos is widespread on both estuaries and inland waters throughout Australia (Lindsey 1986). In both freshwater and estuarine localities in south west Australia, Victoria, and New Zealand, it has been recorded as feeding primarily on Crustacea (Serventy 1938, Dickinson 1951, McNally 1957). Its diet in fresh waters of inland New South Wales consists of 60% Crustacea and only 38% fish (Miller 1979). The mean length and length range (23 to 160 mm) of these fish were similar to those of the present study.

The tern *Sterna bergii* eats a wide variety of fish, of which a substantial proportion are pelagic species (Hulsman 1977, 1984, Harris and Last 1982), many of which are taken over shallow seagrass beds (Harris and Last 1982). In Moreton Bay, however, the bulk of the diet consisted of benthic or benthopelagic species (Table 5) from deeper waters; these species would normally be inaccessible to the terns. The mean lengths and weights of prey in Moreton Bay were similar to, but slightly less than, those recorded for *S. bergii* in other areas (Hulsman 1977, 1981).

Although the major prey species occurred in the diet of *Phalacrocorax varius* in almost all months, seasonal variations in quantities were marked (Figs. 2 and 3). *Sepia* sp. and *Apogon fasciatus* made their greatest contribution in spring, while *Johnius australis* and *Leiognathus moretoniensis* peaked in summer and *Sillago maculata* in autumn and winter. Such variations in the diet may be a reflection of changes in abundance or availability of the prey species. Unfortunately, comparison of the composition of the diet with published data on fish abundances gives somewhat conflicting results. The estimated times of maximum abundance of *A. fasciatus*, *L. moretoniensis*, and *S. maculata* given in Stephenson et al. (1982a) do not correspond with the peaks in Figs. 2 and 3 of the present paper. *S. maculata* ("winter whiting") contributed most significantly to the diet from March to June, but it is trawled commercially in largest numbers from April to September (Weng 1986). *Gerres ovatus* and *Pelates quadrilineatus*, which showed no definite peaks in the diet, are common in Moreton Bay throughout the year (Blaber and Blaber 1980). No data are available on seasonal abundances of *Sepia*. sp.

Relationships between bird diets and trawling

Large numbers of *Phalacrocorax varius*, *P. melanoleucos* and *Sterna bergii*, gulls (*Larus novaehollandiae*) and other birds congregate around Moreton Bay prawn trawlers when the fish by-catch is being discarded. There is some partitioning of these discards among the various scavengers: Wassenberg and Hill (in preparation) estimated that *P. varius* take 14.6% of the biomass of trawl fish that are discarded, while terns and gulls (no distinction made) take 34.3%. Much of the remainder goes to dolphins.

The species composition of the discarded trawler by-catch can be deduced from data in Stephenson et al. (1982 a, b) and Maclean (1972), while Wassenberg and Hill (1988) list the fish families discarded. Almost all of the species of fish we found in the birds diets also occur in the trawl by-catch. Furthermore, the commonest and most numerous species in the by-catch are also the most important in the diets. Since the commonest species in the by-catch are probably abundant in the environment, this may seem logical. However, several points suggest that much of the food of *Phalacrocorax varius* is obtained solely from discards. Firstly, the majority of species eaten are benthic or benthopelagic and occur in greatest numbers in deeper water where *P. varius* is unlikely to fish; the similar-sized *P. carbo* can dive to 9 m, but commonly dives to 2–3 m (Green 1968, Whitfield and Blaber 1979); secondly, there is a significant rank-order correlation between species in the diet and by-catch. An exception is the mullet, *Mugil georgii*, which constituted 2% of the overall diet of *P. varius* (Table 2) but is rare in the by-catch according to published records. However, it appeared in the diet between July and November, which is when it is absent from inshore waters (Blaber and Blaber 1980), so perhaps they move at this time to the offshore fishing grounds frequented by *P. varius*.

Most of the fishes taken by *Phalacrocorax melanoleucos* and *Sterna bergii* are also benthic or benthopelagic and the most important ones in the diet are also the commonest in the by-catch, but there is no rank order correlation between diets and by-catch. Nevertheless, it is probable that much of the prey taken by these species is derived from discards. The lack of correlation may be accounted for by *P. melanoleucos* and *S. bergii* being unable to take the larger fishes that are accessible to *P. varius*. The similarity in the diets of the three piscivorous birds also suggests that the prey may be derived from a common source.

When discarded as by-catch, 86% of *Apogon fasciatus* and *Sillago maculata* – two of the commonest food items (Tables 2, 4 and 5) – float for at least 10 h (Wassenberg and Hill (1988). These fish would therefore remain available to birds for a long time after dumping and, allowing for drift, at sites away from the immediate vicinity of trawling. By-catch is generally discarded around sunrise (Wassenberg and Hill in preparation) *Phalacrocorax varius* and *P. melanoleucos* are reported to start feeding soon after dawn (McNally 1957). The feeding peak of *P. carbo*, which is similar in size to *P. varius*, is between 06.00 and 08.00 hrs (Whitfield and Blaber 1979). Hence it is likely that the natural feeding periodicity of the cormorants in Moreton Bay coincides with the maximum availability of trawl by-catch. Wassenberg and Hill (1988) observed that cormorants feed on by-catch only in daylight, but that *Sterna bergii* feeds on fish discards at night as well as during the day. *S. bergii* on the Barrier Reef forages most intensely in the early morning or late afternoon but its feeding is also strongly influenced by the tidal cycle, and may occur at any time of the day (Hulsman 1977).

The roosting sites of the large *Phalacrocorax varius* and smaller *P. melanoleucos* are spatially segregated: the former occupies offshore roosts over deep water and the latter inshore platforms over shallow water (Fig. 1: Platforms 2 to 5 and 1,6 and 7, respectively). It is likely that this segregation is related to the foraging habits of the species, as it is with the large cormorant *P. carbo* which feeds in deeper water and usually takes larger fish than the smaller *P. africanus* (Whitfield and Blaber 1979). If *P. varius* and *P. melanoleucos* have a similar feeding segregation, it is likely that it has broken down in Moreton Bay in response to the abundance of trawl discards, where the only factor separating the species is the maximum size of prey which can be taken. The differences noted earlier between the food of *P. melanoleucos* in Moreton Bay and that in other areas, where crustaceans predominate in the diet, may be accounted for by the presence of this artificial source of fish and cephalopods in Moreton Bay.

The amount of trawling effort in Moreton Bay varies both seasonally and daily. Counts (Table 7) show, however, that the mean number working during the night was 20 boats. This number of trawlers would produce about 790 kg of fish by-catch per night (3.95 kg/trawl; 10 trawls/night) (Wassenberg and Hill in preparation). Although 41% of this by-catch is eaten by dolphins (Wassenberg and Hill 1988) much of the remainder is available to the birds. The mean number of *Phalacrocorax varius* in Moreton Bay was 350 and, assuming a daily consumption rate of 400 g/bird [similar to, but slightly less than *P. carbo* (Serventy 1938, Du Plessis 1957, Whitfield and Blaber 1979)], the total food consumption by the population of *P. varius* is of the order of 140 kg, d^{-1}. Of this total, 23.1% is cephalopods (Table 2), for which no by-catch data are available. Hence, if cephalopods are excluded, the daily consumption of fish is 108 kg, that is, 13.7% of the total fish by-catch. This percentage is close to the 14.6% estimated by Wassenberg and Hill (in preparation) by visual observation.

The results of the present study suggest that the feeding habits and diets of the major piscivorous birds in Moreton Bay have been modified to take advantage of a substantial source of food, a by-product of the prawn fishery. Furness (1982 b) postulates that the numbers of several species of seabirds in the North Sea have increased markedly in response to increased availability of food caused by ecosystem changes induced by fishing; populations of herring gulls, skuas and fulmars are now dependent on discards from fishing boats. It is not known to what extent the population of birds, now possibly artificially enlarged in Moreton Bay, will respond to future changes in the fishery and levels of fishing activity. However, the present study should provide data for future comparisons.

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ABSTRACT

MANAGEMENT OF THE EAST COAST PENAEID PRAWN FISHERY

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Limited entry was introduced to the Gulf of Carpentaria during 1977 and a poorly-defined boat replacement policy generated a rapid increase in vessel numbers of the east coast via licence-splitting and transfer of replaced vessels. Speculative investment exacerbated this expansion. In 1979 the Queensland Government unilaterally introduced a freeze on new entry, and New South Wales followed in 1982. In 1984 a total freeze was introduced by New South Wales with complementary federal legislation in Commonwealth waters off New South Wales and Queensland. Attempts were made to contain effort by controls on efficiency and in 1986 a system of vessel description incorporating measures of fishing power was legislated, defining the fleet in a quantifiable way to allow penalities for upgrading of fishing power. However attempts to limit effort could not be judged a success and it is considered that real effort is still increasing.

Seasonal closures were implemented in 1984 following industry concern at targeting of juvenile P. esculentus north of Cooktown. Successive closures have been implemented in 1985, 1987 and 1988 with the area closed varying with industry negotiation. Two issues are apparent - the desire to protect juvenile P.esculentus and concern as to the pulse effected of targetted effort along the coast from migratory non-resident vessels. The total northern closure is aimed at juvenile prawn protection whilst the southern extension has been negotiated to spread the pulse of fishing effort over a wider range of coast, as well as protecting inshore prawn populations.

The seasonal northernly movement of fishing effort has been exacerbated by industry uncertainty as to longer term management, particularly zoning. This has encouraged mobility since the usual criteria for entry into suddenly restricted fisheries has been an established history of participation.

The principle of resource conservation has been endorsed by industry, managers, biologists, economists and marketers as the primary objective of management of the east coast fishery. Research is needed to adequately satisfy concerns regarding biological impacts of fishing on stocks in northern areas. Investigations of multispecies interactions particularly those of the timing of seasonal closures and life cycles of prawn species are needed. Definition of the real objectives of management, whether they be economics, social welfare or politics would assist in the secondary objective of management of the east coast fishery, that of allocation.

Abst-Glaister

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WORKSHOP ON EFFECTS OF FISHING IN THE GREAT BARRIER REEF REGION
MAGNETIC ISLAND, 20-24 FEBRUARY 1989

Discussion Paper

MANAGEMENT OF THE EAST COAST PENAEID PRAWN FISHERY

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INTRODUCTION

The Queensland east coast includes 15 degrees of latitude ranging from tropical through to subtropical-temperate climates (Fig. 1). The coast encompasses a diverse habitat strongly influenced by a combination of circulation resulting from the Coral Sea Trade Drift and South Equatorial Water and the complex known as the East Australian Current. Consistent with such a diversity of estuarine coastal and oceanic habitats, the region supports a diverse fauna, not the least of which are penaeid prawn populations. It is this species diversity that is one of the principal difficulties in management of the east coast penaeid prawn fisheries.

Management of Australian prawn fisheries is a recent phenomenon with significant exploitation and subsequent management only occurring during the last twenty-five years. The resultant fisheries have ranged from single species (South Australia) to multispecies (Queensland east coast, Gulf of Carpentaria). The prawn population distributions have encouraged the evolution of State zones. Exceptions are the eastern king prawn (*Penaeus plebejus*) fishery across Queensland/New South Wales border, the banana/indian banana (*Penaeus merguiensis/indicus*) fishery across the Western Australian/Northern Territory border (Joseph Bonaparte Gulf) and of course the Northern Prawn Fishery (Queensland, Northern Territory and Western Australia).

Thus the development of management regimes within Australian prawn fisheries has largely been independent, with objectives, rules and regulations dependent on local authorities. An early decision to limit entry to prawn fisheries in Western Australia in 1963 was undertaken based broadly on a philosophy outlined by Gulland (1972). The main considerations were "... economic viability of the fishing unit, economic viability of the processing unit and the effect of exploitation ..." (Bowen, 1975). A domino effect of licence limitation introduction was soon apparent in other managed fisheries and supporting regulations generally included closed seasons, permanently closed nursery areas, gear and vessel restrictions.

Objectives of management vary from area to area but usually include a commitment to resource maintenance (conservation) and the assignment of rights to a common property resource through the reduction of excess effort (allocation). Although recruitment overfishing has been identified in Exmouth Gulf for *P. esculentus* (Penn and Caputi, 1985) and perhaps in the NPF, most management strategies are directed at prevention of growth overfishing and over-capitalisation of fishing fleets through effort reduction.

Bowen and Hancock (1985) provide a comprehensive review of penaeid prawn management in Australia. Among their principal conclusions were that all prawn stocks were subject to a declared management regime, each had some form of limited entry and that the major management objectives were seen to be resource maintenance and reduction of excess fishing capacity to improve economic returns.

The Queensland prawn trawl fishery can be considered in terms of four distinct regions, each with quite different management strategies:

1. The Gulf of Carpentaria/Northern Prawn Fishery - management is sectionalised with prawn fishing entitlements controlled by an entry licence.

2. Torres Straits - closed since 1987 to all but 140 endorsed vessels. Closures mirror Gulf closures and east coast closures where possible and management based on a total allowable catch objective.

3. Queensland/New South Wales Eastern Seaboard - management of the total resource with a geographic division at the Queensland/New South Wales border by a "concessional zone" across a defined border area and a prawn entitlement.

4. Moreton Bay - management based on maximum vessel and gear sizes in conjunction with closed areas.

The focus of this paper is the Queensland sector Eastern Seaboard (subsequently referred to as the east coast fishery) and the management of the prawn trawl fishery confluent with this area.

LIMITED ENTRY

Early development of offshore prawning on the east coast was characterised by steady growth in fleet size as exploitation of grounds between Jumpinpin and the New South Wales/Queensland border gave away to grounds off Bundaberg. Ruello (1975) reported "about 100 trawlers" participated in this fishery and the off-season scallop fishery in the same area. Surveys by Racek between Mackay and Proserpine in 1954 and the FRV "Challenge" in 1957 played a significant role in the development of the east coast fishery.

In the early 1960s, the Gulf of Carpentaria banana prawn fishery commenced and east coast prawn vessels soon joined in. These were rigged for the east coast, carried ice and were inadequate for Gulf conditions. This fact, coupled with restricted unloading facilities and the high catch rates led to the evolution of vessels designed specifically for the Gulf, particularly onboard processing facilities.

In the mid-1960s effort controls were requested by industry for the Gulf fishery in addition to other management measures. The fleet grew rapidly and in the 1970s a licence limitation scheme was introduced. Concurrently, prior to 1975, vessels larger than 21 m or over 150 gross tons were the subject of a 25% government subsidy (Hundloe, 1985). After 1975, the Ship Construction Bounty Act 1975 and the Bounty (Ships) Act 1980 restricted the Bounty to vessels constructed in Australia for use in Australia (ibid). A limited entry regime was introduced during 1977. Boat replacement in the Gulf had a dramatic impact on the east coast with the fixing of the fleet size in the Gulf resulting in a rapid fleet upgrading.

Owners replaced smaller ex-east coast vessels with larger freezer vessels and sold the replaced vessel to the east coast. Gulf entitlements had also attracted a monetary value. Some owners sold their entitlements, purchased a new vessel and returned to the east coast. The new owners in these cases invariably transferred the entitlement to a purpose-built Gulf vessel and again, retired the replaced trawler to the east coast.

Coincidentally, speculators were investing in prawn vessels, further fuelling east coast fleet expansion. Hill and Pashen (1981) provide a comprehensive review of developments to 1979. They found that despite the increased fleet, the increased time spent at sea, improved gear efficiency and expansion in fishing grounds, that total landings had risen only marginally and landings per vessel had declined. Concomitant increasing costs meant that the economic position of most fishermen deteriorated.

In September 1979, the Queensland Government unilaterally introduced a freeze on the numbers of State licenced vessels (allowed to operate in State's waters within 3 nm territorial baseline). Hill and Pashen (1981) described some of the reasons for the rapid fleet increase following the freeze (Fig. 2).

Developments in Queensland also impacted New South Wales. Fishermen who had traditionally fished the seasonal offshore deepwater fishery in southeast Queensland were technically still entitled to as it was outside Queensland's State jurisdiction. Constitutional grounds prohibited any restrictive policy based solely on place of residence and under the conditions of entry, commitment to the fishery was established if the vessel held a Queensland State licence. This permitted Gulf vessels to be granted entitlements and led to licence splitting as described earlier. It also caused confusion as some New South Wales fishermen licenced for the deepwater eastern king prawn fishery in the southeast anticipated a windfall gain in being entitled to entry to the east coast limited entry fishery. Negotiations established a buffer zone around the New South Wales/Queensland border to Sandy Cape in Queensland to include the then-known deepwater fishery.

Vessel prices in New South Wales, boosted by the "gold rush" mentality of speculators wanting to purchase vessels quickly to establish an entitlement to entry to the east coast fishery, gradually stabilised as the limits to entry began to take effect. New South Wales industry feared that as the last

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remaining open entry fishery, they would become the dumping ground for replaced east coast and Gulf vessels. Again speculators, anticipating the likelihood of limited entry in New South Wales again started purchasing prawn vessels. By 1982, the licence limitation regimes had slowed entry to the Queensland east coast fishery and industry concern in New South Wales of "an invasion" prompted action.

In December of 1982, the New South Wales Government prohibited the entry of any new licenced fishing vessels into the New South Wales sector of the prawn fishery but any vessel licenced at that time was permitted to trawl for prawns. In January 1984 a total freeze was introduced by New South Wales and in the same month the federal government introduced a 12 month complementary limited entry scheme in Commonwealth waters off New South Wales and Queensland.

In addition to limiting numbers on the east coast attempts were made to contain effort by controls on efficiency. In 1983 Queensland replacement restrictions allowed an increase in vessel size of only up to one metre for the replacement vessel. Thus there was no freeze on vessel horsepower or total trawling gear other than mesh and net headrope length restrictions. An overall length restriction of 20 m for vessels was aimed at prevention of Gulf vessels trawling in State (east coast) waters. It was in recognition of this lack of ability to control increasing effort that prompted consideration of vessel unitisation. It is generally accepted that the fishing capacity of a prawn trawler is related to the length of the vessel, the engine horsepower and other equipment such as number and size of nets, electronic fish finding and positioning equipment and freezing capacity.

Attempts to more closely define the fleet and fishing activity were evident from the classification of vessels into "primary" activities in September 1984. Primary was defined as supporting a full-time fishing operation and such endorsement required substantiation through records of sales. The question of vessel fishing power continued to be debated and in late 1986 a system of vessel description was introduced incorporating measures of fishing power (hull units representing length, beam and depth dimensions). This system sought to define the fleet in a quantifiable way and additionally, once so defined, to allow penalties for upgrading existing vessels with vessels of greater fishing power.

The legislation allowed licences to be separated from the vessel and had provision for a 2:1 licence amalgamation for upgrade of existing vessels by combining vessel units. The initial system included main engine horsepower constraints, an upper limit of 20 m LOA and provision that replacement vessels could not increase dimensions (including horsepower) without purchasing additional units. Management authorities persevered with horsepower constraints but practically, enforcement was nearly impossible. A major difficulty was that engine modifications made it possible to increase engine power without replacing the rated engine.

The system has recently been modified in recognition of these difficulties to allow all vessels a maximum of 300 KW (400 HP) without any purchase of extra units. Authorities have retained the absorption of total units (2:1) provisions. There are concerns that relaxation of the horsepower constraints will induce a further expansion of effort but opponents to this view consider that it was happening in reality (engine modification) and that there are physical limits (size of vessels).

In 1986 the Commonwealth and Queensland Governments jointly signed the Offshore Constitutional settlement, part of which ceded the management authority for the prawn fishery on the east coast to the Queensland Government. Net size restrictions in State waters under State law remained at 88 m whilst in Commonwealth waters different requirements necessitated a maximum of 184 m. This difference approximated the 50 fm depth contour but created an enforcement problem. In 1987 the Commonwealth also conceded management of additional waters. A compromise under current consideration is to restrict combined headrope-footrope net dimensions to 88 m inside the Great Barrier Reef (the "inshore" fisheries) and in waters greater than 50 fm in depth outside the reef, not to restrict net size.

The fishing power restriction could not be judged an outstanding success in limiting effort. Limits on hull units (70 UDV) and total length (20 m) meant that configurations of 19.9 m and up to 70 UDV were possible that were capable of more real effort than older, smaller vessels and certainly more than the combined two single vessels and units replaced. It would appear that these restrictions have been ineffective. It is apparent that real effort is increasing and is capable of further increases, even given the 2:1 replacement. This is possible through the amalgamation of older smaller units into a single efficient unit. The addition of technological improvements such as side scan sonar, the ability to fish unfavourable weather and the ability to remain at sea longer together suggest effort is still increasing.

In an attempt to slow down effort, industry are currently considering a 4:1 replacement policy as it is felt that the 2:1 policy has only reduced potential effort rather than real effort. An industry-funded buy back is also under consideration. In recognition of difficulties in escalating real effort, the Minister for Primary Industries announced a twelve month freeze on vessel replacement in December 1988. This was to allow time to develop a mechanism of vessel replacement which will control effort growth more effectively. The freeze, introduced by the Minister on the recommendation of the management authority (the Queensland Fish Management Authority) prohibits any replacement, modification or upgrading of otter trawl hulls, with an upper limit of 300 KW for the main engine still in force. Effort constraint thus remains a major concern.

CLOSURES

Closures of trawlable areas to fishing have been widely applied as a management tool in penaeid prawn fisheries. Permanent closure of areas as protection for nursery areas from physical damage by trawling, temporary or seasonal closure of areas as protection for aggregations of juvenile prawns of submarketable size and temporal closure (closed seasons) over the entire fishery, regularly have been instrumental in the management of penaeid prawn fisheries. Permanent closures for protection of nursery areas (industry generated) or protection of the Great Barrier Reef (GBRMPA generated) will not be addressed in this paper.

East coast closures originated with industry concern in 1982 as to the capture of juvenile brown tiger prawns (*Penaeus esculentus*) in three areas north of Cooktown. A closure to protect small prawns from premature exploitation (so called "growth overfishing" or an economic closure) was sought by industry to protect the export-oriented fishery. This gradually was adopted by fishermen and the decision to support the Torres Strait to Cape Tribulation closure was unanimously supported by the industry organisation in 1984 (Fig. 3). The Queensland Fish Management Authority in addition extended (to State waters only) the closure south to Bowen. This was because of concerns to protect a larger part of the fishery and that there would be an increase in fishing effort on grounds between Bowen and Cape Tribulation as a result of the northern closure.

Coles *et al.* (1985) provided an assessment of the 1985 closure. They reported the species captured included brown tiger (*P. esculentus*), endeavour (*Metapenaeus endeavouri*), grooved tiger (*P. semisulcatus*) and western king prawns (*P. latisulcatus*). They concluded that the closure was effective in reducing the catch of juvenile brown tiger and endeavour prawns and less effective in protecting juvenile grooved tiger and western king prawns. They considered that a longer closure, extending into December may be more appropriate and they commented on the need for a more extensive database if quantitative assessment was contemplated.

The east coast closure was again implemented in 1985/86 with Commonwealth waters closed from Cape York to Lucinda Point out to the outer boundary of the Great Barrier Reef. State waters were closed from Cape York to Airlie Beach (Fig 4). However there was criticism from northern resident fishermen at the influx of southern trawlers into the area to fish the opening of the North Queensland season. Many considered that the purpose of the closure - protection of juvenile brown tiger prawns to acceptable export market size - had not been achieved since a "pulse" of effort early in the season had achieved the same result.

As a result of industry concern, the east coast closures were not implemented in 1987. The catching sector of the industry had as an alternative, proposed a variable licence endorsement system (a 9½ months trawling endorsement plus observance of closure versus a 12 months trawling endorsement to fish anywhere except seasonal closures) to provide for a form of area management. This was not supported.

The closure was again implemented in 1987/88 between Cape York and 22°S, through an irregular line out to Hydrographer's Passage to the outer boundary of the Great Barrier Reef (Fig. 5). Again it was criticised by sections of the industry since the extended area of the closure included previously exempt king prawn grounds. Undertakings were given that future closures would be discussed on a port-by-port basis.

These meetings reaffirmed industry's desire for protection of juvenile brown tiger prawns and seagrass habitat but considered pulse fishing negated benefits of the closure. Debate within the fishing industry has continued and the northern closure again has been implemented for 1988/89. The area closed extends to the Offshore Constitutional Settlement line from Cape York to Clump Point and then south to 22°S in (old) State waters (Fig. 6). The aims of the closure are "... to protect the prawn stock and to allow the prawns to reach a larger and more economic size before they were caught". The total closure of all waters above Clump Point is designed "... to give maximum protection to the (brown) tiger prawn resource and the closure of inshore waters south of Clump Point continued that protection for tiger prawns whilst allowing king prawns to be fished" (Anon, 1988).

Thus with the exception of the initial industry-generated decision to protect juvenile *P. esculentus* in the area north of Cooktown for essentially economic reasons (export marketability) - to protect against "growth overfishing" - the subsequent southern closure extension has been largely negotiated to spread the pulse fishing effect over a wider range of coast and provide additional protection to inshore prawn populations. There also has been recent industry concern that roed *P. esculentus* and *P. semisulcatus* may be vulnerable and mid-year "spawning closures" have been suggested to avoid the threat of "recruitment overfishing". The problems that haven't been addressed are the impacts on pocket fisheries for other species (multispecies problem) and the sequential exploitation by a mobile fleet (pulse fishing problem).

FLEET MOBILITY

Data from Williams (1980) and QFMA annual reports suggest a northerly shift of resident port by trawlermen. Beurteaux and Coles (1987) convincingly demonstrated a significant increase in effort for the northern sector of the east coast fishery between 1983 (pre-closure) and 1986. They found a threefold increase in the number of vessels berthing at Cairns port, that the larger dual-endorsed (Gulf and east coast) trawlers spent a significantly longer time at sea than the smaller trawlers licenced for the east coast only and that annual effort expended had not changed significantly as a result of the closures (compression of effort).

Williams (1980, Fig. 3) demonstrated a sequential movement of fishing effort along the east coast (areas 1 to 5). Combining her data for areas 4 and 5 produced a bell shaped monthly distribution of numbers of trawlermen in the northern region with a peak during June-July. Beurteaux and Coles' (1987) analysis of surveillance records show a similar distribution in 1983 (pre-closure) and an effort shift with a marked spike or concentration of effort at the opening of the closure (pulse fishing) in 1986 (Fig. 7).

The partitioning of trawl grounds in the Gulf of Carpentaria and subsequently, the Torres Straits has been seen by east coast fishermen as an erosion of available fishing area. Further reduction of traditional areas through GBRMPA zoning and concessions to the tourism industry has meant a fully exploited resource is shrinking through an areal reduction and increases in efficiency of fishing units.

Consideration by industry of area management of the east coast (each of four zones to be established along the coast having its own management, though free access) and zoning (as is the case with the Gulf and Torres Straits) have encouraged mobility, since the usual criterion for entry into a suddenly-restricted fishery has been an established history of participation. Thus vessels that may have been content to remain "at home" are obliged to travel to northern grounds to establish *bona fides* and thus have exacerbated the "pulse" effect.

The impact of mobile effort is a sequential local depletion along the coast, fishermen's exasperation at a "gold rush" exploitation of stocks that would have, in the past, supported local vessels over a season and an increasing necessity to join in the northerly migration.

MANAGEMENT OBJECTIVES

The principal of resource conservation is the primary objective of management for the east coast fishery. This has been enunciated by fishermen, managers, biologists, economists, marketers and all remaining sectors of the industry at various times. It is generally accepted by biologists given the current state of knowledge that *P. esculentus* is the main species to which recruitment overfishing is a potential threat. This belief is based on the extrapolation of published Western Australian work (Penn and Caputi, 1985) and unpublished preliminary results from Northern Prawn Fishery research. To the author's knowledge, no other substantive evidence has been presented for any other east coast penaeid prawn species which would suggest any threat to its continued biological viability under exploitation by trawlers. Reclamation of foreshore and other degradation of nursery habitat possibly hold the greatest potential threat to stocks.

The principle of resource allocation is the second major objective of management for the east coast fishery and the most contentious of the two, since no clear objectives of allocation have been clearly stated. In their definitive paper on the management of the east coast fishery ten years ago, Hill and Pashen (1981) forecast the likely development of pulse fishing, accelerating fishing capacity and continuation of problems due to excess effort. They highlighted possible economic objectives and found that "... the managers have not clearly stated their objectives". They further concluded that the main concern "... (was) to restrict further capitalisation and potential fishing effort".

The east coast fishery is not unique in lacking clearly defined management objectives. Few fisheries are so defined and many of those that are have contradictory (at best) or mutually exclusive objectives, that are statements of hope rather than achievable in reality.

Following a policy decision by the federal government in the early 1980s that the fishing industry should pay - either partly or completely - for fisheries management, the fishing industry has increasingly taken a higher profile on management issues. The trawl committee of the Queensland Commercial Fishermen's Organization is currently defining what it sees as desirable management objectives for the east coast. Bowen (1988) succinctly defined the functions of fisheries management as biological research, economic research, fisheries management understanding, administration and law compliance. He further cautioned that "... the greater the extent of the movement of the fisheries management responsibility to instrumentalities outside government, the greater the potential for management decisions to disadvantage the wider community".

The east coast fishery is an example of this trend. Ten years after Hill and Pashen's (1981) paper, it is still true that "... part of the present problem of the East Coast prawning fleet lies in an inability to land sufficient product ... management should aim at reducing the number of vessels".

Research is needed to adequately satisfy concerns of biological impacts of fishing on *P. esculentus* stocks in northern areas. Investigations of multispecies interactions are also needed, particularly that of the timing of seasonal closures and lifecycles of species. Definition of the "real" objectives of management, whether they be economics, social welfare or

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politics, would then assist in logical decisions on allocation.

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FIGURE CAPTIONS

Figure 1. Distribution of prawn trawling grounds along the Queensland east coast. Northern distributions are after Beurteaux and Coles (1987) and southern distributions are after Dredge and Courtney (pers. comm.). Percentages are numbers of vessels resident in those areas (QFMA licence data).

Figure 2. Growth of the east coast prawn trawling fleet. Data from 1971-82 after Hill and Pashen (1981) and those from 1986-89 from QFMA licence data. Data between 1982 and 1986 are not available.

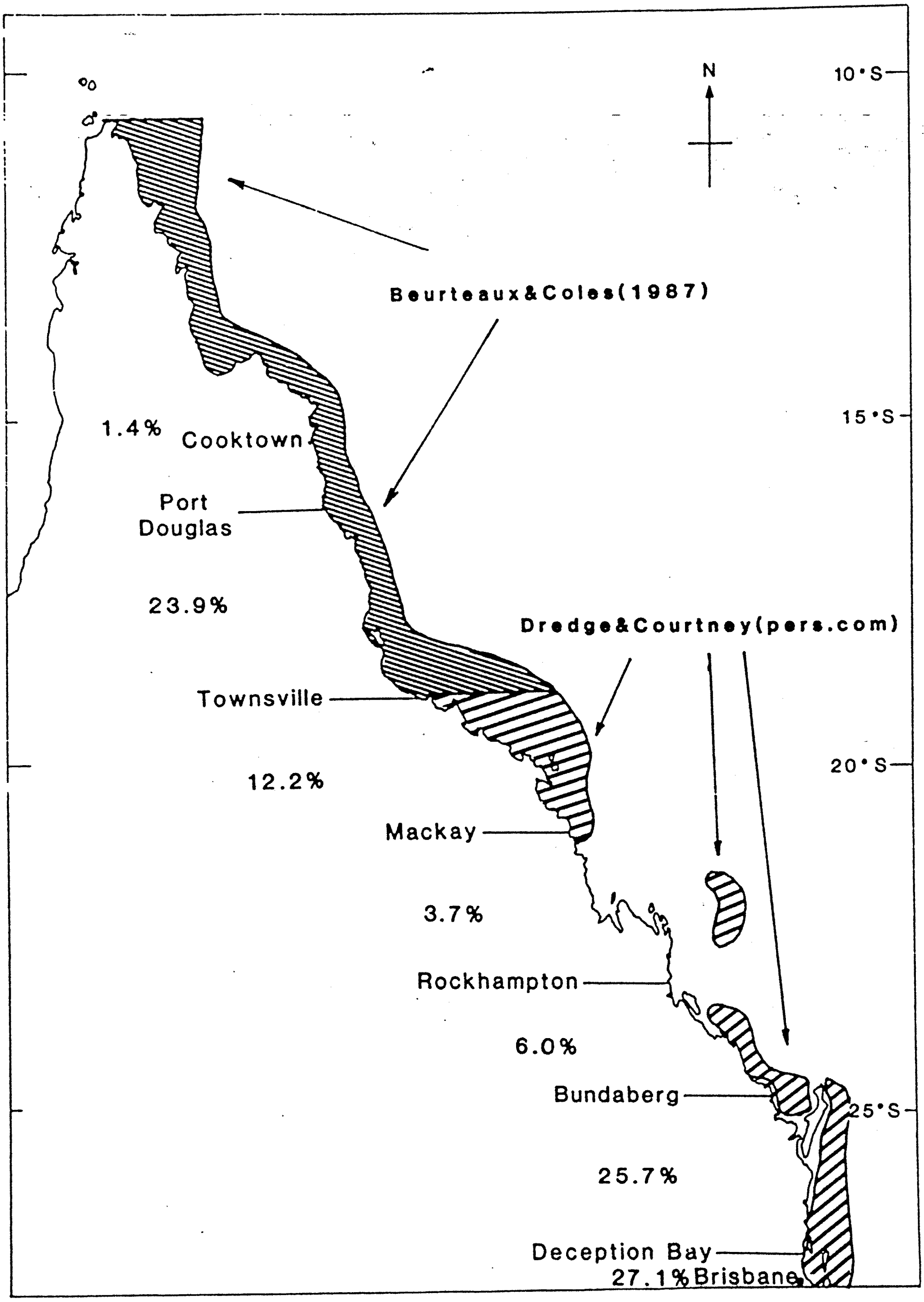
Figure 3. Seasonal prawn fishing closure 1984/85. Area includes Cape York to Cape Tribulation and out to the outer boundary of the Great Barrier Reef (Commonwealth waters) and Cape York to Bowen and out to the Territorial Seas baseline (State waters).

Figure 4. Seasonal prawn fishing closure 1985/86. Area includes Cape York to Lucinda Point and out to the outer boundary of the Great Barrier Reef (Commonwealth waters) and Cape York to Airlie Beach and out to the Territorial Seas baseline (State waters).

Figure 5. Seasonal prawn fishing closure 1987/88. Area includes Cape York to 22°S through an irregular defined line out to Hydrographer's Passage to the outer boundary of the Great Barrier Reef.

Figure 6. Seasonal prawn fishing closure 1988/89. Area includes Cape York to Clump Point and out to the Offshore Constitutional Settlement line (Commonwealth waters) and Cape York to 22°S out to the Territorial Seas baseline (State waters).

Figure 7. Monthly distribution of prawn trawling effort in the northern sector (Townsville to Cape York). Data for 1979 are pre-closures and are in total numbers of fishermen per month (Williams, 1980). Data for 1983 (pre-closure) and 1986 (closure) are in average numbers of vessels per day for each month (Beurteaux and Coles, 1987).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Beurteaux&Coles(1987)
Dredge&Courtney(pers.com)
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Cooktown
Port
Douglas
23.9%
Townsville
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Mackay
3.7%
Rockhampton
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Deception Bay
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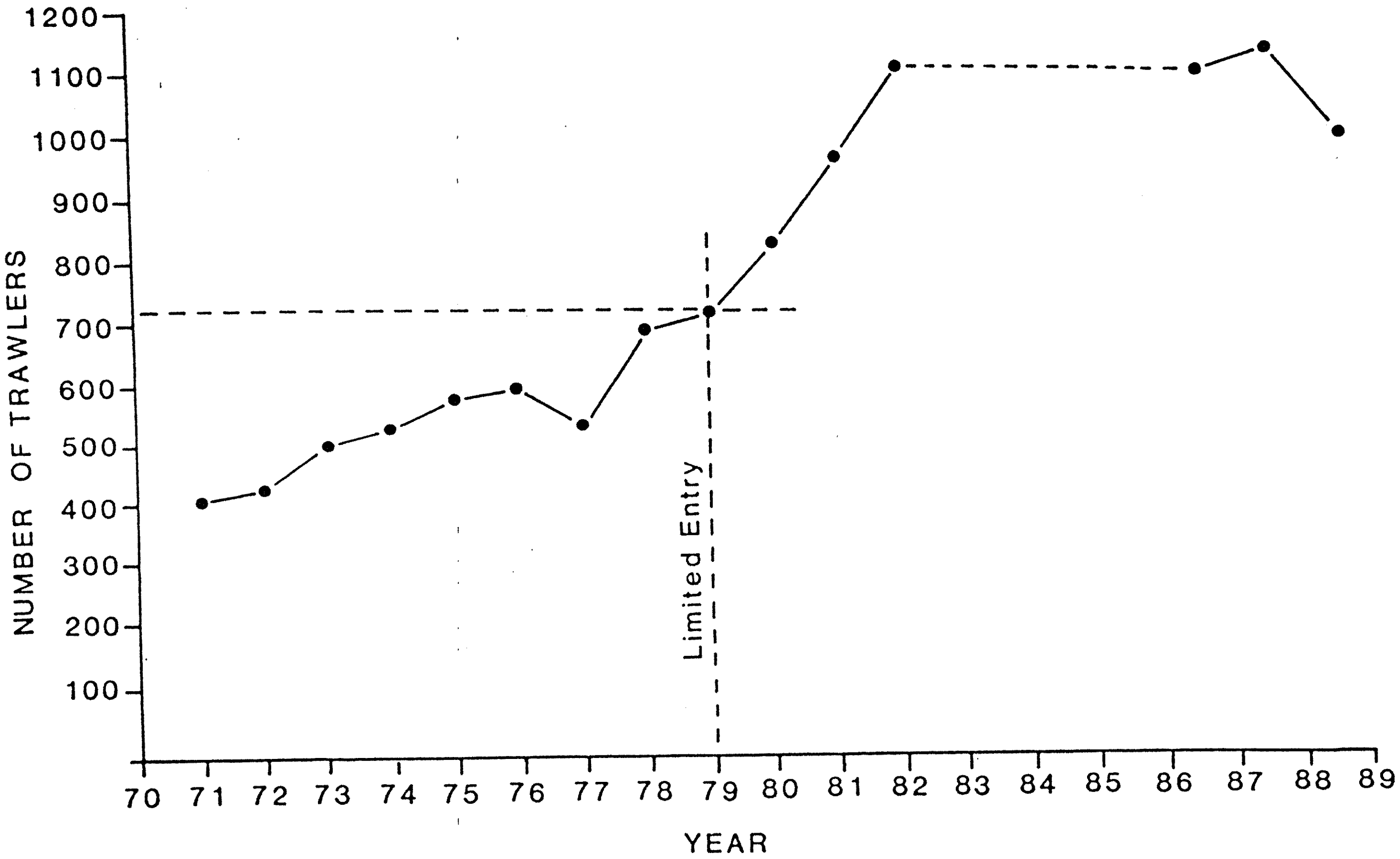
1200
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NUMBER OF TRAWLERS
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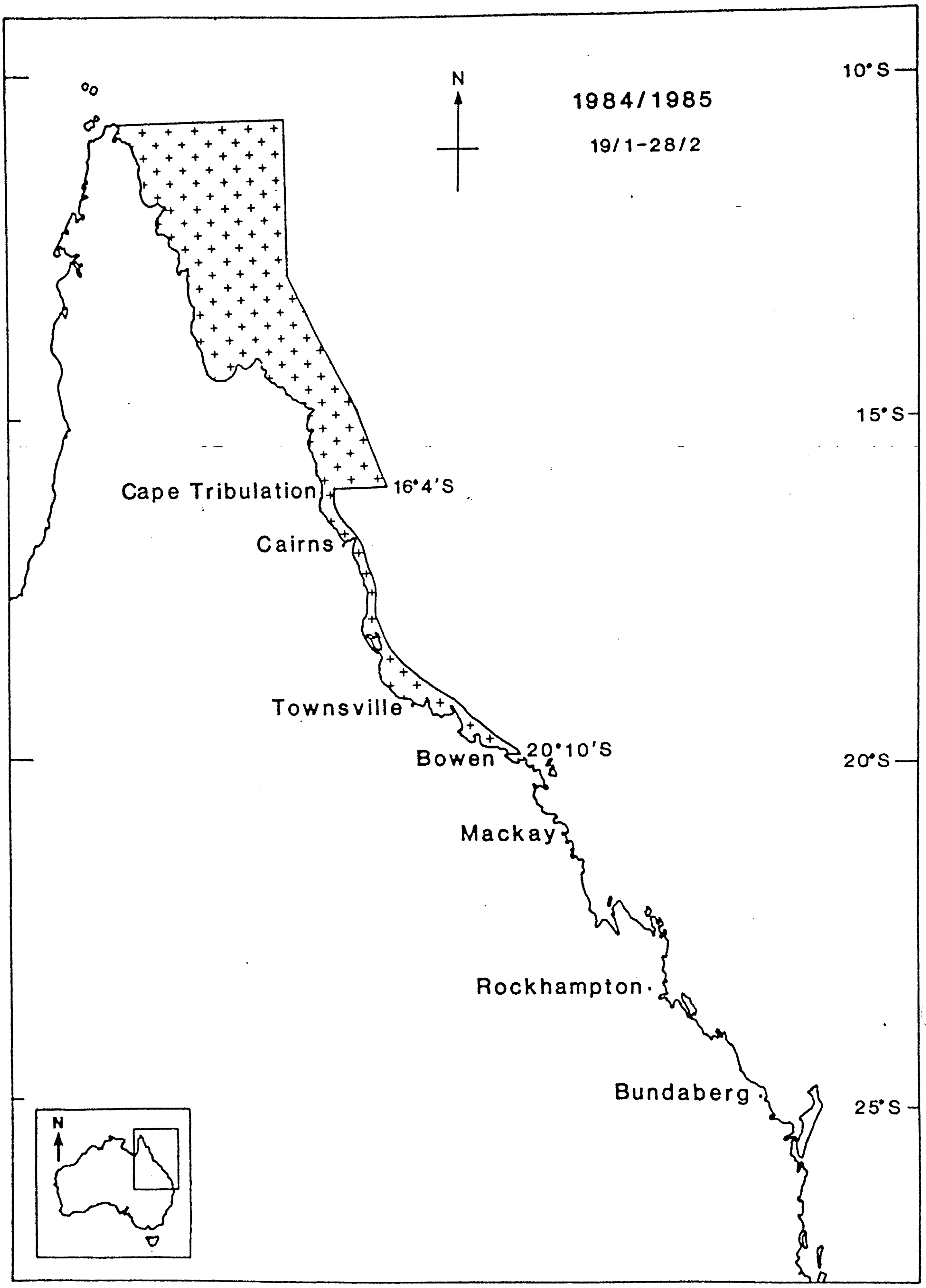

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Bundaberg
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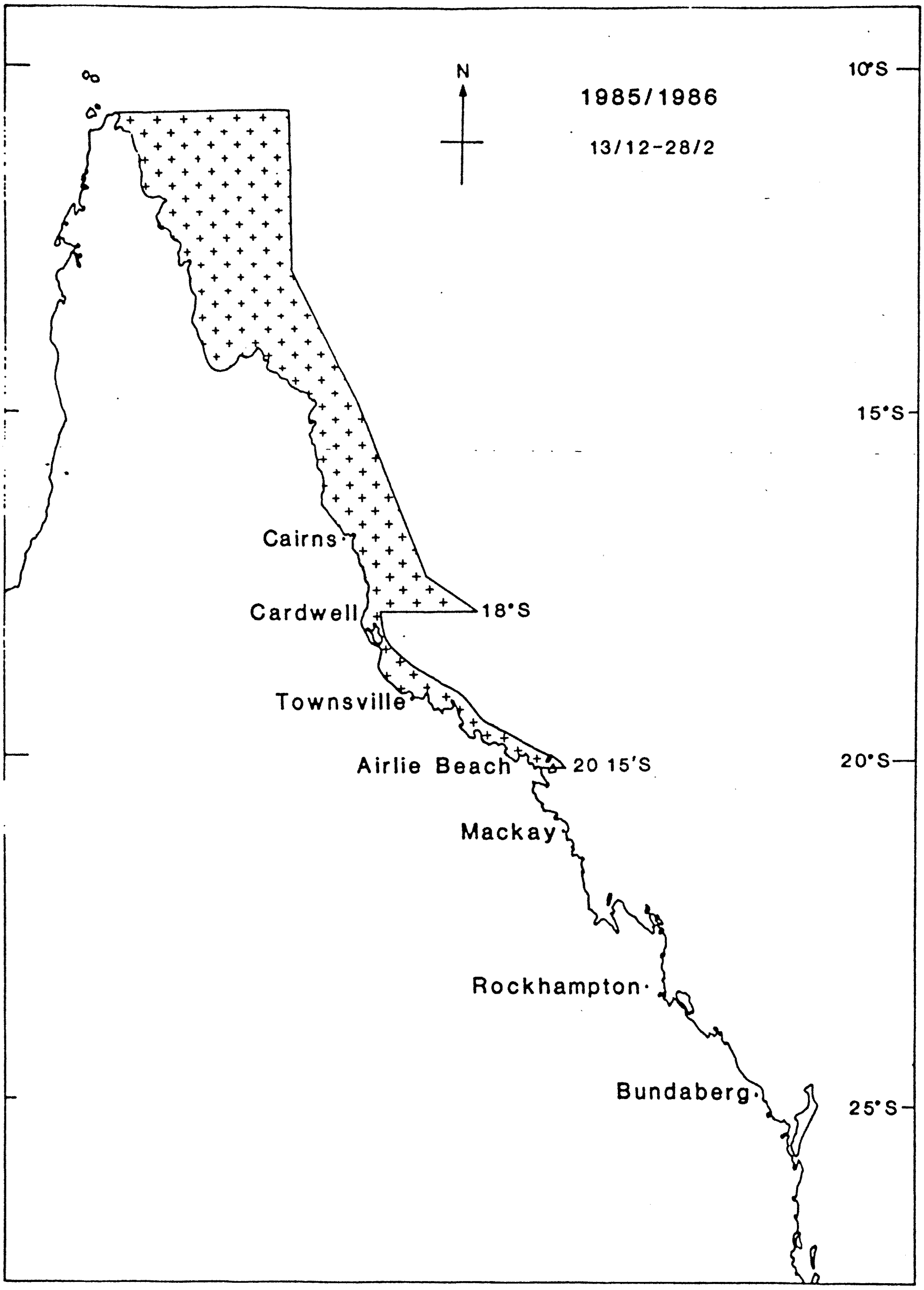
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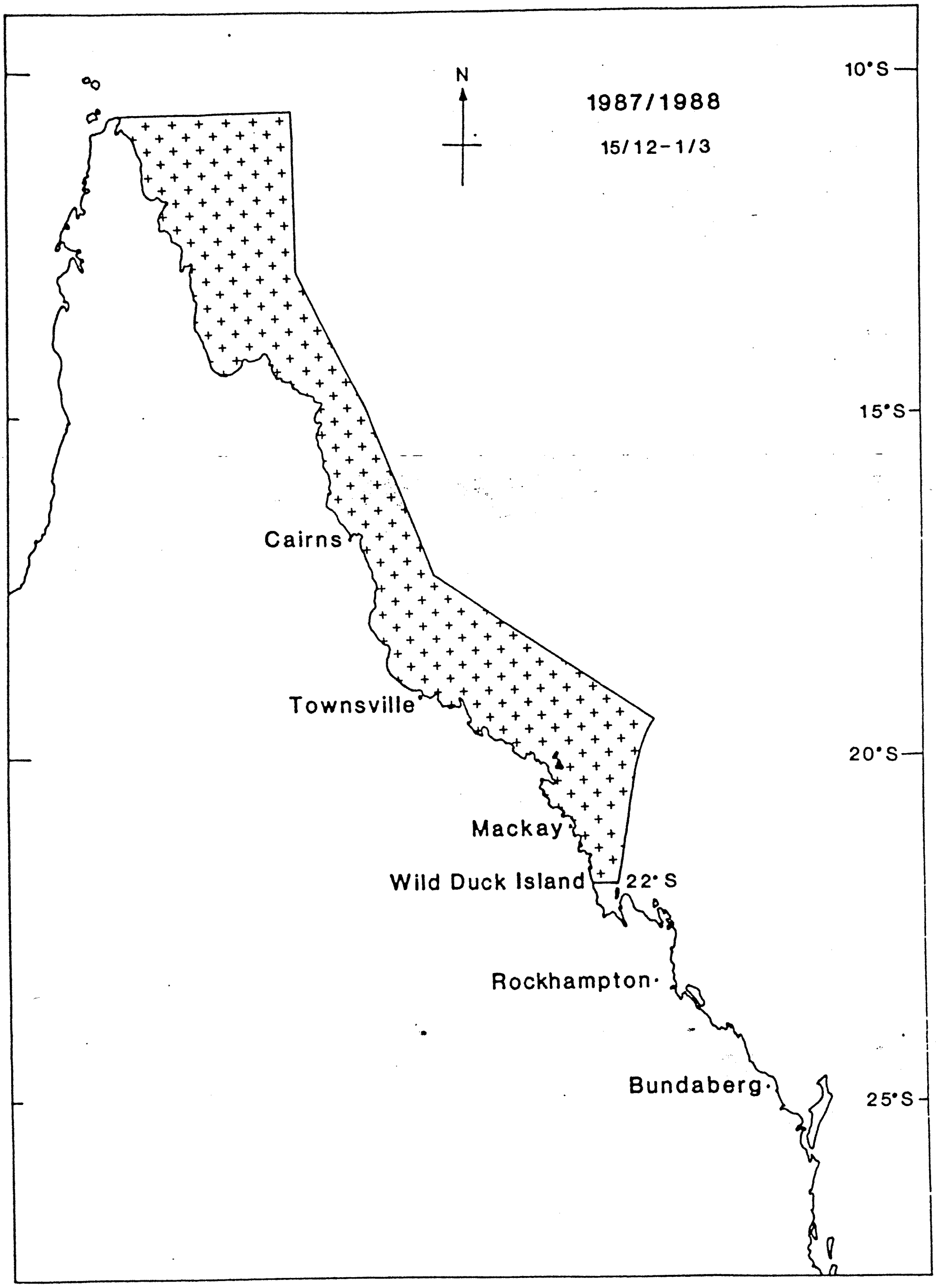

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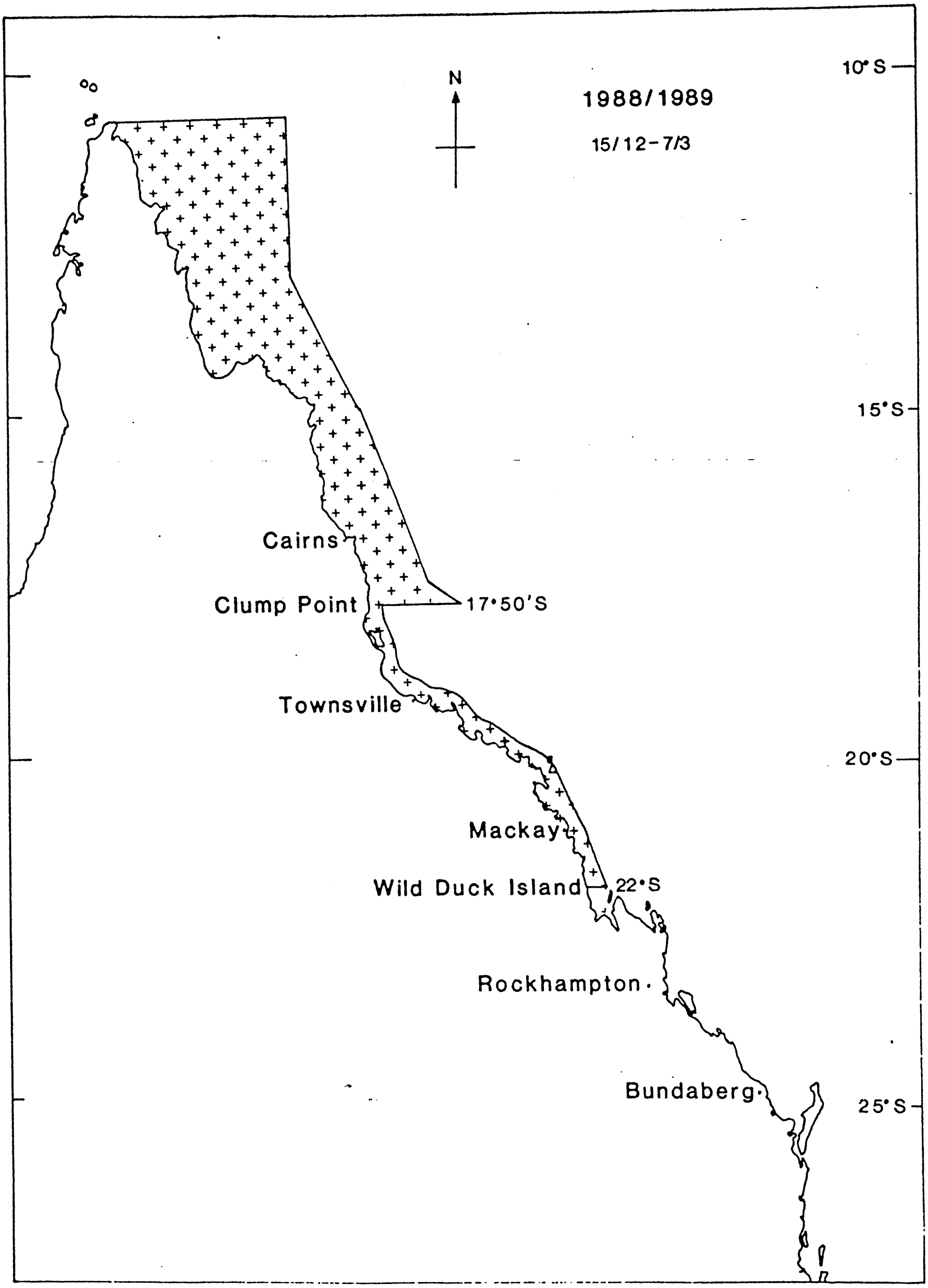

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Mackay
Wild Duck Island
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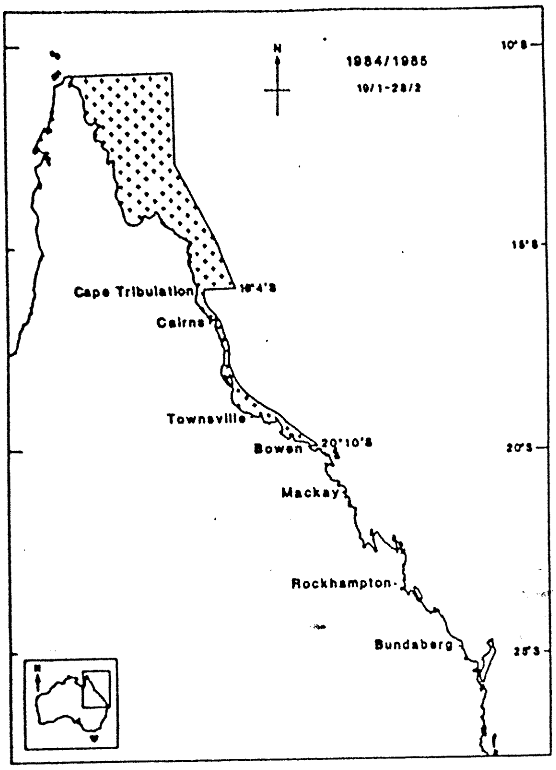
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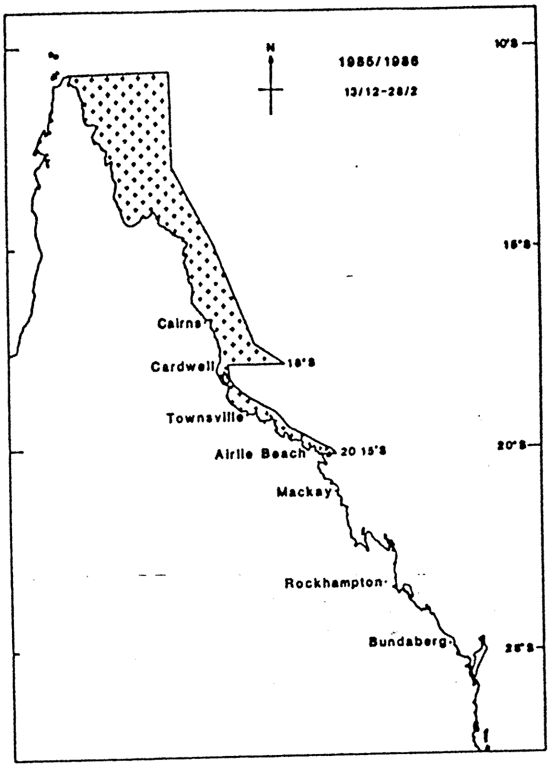
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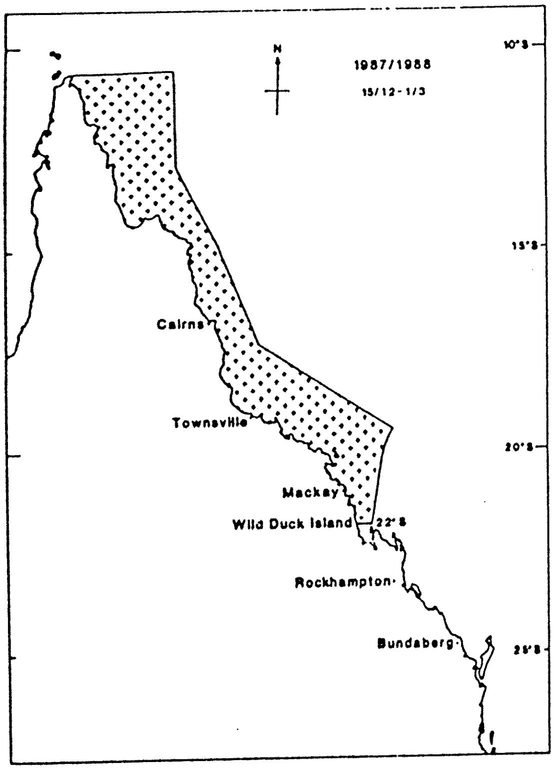
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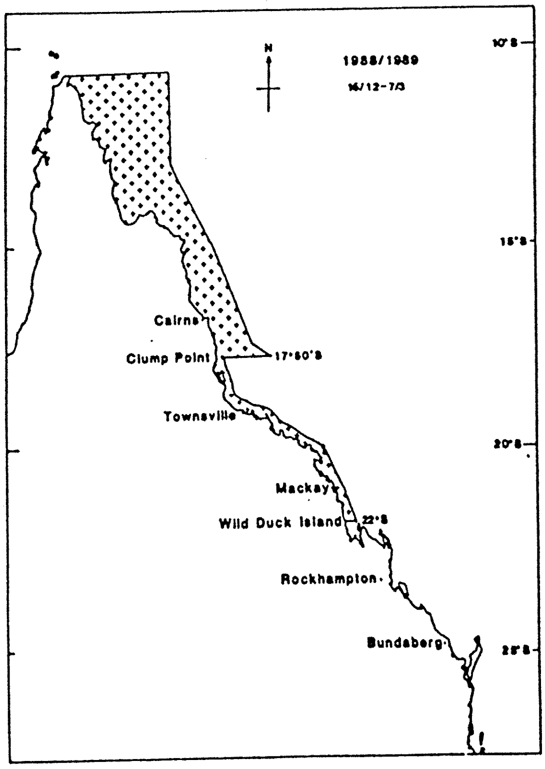
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Rockhampton
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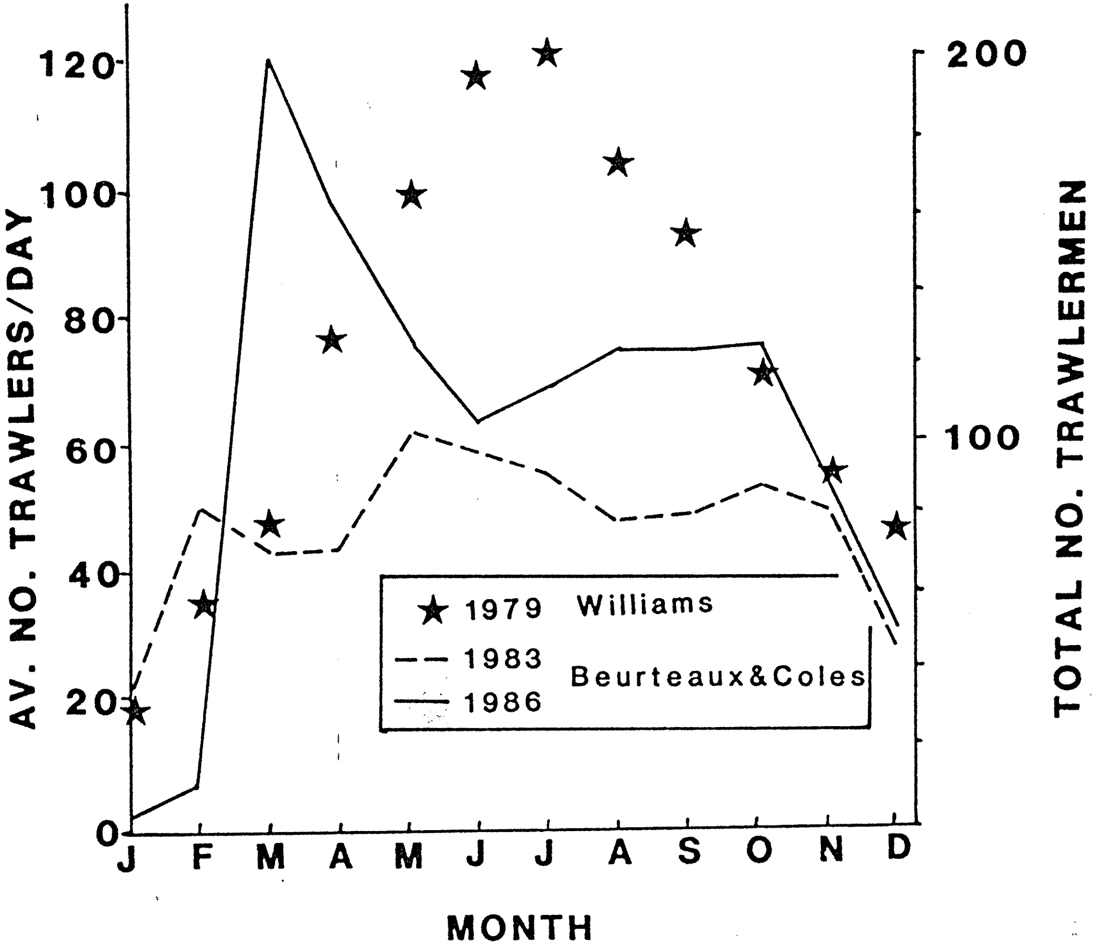

AV. NO. TRAWLERS/DAY
TOTAL NO. TRAWLERMEN
0
20
40
60
80
100
120
100
200
J F M A M J J A S O N D
MONTH
1979 Williams
1983
1986
Beurteaux&Coles

ABSTRACT

THEORETICAL EFFECTS OF TRAWLING ON PRAWN POPULATIONS

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Historically, prawn fisheries have been managed on direct effects and economic implications, rather than on indirect biological repercussions resulting from the fishery.

Direct effects are short and long term and they are primarily concerned with the reduction in prawn population numbers. Indirect effects include predator-prey relationships and substrate modification.

With regard to direct effects, a number of management options were explored for optimising sustainable yields and economic viability. Restrictions on mesh size and setting minimum legal sizes have historically not worked because of problems with enforcement, economic inefficiencies and dumping. Seasonal closures are seen as the most appropriate option. There are disadvantages such as trawlers moving between fishing grounds and across state borders, but it is the simplest and the most economically sensible way to regulate the fishery.

In the long term, the environment is one of the major variables affecting recruitment, however increased fishing effort can be responsible for recruitment failures, irrespective of environmental conditions. Long term impacts relate to a depleted stock's ability to reproduce and remain in equilibrium.

If we want to reverse a downward trend in annual recruitment, the only management tool that we have is to increase the number of mothers spawning during the critical time window. The timing and duration of closures has a number of biological and economic repercussions. Although biological effects may be minimal under certain closure conditions (in terms of the numbers of spawners, see Figure 1), economic effects may be quite variable (Table 1).

Indirect effects are less clear, especially offshore. Data on predator-prey relationships are not available, nor is there any information on substrate modification.

WORKSHOP DISCUSSION OF PAPER

Discussion focussed on various aspects of closures. It was noted that closures have repercussions for fleet dynamics in that there is a tendency for fishermen to intensify effort to make up for lost time during closures or move to other fishing grounds.

The effectiveness of small, long-term spatial closures was questioned and it was noted that this regulatory mechanism was unlikely to be effective for adult prawn populations, though there is value in having inshore protected areas for juveniles.

Theoretical effects of trawling on prawn populations

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Introduction

In their review, my learned colleagues (Drs Poiner and Sainsbury or should that be Sainsbury and Poiner) have classified the effects of trawling into two categories - direct (or intraspecific) and indirect (or interspecific) effects. As this seems emminently sensible, I will use this same classification in this presentation. By direct effects, I refer to the effect of removing prawns from the population and by indirect effects, I refer to those such as altered predator/prey abundances and changes to the habitat.

Direct Effects of Trawling on the Population

It should not come as a surprise to anyone that the short term effect of removals from a prawn population results in less prawns left in the population and money (from their sale) in someone's pocket. As simple as this may sound, when it comes to describing (or modelling) the process in detail, it can become quite complex. Historically, the management of prawn fisheries has been almost exclusively concerned with these direct effects and the large variety of regulations, together with the continuing debate over more appropriate management schemes attest to this complexity.

Another point which should also be made clear at the outset is that prawn fisheries have not been managed on a biological basis as such. Rather, the biological data has been used to identify the constraints in achieving social objectives. Fishing is not conducted for the welfare of the exploited stock and the real issue, the allocation of that resource, is a political, not a biological problem. For a complete review of these issues, see Wooster (1988).

However, the biological data have been critical in modelling the fishing process and its impact on both the target stocks and the economic well being of those benefitting from that exploitation. These models can also be divided into two categories - short and long term processes.

Short-term impacts – no's changes but this changes pop. structure.

Short-term models generally ignore any relationship between stock levels and subsequent recruitment. As the exploited component of a prawn population is largely composed of the one year class, these short-term models are usually concerned with balancing growth and mortality for the individual year class.

Management techniques to gain optimum returns have varied considerably but they are all aimed at determining the age composition of the catch. This will be affected by changes in such things as fishing patterns, mesh size, or minimum size regulations.

Mesh regulations have been used (eg in Qld) but are generally not favoured because the selection process in prawns is not very effective and the selection range covers a large part of the life span (Garcia, Llhomme). There may be some merit in mesh regulations when considered in relation to reducing the by-catch. Mesh-size is difficult to enforce on depleted stocks and the use of small mesh is often a consequence of excessive effort rather than its primary cause (Garcia).

Minimum size regulation is meant to make fishing in areas/times where/when small prawns are abundant and to maybe make the enforcement of a mesh size more effective. This method of regulation has inevitably lead to large amounts of discarding small dead prawns - particularly when large individuals of one species are mixed with small individuals of another species (eg adult white shrimp and juvenile brown shrimp in the Gulf of Mexico).

The most popular management method in Australian prawn fisheries has been the used of seasonal and area closures to determine the fishing patterns and hence the size composition of the catch. Although the particular habitat types may differ between species, virtually all of the important commercial penaeids in Australia use shallow inshore waters as nursery areas. As they grow, they move offshore into deeper water, the distance and depths depending on species and location. Thus by closing certain areas/times to fishing, it may be possible to prevent prawns below a defined size from being caught.

Closures have several advantages over other management measures, the main one being that they can reduce operating costs without necessarily reducing annual revenues. Another important advantage over alternative measures is that seasonal closures are administratively simple and easily enforcible (especially if the whole fishery is closed). Because of the closure, seasonal peaks in catch rates become more predictable and make the financing and refitting of fishing vessels far more efficient (eg Mexico east and west coasts under extremely high inflation rates). In isolated regions like the GOC, seasonal closures offer the most acceptable means for arranging crewing (holidays etc) and in populated centers like Moreton Bay in SE Qld, the weekend closures help separate trawlers from recreational fishermen (thereby reducing conflict accordingly) and also give prawn fishermen some semblance of a normal lifestyle (i.e. 5 days weeks with weekends off with the family).

Nevertheless, there can be some problems with closures and these always come back to problems of allocation. For example, seasonal closures along the Texas coast were unpopular with Texas fishermen because they felt that many of the prawns escaped across the border to be caught by Mexican fishermen. The same can be said of king prawns migrating from NSW to Qld and of king prawns migrating offshore from the Moreton Bay fishery to the offshore fishery. Another conflict can arise when a seasonal closure does not affect all fishermen equally eg. in the Gulf of Carpentaria we have some fishermen who are licensed to fish in alternative fishery to which they can turn during the Gulf fishery closure. These alternative fisheries may be fisheries other than prawns (eg scampi). A slight variation on this theme is where you have variation in closure times between adjacent areas and where some fishermen are more mobile than others (eg Qld east coast or the west coast of Mexico). Here there will be conflict between the residents and the itinerants.

Long-term impacts

The long term impacts relate to a depleted stock's ability to reproduce and remain in equilibrium. This is a far more serious problem for fishery management than that of short term optimisation of yields. Whereas short-term yields may be 10-20% below optimum levels because of ill-adjusted fishing effort patterns and catch size composition, near complete recruitment failure can result from excessive fishing effort and a lack of spawners.

What seems to be emerging from the biologists about the general penaeid life cycle is that peaks in spawning activity occur at about 6, 12 and 18 months of age (if they live that long). In Australian fisheries, even though we have variations on this hypothetical scheme, it would seem that there are discrete windows whereby larvae/juveniles survive to the extent that there is generally only one main period of recruitment to the fishery a year.

For a given level of recruitment, the level of spawning that will be obtained will depend solely on the pre-spawning, and during-spawning level of fishing effort. If we want to reverse a downward trend in annual recruitment, the only management tool that we have is to increase the number of mothers spawning during the critical time window. To do this we must catch less prior to this window. In some fisheries (even prawn fisheries) closing dates to the season are adjusted according to a pre-determined level os escapement (i.e. at a set catch rate, fishing is stopped). Prawn fisheries do not lend themselves to high degrees of precision in such determinations and are generally not geared for flexible regulations such as 24 hrs notice on closures. In the NPF, management decided on various courses of action to help increase the spawning levels during the August-October window. These included closed periods for the fishery over and above those set for optimising within year harvests; gear restrictions; bans on daylight trawling and; increased levies for their buy-back scheme.

The subject of closures for this purpose is an interesting one. If the aim is to increase the spawning biomass at a certain time, and the management body has decreed that they are prepared to adopt an additional closed period of 6 weeks, just when should this closure be implemented? The theoretical answer is that, in relation to a gain in spawners from a given level of recruitment, it does not matter when it is implemented as long as it is before the spawning season.

$$Nt = N0 \exp(-(t-c)Z) \exp(-(cM)Z)$$

for a closure immediately before spawning and

$$Nt = N0 \exp(-cM) \exp(-(t-c)Z)$$

which is the same as above.

However, other things will influence just when the closure should be implemented. For example, from the point of view of optimising the harvest, such a closure should be appended to the existing pre-season closure, thereby maximising the value of the catch while still maintaining the objective of increased spawing levels. In reality other factors like cash flows and crewing arrangements were also taken into account and eventually the season was divided into two parts.

Indirect effects

Pauly (1982) was not deterred by the paucity of data in publishing a paper on the relationship between prawn trawling and the interaction between predators and prawns. He was able to massage the data to the stage that virtually also the variation in annual recruitment of prawns could be explained by spawning stock size and the biomass of potential prawn predators. He method of determining pre-recruit mortality showed a very consistent trend with the total demersal stocks. Whether these data are to believed (and there has been no shortage of critics) or not is not as important as the concept that Pauly is espousing. It is merely a lack of robust data that has prevented more credible analyses from being undertaken. Maybe Pauly's study will enthuse others into undertaking such studies and collecting the data necessary.

Impact of substrate modification

No prawn fishermen would knowingly destroy the prawns habitat, particularly if he knows that it would cost him less to prevent the damage than to bear the longer time cost. This may not be the case where the benefits accruing to the damager outweigh his individual long term cost which is spread throughout his colleagues - eg fishing small prawns. The prawning industry has been very quick to regulate to prevent the destruction of inshore nursery area habitats (seagrasses). This is has always been an easy decision to make because it usually mean short term gains in terms of optimising harvests as well as the long term advantage in ensuring recruitment levels are not effected by reduction in the nursery area carrying capacity.

The impact of substrate modification offshore is less clear. There is no shortage of annectodal information about the pioneers of an industry having "cleaned up" a trawl ground of all the "rubbish" (sponges etc) only to have all of the late comers take advantage of the clean trawlable grounds so created. Just how this has effected production is not clear and most difficult to dissociate from other factors which cause annual recruitment to decline.

Certainly it has been noted that different species may prefer different sediment types (Somers 1987, etc etc) and one could speculate on possible species changes if trawling were to erode an area over a period of time, changing the substrate from a fine to a course sediment.

Summary

Fishing obviously has an impact on prawn populations. The long term effects are still a matter of debate in the prawn scientist world. The fishing industry has been very progressive and generally very responsible in introducing regulatory measures to manage the resources on which they depend. There are usually many alternative measures to achieve the same end for their perceived needs and they will have chosen the one that has best met the constraints as perceived at that time. If there are new constraints to be considered due to new biological research, then it may simply mean that another of the alternatives best meets all objectives while satisfying the new constraints.

ABSTRACT

THE USES OF MODELLING IN THE MANAGEMENT PROCESS

KEITH SAINSURY and JOHN PARSLOW
CSIRO

The way modelling is used in the management process can be described under two broad approaches.

The first approach can be described as "one model, take it or leave it", or more formally as a certainty-equivalent approach. In this approach one model is somehow derived, usually after much unresolved scientific disagreement about mechanisms, management implications of the model are then derived, and these implications are applied to the whole of the resource as if that model were true. The management action is not greatly altered by the level of uncertainty in the model. This process is typical of what happens in management of most fisheries. There are several consequences and problems with this approach, particularly when dealing with the management of complex biological communities. Some of these are

Because the biological research modelling and target steps are usually sequential,

- the models used are usually highly focused on the resource dynamics, with little explicit consideration of the management context and industries involved at the next step in the sequence.

- there is great uncertainy about the best model stratum and parameter values to use to represent a biological community, because there is little scientific understanding about the principles of community dynamics, but the consequences of this uncertainty in implying a wide range of possible outcomes to a given management decisions is not de-emphisised.

- applying the selected management measure to the whole resource at once puts the whole resource at risk if the decision is incorrect, and leads to severe temporal confounding of control variables so that data collected about the communities behaviour under management have little power in allowing recognition of incorrect decisions.

- This approach takes no formal account of the basically empirical nature of the management procress. Scientific input and model building can help guide management decisions, but always there are many things about the system that are simply unknowable. Management regimes usually involve unique perturbations to the system, so some time of extrapolation of previous knowledge is involved in predicting the outcome. Research conclusions made for small space and time scales often must be extrapolated to larger space and time scales to predict the outcome of management.

The second approach to the use of modelling in management follows directly from explicit acceptance of the empirical nature of the management process, and may be described as an experiential or adaptive approach. It focuses on

identification of a management regime that, while meeting management objectives, will provide a good structure for empirically learning about the response of the system to the management action. This changes the emphasis of the modelling involved. Specifically, it places emphasis on

- Explicitly identifying and considering uncertainties, usually by providing several models, and their management consequences.

- Consideration of the management process involved, and specifically the importance managers place on the various outcomes implied by the various models, leading to identification of the models it is important from a management viewpoint to distinguish.

- What observations can be made, at what cost and precision.

- How will the observations made through time be used via model discrimination, in reaching future management decisions.

The adaptive management approach searches for policies that are economically efficient and robust in leading to management goals and subject to management and industry constraints. The management regime must provide a good experimental design, in addition to meeting management and industry constraints.

Such an approach seems 'tailor made' for providing a rational basis for zoning in the GBR. A preliminary model of the GBRMP was developed to illustrate the incorporation of the resource dynamics, observation process, fishing industry respnses and management decisions into a model to evalue a zoning scheme. The model used the spatial structure of the GBR, with reefs grouped into 10 mile wide cross-shelf units. The dynamics of a single species was modeled with

- recruitment (and its variability) to a given reef being provided at local, unit and reef-wide scales
- post-recruit movement between reefs, scaled to agree with GBRMPA tagging studies
- A line fishery operating from 10 centres along the coast, and allocating effort to reefs according to the catch rates and trawling times involved
- fishing effort was considered to have began 20 years ago, and has been increasing since then and a zoning structure of reefs open and closed to fishing was introduced 10 years ago.
- information about the abundance of the population in 5 fished and 5 unfished reefs common to the managers via visual surveys, with the precision found to apply to such surveys. Observations began 10 years ago.
- the management objective was to provide protected reef systems which were not being affected by fishing in the nearby reefs.

The model was used to illustrate

1) the effect that of uncertainty in the space scale of the recruitment has on the population sizes of the fished and unfished reefs, and

2) the way in which a 'wrong' observation method and high spatial variability in recruitment can mask detection of the transmitted effects of fishing onto the unfished reef even if those effects are quite large.

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ABSTRACT

TECHNIQUES FOR THE DIRECT MEASUREMENT OF THE IMPACT OF TRAWLING ON SCALLOP AND PRAWN POPULATIONS

L.M. JOLL AND J.W. PENN *
W.A. Fisheries

A high resolution navigation system adapted from the marine survey industry, has been used to enable Leslie De Lury depletion experiments to be conducted in open sea locations. Research vessel operation with one metre accuracy has allowed the delineation and repetitive trawling of discrete areas without the aid of marker buoy systems.

The results from two depletion experiments have been reported which illustrate the capabilities of the navigation system and demonstrate the use of the Leslie De Lury technique for estimating capture efficiency for scallops (*Amusium balloti*) and western king prawns (*Penaeus catisulcatus*). Commercial otter trawl effiency for the scallops was shown to be consistently high with approx 60% of the animals in the path of the net being taken. More variable capture efficiences, of 31-15% and 50-53% were recorded for male and female prawns respectively.

The assumptions inherent in the method particularly in relation to the mobility of the target species have been listed and their validity considered. Potential applications for their combination of nativation technology and depletion methodology in the future investigation of short term/seasonal changes vulnerability and mesh selection changes with size for demersal species with limited mobility have been outlined and discussed.

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ABSTRACT

ESTABLISHMENT OF A COMMERCIAL FISHERIES DATABASE IN QUEENSLAND

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In past years it has been difficult to estimate the total line-fished catch from Great Barrier Reef waters, and virtually impossible to obtain any indication of fishing effort. Gross estimates of catch have been derived from published Queensland Fish Board records, but these were incomplete because of alternative marketing arrangements.

Where detailed statistics were required for projects in specific fisheries, research staff had no option but to implement voluntary logbook programmes.

Within the past few years the Queensland Fish Management Authority and the fishing industry jointly decided that there was a need to establish a State-wide data collection system. QDPI was given the responsibility of setting up and operating the system and its associated infrastructure,and had established the scheme within the trawling sector by early 1988, and in all other fisheries soon after.

There are two logbooks; one for otter trawling and the other for "mixed fishing" (netting, line-fishing, crabbing etc.) . Provision is made in the latter for recording catch (weight) by species, effort (days fishing, number of crew, number of tender vessels) and a 30' x 30' grid locality data on a daily basis.

The QFMA has decided not to permit general release of any of the data at this stage because of their indicative nature. This restriction will remain in place until the end of this year, at which time some summarised statistics may be released provided the data have been appropriately validated. The matter of future access to this data base will be the topic of future discussins, between the industry and QFMA to ensure that suitable mechanisms for confidentiality are in place.

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ABSTRACT

PROPOSED QDPI STUDY ON INTER-REEF EPIBENTHOS AND ASSOCIATED FISH FAUNA

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Little information exists on the effects of trawling activities on populations of commercially or recreationally-important fish which as adults frequent coral reefs in the GBRR. One hypothesis suggests that the physical structure of the macro-epibenthos may provide cover for juvenile fish or food organisms utilised by the adults.

This project aims to describe the characteristics of fish communities inhabitating a non-trawled inter-reef habitat, and to determine what changes occur as a result of depletion of the epibenthic structure by trawling. The relationship between regenerating structural diversity and associated demersal fish faunas would be determined by periodic assessment of the experimental site(s) over an appropriate time-period.

The proposed experimental area is in the northern Capricorns, with possible spatial replication in the Swains. Control sites would be established within both trawled and un-trawled zones. Epibenthic structure would be estimated remotely by hydroacoustic and underwater video techniques, while sampling of the fish assesmblage would involve non habitat-destructive gear including traps, handlines, bottom short-lines and bottom-deployed light traps. Details of the experimental design and geographical scale of the manipulative experiment area under discussion.

A pilot study in late 1988 revealed that traps would be appropriate sampling tools, although the catch rates were low in comparison with those from drift handlines. Logistic problems were experienced with the trial longlines; bottom shortlines are currently being assessed at NFRC (Cairns). Handlining yielded a substantially different catch size range and species composition from the traps.

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ABSTRACT

FIRDTF PROPOSAL FOOD CHAINS AND NUTRIENT CYCLES - SUPPORTING ADULT PRAWN STOCKS (CENTRAL GBR)

ALISTAR ROBERTSON
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Australian Institute of Marine Science

Models of benthic processes enable better prediction of environmental changes by:

1. Trawling
2. Increased nutrient loading
3. Destruction Adjacent Wetlands.

3 Components:

1. Seasonal and Interannual (2.5y) changes in:

    - diet of prawns
    - diet of potential competitors (small trash fish)
    - relative abundance prawns and fish
    - density and biomass prawn prey (macro+meis-fauna)
    - microbial standing stocks and productivity
    - sediment N+Ps standing stocks
    - fluxes of nutrients across sediment/water.

    MODEL of Food Chain and Sediment Nutrient Dynamics on Prawn grounds:

    Both Lagoon and Interreefal Areas.

2. Exptl. Test of Effects of Trawling

3. Lab + Field Expts.

    - effects of trashfish biomass

      (- nutrient fluxes and microbial popns)