COTSAC Funded Research on the Ecological Aspects of the Crown-of-thorns Starfish (*Acanthaster planci*) : AIMS Project Proposals

Edited by P. Moran, Study Leader

Australian Institute of Marine Science

The Crown-of-thorns Study

Crown-of-thorns Study Report 1

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1. SUMMARY

Recently, the Federal Govenment allocated $971,000 for research on the Crown-of-Thorns starfish during the 1985/86 fiscal year. This amount was given in accordance with the recommendations of the Crown-of-Thorns Starfish Advisory Committee (COTSAC) and as such is seen to represent funds for the first year of what is hoped will be a four year Research Program. These funds have been given to the Great Barrier Reef Marine Park Authority (GBRMPA). However approximately 57% of this allocation ($558,000) is to be given to the Australian Institute of Marine Science (AIMS) under an agreement reached between the two institutions. As part of this Record of Understanding AIMS is to undertake the mainly ecological component of research identified by the Crown-of-Thorns Starfish Advisory Committee.

In a bid to address many of the important scientific questions identified by COTSAC, the Institute proposes to increase its commitment to research on the Crown-of-Thorns starfish by; further developing its on-going studies on this animal and initiating new studies with a view to addressing aspects of the phenomenon in which it has considerable expertise.

A total of 26 projects are proposed in this document, almost half of which are already underway at the Institute and have been conducted as a part of Core Research (e.g. Effects of outbreaks of Acanthaster planci on fish communities). While many of these studies will continue to function within Core Programs, COTSAC funds will be used to extend the objectives of these projects to a level which cannot be undertaken using present Institute facilities. As stated previously, the new projects proposed in this document address ecological questions in which the Institute has a large amount of experience (e.g. Geographical patterns in genetic variation of Acanthaster planci). These new projects cannot be conducted using the manpower and equipment presently available at the Institute and therefore a number of scientific staff are required for this Study. While most of these studies are planned to be undertaken over 2-3 years, some are seen only as pilot studies (i.e. they are high risk studies but would produce scientifically significant results should they be successful) and of short duration.

All of the 26 projects described in this proposal address aspects of the crown-of-thorns phenomenon which were recognised as being of importance by COTSAC. Not only this but the projects are related to one another and are structured so that a synthesis of the phenomenon can be developed from the their many results. No one project is seen in isolation but each builds on the other so that the Study is a coordinated and integrated attack on the major ecological questions identified by COTSAC. Such an approach will provide a sound scientific framework within and upon which collaborations with other individuals and institutions can be forged. Indeed,

plans have been made within the budget of this proposal to provide various facilities for researchers interested in undertaking collaborative studies (see Tables of Expenditure).

A detailed budget for the Study including such items as salaries, capital equipment, on-costs, vessel charter and consumables, has been formulated for 1985/86 and has been estimated for subsequent years. Also, a budget has been developed which details the notional support to be given by AIMS to this Study.

2. INTRODUCTION

2.1 AIMS COMMITMENT TO ACANTHASTER RESEARCH

Since October 1982 the Institute has become increasingly involved in undertaking research that is either directly or indirectly related to the crown-of-thorns starfish, Acanthaster planci. At first, these studies concentrated on investigating the recovery and development of coral communities after outbreaks of this animal. They were expanded later on to include surveys of the distribution and abundance of Acanthaster planci. The information gained from them was used in conjunction with previous data on starfish outbreaks to produce several models of the phenomenon. These models were developed further as the data base itself grew.

With the advent of outbreaks on reefs off Townsville new studies of the recovery and recolonisation of coral communities were initiated in which information was collected before, during and after an outbreak. These data were obtained from permanent sites using stereophotogrammetric and line transect techniques. In addition, this type of data was also collected in studies of the effects of outbreaks on fish communities.

During 1985 a pilot study (funded by a Marine Sciences and Technology grant) was initiated that attempted to determine whether passive integrated transponders could be used as a means of tagging adult Acanthaster planci. Also during this time a large scale survey program (funded by the Department of Employment and Industrial Relations) costing $1.016m was conducted by the Institute and preliminary studies of the in situ development of larvae of Acanthaster planci were undertaken.

A more detailed account of much of this research, including a general discussion of the results achieved, is given by Bradbury et al. (1985) (see section on Relevant Publications). To date, a total of 9 published papers (including a major review of all research) have emanated from this research. These are given (along with those that provide background information for specific proposals) in the section entitled Relevant Publications.

2.2 PLANNING COMMITTEE: COTSAC RESEARCH PROGRAM

A committee was formed to begin preparations for planning the Research Program recommended by the Crown-of-Thorns Starfish Advisory Committee. The Planning Committee comprised representatives from the Great Barrier Reef Marine Park Authority and AIMS. They were:

Dr D. Kinsey	(GBRMPA)
Dr W. Craik	(GBRMPA)
Mr R. Kenchington	(GBRMPA)
Dr R. Bradbury	(AIMS)
Dr R. Reichelt	(AIMS)

The first task of the Committee was to develop a Record of Understanding between the two institutions. This document defined the scientific responsibilities of each within the overall Research Program. Under this agreement it was proposed that "the mainly ecological research tasks (Attachment A, Part 1) be undertaken by the Institute. These would be organized together with the Institute's other research on the Crown-of-Thorns phenomenon as a discrete Crown-of-Thorns Study (hereinafter called "the Study") in association with the Institute's core research program in coral reef ecology." (Record of Understanding relating to the Crown-of-Thorns Advisory Committee recommended Research Program, pages 2 & 3). Apart from outlining the responsibilities of each institution the agreement also defined how funds were to be allocated over the ensuing 4 years.

The Planning Committee met at regular intervals throughout 1985. On the 15th August the Record of Understanding was signed by Dr J. Bunt and Dr R. Bradbury on behalf of AIMS and by the Chairman of GBRMPA, Mr G. Kelleher. At a meeting of the Planning Committee just prior to this date Dr P. Moran was nominated as leader of the Study to be conducted at and through the Institute. He attended subsequent meetings of the Planning Committee during which time a joint advertisement was drawn up, describing the forthcoming starfish program and the types of research to be coordinated by each institution. In this advertisement expressions of interest and formal research proposals were solicited for both areas of research (i.e. ecological and management). It appeared subsequently in the Australian and Townsville newspapers on the 19th October. In the weeks following the publication of this advertisement the Study Leader at the Institute undertook two trips to promote the research program, particularly the submission of proposals and discuss possible collaborative research. During these trips discussions were held with researchers from the following institutions: Queensland University, Griffith University, Sydney University, Macquarie University, CSIRO Division of Water and Land Resources, Victorian Institute of Marine Sciences, Melbourne University, Deacon University, Monash University and La Trobe University. It should be mentioned that all discussions held in Melbourne were coordinated by Dr L. Hammond, Director of the Victorian Institute of Marine Science.

3. PROJECTS

3.1 STRUCTURE OF STUDY

The ecological research which is proposed in this document builds on the program which is currently underway at the Institute. A total of 26 projects have been described in this proposal, and they address many of the research questions identified by the Crown-of-Thorns Starfish Advisory Committee. These projects essentially fit into either one of the following 4 groups:

I) Population dynamics of predator (Program Leader: Dr P. Moran).
II) Dynamics of prey and ecosystem context (Program Leader: Dr T. Done).
III) Interaction of predator and prey (Program Leader: Dr P. Moran).
IV Technological and analytical methodology (Program Leader: Dr. R. Reichelt).

These four titles are based on the research structure which has already been established at the Institute and which was outlined by Bradbury et al. (1985) in a recent paper in the journal Search (see section entitled Relevant Publications). This structure has been modified in the present Study in to order to accomodate new research initiatives, such as those associated with advances in technology and methods of analysis. Each group will have a Program Leader who will be responsible for coordinating research in that particular group. It is envisaged that a panel of external consultants will be used to review the results of each group (on an annual basis) and provide a stimulus for research.

3.2 PROJECT TITLES

A list of the titles of projects in the Crown-of-Thorns Study is given below under the four main research areas. Each project has been assigned a number (e.g. Project I(e): Substrate selection by larvae of Acanthaster planci) which is used as a reference in later sections of this proposal.

I. Population dynamics of predator

- (a) Geographic patterns in genetic variation of Acanthaster planci populations
- (b) Inheritance patterns of isoenzymes in Acanthaster planci
- (c) A field test of the larval starvation hypothesis for Acanthaster planci
- (d) Fertilization rates of Acanthaster planci in the field
- (e) Substrate selection by larvae of Acanthaster planci
- (f) Development of techniques for the production of large numbers of larvae and juveniles of Acanthaster planci
- (g) Feeding rate of Acanthaster planci in the field
- (h) Feeding preferences of Acanthaster planci in the field
- (i) Rate of decomposition of adult Acanthaster planci in the field
- (j) Ephemeral patches of phytoplankton in the central Great Barrier Reef as a potential food source for larvae of Acanthaster planci

II. Dynamics of prey and ecosystem context

- (a) Recolonisation and recovery of coral communities
- (b) Interpretation of the history of disturbance to coral communities through analysis of morphology and population structure in massive Porites
- (c) Genetics of population fluctuations of corals
- (d) Growth and survivorship of coral remnants following outbreaks of Acanthaster planci
- (e) Effects of outbreaks of Acanthaster planci on fish communities
- (f) Effects of outbreaks of Acanthaster planci on the interaction between corals and algae: trophodynamic implications
- (g) Effects of outbreaks of Acanthaster planci on the interaction between scleractinian and alcyonacean corals

III. Interaction of predator and prey

(a) Macro-scale studies of the distribution and abundance of *Acanthaster planci* and corals on the Great Barrier Reef

(b) Meso-scale studies of the distribution and abundance of *Acanthaster planci* and corals on selected reefs

IV. Technological and analytical methodology

(a) Enhancement of substrate reflectance in Landsat imagery with special attention to reef damage by *Acanthaster planci*

(b) Evaluating procedures for the verification of Landsat images with reference to the effects of *Acanthaster planci* on reefs.

(c) Numerical models of the hydrodynamic regime around schematized and actual reefs.

(d) Numerical models of the hydrodynamic regime at John Brewer Reef

(e) Dispersal of *Acanthaster planci* outbreaks over the whole Great Barrier Reef - a simulation study.

(f) Analyses and models of existing data

(g) Tagging of *Acanthaster planci* using micro-injectable transponders

3.3 PROJECT INVESTIGATORS AND COLLABORATIONS

Eight scientists at the Institute are designated as Chief Investigators for 22 of the 26 proposed projects in the Crown-of-Thorns Study. It is envisaged that new scientific staff (including Research Scientists) will need to be hired to conduct the remaining projects. A list of the names of the Chief Investigator(s) for each project are given in Table 1 along with the names of scientists who will be collaborating in this research. It should be pointed out that the research outlined in this study involves the collaboration of 22 different scientists (from 13 institutions) from Australia and overseas.

Table 1. List of AIMS personnel associated with project, including collaborations.

Project No.	Page No.	Chief Investigator(s)+	Collaborations
I(a)	9	J. Stoddart RS*	J. Lucas (JCU)
(b)	13	J. Stoddart R. Olson	-
(c)	15	R. Olson	J. Lucas (JCU)
(d)	25	R. Olson	J. Lucas (JCU)
(e)	29	R. Olson	J. Lucas (JCU)
(f)	33	R. Olson	J. Lucas (JCU)
(g)	36	P. Moran	P. Fairweather (Macquarie Uni.)
(h)	40	P. Moran	R. Reichelt (AIMS)
(i)	44	P. Moran	R. Reichelt (AIMS)
(j)	47	M. Furnas	J. Parslow (Griffith Uni.)

* new position within AIMS Study

\+ non-AIMS personnel identified

Table 1 cont'd.

Project No.	Page No.	Chief Investigator(s)+	Collaborations
II (a)	53	T. Done P. Moran	R. Pearson (Qld. Dept. Fish.)
(b)	58	T. Done P. Sale (Syd. U.)	D. Potts (University of California)
(c)	61	J. Stoddart	-
(d)	64	T. Done	-
(e)	66	D. Williams	P. Doherty (Griffith Uni.)
(f)	76	D. Klumpp RS*	-
(g)	82	T. Done RS*	-
III (a)	90	P. Moran R. Bradbury R. Reichelt	W. Craik (GBRMPA)
(b)	93	P. Moran	R. Bradbury (AIMS) R. Reichelt (AIMS)
IV (a)	96	D. Jupp (CSIRO) R. Reichelt	P. Guerin (ASO) D. Kuchler (CSIRO) B. Harrison (CSIRO) K. Mayo (CSIRO) R. Kenchington (GBRMPA) D. Van Claasen (GBRMPA)
(b)	101	R. Reichelt	D. Kuchler (CSIRO) P. Moran (AIMS) R. Kenchington (GBRMPA)
(c)	105	K. Black (VIMS) J.C. Andrews	L. Hammond (VIMS) R. Reichelt (AIMS) P. Moran (AIMS)
(d)	112	J.C. Andrews K. Black (VIMS)	R. Reichelt (AIMS)
(e)	119	R. Reichelt	K. Black (VIMS) R. Bradbury (AIMS) D. Green (ANU)
(f)	125	R. Reichelt R. Bradbury P. Moran RS*	P. Antonelli (University of Alberta) L. Marsh (JCU) D. Green (ANU)
(g)	132	P. Moran	D. Cooper (CSIRO) B. Peden (Deacon Uni.)

* new position within AIMS Study

\+ non-AIMS personnel identified

3.4 PROJECT DESCRIPTION

Project I (a): Geographic patterns in genetic variation of Acanthaster planci populations

Introduction

The level of difficulty in determining the geographic origins of recruitment in species whose larvae spend a long, or unknown, time in the plankton is directly related to the extent of that species distribution. In the case of Acanthaster planci, larvae spend at least 15-20 days in the water column and the species is distributed over thousands of kilometres, spanning several oceans and seas. It is unsurprising that theories of how populations are recruited at low densities, high densities and during the transition between these states are restricted to speculation at present.

Studies which relate larval biology to patterns of water movement are valuable indicators for forging theories of larval dispersal, but are rarely able to falsify alternative theories as they cannot effectively perceive settlement processes leading through to recruitment. The use of population genetics theory to relate geographically separate populations through their genetic structure employs parameters which reflect the sum of the entire recruitment process. These techniques can assign relative probabilities to alternate hypotheses and are used extensively as arbiters of dispersal models by fisheries managers. They have become particularly refined for studies of marine benthos.

The utility of this type of genetic analysis requires the presence of variation at one or more enzyme encoding loci. Preliminary work on A. planci by Nash (1983) and Lucas et al. (1985) has shown that there is an abundance of isoenzyme polymorphisms. Nash (1983) showed that over the length of the GBR, gene frequencies appeared quite uniform but this study was not designed specifically to examine spatial relationships and made no specific reference in experimental design to dispersal theories. Dr Lucas' genetic work is continuing on a single reef with the emphasis on temporal changes in gene frequency. It would make an excellent companion to an extensive study aimed at spatial patterns.

Research plan

In this study isoenzyme techniques will be used to relate the spatial pattern in genetic variation and genetic structure of Acanthaster planci populations to hypotheses of dispersal. A rigorous sampling strategy will be implemented drawing on the survey results of the AIMS CEP Crown-of-thorns Study. The experimental design of the study will be decided upon in consultation with AIMS' population geneticist, Dr J. Stoddart.

It is envisaged that this study will run for 2 years with a possible extension to a third year if results are promising. A general research plan for these 3 years is given below.

Year 1 -

a) Appointment of Research Fellow/Scientist - Jan/Feb.
b) Establish equipment and protocols for A. planci within AIMS' genetics lab.
c) Initial Surveys - intensive search for 1st yr. class starfish.

Year 2 -

a) Extensive/Intensive Surveys; modify to test hypotheses emanating from other projects on Acanthaster planci.
b) Resurvey of 1st year class of yr.1.
c) Analysis of results.

Year 3 -

a) Further surveys/resurveys to provide definitive tests of hypotheses of yr. 2.

The study outlined above would have liaisons with several other programs as it is:

a) Closely related to other projects on Acanthaster planci; especially those concerning larval dispersal and inheritance of isoenzymes (see Projects I(b), II(c))

b) Complimentary to James Cook University's A. planci genetics study being carried out by Dr J. Lucas.

c) Intermeshes with existing AIMS projects examining spatial patterns in the population genetics of reefal benthos.

Resources needed:

Interpretation of patterns in gene frequencies is complex, requiring extensive familiarity with genetic processes and analyses. The day-to-day analysis of results and retuning of designs and tests is beyond the time commitment available from existing AIMS staff. To be successful, this project requires the full time services of an experienced population geneticist.

The early appointment of this person is desirable to:

a) Ensure that the project has access to large numbers of starfish,

b) Ensure that the project is ready to respond to hypotheses of dispersal when these come from other areas of the program.

A small balance (Sartorius) is required to measure sample weights and is to be dedicated full-time to the project.

Literature cited

Lucas, J.C., W.J. Nash, and M. Nishida (1985). Aspects of the evolution of *Acanthaster planci*. Proc. Fifth Int. Coral Reef Congress, Tahiti.

Nash, W.J. (1983). Population genetic and morphometric studies on the Crown-of-thorns Starfish, *Acanthaster planci* (L.), in the Great Barrier Reef region. M.Sc. thesis, James Cook University of North Queensland, 163 p.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries :		
Research Fellow*	12911	-
Research Scientist+ (Dr J. Stoddart)	-	1586
2. Vessel charter :		
7 day-trips @ $500/day	3500	-
3. Capital equipment :		
Electronic balance (Sartorius 1465)	1125	-
4. Consumables :		
Chemicals (e.g. isoenzyme assays)	4000	-
Glassware	500	-
Field equipment	500	-
Liquid nitrogen	200	-
TOTAL	**$22736**	**$1586**

* includes leave loading and district allowance and is based on 6 month's salary

+ based on 10% of available time

Project I (b): Inheritance patterns of isoenzymes in Acanthaster planci

Introduction

Empirical tests of the genetic basis of locus/allele models of isoenzyme banding patterns are an essential complement of any confident interpretation of processes behind perceived genetic patterns. They remove the need for major assumptions concerning qualitative and quantitative parameters of inheritance which build into causal explanations of the genetic structure of adults. When the technology exists for raising larvae from crosses between adults of known genotypes, it is possible to perform such tests. This project will examine the proposed genetic basis of Acanthaster planci isoenzyme banding patterns and also test the assumption that the genotypes of potential recruits entering from the plankton are distributed according to Hardy-Weinberg predictions based on the genotypic frequencies of adult stocks.

Research plan

The aims of this study are to:

a) Test locus/allele models of isoenzyme banding patterns by segregation analysis of the progeny of breeding trials.
b) Examine genotypic frequencies of F1 larvae for conformation to Hardy-Weinberg predictions.

Specifically, this will involve the following tasks:

a) Return starfish with mature gonads to lab in mid-November to early December.
b) Analyse adult genotypes electrophoretically.
c) Early January - extract spawn and establish 5 crosses of appropriate individuals.
d) Raise larvae to brachiolaria stage.
e) Electrophoresis of larvae (20-50 per cross) and analysis of genotypes.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries :		
Research Scientist (Dr R. Olson)	-	-
Research Scientist* (Dr. J. Stoddart)	-	714
2. Vessel charter :		
1 day-trip @ $500/day	500	-
3. Consumables :		
Chemicals (e.g. isoenzyme assays)	500	-
Larval rearing equipment	150	-
Glassware	150	-
TOTAL	**$1300**	**$714**

* based on 5% of available time

Project I (c): A field test of the larval starvation hypothesis for Acanthaster planci

Background

"... the relation between phytoplankton production and larval occurrence is one of the most urgent problems in marine larval ecology ..." - Thorson (1950).

Though it has been 35 years since Thorson (1950) discussed whether plankton-feeding invertebrate larvae ever starve in nature, the issue remains unresolved. Vance (1974) developed a mathematical model to examine the effects of food shortage on feeding larvae. Despite his derivation these exists today virtually no field data to confirm or reject the notion that planktotrophic invertebrate larvae experience starvation.

Starvation can affect survivorship either directly or indirectly. The death of larvae from malnutrition is a direct result of starvation. Indirectly, the rate of larval development is often proportional to food availability; reduced food supply can prolong the larval phase, leading to greater losses to predators (see Vance, 1974 for a theoretical treatment of this).

Starvation has been suggested to be a crucial aspect of larval fish ecology. Studies by Lasker et al. (1970) and Lasker (1975) have shown the potential for the availability of larval food to strongly affect recruitment. The hypothesis of Hjort (1914), that larval food determines recruitment success, has been resurrected (Lasker, 1981). Laboratory studies demonstrate the importance of time to first feeding and the existence of irreversible starvation (see Hunter, 1981 for a review of recent literature). Field studies confirm that larval starvation does occur at least in some species (Thielacker, 1978; O'Connell, 1979), and that fish larvae are more abundant where larval food is greater (Blackburn and Nellen, 1976; De la Fontaine et al., 1981). Although there is not complete agreement on the extent to which starvation occurs (Houde, 1978), the evidence is clear for fish that larval starvation does occur and can potentially limit recruitment, and thus population size.

Invertebrate larvae differ from fish larvae in a number of important ways. Few fish larvae are less than 2.0 mm in length (Moser, 1981), while few invertebrate larvae are greater than 2.0 mm in length (Thorson, 1950). In general, fish larvae are unlikely to sustain much of their energetic requirement through the uptake of dissolved organic matter (DOM) (although there are a few possible exceptions such as the larvae of the European eel (Hulet, 1978)). Many invertebrate larvae, however, have recently been shown to be capable of substantial rates of uptake of DOM (Manahan, 1983; Manahan et al., 1983; Davis and Stephens, 1984). Manahan (in press) has suggested that larvae of the echinoid Stronglocentrotus purpuratus can meet 79% of their energetic needs from uptake of DOM in micromolar solutions of amino acids alone.

Invertebrate larvae generally feed on a different trophic level (phytoplankton) (Thorson, 1950) than fish larvae, which feed either partially or entirely on zooplankton (Hunter, 1981). Thus there is roughly an order of magnitude difference in the standing crop of food resources for the larvae of fish versus invertebrates.

The extent to which starvation occurs among invertebrate larvae is unknown. Thorson (1950) notes that larvae collected in plankton tows seldom, if ever, resemble starved larvae from the laboratory. However, Mann (1984) has suggested that the consumption of lipids during starvation changes the buoyancy of larvae, resulting in their drifting to the bottom where they will not be sampled by plankton nets.

Introduction

Attempts to explain the cause of outbreaks of A. planci, until the late 1970's, consisted of simplistic, single factor explanations (see Potts, 1981). The more well known hypotheses concerned the role of man's disturbance and pollution (Randall, 1972), removal of predators (Endean, 1977), or simply aggregation of already existing populations (Dana et al., 1972). A dichotomy developed over whether the ultimate cause was natural (Frankel, 1977) or man induced (Fischer, 1969; Endean, 1977).

The first, and only, testable hypothesis to date which combines the life history data for A. planci with records of past outbreaks, is that of Birkeland (1982). His hypothesis, which he has termed the terrestrial runoff hypothesis, involves the following four main parts.

a) Extremely heavy rainfall (>30 cm in 24 hrs) or heavy rainfalls after droughts, on high islands result in heavy nutrient runoff into the nearshore marine environment.
b) Heavy nutrient runoff into the marine environment elevates levels of primary production, increasing phytoplankton standing crop, during A. planci spawning time.
c) The larvae of A. planci, through some mechanism associated with terrestrial runoff, experience reduced levels of mortality, resulting in heavy larval recruitment.

d) Larvae recruit and grow for three years (starfish that first appear in outbreaks are 3 yrs old, according to Lucas' (1984) and Yamaguchi's (1974) laboratory determined growth curves), then appear in large aggregations on the reef.

For the mechanism of reduced larval mortality (part C), Birkeland (1982) has chosen to invoke what can be termed the larval starvation hypothesis. He suggests that the increase in phytoplankton either directly (through decreased mortality due to malnutrition) or indirectly (through more rapid larval development, decreasing exposure to other sources of mortality such as predation) reduces mortality.

The larval starvation hypothesis is based on research conducted in the laboratory by Lucas (1982). Of nine species of phytoplankton tested, Lucas found Dunaliella primolecta and Phaeodactylum tricornutum to give the best results in terms of larval survivorship and development to the late brachiolaria stage. He raised A. planci larvae on various cell densities of these two species, feeding them only single species diets. Larval development success was highest at cell densities of 10^3 to 10^4 cells/ml. At lesser densities survivorship and development were markedly decreased. In an effort to extrapolate these results to the field, Lucas determined the amount of chlorophyll a per volume of the cultured phytoplankton at the various cell densities, then compared this measure of standing crop to published values for waters of the GBR. The implication is that based on this measure of biomass, there is insufficient food available to support the larvae of A. planci to settlement.

There is currently insufficient information to accept or reject larval starvation as the mechanism responsible for larval mortality in part C.

The following five arguments emphasize that the larval starvation hypothesis needs to be tested in the field before it can be accepted as an explanation of A. planci outbreaks.

a) Diet diversity :

Although the standing crop of phytoplankton, in terms of chlorophyll a, in waters of the GBR may be relatively low compared to levels needed to support larval development of A. planci in the laboratory (Lucas, 1982), the decreased biomass might be offset by nutritional benefits of a mixed diet of phytoplankters. The benefits of a mixed diet have been documented for bivalve larvae (Davis and Guillard, 1958; Walne, 1963; Bayne, 1965), and copepods (Gaudy, 1974; Hag, 1967).

b) Dissolved organic matter (DOM) :

The idea that echinoderm larvae can obtain a major portion of their energetic needs through the uptake of DOM is being supported through recent laboratory studies using high performance liquid chromatography (Manahan, in press). Strathmann (1975) used the data of several studies to calculate that early echinoid embryos might be able to uptake 14 to 48% of their energetic requirement, based on measurements of oxygen consumption. More recently, Manahan (in press) verified that larvae of the echinoid Stronglyocentrotus purpuratus can meet up to 79% of their total energy demand by DOM uptake.

The importance of DOM to A. planci larvae was discussed by Lucas (1982). He suggested that it might not be a major source of nutrition. However, it is likely that DOM uptake could sustain larvae as they drift between patches of food, minimizing the likelihood of starvation as a direct cause of mortality.

c) Carbon/chlorophyll a of laboratory algae :

Lucas (1982) extrapolated the results of dietary studies to the field using values of chlorophyll a for standing crop of phytoplankton. The ratio of carbon/chlorophyll a is known to be considerably higher for natural phytoplankton than for laboratory culture (Eppley et al., 1977). Even though much of this difference can be attributed to zooplankton and non-living organic matter (Banse, 1977), chlorophyll a is still an underestimate of total carbon available for larval consumption in natural seawater.

d) Recruitment of other planktotrophic larvae :

A nagging question, that is often raised, is why no other species of invertebrates with planktotrophic larvae show outbreaks in conjunction with the phytoplankton bloom from terrestrial runoff that causes A. planci outbreaks.

e) Application of the larval starvation hypothesis to the GBR :

Birkeland (1982) developed his terrestrial runoff hypothesis primarily around the data for outbreaks in Micronesia. The only mention of primary outbreaks on the GBR is found in his table of major outbreaks (his Table 1). No attempt is made to explain the secondary outbreaks which occurred on the GBR in the 1960's and 1970's, and are occurring again now. The problem with the terrestrial runoff hypothesis, for the GBR, is how to explain outbreaks which occurred on outer shelf reefs such as Dip Reef or St. Crispin Reef (Pearson and Endean, 1969) which are not likely to be affected by terrestrial runoff. Potts (1981) suggests that the primary outbreak on the GBR near

Green Island comprised a breeding population capable of producing so many larvae that losses due to larval mortality (as the outbreaks moved progressively southward) were swamped out by the sheer numbers of offspring produced. This is contrary to conventional notions of the independence of breeding stock size and recruitment success, particularly in echinoderms (Burkenroad, 1957; Lossanoff, 1964; Ebert, 1983). If this is the mechanism that causes outbreaks on the GBR, then why hasn't the same effect taken place in Micronesia, with islands having repeated secondary outbreaks for years after a primary outbreak?

There are two possible solutions to this inconsistency. Either the two systems (Micronesia and the GBR) operate under different processes, or there is a single mechanism which can explain both systems. In the absence of any firm evidence to show that GBR outbreaks are inherently different from Micronesian outbreaks, the most parsimonious and productive approach is to assume that a single mechanism can explain all outbreaks.

Research plan

The reseach outlined below will provide a field test of the larval starvation hypothesis. Larvae of Acanthaster planci will be cultured in-situ in an attempt to determine whether they can develop to settlement in the waters of a "normal" coral reef (i.e. in the absence of terrestrial runoff).

To measure the growth rates of A. planci larvae under as natural conditions as possible, submersible larval culturing (SLC) systems have been constructed. Two prototype SLC systems were tested during a 2-week research cruise in January 1985 and were found to be successful for raising larvae in-situ (Olson, 1985).

Six SLC systems (two treatments, three replicates) will be set up in an area of approximately 5 m depth on the leeward side of John Brewer Reef. Each system will be suspended on lines from a buoy, placing it 2 m beneath the sea surface. The lines will attach to the four corners of the SLC system and join in the center where they will clip on to the line from the buoy above. To work with a system, the line will be unclipped and the whole system will be carefully taken to the benthos.

The first treatment will consist of a "natural" diet of ambient water. The second treatment will be the same "natural" diet, but supplemented with Dunaliella primolecta culture. The six systems will be installed 5 m apart from each other in a row perpendicular to the prevailing current and with the treatments alternating. At the start of the experiment 40 two day old bipinnaria larvae (developed in the laboratory) will be placed in each culture chamber. Once this has been accomplished all culture chambers, mesh lids, intake sieves, and batteries will be changed every morning. Each day four 100 ml water samples will be collected next to the SLC systems to quantify the phytoplankton standing crop in terms of chlorophyll a. These samples will be filtered onto Whatman GF/F filters, extracted in 10 ml of 90% acetone for 30 min, centrifuged at 2500 G for 5 min, then analyzed on a Turner fluorometer, following the methods of Strickland and Parsons (1965). Every five days one chamber from each SLC system (selected randomly from the remaining chambers using a random number table) will be removed for analysis. The chambers will be placed in a water-tight box and taken to the lab. Four groups of 3 larvae each will be taken from each sample for analysis of the chlorophyll a and phaeophytin pigment in their guts. The larvae will be extracted, three at a time in 10 ml. of 90% acetone. The pigment extract will be analyzed with the fluorometer. The rest of the larvae will be preserved by first relaxing them in $MgCl_2$ for 15 min then fixing them in 4% formalin.

The developmental stage of all larvae, will be recorded according to the stages described by Lucas (1982). Also, larvae will be measured for length and width using an ocular micrometer. On day 10, to promote larval settlement, small pieces of coralline algae (2 cm approximate diameter), cleaned of all infauna, will be placed in all remaining chambers in the field.

The data resulting from this experiment will be larval growth, development, and gut contents at 5, 10, 15 and 20 days under a "natural" diet versus an enriched diet. The data will be fitted to growth curves and the effect of the treatment (diet enrichment) will be determined by analysis of covariance.

Resources needed :

It is anticipated that Dr R. Olson (currently a Post-Doctoral Fellow at AIMS) would be appointed to continue the research he has been involved with over the last year. He would be responsible for conducting the research described above and that mentioned in Projects I(d) and (e). An Experimental Scientist also will be needed to assist in this research as the methods involved in these Projects are time consuming and cannot be undertaken solely by the Chief Investigator. The Experimental Scientist would be responsible for culturing both larvae and juveniles in the laboratory (also see Project I(f)), estimating concentrations of chlorophyll a, maintaining algal cultures and providing assistance in the field.

In order to follow the development of larvae, through to settlement, 16 days of shiptime are required 10 days of which will be provided by AIMS as part of on-going research activities.

As the developmental stages of larvae will be identified, a stereomicroscope and light source will need to be purchased. These are not available within the Institute on a full-time basis.

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Budget 1985/86

Item	Cost COTSAC	AIMS
1. Salaries :		
Research Scientist* (Dr R. Olson)	14366	-
Experimental Scientist+	14893	-
2. Vessel charter :		
6 day field trip @ $700/day	4200	-
Fuel @ $150/day	900	-
Victuals @ $150/day	900	-
10 day field trip @ $2600/day	-	26000
3. Capital equipment :		
Stereomicroscope (Wild M7A)	4000	-
Light source (Schott KL1500)	700	-
4. Consumables :		
Microrespiration cell	450	-
Field equipment (e.g. SLC material)	2000	-
Other (e.g. film)	100	-
TOTAL	**$42509**	**$26000**

* includes leave loading and district allowance and based on 6 month's salary

+ includes leave loading and district allowance and based on 6 month's salary.

Project I (d): **Fertilization rates of Acanthaster planci in the field.**

Introduction

In a recent review on echinoderm recruitment, Ebert (1983) stated that "No studies have attempted to measure fertilization as a function of density for any marine animal". Pennington (1984) reviewed evidence which he felt inferred that fertilization rates of free-spawning species are probably high. He listed 37 species in which female gamete shedding is cued by the presence of active sperm, presumably assuring high fertilization.

A. planci has been shown to spawn in response to gametes in the water (Beach et al., 1975) and reports have described "breeding aggregations" (Ormond and Campbell, 1973; Vine, 1973). Vine (1973) hypothesized that aggregating during breeding increases fertilization rates, but no data has ever been collected to test this.

Research plan

The aim of this study is to determine whether distance and density of spawning males affects fertilization rates of Acanthaster planci. This research will be conducted in situ (using submersible larval culture chambers) on an outbreaking reef. This will be a reef where at least one large aggregation of A. planci, (i.e. more than 100 starfish) can be seen within a short swim. Information from the AIMS CEP Crown-of-Thorns Study (which will have data from recent censuses of the central section of the GBR) will be used to determine at which reef to work. If the southward movement of outbreaks continues to follow the pattern of the previous wave (1962-1974), then Bowden Reef should provide the ideal site for these experiments.

The submersible larval culture chambers will be used to hold ripe eggs at various distances from spawning males to assay for fertilization rates. Two types of experiments are envisaged in this study

a) Experiment 1 - Effect of distance :

This experiment will be conduced on an outbreaking reef during the first two weeks of January, the most probably time of A. planci mass spawning. Each replication will consist of 3 SLC systems (see Project I(c)) placed in the center of an isolated A. planci aggregation, and 3 SLC systems placed at 100 m distance from the aggregation. Each SLC chamber will contain 40 ripe eggs. These eggs will be obtained from dissected ovaries soaked in 10^{-5} M 1-methyl adenine. This induces breakdown of the germinal vesicle, preparing the eggs for fertilization (Stevens, 1970).

The chambers will be changed every morning and the collected samples fixed in 4% formalin. The samples will be analyzed later by recording the number of eggs with fertilization membranes, and the developmental stages (1 cell stage to blastula). If mass spawning is observed during this time period, then samples will be changed every 6 hr to examine the effects on a shorter time scale. The data will be analyzed with a 2-factor analysis of variance with the factors being distance and days.

b) Experiment 2 - Effect of density :

Three SLC systems each will be placed at 0 and 10 m from the source point. All chambers will contain 40 ripe eggs. The source point will be a 1 m x 1 m x 0.5 m cage of 2 cm mesh. In the first treatment, one adult male starfish will be placed in the cage and injected with 10 ml of 10^{-5} M 1-methyl adenine, which will induce spawning within 15 min (J. Lucas, pers. comm.). Four hrs later, the contents of all chambers from each SLC system will be collected and preserved for analysis (same method of analysis as Experiment 1). The experiment will be repeated with 4, and 8 males as the source, and with no males as control. Each density treatment will be replicated four times on separate days. The data will be analyzed with a 2-factor analysis of variance with the factors being density and days.

Resources needed:

A Research Scientist and Experimental Scientist are needed to undertake the work in this project. For more details see Project I(c).

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Budget 1986/87

Item	Cost COTSAC	Cost AIMS
1. Salaries :		
Research Scientist (same as Project I(c))	-	-
Experimental Scientist (same as Project I(c))	-	-
2. Vessel Charter :		
15 days @ $700/day	10500	-
Fuel @ $150/day	2250	-
Victuals @ $150/day	2250	-
3. Consumables :		
Field equipment (e.g. SLC material)	3000	-
Chemicals	400	-
Other (e.g. film)	100	-
TOTAL	**$18500**	-

Project I (e): Substrate selection by larvae of Acanthaster planci

Introduction

The larvae of Acanthaster planci are known to settle on coralline algae (Yamaguchi, 1973a; Lucas, 1982). Yamaguchi used coralline algae of genus Porolithon but no survey has been conducted to examine whether there is any species specificity. Lucas (1973) found that larvae would settle even in the absence of coralline algae. However, since juveniles feed on coralline algae for their first four months of growth (Lucas, 1984), it is likely that most settlement does take place on coralline algae.

The most extensive research to date on induction of settlement and metamorphosis of invertebrate larvae by coralline algae has been conducted by Morse and colleagues (Morse et al., 1979; Morse et al., 1980; Morse and Morse, 1984; Trapido-Rosenthal and Morse, in press) working with abalone larvae. They have found that the natural inducer of settlement and metamorphosis is a peptide with a structure similar to gamma-aminobutyric acid (GABA), a neurotransmitter. The process appears to be mediated by a depolarization of GABA-sensitive cells. Baloun and Morse (1984) showed that changing the ionic environment, using K^+, can enhance or inhibit settlement of abalone larvae. They suggest that manipulating the ionic environment might be effective with other invertebrate larvae.

According to Morse some of the compounds which promote abalone larval settlement, such as some diamino acids, can be found in decaying terrestrial plant matter. Thus it is possible that terrestrial runoff might either alter the ionic environment or contain chemical compounds which promote settlement of A. planci larvae.

Research plan

This study aims to examine the effects of relevant species of coralline algae on settlement and metamorphosis of the larvae of Acanthaster planci.

It is assumed that coralline algae is the preferred settlement substratum of Acanthaster planci larvae. This is based on the results of past research (Lucas, 1984) and on the fact that coralline algae is the juvenile food source.

Using the methods of Lucas (1982), larvae will be raised at AIMS in the invertebrate larval culture laboratory that has been set up by Dr R. Olson. Larvae will be grown in 0.5 l beakers at approximate densities of 2 larvae/ml, and fed Dunaliella primolecta. Coralline algae will be collected from the field and portions will be preserved for species identification. The algae will be collected by dives from exposed (full sunlight) and cryptic locations on the reef flat (1-2 m depth), the reef slope (10 m and 30 m depths), and, through the use of a benthic grab sampler, from 50, 70 and 100 m depths. Small portions of the coralline algae (approx. 2 cm width) will be thoroughly cleaned of all infauna, then placed into the beakers when larvae are 10 days old. At least four replicate cultures of 1000 larvae each will be conducted for each species of coralline algae collected from each site. Settlement of larvae will be monitored daily. The maintenance of the larval cultures and phytoplankton will be performed by an experimental scientist working within the program. Results for each type of algae will be compared statistically.

Resources needed:

A Research Scientist and Experimental Scientist are needed to conduct the research in this project. For more details see Project I(c).

Literature cited

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Budget 1985/86

Item	Cost COTSAC	AIMS
1. Salaries :		
Research Scientist (same as Project I(c))	-	-
Experimental Scientist (same as Project I(c))	-	-
2. Vessel charter :		
1 day-trip @ $500/day	500	-
4 day field trip @ $700/day	2800	-
Fuel @ $150/day	600	-
Victuals @ $150/day	600	-
3. Consumables :		
Glassware	500	-
TOTAL	**$5000**	-

Project I (f): Development of techniques for the production of large numbers of larvae and juveniles of Acanthaster planci

Introduction

Perhaps one of the most well known aspects of the biology of Acanthaster planci is its life cycle. Mortensen (1931) was the first to rear larvae of this species to the brachiolaria stage in the laboratory. While other early larval studies were unsuccessful those undertaken in the late 1960's and early 1970's succeeded in rearing larvae in the laboratory to the juvenile starfish stage (Henderson, 1969; Branham et al., 1971; Henderson and Lucas, 1971). In so doing, it was demonstrated that the rate of development of larvae could be greatly affected by several factors, particularly temperature and salinity (Lucas, 1973, 1975).

With the ability to be able to rear larvae and develop them through the juvenile stages to adult starfish a range of studies was conducted by Lucas (1982, 1984) and Yamaguchi (1974). As noted by Potts (1981) these studies were all conducted in the laboratory. Also, the techniques were used on a relatively small number of larvae and juveniles.

Research plan

The aim of this study is to develop the culturing techniques pioneered by earlier workers (e.g. Henderson, 1969; Lucas, 1975, 1982; Yamaguchi, 1973) to a state where large numbers of larvae and juveniles of Acanthaster planci can be produced. It is important to have this ability so that a ready supply of larvae is available to the projects proposed in this Study (i.e. Projects I (c)(d) and (e)) and to any which may be initiated in future years. Also, it may be possible to undertake well designed manipulative experiments on various aspects of the ecology of juvenile starfish (e.g. feeding rate and preferences) should large numbers (e.g. 500 - 1000) of them be produced.

Techniques similar to those used by Lucas (1975, 1982, 1984) will be adopted in this study. Larvae will be developed in large culture chambers (4 litre volume) in which the food levels (D. primolecta) will be constant. This method is similar to that which has been used by CSIRO in the development of large numbers of nauplii (Rothlisberg, pers. comm.). Once metamorphosis has taken place the juveniles will be transferred to outdoor holding tanks where they will be fed a diet of coralline algae.

Resources needed:

The development of suitable culture techniques will be undertaken by the Experimental Scientist employed to assist with research in Projects I (c)(d) and (e). Facilities are available at the Institute to undertake the laboratory culture of larvae. Outdoor holding tanks will need to be purchased for keeping juvenile Acanthaster planci. This requires that funds be allocated to complete the outdoor aquarium at the Institute (see section 4.1 Justification of Budgetary Items). A small amount of funds are sought to purchase additional equipment for this project.

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Budget 1985/86

	Item	Cost COTSAC	AIMS
1.	Salaries:		
	Experimental Scientist (same as Project I (c))	-	-
2.	Capital Works:		
	Completion of outdoor aquarium facility	20000	37000
3.	Consumables:		
	Equipment (e.g. tanks, pumps)	500	-
	TOTAL	**$20500**	**$37000**

Project I (g): Feeding rate of Acanthaster planci in the field

Introduction

Four post-metamorphic stages have been described in the life cycle of Acanthaster planci from studies conducted in the laboratory. These have been recently defined by Lucas (1984) as; algal feeding juvenile, coral feeding juvenile, coral feeding adult and senile adult.

After metamorphosis the juvenile starfish has five arms and is between 0.3-0.5 mm in size (Henderson and Lucas, 1971; Yamaguchi, 1973). Over the next 4-5 months the starfish, which feeds on encrusting and epiphytic algae grows to 8-10 mm in diameter (Yamaguchi, 1972). The growth rate at this stage is relatively slow and after about 6 months the starfish possesses all the external features of an adult with about 16-18 arms. At about this time it changes its diet and begins to feed on corals (Lucas, 1975). Once this transformation has been completed the growth rate increases and starfish may reach a size of 60-70 mm within 1 year and 200 mm after 1.5-2 years (Yamaguchi 1974). Lucas (1984) defined this as a phase of Von Bertalanffy-type growth and he suggested that it continued until the starfish reaches sexual maturity. Most starfish become sexually mature when they reach 160 mm in diameter, which is normally late in their second year of life (Lucas and Jones, 1976).

Studies by Yamaguchi (1974) and Lucas (1984) have demonstrated that the growth rate of starfish declines greatly once sexual maturity is attained. That is, 17-20 months after metamorphosis. From his laboratory studies Lucas (1984) recognised a phase of non-growth in starfish at 3 years of age (about 350mm). During this "senile" (sensu Lucas) period the size of some individuals was found to decrease and gametogenesis also began to decline. Lucas (1984) indicated that this phase may last for several years, after which time the starfish die.

The four post-metamorphic stages identified by Lucas (1984) have arisen from studies conducted in the laboratory. As yet there has been no attempt made to verify the existence of these stages in the field. This is necessary as the findings of Lucas and Yamaguchi have been criticised on the grounds that they may be an artifact of laboratory conditions and may represent the effects of such factors as disease and infection (Kenchington, 1977).

Research plan

The aim of this study is to determine whether the feeding rate of different sized starfish is variable and if so, whether these changes correspond to the different life history stages described in the laboratory by Lucas (1984).

Feeding rate experiments will be conducted on starfish which belong to the size categories that correspond to the different stages identified by Lucas (1984). These are:

a) 7 - 14 cm (coral feeding juveniles).
b) 20 - 35 cm (coral feeding adults).
c) 40 - 60 cm (senile adults).

Experiments on algal feeding juveniles will not be attempted because of their small size and cryptic behaviour.

In each experiment 6 starfish of the one size category will be placed within separate enclosures (i.e. 2m x 2m wire cages) on Helix reef in areas which have high coral cover and have been free of starfish. The extent of mortality of corals (determined from the feeding scars that appear) in each of these cages will be measured (using maps and photographs) every 6 hours over a five day period. This experiment will be repeated for each of the other starfish categories mentioned above.

In order to control for the effects of caging on feeding rates, individual starfish of the same category being tested will be tagged by placing coloured caps over their spines (laboratory studies have shown that this technique is suitable for identifying individual starfish over a period of a few days) (pers. obs.). These starfish will then be placed in areas of high coral cover where there are no feeding scars and in close proximity to the feeding enclosures. The feeding rate of these starfish will be determined in the same manner as the caged individuals and over the same period of time.

The results of this experiment will be analysed statistically using Analysis of Variance and will complement the work already being undertaken by Dr Lucas on Helix Reef.

Resources needed:

The research described above would be suitable for a postgraduate student. It could be incorporated into a more general study on the feeding of Acanthaster planci. With this in mind funds for a postgraduate scholarship are requested for a three year period. Dr D. Klumpp (a staff member within the Institute) would provide on-site supervision in this study.

All shiptime required in this project will be met by the Institute. A small amount of funds are requested to purchase field equipment and to make the feeding enclosures.

Literature cited

Henderson, J.A., and J.S. Lucas. (1971). Larval development and metamorphosis of Acanthaster planci (Asteroidea). Nature. 232: 655 - 657.

Kenchington, R.A. (1977). Growth and recruitment of Acanthaster planci (L.) on the Great Barrier Reef. Biol. Conserv. 11: 103 - 118.

Lucas, J.S. (1975). Environmental influences on the early development of Acanthaster planci (L.). Proc. Crown-of-thorns Starfish Sem., Brisbane. AGPS, Canberra, p. 103-121.

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Yamaguchi, M. (1972). Why so many starfish? Guam Rail. 6: 4 - 5.

Yamaguchi, M. (1973). Early life histories of coral reef asteroids, with special reference to Acanthaster planci (L.). In: Biology and Geology of Coral Reefs. Vol 2. O.A. Jones and R. Endean. eds. Academic Press, New York, p. 369 - 387.

Yamaguchi, M. (1974). Growth of juvenile Acanthaster planci (L.) in the laboratory. Pac. Sci. 28: 123 - 138.

Budget 1985/86

Item		Cost COTSAC	AIMS
1.	Salary:		
	Postgraduate scholarship*	3334	-
	Research Scientist^{+} (Dr P. Moran)	-	1534
2.	Vessel Charter:		
	5 day field trip (x2) @ $500/day (R.V. Sirius)	-	5000
3.	Consumables:		
	Field equipment (e.g. cage material, underwater paper, slates)	1000	-
	TOTAL	**$4334**	**$6534**

+ based on 10% of available time

Project I (h): Feeding preferences of Acanthaster planci in the field

Introduction

There is a wealth of information on the feeding preference of Acanthaster planci in the field however, most of them have come from qualitative observations and studies (Potts, 1981). Of the numerous reports available there are only three studies where A. planci has been demonstrated to show a preference for a particular type of coral or corals. In two of these studies starfish were reported to feed on corals which were considered to be less abundant. Branham et al. (1971) observed in Hawaii that 80-90% of individuals fed on Montipora verrucosa which made up only 5% of the total coral cover. Similarly, Glynn (1974, 1976) showed that almost 50% of the diet of starfish in Panama comprised species that made up only 7.2% of total coral cover. In contrast, Ormond et al. (1976) reported from the Red Sea that A. planci preferred the most abundant corals, particularly Pocillopora spp. and Acropora spp. This preference clearly was not distinct as the information they presented was somewhat conflicting. Potts (1981) has reviewed the results of these three experiments in greater detail.

While the studies described above provide the best information to date on the feeding preferences of Acanthaster planci in the field they were inadequate for either of two reasons. Firstly, they relied largely on qualitative assessments of the amount of coral eaten and the relative abundance of each coral genus. Secondly, and more importantly, they attempted to demonstrate feeding preference by comparing the proportion of a particular type of coral eaten (normally genus) with its proportion at a community or reef level. As the distribution of corals may be patchy over different scales of the system (Reichelt and Bradbury, 1984) this comparison may have little meaning. Indeed, feeding preference measured at the community level may not bear any relationship to that determined in close proximity to a feeding starfish because of the confounding effects of patchiness and scale.

Research plan

The aim of this study is to obtain field data on the feeding preferences of starfish using a method which relates the choices of coral available to feeding starfish within a defined one square meter quadrat. Thus in the present study feeding preferences will be derived from information obtained at the colony level rather than the community or reef level. In so doing this information will provide a more accurate description of feeding preferences than those given previously as it will not be as susceptible to the problems of scale mentioned earlier.

In this method, a one square meter quadrat will be placed around a starfish so that it is in the centre of the quadrat. Once this has been done information on a number of variables will be recorded. They are as follows:

a) Weather conditions - sea (slight, moderate, rough) - wind (light, moderate, strong very strong)
b) Light
c) Depth (at which measurements taken)
d) Date
e) Time
f) Reef
g) Reef location (windward side, leeward side, lagoon)
h) Reef habitat (crest, slope, flat, patch reef, sand)
i) Size of starfish
j) Condition of starfish (poor, good, excellent)
k) Feeding or not
l) Population density (low, moderate, high, very high)
m) Coral species starfish feeding on
n) Corals within quadrat available for predation (i.e. greater than 5 cm in diameter and also able to be predated)
o) Behaviour (cryptic or not)

It is hoped that this information will be recorded for approximately 1000 starfish on a reef which is experiencing an outbreak. The reef to be sampled will be chosen just prior to the field work commencing. The accumulated information from each individual will provide data on not only the feeding preference of starfish but also those factors which are likely to affect it. Statistical comparisons may be undertaken to determine whether, for example, the feeding preferences of starfish change in response to different environmental conditions.

Apart from recording the information on these variables surveys of the overall coral cover and structure will be determined, within the area containing the outbreak, using 100 m line transects at 3 depths (i.e. 3m, 6m, 9m). Corals will be classified down to the generic level. This data will then be compared with that collected from the starfish to determine whether feeding preferences can be related to coral data based at a community/reef level.

Resources needed:

Large amounts of field data will be produced in the field using the method described above. Information on fifteen variables will be recorded for each starfish. Because of the large data array which will be produced a small sea-going computer is requested to undertake this research. Use of this equipment will greatly speed up the rate at which the data can be analysed and lead to fewer mistakes (which are normally attributable to transferring such data). Aprt from this item a small amount of funds are requested to purchase field equipment such as underwater paper and slates. Costs associated with shiptime will be met by the Institute.

Literature cited

Branham, J.M., S.A. Reed, J.H. Bailey, and J. Caperon. (1971). Coral eating sea stars Acanthaster planci in Hawaii. Science. 172: 1155 - 1157.

Glynn, P.W. (1974). The impact of Acanthaster on corals and coral reefs in the eastern Pacific. Environ. Conserv. 1: 295 - 304.

Glynn, P.W. (1976). Some physical and biological determinants of coral community structure in the eastern Pacific. Ecol. Monogr. 46: 431 - 456.

Ormond, R.F.G., N.J. Hanscomb, and D.H. Beach. (1976). Food selection and learning in the crown-of-thorns starfish, Acanthaster planci (L.). Mar. Behav. Physiol. 4: 93 - 105.

Potts, D.C. (1981). Crown of thorns starfish - man-induced pest or natural phenomenon? In: The Ecology of Pests. R.L. Kitching and R.E. Jones. eds. CSIRO, Melbourne, p. 55 - 86.

Reichelt, R.E., and R.H. Bradbury. (1984). Spatial patterns in coral reef benthos: multiscale analysis of sites from three oceans. Mar. Ecol. Prog. Ser. 17: 251 - 257.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salary:		
Research Scientist* (Dr P. Moran)	-	3068
2. Vessel Charter:		
5 day field trip (x2) @ $500/day (R.V. Sirius)	-	2500
3. Capital Equipment:		
Field computer (Sharp PC 7000)	3500	-
4. Consumables:		
Field equipment (e.g. underwater paper, slates)	750	-
TOTAL	**$4200**	**$5568**

* based on 20% of available time

Project I (i): Rate of decomposition of adults in the field

Introduction

One very mysterious, yet interesting feature of outbreaks of Acanthaster planci is the sudden way in which they end (e.g. Moran, Bradbury and Reichelt, in press). There is no record in the scientific literature as to what happens to the large numbers of individuals in such populations (see Moran, in press). This is despite the fact that more intensive surveys of reefs have been undertaken in recent times. One theory suggests that when the starfish run out of food they move to another nearby reef where the abundance of coral is high (Endean, 1969). In truth, it is not even known whether this occurs.

If starfish do not move to other reefs in search of food then there appear to be only two possible explanations to account for their disappearance:

a) Towards the end of an outbreak the starfish become cryptic and hide within the reef substratum.
b) As food becomes scarce the starfish die and their bodies decompose very rapidly.

The first explanation would seem to be most unlikely given the large number of starfish which have been reported to occur in outbreaks (Endean, 1982). Therefore of the two, the second explanation would appear to be more plausible. If starfish decompose rapidly in the field (i.e. of the order of 1-2 days) then their carcasses may not be observed on reefs despite intensive surveys and the outbreak would appear to end abruptly.

Research plan

The aim of this study is to determine the rate of decomposition of adult starfish in the field. The experimental design of this project is as follows: Four 2 m x 2 m quadrats (permanently marked and staked) will be positioned at a depth of 6 m and 3 m on sandy substrata and coral substrata (Acropora hyacinthus dominated) respectively. Eighty adult starfish (250 - 350 mm) will be collected and killed by keeping them overnight in bins of fresh water. On the following morning 10 starfish will be randomly positioned in each of the 8 quadrats. The positions of these starfish within the quadrat will be recorded using hand-drawn maps and colour photographs. Information on the state of decomposition of the starfish will be recorded by referring to one of the following decomposition categories: intact starfish, half starfish, three-quarters starfish, starfish arm, collection of starfish arms (presumed to be from the same animal), early stages of disintegration of starfish (body still intact but part of skeleton, stomach and gonads showing), mid stages of disintegration (body still intact and recognisable as A. planci but tissue degenerating), mass of skeletal debris. This will be carried out twice daily at each quadrat. During each recording period observations of predation of the starfish bodies also will be noted. Preliminary studies conducted at John Brewer Reef indicate that this experiment will need to be run for approximately 6-7 days.

The quadrats will be left undisturbed for 6 - 12 months after which time 4 randomly positioned cores (30 cm in length) will be taken from each of the 4 quadrats at 6m depth to check for the presence of spines and other skeletal debris of A. planci. Identification of this material will be made using the atlas developed by Walbran (1984).

Resources needed:

No resources are needed for this project. Shiptime will be supplied by AIMS.

Literature cited

Endean, R. (1969). Report on investigations made into aspects of the current Acanthaster planci (Crown-of-thorns) infestations of certain reefs of the Great Barrier Reef. Qld. Dept Primary Industries, Brisbane, 30p.

Endean, R. (1982). Crown-of-thorns starfish on the Great Barrier Reef. Endeavour 6:10-14.

Moran, P.J. (in press). The Acanthaster phenomenon. Ocean. Mar. Biol. Ann. Rev.

Moran, P.J., R.H. Bradbury and R.E. Reichelt (in press). Mesoscale studies of the crown-of-thorns/coral interaction: a case history from the Great Barrier Reef. Proc. Fifth Int. Coral Reef Congr., Tahiti.

Walbran, P.D. (1984). An atlas of the skeletal components of the crown-of-thorns starfish. Report to the Great Barrier Reef Marine Park Authority, 15p.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries:		
Research Scientist* (Dr P. Moran)	-	767
2. Vessel Charter:		
7 day field trip @ $500/day (R.V. Sirius)	-	3500
TOTAL	-	**$3756**

* based on 5% of available time.

Project I (j): Ephemeral patches of phytoplankton in the central GBR as a potential food source for larvae of Acanthaster planci.

Introduction

A limited body of early laboratory data (Lucas, 1982) has suggested that inter-reefal phytoplankton standing crops in the central GBR are inadequate to support larval development of A. planci. The presence of large Acanthaster planci populations throughout the central GBR would suggest that: 1) the laboratory data may not adequately reflect the ability of A. planci larvae to grow and develop on natural phytoplankton diets in central GBR waters; and/or, 2) the phytoplankton biomass data available to Lucas did not include samples from water bodies capable of supporting A. planci larval development or higher survivorship. Recent field experiments (Olson, 1985) now show that A. larvae can be cultured with natural phytoplankton populations. The extent to which these new results can be extrapolated over wider areas of the GBR are unknown.

Research plan

We propose to conduct a phytoplankton biomass survey of central GBR waters using continuous-flow in-vivo fluorometric detection of chlorophyll and pumped vertical profiling techniques to search for and map discrete patches and/or layers of enhanced phytoplankton biomass derived from or associated with summer intrusions of nutrient enriched water into the GBR. Horizontal distributions of phytoplankton in surface layers will be sampled using continuous chlorophyll sampling on steaming transects over distances of kilometers. Vertical distributions of chlorophyll, light and oceanographic properties (temperature, salinity) over length scales of meters will be sampled with AIMS instruments and a pumping system delivering seawater from depth to a shipboard fluorometer. Using straightforeward size-fractionation and biomass estimation techniques we will make preliminary assessments of the suitability of phytoplankton patches as potential food sources for A. planci larvae. The proposed sampling can readily be carried out in conjunction with and in support of ongoing AIMS phytoplankton field studies in the central GBR.

The proposed research is significant for several reasons :

a) The results obtained will, for the first time, resolve spatial details of contiguous phytoplankton biomass distributions in the central GBR over both horizontal (0.1 - 10 km) and vertical (ca. 1 m) distance scales.

b) Continuous vertical profiling methods will be employed to allow realistic correlations to be made between vertical gradients of potential larval food concentrations (phytoplankton biomass), the submarine light field and the known phototropic behavior of A. planci larvae.

c) The phytoplankton biomass distribution data collected will provide a context within which to evaluate the results of larval culturing studies currently being carried out or proposed (see Projects I(c), (d) and (e)).

d) In an oceanographic environment frequently lacking pronounced or measurable physical gradients, the ability to detect and map spatial distributions of biological structures may provide a means to calibrate or parameterize physical mixing models of the GBR shelf seas.

Lucas (1982) compared the then available field data (Marshall, 1933; Ikeda et al., 1980; Wolanski and Jones, 1981) on phytoplankton cellular abundances and chlorophyll concentrations with laboratory data on larval growth and feeding of A. planci and concluded that in-situ phytoplankton concentrations were suboptimal for the growth and development of A. planci. Widespread outbreaks of A. planci do occur throughout the central GBR, however. Recent field experiments (Olson, 1985) show that A. planci larvae can develop in some inter-reefal waters. The extent to which experimental results from one or a few sites can be extrapolated over regional scales throughout the GBR requires some knowledge of available larval food distributions in both time and space. Close examination of historical and more recent data (Andrews and Gentian, 1982; Kinsey, 1983; Furnas and Mitchell, 1985) indicates that phytoplankton populations in the central GBR can be patchily distributed and that both absolute chlorophyll concentrations and the degree of patchiness are highest during the summer spawning season of A. planci, which coincides with a seasonal intensification of upwelling along the seaward margin of the GBR. Absolute chlorophyll concentrations within and spatial distributions of chlorophyll in a patchy field are difficult to sample with the discrete sampling designs used to date. Such fields can, however, be readily resolved by continuous flow profiling techniques (e.g. Denman, 1976).

While development of A. planci larvae can occur at sub-optimal food levels, growth will be slowed and adult recruitment diminished due to increased predation while in the planktonic phase. It may be that local or regional episodes of enhanced recruitment depend upon the fortuitous development of patches or populations of larvae within discrete water masses with food levels or qualities exceeding those of bulk local water masses. The critical importance of temporal and spatial co-occurrance of pelagic larval development with ephemeral bloom patches of suitable phytoplankton has been demonstrated for other marine organisms with pelagic larvae (Lasker, 1973). It has been proposed that local nutrient enrichments and phytoplankton bloom development following terrestrial runoff events may trigger A. planci outbreaks (Birkland, 1982). The recent elucidation of upwelling processes and their effects on the plankton environment of the central GBR (Andrews and Gentian, 1982; Furnas and Mitchell, 1985) suggest an additional mechanism for providing enriched phytoplankton food supplies for larval development in GBR waters.

Integration with ongoing AIMS research activities

The proposed study would be carried out in conjunction with ongoing phytoplankton and oceanographic studies in the central GBR. Planned scientific work for the next several years is of a nature that would involve appreciable "free" shiptime while on-board experiments are being carried out. We propose to use that shiptime to conduct the survey operations. Quite apart from its direct use in crown of thorns research, the oceanographic and phytoplankton distribution data collected as part of the survey operations would also be directly usable for the interpretation of phytoplankton experiments being carried out in the central GBR.

The bulk of the projected work would be carried out by a supported graduate student. The role of the principal investigator (Dr M. Furnas) would be largely supervisory (20 % of time), although as time permitted, all available personnel would assist with seagoing operations. Development of a continuous pumping and data logging system has been underway on a part-time basis at AIMS so the hardware basics are well started.

Justification of budget

Salaries:

A major limitation in being able to undertake the proposed project is manpower. A nucleus of the required capital equipment is already in hand and shiptime can be accommodated within ongoing programs over the next several years. Current committments by the principal investigator (Dr M. Furnas) and the assigned experimental scientist preclude a full-time or even major part-time committment to such a project over the next several years. It is estimated that one additional person would be required for 3 years to accomplish the stated goals including system integration and development (0.5 - 1 year), operation at sea (1 year) and data analysis (1 year).

It is felt that this project would make a worthy Ph.D. project, both for the crown-of-thorns problem, and at a wider level, on processes regulating phytoplankton distributions in the unique oceanographic environment of the GBR. It is proposed that three years of a post-graduate level stipend be provided to carry out this work.

Capital Equipment:

A first-generation pump-profiling system comprising a 1600 lpm pump, 80 m hose, CTD, submarine light sensor and microcomputer controller is being assembled at AIMS for use with ongoing work. With more attention and development, this system would be suitable for the proposed research. Preliminary tests have shown that some additional items would be required for heavy field use.

a) An upgraded field fluorometer to replace the present unsafe/unreliable fluorometer currently available at AIMS. The present instrument is not a field instrument and in the highly likely event of a saltwater spill, would expose operators to a dangerous electrical shock hazard. The proposed instrument is a low voltage, water "resistant" field instrument widely used for in situ profiling applications. This piece of equipment will be supplied by AIMS.

b) Dedicated microcomputer data logger at AIMS. It is anticipated that this piece of equipment will be supplied by AIMS. Some upgrading of this microcomputer (IBM PC) will be needed for it to perform the tasks required by this study.

c) Cables, datastream digitizer and interfaces. To connect the CTD, fluorometer and underwater light sensor, digitize and format the data for storage by the microcomputer.

Consumables:

Store items, filters, reagents for chlorophyll determinations, hardware and workshop fabrications.

Literature cited

Andrews, J.C. 1983 Water masses, nutrient levels and seasonal drift on the outer central Queensland shelf (Great Barrier Reef) Aust. J. Mar. Freshw. Res. 34: 821-834.

Andrews, J.C. and P. Gentian 1982 Upwelling as a source of nutrients for the Great Barrier Reef ecosystems: A solution to Darwin's question. Mar. Ecol. Prog. Ser. 8: 257-269.

Birkland, C. 1982 Terrestrial runoff as a cause of outbreaks of Acanthaster planci (Echinodermata: Asteroidea). Mar. Biol. 69: 175-185.

Denman, K.L. 1976 Covariability of chlorophyll and temperature in the sea. Deep-Sea Res. 23: 539-550.

Furnas, M.J. and A.W. Mitchell 1985 Phytoplankton dynamics in the central Great Barrier Reef I. Seasonal changes in biomass and community structure and their relation to intrusive activity. Continental Shelf Res. (in press).

Ikeda, T., M. Gilmartin, N. Revelante, A.W. Mitchell, P. Dixon, S.M. Hutchinson, E. Hing Fay, G.M. Boto and K. Iseki. 1980 Biological, chemical and physical observations in inshore waters of the Great Barrier Reef, North Queensland, 1975-1978. Australian Insititute of Marine Science Tech. Bull. AIMS-OS-1 56 pp.

Kinsey, D.W. 1983 Short-term indicators of gross material flux in coral reefs - How far have we come and how much further can we go? pp. 333-339. In: Proc. Great Barrier Reef Conference, J.T. Baker, R.M. Carter, P.W. Sammarco and K.P. Stark (Eds.) Townsville.

Lasker, R. 1975 Field criteria for survival of anchovy larvae: The relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull. 73: 453-462.

Lucas, J.S. 1982 Quantitative studies of feeding and nutrition during larval development of the coral reef asteroid Acanthaster planci (L.). J. Exp. Mar. Biol. Ecol. 65: 173-193.

Marshall, S.M. 1933 The production of microplankton in the Great Barrier Reef region. Sci. Rept. Gt. Barrier Reef Expd. 1928-9, Vol. 2: 111-158.

Olson, R.R. 1985 In situ culturing of larvae of the crown-of-thorns starfish Acanthaster planci. Mar. Biol. Prog. Ser. 25: 207-210.

Wolanski, E. and M. Jones 1981 Biological, chemical and physical observations in inshore waters of the Great Barrier Reef, North Queensland, 1979. Australian Institute of Marine Science Data Rept. AIMS-OS-2. 72 pp.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries:		
Postgraduate scholarship	3334	-
Research Scientist* (Dr M. Furnas)	-	3069
2. Vessel Charter:		
20 days @ $2,600/day (R.V. Harry Messel)	-	52000
3. Capital Equipment:		
Turner Model 10 Field Fluorometer with flow cell door	-	17000
150 m of underwater electrical cable at $10/m	1500	-
Data-stream digitizer and interfaces	2000	-
IBM microcomputer for system control, data logging and data processing	-	-
Upgrading of IBM PC	3000	-
4. Consumables:		
Field equipment (e.g. filters, reagents)	1000	-
TOTAL	**$10834**	**$72069**

* based on 20% of available time

Project II (a): Recolonisation and recovery of coral communities

Background

This proposal seeks support for two established research projects that address issues which are of fundamental importance to our understanding of the nature and implications of starfish outbreaks on coral communities. These issues can be posed in the form of questions: Are there lasting changes in the character of the reef communities such as wholesale replacement of perennial corals with more "weedy" or opportunistic species? What are the expected time scales for reversion to the pre-outbreak condition? Does complete recovery of the coral communities occur? Are the considerable changes in the recovery- outbreak- recovery transition within the normal scope of temporal variability of the system?

There may be general answers to such questions, or the answers may differ from one reef to the next. The work proposed here builds on established research to examine these issues.

Introduction

Three long term studies of the effects of outbreaks on coral communities have been conducted in Guam and the Great Barrier Reef (Randall, 1973a,b,c,d; Pearson, 1974, 1981; Colgan, 1981, 1982). Despite this there is little 'before' and 'after' documentation of the impact of starfish outbreaks on coral communities and virtually no quantitative accounts of the species or even the generic composition of the coral victims or the survivors. Lack of this type of data is unfortunate since our knowledge of the contrasting life history characteristics of corals is advancing rapidly and our ability to interpret the impact of Acanthaster planci in terms of replacement time for victims and the regenerative potential of injured survivors is also improving.

There now exists at AIMS an unique archive of vertical, close-range (ca. 2m) stereophotographs of coral communities in a wide range of habitats which contain:

a) 'Before' and 'after' records of starfish outbreaks on several permanently marked and mapped coral communities.

b) A source of growth rate and survivorship data for a wide range of coral species, especially as juvenile and adult colonies in the 4 to 50 cm diameter range. These data are the essential basis of much population analysis and prediction.

Parts of this photographic archive are presently being analysed at AIMS, but it is sufficiently large (annual records since 1980 of about 30 areas each 10 to 30 sq. m in size) that much of the information pertinent to analysis and prediction of the impact of crown-of-thorns starfish cannot be extracted without an expansion of manpower and facilities.

Apart from this valuable archive of photographic material there also is a large data base containing information (to the species level) on the changes in the structure of the coral communities before, during and after the recent outbreak of starfish on John Brewer Reef. This information is based on surveys taken on several occasions (since May 1983) at 4 permanent study sites using line transect techniques. The preliminary results of these surveys have been reported by Moran, Bradbury and Reichelt (in press).

Research plan

This proposal seeks funds to undertake two types of studies:

a) Acanthaster planci caused minor damage to sites near Lizard Island in 1982, and major damage to other sites in 1983/84. The proposed study will use the archive of stereophotographs of damaged sites (before, during and after outbreaks of starfish) to contrast the impact on reef sites at depths ranging from 1-36 m. Stereopairs will be interpreted using a photogrammetry workstation and analytical software to be implemented at AIMS. A data base will be constructed which follows the time of first sighting, growth and mortality of a large sample of individual corals in each site. Data will be collated by species to provide population estimates for growth and colony turnover. Interactions between colonies and other natural history observations will be quantified using existing menu-driven interpretation software. In the long term, with the development of spatially discrete benthic models, the study could lead to projections about the nature and timing of recovery, based on the composition, density, size frequency distribution and survivorship of recruits and survivors (entire colonies and remnants) and on estimates of growth rates of different species. In order to further extend the information currently available, stereophotographs will be taken of several permanent study plots on John Brewer Reef. Photographs of these plots go back to 1974 when they were first taken by Pearson (1981).

b) Intensive surveys of the distribution and abundance of Acanthaster planci and corals have been conducted on John Brewer Reef over the last 2 years. In the present study it is proposed to resurvey the coral communities at four permanent sites to assess their recovery. This will be done initially on an annual basis using line transect techniques (to the species level). The methods to be used in this study have been given by Moran, Bradbury and Reichelt (in press) (see Section on Relevant Publications).

Resources needed:

In order to undertake the stereophotogrammetric interpretations an Experimental Scientist is required for 3 months of full-time work, either as a single block, or subdivided into blocks of no less than 3 weeks duration. Work consists of digitisation and interpretation of stereophotographs. This person will be drawn from those hired to undertake the macro-scale surveys in Project III (a). Some manipulation of the stereophotographic data (approximately 4-6 weeks of work) is required. This will be undertaken by another of the Experimental Scientists employed within one of the other projects.

Apart from personnel, the photogrammetric study requires funds to set up a second workstation (because the one currently at AIMS is being used full-time for other studies). The design of this second workstation would be similar to the one already at AIMS and would use existing menu-driven software for digitisation and interpretation.

Funds are also requested to purchase new camera equipment to continue the stereophotographic archive from John Brewer Reef. Only one set of gear is requested, the other which is needed will be supplied by the Institute.

No funds are being sought to undertake the resurveys of the coral communities on John Brewer Reef. The shiptime needed to undertake this work will be supplied by AIMS.

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Colgan, M.W. (1982). Succession and recovery of a coral reef after predation by Acanthaster planci(L.). Proc. Fourth Int. Coral Reef Symp. 2: 333 - 338.

Moran, P.J., R.H. Bradbury, and R.E. Reichelt. (in press). Mesoscale studies of the crown-of-thorns/coral interaction: a case history from the Great Barrier Reef. Proc. Fifth Int. Coral Reef Congr., Tahiti.

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Pearson, R.G. (1981). Recovery and recolonization of coral reefs. Mar. Ecol. Prog. Ser. 4: 105 - 122.

Randall, R.H. (1973a). Coral reef recovery following extensive damage by the Crown-of-thorns' starfish, Acanthaster planci (L.). Pub. Seto Mar. Biol. Lab. 20: 469 - 489.

Randall, R.H. (1973b). Reef physiography and distribution of corals at Tumon Bay, Guam, before crown-of-thorns starfish Acanthaster planci (L.) predation. Micronesica. 9: 119 - 158.

Randall, R.H. (1973c). Distribution of corals after Acanthaster planci (L.) infestation at Tanguisson Point, Guam. Micronesica. 9: 213 - 222.

Randall, R.H. (1973d). Effects of Acanthaster predation on Tanguisson corals. In: A Study of Biological Impact caused by Natural and Man-induced changes on a Tropical Reef. R.S. Jones and R.H. Randall. eds. Univ. of Guam, Mar. Lab. Tech. Rep. No. 7: 94 - 145.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries:		
Research Scientist* (Dr T. Done)	-	1695
Research Scientist* (Dr P. Moran)	-	1534
Experimental Scientist (same as Project III (a))	-	-
2. Vessel charter:		
5 day field trip @ $500/day (R.V. Sirius)	-	2500
3. Capital equipment:		
Sonic digitiser (SAC 24" x 24")	5000	-
Graphics workstation	6000	-
Nikonos v camera	659	-
Nikonos 103 speedlight	556	-
Nikonos 28mm lens	347	-
Nikonos 35mm lens	144	-
TOTAL	**$12706**	**$5729**

* based on 10% of available time

Project II (b): **Interpretation of the history of disturbance to coral communities through analysis of morphology and population structure in massive Porites spp.**

Introduction

This proposal is to collect supplementary field data to support promising preliminary findings made in two recent studies. During 1985 a CEP funded study at AIMS (COT CEP, in press) conclusively demonstrated that recent outbreaks of Acanthaster planci leave a strong signal as scarred surfaces on massive corals of the genera Porites and Diploastrea. However it was not conclusive as to whether older scarred surfaces were inflicted episodically, which might have been circumstantial evidence for A. planci outbreaks earlier than those we are presently aware of.

In a second study (Done, in prep.) a simulation of starfish impact on Porites was based upon data on both the degree of damage to corals of different sizes and the size frequency distribution of the populations. It incorporated also a theoretical population dynamics of Porites in non-outbreak periods. The study however, was based on minimal data and limited to a single reef.

Research plan

In this study it is proposed to:

a) Resolve whether scarred surfaces on old Porites could constitute a record of outbreaks prior to the 1960's

b) Extend the generality of the Porites simulation by gathering additional data from a range of reefs both with and without a history of starfish outbreaks.

In order to achieve these objectives two types of field data are to be collected :

a) Location and dating of older scarred surfaces on Porites estimated to be at least 50 years old (i.e. corals greater than 1 m diameter) :- Older scarred surfaces were rather rare in previous surveys (COT CEP, in press) and it will be necessary to concentrate field effort on older corals to obtain a large sample size of old scars. Scar positions are measured in relation to the living surface, shallow cores taken through dead surfaces using an air drill, and date of death estimated using fluorescent banding (see COT CEP, in press). Frequency histograms of the dates will be examined for the existence of episodic tissue death consistant with outbreak predation by Acanthaster planci.

b) Population structure of Porites in disturbed and undisturbed reefs:- Size frequency distributions and damage levels will be recorded for Porites under 30 cm diameter on the same reefs as those surveyed previously (COT CEP, in press). These include reefs both with and without a history of outbreaks. In addition, it is proposed that a full population size structure be determined for Porites on other reefs believed not to have been subjected to large starfish populations. The work would be conducted in collaboration with Prof. P. Sale of the University of Sydney and would be based in the Capricornia area. Population structure will be assessed using a combination of line transects and scuba swims as described in Done and Fisk (1985). The data will provide an improved basis for estimation of model parameters in simulations of effects of A. planci outbreaks on the structure of Porites populations at different reefs.

Resources needed:

Two types of personnel are required for this project. They are as follows:

a) Experimental Scientist: Total of 5 working weeks full time, consisting of one 2 week block for field work and one 3 week block for interpretation of cores and data analysis.

b) Casual Field Assistant: To be supervised by Prof. Sale for a total of 1 month of field work in the Capricornia region.

Equipment used in the previous study conducted at AIMS (COT CEP, in press) will be available for this study.

Literature cited

Done, T.J. (in prep.). Simulation of the effects of outbreaks of A. planci on the population structure of massive corals in the genus Porites; evidence for population resilience?

Done, T.J. and D.A. Fisk (in press). Effects of two Acanthaster outbreaks on coral community structure - the meaning of devastation. Proc Fifth Int Coral Reef Congress Tahiti.

COT CEP (in press). An analysis of crown-of-thorns damage to massive corals of the genus Porites. Australian Institute of Marine Science Data Report.

Budget 1985/86

Item	Cost COTSAC	AIMS
1. Salaries :		
Research Scientist* (Dr T. Done)	-	1695
Experimental Scientist (same as Project III(a))	-	-
Casual field assistant (Sydney University)	2000	-
2. Vessel charter :		
12 day field trip @ $500/day (R.V. Sirius)	-	6000
3. Consumables :		
Field equipment (e.g. spare drills)	200	-
TOTAL	**$2200**	**$7695**

* based on 10% of available time

Project II (c) : Genetics of population fluctuations of corals

Introduction

High levels of predation cause a 'bottleneck' effect on population numbers, which acts essentially as a diversity reducing phenomenon. Such reduction in diversity could be catastrophic if it leaves populations so genetically uniform that they are not buffered against environmental challenges. However, low within-population diversity together with highly differentiated populations may be a common pattern in coral evolution (sensu Potts 1983, 1984) and the intensity of the genetic effects of predation may be no more than that experienced in a small populations, or in populations subjected to other forms of decline and recovery. The periodicity of predation will be of primary interest in determining the intensity of the phenomenon and at some level may alter its genetic consequences qualitatively.

Research plan

The aims of the proposed study are to :

a) Examine the effects of Acanthaster planci outbreaks on the genetic structure of populations of Acropora humilus (choice of species could alter after preliminary attempts at electrophoresis).

b) Compare the effects of repeated vs. sustained outbreaks.

c) Compare predation 'bottleneck' effects with the effects of non-predation population reductions and small population size on genetic structure.

The following tasks would need to be completed in order to achieve these objectives :

a) Surveys of populations with varying histories of Acanthaster predation, in particular collecting a before-during-after series.

b) Survey populations which have suffered non-predation crashes due to physical factors (i.e. cyclones, exposure).

c) Survey populations on small isolated reefs.

During the first year of this planned 2 year study initial surveys would be made of a :

a) Population in early stages of outbreak with low predation history.
b) 'Large' population with low predation history (Heron Island).
c) Population with history of heavy predation within last 10 yr, currently in 'recovery' phase (Green Island).

Survey results from the CEP Crown-of-thorns Study will be useful in planning the survey component of this study.

Resources needed :

Approximately 3 day-trips will be needed to undertake part of the field work in this project. It is expected that a 5 day field trip will need to be undertaken to Heron Island to survey a 'large' population with low predation history. Funds are requested (which include travel and bench fees) for this trip. A variety of chemicals and glassware are required to conduct the electrophoretic analyses.

Literature Cited

Potts, D.C. (1983). Evolutionary disequilibrium among Indo-Pacific corals. Bull. Mar. Sci. 33: 619-632.

Potts, D.C. (1984). Generation times and the quaternary evolution of reef-building corals. Paleobiology 10: 48-58.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries :		
Research Scientist* (Dr J. Stoddart)	-	2856
2. Vessel Charter :		
3 day-trips @ $500/day	1500	-
4 day field trip @ $500/day (R.V. Sirius)	-	2000
3. Travel :		
5 day field trip to Heron Island (travel & bench fees)	1200	-
4. Consumables :		
Chemicals (e.g. isoenzyme assays)	1500	-
Glassware	500	-
Liquid nitrogen	500	-
Field equipment	500	-
TOTAL	**$5700**	**$4856**

*based on 20% of available time

Project II (d): **Growth and survivorship of coral remnants following outbreaks of Acanthaster planci**

Introduction

While much has been made of the issue of the dependance of reefs upon one another as sources of coral propagules, there is also a major stock of corals remaining within damaged reefs which seem independent of other reefs for continued survival of local populations. These are the 'remnants', portions of viable tissue on corals injured by A. planci.

On the slopes at John Brewer Reef, a high density of 'remnants' (size range 1 to 10 cm maximum dimension) survived the 1983/4 outbreak (Done and Fisk, in press). These remnants (primarily non-Acorpora corals of encrusting, massive and branching form) may form an important stock for regeneration of coral cover on the slopes, as they have a head start over Acropora and other species which must recolonise as planktonic larvae. However continued survival of the remnants is not assured, as they are small and as a consequence, potentially subjected to high mortality rates.

Research Plan

Growth and survivorship of remnants within the stereo-phototransects (density ca. 20 per sq. m.) has been monitored by hand mapping on three occasions since the outbreak and in general, survival rates have been high and growth rates have been low. Monitoring of the remnants will be continued at approximately 6 month intervals by further hand mapping and by stereophotography. It is proposed to continue monitoring as long as possible to establish whether the remnants do in fact make a significant contribution to coral community structure following outbreaks.

Differences among species in their ability to maintain genetic continuity at a place in spite of severe disturbance is also of considerable interest in an evolutionary context. Species with a high genetic continuity might be expected to have very long mean generation times and consequently low speciation rates (Potts 1984).

Resources needed :

No resources are required to conduct this project. Shiptime will be provided by AIMS.

Literature Cited

Done, T.J. and D.A. Fisk. (in press). Effects of two Acanthaster outbreaks on coral community structure - the meaning of devastation. Proc. Fifth Int. Coral Reef Congress, Tahiti.

Potts, D.C. (1984). Generation times and the quaternary evolution of reef-building corals. Paleobiology 10: 48-58.

Budget 1985/86

	Item	Cost COTSAC	AIMS
1.	Salaries:		
	Research Scientist* (Dr T. Done)	-	1695
	Experimental Scientist* (Mr K. Navin)	-	1150
2.	Vessel charter:		
	7 day field trip @ $500/day (R.V. Sirius)	-	3500
3.	Capital equipment :		
	Stereophotogrammetry (see Project II(a))	-	-
4.	Consumables :		
	Film	-	200
	TOTAL	-	**$6545**

* based on 10% of available time.

Project II (e): Effects of outbreaks of Acanthaster planci on fish communities

Introduction

Despite predictions of dire effects of Acanthaster planci outbreaks on coral reef fishes (e.g. Endean 1973), no significant data on such effects at spatial scales greater than 1 m (Sano et al. 1984) or on time scales of years has been published until recently (Williams 1985). Outbreaks of A. planci on three Townsville mid-shelf reefs - Rib, John Brewer and Lodestone - in 1983 provide an ideal opportunity to test for their effects on fish communities (Fig 1). A number of detailed studies of the structure of the fish communities on these reefs had been carried out prior to the outbreaks occurring. In 1980, Williams (1982) censused the abundance of 146 species belonging to 7 families on the slopes of Rib, John Brewer and Lodestone, together with Davies Reef (a mid-shelf reef unaffected by A. planci) as part of a study of the cross-shelf distribution of fishes off Townsville. In 1982, Williams and Hatcher (1983) examined patterns of trophic structure and species diversity of fishes on Rib, Pandora and Myrmidon reefs using quantitative explosive collections. During the summer of 1982/83 Williams and English initiated a 3 year study of patterns of recruitment of fishes to the slopes of Pandora (nearshore), Rib, John Brewer, Lodestone and Myrmidon (outer shelf) reefs. These pre-outbreak data permit before-and-after comparisons of the abundances of adult fishes, patterns of recruitment, trophic structure and species diversity of the fish communities. Ayling and Ayling (unpublished report for GBRMPA) assessed densities of coral trout - a species of major commercial interest - on Pandora, Davies, Myrmidon, John Brewer and Lodestone Reefs in 1984, less than one year after outbreaks on the latter two reefs began. At this time the densities of coral trout on John Brewer did not differ significantly to those determined prior to the outbreak, suggesting that the 1984 density estimates for the other reefs could be used as reasonable estimates of coral trout abundance prior to outbreaks of A. planci.

Research plan:

Three types of study are proposed to determine the effects of A. planci outbreaks on fish communities.

Adu't abundances:

Visual censuses of the abundances of adult fishes conducted in 1980 on mid-shelf reefs off Townsville (Rib, John Brewer and Lodestone) were repeated in November 1983 after outbreaks of A. planci and at 6-monthly intervals thereafter (AIMS Reef Ecology Program). Davies, Pandora and Myrmidon reefs were also censused in the original survey and as yet have not suffered any A. planci disturbance. The latter two reefs were therefore resurveyed in November 1983 and Davies in June 1984 to serve as controls for any observed changes in species composition.

Surveys of mid-1984 revealed, not surprisingly, a significant decrease in the densities of several scleractian-feeding butterflyfishes (f. Chaetodontidae) which had previously been abundant. However, no other species showed any significant changes in density at that time. The most recent surveys (November 1985) have indicated major decreases in the densities of adults of two species of planktivorous fish, Chromis atripectoralis and Pomacentrus popei, that were very common on the mid-shelf prior to the outbreak of A. planci. Longer-term effects on other species - particularly herbivores - have been hypothesised (Williams 1985). It is proposed to continue these surveys of adult abundances on Rib, John Brewer and Lodestone reefs at 6-monthly intervals and at Davies, Pandora and Myrmidon reefs every 12 months through to May 1988. These surveys will be carried out using the visual census technique described by Williams (1982): The fixed species list contains a total of 146 species including: all species of chaetodontid in the area, the majority of the common pomacentrids (47 spp.) and acanthurids (19 spp.), virtually all scarids (21 spp.), selected labrids (13 spp.), caesionids (3 spp.) and siganids (5 spp.). A census dive will involve a 45 minute swim (using SCUBA) along the reef slope, swimming in a zig-zag pattern up and down the reef face from the surface to a depth of 13 m and recording the presence of species and their abundance (on a log5 abundance scale) along oblique transects stretching approximately 5 m either side of diver. All data will be recorded on prepared census forms of water-proof paper and all censuses will be made by one observer (D.McB.W.) to ensure consistency. Five censuses of non-overlapping area of reef slope will be made on each reef. Each 45 min swim covers approximately 150 m of reef front.

The above surveys do not include assessments of coral trout which must be surveyed by a different technique to achieve relatively accurate estimates. I propose that while the former surveys are being undertaken, a second team under the leadership of an appropriately experienced scientist (Dr Peter J. Doherty of Griffith University of Ms Melita Samoilys of University of Queensland) resurvey Aylings' study sites to determine the effect of A. planci outbreaks on the abundance of coral trout. Survey techniques similar to those developed by Ayling and Ayling will be used: Abundance estimates of coral trout will be based on ten replicate 50 x 20 m transects that are visually searched for coral trout on each reef. The ten counts will be positioned randomly along approximately one kilometre of reef edge. Counts will be made by two divers along a 50 m fibreglass tape run from the reef edge down the slope at right angles to the reef edge. Depth at the end of each transect is usually between 10 and 15 m but on some of the steeper sided reefs may be 20-25 m. The observers will count all Plectropomus spp. within 10 m of the central tape, each observer searching a 10 m wide strip on one side of the tape only. The species and estimated total length (TL) in cm will be recorded for each coral trout seen. Doherty is currently analysing the power of this technique to detect significant changes in trout abundance. Results suggest that it is of sufficient power to detect the kinds of changes (several-fold) detected by Williams (1985) for other species post. A. planci infestations (P.J. Doherty pers. comm.).

Recruitment:

The relatively rapid decrease in abundances of several common species of chaetodontids observed by Williams (1985) in the post-Acanthaster surveys was almost certainly due to starvation and mortality of adults following massive reduction in areal cover of the scleractinian corals which are their exclusive food supply. Early comparisons of recruitment of juvenile fishes to Rib, John Brewer and Lodestone in 1982/83 (pre-A. planci) and in 1983/84 (post A. planci) suggested that the outbreaks had also had a signficant effect on recruitment patterns of juvenile fishes (Williams 1985). The significant decreases in densities of adult Chromis atripectoralis and Pomacentrus popei observed in 1985 appear to be a consequence of recruitment failure of these species following outbreaks of A. planci.

To determine the longer-term effects of A. planci on recruitment of reef fishes, it is proposed to continue monitoring of recruitment to the existing study sites on Rib, John Brewer and Lodestone, Pandora (nearshore) and Myrmidon (outer shelf) for the 1985/88 triennium (1983-85 supported by AIMS Shelf Seas Program). Since all the mid-shelf recruitment sites were infested by A. planci (recruitment to Davies was not examined pre-A. planci), the Pandora and Myrmidon sites (unaffected by A. planci) will be resurveyed to estimate natural interannual variation in recruitment in the absence of A. planci disturbance.

The methods adopted in this study will follow Williams and English (in prep.). Three sites, 100-200 m apart have been set up on the reef slopes of Pandora, Rib, John Brewer, Lodestone and Myrmidon reefs. Each site comprises ten 5 m x 5 m quadrats permanently marked by steel stakes and rope. All quadrats are in the same habitat examined for adults (Williams 1982, 1985; Williams and Hatcher 1983) at depths of 3-8 m. Recruitment will be measured by the number of young-of-the-year counted in each quadrat in mid-late February of each year.

Trophic structure and species diversity:

If the visual censuses of adults suggest that changes in the densities of adult fishes as a result of A. planci outbreaks have lead to significant changes in the trophic structure and species diversity of the fish communities, it is proposed in 1986/87 or 1987/88 to repeat the quantitative explosive collections of Williams and Hatcher (1983) on Rib (A. planci affected) and Pandora and Myrmidon reefs (unaffected by A. planci).

The census technique follows that of Williams and Hatcher (1983): Fish will be collected using small standardised charges of plastic explosives as discussed by Russell et al (1978). Five collections will be made at 5 m and five at 9 m depth on each of the three reefs. Collecting sites will be adjacent to those used by Williams and Hatcher (1983). The charges will be set off using detonator cord. Immediately after detonation, a team of 6 divers plus 2 people in a boat collecting all dead and stunned fish on the surface with handnets. Explosives provide an excellent non-selective method of collecting fish which is highly effective. At the depths used, the charge effectively kills fish over a radius of about 7 m or 150 m (Russell et al. 1978). If careful attention is taken in laying the charge on the bottom so as not to create 'shadow' areas, the area affected is remarkably consistent from one station to the next.

Resources needed :

A small amount of funds for travel and field equipment are all that is required for this project in 1985/86 fiscal year.

Literature Cited

Ayling, A.M. and A.L. Ayling (1985). A biological survey of selected reefs in the Central Region of the Great Barrier Reef Marine Park. Report prepared for the Great Barrier Reef Marine Park Authority by Sea Research.

Endean, R. (1973). Population explosions of Acanthaster planci and associated destruction of hermatypic corals in the Indo-West Pacific Region. In: Jones, O.A., Endean, R. (ed.) Biology and Geology of Coral Reefs Vol. II. Biology 1. Academic Press, New York, 389-438.

Russell, B.C., Talbot, F.H., Anderson, G.R.V., and B. Goldman (1978). Methods of collection and sampling of coral reef fishes. In: Stoddart, D.R., Johannes, R.E. (ed.) Coral reefs: research methods. UNESCO, Paris, 329-345.

Sano, M., Shimizu, M. and Y. Nose (1984). Changes in structure of coral reef fish communities by destruction of hermatypic corals: observational and experimental view. Pacif. Sci. 38:51-79.

Williams, D.McB. (1982). Patterns in the distribution of fish communities across the Central Great Barrier Reef. Coral Reefs 1:35-43.

Williams, D.McB. (1985). Temporal variation in the structure of reef slope fish communities: short term effects of Acanthaster planci. Mar. Ecol. Prog. Ser. in press.

Williams, D.McB. and A.I. Hatcher (1983). Structure of fish communities on outer slopes of inshore, mid-shelf and outer shelf reefs of the Great Barrier Reef. Mar. Ecol. Prog. Ser. 10:239-250.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
<u>Adult abundances</u>		
1. Salaries:		
Research Scientist* (Dr D. Williams)	-	2382
Experimental Scientist (same as Project III(a))	-	-
Experimental Scientist (same as Project III(a))	-	-
Experimental Scientist (same as Project III(a))	-	-
2. Vessel charter:		
5 day field trip @ $2600/day (R.V. Harry Messel)	-	13000
3. Travel:		
Brisbane/Townsville return airfare	393	-
<u>Recruitment</u>		
1. Salaries:		
Research Scientist+ (Dr D. Williams)	-	1588
Experimental Scientist (same as Project III(a))	-	-
2. Vessel charter:		
10 day field trip @ $2600/day (R.V. Harry Messel)	-	26000
3. Consumables :		
Field equipment (e.g. rope, stakes)	400	-
TOTAL	**$793**	**$42970**

* based on 15% of available time

+ based on 10% of available time

Budget 1986/87

Item	Cost COTSAC	Cost AIMS
Adult abundances		
1. Salaries : (as for 1985/86*)	-	4764
2. Vessel Charter : 15 day field trip @ $2600/day (R.V. Harry Messel)	-	39000
3. Travel : Brisbane/Townsville return airfare (x2)	786	-
4. Consumables : Field equipment (e.g. underwater paper, slates)	175	-
Recruitment		
1. Salaries : (as for 1985/86*)	-	3176
2. Vessel charter : (as for 1985/86)	-	26000
3. Consumables : (as for 1985/86)	400	-
TOTAL	**$1361**	**$72940**

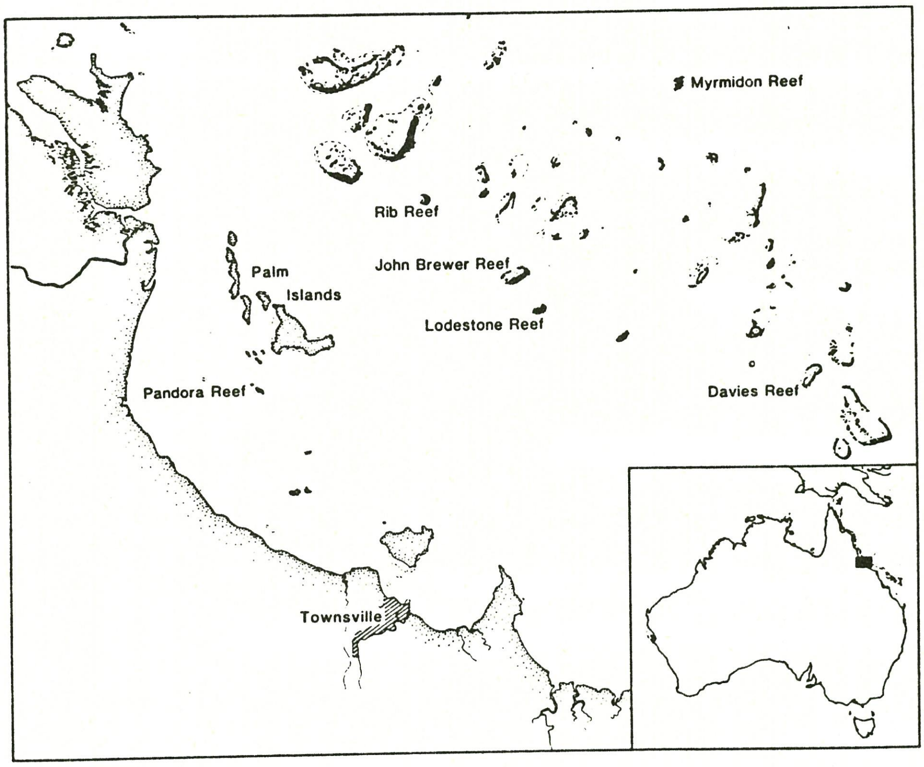
* based on full year's salary

Budget 1987/88

Item	Cost COTSAC	Cost AIMS
Adult abundances (as for 1986/87)	961	43764
Recruitment (as for 1986/87)	400	29176
Trophic structure and species diversity		
1. Salaries :		
Research Scientist* (Dr D. Williams)	-	3176
Experimental Scientist (x3) (same as Project III(a))		- -
2. Vessel charter :		
20 day field trip @ $2600/day (R.V. Harry Messel)	-	52000
3. Consumables :		
Containers (60l brewer's bin)	600	-
Chemicals (e.g. formaldehyde)	200	-
Field equipment (e.g. explosives)	300	-
TOTAL	**$2461**	**$128116**

* based on 10% of available time

Figure 1. Locations of study reefs discussed in proposal



Project II (f): Effects of outbreaks of Acanthaster planci on the interaction between corals and algae: trophodynamic implications.

Introduction

In the recently established study of reef trophodynamics at the Institute, the contribution of the epilithic algal community (coralline and turf algae) was identified as one of the priority research topics. This community which usually covers a high proportion of reef substrate, is ostensibly the dominant component of primary production on coral reefs (Larkum 1983) and is considered to be a potential major food source to the reef community (Hatcher & Larkum, 1983). Algal turfs are known to be grazed intensively by an abundant herbivorous fish fauna and these activities may influence ultimately the more complex processes of detrital pathways. They may be particularly important on the reef flat and in the lagoon, since recent observations have indicated that these regions are to a large degree trophically isolated from deeper water and from the reef slope areas (Hamner, pers. comm.). The aims of the trophodynamics project at this stage are to examine the functions of this complex and dynamic algal community in structuring food webs of reefs. Principally this involves determining the production of carbon by the algal community over time and space and to define the ultimate fate of such material.

The establishment of extensive and lush mats of turf algae and the expansion of coralline crusts that is characteristic of the early stages of recovery of coral reefs following their decimation by Acanthaster planci (Endean 1973, 1976), represents a major shift that is likely to be of considerable consequence to the trophic dynamics and structure of outbreaking reefs. Not only may proliferation of turf algae affect overall levels of primary production, but major changes in trophic pathways and in the composition of the primary consumer guild may also occur. Extensive coral mortality with a shift to a turf-dominated phase also represents a vital reorganization and release of the space resource. The pattern of reef recovery will depend to a large degree on the outcome of interactions among the major groups that can potentially utilize space on outbreak reefs, i.e. the coralline algae, turf algae and corals. It is therefore of fundamental interest to know :

a) How do living hard corals prevent themselves being overgrown by turf algae?
b) How do hard corals re-establish in an area dominated by turf algae?
c) What is the response of crustose coralline algae to coral mortality?
d) Do coralline algae affect the distribution of turf species and corals, or influence the nature of the interaction between turfs and corals?

As part of the AIMS Crown-of-thorns Study and in order to complement on-going research on the productivity of turf algae and the contribution of turf algae to detritus pathways, a study is proposed that will attempt to address these questions over a 2-3 year period. In so doing several critical hypotheses will be tested concerning the biological interactions that influence the abundance and distribution of turf algae on coral reefs. It is intended that the work contribute to the overall study by providing some insight into the questions of the effect of crown of thorns outbreaks on the biological and trophic structure of coral reefs, and the processes of recovery of corals following outbreaks of Acanthaster planci. Testable hypotheses can be formed in relation to each of the four questions delineated above. The hypotheses and a brief outline of methods follows.

Question 1: How do the dominant living hard corals prevent their overgrowth by turf algae?

a) Hard corals possess innate antifouling mechanisms, e.g. allelopathy, extracoelenteric feeding, passive physical deterrants to settlement, etc.

b) The dominant hard corals require grazers to keep their surfaces clean.

c) The rapidly growing algae that establish on outbreaking reefs inhibit the recruitment and growth of corals, and grazers are required to break this stranglehold on the space resource to enable the slower growing but grazer resistant corals to colonize and eventually dominate.

d) Although the establishment of extensive turfs retards the recruitment of corals, the slower growing corals do establish and eventually outcompete the turf algae even if grazers are absent.

e) In the absence of grazers, hard corals can establish and outcompete turf algae for space only by encroaching from the edges of patches of turf.

Several experiments are proposed to test these ideas. They are:

(a) The effect of turf algae on coral recruitment will be examined by comparing the recruitment of corals onto dead coral substratum that supports extensive algal cover with others maintained free of algae while grazers and predators are excluded.

(b) Whether or not grazers are required for recruitment and growth of corals in patches where turfs establish will be tested by comparing community development in treatments C and D of the experiment outlined in Table 1.

(c) Also, since turf algae on recovering reefs do not uniformly cover all of the available dead substratum, the outcome of the algae/coral interaction at the edges of turf areas will be examined. This will be attempted by following community development on dead coral in an experiment duplicating the treatment effects C and D shown in Table 1., but where one half of each substratum unit is maintained clear of algae.

These hypotheses would be tested initially by in situ manipulation experiments in which the recruitment of sessile species is examined on live and on dead coral heads initially clear of colonizing organisms, both in the presence and in the absence of grazers and predators of newly settled coral spat (see Table 1). The design enables testing for interaction of grazing and innate coral antifouling effects (e.g. both grazers and live corals may be necessary to prevent algal recruitment onto some corals). Conducting the experiment on both a recovering and coral-dominated reef may indicate whether different compositions of the spore/larvae pool in the water column influence the ability of corals to remain free of fouling organisms.

Careful observations of these experiments should aid in generating testable hypotheses concerning the mechanisms of innate antifouling.

Question 2: How do hard corals re-establish in areas covered with turf algae?

Question 3: What is the response of encrusting coralline algae to coral mortality following starfish outbreaks?

The rates of crust expansion will be compared on outbreaking and on coral-dominated reefs by sequential measurements of plants from photoquadrats.

Table 1. Experimental design of *in situ* manipulation experiment to test the hypotheses that (i) live corals inhibit the settlement of turf algae, and (ii) grazers prevent overgrowth of corals by turf algae. The design allows for testing for interaction of the effects of innate coral antifouling and grazers/predators.

		Grazers and predators of newly settled corals	
		PRESENT	ABSENT
LIVE CORAL	Species 1 Species 2 Species 3	Treatment A	Treatment B
DEAD CORAL	Species 1 Species 2 Species 3	Treatment C	Treatment D

Question 4: Do coralline algae affect the distribution of turf species and corals, or influence the nature of the interaction between turfs and corals?

Encrusting coralline algae comprise a large portion of the hard substratum of coral reefs that is available for colonization by algae and invertebrate species, including turf algae and corals. Moreover, since crustose corallines are known to inhibit settlement of fleshy algae (Masaki et al. 1981, 1984; Johnson & Mann in press) but promote the settlement and metamorphosis of a wide variety of invertebrate larvae (Breitburg 1984; Morse & Morse 1984) including those of corals (Sebens 1983 a,b), these crusts may have a major effect on the outcome of the interaction of turf algae and corals, and therefore on reef trophic structure and the process of reef recovery.

Their effect on the settlement and metamorphosis of coral larvae would be examined in laboratory trials, and on the establishment of turf algae in field manipulation experiments that are protected from grazers and competitors of the turfs. The outcome of overgrowth interactions among coralline algae and turf algae, and corallines and corals, in the presence and absence of grazers/predators, will be examined by laboratory trials and in situ manipulation experiments.

Anticipated Problems:

The single greatest problem in this work is likely to be in developing methods to maintain the treatment effects of grazer, predator and competitor exclusions without introducing bias from apparatus artifacts that cannot be accounted for by control treatments.

Resouces needed:

In order to achieve the objectives of this study the appointment of a Research Scientist is proposed for a 2-3 year period. This person would work in closely with Dr D. Klumpp who is undertaking trophic studies at AIMS. The assistance of an Experimental Scientist is also required. This person would assist with field work and would be one of the Experimental Scientists hired within other projects (e.g. Project III(a)).

The facilities of the AIMS trophodynamics study will be at the disposal of the person appointed to collaborate on the above projects. Additional equipment is required for the present study. This includes: filter blocks (for fluorescence microscope work) and oxygen sensors (for algal productivity measurements).

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Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries :		
Research Scientist*	2394	-
Research Scientist** (Dr D. Klumpp)	-	3702
Experimental Scientist** (Mr D. McKinnon)	-	2685
Experimental Scientist (same as Project III(a))	-	-
2. Vessel Charter :		
5 day field trip @ $2600/day (R.V. Harry Messel)	-	13000
3. Capital equipment :		
Oxygen sensors (x 12)	660	-
Filter blocks	700	-
4. Consumables :		
Field equipment	1000	-
Glassware	100	-
Chemicals	500	-
Other (e.g. film)	50	-
TOTAL	**$5404**	**$22072**

* includes leave loading and district allowance and is based on 1 month's salary.

** based on 25% of available time.

Project II (g): **Effects of outbreaks of Acanthaster planci on the interaction between scleractinian and alcyonacean Corals**

Introduction

Acanthaster planci outbreaks on coral reefs throughout the Indo-Pacific region have led to the widespread and widely reported loss of living hard coral (scleractinian) cover. Although in itself dramatic, the most important effect of Acanthaster grazing may reside in its long term effects on the community. These effects can be characterized as lying on a continuum between the two end-member states :

a) Hard coral cover may return to pre-Acanthaster levels rather rapidly after an outbreak, or

b) Dominance early on in the succession by other groups may lead to the permanent (or prolonged) development of reef communities dominated by species other than hard corals.

Randall (1973) and Pearson (1981) have published data indicating that hard coral populations exhibit relatively rapid recovery from Acanthaster attacks. These authors suggest that full recovery may occur on a scale of tens of years. However, there are aslo reports of areas becoming dominated by soft corals (alcyonaceans) following Acanthaster attacks (Endean, 1976; Nishihira and Yamazato, 1974). In an ongoing study at Green Island, Harriott and Fisk (1985) report the presence of both areas of hard coral recovery and areas of soft coral dominance.

Soft corals must be considered one of the most likely groups of organisms to replace hard corals after an outbreak due to their abundance and their taxonomic and ecological similarities with the scleractinians. A number of authors have commented on this capability, often reaching different conclusions. Endean (1976) and Nishihira and Yamazato (1974) both indicate that soft corals replace hard corals following Acanthaster outbreaks; whereas Garrett (1975) and Pearson (1981) suggest that replacement is unlikely. To date there are insufficient data on the dynamics and interactions of hard and soft corals to identify the circumstances in which hard corals can be replaced by soft corals. In the proposed research investigations will be made of the effects of A. planci outbreaks on the community dynamics of the hard and soft coral faunas. Also, an evaluation will be made of the hypothesis that the destruction of hard coral during A. planci outbreaks leads to the ecological release of the soft coral community, and retards the redevelopment of the hard coral community.

Although hard and soft corals are common members of reef communities, the relationship between these two groups of anthozoans is poorly known. Dinesen (1983) reported that on many reefs the two groups exhibit somewhat complementary depth distributions; hard corals having their greatest abundance in the shallows and soft corals having their greatest abundance at depths below 10 m. Competitive interactions could explain this pattern and Sammarco et al. (1985) have shown that hard and soft corals are capable of complex competitive interactions. Similarly, Fishelson (1973) and Garrett (1975) both suggest that some soft coral species actively compete with hard corals. If competition contributes to maintaining the observed complementary zonation patterns, then the death of hard corals during A. planci outbreaks may have large scale effects on soft coral distributions. These effects may be short term lasting only during the early stages of reef recovery or they may result in long term alterations to the community which inhibit coral recruitment and retard the return of the reef to pre-outbreak conditions. Furthermore the magnitude of the effect may be dependent on the "history" of the site (i.e., which species were present at the time of the Acanthaster outbreak).

Research plan

The research in this study will involve experimental manipulation and monitoring of hard and soft corals in Acanthaster affected and unaffected areas. These techniques will be used to follow the population dynamics of select species and so provide a detailed account of the relationship between hard and soft corals. The hard corals studied will be a Pocillopora sp., a tabular Acropora sp. and a massive Porites sp. The actual species chosen will depend on local abundances on the study reefs. The species have been chosen to represent the most common taxonomic and life form groups. The soft corals examined will be from the genera Efflatounaria, Nephthea, and Sarcophyton. These three cover a range of growth rates and space holding abilities.

The effects of Acanthaster on the hard coral-soft coral interaction will depend on several aspects of the ecology of the two groups. These include the susceptability of the two to Acanthaster attack, the relative growth rates of survivors following an attack, the ability of the two groups to recruit into affected areas and finally the interactive effects of hard and soft corals on each other's growth and recruitment. The experiments and observations to be made can be divided into four categories based on these potential effects.

a) Acanthaster planci feeds on soft corals as well as hard corals. Thus the primary affect of A. planci outbreaks will be the depression of both populations. The effects of this predation on soft corals and on their abundance relative to hard corals depends on the feeding preferences exhibited by A. planci. The potential for ecological release of the soft corals will be greatest if the soft corals survive A. planci outbreaks in proportionately greater numbers than hard corals. In order to examine this it will be necessary to follow the survival of marked colonies on a reef in the midst of an outbreak. All colonies in marked quadrats will be followed over the course of an outbreak. Quadrats will be established at 2 sites, where hard coral cover is high and where hard coral cover is low. If necessary soft coral colonies will be transplanted to the high hard coral cover zone and hard corals to soft coral areas in order to determine A. planci preferences. Two aspects of Acanthaster grazing will be examined; overall feeding preferences and the extent to which Acanthaster leaves small surviving fragments of the colonies it feeds on. This latter feature may be very important in the dymanics of the recovery and greater numbers of surviving fragments among some species could have a large impact on the recovery process.

b) Once an outbreak has occurred community structure may be affected in several indirect ways depending on the mechanisms which control abundances on unaffected reefs. The simplest interaction to hypothesize is that scleractinians and alcyonaceans do not actively exclude one another but successfully hold space, preventing invasion by the other group. If this is the case dynamics of communities with high cover (i.e. Acanthaster unaffected reefs) will be determined by the relative turnover rates of colonies of the two groups and the dynamics in low cover communities will depend on their relative growth rates.

On "normal" high cover reefs soft corals may be effectively excluded from the shallows by the high cover and longevity of the hard corals. Death of corals during an A. planci outbreak could then lead to the spread of surviving soft coral clones. This is particularly likely given the ability of many species to produce new colonies vegetatively (Benayahu and Loya, 1981; Tursh and Tursh 1982; Dinesen, 1985) and to "locomote" across the reef through a process of directional growth (LaBarre and Coll, 1982, Benayahu and Loya, 1985). This will occur if the presence of hard corals prevents soft corals from occupying space, but this hypothesis does not require that hard corals be competitively dominant merely that they maintain space.

This type of ecological release will be studied by following the fate of hard and soft coral colonies in marked quadrats. If ecological release occurs then soft corals in sites with high initial hard coral cover should exhibit greater growth on reefs on which the surrounding corals have been killed than on unaffected reefs. Soft corals at sites with low initial hard coral cover should be relatively unaffected since the amount of space opened up by Acanthaster will be low. Under this hypothesis hard coral growth rates will be unaffected by the abundance of soft corals as long as there is space available for growth. In quadrats with high levels of living cover hard coral growth will be retarded equally by both hard and soft corals. These experiments will be carried out in areas where there are both hard and soft corals survivors. If necessary treatments involving transplants of small survivors into the vicinity of each other will also be undertaken.

c) Larval recruitment will play an important role in determining the patterns of short and long term recovery of the community. Whether scleractinians or alcyonaceans dominate the community will depend on their relative abilities to occupy newly freed space on Acanthaster planci affected reefs. To a limited extent this expansion occurs through vegetative growth and reproduction. The observations described above will provide data on this vegetative expansion. -However, there will be relatively few loci for soft coral expansion in the hard coral zone, and vice versa since soft corals are less common in areas of high hard coral abundance. Therefore, changes in abundance patterns may be dependent on the recruitment of new colonies into the zone via larval settlement.

Longer term recovery will also be affected by the interaction between recruitment success and the extant cover. Living cover (soft or hard coral) may inhibit subsequent recruitment success which will retard the return of the community to its pre-Acanthaster state. Alternatively, the effects of soft corals on hard coral recruitment (or vice versa) may be unidirectional leading to the formation of stable communities which are very different from those present prior to the Acanthaster attack.

In order to examine these facets of population growth quadrats will be established at the start of the spawning season in November. Quadrats will be set up in areas of low living cover, high hard coral cover and high soft coral cover. The numbers of successfully settled planulae will be determined at the end of the season in late January and again in March or April (in order to monitor non-seasonal spawners). It will not be possible to identify recently settled planulae to species or even genus and planular recruitment of scleractinians and alcyonaceans will be compared at the family level.

d) Finally we must consider the possibility that hard corals actively exclude soft corals. After an Acanthaster outbreak the soft corals will have the potential to utilize space previously monopolized by competitively dominant hard corals. If hard corals are the competitive dominants, then soft corals even if successful in the short term will eventually be excluded. The speed with which the exclusion will occur will depend on the initial buildup of soft corals and on the subsequent rates of recruitment of the hard corals. Both of these parameters will be known from the observations and experiments outlined above.

Competitive dominance will be tested by comparing the success of soft coral colonies transplanted into areas of high hard coral abundance and vice versa. Growth and survival of transplants on reefs affected by Acanthaster planci will be compared to that of transplants on unaffected reefs. If hard corals inhibit the survival and growth of soft corals then the transplants on unaffected reefs (i.e. reefs with abundant hard coral) should have lower growth and survival than those on affected reefs. Comparisons between survival of colonies transplanted within areas of low hard coral abundance with those transplanted into the high abundance zone will indicate whether the zonation is maintained by factors which are independent of hard coral cover.

The design of the 4 experiments will follow a three-way analysis of variance protocol. Measurements will be made on each of the two groups (soft and hard corals), each of two reefs (Acanthaster affected vs. unaffected) and at each of two sites (high vs low hard coral density). High and low hard coral density sites will usually correspond to shallow and deep sites. Surveys from the control reef will be used to determine substrate preferences of the test species and sites will be chosen so that differences in hard corals abundance are the primary variate. The parameters to be monitored will be survival of colonies and population growth (number of colonies and area occupied). Changes in the number of colonies will be ascertained from field censuses and areal cover from analysis of calibrated photos.

In concert these experiments will indicate :

- Whether soft corals are excluded from areas with high hard coral cover?
- Whether this exclusion is a consequence of competition or of differential turnover rates?
- Whether the removal of hard corals by Acanthaster planci leads to the vegetative expansion of the soft coral fauna?
- Whether settlement of soft corals will allow them to expand into new areas of the reef following Acanthaster planci outbreaks?
- Whether changes in the coral community can be predicted on the basis of pre-outbreak cover?
- Whether changes in the relative abundances of different groups represent stable communities which will persist over long periods of time?

Resources needed :

It is proposed that a Research Scientist be appointed to conduct the research described above. This appointment is likely to be for 2-3 years depending on the results of the project. Field support for this project will be provided by Experimental Scientists hired for other studies (e.g. Project III(a)). Ten days of ship time are required to initiate this research (i.e. set up study sites) in the 1985/86 fiscal year. A small amount of funds are requested to purchase field equipment.

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Tursch, B., Tursch, A. 1982. The soft coral community on a sheltered reef quadrat at Laing Island (Papua New Guinea). Mar. Biol. 68: 321-332.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries :		
Research Scientist*	2394	-
Research Scientist+ (Dr T. Done)	-	1695
Experimental Scientist (same as Project III(a))	-	-
2. Vessel charter :		
10 day field trip @ $700/day	7000	-
Food @ $150/day	1500	-
Victuals @ $150/day	1500	-
3. Consumables :		
Field equipment (e.g. dive gear, underwater paper, slates, ropes)	1000	-
TOTAL	**$13394**	**$1695**

* includes leave loading and district allowance and is based on 1 month's salary

+ based on 5% of available time

Project III (a): Macro-scale studies of the distribution and abundance of Acanthaster planci and corals on the Great Barrier Reef.

Introduction

The Institute with the extensive support of the Commonwealth Community Employment Program, is presently conducting a large-scale study of the Acanthaster phenomenon. The major objective of this Study is to determine the current extent of activity of the crown-of-thorns starfish and its coral prey on the Great Barrier Reef and assess its effects on coral communities. A thorough account of the Study has been published eleswhere (COT CEP, 1985).

During the Study surveys of the abundance of starfish and corals are being undertaken on 228 reefs along the entire length of the Great Barrier Reef. This information is collected using manta tow techniques (Done et al., 1982). The benthic communities on 84 of these reefs are being studied in more detail using line transect techniques in conjunction with benthic life form categories. These techniques have been described in a recent data report produced by the Study (COT CEP, in press).

To date, 188 reefs have been surveyed and it is expected that all the reefs designated for survey will be completed by the end of the Study in late February 1986. The results of this survey program are of great importance because:

a) It is the first time that detailed information about the crown-of-thorns starfish and its coral prey and other major benthic communities has been collected for so many reefs.

b) In addition, never before have so many reefs been surveyed at the one time.

c) It is the first time that reefs encompassing the entire length and breadth of the Great Barrier Reef have been surveyed in one year.

This Study will provide the most accurate picture, to date, of the extent of the current starfish outbreaks. More importantly however, it will provide a data base which will be invaluable in not only assessing the risk posed by the crown-of-thorns starfish to the Great Barrier Reef but also in gaining a better understanding of the phenomenon.

Research plan

The aim of this study is to resurvey on an annual basis about 60 of the reefs surveyed during 1985 in the CEP Crown-of-Thorns Study. This research will not only extend the present data base on the phenomenon but it will introduce a more extensive temporal dimension to the data. Such information will be more amenable for the purposes of modelling and statistical analyses.

The reefs to be resurveyed will be chosen once the CEP Crown-of-Thorns Study has been completed. They will be selected according to the following criteria:

a) The quality and quantity of information that already exists on the abundance of starfish and corals for each reef.
b) Location of reef (both latitude and longitude).
c) Type of reef (i.e. in-shore, mid-shelf, outer-shelf).
d) Size of reef

Synoptic surveys (COT CEP, 1985) will be undertaken on all these reefs and the more intensive life form transects will be conducted on a subset of them (approximately 20 reefs).

Resources needed:

The work delineated in this proposal is heavily field oriented (about 50 days at sea per year). Three Experimental Scientists are required to undertake these surveys and they will be supervised by the Chief Investigators. In between times these personnel will assist workers in other projects (e.g. see Project IV (b)). As large amounts of data are produced with surveys of this type one micro-computer is requested which can be taken to sea to process this information. This practice reduces the amount of time spent in transferring data and leads to fewer errors being incorporated into the main data base.

As the CEP Crown-of-Thorns Study does not finish till the end of February 1986 the resurvey of reefs in the present study will not be commenced until the following May. This will give the Experimental Scientists time to plan the field program in detail and select the reefs to be resurveyed. A 10 day field trip is planned towards the end of this fiscal year and this will be on board an Institute ship.

Some additional capital equipment is needed to undertake these surveys. This includes a zodiac and outboards (for towing the manta observer) and a two-way radio (for communications between the mother vessel and the zodiac). These items are in short supply at the Institute.

Literature cited

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Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries:		
Research Scientist* (Dr P. Moran)	-	1534
Research Scientist+ (Dr R. Bradbury)	-	1049
Research Sceintist+ (Dr R. Reichelt)	-	740
Experimental Scientist**	7544	-
Experimental Scientist**	7544	-
Experimental Scientist**	7544	-
2. Vessel charter:		
10 day field trip @ $500/day (R.V. Sirius)	-	5000
3. Capital equipment:		
Field computer (Sharp PC 7000)	3500	-
Zodiac	4500	-
Outboard motor (x2)(Evinrude)	1740	-
Two-way radio (Micom 60)	1800	-
TOTAL	**$34172**	**$8323**

* based on 10% of available time

\+ based on 5% of available time

** includes leave loading and district allowance and is based on 4 months salary

Project III (b): Meso-scale studies of the distribution and abundance of Acanthaster planci and corals on selected reefs

Introduction

Despite the extensive series of surveys that have been undertaken in the Indo-West Pacific region over the last 20 years very little is known about the temporal change in the distribution and abundance of starfish and corals on coral reefs. Consideration of the dynamic behaviour of a predator and its prey is necessary if a greater understanding of the phenomenon is to be achieved (Levins and Lewontin, 1982). Although the studies of Ormond and Campbell (1974) and Glynn (1974) have provided some of this information they were carried out on reefs which had a relatively low density of starfish. Apart from the studies by Kenchington (1976) those conducted on the Great Barrier Reef have not considered both the predator and its coral prey in a uniform manner. Despite their importance even the studies of Kenchington (1976) and Kenchington and Morton (1976) are lacking in the sense that they did not view the whole outbreaking process (i.e. going from before the outbreak, through to the end of the outbreak and the subsequent recovery).

To date, there is little if any information available on the change in the distribution and abundance of the "pair object" (Bradbury et al., 1985) throughout a complete outbreak cycle on one reef. Studies at the Institute over the last two years have begun to obtain this type of information. The preliminary results of one of these was reported by Moran, Bradbury and Reichelt (in press).

Research plan

In this study it is proposed to undertake surveys of the abundance of Acanthaster planci and corals at 4 monthly intervals on the following reefs:

a) John Brewer Reef
b) Helix Reef
c) Wheeler Reef
d) Davies Reef
e) Bowden Reef

Surveys of this sort (for detailed description of methods see: Moran, Bradbury and Reichelt, in press) have already been conducted on at least six occasions over the last two years on all but the last mentioned reef. Recently, manta surveys were conducted on Bowden Reef which indicated that it was relatively free of starfish and that it had good coral cover. The "pair object" will continue to be monitored on this reef in the hope that it will experience an outbreak as it did in the mid 1970's. Surveys of Davies Reef are being continued for just this same reason. The other reefs that were mentioned above are all in various stages of an outbreak. It is envisaged that these surveys would proceed for at least 2 years. The surveys to be conducted at Helix would complement the work already being conducted there by Dr J. Lucas of James Cook University.

Resources needed:

At this stage, no funds are requested to undertake the research described above. Some field assistance will be needed during the surveys of the reefs and this will be provided by some of the Experimental Scientists hired for other projects. The major expense in this study is associated with shiptime and this will be provided by the Institute.

Literature cited

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Budget 1985/86

	Item	Cost COTSAC	AIMS
1.	Salaries:		
	Research Scientist* (Dr P. Moran)	-	3068
	Experimental Scientist (same as Project III (a))	-	-
2.	Vessel charter:		
	5 day field trip @ $500/day (R.V. Sirius)	-	2500
3.	Capital equipment:		
	Field computer (same as Project I (h))	-	-
	TOTAL	-	**$5568**

* based on 20% of available time

Project IV (a) :Enhancement of substrate reflectance in Landsat imagery with special attention to reef damage by Acanthaster planci

Introduction

Landsat imagery has provided a broad scale image data base for the Great Barrier Reef. The Great Barrier Reef Marine Park Authority (GBRMPA), Australian Survey Office (ASO) and CSIRO (Division of Water and Land Resources) have collaborated to develop methods for base data analysis which maximize the cartographic and thematic information available from the imagery. This work has been reported by Jupp et al. (1985a,b,c).

The separation of Landsat data into effects due to water depth, water properties and the condition of the substrate as well as transient atmospheric effects is limited in the low contrast marine environment. The degree to which this separation has been achieved by research and data processing during the GBR Projects between GBRMPA, ASO and CSIRO is described in detail in the accompanying papers and reports. However, that process can be considerably enhanced through the provision of ancillary data and multiple data image analysis.

Research Plan

It is clear from the work done by CSIRO Division of Water and Land Resources in the period 1980/85 that to achieve higher resoltuion information about the cover type and condition on reefs from the considerable historical Landsat data archive, or future acquisitions, we need to:

a) Adopt a multi-date image context for the interpretation,

b) Combine the image data with collateral data on water depth and baseline cover interpretations in a Geographic Information System context, and

c) Establish much more precisely the relationships which exist between substrate type and spectral reflectance in a variety of wavelength bands.

In attempting to apply remote sensing from Landsat to the question of fine scale reef damage by Acanthaster planci we therefore believe that a useful answer requires that the following two conditions be satisfied and makes use of integration between Landsat data and independently obtained bathymetric data.

The two conditions are :

a) That the response to damage occurs at a sufficiently coarse scale (large patch size) to be resolvable by the imagery, and

b) That the spectral properties of damaged reefs, or the response of reefs following damage, are characteristic and resolvable.

Based on experience of reef scientists at AIMS the first condition seems to be satisfied in many cases and the second will be assumed pending a more complete investigation of the spectral properties of reefs and reef materials by Dr D. Kuchler as part of an MST funded collaborative CSIRO/GBRMPA Project. In that project, the spectra of algal dominated damaged areas as well as the water associated with them will be investigated along with a wide range of common reef conditions and component structures. There is therefore an important liaison between that project and this.

As ground data for the study, the investigators will make use of the extensive data collected on John Brewer Reef off Townsville by AIMS over a period of some years. This data is at a scale appropriate for comparison with that obtained from Landsat and will be integrated with the imagery and a model of the true reef bathymetry using the cartographic facilities and background survey data available through the ASO.

Mapping Substrate Reflectance using Collateral Depth Data :

Assuming the background given in the attached papers, and neglecting for the present the effects of the atmosphere and water surface, the essential equation is that describing the radiance above water :

$$Li = Lwi + (Lbi - Lwi) \exp(- 2 Ki z) \qquad \text{.....} \ (1)$$

where;

Li is the radiance in channel i
Lwi is the deep water radiance
Lbi is the (wet) substrate radiance
Ki is the water attenuation coefficient, and
z is the depth below the surface to the substrate.

In the current situation the objective is to map Lbi for all possible channels and under a variety of depths and (possibly) water conditions.

The hypothesis being advanced is that if the actual water depth is available independently of the remotely sensed data then that objective may be met with some success.

Mathematically, let

$$Xi = \text{Log}(Li - Lwi)$$

so that equation (1) becomes :

$$X_i = \text{Log}(L_{bi} - L_{wi}) - 2\,K_i\,z \qquad \text{..... (2)}$$

This linear relationship is the basis for the depth mapping capacity in Landsat data and if two or more channels are operating for which Ki are known then it is possible to separate out depth and substrate in a systematic way.

The problem is that with Landsat data only two bands are operating when the water depth is less than about 5 metres. This means that for many important reef top areas depth and substrate type are inextricably confounded. However, even with one channel, if z were known then the transformation:

$$\text{Log}(L_{bi} - L_{wi}) = X_i + 2\,K_i\,z \qquad \text{..... (3)}$$

may provide a map of Lbi in that channel relative to the deep water signal Lwi. In practice, of course, this could be done without estimating Ki by regressing z on Xi and using the residuals as a substrate enhancement.

A similar residual enhancement may be used with the Exposure Image (Jupp et al., 1985a,b,c) to delineate boundaries and eliminate slowly varying trends in reef cover which may mask subtle substrate changes. The theory is in the attached papers and the methods will be tested on John Brewer Reef.

Based on the attached papers, for a single overpass the Landsat band 4 reflectance could be mapped approximately down to about 15 metres under reasonable conditions and Landsat band 5 down to about 5 metres.

Specific Methodology :

The method which can therefore be applied where Landsat data and depth data exist together for a reef is as follows :

a) Determine Lwi and the Depth of Penetration data as described in Jupp et al. (1985a,b,c).

b) Use the depth data to fit exponential models to band 4 data in the band 4 and deep water zones and to band 5 in the band 4 and band 5 zones and obtain K4 and K5.

c) Use equation (3) with appropriate spatial filtering to map Lbi in the band 4 zone (one value) and band 5 zone (two values) either by regression or the use of K4 and K5 obtained in (ii), and

d) Repeat the analysis for a set of images at different times to assess consistency of interpretation and identify temporal change.

The results will be compared directly with reef survey data collected by AIMS on John Brewer Reef off Townsville to assess the degree of correlation between the derived substrate images and the known damaged areas.

Resources Needed :

The exercise will be carried out jointly at CSIRO Division of Water and Land Resources and AIMS with resource inputs from ASO. The task will be completed using a micro-BRIAN workstation which is fully compatible with the prototype (and any follow-up systems) purchased by AIMS and be done during the period of establishment of the AIMS system(s).

It is expected that during the project at least one of AIMS staff will assist with processing for a period in Canberra to become familiar with the use of the micro-BRIAN system applied to this research and be involved in the establishment of the AIMS micro-BRIAN system. Towards the later stages of the project the AIMS staff member will be able to process data on the AIMS micro-BRIAN system in Townsville.

CSIRO and ASO currently have two satisfactory images of John Brewer reef within the period of AIMS data collection (1980-1983) but at least two more will be needed to carry out the testing. ASO may be able to increase this data base. CSIRO will also need to offset the resource costs of the project (including time spent training the AIMS staff member) to the equivalent of three months of technical staff time with allowance for overheads.

Some travel will be needed to liaise between Canberra and Townsville and this will be organized by AIMS when the occasion arises. The resources allowance, however, should not be specifically tied to a salary requirement as it is an offset against a number of costs the project will entail for CSIRO.

The product will be in the form of appropriate inkjet plotted imagery and a report to AIMS on the result which will include a detailed account of the implementation of methods developed for the analysis within the micro-BRIAN system. If the project is successful in its aims then the work will also be published openly as a scientific paper by the collaborators.

Literature cited

Jupp et al. (1985a). Remote sensing for planning and managing the Great Barrier Reef of Australia. Photogrammetria 40: 21-42.

Jupp et al. (1985b). The Brian Handbook. Natural Resources Series No. 3. CSIRO Division of Water and Land Resources 43 p.

Jupp et al. (1985c). Landsat based interpretation of the Cairns section of the Great Barrier Reef Marine Park. Natural Resources Series No. 4. CSIRO Division of Water and Land Resources. 51 p.

Budget 1985/86

	Item	Cost COTSAC	AIMS
1.	Salaries :		
	Experimental Scientist+	7544	-
	Research Scientist** (Dr R. Reichelt)	-	1534
2.	Travel :		
	Townsville/Canberra return airfare	800	-
	Allowances	500	-
3.	On-costs :		
	CSIRO	6,000	-
	TOTAL	**$14844**	**$1534**

* microBRIAN expertise provided by CSIRO; imagery and survey data provided by ASO

\+ includes leave loading and travel allowance and is based on 4 month's salary

** based on 10% of available time

Project IV (b): Evaluating procedures for the verification of Landsat images with reference to the effects of Acanthaster planci on reefs.

Introduction

Outbreaks of the crown-of-thorns starfish, Acanthaster planci, and their associated destruction of reefs and reef areas on the Great Barrier Reef have been recorded for a second time in recent years. An extensive ground study of the phenomenon has begun, involving underwater surveys. However, given the regional extent of the Great Barrier Reef, the logistics of such ground-based surveys, the high cost of repeated surveys and the expense of ship-based reef work, remotely sensed surveys show potential as a viable cost-effective alternative. In addition, for most reefs remotely sensed data is the only historical survey data available.

Research plan

The long term aim of this study is to establish a remote sensing strategy for monitoring the effects of Acanthaster planci outbreaks on the Great Barrier Reef. It is regarded initially as being a pilot study with the aim of attempting to evaluate the procedures for verifying remotely sensed data on coral reefs. The study would establish the optimum procedures, in terms of personnel, ship costs and time, for accurate ground-truth studies of reef substrata classifications. The study would include:

a) The location and assessment of available ground and remotely sensed data on John Brewer and Wheeler Reefs.

b) Analysis of remotely sensed imagery for the purpose of precisely establishing the relationships between ground and remotely sensed reef cover data.

c) Field studies using several data collection procedures in order to verify the interpretation of remotely sensed images.

d) Map the changes in reef cover types through time using remotely sensed imagery.

The following methods would be undertaken in order to perform these tasks.

Image analysis:

The micro-BRIAN image analysis facility at AIMS would be used to produce classified images of John Brewer and Wheeler Reefs.

Field studies:

One field trip of 10 days duration would be undertaken with sampling at John Brewer and Wheeler Reefs following two protocols:

a) Small, homogeneous, pixel-sized areas would be sampled by manta tows and swims. Substrate categories would be recorded and integrated over each sampling area. The number of these samples is yet to be determined but would be between 10 and 15 per reef. A similar method was used recently by Kuchler et al. (in prep) for surveying reefal communities at Hook Reef off the Whitsunday Islands.
b) The entire reef perimeter and selected cross-reef transects would be performed using the management-oriented sampling procedure designed by GBRMPA (see Done et al. 1982).

Resources needed:

The Experimental Scientist hired to undertake work in Project IV (a) will also be responsible for operating the micro-BRIAN. An allowance has been set aside in the budget of Project IV (a) for this person to spend 4 weeks in Canberra at the CSIRO Division of Water and Land Resources to train in the operation of the micro-BRIAN. The field component of this study basically requires shiptime and personnel. It is likely that the shiptime can be accommodated within the activities of Project III (b) a part of which involves meso-scale surveys of Wheeler and John Brewer Reefs. The two Experimental Scientists and one Technical Assistant employed in other Projects (e.g. Projects III (a), IV (g)) will work with the Experimental Scientist in the present study to complete the two types of surveys.

Literature cited

Kuchler, D.A., C. Maguire, A. McKenna, R. Priest and J. Mellor. (in prep). Survey method for verification of Landsat MSS image data.

Done, T.J., R.A. Kenchington and L.D. Zell. (1982). Rapid, large area, reef resource surveys using a manta board. Proc. Fourth Int. Coral Reef Symp. Manila. 1: 299-308.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries:		
Experimental Scientist (same as Project IV (a))	-	-
Experimental Scientists (same as Project III (a))	-	-
Technical Assistant (same as Project IV (g))	-	-
Research Scientist* (Dr. R. Reichelt)	-	767
2. Vessel charter:		
10 day field trip @ $500/day (R.V. Sirius)	-	5,000
3. Travel:		
Townsville/Canberra return airfare (same as Project IV (a))	-	-
Allowances (same as Project IV (a))	-	-
4. Consumables:		
Field equipment (e.g. manta boards, underwater paper)	500	-
TOTAL	**$500**	**$5767**

* based on 5% of available time

Project IV (c) Numerical models of the hydrodynamic regime around schematized and actual reefs

Background

The dispersal of larvae of Acanthaster planci, and its relationship to the large-scale patterns of starfish outbreaks on coral reefs, remains poorly understood. Settlement patterns on particular reef types, or within reefs, are also largely unknown. However, an understanding of the scope for advection of larvae away from or onto reefs of different types, and for settlement in particular habitats, must underpin an assessment of the nature of the crown-of-thorns phenomenon. These questions were among those identified as important by COTSAC (1985).

Acanthaster larvae are distributed within and among coral reefs by water currents forced by the physical environment. Large-scale processes such as tidal and wave currents, wind-driven circulation and turbulent mixing will determine the larval excursion although this may be modified by the interaction between vertical mixing processes and larval behaviour in the water column. Later stages in the starfish life-cycle may also be influenced by the hydrodynamic regime; e.g. the relative distributions of juveniles and adults, and the variations in these between different types of reefs.

The major physical influences and their relationship to spawning, dispersal, recruitment and post-settlement distribution patterns of the crown-of-thorns starfish may be elucidated through a numerical computer modelling program. It could be designed to specify the physical processes (water currents, wave conditions, wind-driven circulation and vertical velocity profiles) for selected reef types, classified by their bathymetry, plan-shape and exposure to tidal currents, winds and waves. The modelling would provide detailed information on the physical processes for comparison with the results of the concurrent biological investigations being planned by other researchers.

Introduction

Northern and southern zones of the Great Barrier Reef are characterised by close-packed outer barrier reefs near the shelf break. The central zone has a wide open matrix of reefs on the outer half with no well defined outer barrier. In the central zone, platform reefs rise abruptly from 40-80 m depths to the sea surface (Andrews and Furnas, in press), from a shelf 70 to 130 km wide.

Throughout the region, because of the widely varying reef geomorphology, a range of relative wave and current intensities occurs. A range of factors, including wave attenuation over the rough, shallow coral reefs, sheltering by sub-aerial features, the large-scale morphology and the smaller scale bathymetric characteristics, all control a variety of wave and current intensities. These intensities are further governed by offshore conditions. Andrews and Furnas (in press) described sub-surface, low-frequency intrusions of Coral Sea Water into the central Barrier Reef, noting speeds of up to 60 cm/s at the outer half of the reef. Seasonally-varying poleward flow was found to be modified by local wind-forcing with near-bottom flow being of the order of 15 cm/s.

Tidal currents in the central Barrier Reef (Church et al., 1985) reach the order of 20 cm/s with the major axes of the tidal ellipses tilting left of cross-shelf, especially for the diurnal constituents.

Wave activity varies from ocean swell conditions to locally-generated wind waves in the sheltered inner reef zones. For example, there is no significant ocean swell at the more shoreward John Brewer Reef, and wind waves are commonly about 1 m high for a moderate 10 m/s wind (J. Andrews, pers. obs.).

Research Plan

The essential purpose of the study is to identify what variations in the larval dispersal and settlement patterns may occur as a result of interaction with tidal currents and waves over different reef morphologies and hydrodynamic regimes. This will be achieved by modelling of schematised morphologies to provide a general overview of the phenomena, supplemented and verified by a simulation applied to a particular, well-known reef. This numerical modelling program will thus provide simulations of a wide range of conditions on the Great Barrier Reef and a reef-scale view of the physical hydrodynamic processes prevailing on the common types of reef.

The study will be conducted in three stages; the first stage will be completed during 1986, and is described in detail below; the second stage will be commenced in late 1986 and will continue into 1987. The final stage will be more fully specified after the results of the preceding work become available, and will be conducted during 1987 and 1988. Budgets for these years, given in Section 5, are indicative only.

The first stage requires the modelling of a series of "schematised" coral reef types. These will arise from general classifications of reef morphologies. For example, cases studied would be as simple as a rectangular step or a circular platform reef, becoming more complex to include actual sea bed slopes and schematised plan shapes. It is envisaged that some 10-15 schematised reefs would be examined.

Modelling of the schematised reefs will establish a base of information on the processes related to tidal current, wind and wave-induced hydrodynamics over the selected configurations, and will provide for classification of the important geomorphic/hydrodynamic interactions.

The relevant environmental factors to be considered are tidal, long-wave and wind-induced currents, and wave conditions. The first three would be simulated numerically in a 2-dimensional non-linear hydrodynamic model of long-wave propagation (Black, 1983). This will provide a fully 2-dimensional flow pattern including eddy circulation. There is no allowance at this stage, however, for a three-dimensional layered simulation, although sea bed or near-surface currents would be predicted from boundary layer theory, using an estimated or measured bed roughness (Black, 1975; Lee and Black, 1978). In shallow reef conditions, this simulation is expected to give adequate results for the research task under consideration.

Wave-induced circulation and wave energy would be simulated in a short-wave model forced by wave-induced set up, refraction and diffraction. A model of this nature (excluding diffraction) has been applied by Black (1975) utilising a procedure described by Noda (1972).

The schematised modelling will provide useful information for the formulation and generation of the numerical modelling study of John Brewer Reef, described in Project IV (d). This reef is one for which there are extensive biological data sets. The detailed model for John Brewer Reef, using actual morphology and bathymetry, will be supported by a field data collection programme (see Project IV (d)). These data and the John Brewer simulation will constitute an important process of verification of the schematized simulations. They provide a means to relate the schematized simulations back to known conditions on the Great Barrier Reef, thereby validating the schematized reef models.

The second stage of the proposed study involves utilizing the outcomes of the modelling of schematized and actual reefs to predict probabilities of dispersal and settlement distribution of larvae away from, onto and within particular reef types and reef zones. This involves simulation of advection of hypothetical pulses of larvae from within and outside of particular reefs.

The final stage of the study will examine questions which arise from the preliminary simulations carried out in stage 2. This stage will be more closely defined after the preliminary work is carried out, and is expected to require systematic comparison with information on the distribution and abundance of starfish, in space and time, on a variety of reef types and within particular reef types. One aspect of this should be a comparison of the distribution of starfish populations within and around various reef types with the spatial variations in wave- and current-driven fluid energy intensities. The biological information will be drawn from the AIMS/GBRMPA databases.

Collaborations:

This project represents a collaboration between Dr K. Black (Victorian Institute of Marine Science) and Dr J.C. Andrews (AIMS). The three study phases described above will be carried out at VIMS by Dr Black who will need to travel from time to time to AIMS to consult with Dr Andrews and Dr Reichelt (see Project IV (e)).

Duration:

The timetable for the first phase of the study, and for the commencement of the second phase, is given in Table 1. This gives a total of some 25 working weeks or 6 months of full time involvement to be spread unevenly over 12 months. The timetable is based upon the expected availability to Dr Black of a full-time Experiment Scientist for the first six months of the study (see Project IV (d)).

Table 1. Timetable for study.

Task	Duration (days)	Time at AIMS (days)
Background information, previous studies, biological data field program design	10	5
Establishment of schematised cases (estimated as 15)	15	
Establishment of model inputs (field data such as waves, currents currents winds etc.)	5	
Modelling and verification (incl. various wind, tide and wave inputs)	45	
Review of output with collaborators	5	5
Comparisons of John Brewer Reef model with schematised results (includes collaboration on development of model)	20	
Assessment of modelling outcomes, simulations using biological inputs and formulation of final phase of study	10	5
Preliminary Report preparation	15	
TOTAL	**125**	**15**

Literature cited

Andrews, J.C. and Furnas, M.J. (in press). Subsurface intrusions of Coral Sea water into the central Great Barrier Reef - I. Structures and shelf-scale dynamics. Continental Shelf Research.

Black, K.P. (1975). Rip currents. B.Sc. (Hons) thesis. Melbourne University. 187 pp.

Black, K.P. (1983). Sediment transport and tidal inlet hydraulics. Ph.D. thesis. University of Waikato. Vol. 1 (Text). 330 pp and Vol. 2 (Figures and Tables).

Church, J.A., Andrews, J.C. and Boland, F.M. (1985). Tidal currents in the central Great Barrier Reef. Continental Shelf Research. Vol. 4, 5:515-531.

COTSAC (1985). Report of the Crown-of-Thorns Starfish Advisory Committee. GBRMPA, mimeo, 29 pp.

Lee, T.T. and Black, K.P. (1978). The energy spectra of surf waves on a coral reef. Proc. 16th Int. Conf. on Coastal Engineering (ASCE). pp. 588-608.

Noda, E.K. (1972). Wave induced circulation and longshore current patterns in the coastal zone. Tetra Tech. Rep. No. TC:149-3. Calif. 120 pp.

Budget 1985/86

Item	Cost COTSAC	AIMS
1. Salaries:		
Experimental Scientist (same as Project IV (d))	-	-
2. On-costs:		
VIMS	500	-
3. Travel:		
Return air fares (Melbourne-Townsville)	4000	-
4. Consumables:		
Supplementary materials (e.g. marine charts)	500	-
5. Computing time:		
VIMS	1000	
TOTAL	**$6000**	-

Project IV (d) : Numerical Models of the Hydrodynamic Regime at John Brewer Reef

Introduction

The title of this proposal is misleading in that the ultimate aim is to calculate the patterns of trajectories, residence times, probabilities of retention and dispersal of larvae of A. planci, for situations where they are released within the reefal environs and where they are advected into the region from the far field of John Brewer Reef by prevailing ocean currents.

Where a sufficiently well defined system of currents exists the problem is essentially a simple application of finite difference particle advection experiments (e.g. Maier-Reimer, 1973).

However the currents are not well defined so the solution of the problem of larval dispersion and advection hinges upon simulation of the currents. This is particularly difficult in a topographically complex environment where resort is made to computer models. As there is detailed information available on the change in distribution and abundance of Acanthaster planci for John Brewer Reef, it has been proposed as a focal area for study of small scale phenomena. Also, since the large scale current regime in extra-reefal waters is well understood in that region (Andrews and Furnas, 1985; Andrews and Pickard, 1986) the remaining elements leading to a solution of the problem defined in the opening paragraph are encapsulated in the proposal title.

Research Plan

There are several distinct components that can be laid out more or less chronologically:

a) Bathymetric data bank: A grid system will be employed for numerical modelling and the depth is required at each grid point. Existing data on the bathymetry of John Brewer Reef will be collated and supplemented by survey where required. A computer routine will then be written to allow generation and storage of depths in forms suitable for numerical experiments (Timescale: 3 months).

b) Construction and testing of hydrodynamic model(s): There are two distinct regions of the frequency spectrum for currents, associated with tides and winds. In the GBR region they can be modelled separately (e.g. Andrews, Mitchell and Bellamy, 1983; Church, Andrews and Boland, 1985; Kelly and Andrews, 1985) or together (e.g. Bode and Stark, 1983; Fandry, 1983). In addition to determining basic (or barotropic) current patterns it is necessary to account for vertical variations in current strengths and directions if position of larvae in the water column is a component of the study. There is no intention to derive a suite of models. The required ingredients are a free surface, nonlinear terms, surface and bottom stresses, Coriolis parameter, pressure gradients, temporal variability and vertical shear. The model(s) will be chosen from an available range in consultation with Dr K. Black (VIMS) and Dr L. Bode (JCU). The former is a direct collaborator (see Project IV (c)) while the latter is a collaborator in a similar modelling program being conducted for the Great Barrier Reef Marine Park authority (Timescale: 8 months).

c) Field calibration and model validation: Once the model is working satisfactorily with the appropriate bathymetry, and with the boundary and surface forcing appropriate to observed tides, winds and low frequency currents, it will be run for a wide range of conditions. These laboratory runs will show critical areas for placement of current meters and water level recorders. The field metering is necessary for proper calibration and validation of the model. The meters will be deployed for 8 months and during this time four sorties will be made for short-term monitoring of the trajectories of drogues in an attempt to cover the following conditions: spring and neap tides, southeast tradewinds, northerly winds and calm conditions (Timescale: 2 months preliminary model runs, 8 months fieldwork and drogue analysis; 2 months analysis of data from meters; 2 months for final calibration and validation of model).

d) Particle trajectory simulations: Larvae will be released in the model and tracked through time under the full range of probable environmental conditions and with release points on the boundaries of the model grid as well as on the reef. In addition random velocities can be added to model-determined velocities for monte-carlo determination of probabilities over many trials. Particles can be tracked forwards in time to determine destinations for given origins, and they can also be tracked backwards in time to determine origins for given destinations (Timescale: 4 months).

Resources needed :

Most of the costs associated with obtaining the hydrodynamic data in this study will be met by the Institute. This includes particularly vessel charter and use of current meters and other instrument packages. As some assistance will be required during field trips experimental scientists hired for other projects within the Crown-of-thorns Study (see Project III (a)) will be drawn upon when needed.

An Experimental Scientist is required to develop the model(s) for John Brewer Reef as neither the Principal Research Scientist or his assistants can dedicate themselves full time to the task. Also, during field trips a small, portable computer will be needed for data collection, drogue tracking and coarse modelling.

Collaborations :

This project also represents a collaboration between Dr J.C. Andrews (AIMS) and Dr K. Black (VIMS). Dr Black proposes to study the hydrodynamics around a range of reef shapes commonly encountered in the Great Barrier Reef (see Project IV (c)). It is appropriate for his study and the present one to use the same basic flow model. Discussions to this end will take place in March 1986. In addition the study proposed here is complementary to and concurrent with a study of large-scale circulation being undertaken by AIMS, JCU and GBRMPA. The co-principal investigators are J.C. Andrews and Dr L. Bode and to the extent possible the model used by Andrews and Black will be compatible with that used by Bode and Andrews. It is hoped that the Experimental Scientist for whom funds are requested in the budget of this proposal will spend the first six months of his/her tenure assisting Dr Black. In this way the maximum degree of compatibility would be ensured.

Literature cited

Andrews, J.C. A.W. Mitchell and N.F. Bellamy (1983). Field studies of currents and simulation of oil dispersion in the central Great Barrier Reef. IE Aust Sixth Australian Conf. Coastal & Ocean Eng. pp 80-84.

Andrews, J.C. and M.J. Furnas (1985). Subsurface intrusions of Coral Sea water into the central Great Barrier Reef - I. Structures and shelf-scale dynamics. Continental Shelf Research (in press).

Andrews, J.C. and G.L. Pickard (1986). The physical oceanography of coral reef systems. In: Dubinsky, Z. (Ed.), Coral Reef Ecosystems, Ecosystems of the World, Elsevier, Amsterdam (in press).

Bode, L. and K. Stark (1983). Numerical modelling - Great Barrier Reef region. In: Baker, J.T., Carter, R.M., Sammarco, P.W. and Stark, K.P. (Eds.) Proc. Inaug. Great Barrier Reef Conf. JCU Press pp 409-414.

Church, J.A. J.C. Andrews and F.M. Boland (1985). Tidal currents in the central Great Barrier Reef. Continental Shelf Research, 4: 515-531.

Fandry, C.B. (1983). Model for the three dimensional structure of wind-driven and tidal circulation in Bass Strait. Aust. J. Mar. Freshw. Res., 34: 143-154.

Kelly, L.R. and J.C. Andrews (1985). Numerical models for planning coastal circulation studies. 1985 Australasian Conf. on Coastal and Ocean Eng. II pp 445-454.

Maier-Reimer, E. (1973,in German). See: vanDam, G.C., Models of dispersion. In Kullenberg, G. (Ed.), Pollutant Transfer and Transport in the Sea, Vol 1 (1982) CRC Press, Boca Raton.

Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries :		
Principal Research Scientist* (Dr J.C. Andrews)	-	5000
Senior Technical Officer+ (Mr R. McAllister)	-	1300
Experimental Scientist+ (Mr L. Kelly)	-	1250
Experimental Scientist**	7544	-
2. Vessel charter :		
7 day field trip @ $500/day (R.V. Sirius)	-	3500
3. Consumables :		
Navigational aids (e.g. maps, charts, photos)	100	-
4. Computing time++:	-	2400
@ $266/CPU-hour		
5. Capital equipment :		
Field computer (Sharp PC 7000)	3500	-
TOTAL	**$11144**	**$13450**

* based on 20% of available time

** includes leave loading and district allowance and is based on 4 month's salary

\+ based on 10% of available time

\++ based on figures given by Mr N. Harcock (AIMS Computer Manager)

Budget 1986/87

	Item	Cost COTSAC	Cost AIMS
1.	Salaries : (as for 1985/86*)	22633	10100
2.	Vessel charter :		
	3 x 5 day field trips (for metering) @ $2800/day (R.V. Lady Basten)	-	42000
	4 x 4 day field trips (for drogue tracking) @ $2800/day (R.V. Lady Basten)	-	44800
3.	Capital equipment :		
	Current meter moorings (10 @ $600)	6000	-
4.	Consumables :		
	Field equipment (e.g. drogue construction, batteries, ropes)	3000	3000
5.	Computing time** :		
	(10 hrs/week @ $266/CPU-hour)	-	79800
	TOTAL	**$31633**	**$179700**

* based on full year's salaries

** based on figures given by Mr N. Harcock (AIMS Computer Manager)

Budget 1987/88

Item	Cost COTSAC	AIMS
1. Salaries :		
Principal Research Scientist* (Dr J.C. Andrews)	-	5000
Experimental Scientist* (Mr L. Kelly)	-	1250
Experimental Scientist**	11317	-
2. Consumables :		
General stores	100	-
3. Computing time :		
(10 hrs/week @ $266/CPU-hour)	-	39900
TOTAL	**$11417**	**$46150**

* based on 20% of available time over 6 months

** includes leave loading and distict allowance and is based on 6 month's salary.

Expenditure 1985/88

Fiscal Year	COTSAC	AIMS
1985/1986	11144	13450
1986/1987	31633	179700
1987/1988	11417	46150
TOTAL EXPENDITURE	**$54194**	**$239130**

Project IV (e): Dispersal of Acanthaster planci outbreaks over the whole Great Barrier Reef: a simulation study

Introduction

Australia's Great Barrier Reef is part of the World Heritage and it is the exemplar of the coral reef ecosystem because of its large size and complexity. A. planci has been acknowledged as causing major disturbances to the Great Barrier Reef (COTSAC, 1985) and yet our current knowledge of the phenomenon is very limited because empirical data on the large scale distribution is very expensive to collect.

For several years the Australian Institute of Marine Science (AIMS) has been conducting research into the medium- and large-scale distribution of A. planci and the first results are now emerging (Bradbury et. al., 1985; Moran et al., 1985). This year AIMS is undertaking a survey of A. planci over the entire Great Barrier Reef ($1 millon funding from the Commonwealth Community Employment Program). The work proposed here is intended to make use of this growing data set on starfish distributions and to generate hypotheses that will give the Acanthaster 'debate' more of a conceptual framework than it has had in the past.

The need for better models:

While the national significance of broad scale ecological research on the Great Barrier Reef has been recognized, the models that would give the research a proper context have been lacking. In fact the study of Acanthaster has a very small theoretical base (see Antonelli and Kazarinoff, 1984; Bradbury et al., 1985). The problem is that models encompassing realistically large areas have been beyond the reach of ecologists up until now.

Within reef ecosystems many species have a planktonic larval stage that can, potentially, disperse over very large distances (Jokiel, 1984). Whether this dispersal actually takes place, however, is very difficult to determine and one of the key issues in reef ecology today is the problem of ascertaining the degree of connectedness of individual reefs in the system. To date this problem has received scant attention (see Doherty et al., 1985; Williams, et al., 1984). The outbreaking populations of A. planci represent ideal experimental subjects to analyse the problem because the pattern of outbreaks can be tracked through the system.

The modelling study proposed here would, by simulation of the dispersal process, allow testable predictions to be generated under varying model assumptions about the nature of the dispersal process. The first stage would be to analyse the sensitivity of the model to variations in the model parameters and to determine the range of values that will lead to the outbreak patterns that have been proposed, but not necessarily observed, earlier (e.g. the 'southward migration hypothesis' - Potts, 1981). The second stage would be to classify the outcomes of particular types of dispersal and preserve the 'genetic' information implicit in the model for each type of outcome. That is to say, any outbreaking population will bear a certain genetic relationship to any other outbreaking population that depends on the origins of each population. At any stage of a simulation run an index of genetic similarity could be dumped. These genetic maps would constitute predictions that could be tested during the detailed electrophoretic studies of A. planci genetics that will be undertaken in Project I (a).

Research plan

The model is a simulation of the dispersal, settlement and growth of Acanthaster planci in the Great Barrier Reef ecosystem. The system consists of about 2500 individual reefs spread over an area of approximately 1500 x 100 km and would be represented in the model by a 2-dimensional grid, with a resolution of 0.5 to 1 km necessitating a matrix of over 500,000 elements. Each element in the matrix represents an area that can be either reefal or inter-reefal waters. The reefal areas are sites where A. planci larvae can settle, develop into outbreaking populations and subsequently spawn further drifting larvae. The necessary life history parameters such as age to first reproduction have been estimated from laboratory work (mainly that of Lucas, 1984) and estimates will be used as the starting points for the model's parameters. Similarly, estimates of dispersal rates will be drawn from the available literature (e.g. Williams et al., 1984). The initial conditions of each run would be chosen to reflect one of the various different hypotheses concerning the triggering of outbreaks (Potts, 1981).

Many of the parameters will be stochastic and therefore, for any single set of values (model assumptions), a number of runs will need to be done and the variability, or lack of it, in the outcomes will play an important part in assessing the sensitivity of the individual parameters. Some of the parameters relating to the probability of settlement of larvae may be obtained from other projects proposed within the Crown-of-Thorns Study (see Project IV (c)).

Ecological Significance:

The model as outlined above would be both valid and useful. It is 'valid' because the assumptions required are simple and reflect what we know (or strongly suspect) to be important parameters in determining the distribution of coral reef organisms - parameters such as length of breeding season, rates and extent of larval dispersal and recruitment success. The model is simple in that, for instance, the fine scale hydrodynamic questions relating to dispersal of larvae can be sidestepped because the geographic scale of the model space is large enough that the oceanographic assumptions can be represented in very general terms.

The model is 'useful' in that the simulation results can be easily compared with the real distributions of starfish outbreaks. The literature on A. planci already contains a number of hypotheses concerning large scale distributions. A database that partially documents the actual distribution of starfish on the Great Barrier Reef has been created by the Great Barrier Reef Marine Park Authority. This database will be significantly enhanced by the AIMS 1985 Starfish Survey (which is almost completed).

The predictions made by the model may eventually be testable using remote-sensing data if another proposed pilot study is successful (see Project IV (a)). Apart from the dispersal study, the proposed model has considerable potential to produce testable predictions about the genetic structure of the A. planci populations on the Great Barrier Reef.

Finally, the model addresses ecological problems that are wider than just the crown-of-thorns starfish. The problem of studying the system's connectedness is one of great significance. It carries implications not only for the pure research aspects of coral reef studies but also for policy development and management of the system as a whole by organisations such as GBRMPA.

Computing Justification:

The author has undertaken relatively small scale discrete simulations previously (Reichelt et al., 1985) but has been unable to tackle the larger scale question described in this proposal because of a lack of computing power. The work proposed here is the subject of a grant application to CSIRO for access to the Cyber 205 Supercomputer. Super-computers of the Cyber 205 class will allow the ecological processes to be simulated in usefully realistic ways. While the number of model parameters may not need to be very large, the model space must be large and the simulation will require very large numbers of interative operations on that matrix.

The manipulation of very large matrices, required by the proposed model, would seem to be an ideal application to fully exploit the vector-piping abilities of the Cyber 205. The Institute has a VAX 11/785 with Csironet node software installed and can therefore support the project with pre- and post-processing of data used in the model, while the simulation runs themselves would be done on the Cyber 205.

Collaborations:

This research will involve consultations between the Chief Investigator (Dr R. Reichelt, AIMS) and Dr R. Bradbury (AIMS), Dr D. Green (ANU) and Dr J. Parslow (Griffith University).

Budget:

It is anticipated that all computing costs can be met through the CSIRO Computing Grant Scheme and by the use of AIMS in-house VAX 11/785 computer. The contact required between Dr D. Green and Dr R. Reichelt would be achieved mostly by electronic mail and telephone, but augmented by meetings that could coincide with othe travel envisaged to attend workshops. Dr Reichelt will have access to the computing resources allocated to the Crown-of-Thorns Study as a whole. These resources include general items such as disk storage space.

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Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries:		
Research Scientist* (Dr R. Reichelt)	-	1534
2. Travel:	2000	-
TOTAL	**$2000**	**$1534**

* based on 10% of available time.

Project IV (f): Analyses and models of existing data

Introduction

Studies conducted by the Institute over the last 3 years, particularly the CEP Crown-of Thorns Study (which is almost completed), have produced several large data sets which have direct relevance to the Acanthaster phenomenon. Analyses and models of these data will be produced during the next few years. In some areas this has already begun and has produced a number of interesting results (Bradbury et al., 1985, in press; Moran et al., in press). These preliminary studies provide the basis for a variety of future analyses and models. In the present study 11 different types of mathematical procedures are to be carried out over the next two years. The chief investigator for each is listed in Table 1 along with the names of any collaborators.

Research plan

a) Qualitative models of the crown-of-thorns phenomenon:

This work will extend the model of Bradbury et al. (1985, in press) on qualitatively stable cycles. The aim of this study is to discriminate between the various hypotheses about the factors controlling outbreaks. This will be achieved by attempting to model the qualitative dynamics of the predator, Acanthaster planci. Previous modelling studies by Bradbury et al., (1985, in press) have demonstrated that consideration of the qualitative aspects of the dynamics of the "pair object" can provide useful information on the phenomenon.

b) Discriminate analysis of the Great Barrier Reef database:

This study aims to generate a discriminant function to separate coral phase reefs (i.e. those with high coral cover and low numbers of Acanthaster planci) from crown-of-thorns phase reefs (i.e. those with large numbers of Acanthaster planci and low coral cover) (Bradbury et al., 1985). It will draw on the information contained in the Great Barrier Reef database. The function will be generated using a range of variables, including geographical ones.

c) Analysis of the size frequency distributions of outbreaking populations of Acanthaster planci:

During the last 3 years approximately 3,500 measurements have been taken of the diameters of starfish. These have all come from reefs with outbreaking populations and in some instances have been recorded from the same reef over several time periods. In the proposed study a comparison will be made of the size frequency distributions of populations from different reefs. Also, for those reefs where temporal data is available changes in the size frequency distribution of the same population will be compared. Using this method, Moran et al., (in press) detected the influx of new recruits to an outbreaking population on John Brewer Reef.

d) Multivariate analysis of microscale changes in the community structure of John Brewer Reef:

Surveys of the hard coral communities on John Brewer Reef have been conducted since 1974 (see Project II (a)). As a result there is now a large amount of information available on the changes in community structure of hard corals on this reef. This information documents; the recovery of corals since the first recorded outbreak of Acanthaster planci during the early 1970's; the state of the community just prior to a second outbreak of starfish in 1983; the response of the community to this outbreak; the recovery of the community after the outbreak declined.

The proposed study uses life form and species level data collected intensively on John Brewer Reef over the last 12 years to examine the microscale structure and dynamics of reef communities as they respond to starfish outbreaks and recover from them. This study continues established work on this reef (Moran et al., in press).

e) Multivariate analysis of the recovery of reefs from outbreaks of Acanthaster planci:

This study will attempt to analyse the large amount of data (25,000 records) available on the recovery and recolonisation of reefs after outbreaks of Acanthaster planci. These data were collected over a 2 year period during an AIMS postdoctoral program from 7 reefs between Cairns and Townsville (for more information on these studies see Project II (a)). Multivariate analyses will be used to provide a quantitative description of the recovery processes on these 7 reefs and to determine whether the recovery of reefs follows the same general pattern. Information obtained from 1974-1978 by Mr R.G. Pearson also will be used in these analyses.

f) Continuous analogues of state transition models of the crown-of-thorns phenomenon:

This work derives from Antonelli's population genetics models which generate continuous analogues of state transition models. The analytical solutions to a preliminary two-state model (good or bad reefs) have been found and are being fitted to empirical data by hand. The analytical solutions to a more realistic 9-state model have been found and will require intensive computing to fit the empirical data.

g) Statistical summary of the GBR database:

This study will provide a basic statistical summary of the scale and level of the crown-of-thorns phenomenon across about 230 reefs throughout the GBR. It will also be coupled to the validated set of historical records of the crown-of-thorns phenomenon culled from the GBRMPA database.

h) Predictive analysis of GBR database:

This study will attempt to generate GMDH models to predict outbreaking reefs using a set of geographical and other similar variables.

i) Multivariate analysis of macroscale reef community structure:

This work uses the life form data collected on the 80 priority reefs throughout the length of the GBR to examine macroscale structure. It will provide the first synoptic macroscale description of all the major benthic communities of the GBR.

j) Multivariate analysis of mesoscale reef community structure:

This work uses the life form data collected on 11 reefs of the central Section of the GBR to examine mesoscale structure of the reef communities and their response to crown-of-thorns outbreaks. It will complement work on fish communities planned by the Institute.

k) A macroscale epidemiological model of the dynamics of starfish outbreaks:

A non-spatial model of outbreak spread among reefs will treat the reefs as a population, the outbreaks as an infection, and the distribution of outbreaks as an epidemiological problem.

Table 1. Chief investigators and collaborators for each study.

Study type	Chief investigator	Collaborators
(a)	R. Bradbury	–
(b)	R. Reichelt	R. Bradbury P. Moran
(c)	P. Moran	R. Bradbury R. Reichelt
(d)	P. Moran	R. Bradbury R. Reichelt
(e)	P. Moran	R. Bradbury R. Reichelt
(f)	P. Antonelli	R. Bradbury R. Reichelt L. Marsh
(g)	R. Reichelt	R. Bradbury P. Moran
(h)	D. Green	R. Reichelt R. Bradbury
(i)	R. Bradbury	R. Reichelt P. Moran
(j)	R. Reichelt	R. Bradbury P. Moran
(k)	R. Bradbury	R. Reichelt

Resources needed:

The mathematical procedures outlined above require heavy use of computing time. This cost will be borne by the Institute. As the chief investigators also are committed to other projects both within the Study and at the Institute it is proposed that a Research Scientist be appointed to oversee the development of these tasks as well as initiate new studies using the large data array currently available. This person would work in close collaboration with Dr R. Reichelt and would liase with researchers conducting other modelling studies on the Acanthaster planci phenomenon.

An Experimental Scientist, with database skills, also will be required to assist in this study as the analyses will involve the manipulation of large amounts of data. This person would be responsible for the storage and access of all data generated within the Crown-of-Thorns Study, particularly the data produced by the macro-scale surveys in Project III (a).

Apart from the request for personnel, funds are required to purchase one portable computer which can be used for checking field data and transferring it to the AIMS main frame (VAX 785). An allocation of funds is needed to buy the necessary software so that these tasks may be accomplished. It is planned that one IBM PC within the Institute be upgraded (in terms of memory capacity) so that large data files may be more efficiently manipulated and analysed. A small amount of funds are requested in order to carry this out.

Funds are also sought to support travel by one of the principal investigators, Dr Green. A minimum of two trips have been budgeted for in this fiscal year. It should be noted that these trips will enable collaboration between Dr Green and Dr Reichelt on other projects.

Literature cited

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Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries:		
Research Scientist*	2394	-
Principal Research Scientist** (Dr R. Bradbury)	-	2097
Research Scientist+ (Dr R. Reichelt)	-	740
Research Scientist+ (Dr P. Moran)	-	767
Experimental Scientist (same as Project III (a))	-	-
2. Capital equipment:		
Computer (Sharp PC 7000)	3500	-
Software (IBM PC compatible)	2000	-
Upgrade IBM PC (10Mb Hard disc)	2000	-
3. Travel:		
Return air fares (Canberra-Townsville)	2000	-
4. Consumables:		
Computer accessories (e.g. disks, spares)	2000	
5. Computing time++:		
5 hrs/week @ $266/CPU-hour	-	33250
TOTAL	**$13894**	**$36854**

* includes leave loading and district allowance and is based on 1 month's salary

** based on 10% of available time

\+ based on 5% of available time

++ based on figures given by Mr N. Harcock (AIMS Computer Manager)

Project IV (g): Tagging of Acanthaster planci using micro-injectable transponders

Background

In ecology a group of individuals of the same type or species is referred to as a population. One thing that can be said in all certainty about populations is that they will fluctuate in size (Pielou, 1977). The study of how populations increase and decrease with time (often termed population dynamics) has received considerable attention from biologists. In order to study such dynamics the population is regarded as a single entity which may be defined by a certain set of characteristics or parameters. These parameters, which are similar for most populations, include such terms as: density, birth and death rates, immigration and emigration rates, age distribution, growth, dispersion and movement, longevity, size of individuals and sex ratio. It is true to say that a study of these parameters often can lead to a greater understanding of the ecology of this species (Krebs, 1978).

In the case of *Acanthaster planci* there is little information available on its population dynamics. A major reason for this is that it is extremely difficult to recognise individuals in the field and follow them for long periods of time. O'Gower *et al.* (1973) stated that it has not been possible to undertake long term field studies on Acanthaster planci due to the difficulties involved in tagging or marking starfish. Consequently there is a lack of field data on such basic biological parameters as: growth, longevity, mortality and movement. Up to the present time a large number of techniques have been tried as possible ways of tagging *Acanthaster planci*. Most have been unsuccessful. Indeed, no method has been developed which would allow a large population of starfish to be followed efficiently over a long period of time. Recently, Moran (in press) has reviewed the tagging studies which have been carried out on this animal.

Introduction

During 1985 a pilot study has been in progress at the Institute which has attempted to determine the suitability of passive, integrated transponders for tagging *Acanthaster planci*. This study was funded by an MS&T Grant and was conducted by Dr P. Moran. The broad aim of the study was to determine whether minature transponders capable of being injected inside starfish could be used as a means of tagging individuals and following them in the field over a period of at least one year. Specifically, this involved attempting to determine:

a) The best site for implanting the transponder.
b) The best method of implant.
c) The likely causes of rejection, should this occur.

All these tests were conducted in the laboratory using individually caged starfish. Over the year approximately 125 tagging tests have been conducted. Initially, sham transponders (i.e. transponders with the same specifications as production model tags but lacking the microelectronics) were used in the tests (at the recommendation of the manufacturer) but they were found to corrode and hence proved unsatisfactory in the tests. Approximately 90 different trials were undertaken using the production model transponders. The results of these tests are encouraging although there are still several problems to be overcome. To date, transponders have been recorded in animals for up to 6 months. As these individuals are not feed while in captivity (this is not possible given the large number of starfish being held) often this is the maximum length of time that they remain alive.

While some tags remain in animals for long periods of time others do not. This is likely to occur for the following reasons:

a) The transponder was poorly implanted or implanted in the wrong place (e.g. it has been found that those implanted near the tip of the arm almost invariably are shed within one week).
b) The transponder is moved within the coelomic cavity of the starfish (by the coelomic currents) to more confined areas (e.g. tips of the arms) where they puncture the skin and are shed when the animal constricts its arm (transponders have been observed to be shed in this manner).

Since animals that lived longest were found to keep the transponders longest it is possible also that starfish condition is an important determinant of the implant life of the tags.

Apart from the problem of variability in the implant life of tags a further problem has emerged relating to the interrogation distance of this method (i.e. the distance over which the transponder's signal can be picked up). Tests in the laboratory have shown that the antenna of the Data Scan Unit (i.e. the piece of equipment which transmits the radio signal to, and receives a signal from, each transponder) needs to be within 9 cm of a transponder in order to get its number (i.e. the signal from the antenna sends out a low frequency (4 mHz) radio wave to the transponder which stores the energy from this pulse, alters its frequency and sends it back. This altered pulse (each transponder alters the radio wave differently) is picked up by the antenna and it is recorded by the Data Scan Unit as a 10 digit code). This distance may decrease depending on the position of the transponder. Salt water does not appear to cause a further reduction in interrogation distance.

Research plan

Given the fact that the spines of some starfish may be up to 6-8 cm the present interrogation distance being achieved is unsatisfactory. Also, further studies are required to determine the likely causes of rejection and whether this is an artifact of laboratory conditions. Therefore a study is proposed which will attempt to:

a) Improve the interrogation distance of the technique (i.e. by altering the electronics of the available equipment)
b) Determine whether the condition of animals is an important cause of tag rejection.
c) Determine the suitability of the technique using animals in the field.

Discussions with Dr D. Cooper, an antenna engineer with the CSIRO Division of Radiophysics, have revealed that it may be possible to improve the "coupling" between the Data Scan Unit and the transponder by changing the design of the antenna. The CSIRO are willing to undertake this alteration and will only charge for the cost of materials (mainly ferrite material). It also may be possible to increase the interrogation distance by increasing the power output from the Data Scan Unit. This may also be attempted depending on the results of alterations to the antenna.

Further tests will be conducted in the laboratory to compare the effects of starfish condition on the implant life of the transponders. Replicates (20) of animals in poor condition (i.e. individuals kept in captivity without food for over 3 months) will be injected with transponders and the results of these tests will be compared with those of starfish in good condition (i.e. newly acquired from the reef and showing no signs of ill-health).

If the interrogation distance of the technique can be improved a series of tests will be performed using a small isolated population of starfish (approximately 50 individuals) on John Brewer Reef. These tests will be used to assess whether the method is suitable for following large numbers of starfish in the field. They also will provide information on the likely logistic problems which may occur if such a study were to be undertaken. If this technique is to be used underwater then the Data Scan

Unit and antenna will have to be waterproofed and self-powered. Examination of the equipment by the AIMS Electronics Section has indicated that this can be done.

Resources needed:

Some funds are requested to purchase a second Data Scan Unit as a backup for the Unit which is being altered. Also, funds are needed for purchasing materials used in altering the antenna, and waterproofing and self-powering the Data Scan Unit.

As Study Leader Dr Moran is committed to, or collaborating in, several other projects. Consequently, he is unable to undertake this research on a full-time basis. A technical assistant is required to undertake the general duties associated with the proposed study. This person would also assist in several other projects (e.g. Project III (a)).

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Budget 1985/86

Item	Cost COTSAC	Cost AIMS
1. Salaries:		
Research Scientist* (Dr P. Moran)	-	1534
Technical Assistant+	7550	-
2. Capital equipment:		
Data Scan Unit (Identification Devices Inc.)	2000	-
3. Consumables:		
Micro-injectable transponders (100 @$15 each)	1500	-
Workshop material (e.g. new antenna)	1000	-
TOTAL	**$12050**	**$1534**

* based on 20% of available time

\+ includes leave loading and district allowance and is based on 5 months salary.

3.5 PROJECT DURATION

The duration of each project within the Crown-of-Thorns Study is given in Table 2. While most of the projects will be conducted over a 2-3 year period (subject to satisfactory progress and results) others are likely to be completed within this fiscal year (e.g. Project IV (a)). Of course, there is the likelihood of new research being initiated in subsequent years which stems from that conducted in the present projects (e.g. field studies of the population dynamics of starfish; should Project IV (d) be successful). However, the development of new studies will be subject to the recommendations of the Evaluation Panel.

Table 2. Duration of projects in the Crown-of-Thorns Study

Project No.	Timing (Calendar Years)	Duration
I (a)	1986/87	2 years (possible 3)
(b)	1986	1 year
(c)	1986	1 year (possible 2)
(d)	1987	1 year (possible 2)
(e)	1986/87	2 years (possible 3)
(f)	1986/87/88	3 years
(g)	1986/87	2 years (possible 3)
(h)	1986/87	2 years (possible 3)
(i)	1986	1 year (possible 2)
(j)	1986/87/88	3 years
II (a)	1986/87/88	3 years
(b)	1986/87	2 years (possible 3)
(c)	1986/87	2 years (possible 3)
(d)	1986/87	2 years (possible 3)
(e)	1986/87	2 years (possible 3)
(f)	1986/87	2 years (possible 3)
(g)	1986/87	2 years (possible 3)

Table 2 cont'd.

Project No.	Timing (Calendar Years)	Duration
III (a)	1986/87/88	3 years
(b)	1986/87	2 years (possible 3)
IV (a)	1986	1 year
(b)	1986/87	2 years
(c)	1986/87	2 years (possible 3)
(d)	1986/87	2 years (possible 3)
(e)	1986/87	2 years (possible 3)
(f)	1986/87	2 years (possible 3)
(g)	1986/87	2 years

3.6 NEW PERSONNEL

It is envisaged that a total of 15 staff will be appointed during the 1985/86 fiscal year within the Crown-of-Thorns Study. Justifications for hiring these people are given where necessary in each individual project proposal under the heading "Resources needed". Most of these staff will be involved in either conducting research (in the case of Research Scientists) or assisting with research (in the case of Experimental Scientists or the Technical Assistant). Two postgraduate students will be conducting research, under supervision, towards the completion of a Ph.D degree.

Given the size of this Study and the organisational and personnel problems which will undoubtedly arise in the future it is proposed that a person be appointed to act as an administrator within the Study. This person would be responsible (under the direction of the Study Leader) for organisation in the following areas: personnel, budgets, purchasing, recording keeping, general adminstration, ship charter and collaborations. It is necessary that an administrator be employed as this task cannot be undertaken by present staff at the Institute and it would allow the Study Leader to concentrate fully on directing research in the Study.

All staff will be appointed to the Study for a minimum of 2 years (assuming that additional funds become available) with a possible extention to a further year. This will depend on the progress of research and the results achieved. A schedule for the employment of staff in the Study is given in Table 3.

Table 3. The schedule for personnel hired to undertake projects within the Crown-of-Thorns Study

Position	Project No.	Commencement	Finish
Scholarship	I (g)(h)	Mar 86	Mar 89
Scholarship	I (l)	Mar 86	Mar 89
Dr R. Olson	I (c)(d)(e)	Jan 86	Jan 89
Research Scientist	IV (e)	Jun 86	Jun 88
Research Scientist	II (f)	Jun 86	Jun 89
Research Scientist	II (g)	Jun 86	Jun 88
Research Scientist	I (a)	Jan 86	Jan 88
Experimental Scientist	I (c)(d)(e)(f)	Jan 86	Jan 89
Experimental Scientist	IV (c)	Mar 86	Mar 88
Experimental Scientist	III (a), IV (a)(e)	Mar 86	Mar 89
Experimental Scientist	I (g)(h), II (a)(b)(e)(f)(g), III (a)(b), IV (d)	Mar 86	Mar 89
Experimental Scientist	I (g)(h), II (a)(b)(e)(f)(g), III (a)(b), IV (d)	Mar 86	Mar 89
Experimental Scientist	I (g)(h), II (a)(b)(e)(f)(g), III (a)(b), IV (d)	Mar 86	Mar 89
Technical Assistant	III (a)(b), IV (d)	Feb 86	Feb 88
Clerk (Class 4)	Administration	Jan 86	Jan 89

4. BUDGET

4.1 JUSTIFICATION OF BUDGETARY ITEMS

The justification of budgetary items such as appointment of personnel, capital equipment, vessel charter and travel have been given where appropriate in the individual project proposals and descriptions. Only one aspect of expenditure relating to capital equipment has not been mentioned already. Because tremendous amounts of information are likely to be generated by a research program of this size it is necessary that a new data storage unit (i.e. hard disk) be purchased for the main computer at the Institute. At present space problems are being experienced from time to time by users on this newly installed system. The increased usage expected with the development of this research program is likely to result in these problems becoming more acute in the future. This may well retard the progress and performance of certain projects (e.g. modelling studies). Purchase of this storage unit in this fiscal year will cater for the data storage requirements of all projects (including those of collaborators) over the next 3-4 years.

Apart from the travel mentioned specifically in the separate project descriptions further funds are required to enable the Study Leader to attend the Western Society of Naturalists meeting to be held at Guam during June 1986. A special session on research relating to Acanthaster planci is being organised and the Study Leader has been invited to talk about the forthcoming research program being coordinated by the Institute. The remaining amount of funds (approximately $10,865) not accounted for in the proposal so far is to enable chief investigators (AIMS) to travel to consult with their collaborators and vice versa.

Six of the 12 items listed in the budget for 1985/86 have not been taken into account within the separate proposals described in section 3.4. These relate to:

Allowances:

In accordance with Institute policy a diving and travel allowance will be paid to each member of a field trip where appropriate. The figure given in the budget for 1985/86 is based on the total number of charter days (field trips) for this period.

Superannuation:

An estimate for superannuation has been included in the budget on the grounds that some staff hired within the Study may already contribute to this scheme and want to continue subscribing. The figure given for this fiscal year is based on the assumption that 50% of staff will avail themselves of this benefit.

On-costs:

This Study will place an enormous strain on the administration and services of the Institute. In order to alleviate some of this strain it is proposed that the Study contribute to the costs associated with operating these facilities and services. This will ensure that the running of other established core research programs within the Institute are not adversely affected by this Study. Payment of such costs to the Institute will enable all personnel and collaborators within this program of research to use the facilities and services afforded by the Institute. The figure given for on-costs in the budget for 1985/86 was derived from the Explanation of Estimates 1985-86. The figure obtained represents approximately 15% of the amount paid in salaries over one year for the entire Study.

Capital works:

A major part of the research in this Study is directed towards investigations of the larvae of Acanthaster planci as well as the field ecology of adults (and possibly juveniles). If these studies are to go ahead facilities will be needed so that up to 200 adults can be kept on site (see Project IV (d)) and large numbers of larvae and juveniles can be successfully reared (see Project I (c)(d)(e)(f)). At present the Institute has a half-completed outdoor aquarium system (at a cost to AIMS of $37,000) which has provision for recirculation and flow-through water. Given the requirements of this Study, it is proposed to use funds to complete the building of this system (i.e. complete the roof and add in more large holding ponds) so that present and future aquarium needs will be met. This facility will be available to members of the Study from other institutions.

Vehicles:

Three vehicles will need to be purchased to transport new personnel between Townsville and the Institute each day. They will be acquired under a leasing arrangement (over 18 months) which has proved successful over the past year with the CEP Crown-of-thorns Study.

Incidentals:

This item includes the costs associated with the establishment of new staff (i.e. removal expenses), advertisements, on-costs to other institutions (CSIRO, VIMS), diving medicals and chest X-rays (in accordance with Institute diving regulations) and scientific workshops (to be paid to GBRMPA).

4.2 AIMS COMMITMENT TO STUDY

In notional terms, the Institute is committing to this Study an extra 79% of funds to those requested from COTSAC in this document. This support is in the five areas of personnel (i.e. salaries), shiptime, computing time, capital works and capital equipment. It is worth mentioning that many of the projects in this proposal could not go ahead without this support. A breakdown of the notional commitment given by AIMS to research in the Crown-of-Thorns Study for the 1985/86 fiscal year is given in Table 4. Similar levels of support are expected to be given in subsequent years.

Table 4. Notional commitment of AIMS to Study: 1985/86

	Item	Cost
1.	Salaries:	57096
2.	Vessel charter:	168000
3.	Computing time:	35650
4.	Capital works:	37000
5.	Capital Equipment:	17000
	TOTAL	**$314746**

4.3 FUNDS ALREADY COMMITTED

Some of the funds which have been requested in this proposal have already been used. The decision to commit these funds was made at the discretion of the Study Leader and in consultation with the Director of AIMS. A breakdown of the areas in the budget where these funds have been committed is given in Table 5. Most of them have been used to extend the employment of several staff in the current CEP Crown-of-Thorns Study in order to ensure that its objectives and the reports emanating from it are completed on time. A more detailed breakdown of these salaries is given in the Tables of Expenditure: COTSAC Funds (see Other Salaries 1985/86). Funds were allocated to this Study because it will provide a data base which will be of enormous significance to the forthcoming COTSAC Research Program.

The remaining amount of funds has been committed in areas directly related to the present Program. Apart from using a small amount for chartering a vessel (to obtain gametes for larval research) they have been spent by the Study Leader on advertising the forthcoming Program (in conjunction with the Great Barrier Reef Marine Park Authority) and on travel to various cities to discuss future research and collaborations. A large number of the research proposals submitted to the Evaluation Panel have developed as a result of these discussions.

Table 5. Areas in the budget where COTSAC funds have been already committed

	Item	Cost
1.	Salaries:	
	CEP Crown-of-Thorns Study	17975
2.	Travel and Allowances:	
	Discussions of collaborative research	2500
3.	Vessel Charter:	
	1 day-trip (for larval research)	500
4.	Advertisements:	1000
	TOTAL	**$21975**

4.4 TABLES OF EXPENDITURE: COTSAC FUNDS

Budget 1985/86

	Item	Cost $
1.	Salaries	116,647
2.	Allowances	2,424
3.	Superannuation	8,600
4.	Other salaries (carried from CEP)	17,975
5.	On-costs	15,309
6.	Capital works	20,000
7.	Vessel charter	26,000
8.	Capital equipment	89,506
9.	Vehicles	11,400
10.	Consumables	24,850
11.	Travel	19,865
12.	Incidentals	42,500
	TOTAL	**395,076**

Salaries 1985/86

Position	Gross salary * $	No. Months Paid	Total $
Scholarship	10,000	4	3,334
Scholarship	10,000	4	3,334
Dr R. Olson	28,732	6	14,366
RS	28,732	1	2,394
RS	28,732	1	2,394
RS	28,732	1	2,394
RF	25,823	6	12,911
ES	29,786	6	14,893
ES	22,633	4	7,544
ES	22,633	4	7,544
ES	22,633	4	7,544
ES	22,633	4	7,544
ES	22,633	4	7,544
TA	18,120	5	7,550
TA (part-time)	2,000	-	2,000
Clerk (Cl 4)	21,979	6	10,990
TOTAL	-	-	**$116,674**

RS: Research Scientist
ES: Experimental Scientist
RF: Research Fellow
TA: Technical Assistant

* with leave loading and district allowance

Allowances 1985/86

Type	No. Persons	No. Days	Rate	Cost $
Diving	6	20	$13.50/day	1,620
Camping/Travel	6	20	$6.70/day	804
TOTAL	-	-	-	**2,424**

Superannuation 1985/86

Salaries 85/86+ $	Estimated % Staff in Fund	Salary $	Superannuation cost * $
114,674	50	57,337	**8,600**

+ Full-time

* 15% of salary

Other Salaries 1985/86

Designation	Duration	Cost/Wk $	Salary $	Loading $	Total Cost $
Technical Assistant	33 wks	299	9,867	907	10,774
Technical Assistant	12 wks	299	3,588	340	3,928
Technical Assistant	10 wks	299	2,990	283	3,273
TOTAL	-	-	-	-	**17,975**

On-Costs 1985/86

Annual Cost $	No. Months Payment	Cost $
45,929	4	**15,309**

Capital Works 1985/86

Completion of outdoor aquarium facility

Item	Cost* $
Steelwork	20,000
TOTAL	**20,000**

* Quote given by AIMS Engineer, Mr M. Beecher, 18.11.85

Vessel Charter 1985/86

Vessel Type	No. Days	Cost/Day $	Total Cost $
Sharkcat (day-trips)	12	500	6,000
MV Hero (field trips)	20	700	14,000
Fuel	20	150	3,000
Victuals	20	150	3,000
TOTAL			**26,000**

Vehicles 1985/86

No. Cars	Leasing Cost* $	Operations $	Total Cost $
3	9,000	2,400	**11,400**

* over 18 months.

Capital Equipment 1985/86

Item	Project No.	Cost $
Computing :		
1. Lap computers (x 4) (Sharp PC 7000)	I (h), III (a),IV (d)(f)	14,000
2. IBM PC Software (Crosstalk, dBase III, Lotus 1,2,3)	IV (f)	2,000
3. Upgrading IBM PC's (Toshiba Printer, Monitor B/W, 10 Mb Hard disc)	I (j), IV (f)	5,000
4. Mass storage unit (Dec RM81)	All	35,000
		56,000
Photogrammetry :		
1. Sonic digitiser (SAC 24" x 24")	II (a)	5,000
2. Graphics Workstation (Olivetti microcomputer and graphics software)	II (a)	6,000
		11,000
Photography :		
1. Nikonos v̄ camera	II (a)	659
2. Nikonos 103 speedlight	II (a)	556
3. Nikonos 28 mm lens	II (a)	347
4. Nikonos 35 mm lens	II (a)	144
		1,706
Phytoplankton :		
1. 150 m underwater cable	I (j)	1,500
2. Data stream digitiser & interface	I (j)	2,000
		3,500
Genetics :		
1. Balance (Sartorius MP8)	I (a)	1,200

Item	Project No.	Cost $
Larval identification :		
1. Stereomicroscope (Wild M7)	I (c)	4,000
2. Light source (Schott KL1500)	I (c)	700
		4,700
Starfish tagging :		
1. Data scan unit (Identification Devices Inc.)	IV (d)	2,000
Trophodynamics :		
1. Oxygen sensors	II (f)	660
2. Filter blocks	II (f)	700
		1,360
Surveys :		
1. Zodiac	III (a), IV (b)	4,500
2. Outboards (x 2) (Evinrude 15 HP)	III (a), IV (b)	1,740
3. Two-way radio (Micom 60)	III (a), IV (b)	1,800
		8,040
TOTAL		**89,506**

Consumables 1985/86

Item	Cost $
Chemicals (e.g. isoenzyme assays, formaldehyde)	6,500
Glassware (e.g. beakers, flasks)	1,750
Field equipment (e.g. underwater tapes, wet suits, servicing, spares)	12,000
Film (e.g. Kodachrome 64 ASA)	600
Tagging accessories (e.g. transponders)	1,500
Marine charts (VIMS)	500
Computer accessories (e.g. disks, spares)	2,000
TOTAL	**24,850**

Travel 1985/86

Item	Cost $
Overseas travel:	
Study Leader to attend WSN Conf. Guam	3,000
Interstate travel:	
VIMS	4,000
ANU	2,000
Other collaborators	3,000
Chief investigators (AIMS)	7,865
TOTAL	**19,865**

Incidentals 1985/86

Item	Cost $
On-costs (CSIRO)	6,000
On-costs (VIMS)	500
Medicals/X-rays	1,000
Establishment costs	15,000
Advertising	3,000
Accommodation (for collaborators)	1,000
Workshop (GBRMPA)	15,000
Computing time (VIMS)	1,000
TOTAL	**42,500**

Projected Budget

	Item	1985/86 $	Year 1986/87 $	1987/88 $
1.	Salaries	116,674	346,378	346,378
2.	Allowances	2,424	12,120	12,120
3.	Superannuation	8,600	24,631	24,631
4.	Other salaries (carried from CEP)	17,975	-	-
5.	On-costs	15,309	45,929	45,929
6.	Capital works	20,000	20,000	-
7.	Vessel charter	26,000	85,000	85,000
8.	Capital Equipment	89,506	10,000	10,000
9.	Vehicles	11,400	7,200	16,200
10.	Consumables	24,850	35,000	35,000
11.	Travel	19,865	10,000	10,000
12.	Incidentals	42,500	21,000	15,000
	TOTAL	**395,076**	**617,258**	**600,258**

Salaries : Annual Costs

Position	Salary $	Leave Loading $	District Allowance $	Recreation Leave $	Total Cost $
Scholarship	10,000	-	-	-	10,000
Scholarship	10,000	-	-	-	10,000
RS (Level 1)	27,475	497	760	2,381	31,113
RS (Level 1)	27,474	497	760	2,381	31,113
RS (Level 1)	27,475	497	760	2,381	31,113
RS (Level 1)	27,475	497	760	2,381	31,113
RF	24,696	367	760	2,147	27,970
ES (Grade 2)	28,511	515	760	2,469	32,255
ES (Grade 1)	21,482	391	760	1,876	24,509
ES (Grade 1)	21,482	391	760	1,876	24,509
ES (Grade 1)	21,482	391	760	1,876	24,509
ES (Grade 1)	21,482	391	760	1,876	24,509
ES (Grade 1)	21,482	391	760	1,876	24,509
Clerk (Class 4)	20,794	318	760	1,817	23,689
TA (Grade 1)	17,096	264	760	1,506	19,626
TOTAL	**328,407**	**5,407**	**9,880**	**26,843**	**370,537**

Salaries with Pro-rata Payments: Annual Costs

Item	Cost
Salaries	328,407
District allowance	9,880
Leave loading	5,407
Recreation leave (10% of total)	2,684
TOTAL	**346,378**

Allowances: Annual Costs

Item	No. People	No. Days	Rate/Day $	Cost $
Diving	10	60	13.50	8,100
Travel/Camping	10	60	6.70	4,020
TOTAL	-	-	-	**12,120**

Superannuation: Annual Costs

Salary	Estimated % Staff in Fund	Salary $	Superannuation cost* $
328,407	50	164,204	24,631

* 15% of salary

Vehicles: Costs 1986-1988

Year	Leasing Cost* $	Operations $	Total $
1985/86	9,000	2,400	11,400
1986/87	-	7,200	7,200
1987/88	9,000	7,200	16,200

* over 18 months

Vessel Charter: Annual Costs

Vessel Type	No. Days	Cost/Day $	Total Cost $
Shark Cat (day-trips)	20	500	10,000
MV Hero (field trips)	60	700	42,000
Fuel	60	150	9,000
Victuals	60	150	9,000
Part-time salary (for R.V. Sirius)	-	-	15,000
TOTAL			**$85,000**

Capital Works: Annual Costs

Completion of outdoor aquarium facility

Item	Year	Cost* $
Steelwork	1985/86	20,000
Glass roof	1986/87	18,000
Wiring, piping	1986/87	2,000
TOTAL		**40,000**

* Quote given by AIMS Engineer, Mr M. Beecher, 18.11.85

On-Costs: Annual

	Item	Institute Cost * 85/86 $	On-cost ** $
1.	Office requisites	60,000	4,200
2.	Office services	292,000	20,444
3.	Annual repairs and maintenance	56,000	3,919
4.	Computer services	130,000	9,103
5.	Library	18,000	1,260
6.	Postage and telephones	100,000	7,003
TOTAL			**45,929 ****

* taken from Institute estimates 1985/86

** 15% of annual salary cost

On-Costs Dissection

	Item	Breakdown
1.	Office requisites :	Office requisites and stationery Printing of forms etc. Office machines: purchase, parts, maintenance Photocopy machines
2.	Office services :	Electricity charges Water rates
3.	Annual repairs and maintenance :	Recurring maintenance DHC Residence and single quarters Air compressor Cold and constant temperature rooms Seawater pump and intake
4.	Computer services :	Hire charges: 'inhouse', CSIRONET Maintenance Consumables : stationery, software
5.	Library :	Inter-library loans, reprints, maps, aerial photographs
6.	Postage and telephones :	Postage Telephones Telex Telegrams, OTC cables, PO box fees

5. RELEVANT PUBLICATIONS

Only the title page and abstract of papers are given. Complete copies of each paper have been lodged with the Chairman of the Evaluation Panel.