Progress Report on Research 1986/87

Edited by P. Moran, Study Leader & C. Hughes, Administrator

Australian Institute of Marine Science

The Crown-of-thorns Study

Crown-of-thorns Study Report 7

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INTRODUCTION

This document has been prepared in order to fulfill the following functions:

1. To review the progress of all projects within the Study (termed The Crown-of-Thorns Study) that is being coordinated by the Australian Institute of Marine Science (AIMS).
2. To preview those projects which seek financial support for the forthcoming fiscal year; 1987/88.
3. To describe the AIMS component of the Study with a view to highlighting its structure and organisation as well as the additional financial support it receives from the Institute.
4. To consider future developments in the Study both in terms of research and funding.

The reports given in this document have been written by the Chief Investigator(s) of each project and have been edited by the Study Leader, Dr P. Moran, so that a consistent structure and style has been maintained. The projects have been reported in the same order as that used in previous documents. The only changes which have been made to this format have come about as a result of the completion of certain projects. Two new proposals to undertake research on the crown-of-thorns starfish have been received for the 1987/88 fiscal period. They are described in detail in the last section of this document.

SUMMARY OF ACHIEVEMENTS

It is about one and a half years since funds were first given to undertake research in this Study. At that time there were only a few projects being conducted on the crown-of-thorns starfish and these were being carried out mainly at AIMS and James Cook University. In general, the majority of projects in this Study have been underway for just over 1 year as it took almost 6 months to organise the Study; which included the selection and funding of projects. The progress of these projects was reviewed by an Assessment Panel (formulated by AIMS) in October 1986. At that time it was recommended that all projects be funded during 1986/87 as it was difficult to determine their progress, given that they had only been underway for a relatively short period of time. This is not so much a problem now, given that sufficient time has elapsed to be able to obtain a more informed account of how well research has proceeded in this Study.

Overall, progress in the Study has been good given that funds for research during the present year (1986/87) were cut by approximately 23%. This lead to the cancellation of two projects in the AIMS programme which were scheduled to commence in early August 1986. As an aid to understanding the present status of research in this Study the progress of all projects has been summarised in Table 1. Several conclusions can be drawn from this Table relating to the achievements of the projects to the present time. They are:

1. Most projects are at the stage where significant results are now starting to be produced which have a direct relevance to the main research questions that were originally proposed. It should be pointed out that some projects have not reached this advanced stage either because they have encountered difficulties (see below) or

because they have involved extensive preliminary work (e.g. developing suitable sampling techniques) which was necessary if the research objectives of the projects were to be achieved.

2. One very pleasing aspect of the Study is the number of scientific papers which have already been produced as a result of this research. A total of 12 papers have originated from projects connected with the Study. It is worth noting that a further 6 papers and 4 technical reports (published by AIMS) are in various stages of preparation.

3. Whilst progress has been satisfactory throughout the Study most projects have experienced problems of some form (see Table 1). These have come about as a result of technical (e.g. equipment failures, computing problems) or logistic (e.g. inclement weather, sampling problems) difficulties. Whilst problems have been encountered in all areas of research they have not been serious enough to cause major delays to any of the projects.

Given the progress which has been achieved to date the following fiscal year promises to be a challenging and exciting one. During this time it is expected that a synthesis of the many different, but often related, project results will take place. This process will allow scientists to obtain a better understanding of the *Acanthaster* phenomenon by defining the relative importance of the complex interactions that comprise the ecology of this starfish. It is important to bear in mind that this Study provides scientists with the opportunity to understand processes which are important not just in relation to the crown-of-thorns starfish but also to the whole of marine science. It is essential therefore, that funds be given in the following years so that the major objectives of this study can be achieved.

Table 1. Summary of the progress of projects.

Project No.	Project status	Problems	Results	Papers*
1(A)	Laboratory analyses underway	Field	In Progress	No
(B)	Pilot studies unsuccessful	Laboratory	Preliminary	No
(C)	Main objectives achieved	Equipment	Yes	Yes[2]
(D)	Experiments being planned	-	No	No
(E)	Preliminary experiments complete	Laboratory	Preliminary	Yes[1]
(F)	Larval cultures successful	Laboratory	Yes	No
(G)	Short term tags developed	Field	Yes	No
(H)	Fieldwork almost complete	Field	Yes	No
(I)	Preliminary study complete	Field	Preliminary	No
(J)	Fieldwork underway	Equipment	Yes	No
2(A)	Field data being analysed	Field/Lab.	Yes	No
(B)	Field data being analysed	Computing	Yes	Yes[1]
(C)	Field samples being analysed	Field	Yes	No
(D)	Field data analysed	Computing	Yes	No
(E)	Field data analysed	Field	Yes	Yes[1]
3(A)	Fieldwork continuing	Field	Yes	No
(B)	Fieldwork continuing	Field	Yes	Yes[1]
4(A)	Analyses nearing completion	-	Yes	No
(B)	Fieldwork completed	Field	Yes	No
(C)	Dispersion analyses underway	Computing	Yes	Yes[2]
(D)	Field data being collected	Computing	Preliminary	No
(E)	Non-spatial model complete	Computing	Yes	No
(F)	Catastrophe models underway	Computing	Yes	Yes[3]
(G)	System redesigned and constructed	Equipment	Preliminary	No
6(A)	Analyses of field data underway	Laboratory	Yes	Yes[1]
(B)	Field samples being examined	Field	Preliminary	No
(C)	Hydrodynamics complete	Computing	Preliminary	No
(D)	Fieldwork continuing	Field	Yes	No
(E)	Fieldwork continuing	Field	Yes	No
(F)	Model developed	-	Yes	No
(G)	Antibodies being developed	Field/Lab.	Preliminary	No
(H)	Fieldwork continuing	Field	Yes	No

* Value refers to the number of scientific papers produced.

THE FUTURE

As sufficient time has now elapsed to enable a more informed view of the directions of research in the present Study it is necessary that thought be given to what is to happen in the future. If funding is to continue along the lines recommended by the Crown-of-Thorns Starfish Advisory Review Committee (COTSAC) then consideration must be given to:

1. Determining how the Study will end. Specifically, this would include deciding which of the projects presently being funded will continue until the end of the Study and which will be phased out (and when) before that time. Such a schedule is needed to allow the proper completion of projects and give research staff adequate warning of termination of employment.
2. Determining whether it is necessary that certain types of research continue even after the Study has been completed (e.g. surveys of crown-of-thorns and corals). If research is to continue into the future then plans should start to be made which seek to determine how this will be organised and funded.

In the light of these goals it is envisaged that a workshop, involving scientists in the Study (and other experts), will be held within the next year which will seek to determine where the current research on *Acanthaster* is heading and what needs to be done in the future. The specific aims of such a workshop would be to:

1. Identify more clearly the relationship between results from different projects.
2. Highlight conflicting results from different projects.
3. Indicate areas of important research.

4. Indicate areas of research which need to be undertaken.

5. Indicate areas of research which are unproductive.

A consideration of these points is important at this stage since it will allow adequate time for plans to be made which will define the path that research will take in the future. It is essential that this opportunity not slip by (as it has done in previous times), particularly should another series of outbreaks of the crown-of-thorns starfish occur in the future.

RESEARCH PROPOSALS: 1987/88

A total of 9 research proposals have been received which seek funds to conduct ecological research on the crown-of-thorns starfish during the 1987/88 fiscal period. A list of these proposals and the amount of funds requested by each are given in Table 2. Two of these proposals are new whilst the remaining 7 proposals comprise research which has been funded as part of this Study for at least 1 year. The proposal put forward by AIMS comprises 24 individual projects. The amount of funds which have been requested for 1987/88 are about $172,000 in excess of the projected estimates (i.e. $605,000) which were supplied to the Department of Finance in October last year. These estimates were similar to those which were proposed in the schedule of funding determined for ecological projects in the Record of Understanding established between AIMS and the Great Barrier Reef Marine Park Authority (GBRMPA).

Table 2. List of ecological projects for which COTSAC funds have been requested for the 1987/88 fiscal period.

Chief Investigator	Project No.	Institution/Organisation	Cost ($)
Lucas	6(A)	James Cook University	25,764
James et al.	6(C)+	James Cook University	5,183
James et al.	*	James Cook University	28,905
Endean and Cameron	6(D)	University of Queensland	61,863
Doherty	6(E)	Griffith University	46,403
Hanna et al.	6(G)	Deakin University	29,959
Fisk	6(H)	Reef Research and Information Services	25,450
Wolanski	*	Australian Institute of Marine Science	45,000
Programme	-	Australian Institute of Marine Science	499,660
	TOTAL		768,187

+ to end in February 1988
* denotes new project

AIMS RESEARCH PROGRAMME

Budget

As stated above the AIMS component of the Study comprises 24 separate projects covering a wide range of topics and disciplines (from population genetics to Landsat imagery). In the past this research has utilised approximately 75% of the total funds allocated for ecological projects by the GBRMPA, with the remaining funds going to external projects. A breakdown, by project, of the AIMS programme budget for the 1987/88 fiscal period is given in Table 3. The total amount of funds requested represents about 82% of the projected estimate of expenditure for this period. This figure has increased because unlike other years it is unlikely (given the funding restrictions of this year) that many funds will be carried forward from the previous fiscal year as a result of savings in the AIMS programme (approximately $134,000 was carried forward into the 1986/87 fiscal period).

A breakdown of the AIMS 1987/88 budget, by expenditure heading, (Table 4) shows that a high proportion of the funds being requested for the AIMS programme (about 62%) goes towards paying the costs of salaries of personnel. A total of 10 full-time and 2 part-time staff are currently being employed to undertake or assist with research in the programme. Funds are also being used to support the research activities of 2 Ph.D. students (see Projects 1(G) and 1(J)) as well as provide them with a stipend and co-supervision.

Notional support

The information given in Tables 3 and 4 highlights the large amount of support that AIMS is giving to this programme of research. Much of this is in the form of shiptime or use of facilities such as computing. About 15 members of the research staff at AIMS (including research scientists and support staff) are directly involved in undertaking research in the Crown-of-Thorns Study. It will be noticed that the financial support given by AIMS is likely to exceed the amount of funds that have been requested for this research programme during 1987/88.

Administration

As in all programmes of this size a tremendous amount of organisational support is required to ensure that all projects run as smoothly as possible. In order to achieve this, funds (approximately 25% of the total budget) are required to support the administration of this programme. A breakdown of the funds which have been requested for this particular part of the programme for 1987/88 is given in Table 5. The major items of expenditure in this area are:

1. Payment of salary to the programme administrator.
2. Payment of superannuation for all employees.
3. Payment of on-costs to AIMS (15% of salaries) to cover expenses associated with using such facilities as electricity, phones, water, (and saltwater) maintenance of laboratory facilities (e.g. constant temperature rooms) mail and stationary.
4. Payment of costs associated with transporting staff to and from AIMS during each day.
5. Payment of freight and transportation costs associated with the shipment of starfish specimens and field equipment for several projects.
6. Payment of travel costs incurred by the Study Leader in visiting the Chief Investigators of external projects to discuss progress of research.

7. Payment of incidental items, such as diving medicals, purchasing of dive gear, advertising, relocation expenses and on-site accommodation for visiting collaborators.

Funding problems

One major problem which has been encountered in the administration of the AIMS research programme concerns the fact that no provision has been made to cover expenditure during the supply period. Due to the size of the AIMS budget and the time at which funds were originally given it has not been possible to adjust the programme budget to calendar year funding (like the external projects) rather than fiscal year funding. Because of this there is a gap of approximately 5 months (from July to early December) during which time no funds are available to support the research being conducted in this programme. In the past AIMS has had to meet all costs incurred by research in this period. This can be quite considerable since at the end of last year the programme had incurred debts of approximately $70,000. In order to overcome this problem in the future it is requested that funds be given to cover research expenditure in this programme during the supply period.

Should the Federal Government decide not to fund research on the crown-of-thorns starfish in the 1987/88 fiscal year then arrangements need to be made to ensure that sufficient funds are given to enable scientists to complete research tasks presently underway. It is envisaged that funds sufficient to allow research to proceed till the end of the year should, at the very least, be provided. Payment of this allocation would mean that research staff would be given enough time to find alternative employment and most importantly (as far as the Study is concerned) that staff are allowed to write up the results of their past research.

Table 3. AIMS Study budget for 1987/88: Breakdown (by Project) showing costs to COTSAC and notional costs to AIMS.

Project. No.	Description	Cost ($) COTSAC	AIMS
1(A)	Geographic patterns in genetic variation of starfish	38,200[1*]	3,320
(B)	Inheritance patterns of isoenzymes	-	2,120
(C)	Field test of the larval starvation hypothesis	66,400[2*]	-
(D)	Vertical orientation and phototaxis of larvae	500	-
(E)	Substrate selection by larvae	500	-
(F)	Development of larvae and juveniles	2,340	-
(G)	Feeding rate of starfish	19,800 +	7,400
(H)	Feeding preference of starfish	1,100	44,700
(I)	Decomposition rates of starfish	-	-
(J)	Ephemeral patches of phytoplankton	11,200 +	21,405
2(A)	Recovery of corals	12,300 *	35,400
(B)	History of disturbance to corals using <u>Porites</u> sp.	800	30,050
(C)	Genetics of coral population fluctuations	2,100	7,300
(D)	Growth and survival of coral remnants	-	14,100
(E)	Effects of outbreaks on fish	1,920	69,700
3(A)	Macroscale surveys of starfish and corals	133,000[4*]	9,000
(B)	Mesoscale surveys of starfish and corals	1,200	19,500
4(A)	Enhancement of substrate reflectance	-	3,440
(B)	Evaluation procedures for verification of Landsat images	27,300[1*]	21,800
(C)	Hydrodynamic models for schematized and actual reefs	7,500	2,500
(D)	Hydrodynamic models of John Brewer Reef	27,000[1*]	140,400
(E)	Models of the dispersal of outbreaks	1,750	42,900
(F)	Analyses and models of outbreaks	28,000[1*]	52,100
(G)	Tagging of starfish	1,000 *	3,200
5(A)	Administration	115,750	-
	TOTAL	**499,660**	**530,335**

NB. indices denote project includes:

- * Part-time salary
- 1* 1 salary
- 2* 2 salaries
- 4* 4 salaries
- \+ Postgraduate scholarship

Table 4. AIMS Study budget for 1987/88: Breakdown (by expenditure heading) showing costs to COTSAC and notional costs to AIMS.

Expenditure Heading	Cost ($) COTSAC	AIMS
Salaries and Allowances:	321,600	130,030
Travelling and Subsistence:		
Field travel	8,600	1,000
Domestic travel	10,640	-
Overseas travel	2,500	-
Interview and appt expenses	1,500	-
Stores:	15,995	8,000
Freight and Cartage:	1,400	-
Operating Costs of Vehicles:	11,000	-
Charter of Ships:	36,900	221,025
Charter of Aircrafts:	2,200	-
Incidentals:		
Advertising	200	-
Dive ops. and medical	1,000	-
Equip. Hire and Other	500	-
Fringe Benefit Taxes	2,000	-
University Fees	500	-
Bench Fees	6,600	-
Food	1,500	-
Car Rental	400	-
Publications:	500	-
Collaborations:		
Fares and travel costs	2,700	-
Accommodation	500	-
Salaries and On-costs - external	25,000	-
Other external costs	44,550	-
Non-consumable Equipment:		
Computer	500	6,780
Computing Time:	-	163,500
TOTAL	499,660	530,335

Table 5. AIMS Study budget for 1987/88: Costs associated with administration (referred to as Project 5).

Item	Cost ($)
Salaries and Allowances:	47,300
Travelling and Subsistence:	
Field	1,000
Domestic travel	3,000
Interview and appointment expenses	1,500
Stores:	1,000
Freight and Cartage:	
Field trips	700
Operational Costs Vehicles:	11,000
Incidentals:	
Advertising	200
Diving Ops and Medicals	1,000
Equipment Hire	500
Fringe Benefits Tax	2,000
University Fees	500
Collaborations:	
Accommodation	500
On-Costs (AIMS):	44,550
Non-consumable Equipment:	
Computer	500
Publications (graphics):	500
TOTAL	**115,750**

PROGRESS OF RESEARCH: AIMS PROJECTS

PROJECT 1(A) GEOGRAPHIC PATTERNS IN GENETIC VARIATION OF ACANTHASTER PLANCI POPULATIONS

Chief Investigator(s) Dr J. Benzie and Dr J. Stoddart

Research Objectives

To obtain a detailed description of the genetic variation in *A. planci* throughout the Great Barrier Reef that allows for testing specific hypotheses of larval dispersal in relation to outbreaks.

Research Plan

Year 1:
- a) Establish protocols for electrophoretic analysis of *A. planci*.
- b) Sample outbreaking and non-outbreaking populations from the central Great Barrier Reef, with suitable replication to allow tests of hypotheses of larval dispersal.
- c) Initial survey of several enzymes using these samples.
- d) Intensive search for 1st year class starfish.

Year 2:
- a) Extensive and intensive surveys of a large number of enzyme systems to specifically test hypotheses of larval dispersal and other hypotheses emanating from other projects on *A. planci*.
- b) Resurveys of 1st year class of year 1.
- c) Analyses of results.

Year 3: As outlined in the project proposal (The Crown-of-Thorns Study Reports, December 1985)

Progress and Results

1. Protocols for some 40 enzyme systems have been developed. In total 86 systems (involving some 600 test runs) were tested and three quarters of the systems for which protocols were developed showed variation - a prerequisite for determining the population structure of *A. planci* with adequate resolution.

2. A total of 6 outbreaking and 4 non-outbreaking populations have been sampled from the Townsville and the Swain Reef complex (a total of about 1000) individual animals (Table 1). The samples were suitably replicated to allow for a full hierarchical analysis of population structure, and specific tests of larval dispersal with respect to outbreaks.

3. An initial survey of these samples using the most robust and obviously polymorphic of the enzyme systems developed is currently in progress. To date, about 6,000 individual enzyme assays have been carried out in this survey. The remaining animals should be completed by July 1987.

Problems experienced

Difficulty has been experienced in finding suitable non-outbreaking populations near Townsville. So far, only one such population has been found (Table 1) and a considerable amount of underwater time had to be expanded to obtain this relatively small sample. Difficulty also has been encountered in finding any significant numbers of 1st year class animals. It will be necessary to obtain at least one further non-outbreaking population near Townsville to provide regional comparison with those in the Swain Reef Complex (recent bad weather has delayed achieving this objective). However, these difficulties do not present problems in achieving the major aim of the project; testing hypotheses of dispersal of outbreaking populations.

Future Research

1. Analysis of the preliminary survey of the limited number of enzymes (10) to assess the best means of completing the survey with respect to testing hypotheses of dispersal. Dependent on these results:-
   a) sampling of further geographic populations, and/or;
   b) increased sample sizes from outbreaking populations, and/or;
   c) surveying the samples already obtained for a greater number of enzyme systems will be carried out as required.
2. Further searches for 1st year class individuals.
3. Analyses of the results from the extensive surveys as above (1a-c).
4. Examination of hypotheses derived from other projects on *A. planci*.

The first three aims should be completed by July 1988, the fourth is dependent upon results from other projects. A budget for the 1987/88 fiscal year is given in Table 2.

References

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (*Acanthaster planci*) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December 1985, 160 p.

Table 1. Sampling design of Project 1(A)

Region	Population type	Reef	Number of starfish Site 1	Site 2
Townsville	Outbreak	Helix	50	50
		Wheeler	50	50
		Stanley	50	50
		Holbourne Is.	50	46
	Non-outbreak	Davies	35	28
Swains	Outbreak	22112	54	38
		22110	39	25
	Non-outbreak	Gannet	30	16
		Sanctuary	29	28
		22144	11	-
TOTAL			**398**	**331**

Table 2. Project 1(A): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Fellow (Dr J. Benzie)	36,000	-
Research Scientist (Dr J. Stoddart)*	-	1,500
Support Staff (Ms E. Ballment)+	-	620
Travel:		
Field Travel (T/A)	200	-
Domestic Travel (Conferences)	1,000	-
Consumables:		
Chemicals/gels	1,000	-
Assay Chemicals	-	1,200
TOTAL	**38,200**	**3,320**

* based on 5% of available time
\+ based on 2% of available time

PROJECT 1(B) INHERITANCE PATTERNS OF ISOENZYMES IN ACANTHASTER PLANCI

Chief Investigator(s) Dr J. Stoddart

Research Objectives

Confidence in the results of studies using isoenzymes as genetic markers may be increased dramatically by demonstrating that a) the genetic model proposed to explain population variation is correct, and b) the pattern of genotypic occurrences is maintained by gene flow and not selection. Controlled breeding studies can be effective tests of locus/allele models and go some way to demonstrating selection, if this occurs in the early stages of the life cycle.

The objectives of this study are to assess the genotypic frequencies of *Acanthaster planci* larvae produced from adults of known genotype for concordance with genetic models of variation proposed from Project 1(A). A subsidiary result of this work is that it should be possible to distinguish *Acanthaster planci* larvae from other larvae. Although this would be a time consuming and laboratory-based operation, it would provide a high degree of confidence.

Research Plan

Larvae will be produced from laboratory crosses of adult starfish selected on the basis of their electrophoretic phenotypes. These larvae will be processed individually on electrophoretic gels (20-40 larvae per isoenzyme per cross) and the results contrasted to existing genetic models.

Progress and Results

Pilot studies have not been successful to date, due to reasons outlined in the following section. However, experiences gained in these studies leave room for optimism that we may achieve some success in 1987/88. At present, the one enzyme system for which larvae can be analysed effectively (glucosephosphate isomerase, EC 5.3.1.9) represents a low frequency polymorphism for which adults of different genotypes are hard to find.

Problems Experienced

A major problem in working with a restricted seasonal phenomenon, such as reproduction, is that each year has only a single window for carrying out experiments. Development of larval storage (using cryogenic techniques: see Project 1(F)) or in vitro fertilization techniques could overcome this problem.

In year 1 of this study (1985/86) a lack of larvae hindered progress. In year 2 our initial attempts to develop electrophoretic techniques for larvae using the same systems developed in Project 1(A) for adults have not been successful. This results from problems with the type of gel used for adults, where large amounts of tissue can be obtained. This is a cellulose acetate gel which is designed for running a large number of samples with high activity and rapid incubation. Techniques developed for electrophoresis of coral larvae in starch gels (Stoddart, 1983; Stoddart et al., in prep) have since been applied and have proven able to visualize enzymes of individual larvae. However, the enzyme-buffer combinations have not been fully developed yet for this system and the resolution of bands is insufficient for analysis at present.

Future Research

Enzyme-buffer systems for starch will be developed with adult tissue before the next breeding season. When it is possible to obtain more larvae, these systems will be applied. However, given the minute amounts of enzyme able to be obtained from larvae, only very active enzymes will be able to be assayed: perhaps 5-8 isoenzymes. No funds are required for this research during the 1987/88 fiscal year. The costs to AIMS are given in Table 1.

References

Stoddart, J.A. (1983) Asexual production of planulae in the coral Pocillopora damicornis. Marine Biology 76, 279-284.

Stoddart, J.A., A.J. Heyward and R.C. Babcock. in prep. Self-fertilization and maternal enzymes in coral planulae.

Table 1. Project 1(B): 1987/88 budget showing notional costs to AIMS.

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr J. Stoddart)*	–	1,500
Support Scientist (Ms E. Ballment)+	–	620
TOTAL	–	**2,120**

* based on 5% of available time
\+ based on 2% of available time

PROJECT 1(C) A FIELD TEST OF THE LARVAL STARVATION HYPOTHESIS FOR ACANTHASTER PLANCI

Chief Investigator(s) Dr R.R. Olson

Research Objectives

The primary purpose of this project is to critically test the widely accepted hypothesis that fluctuations in larval food levels might cause the large scale fluctuations in adult population size of *Acanthaster*. This hypothesis arose from the work of Lucas (1982), who reared *Acanthaster* larvae in the laboratory. He found that the larvae required high levels of phytoplankton to survive. Comparison of the minimum threshold phytoplankton levels needed to support *Acanthaster* larvae, to field levels showed that the waters of a coral reef (in the absence of a phytoplankton bloom) have considerably less phytoplankton than is required by the larvae. From this, Lucas (1982) hypothesized that the larvae might normally suffer high levels of mortality due to starvation, and that anything which would increase phytoplankton levels during the *Acanthaster* spawning season, might also increase *Acanthaster* larval survival, resulting in a population outbreak 2-3 years later. Birkeland (1982) used this hypothesis to explain the correlation he noted between terrestrial runoff events and *Acanthaster* outbreaks.

To test the first assumption of this mechanism for starfish outbreaks, equipment and methodology have been developed over the past two years to rear larvae *in situ* in the waters of a coral reef. With this equipment it has been possible to test whether the larvae starve to death in the absence of a phytoplankton bloom.

Research Plan

To rear larvae *in situ* flow-through chambers were constructed which have 100 um mesh on both ends and are flushed periodically by electric pumps with timers. The equipment and methodology for *in situ* larval rearing is explained in detail in Olson (1985). The project has followed the following stages:

1. Initial development of *in situ* culturing methodology (Dec 1984-Sept 1985)
2. *In situ* larval culturing in Antarctica (Oct 1985)
3. Natural versus enriched diet experiment (Nov-Dec 1985)
4. Equipment modification (March 1986-Oct 1986)
5. Effect of chamber size and flushing rate (Nov 1986)
6. Effect of habitat (Dec 1986).

Progress and Results

The results of this study have proven to be of interest to invertebrate larval ecologists in general. The extent to which invertebrate larvae are food-limited has emerged as a major issue in larval ecology (i.e. Paulay *et al*., 1985; Rivkin *et al*., 1986). This is the first study of *in situ* growth and development of an invertebrate larva.

At present, the conclusions from this study are:

> The larvae *are* food-limited in nature, but the extent of food-limitation does not appear to be sufficiently large to account for much variation in annual larval recruitment success.

This is based on the fact that larval development was most rapid under conditions of diet enrichment, slightly slower on the natural diet at Lizard Island (a lagoonal site), even slower on the natural diet outside John Brewer Reef (an inter-reefal site), and slowest of all on Yonge Reef (an outer barrier reef site). These data show that the larvae probably are food-limited and do not attain their maximum possible growth and development rate under natural conditions. However, the differences observed between all of these sites have been slight (no significant difference in survivorship, only slight differences in development time of approximately 10-15 percent), and of insufficient magnitude to account for large scale fluctuations in *Acanthaster* recruitment success. The results of this study (as well as the side project on larvae of the Antarctic asteroid, *Odontaster validus*) are reported in a number of papers (Olson, 1985; Olson, Bosch and Pearse, in press; Olson, in press; Olson and McPherson, in prep.).

Future Research

Within this project, there are two major experiments remaining to be conducted. They are as follows:

1. *In situ* culture of larvae in oceanic waters: This experiment will provide the ultimate examination of the larval starvation hypothesis -- Can the larvae survive in oceanic waters which contain extremely low levels of phytoplankton? Past efforts in trying to culture larvae *in situ* on the outer barrier reef (Yonge Reef) have not been satisfactory. As it was difficult to change the larvae in the small boat that was used at Lizard Island, large numbers of larvae were lost. Also, because the culture table had to be located in the

channel between Yonge and Carter Reefs, the phytoplankton levels ended up being almost as high as in the Lizard lagoon. Clearly this is a project which must be conducted from a ship.

2. Total swimming time of larvae: It is essential to know how long larvae can delay metamorphosis when reared on a natural diet. In the laboratory, under stressful conditions, larvae will delay settlement up to 40 days. However, it is possible that when reared on a natural diet, the larvae may settle out in the chamber by 20 days, whether there is a suitable surface or not. To properly address this problem, it will be necessary to rear larvae in chambers with and without stirring, to prevent them from drifting to the bottom of the chamber.

This research will be conducted on Lizard Island during the forthcoming summer period. A budget for this project, for the 1987/88 fiscal period, is given in Table 1.

References

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Rivkin, R.B., Bosch, I., Pearse, J.S. and Lessard, E.J. (1986) Bacteriovory: A novel feeding mode for asteroid larvae. Science 233, 1311-1314.

Table 1. Project 1(C): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr R. Olson) (2 mths)	7,000	-
Experimental Scientist (Mr P. Dixon)	36,800	-
Experimental Scientist (Ms K. Osborne) (1 mth)	2,500	-
Travelling and subsistence:		
Field travel	1,300	-
Overseas travel (for Dr Olson)	2,500	-
Consumables:		
General	200	-
Hire of aircraft and ships:		
Vessel charter (10 days @ $500/day)	5,000	-
Aircraft charter	2,200	-
Incidentals:		
Bench fees	6,600	-
Food	1,500	-
Car rental	400	-
TOTAL	**66,400**	-

PROJECT 1(D) VERTICAL ORIENTATION AND PHOTOTAXIS OF LARVAE OF ACANTHASTER PLANCI

Chief Investigator(s) Dr R.R. Olson

Research Objectives

If we accept the assumption that population outbreaks of Acanthaster are caused by years of heavy larval recruitment, then to be able to predict where Acanthaster outbreaks will occur, we must be able to predict where the larvae will settle. This requires a knowledge of three factors:

1. Physical Oceanography - We know that the direction in which larvae will be transported is largely determined by water currents since Acanthaster larvae, for the most part, drift like passive particles.

2. Vertical Orientation - Since surface currents sometimes run opposite to deeper water currents, we must know in which vertical strata the larvae are located during their free-swimming stage.

3. Settlement behavior - To predict the location of larval settlement, we need to know how long the larvae are in the water, and what factors finally cause them to descend to the benthos to settle.

The Crown-of-Thorns Study is devoting considerable effort towards factor #1 (understandably so, since physical oceanography requires large budgets). But models of dispersal will mean little if factors #2 and #3 are not understood.

Project 1(E) (on settlement behavior) will provide the bulk of the data for factor #3. However, in addition to knowing what surfaces the larvae will attach to, we also need to know what initially causes the larvae to descend in the water column. Within the in situ larval culture chambers, larvae persist at the top of the chamber until just before settlement. Studies of sand dollar larvae by Pennington and Emlet (1986) show the same pattern. Their work showed that the larvae occurred in the top few meters depth up until settlement time. If this is the case, then how do larvae know when to descend to the reef, or do they know?

Research Plan

Between the studies of Williams et al. (1985) on the direction of currents on the Great Barrier Reef in relation to larval dispersal, and Pennington and Emlet (1986) on the vertical orientation of sand dollar larvae (which are probably very similar to Acanthaster larvae in their behaviour) it is possible to make a reasonable guess as to what to expect for Acanthaster larval dispersal. Considerable effort will be required to improve on this guess. There exists considerable debate over the correct methods for studying vertical orientation and phototaxis. Both topics are plagued by the artefacts involved in the containment of pelagic organisms, and the need to use natural sunlight. Experiments are presently being developed to study this properly.

A few short experiments will be conducted on this subject at the end of this year on Lizard Island. It will then become a major focal point of next year's research efforts. This year 1 m high in situ culture chambers will be constructed which have ports at 5 heights for sampling of larval density. The chambers will be sampled every 4 hours at 2, 5, 8, 11, and 14 days post-fertilization. In a second experiment, the responsiveness of larvae to ultra-violet light (a phenomenon documented by Pennington and Emlet (1986)) will be examined by placing larvae at different stages into a large, wide, shallow, and clear container in full sunlight.

During the following summer (Nov-Dec. 1988) more extensive experiments will be undertaken on the behaviour of the larvae. These will include laboratory studies on directional swimming in response to light, the effect of particulate densities on larval vertical orientation, and effect of water currents on settlement behaviour. These experiments will be designed during the forthcoming year.

Progress and Results

As this project is still being planned no results have been produced as yet. The results from the preliminary projects should come to hand by the end of 1987. More detailed results are expected by the end of 1988.

Future Research

The research which is to be conducted has been outlined in previous sections. By the end of 1988 it would be extremely useful to organise a working session with the physical oceanographers to attempt to integrate the findings of this (and related projects) project with their knowledge of currents to assemble a predictive model of Acanthaster larval dispersal. Only a small amount of funds are required for this Project in the 1987/88 fiscal period (Table 1).

References

Pennington, J.T. and Emlet, R.B. (1986) Ontogenetic and diel vertical migration of a planktonic echinoid larva, Dendraster excentricus (Eschscholtz): occurrence, causes and probable consequences. J. Exp. Mar. Biol. Ecol. 104, 69-96.

Williams, D.McB., Wolanski, E., and Andrews, J.C. (1984) Transport mechanisms and the potential movement of planktonic larvae in the central section of the Great Barrier Reef. Coral Reefs 3, 229-241.

Table 1. Project 1(D): 1987/88 budget showing costs to COTSAC and AIMS (notional)

Item	Cost ($)	
	COTSAC	AIMS
Consumables:		
Field equipment	500	-
TOTAL	**500**	-

PROJECT 1(E) SUBSTRATE SELECTION BY LARVAE OF ACANTHASTER PLANCI

Chief Investigator(s) Dr R.R. Olson

Research Objectives

At present, there are no data which strongly support the idea that fluctuations in larval food levels might explain *Acanthaster* outbreaks (see Project 1(C)). Rather, the information gathered to date suggest that variation in larval food levels is unlikely to be important in *Acanthaster* larval ecology. For this reason, it is necessary to begin examining other aspects of *Acanthaster* larval ecology in search of a mechanism to explain population outbreaks.

One important aspect which requires investigation is the process through which the larva "decides" to settle on a surface which it contacts. This process may be described by either of two models:

1. Non-selective settlement.

   In Olson (in review) it is argued that *Acanthaster* larvae may be very unspecific in their settlement behaviour and settle quite rapidly. This is based on the fact that larvae must suffer a high rate of predation when contacting the benthos (thus a prolonged search is likely to be very risky), and the larvae appear to settle as rapidly on coral rubble as on crustose red algae -- which was previously believed to be their "settlement cue". In the paper an explanation is given of how a difference in searching behavior can translate into differences in recruitment variation in space and time.

2. Chemical induction of settlement.

In spite of the previous arguments it can't be denied that the larvae of Acanthaster have shown some interesting responses to crustose red algae. For example, although mean settlement on coral rubble is higher that on crustose algae, the variation in settlement may be more important. Although most pieces of crustose algae in the settlement experiments conducted this past summer at Lizard Island held only 2 or 3 newly settled juveniles when examined, there were a few interesting exceptions. On at least three occasions, fragments of crustose algae ended up with over 30 newly settled juveniles. In all cases, the larvae had settled on a small portion of the total algal area. These settlement events were impressive sights and demonstrated the need to investigate in greater detail the idea of chemical induction of larval settlement.

The aim of this project is to investigate these two models of settlement behaviour as a means of obtaining a better understanding of the cause of outbreaks.

Research Plan

Whilst undertaking this project it is important to keep an open mind to both of the above models of Acanthaster settlement. The data are insufficient to say which is more appropriate. It is even possible that both are correct, i.e. settlement ordinarily follows the first model, but every once in a while the crustose algae produce large amounts of settlement inducing compounds which result in heavy larval settlement. Who knows at this point!

The first data on larval settlement were collected in the *in situ* culture experiments when coralline algal fragments were placed in the larval chambers at settlement time. A second data set was collected last summer at Lizard Island. It consisted of the following:

1. Settlement onto single surfaces (crustose algae, coral rubble, etc.)
2. Substratum choice experiments (all surfaces present in chamber)
3. Chemical induction by GABA and KCl
4. Settlement onto unfouled coral blocks
5. Settlement onto unfouled black perspex with holes
6. Diel variation in larval settlement (every 6 hours)

The results of these experiments have provided the directions for the efforts of this next summer (see section on Future Research). Experiments on this subject will require approximately 60-80% of the time this year at Lizard Island. They will consist of a variety of experiments to verify whether there is a chemical basis to the settlement behaviour of *Acanthaster* larvae.

Progress and Results

The results of the preliminary experiments on the settlement of *Acanthaster* larvae have been compiled in a manuscript which is currently under review (Olson, in review). The analogy drawn in this paper between invertebrate larval searching behavior and risk-sensitive foraging has produced considerable interest. Discussions have also proceeded with Dr Dan Morse (University of California, Santa Barbara) who has produced the most extensive studies on chemical induction of larval settlement by crustose algae to date. He is very interested in collaborating on further studies of chemical induction of *Acanthaster* larval settlement.

Future Research

It is difficult to provide specifics on experiments to be conducted in the future since the results of each experiment point the way for the next. However, during the forthcoming summer it is planned to undertake research in the following areas:

1. Investigation of possible "hot" crustose algal fragments.

   In the settlement experiments last summer on several occasions more than 30 larvae were observed to settle on one piece of crustose algae. In each case there were at least two other fragments in the chamber, all of which came from the same original algal specimen. The other fragments never had more than 5 larvae settled on them. Furthermore, all of the 30+ larvae attached to the one piece were clustered into a small area. In a preliminary experiment which was conducted in the last few days at Lizard Island, all newly settled larvae were removed from each of the three fragments in a chamber. In addition, the shape of each fragment was noted and they were placed back in the chamber with another 100 larvae, and returned to the field. Two days later, the numbers of larvae which had settled on each fragment were almost identical to those obtained before (1st time - 32, 7, 0; 2nd time - 43, 6, 0) with the same fragment receiving the most and the same fragment receiving 0. These results suggest that a certain portion of the crustose alga might be "hot", containing a high level of settlement inducing biochemicals. To test this, I plan to replicate this experiment with a variety of the species of crustose algae. If a fragment is found which is very active, it will be frozen and saved for later analysis to determine whether it is biochemically different from other fragments of the same alga.

2. Experiments on Chemical induction of settlement.

There are a variety of experiments, perfected by Morse's group, to resolve: a) whether chemical induction is involved in settlement, b) what the approximate size of the inducer chemical is, and c) whether surface contact is necessary for settlement. These experiments involve using permeable membranes, boiling crustose algae, wrapping the algae in mesh, and a variety of other techniques. Last year at Lizard Island tests were performed to determine the effectiveness of Gamma amino-butyric acid (GABA) and KCl at inducing settlement (both are known to be very effective with some invertebrate larvae). Neither proved active. This year we will run a series of the above experiments to try to determine the basis of the settlement response (if there is a chemical basis to it). Since our time is limited there, we cannot simply run all of the experiments for all species. We will decide which experiment to run based on the results of the previous set of experiments.

3. Juvenile growth on different surfaces.

An essential set of information to know is how important it is for a larva to settle on crustose algae versus other surfaces. To date, settlement experiments have produced a large number of juveniles, but unfortunately there has been insufficient time (given other priorities) to monitor their growth. This is a very important project and needs to be conducted this next year at Lizard Island.

Given that the above research will be carried out in conjunction with that being conducted in Projects 1(C) and 1(D) only a small amount of funds are required for the 1987/88 fiscal period. A budget for this project is given in Table 1.

References

Olson, R.R. (in review) Larval habitat selection by the Crown-of-Thorns Starfish, *Acanthaster planci*: Are larvae risk-sensitive? Ecology.

Table 1. Project 1(E): 1987/88 budget showing costs to COTSAC and AIMS (notional)

Item	Cost ($)	
	COTSAC	AIMS
Consumables:		
Store Items	500	-
TOTAL	**500**	**-**

PROJECT 1(F) DEVELOPMENT OF TECHNIQUES FOR THE PRODUCTION OF LARGE NUMBERS OF LARVAE AND JUVENILES OF ACANTHASTER PLANCI

Chief Investigator(s) Mr P. Dixon and Dr R. Olson

Research Objectives

Large numbers of larvae and early juvenile starfish are required for the COTSAC projects involving genetics, monoclonal antibodies, juvenile feeding rates, and feeding and settlement of larvae. These many thousands of larvae have been successfully produced using either a laboratory based system or *in situ* culturing. A cryogenics program was also initiated to provide larvae for year-round studies.

Research Plan

To date, eggs have been obtained by removing gonads from ripe or almost ripe individuals and inducing the release of ova by the addition of 1-methyladenine. After fertilization and hatching the larvae were cultured in five litre beakers in the laboratory or in the *in situ* culture chambers developed and used in other projects (Project 1(C)). Upon reaching the mid brachiolaria stage the larvae were frozen for analysis (e.g. monoclonal antibodies studies) or reared to settlement.

Progress and Results

To date, it has been possible to produce only three large cultures using the lab-based system. This was partly because of other commitments to the COTSAC program, and partly because of the failure of larvae to develop. Two of these cultures were used for genetics studies, while the third (containing approximately 40,000 larvae) was sent to Deakin University for the development of monoclonal antibodies.

The *in situ* culture chambers used at Lizard Island were also very successful. Both culture methods require a high degree of maintenance. The lab system requires one person to change and clean beakers, and check food supply every day. Whereas the *in situ* culturing requires a minimum of two divers to change and clean chambers every two days.

Experiments with cryogenics have yielded few results, although some success was achieved using sand dollar larvae instead of *Acanthaster* larvae. Despite this the most suitable cryoprotectant has been found and all that remains now is to determine the optimal freezing and thawing rates of larvae.

Problems Experienced

A few minor problems have been experienced with equipment failure, but of major concern has been the failure of fertilized eggs to develop even to early larvae. This developmental failure occurs only in eggs obtained after the completion of the breeding season. Since the gonads were "forced" to produce eggs, these eggs may not be competent or mature enough for complete larval development to occur. Even though the maturation hormone (1-methyladenine) was used. If this is occurring then successful mass culturing and cryogenics are limited to November and December.

At present the greatest problem in the cryogenics project has been the lack of specialized freezing equipment. Such equipment (controlled rate freezer) has now become available in Brisbane and arrangements are being made to use this facility.

Future Research

Future research is required into the competence of eggs and the correct freezing rate for successful cryogenics. To a certain extent research into both these problems can be carried out on sand dollars. This research would provide the necessary background information and techniques for the *Acanthaster* work in November and December.

Collaborative research will also be undertaken with the Sir George Fisher Centre (JCU), using both mass culture systems, to study the importance of certain naturally occurring bacteria on the development and survival of larvae, and possibly early juvenile starfish. Preliminary experiments have yielded interesting results. A budget for this project, covering the 1987/88 fiscal period, is given in Table 1.

Table 1. Project 1(F): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Travelling and subsistence:		
Domestic travel (to Brisbane)	1,440	-
Consumables:		
Culturing equipment	500	-
Chemicals	300	-
Freight and cartage:	100	-
TOTAL	**2,340**	-

PROJECT 1(G) FEEDING RATES OF ACANTHASTER PLANCI IN THE FIELD

Chief Investigator(s) Dr D. Klumpp, Dr J. Lucas (JCU), Mr J. Keesing and Dr P. Moran

Research Objectives

The aim of this project is to determine the rates of feeding of different size classes of Acanthaster on hard corals in the field and to determine whether any variation in feeding rates correspond to the life history stages proposed by Lucas (1984).

Lucas (1984) suggested, from laboratory studies, that three distinct stages occur during the coral feeding phase of the life history of Acanthaster planci. These stages; juvenile, adult and senile adult, being defined by differences in growth rate and physiology. It is possible that this final stage is an artefact due to animals being kept under artificial conditions (Lucas, 1984).

As some outbreaking populations of starfish have been found to consist of large numbers of big (> 35 cm) starfish (Moran, Bradbury and Reichelt, 1985), measurements of feeding rates of different size classes of A. planci may help to validate or otherwise the existence of this "senile" phase and thus provide information with important implications for management.

Research Plan

The methodology outlined in the original project proposal (The Crown-of-Thorns Study Reports, 1985) described the use of caging experiments and tagging techniques to obtain measurements of feeding rates of A. planci. As outlined below the use of cages appears to modify the behaviour of the starfish and thus the use of enclosure experiments is probably inappropriate. As a result greater emphasis has been placed on developing suitable short term tagging methods to enable individual starfish to be followed in the field.

Progress and Results

Preliminary trials of measuring feeding rate using animals caged in the field were not encouraging. Only one feeding episode took place in five days amongst eight starfish enclosed in 1 m x 1 m x 0.6 m wire cages containing live branching *Acropora* as a food source.

Trials of a number of tag types placed over the spines of *A. planci* kept in large outdoor aquaria have resulted in the development of tags which are suitable for short term monitoring of movement and feeding activity. Polyethylene tags were trialed on a number of starfish ranging in size from 16-51 cm. The most successful tags resulted in an average retention time of 41, 74, 53 and 80 hours in starfish $<$ 20 cm, 20-30 cm, 30-40 cm and $\geq$ 40 cm respectively. Time taken to throw the spine tags was highly variable among starfish and it is considered that multiple tagging of each starfish would result overall in a greater average tag retention time. Trials to develop tags with longer retention times are continuing on the smaller size class of starfish.

The tags have been trialed in the field twice during their development. Movement and diurnal feeding activity were monitored over a three day period on a number of tagged starfish at Wheeler Reef in November 1986. Searches were made for the tagged starfish every 4 hours over the three day period. Although information on individual feeding patterns of a number of starfish was obtained in this way, recovery rates of tagged starfish were poor. The main problem was that large numbers of starfish in a small area in relatively shallow water (the ideal conditions for this type of study) could not be found, and thus starfish had to be tagged over a large area and in water 8-15 m deep. This meant a large area had to be searched in a relatively short period of time resulting in many tagged starfish being missed, particularly at night.

The tags were trialed again more recently at Holbourne Is. in March 1987. Eighteen starfish were tagged in a small area in shallow water and the feeding activity was monitored eight times over a 40 hour period. The results indicated that the tagged starfish were feeding primarily nocturnally. Most tagged starfish were recovered during each search indicating that a larger scale study over a longer period with more frequent re-searching was feasible. What also became clear was that although this type of study gave us information on the feeding behaviour of A. planci more frequent monitoring is needed to obtain data on actual rates of feeding because it was evident that more than one episode of feeding was taking place per night.

Problems Experienced

The failure of caged starfish to feed in the field indicates that the use of this technique is unsuitable for obtaining reliable measurements of feeding rates. Although Pearson and Endean (1969) had success using caged starfish to measure feeding rates it is felt that pursuing this method of experimentation in terms of larger cages and enclosures would prove very expensive (in terms of ship time) and may still not prove fruitful.

Thus considerable time and effort has been allocated to establishing a suitable short term tagging technique with a view to determining feeding rates from following tagged starfish in the field over a number of days. There have been many attempts to develop suitable methods of tagging *A. planci*. These trials and the problems encountered are well documented (see Moran, 1986 for review).

Tags placed over the spines of *Acanthaster* for the monitoring short term activity have been used by Pearson and Endean (1969), who found that the tagged spines were shed "after a few days", and Crump (1971), who monitored starfish behaviour over a 24 hour period during which time some tag loss was incurred. The tags proposed for use in this study have been trailed in aquaria and in the field and will remain intact for periods suitable for short term monitoring of *A. planci*.

Future Research

A five day field trip will be undertaken to carry out a starfish tagging and monitoring program using different size classes of *A. planci*. Feeding activity of the starfish will be monitored several times daily. In addition a continuous watch on groups of tagged starfish will be carried out over a period of about 10 hours to get an accurate account of number of feeding episodes individual animals undertake. Whilst this method will prove more logistically difficult and labour intensive than caging, it should result in much more reliable measurement of feeding rates.

It is anticipated that the study (which forms part of an overall programme of research on the feeding of Acanthaster being undertaken by Mr J. Keesing towards a Ph.D. degree through James Cook University) will be completed. A budget for this project, covering the 1987/88 fiscal period, is given in Table 1.

References

Crump, R. (1971) Nocturnal behaviour in aggregations of Acanthaster planci. In Roads, C.H., and Ormond, R.F.C., (Eds.) Report of the third Cambridge Red Sea Expedition 1970, Cambridge Coral Starfish Research Group, Cambridge, 124 p.

Moran, P.J. (1986) The Acanthaster phenomenon. Oceanogr. Mar. Biol. Ann. Rev. 24, 379-480.

Moran, P.J., Bradbury, R.H., and Reichelt, R.E. (1985) Mesoscale studies of the Crown-of-Thorns/coral interaction: a case history on the Great Barrier Reef. Proc. 5th Int. Coral Reef Congr., Tahiti, 5, 321-326.

Lucas, J.S. (1984) Growth and maturation of Acanthaster planci (L.) (Asteroidea) and hybrids in the laboratory, including observations on the effects of diet. J. Exp. Mar. Biol. Ecol. 79, 129-147.

Pearson, R.G. and Endean, R. (1969) A preliminary study of the coral predator Acanthaster planci (L.) (Asteroidea) on the Great Barrier Reef. Qld. Dept. of Harbour and Marine, Fisheries Notes 3(1), 27-55.

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December, 1985, 160 p.

Table 1. Project 1(G): 1987/88 showing costs to COTSAC and AIMS (notional)

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr D. Klumpp)*	-	1,600
Research Scientist (Dr P. Moran)*	-	1,600
Travelling and subsistence:		
Field travel	800	-
Consumables:		
Field equipment (tags, underwater paper)	1,000	-
Hire of aircraft and ships:		
Vessel charter (8 days @ $1,000/day)	8,000	-
Vessel charter (7 days: R.V. Sirius)	-	4,200
Collaborations:		
Salaries and on-costs (Postgraduate scholarship) (Mr J. Keesing)	10,000	-
TOTAL	**19,800**	**7,400**

* based on 5% of available time.

PROJECT 1(H) FEEDING PREFERENCES OF ACANTHASTER PLANCI IN THE FIELD

Chief Investigator(s) Dr P. Moran, Dr R. Reichelt and Mr P. Speare

Research Objectives

The primary objective of this project is to obtain quantitative data on the feeding preferences of crown-of-thorns starfish in the field. There have been several previous studies of this type but most have based their conclusions on qualitative data (see The Crown-of-Thorns Study Reports, 1985). Those which have tried to demonstrate feeding preference in a quantitative manner have done so by comparing data taken over different spatial scales. The present project attempts to overcome the problems associated with confounding the effects of scale by using nearest neighbour surveys of corals to determine whether starfish exhibit particular food preferences. A more detailed background to this study is given in an earlier document (The Crown-of-Thorns Study Reports, 1985).

A subsidiary, but no less important, objective of this project is to develop a large database comprising information on approximately 20 physical and biological variables (relating to each starfish surveyed in the field) in an attempt to gain a better understanding of the major factors responsible for determining the behaviour of starfish on reefs. Such a database will be extremely useful in addressing questions such as:

1. Are starfish mainly nocturnal or diurnal feeders?
2. Is this type of feeding behaviour density or size (age) dependent and does it vary both within and between reefs?

3. Do physical factors (eg. sea condition, wind speed, light intensity) affect the feeding behaviour of starfish?
4. What other sorts of organisms are fed on, apart from corals, by starfish in the field and is this determined by the amount of coral available?
5. Is there any indication that starfish suffer extensive predation in the field? Is this size (age) related?

Research Plan

The research plan for this project has been outlined previously (The Crown-of-Thorns Study Reports, 1985). To date, information has been obtained on approximately 5,000 individual starfish from 12 reefs (see Table 1). Preliminary results from the project indicate that:

1. Starfish prefer to feed on corals of the genus *Acropora*, particularly branching and tabulate forms. They appear to dislike feeding on corals such as *Porites*, *Pocillopora* and *Galaxea*.
2. Nocturnal and diurnal feeding varies both within and between reefs.
3. Food availability is important in determining feeding behaviour and in some instances may account for the observed differences in nocturnal and diurnal feeding between starfish at different depths in the one study area.
4. A high proportion of starfish were found to feed on organisms other than corals (eg. soft corals, algae, gorgonians etc) at the end of an outbreak when live coral cover was low.
5. There is evidence of moderate predation on starfish in the field. Approximately 25% of all starfish measured had regenerating arms or spines. This did not appear to be correlated with the size of starfish.

Problems experienced

Some problems have been experienced in obtaining equivalent numbers of records for various outbreak and starfish categories. For example, at present there are more records for adult than juvenile starfish and there are about twice as many daytime records as there are for those taken during the night. The later is because it takes almost double the time to measure a starfish during the night as it does during the day. Overcoming this problem is contingent on whether new starfish populations can be found (or are reported) in the next 6 months.

Future research

Surveys in the future will attempt to obtain more records of juvenile starfish and also more nighttime records. Provided suitable populations of starfish can be found the field component of this project will be completed by January 1988. Up until then it is proposed to survey another 3,000 starfish from as many different reefs as possible. A list of the likely survey schedule and research plan is given in Table 2. A small amount of funds are required to complete the field surveys in this project. A budget for the 1987/88 fiscal period is given in Table 3.

References

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (*Acanthaster planci*) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December, 1985, 160 p.

Table 1. Summary of the data recorded for Project 1(H).

Reef	Population type Density/Distribution	Number of records Day	Night	Total
1. Bowden	HIGH/LOW	199	101	300
2. Davies	LOW/MED	184	-	184
3. Gannet	MED/LOW	90	8	98
4. Helix	HIGH/HIGH	407	-	407
5. Holbourne Island	HIGH/MED	365	121	486
6. John Brewer	MED/HIGH	59	6	65
7. Sanctuary	LOW/LOW	87	-	87
8. Stanley	HIGH/LOW	503	654	1157
9. Wheeler	HIGH/HIGH	1023	796	1819
10. 22110	HIGH/MED	209	-	209
11. 22112	HIGH/LOW	274	-	274
12. 22144	LOW/LOW	-	12	12
TOTAL		**3400**	**1698**	**5098**

* DENSITY:
- LOW - Less than 1 starfish per 4 sq m.
- MEDIUM - Between 1-3 starfish per 4 sq m.
- HIGH - Greater than 4 starfish per 4 sq m.

DISTRIBUTION:
- LOW - Covering less than 30% of reef perimeter.
- MEDIUM - Covering between 31-60% of reef perimeter.
- HIGH - Covering greater than 60% of reef perimeter.

Table 2. Research schedule and the type of data to be collected for the remainder of Project 1(H).

	Reef	Data type	Date
1.	Chicken	Normal population (adults, day)	Sept. 87
2.	Bowden	Outbreak (adults, night)	Sept. 87
3.	Stanley	Outbreak (juveniles, night)	Oct. 87
4.	Wheeler	Outbreak (adults/juveniles, night)	Sept. 87
5.	Holbourne Is.	Outbreak (adults, night/day)	Oct. 87
6.	Davies	Normal population (adults, day)	Oct. 87

Table 3. Project 1(H): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr P. Moran)*	-	9,700
Travelling and subsistence:		
Field travel	500	-
Consumables:		
Underwater equipment	600	-
Hire of aircraft and ships:		
Vessel charter (35 days: R.V. Sirius)	-	21,000
(4 days: R.V. Lady Basten)	-	14,000
TOTAL	**1,100**	**44,700**

* based on 30% of available time

PROJECT 1(I) RATE OF DECOMPOSITION OF ADULT STARFISH IN THE FIELD

Chief Investigator(s) Dr P. Moran

Research Objectives

Studies conducted in the field have shown that outbreaks of the crown-of-thorns starfish may diminish in size to low population densities within a relatively short period of time (Moran, Bradbury and Reichelt, 1985). At present there is no field information concerning the likely fate of these sometimes large numbers of starfish. It has been hypothesized that the starfish may move "en masse" to a nearby reef where the abundance of live coral is high (Endean, 1969). Unfortunately, there is no direct evidence to validate this hypothesis. Another possible explanation (see The Crown-of-Thorns Study Reports, 1985) for the rapid disappearance of starfish is that they die and then decompose very rapidly in the field. This would account for the fact that very few starfish remains have been reported in the field despite the large number of starfish which may be present in an outbreak.

The objective of the present project is to investigate this later hypothesis by attempting to determine the rate of decomposition of adult starfish in the field. An earlier report (Progress Report, September 1986) described the results of a series of preliminary experiments which suggested that it may take as long as 5-7 days for the body of a crown-of-thorns starfish to completely disintegrate.

Research plan

The experimental design of this project has not been altered from that which was described in detail in the original proposal (The Crown-of-Thorns Study Reports, 1985).

Progress and results

It was anticipated that the field experiments for this project (see The Crown-of-Thorns Study Reports, 1986) would be undertaken at John Brewer Reef during the early part of April this year. Unfortunately, they could not be carried out at that time because of bad weather. To date, only the study sites for this project have been chosen and marked out.

Problems experienced

See previous section.

Future research

It is anticipated that the field experiments which were delayed by bad weather will be undertaken at John Brewer Reef during June 1987. While these experiments are being conducted samples will be taken of the sediment present in those quadrats used during the preliminary experiments in July 1986 (see The Crown-of-Thorns Study Reports, 1986). These samples will be analysed by researchers from James Cook University who are interested in the accumulation of the skeletal remains of the crown-of-thorns starfish on reefs. No COTSAC funds are required for this project during the 1987/88 fiscal year as the research will be completed in the present fiscal period.

References

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. of Primary Industries, Fisheries Branch, 30 p.

Moran, P.J., Bradbury, R.H. and Reichelt, R.E. (1985) Mesoscale studies of the crown-of-thorns/coral interaction: A case history from the Great Barrier Reef. Proc. Fifth Int. Coral Reef Congr. 5, 321-326.

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December, 1985, 160 p.

PROJECT 1(J) EPHEMERAL PATCHES OF PHYTOPLANKTON IN THE CENTRAL GREAT BARRIER REEF AS A POTENTIAL FOOD SOURCE FOR LARVAE OF ACANTHASTER PLANCI.

Chief Investigator(s) Dr M. Furnas and Mr P. Liston

Research Objective

The aim of this project is to quantify spatial scales and the intensity of horizontal and vertical variability of phytoplankton biomass in GBR waters, particularly during the *A. planci* spawning season.

This research stems from the earlier suggestion (Lucas, 1982) that *A. planci* larvae would not develop at optimal rates on the known densities of phytoplankton in GBR waters. This discrepancy may be resolved in two ways: first, that laboratory results may not reflect the ability of *A. planci* larvae to develop on natural phytoplankton assemblages (see Project 1(C)), or second, that the then available field data was insufficient to resolve small or ephemeral patches of elevated phytoplankton biomass sufficiently dense to support optimal development of *A. planci* larvae.

Research Plan

1. With the aid of a supported post-graduate student, to build a continuous-flow chlorophyll fluorometry system to record high sample density transects of surface chlorophyll fluorescence and also to measure vertical chlorophyll fluorescence profiles at discrete stations in relation to oceanographic variables (salinity, temperature, density, U/W light).

2. Following construction and validation of the pumping/profiling system, to collect a series of representative hydrographic stations and horizontal fluorescence transects in the GBR with the aims of resolving:

   (a) levels of chlorophyll patchiness in the reef matrix, the GBR lagoon and oceanic waters of the East Australian Current.
   (b) scales of chlorophyll patchiness along transects running parallel and normal to the coast.
   (c) relationships between chlorophyll patchiness and reef matrix density.
   (d) seasonal levels of chlorophyll patchiness within the same region.

Progress and Results

The post-graduate student (Mr Peter Liston) arrived at AIMS in September, 1986 and began assembling the profiling system. Prior to his arrival, a Turner Design Model 10 Fluorometer with flow-through sample chamber was purchased for the project, in part with AIMS funds. The profiling system (Figure 1) was assembled from equipment already in use at AIMS for biological oceanographic research. The initial task was to interface and program a micro-computer data logger to accept data in real time from the AIMS CTD, digitize analog signals from U/W and surface light sensors and the fluorometer, assemble all the above data into data strings and transmit these data to the microcomputer for storage and processing.

The fluorometry system was assembled by Christmas, 1986 and field tested in early January, 1987. Fortuitously, a major activity of this cruise was tracking a patch of <u>A. planci</u> larvae from the time of spawning (in conjunction with Project 6(C)). A considerable number of chlorophyll profiling transects were run in the region of the *A. planci* larvae. No significant problems were encountered with the system operating in the horizontal profiling mode. In the vertical profiling mode, some minor problems were encountered, but by the end of the cruise vertical profiles of reasonable quality were being obtained.

Various small problems in the hardware were modified after the first cruise and the system was operated for several days without problems on a second cruise in the Innisfail region during February, 1987. Profiling during the second cruise was curtailed by rough weather, which restricted ship operations to sheltered inshore waters.

Calibration sampling during horizontal transects shows that fluorescence is a valid measure of large scale fluctuations of chlorophyll in surface waters, and hence, a measure of phytoplankton biomass patchiness. Rough plots of unfiltered data show variability over a range of spatial scales. The horizontal transect data sets are now being processed to add navigation data and are being prepared for spectral and other analyses.

Problems

Difficulties encountered to date have largely been "teething" problems associated with assembling the plumbing and electronic items, writing and debugging computer programs to control the system and learning how to handle and deploy the vertical profiling gear at sea. The original hose purchased for the vertical profiling system proved unsuitable (as it tended to collapse) and was replaced prior to the second cruise. The new hose shows no tendency to collapse, and is lighter than the original.

Future Research

With the construction of the profiling system, our next objective is to build a library of transects and stations to allow quantitative assessment of seasonal and regional patterns of patchiness. The horizontal profiling system can be readily deployed on the R.V. Lady Basten and efforts will be made to send it out as often as possible on a cruise-of-opportunity basis. The vertical profiling system is an integral part of another ongoing AIMS research project and will be used frequently in that context. In addition to ride-along cruises, two major cruises are planned for 1987-88 to the Ribbon and Swain Reefs. These cruises will permit data collection along long N-S transects, sampling in a variety of reef matrix densities and sampling in areas with significant levels of topographically derived upwelling likely to produce localized phytoplankton patchiness. A budget for this project is given in Table 1.

References

J.S. Lucas (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.

Table 1. Project 1(J): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr M. Furnas)*	-	3,000
Experimental Scientist (Dr A. Mitchell)*	-	3,100
Travelling and subsistence:		
Field travel	200	-
Consumables:		
Field equipment	1,000	-
Hoses and reagents	-	1,100
Capital Equipment:		
Hard disk for computer	-	1,080
Hire of aircraft and vessels:		
Vessel charter (15 days: R.V. Lady Basten)	-	13,125
Collaborations:		
Salaries and on-costs	10,000	-
TOTAL	**11,200**	**21,405**

* based on 10% of available time

PROJECT 2(A) RECOLONISATION AND RECOVERY OF CORAL COMMUNITIES

Chief Investigator(s) Dr T. Done and Dr P. Moran

Research Objectives

This project is concerned with investigating the recolonisation and recovery of coral communities in study areas established prior to being disturbed by an outbreak of the crown-of-thorns starfish. This research addresses issues which are of great importance to our understanding of the nature and implications of such outbreaks on coral communities (see The Crown-of-Thorns Study Reports, 1985). The project stems from research which has been undertaken at the Institute over approximately the last 5 years.

Research plan

The recolonisation and recovery of coral communities is being investigated in two different types of studies (for more details see The Crown-of-Thorns Study Reports, 1985):

1. The composition and dynamics of coral communities is being sampled (by Dr Done) using annual vertical stereophotography of permanent study areas on several reefs (John Brewer, Yonge and Lizard Island Reefs) which have been damaged since photography was commenced in 1980. Growth, mortality and recruitment rates of coral species is being determined by digitizing all colonies in the stereophotographs, computing colony areas, applying photogrammetric scaling, and collating the data for all colonies over the six year period.

2. The change in the community structure of hard corals following an outbreak of the crown-of-thorns starfish is being studied (by Dr Moran) at four permanent study sites on John Brewer Reef. These sites were surveyed using line transect techniques before, during and just after the outbreak. A detailed description of the research plan is given by Moran, Bradbury and Reichelt (1985). Table 1 lists the number of surveys which have been undertaken at the four study sites since the outbreak commenced in mid-1983.

Progress and Results

The progress and results for the two studies are as follows:

1. Digitization is complete for three sites (10 sq. m) at John Brewer Reef and analyses of the data are complete for two of these. Digitization is incomplete for study areas at Yonge Reef. Background mortality in all three of the Brewer sites was significant in 1980-1983, but negligible compared to mortality caused by the starfish in 1983/4. This mortality was almost total, most of the surviving coral consisting of remnants too small to be resolved in the stereophotographs (see Project 2(D)). By 1986, (3 years after the outbreak), recovery and recolonization is undetectable photographically. The predominant benthic organisms in the plot are presently macroscopic algae, turf algae and zooanthids; soft coral and sponge biomass has remained near its original modest level. There is no comparable data set for the same time after the 1969 outbreak at John Brewer Reef, but by 5 years there was significant recovery in the phototransects, which were originally established by Pearson in 1974 (Pearson 1981). In a set of 10 supplementary, larger scale, samples

around the reef (each sample of 3 belt transects of 50 x .6 m), recolonization by hard corals now >2 cm (January 1987) was at a level which suggests the rate of recovery is comparable to that following the 1969 outbreak.

2. No line transect surveys have been undertaken at the four permanent study sites on John Brewer Reef since September 1984. During the last 6 months the sites have been remarked in preparation for being surveyed in June this year. During this period a series of permanent transects sites on nearby Wheeler Reef will also be surveyed as they have recently been affected by an outbreak of starfish. These sites were surveyed between May and August in 1983 (see Table 1) and were relocated and marked during the last 6 months. Unlike John Brewer Reef, the coral communities on Wheeler Reef were not recorded to have been affected by outbreaks of starfish during the 1960s and 1970s. The data obtained from Wheeler Reef will provide a useful comparation with those collected from John Brewer Reef and may help to highlight certain aspects of the recovery process.

Problems Experienced

Stereophotographic material from Yonge Reef and Lizard Island was not completely processed because of slower than anticipated progress in processing the John Brewer Reef material. The cause was an intermittent fault in the digitizer and now, in the computer to which it inputs. Continuity of digitizing was also disrupted by a temporary transfer of the responsible staff member to Projects 1(C). Overall progress in this study during 1987 has been slower than expected as a result of the illness of Dr Done. No significant problems were encountered in the other study.

Future Research

Stereophotography of the study areas will be continued along with broad scale surveys of recovery. As a consequence, funds are requested to continue the employment of a part-time Experimental Scientist to process these data as well as the data that have been obtained during the year. The significant progress made in this study to date (despite several problems) has been due mainly to the presence of this extra person. A small amount of funds is also requested in 1987/88 to support field travel.

It is anticipated that no further line transects surveys of the permanent study sites on John Brewer Reef will be conducted after June 1987. Analysis of the data will be completed and the results written up during the 1987/88 fiscal year. Consequently, no funds are required for this study. A budget for the overall project is given in Table 2.

References

Moran, P.J., Bradbury, R.H. and Reichelt, R.E. (1985) Mesoscale studies of the crown-of-thorns/coral interaction: A case history from the Great Barrier Reef. Proc. Fifth Int. Coral Reef Congr. 5, 321-326.

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

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December, 1985, 160 p.

Table 1. Summary of the data collected from line transect surveys conducted on John Brewer and Wheeler Reefs as part of Project 2(A).

Reef	Site	Depth (m)	Date surveyed
John Brewer	South-east 1	0,3,6,9,12	Oct. 1982 - Mar. 1983
	South-east 1	0,3,6,9,12	October 1983
	South-east 1	0,3,6,9,12	September 1984
	South-east 1	0,3,6,9,12	June 1987*
	South-east 2	0,3,6,9,12	May - Aug. 1983
	South-east 2	0,3,6,9,12	October 1983
	South-east 2	0,3,6,9,12	November 1984
	South-east 2	0,3,6,9,12	June 1987*
	North-east 1	0,3,6,9	Oct. 1982 - Mar. 1983
	North-east 1	0,3,6,9	January 1984
	North-east 1	0,3,6,9	June 1987*
	North-east 2	0,3,6,9	May - Aug. 1983
	North-east 2	0,3,6,9	January 1984
	North-east 2	0,3,6,9	June 1987*
Wheeler	South-east	0,3,6,9,12	May - Aug. 1983
	South-east	0,3,6,9,12	June 1987*
	North-east	0,3,6,9,12	May - Aug. 1983
	North-east	0,3,6,9,12	June 1987*

* Denotes site to be surveyed during 1986/87 fiscal year.

Table 2. Project 2(A): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr T. Done)*	-	3,700
Research Scientist (Dr P. Moran)+	-	4,900
Experimental Scientist (Mr K. Navin)*	-	2,300
Experimental Scientist (part-time)	12,000	
Travelling and subsistence:		
Field travel	300	-
Consumables:		
Film	-	300
Capital Equipment:		
Stereophotography equipment	-	2,000
Hire of aircraft and ships:		
Vessel charter (6 days: R.V. Harry Messel)	-	16,200
(10 days: R.V. Sirius)	-	6,000
TOTAL	**12,300**	**35,400**

* based on 10% of available time
\+ based on 15% of available time

PROJECT 2(B) INTERPRETATION OF THE HISTORY OF DISTURBANCE TO CORAL COMMUNITIES THROUGH ANALYSIS OF MORPHOLOGY AND POPULATION STRUCTURE IN MASSIVE PORITES

Chief Investigator(s) Drs T.J. Done and P.F. Sale

Research Objectives

The aim of this project is to establish whether population structures and growth anomalies of Porites in the field are consistent with disturbance to this species prior to the 1960s.

Research Plan

A more detailed description of the research to be carried out in this project is given in The Crown-of-Thorns Study Reports (1985). Essentially, this research has involved supplementing the data and observations on massive corals collected during the 1985 CCEP Crown-of-Thorns Study. The research conducted as part of this study established that the two recent starfish outbreaks have left many Porites dead or with persistent scars. The present project is concerned with looking for scars as possible evidence of earlier outbreaks. These scars are to be dated using fluorescent banding techniques under development at AIMS.

Progress and Results

A field trip to reefs in the central section of the GBR returned records of population structure and damage which have been evaluated using a simulation model (Done, in press). The simulations indicate that starfish damage to Porites and the projected time for the replacement of the largest size class from stocks of intermediate size corals is highly variable both among reefs and within individual reefs (Done, in prep.).

Scars were found on a small number of living colonies as much as 1.5 m below the living surface, indicating damage to these colonies last century. While the cause of the old scars is not known, it is consistent with partial colony predation by A. planci.

Problems Experienced

It has not been possible to obtain accurate dates of scarred surfaces since the short cores (to 20 cm) taken so far have had a poor fluorescent signal due to poor recovery (breakage) and distance offshore of reefs. The recovery of these corers has been improved by modifying corer design, and cores are scheduled to be dated in the near future. Capricornia surveys (see The Crown-of-Thorns Study Reports, 1985) have not been made because of staff resignations and temporary closure of the One Tree Island field station.

Future Research

Recoring of scars with improved corer, and surveys to seek further scars will be conducted during the 1987/88 fiscal year. In addition, Capricornia surveys will be commenced in May 1987. A budget for the 1987/88 period is given in Table 1.

References

Done, T.J. (in press) Simulation of the effects of Acanthaster planci on the population structure of massive corals in the genus Porites: evidence of population resilience? Coral Reefs.

Done, T.J. (in prep.) Variability in the severity of impact of crown-of-thorns starfish on slow growing corals in the genus Porites sp.

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December, 1985, 160 p.

Table 1. Project 2(B): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr T. Done)+	-	22,550
Experimental Scientist (Mr K. Navin)*	-	2,300
Experimental Scientist (same as Project 2(A))	-	-
Travelling and subsistence:		
Domestic travel (to One Tree Island)	800	-
Consumables:		
Corers	-	100
Drills		300
Hire of aircraft and ships:		
Vessel charter (8 days: R.V. Sirius)	-	4,800
TOTAL	**800**	**30,500**

+ based on 70% of available time
* based on 10% of available time

PROJECT 2(C) GENETICS OF POPULATION FLUCTUATIONS OF CORALS

Chief Investigator(s) Dr J. Stoddart

Research Objectives

The reduction of population size may be a major long-term problem for management. A decrease in numbers is usually accompanied by a decrease in genetic diversity which may prove a major obstacle to recovery by constraining the potential of the population to respond to environmental challenges and promoting inbreeding. However, the relationship between genetics and conservation has been derived from terrestrial circumstances, and marine species, particularly those with planktonic dispersal, may not conform to accepted theory. Corals may be especially resistant to population reductions if theories of their evolution in small semi-isolated populations are correct.

This study evaluates the changes in the population genetic structure of a common species of coral caused when population size is reduced by predation resulting from aggregations of *Acanthaster planci*.

Research Plan

1. Genetic diversity will be examined by enzyme electrophoresis.
2. Populations of *Acropora digitifera*, a common shallow water coral, from areas with varying histories of starfish densities will be sampled, including before and after situations - if practical.
3. Comparisons of diversity estimates will be made using these populations and related to the findings of a more extensive study of this species' genetics.

Progress and Results

To date, a number of samples have been taken from each of 3 populations. These include: a) 'low' starfish history (Heron Is.), b) 'high' starfish history (Green Is.), and c) a population currently in the path of an aggregation (Wheeler Reef).

Electrophoretic analysis of the approximately 700 individuals collected so far is complete. Statistical analysis of populations from Heron Island and Green Island is complete. Although the data are inadequate to allow any generalization at this stage, Heron Island populations were similar in diversity level to those of other reefs with a record of past aggregations, suggesting that populations may accumulate most of their diversity within their first few recruitments. The spatial partitioning of genetic diversity within this species is consistent with this finding.

Some of the results of this study were presented with those for the species as a whole in the IOC WESTPAC "Symposium on Marine Science in the Western Pacific: The Indo Pacific Convergence", Townsville, Dec. 1986.

Problems Experienced

The coral species selected (*Acropora digitifera*) is a reef-flat coral and as starfish are common on reef flats only in heavy aggregations or during calm conditions, it has been difficult to find a site where there is any surety of a before and after site within a 3 yr period. For this reason, Wheeler Reef may not provide a suitable 'after' sample. The situation at Wheeler Reef will be monitored closely over the next year.

Future research

Further field sampling will occur on reefs with starfish histories intermediate between those chosen (Green Island and Heron Island), to add a greater variety and replication of reef type to the study. Data collection and analysis should be complete by Dec. 1987. A small amount of funds are required to continue this research in the 1987/88 fiscal year (Table 1). The funds are mainly for chemicals used in the electrophoretic analyses.

Table 1. Project 2(C): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr J. Stoddart)*	-	3,000
Experimental Scientist (Ms E. Ballment)*		3,100
Travelling and subsistence:		
Field travel	400	-
Consumables:		
Chemicals/gels	1,500	-
Freight and cartage:	200	-
Capital equipment:		
Balance		1,200
TOTAL	**2,100**	**7,300**

* based on 10% of available time

PROJECT 2(D) GROWTH AND SURVIVORSHIP OF CORAL REMNANTS FOLLOWING OUTBREAKS OF ACANTHASTER PLANCI

Chief Investigator(s) Dr T.J. Done

Research Objectives

Much has been made of the issue of the dependence of reefs upon one another as sources of coral propagules but a major stock of corals remains within damaged reefs which seems independent of other reefs for continued survival of local populations. This stock comprises 'remnant' corals - portions of viable tissues on corals injured by A. planci. The aim of this project is to determine how important these remnants are in the recovery of coral communities after outbreaks of A. planci.

Research Plan

A high density of remnants (size range 1-10 cm maximum dimension) survived the 1983/4 outbreak on John Brewer Reef. Growth and survivorship of these remnants has been monitored on three occasions since the outbreak. Monitoring of the remnants will be continued at approximately 6 monthly intervals by further hand mapping and stereophotography.

Progress and Results

The status of this project is the same as that reported in September 1986 (The Crown-of-Thorns Study, 1986).

Future Research

It is intended that the results of this project will be published along with those of Project 2(A). No COTSAC funds are required to undertake this work during 1987/88. The notional costs of this research to AIMS is given in Table 1.

References

The Crown-of-Thorns Study Reports (1986) Progress report on research: 1985/86. Australian Institute of Marine Science, Townsville. Vol. 7, September 1986. 25 p.

Table 1. Project 2(D): 1987/88 budget showing notional costs to AIMS.

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr T. Done)*	-	3,700
Experimental Scientist (Mr K. Navin)*	-	2,300
Experimental Scientist (same as Project 2(A))	-	-
Hire of aircraft and ships:		
Vessel charter (3 days: R.V. Harry Messel)	-	8,100
TOTAL	-	**14,100**

* based on 10% of available time.

PROJECT 2(E) EFFECTS OF OUTBREAKS OF A. PLANCI ON FISH COMMUNITIES

Chief Investigator(s) Dr D.McB. Williams

Research Objectives

The aim of this project is to determine the long-term effects of *A. planci* outbreaks on adult reef fishes and their recruitment.

Research Plan

The abundance of adults of 146 species belonging to 7 families were determined on four mid-shelf reefs off Townsville prior to the *A. planci* outbreak in 1983 (Williams, 1982). Live coral cover on three of these reefs (Rib, John Brewer and Lodestone) but not the fourth (Davies) was dramatically reduced by *A. planci* in 1983. Densities of adult fishes on these reefs were re-surveyed in November 1983 and at 6-monthly intervals thereafter until May 1986 (The Crown-of-Thorns Study Reports, 1985). It was initially proposed that the censuses of fish on the *A. planci* affected reefs should continue every 6 months and those on the 'control' reef every 12 months.

The commercially important coral trout were not included in the original surveys but had been censused on these reefs at the time of the outbreak, using a specialised census technique (The Crown-of-Thorns Study Reports, 1985) by Dr Tony Ayling. It was proposed that a second party re-census coral trout densities on these reefs at the same time as the above surveys were carried out.

Studies of recruitment of fishes to Rib, John Brewer and Lodestone Reefs plus Myrmidon and Pandora reefs were initiated in 1982/83, prior to the A. planci outbreak. Annual recruitment surveys of fixed sites on these reefs were maintained annually in 1983/84, 1984/85 and 1985/86. It was proposed to continue these annual surveys into 1986/87 (The Crown-of-Thorns Study Reports, 1985).

Progress and Results

Visual surveys of adults in May 1986 confirmed earlier observations of major decreases in the densities of coral-feeding butterflyfishes as well as in the densities of two of the most abundant planktivores, Chromis atripectoralis and Pomacentrus popei, that could be attributed to A. planci outbreaks. The decrease in densities of the latter two species has lagged behind that of the butterflyfishes by almost 12 months. The recruitment surveys of 1985/86 and 1986/87 have confirmed an earlier hypothesis that the decrease in densities of adults of the latter two species is the result of recruitment failure following the outbreaks. No changes in the abundances of algal-grazing species or of coral trout were detected in the May 1986 surveys.

The 1986/87 recruitment surveys have been successfully completed but the data awaits detailed analysis. It is anticipated that a follow up to the paper by Williams (1986) will be published after the adult surveys in November 1987.

Problems Experienced

Three years data on adult densities at 6 month intervals indicated that changes were sufficiently slow that annual surveys would be more than adequate to monitor changes in adult densities. It was thus proposed to survey adults on all reefs in November of each year. The November 1986 census was not undertaken after the French Government offered to fund my examination of fish communities on A. planci affected reefs in French Polynesia during this period. As a result the next proposed survey of adults will be in November 1987. Given the observed rates of change it is believed that the resulting 18 month gap between adult censuses will not significantly alter the effectiveness of the proposal.

Tony Ayling himself (not Dr Doherty or Ms Samoilys as suggested in The Crown-of-Thorns Study Reports, 1985) was fortunately able to re-survey trout densities on the mid-shelf reefs during the May 1986 cruise and proposes to resurvey them again in November 1987 in conjunction with the above studies.

The tentative proposal to examine changes in trophic structure and species diversity did not proceed in 1986/87 due to lack of man-power and other commitments.

Future Research

At this stage, monitoring of adult and recruit densities will continue annually at least until the coral communities on the affected reefs return to a state similar to that immediately prior to the A. planci outbreak. A small amount of funds are required to undertake this research over the next fiscal year (Table 1).

References

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December, 1985, 160 p.

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. (1986) Temporal variation in the structure of reef slope fish communities (central Great Barrier Reef): Short term effects of Acanthaster planci infestation. Mar. Ecol. Prog. Ser. 28, 157-164.

Table 1. Project 2(E): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr D. Williams)*	-	3,550
Experimental Scientist (Ms S. English)+	-	4,150
Travelling and subsistence:		
Field travel	500	-
Domestic travel	500	-
Consumables:		
Field equipment	920	-
Hire of aircraft and ships:		
Vessel charter (10 days: R.V. Harry Messel)	-	27,000
(10 days: R.V. Lady Basten)	-	35,000
TOTAL	**1,920**	**69,700**

* based on 15% of available time
\+ based on 10% of available time

PROJECT 3(A) MACROSCALE STUDIES OF THE DISTRIBUTION AND ABUNDANCE OF ACANTHASTER PLANCI AND CORALS ON THE GREAT BARRIER REEF

Chief Investigator(s) Ms D. Bass, Mr D. Johnson
Mr B. Miller-Smith and Mr C. Mundy

Research Objectives

The major objective of this study is to assess the current extent of Crown-of-Thorns starfish populations, and their effects on corals, on the Great Barrier Reef.

This information is of vital importance to provide both researchers and managers of the GBR with up to date information on the Acanthaster phenomenon, and also a valuable database, for assessing possible risks posed by the starfish. It is important that the collection of this data be continued, building on the database obtained in 1985/86 by the COT-CCEP study. Background to the current study can be found in the original proposal (The Crown-of-Thorns Study Reports, 1985).

Research Plan

Of the 228 reefs surveyed in the 1985 CEP Crown-of-Thorns Study, it was originally proposed that approximately 60 reefs would be resurveyed annually using the same survey techniques that were used in the COT-CCEP Crown of-Thorns Study (COT-CCEP, 1986). The reefs that were resurveyed were selected according to criteria set out in the original research proposal for this project (The Crown-of-Thorns Study Reports, 1985).

It was anticipated that synoptic surveys would be conducted on these reefs each year, and benthic lifeform transects would be undertaken on approximately 20 of the selected reefs.

Progress and Results

Field surveys for the 1986/1987 period are nearing completion with only the last section, Whitsundays/Pompeys remaining to be surveyed in May. To date, a total of 92 reefs have been surveyed. This includes fieldwork for the Princess Charlotte Bay, Cooktown/Lizard Island, Cairns/Innisfail, Townsville, Cape Upstart, and Swains/Capricorn Bunkers sectors. After the scheduled cruise in May, over 100 reefs will have been surveyed on all sectors of the GBR south of Princess Charlotte Bay.

In August 1986, the G.B.R.M.P.A. conducted a starfish control program on Grub reef. The field team undertook surveys both prior to, and following the removal of starfish. It is anticipated that the results from this survey will in due course be published in a scientific journal.

Problems Experienced

All surveys to date have been completed without any problems. Favourable weather conditions and co-operative boat charters have aided us in already surveying far more reefs than originally proposed.

Future Research

It is expected that surveys will continue on an annual basis, beginning in June 1987. It is likely that the same reefs will be resurveyed during the forthcoming year. In light of the need for current information on the distribution and abundance of the crown-of-thorns starfish, these consecutive surveys allow for temporal enhancement of the established database. A list of the reefs surveyed in each sector is given in Table 1. The funds required to continue these important surveys are given in Table 2.

References

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December 1985, 160 p.

COT-CCEP Crown-of-Thorns Study (1986) An assessment of the distribution and effects of the starfish Acanthaster planci (l) on the Great Barrier Reef. Volume 1: Methods; Australian Institute of Marine Science, Townsville, 30 p.

Table 1. List of the reefs to be surveyed during 1987/88 as part of Project 3(A).

Sector	Reef Name/Number
Princess Charlotte Bay	Tydeman
	Davie
	Rodda
	Joan
	Clack
Cooktown/Lizard Island	Hilder
	Hicks
	No Name
	MacGilvray
	Lizard Island
	Linnet
	Eye
	Helsdon
	Two Isles
	Forrester
	Marx
	Startle
	Swinger
	Boulder
Cairns/Innisfail	Norman
	Saxon
	Michaelmas
	Green Island
	Pixie
	Thetford
	Fitzroy
	17-012
	17-013
	Flora
	Noggin
	Peart
	Feather
	Potter
	Elison
	Low Isles
	Sth. Barnard Islands

Table 1. (continued)

Sector	Reef Name/Number
Townsville	Pandora
	Myrmidon
	Havannah
	SW Slashers
	Hopkinson
	Helix
	John Brewer
	Wheeler
	Davies
	Yankee
	Grub
	Fork
	Knife
	Keeper
	Rib
	Lodestone
	Dip
Cape Upstart	Bowden
	Old
	Charity
	Stanley
	Mid
	Prawn
	Shrimp
	Viper
	Jupiter
	Pollux
	Holbourne
	Faith
Whitsundays/Pompeys	Sinker
	Bait
	Rafter
	Plaster
	19-151
	19-152
	19-177
	Gargoyle
	Tideway
	McIntyre
	Bond
	Packer
	Cannon
	Credlin
	Ben
	Abbott
	21-140

Table 1. (continued)

Sector	Reef Name/Number
Swains/Capricorn-Bunkers	Heron
	Fitzroy
	One Tree
	Dicks
	22-144
	22-143
	Sanctuary
	Gannet
	Frigate
	Twin 21-495
	Twin 21-497
	21-285
	21-286
	21-230
	Trout
	Mystery
	21-186
	Hoskyn Island
	Lady Musgrave
	22-114
	22-113
	22-112
	Recreation
	21-200
	Centenary
	Bell Cay
	22110
	22117
	22118
	Wistari
	Broomfield

Table 2. Project 3(A): 1987/88 budget showing costs to COTSAC and AIMS (notional)

Item	Cost ($) COTSAC	AIMS
Salaries:	103,000	-
Experimental Scientist (Mr D. Johnson)		
Experimental Scientist (Ms D. Bass)		
Experimental Scientist (Mr B. Miller-Smith)		
Experimental Scientist (Mr C. Mundy)		
Travelling and subsistence:		
Field travel	2,500	-
Domestic travel	1,200	-
Consumables:		
Field equipment	2,000	-
Hire of aircraft and ships:		
Vessel charter (R.V. Sirius)	24,000	-
(15 days: R.V. Sirius)		9,000
TOTAL	**133,000**	**9,000**

PROJECT 3(B) MESOSCALE STUDIES OF THE DISTRIBUTION AND ABUNDANCE OF ACANTHASTER PLANCI AND CORALS ON SELECTED REEFS.

Chief Investigator(s) Dr P. Moran

Research Objectives

This project attempts to gain a better understanding of the behaviour of outbreaks on reefs. It is concerned with addressing such fundamental questions as:

1. How long do outbreaks persist on reefs?
2. Do they first occur on particular parts of reefs?
3. What sorts of gross changes take place in both the distribution and abundance of the starfish and its coral prey?
4. Do these changes show a pattern which is consistent for different types of reefs?
5. Do such patterns have implications for the management and control of outbreaks?
6. Do outbreaks of varying densities and spatial dimensions behave differently?

These rather fundamental questions cannot be answered at present because very little information has been collected in the past on the broad changes which occur in the distribution and abundance of both the crown-of-thorns starfish and its coral prey over an entire outbreak cycle. Generally, previous surveys have not been conducted at frequent enough intervals on the same reefs and quite often one of the "pair object", not both, have been investigated (see The Crown-of-Thorns Study Reports, 1985). Since 1982 surveys of John Brewer Reef have given the first clear picture of the way in which outbreaks may be behave on reefs. The preliminary results of these surveys, obtained before, during and just after the outbreak, have been reported by Moran, Bradbury and Reichelt (1985).

Research Plan

The original goals of this project (see The Crown-of-Thorns Study Reports, 1985) were to continue to obtain information on the change in the distribution and abundance of starfish and corals on John Brewer Reef and to obtain this type of data from several other reefs located off Townsville including: Helix, Wheeler, Davies and Bowden Reefs. At the time when the original proposal was written both Helix and Wheeler Reefs were in various stages of an outbreak of crown-of-thorns starfish. In contrast, Davies and Bowden Reefs were judged at that time to be relatively free of starfish and it was hoped that either one of them, or both, may experience an outbreak over the following year.

Progress and Results

By September 1986 (see The Crown-of-Thorns Study Reports, 1986) the five reefs had been surveyed on at least two occasions. Since then they have been surveyed only once, primarily for two reasons. Firstly, several additional reefs in the Swain Reef Complex were surveyed over this period of time. Secondly, the amount of field time dedicated to this project has been reduced so that the Chief Investigator could complete field related tasks in several other Projects (1(H), 1(I) and 2(A)).

Details of the surveys which have been undertaken over the last 6 months in this project are given in Table 1. Those conducted on Bowden and Davies Reefs have recently recorded high (thousands of individuals) and moderate (hundreds of individuals) numbers of starfish respectively on these reefs.

These populations will be followed with great interest as both are found only over a small area of each reef. That found on Davies Reef is especially interesting as the starfish were generally dispersed and causing only patchy damage to the corals in the surrounding area. As it comprised very large starfish (generally > 35 cm) it is possible that this is not an outbreak but some sort of "stable" population which has the potential to give rise to secondary outbreaks.

It should be noted that swim surveys have been undertaken in conjunction with the more general manta tow surveys on reefs where starfish densities are relatively low. The results from the swim surveys provide a useful comparison to those obtained from the manta surveys and also yields important information concerning the abundance of crown-of-thorns starfish over an entire reef.

The surveys undertaken in the Swain Reefs Complex have provided important information on the types of outbreaks which occur in this region. For example, small populations of starfish, comprising between 50-100 starfish and occurring over less than about 500 m of reef perimeter were found on Sanctuary and Gannet Cay Reefs. The finding of these populations and intense outbreaks (i.e. hundreds to thousands of starfish over a relatively small areas) on 22110 and 22112 Reefs highlights three important points:

1. The difference between supposedly "normal" and "outbreaking" populations may not be as great as originally suggested.
2. Outbreaks in the Swain Reefs Complex are qualitatively different to those which have been observed over the last few years between Cairns and Townsville.

3. Outbreaks in the Swain Reefs Complex may be occurring independently of those on the rest of the reef given that they are so far away from any other outbreak (the closest being those presently occurring off Townsville). It is possible that this region is a source of primary outbreaks and investigation of this anomaly may help to suggest likely mechanisms for the cause of outbreaks.

Problems Experienced

The progress of this project has been slower than expected since reefs have not been surveyed as regularly as first proposed (see previous section). It is hoped that surveys of the reefs off Townsville will become more frequent by the end of the year once field studies in Project 1(H) are completed.

Future Research

Surveys will be continued of starfish and corals on the reefs included in this project to date. During the later half of next fiscal year it is expected that surveys of these reefs will be conducted at 6 monthly intervals. This project is to be continued until the end of the COTSAC program which will give good temporal data on some reefs for a period of up to 7 years. Such information is of great importance to the management of the reef and to modelling studies. A small amount of funds are required to undertake the field component of this project. A budget for the 1987/88 fiscal period is given in Table 2.

References

Moran, P.J., Bradbury, R.H. and Reichelt, R.E. (1985) Mesoscale studies of the crown-of-thorns/coral interactions: A case history from the Great Barrier Reef Proc. Fifth Int. Coral Reef Congr. 5, 321-326.

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December 1985, 160 p.

The Crown-of-Thorns Study Reports (1986) Progress report on research. Australian Institute of Marine Science, Townsville. September, 1986, 25 p.

Table 1. Surveys of the distribution and abundance of starfish and corals conducted on reefs since August 1986 for Project 3(B).

Region	Reef	Survey Type	Survey Extent	Date
SWAIN COMPLEX	22110	Manta	All perimeter	15/03/87
	22110	Swim	All perimeter	16/03/87
	22112	Manta	All perimeter	25/11/86
	22112	Manta	All perimeter	13/03/87
	22112	Swim	All perimeter	14/03/87
	Gannet	Manta	All perimeter	21/11/86
	Gannet	Manta	All perimeter	17/03/87
	Gannet	Swim	Back	22/11/86
	Gannet	Swim	Back	17/03/87
	Sanctuary	Manta	All perimeter	23/11/86
	Sanctuary	Manta	All perimeter	17/03/87
	Sanctuary	Swim	Back	23/11/86
	Sanctuary	Swim	Back	17/03/87
TOWNSVILLE	Bowden	Manta	All perimeter	21/10/86
	Bowden	Swim	Back (parts)	21/10/86
	Davies	Manta	All perimeter	22/10/86
	Davies	Manta	All perimeter	08/01/87
	Davies	Swim	All perimeter	09/01/87
	Helix	Manta	All perimeter	24/10/86
	John Brewer	Manta	All perimeter	26/10/86
	John Brewer	Manta	Lagoon	26/10/86
	John Brewer	Manta	Flat	26/10/86
	Keeper	Manta	All perimeter	23/10/86
	Lodestone	Manta	All perimeter	23/10/86
	Wheeler	Manta	All perimeter	13/08/86
	Wheeler	Manta	All perimeter	05/01/87

Table 2. Project 3(B): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr P. Moran)*	-	8,100
Travelling and subsistence:		
Field Travel	700	-
Consumables:		
Field equipment	500	-
Hire of aircraft and ships:		
Vessel charter (19 days: R.V. Sirius)	-	11,400
TOTAL	**1,200**	**19,500**

* based on 25% of available time

PROJECT 4(A) ENHANCEMENT OF SUBSTRATE REFLECTANCE IN LANDSAT IMAGERY WITH SPECIAL REFERENCE TO REEF DAMAGE BY ACANTHASTER PLANCI

Chief Investigator(s) Dr R. Reichelt and Dr D. Jupp (CSIRO Division of Water and Land Resources)

Research Objectives

The aim of this project is to enhance the substrate reflectance of Landsat imagery in shallow coral reef areas using bathymetry data in order to test whether the effects of outbreaks of *Acanthaster planci* can be seen in multi-date imagery (i.e. images of the same reef taken at different points in time). The results of this project are of direct importance to the research being carried on in Project 4(B).

Research Plan

In order to achieve the objectives of this project a set of images would be needed that were taken in 1983, 1984 and 1985 and that show John Brewer Reef, among others, clearly. John Brewer Reef has been a focal point for this project because a large amount of biological and ecological data on the crown-of-thorns starfish have been collected on this reef (particularly since later 1982). This reef is also the focus for research in several other projects (e.g. Projects 4(B), (C) and (D)).

For the images that were acquired a standard co-ordinate grid was to be established and Australian Survey Officer (ASO) depth data would be processed to conform with this grid at a resolution of 50 m or less (hopefully 20 m). Both Depth of Penetration (Jupp *et al.*, 1985) and Enhanced Substrate Reflectance Images would be produced using these data (see The Crown-of-Thorns Study Reports, 1985). The changes that have occurred on John Brewer Reef were to be assessed by comparison of these remotely sensed data with the known pattern of the outbreak (Moran, Bradbury and Reichelt, 1985).

Progress and Results

Imagery has been acquired and processed for Depth of Penetration. An extensive upgrade to the MicroBRIAN system has been completed by CSIRO Department of Water and Land Resources (under supervision of D. Jupp) and a key component of this upgrade is the inclusion of the algorithm needed to enhance the substrate reflectance images (see The Crown-of-Thorns Study Reports, 1985).

Initial trials of the technique have been done and are encouraging but were undertaken with limited depth data and for a single image only. To allow multi-date comparisons it has become clear that a means of comparing images (and depths) on a standard co-ordinate grid is essential. This type of grid is being developed at the CSIRO for ASO depth data of John Brewer Reef. The MicroBRIAN upgrade will allow the Landsat imagery to be resampled onto this standard grid.

Problems Experienced

The difficulties of comparing multi-date images is common to all remote sensing work and therefore is not a trivial problem. The research now underway to develop a method of resampling data to a standard grid should allow direct numerical comparisons to be made between images, rather than a visual assessment of similarities and differences. It is anticipated that this research may take several months to complete but it is considered critical to the success of this project.

Future Research

The research plan is to concentrate on the problem of numerical comparison of multi-date imagery. At the same time, the new MicroBRIAN software will be used to produce the enhanced substrate reflectance images, as soon as the re-gridding of the depth data is complete.

The project is expected to be completed within 1 year. A valuable extension of this project would be to extend the testing of the technique to Thematic Mapper, SPOT and MOS-1 data (which have smaller pixels), all of which may be available before the end of the project. No COTSAC funds are required for this project during the 1987/88 fiscal period.

References

Jupp et al. (1985) The BRIAN handbook. Natural Resources Series No. 3. CSIRO Division of Water and Land Resources, Canberra, 43 p.

Moran, P.J., Bradbury, R.H., and Reichelt, R.E. (1985) Mesoscale studies of the crown-of-thorns/coral interaction: A case history from the Great Barrier Reef. Proc. Fifth Int. Coral Reef Congr., Tahiti, 5, 321-326.

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December 1985, 160 p.

Table 1 Project 4(A): 1987/88 budget showing notional costs to AIMS.

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr R. Reichelt)*	-	940
Experimental Scientist (see Project 4(B))	-	-
Capital Equipment:		
Line printer/plotter	-	2,500
TOTAL	-	**3,440**

* based on 5% of available time

PROJECT 4(B) EVALUATING THE PROCEDURES FOR THE VERIFICATION OF LANDSAT IMAGES WITH REFERENCE TO THE EFFECTS OF OUTBREAKS OF ACANTHASTER PLANCI ON REEFS

Chief Investigator(s) Dr R. Reichelt and Mr S. Bainbridge

Research Objectives

The aim of this project is to evaluate the procedures for ground-truthing Landsat imagery of coral reefs in order to determine whether Landsat data is a suitable tool for monitoring the changes that occur on coral reefs after crown-of-thorns starfish outbreaks. A background to this project has been given in an earlier document (The Crown-of-Thorns Study Reports, 1985).

Research Plan

The plan of research is to:

1. Acquire historical images of John Brewer reef before, during, and after the 1984 starfish outbreak at that reef;
2. Process these images using the AIMS microBRIAN system;
3. Undertake a field trip to John Brewer reef to collect ground truth data describing the benthic cover of the shallow reef substrata using a variety of field techniques. The location of ground control points will be done with the assistance of the Australian Survey Office;
4. Analyse and write up the results of the field work.

Progress and Results

Steps 1, 2 and 3 have been completed. As part of step 3 the reflectance values for 5 of the 10 study sites on John Brewer Reef were measured using an airborne radiometer. This work was carried out in collaboration with Dr D. Kuchler (CSIRO). Also, as an adjunct to this project, a SPOT image of John Brewer has been ordered by AIMS. The results obtained during the field trip are highly relevant to the study of infrared photography techniques being undertaken concurrently by James Cook University (The Crown-of-Thorns Study Reports, 1986).

Problems Experienced

No major problems have been experienced to date. However, only one transect (200 m) was able to be surveyed at each site (instead of 3) due to bad weather. It is believed that this size of sample will still be sufficient to enable the objectives of this project to be achieved.

Future Research

Future work will involve the analysis and writing up of the data as a scientific publication. With the addition of aerial infra-red photography, airborne radiometry and SPOT data, the original goals of this project may be extended well beyond the assessment of only Landsat data. The project is expected to be completed within one year. The funds required to continue this important project during the 1987/88 fiscal period are given in Table 1.

References

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (*Acanthaster planci*) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December 1985, 160 p.

The Crown-of-Thorns Study Reports (1986) Progress report on research. Australian Institute of Marine Science, Townsville. September, 1986, 25 p.

Table 1. Project 4(B): 1987/88 budget showing costs to COTSAC and AIMS (notional)

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr R. Reichelt)*	-	3,200
Research Scientist (Dr P. Moran)+	-	1,400
Experimental Scientist (Mr S. Bainbridge)	26,000	-
Travelling and subsistence:		
Domestic travel	1,200	1,000
Consumables:		
Maps, charts, aerial photographs	100	-
Hire of aircraft and ships:		
Vessel charter (5 days: R.V. Harry Messel)	-	16,200
TOTAL	**27,300**	**21,800**

* based on 10% of available time
+ based on 5% of available time

PROJECT 4(C) NUMERICAL MODELS OF THE HYDRODYNAMIC REGIME AROUND SCHEMATISED AND ACTUAL REEFS

Chief Investigator(s) Dr K. Black (Victorian Institute of Marine Sciences) and Dr J.C. Andrews

Research Objectives

The primary objective of this project is to use numerical models of hydrodynamics and dispersion to simulate the wind, tidal, long-period current and wave circulation around GBR reefs, for examination of the dispersal of larvae of the Crown-of-Thorns starfish. The research in the project has been designed to isolate generalised principles of dynamics and dispersion. These results are to be correlated with known outbreak patterns.

The study complements Project 4(D) which entails a detailed data acquisition programme at John Brewer Reef, and subsequent modelling of that reef.

Research Plan

To examine fine-scale circulation and dispersion on coral reefs, numerical model runs were made of a series of schematised and actual reefs using a very fine grid selected in each case to resolve the important bathymetric features. In the first instance, general principles were being sought, so that a range of reef shapes, selected for their varying morphology, range of environmental conditions and outbreak history were simulated. With this wide selection of output, the effect of varying environmental factors over the different reef types were to be examined. The final stages of the project were to relate the results on specific reefs back to the known distribution of starfish on these reefs.

Progress and Results

To do this task, more than 30 separate hydrodynamic simulations of reefs were made. Each of these were then compounded by several simulations of dispersion to adequately cover the various options with respect to larval release patterns. The hydrodynamic model runs are presently being written up and are essentially complete. Some of the dispersion runs are still in progress.

Several important matters have been isolated including identification of the mechanism responsible for the formation of eddies around GBR reefs. The Journal of Geophysical Research has accepted a paper discussing this. Other papers are in progress or have been submitted for review. A major finding, that of long retention times on the reef, is presently being numerically verified and prepared for publication. A paper was given at the Australian Coral Reef Society Conference discussing larval retention times. A paper detailing the important generalisations with respect to small-scale coral reef hydrodynamics has been submitted for the APOC conference at Townsville in May. The full details of this work have been prepared for Continental Shelf Research and is to be submitted before the conference in May.

Stages 1 and 2 of the project (see The Crown-of-Thorns Study Reports, 1985) have been completed as planned. The third stage is in progress at present, and will be partially completed by June 1987, as planned. Stage 4 has been initiated earlier than planned, with some initial comparison of the model results with the specific COT distributions around the selected reefs.

Project 4(D) is using the numerical model of Black (2DD) to do a detailed simulation of a particular time period at John Brewer Reef. The model has been established on the AIMS computer and modified to allow input of very long time series at the boundaries, so that the modelling in this project is able to progress.

Problems Experienced

There have been no significant problems except for the loss of research assistance at the end of 1986. The complexity and detail of the program required full-time work by Mr Stephen Gay during March-December 1986, and heavy commitment of Dr Black's time in 1986. Dr Black presently has MST and other responsibilities, and as his time is not funded by the COTSARC project, he must give these other matters priority. The success of the project, resulting in large amounts of information on larval dispersal patterns, means that the workload is much greater than envisaged in the first proposal. There have been numerous requests from other scientists for output from simulations of particular reefs, adding to the workload.

Some of the problems of workload have been alleviated with the provision of extra funds to cover an assistant's time in the first half of 1987, to help with the final report on reef hydrodynamics.

Future Research

The work has produced a considerable amount of information which was previously unknown about small-scale reef hydrodynamics and dispersion. This information has extremely important implications for the dispersal of larvae of the crown-of-thorns starfish as well as many other different reef organisms (e.g. corals). As a consequence several important avenues of continued research have become evident. Each of these have been examined in part in 1986/87 and the general results are known. The future work will examine these matters in sufficient detail to finalise and report on the work.

The 1987/88 program will see the completion of Stage 3 of the initial proposal (i.e. the dispersion modelling and production of a report, which will complement the report on hydrodynamic modelling presently in preparation). Stage 4 of the project which relates the computer modelling to the distribution of starfish on particular reefs is to be examined in detail in 1987/88, as originally proposed. Therefore, funds are requested to continue this research in the next fiscal year (see Table 1).

References

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Table 1. Project 4(C): 1987/88 budget showing costs to COTSAC and AIMS (notional)

Item	Cost ($)	
	COTSAC	AIMS
Salaries:		
Principal Research Scientist (Dr J.C. Andrews)*	-	2,500
Collaborations (VIMS):		
Salaries	5,000	-
On-costs	875	-
Fares and travel costs	1,000	-
Consumables	625	-
TOTAL	**7,500**	**2,500**

* based on 5% of available time

PROJECT 4(D) NUMERICAL MODELS OF THE HYDRODYNAMIC REGIME AT JOHN BREWER REEF

Chief Investigator(s) Dr J.C. Andrews and Dr K. Black (VIMS)

Research Objectives

The aim of this project is to use field data to calibrate a numerical model for the combined tidal and wind-forced circulation at John Brewer Reef, and to apply those circulation patterns to calculate the trajectories, residence times and likelihood of outbreaks of crown-of-thorns starfish on areas of the reef.

This is an extension of Project 4(C) which is largely schematic, using steady state wind-currents (10 knot SE wind) and mid-range tides with constant amplitudes (no spring/neap cycle) applied to a suite of reefs selected to cover the spectrum of reef shapes encountered in the GBR. Project 4(D) has a particular focus on John Brewer Reef, uses a fine scale grid and near-field time series of field data to simulate actual currents and trajectories around and over the reef.

Research Plan

Four stages in the research were laid out in the original proposal (see The Crown-of-Thorns Study Reports, 1985), and further information can be found in that document. The stages were:

1. Compilation of bathymetric data bank
2. Construction and testing of hydrodynamic models
3. Field calibration and model validation
4. Particle trajectory simulations

Progress and Results

Apart from equipment purchase in 1986, the Project commenced in January 1987 with the arrival at AIMS of the Experimental Scientist who had assisted Dr Black with Project 4(C). The emphasis over the 12 weeks of operation has been on the selection and modification of a model to suit the particular requirements at John Brewer Reef (stage 2) and on the design and installation of an array of current meters and tide gauges (stage 3).

The model (2DD) used by Dr Black in Project 4(C) has been proven appropriate for this project but has required modifications to the boundary conditions to allow efficient simulation of an open sea environment over long periods, and to facilitate transfer to the AIMS VAX computer. The boundary interfacing has been solved by using contemporary currents measured in the water column, filtering into tidal and low frequency wind-forced components, harmonic analysis for tidal constituents, harmonic inversion, resynthesis into noise-free wide-band currents and conversion into sea level gradients which, together with a similarly treated sea level record, allow the far field sea levels to be specified around the model boundary. In addition, provision has been made for perturbations induced by the reef to extend to the boundaries by isolating the perturbations and using a constrained radiation condition on the perturbations. In situ time series or currents are not yet available to test these procedures on John Brewer Reef and historical data from a nearby reef, Helix Reef, have been used to date.

Moorings have been designed and constructed for instrumenting the far field and near field of John Brewer Reef. They were deployed over a week at the beginning of April. They will endure for a sufficient time to cover the full range of normal weather and tide conditions, to allow later synthesis of far field sea levels (to simulate currents) for any weather and tide combination at any time, as well as synthesis for the period of the calibration experiment. Figure 1 shows the locations of current meters (CT) and sea level recorders (WT). Locations CT6, 7, 8, 10, 11 and 12 were identified as important during Project 4(C) where currents caused by a mid range tide and a 10 knot SE wind were simulated. The transect CT8, 9 and 3 has been laid to investigate the interaction between John Brewer and Lodestone Reefs. The model boundary is defined by CT1, 2, 3, 4, 5, and 13; far field sea level gradients will be calculated from these current meters. In addition to water level recorders at locations WT1 and 2, there are recorders near the sea floor at sites CT1, 2 and 4, forming an array having tide gauges at the corners of the model as well as in the centre on the reef. One current meter was placed at mid depth at each CT site, excepting CT1 (sea depth 42 m) where meters were placed at heights of 7, 16, 24 and 32 m from the sea floor in an attempt to define the velocity profile.

Problems Experienced

No major problems have been encountered and the project is proceeding according to plan. The only irritation stems from being constrained to calibrate the reef in winter rather than in summer. It will be necessary to leave some far field meters in place after the main experiment, in order to ensure that the spectral transfer function relating winds to currents does not change with the season (it would be extraordinary if the transfer function was to change).

Future Research

Please see the original proposal (The Crown-of-Thorns Study Reports, 1985); there have been no changes to the research plan since it was proposed, except that the need to use historical data from Helix Reef affords an opportunity to include some discussion of that reef in the COTSAC context. The estimated time to completion is as specified in the original proposal (July 1989). A budget for this Project is given in Table 1.

References

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December 1985, 160 p.

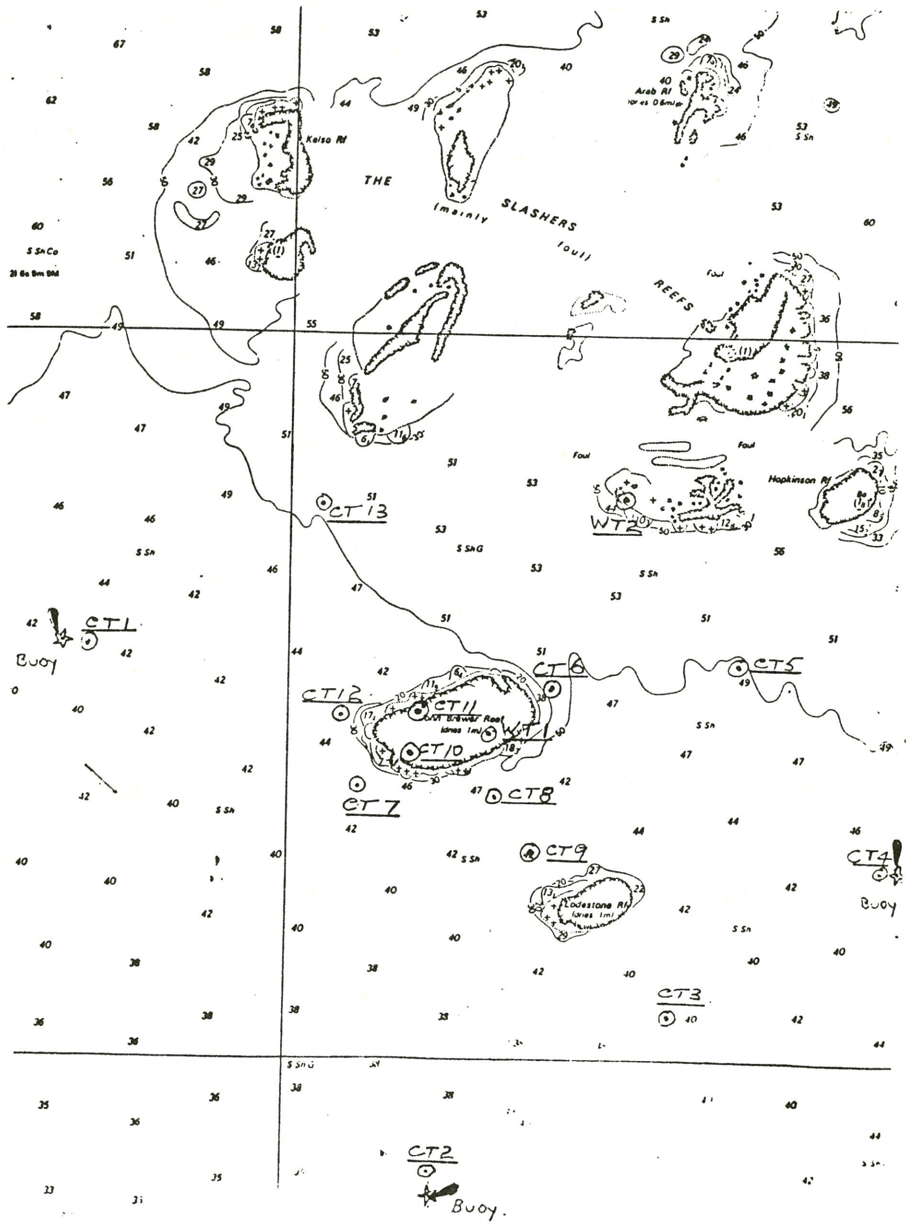

Figure 1. Map showing the locations of current meters deployed around John Brewer Reef

Table 1. Project 4(D): 1987/88 budget showing costs to COTSAC and AIMS (notional)

Item	Cost ($) COTSAC	Cost ($) AIMS
Salaries:		
Principal Research Scientist (Dr J.C. Andrews)*	-	5,000
Experimental Scientist (Mr L. Kelly)+	-	1,400
Experimental Scientist (Mr R. Hughes)+	-	1,000
Experimental Scientist (Mr R. McAllister)*	-	3,000
Experimental Scientist (Mr S. Gay)	24,700	-
Travelling and subsistence:		
Field travel	300	-
Consumables:		
Field equipment	2,000	-
Current meter moorings and drogues	-	5,000
Hire of aircraft and ships:		
Vessel charter (10 days: R.V. Lady Basten)	-	35,000
Computing time:		
VAX: 10 CPU hrs/wk (@$300/CPU hour)	-	90,000
TOTAL	**27,000**	**140,400**

* based on 10% of available time
\+ based on 5% of available time

PROJECT 4(E) MODELS OF THE DISPERSAL OF ACANTHASTER PLANCI OUTBREAKS

Chief Investigator(s) Dr R. Reichelt

Research Objectives

The original goal of this Project was to build simulation models of the dispersal of outbreaks on the Great Barrier Reef (see The Crown-of-Thorns Study Reports, 1985). This has now been refined in the light of initial experiences in the construction of such a model (hence the change in the title of the Project). The goal is now to build a series of simulation models that capture different aspects of the starfish dispersal problem in order to understand the processes occurring over a range of spatial scales.

Research Plan

Given that the aim of this Project has been refined the research plan can now be described by the following stages:

1. Build a non-spatial model of the starfish-coral interaction, treating the interaction as a 2 species predator-prey system with realistic values for the biological parameters.
2. Build a simulation model of the behaviour of starfish outbreaks at the scale of a single reef.
3. Build a simulation model of the dispersal of outbreaks between reefs using the results of the earlier models and allowing the way clear for future incorporation of oceanographic parameters influencing the advection of planktonic larvae of starfish.

Progress and Results

Stage 1 is almost complete as all model runs are finished. The results have been incorporated into a manuscript that is almost ready for submission. The principle result was that the 'predation hypotheses' were more plausible than has been previously credited by some authors. A small change in density-independent predation allows starfish populations to escape the 'predator pit'. Once over this threshold, the prey increase exponentially and with the extraordinary fecundity of Acanthaster planci this increase may appear instantaneous. Other results in this manuscript relate to the problems of controlling adult starfish populations and a model of control options is presented.

Stage 2 is underway. A spatial simulation of a starfish outbreak on a stylized crescentic reef showed that the aggregation effect was an unavoidable consequence of reef shape and starfish population size. The initial recruitment pattern and starfish behaviour appear to be critical and are under further investigation. A paper describing the first version of this model was presented to the Simulation Society of Australia in May 1987.

Stage 3 was originally started as a large scale simulation running on a Cyber 205 supercomputer (see The Crown-of-Thorns Study Reports, 1985). It was found that the first attempt led to an overly complex model that was difficult to code and virtually impossible to understand. This led to the 3 stage design outlined above. Stage 3 will be started when stages 1 and 2 have been completed.

Problems Experienced

As described above, the first attempt at a large scale, complex model led to a change in research plan that has already yielded results. No major problems have been encountered since this change. A future problem is anticipated with regard to the implementation of stage 3. It is not clear how to proceed with stage 3, even after stages 1 and 2 are complete, because of the apparent dependence of larval dispersal on completely unpredictable 'weather-band' oscillations in the shelf currents during the spawning season. Apart from using stochastic modelling of these effects, a better understanding of the phenomenon may be gained by using the seasonally averaged current regimes (known for the central GBR) to model the average behaviour of starfish dispersal and include in this model effects such as density of reefs on the continental shelf, reef shape, and reef size as factors of likely importance.

Future Research

Future research will involve the completion of the manuscript describing the non-spatial model. Further work on the simulation model of an outbreak on a single reef will be undertaken because the present version does not allow experiments with the adult starfish behaviour (eg. attraction to each other at spawning times) and this is likely to be a critical factor. This model will also be run with some realistic, rather than stylized reef shapes (probably derived from Depth of Penetration images from Landsat data), and will also be extended to experiment with different starfish control strategies as an aid to management of outbreaks. The manner of implementation of stage 3 remains uncertain as described above. These models will be developed over the following 1-2 years as new data on the biology and ecology of starfish come to hand. A budget for this research, covering the 1987/88 fiscal period, is given in Table 1.

References

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December 1985, 160 p.

Table 1. Project 4(E): 1987/88 budget showing costs to COTSAC and AIMS (notional)

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr R. Reichelt)*	-	3,200
Experimental Scientist (same as Project 4(B))	-	-
Experimental Scientist (Ms R. Buck)+	-	3,700
Travelling and subsistence:		
Domestic travel	1,500	-
Consumables:		
Computer accessories	250	-
Computing time:		
VAX: 4 CPU hrs/wk (@ $300/CPU hour)	-	36,000
TOTAL	**1,750**	**42,900**

* based on 10% of available time
\+ based on 75% of available time over a 3 month period

PROJECT 4(F) ANALYSES AND MODELS OF EXISTING DATA

Chief Investigator(s) Dr R. Bradbury, Dr R. Reichelt, Dr P. Moran and Mr P. Speare

Research Objectives

The aim of this project is to determine the effects of the crown-of-thorns phenomenon as an aperiodic forcing of the GBR system, using a range of analytical and modelling strategies on an extensive database of the phenomenon, towards an understanding of the phenomenon at the scale of the whole GBR.

Research Plan

Preliminary studies of the phenomenon have provided the basis for a variety of analyses and models to meet the objective above. These tasks are detailed in our original research plan of December 1985, and remain current (The Crown-of-Thorns Study Reports, 1985). In summary they are:

1. Qualitative models of the phenomenon.
2. Discriminant analysis of the GBR database.
3. Analysis of size frequency distributions of outbreaking populations.
4. Multivariate analysis of microscale changes in the community structure of John Brewer Reef.
5. Multivariate analysis of the recovery of reefs from starfish outbreaks.
6. Continuous analogues of state transition models of the crown-of-thorns phenomenon.
7. Statistical summary of the GBR database.
8. Predictive analysis of the GBR database.
9. Multivariate analysis of macroscale reef community structure.

10. Multivariate analysis of mesoscale reef community structure.
11. Macroscale epidemiological model of the dynamics of the phenomenon.

Progress and Results

As described in our report of 1 September 1986 (The Crown-of-Thorns Study Reports, 1986), the first stage of the project has been successfully completed and a series of working databases have been created and disseminated to the scientists involved in the project.

Satisfactory progress has been made in the project as a whole, even though it needs to be emphasized that not all of the individual tasks have been addressed. This is because we have taken advantage of the visits of some of the external collaborators to push ahead on some tasks at the expense of others.

The tasks which have generated the most progress are as follows:

Task (a) - Qualitative models of the phenomenon.

An analysis of the historical aspects of the phenomenon considered as a grammar of reef states written in time has been made by Dr M. Dale and presented to the First International Conference on the Use of Supercomputers in Ecology in Colorado. Further interpretation of the results is underway and a manuscript is expected shortly.

Task (f) - Continuous analogues of state transition models.

Preliminary work by Prof P. Antonelli was completed and the basic model of the phenomenon constructed. Analytical results are now to hand and are being interpreted. A manuscript describing the first results is expected shortly.

Task (g) - Statistical summary of the GBR database.

A numerical classification of the results of 1985 CCEP survey by sector was completed and interpreted in the latter half of 1986. It has been written up and submitted for publication.

Task (h) - Predictive analysis of the GBR database.

For our preliminary efforts, we chose the simple statistical technique of contour mapping the extent of outbreaks in space and time, rather than more sophisticated heuristic techniques. These have shown a high degree of coherence in the phenomenon over large space and time scales. These results have been written up for publication.

Task (i) - Multivariate analysis of macroscale reef community structure.

Preliminary analysis of the 80 reefs sampled for community structure during 1985 has been made. However the analyses have been difficult to interpret and further, more detailed analyses are planned.

Task (j) - Multivariate analysis of mesoscale reef community structure.

Detailed analyses of the 11 reefs sampled for community structure during 1984 has been made. However the analyses have been difficult to interpret and further, more detailed analyses are planned.

Problems Experienced

No major problems have been experienced, and no major deviations from the original objectives have been made.

Future Research

We expect that the tasks described above will continue to develop and yield fruitful results. Most of these studies will produce papers in the next year. Of the other studies not yet begun, we hope to initiate some of them in the coming year if funding permits.

Table 1. Project 4(F): 1987/88 budget showing costs to COTSAC and AIMS (notional)

Item	Cost ($) COTSAC	AIMS
Salaries:		
Principal Research Scientist (Dr R. Bradbury)*	-	4,700
Research Scientist (Dr R. Reichelt)**	-	6,200
Research Scientist (Dr P. Moran)+	-	1,600
Experimental Scientist (Ms R. Buck)*	-	2,100
Experimental Scientist (Mr P. Speare)	26,000	-
Travelling and subsistence:		
Domestic travel	1,500	-
Consumables:		
Computing accessories	500	-
Computing time:		
VAX: 5 CPU hrs/wk (@ $300/CPU hour)	-	37,500
TOTAL	**28,000**	**52,100**

* based on 10% of available time
** based on 20% of available time
+ based on 5% of available time

PROJECT 4(G) TAGGING OF ACANTHASTER PLANCI USING MICRO-INJECTABLE TRANSPONDERS

Chief Investigator(s) Dr P. Moran and Dr R. Peden (Deakin University)

Research Objectives

The main objective of this project is to develop a suitable method for tagging crown-of-thorns starfish so that individuals can be identified in the field over relatively long periods of time (greater than 1 year). Given the large amount of effort which has already gone into investigating this problem (see Moran, 1986) and the poor results obtained using external markers a system using injectable, passive integrated transponders (PITS) has been pursued over the last 2 years. A description of how this system works has been given in an earlier report (The Crown-of-Thorns Study Reports, 1985).

Laboratory based studies during 1985 indicated that this system had potential since tags were retained in some starfish for as long as the animals were in captivity (approximately 7 months). Despite these promising results it became apparent that the system would not be practicable in the field given that the distance over which tags could be read (termed the interrogation distance) was very small (6-9 cms). As the cost of tags is about A$15 it was decided to overcome these difficulties before proceeding with field trails that may be expensive and perhaps futile. Consequently, a new antenna was constructed for the system during the middle of last year in the electronics Department of Deakin University.

Preliminary trails with this equipment demonstrated that tags could be interrogated successfully, in air, over a circular area of 31 cm diameter and some 10 cm on either side of the centre of the circle. However, further trails indicated that the electromagnetic signal produced by the antenna would be absorbed very quickly in seawater (see The Crown-of-Thorns Study Reports, 1986). It was recognised that this signal would have to be amplified for the system to be useful underwater.

Given these results the objectives of this project over the last 6 months have been:

1. To modify the redesigned system (with new antenna unit) so that the interrogation distance underwater is similar to that achieved in air during earlier experiments.
2. To test the new system underwater using a small population of starfish.

Research Plan

In order to achieve the short term objectives of this project the following work was planned to be conducted at Deakin University:

1. Design, construct and evaluate a new 400 kHz high power amplifier to drive the new antenna unit.
2. Fabricate the electronics of the original antenna (data wand) and interface it to the new antenna.
3. Design and build-in a LED indicator to the new antenna and interface this to the ID computer (Data scan unit).
4. Design and construct a new switching mode power supply to drive the new power amplifier.

5. Attempt to place the whole system in underwater housings to make it fully operational underwater.

Progress and Results

To date, tasks 1-4 have been completed. At present several minor modifications are being made to the circuitry of the system and the antenna unit is being waterproofed. The costs associated with undertaking each of the abovementioned tasks are given in Table 1. Most of these costs were associated with purchasing electronic parts and employing a person to assist with the construction of the new system. The results of this research are to be presented at a Conference on Aquatic Tracking and Telemetry Systems to be held in Sydney at the end of May 1987.

Problems Experienced

Development of a more powerful system has been somewhat laborious given that modifications have been implemented without circuit diagrams (the manufacturer in America was unwilling to release this type of information). This has tended to slow the progress of this project.

Future Research

The entire system will not be put in underwater housings until the antenna has been tested to make sure it is waterproof and that the design is practical. It is possible that some minor modifications may have to be made to this particular part of the system. These tests will be conducted at AIMS on a small population of captive starfish during the middle of this year. Subject to the findings of these tests the entire system will be waterproofed and tested on a population of starfish in the field. In order to achieve these objectives a small amount of funds are required to purchase extra transponders and materials to waterproof the ID computer, power supply and cables. A budget for the 1987/88 fiscal year is given in Table 2.

Provided that few problems are encountered during this next phase of research it is anticipated that a fully operational system will be available by the end of this year. In so doing the major objective of this project will have been realised. Given that the system has not been tested as yet in the field it is possible that it may be impractical for studying the crown-of-thorns starfish (i.e. recovery of tagged starfish in the field may be very low). Even if this does eventuate the system in its present form will have tremendous application for the study of a variety of animals including; platypus, freshwater fish, rodents and possibly other marine echinoderms. This new system already has generated tremendous interest amongst other researchers.

References

Moran, P.J. The Acanthaster phenomenon. Ocean. Mar. Biol. Ann. Rev. 24, 379-480.

The Crown-of-Thorns Study Reports (1985) COTSAC funded research on the ecological aspects of the crown-of-thorns starfish (Acanthaster planci) co-ordinated by the Australian Institute of Marine Science: AIMS projects. Australian Institute of Marine Science: Townsville, December 1985, 160 p.

The Crown-of-Thorns Study Reports (1986) Progress report on research. Australian Institute of Marine Science, Townsville. September, 1986, 25 p.

Table 1. Costs associated with achieving the short term objectives of Project 4(G).

Task	Cost $
1. Design, construct and evaluate 400 kHz amplifier.	1,200
2. Fabricate and interface electronics to antenna.	1,350
3. Design and incorporate new LED indicator.	250
4. Design and construct new power supply.	750
5. Waterproof entire system.	1,300
TOTAL	**4,850**

Table 2. Project 4(G): 1987/88 budget showing costs to COTSAC and AIMS (notional).

Item	Cost ($) COTSAC	AIMS
Salaries:		
Research Scientist (Dr P. Moran)*	–	3,200
Part-time Research Assistant (Deakin University)	500	–
Consumables:		
Materials for waterproofing system	300	–
Batteries (rechargeable)	200	–
TOTAL	**1,000**	**3,200**

* based on 10% of available time

PROGRESS OF RESEARCH: EXTERNAL PROJECTS

PROJECT 6(A) THE DYNAMICS OF PHYSIOLOGICAL PARAMETERS OF HIGH DENSITY CROWN-OF-THORNS POPULATIONS

Chief Investigator(s) A/Prof. J.S. Lucas, Mr B. Kettle and Mr R. Stump
Zoology Department, James Cook University of North Queensland

Research Objectives

To determine:

1. Whether there are detectable physiological symptoms of ageing, nutritional status and unfavourable environmental conditions in high density Crown-of-Thorns populations and how these change during the course of population outbreaks;
2. Whether growth is determinate or indeterminate;
3. An energy budget for Crown-of-Thorns starfish;
4. Whether it is possible to age Crown-of-Thorns starfish through: (a) cellular age pigments; (b) growth rings and layering in skeletal components; or (c) analyses of spine length/body diameter ratios.

Research Plan

The research plan follows that outlined in the original submission (December, 1985), with the addition of an analysis of ageing methods as outlined in the proposal for 1987 (The Crown-of-Thorns Study Reports, 1986).

Work has commenced on estimating the energetic intake of Crown-of-Thorns starfish during feeding. Field facilities at Orpheus Island Research

Station have been used for this exercise. To date we have determined the methodology for estimating the calorific value of intact and partly digested coral colonies. This will be used in the next few months to complete calorific intake studies leading to a full energy budget.

With respect to the ageing studies, analysis of growth rings will accompany a detailed ultrastructural study of growth and formation of structure in the skeletal components of the body. Recent talks with Dr H. Marsh (J.C.U.) have identified several approaches to validate the information resulting from the biochemical cellular pigments technique, including tetracycline tagging and histological analyses of lipofuscin.

In conjunction with the laboratory studies, some recent field work has identified a useful population of starfish on Holbourne Island. It appears that these animals have not yet been stressed by low food availability. In addition, these animals seem to cover several age classes, i.e. juveniles, sub-adults and adults, resulting in reasonably accurate "presumed age classes".

These animals are therefore particularly useful for the biochemical technique, and the other methods can be applied to the same animals for validation.

Progress and Results

The December 1986 trip (7 days duration) was used to collect the final sample of starfish from Keeper Reef, as well as the scheduled collections from Helix Reef. Manta tows at Keeper Reef suggested that there were no starfish present, however a small (ca. 200 starfish) remnant population was eventually found immediately behind the reef crest. Their location coincided with remnant coral cover on the reef. (Keeper Reef has been used as a control for the population and physiological changes followed on Helix Reef).

Starfish at Helix Reef in December 1986 had very poor gonads, with respect to both volume and gross macroscopic condition. This coincided with the overall decline in starfish numbers on Helix Reef, suggesting that starvation was limiting both reproduction and survival. During January 1987 a further decline in starfish numbers was observed. Thus, Helix Reef has progressed from an abundant coral/abundant starfish condition to a very sparse coral/declining starfish numbers condition in the course of this study period, which is what was required for this study of dynamics. Coral cover is now extremely low (<1%), even across the reef top. The remnant population is restricted to a narrow band along the southern reef shoulder. The physiological condition of the remaining starfish is declining, with external appearances and internal compartments now closely resembling those of remnant starfish from other post-outbreak populations.

Laboratory analysis of samples is proceeding on schedule with the backlog of 1986 samples completed and samples from the January 1987 trip almost completed. This has resulted in an accumulation of physiological data on almost 700 starfish, most of which has been entered into a microcomputer for statistical analysis. The semi-micro bomb calorimeter has arrived and been successfully installed in the laboratory. It is proving very useful for quantification of the smaller body component samples, and is well suited to analysing the calorific value of coral tissues as required for the energy intake studies.

A paper, presented last year at the Second International Symposium on Indo-Pacific Marine Biology, University of Guam, July 1986, entitled "Biometric relationships between organ indices, fecundity, oxygen consumption and body size in Acanthaster planci (L.) (Echinodermata; Asteroidea)" has been accepted for publication in the Bulletin of Marine Science. This paper demonstrated that larger starfish partition increasingly heavily towards reproduction at the expense of their body wall and caeca. Oxygen consumption measurements on Crown-of-Thorns in the weight range 4 g to ca. 5 kg failed to demonstrate a different relationship for "giant" starfish - their oxygen uptake patterns do not make them unique. This paper suggested that, in view of the reducing proportion of skeletal material in the body wall, size is normally limited by food availability and only rarely "determined" by physiological limitations (in this case body wall partitioning).

Materials to continue the biochemical ageing technique are being acquired. An extensive literature review has been completed for the Cellular Age Pigments method, bringing to light advances in methodology since the inception of this research, while additional information is being gathered for other methods of ageing. Data for ageing using the morphometric relationship between arm-spine length and body diameter is being extracted from the existing physiological database. These data will be analysed statistically after the final Helix Reef field trip (mid-April).

Problems Experienced

A recent field trip to Holbourne Island (off Bowen, Qld.) failed to find any of the "giants" reported to have been greater than 60 cm in diameter. Data on animals in this size range are important for the determinate/indeterminate growth analyses.

Since the application for the 1987 grant was submitted, the cost of the sonication equipment has increased considerably. This has required reassessment of the methodology for ageing studies. As most of the pigments in the cells are accumulated within organelles it is necessary to use a tool which can disrupt membranes at this level. It is intended that a mechanical tissue homogenizer will be used as an alternative to the Sonicator originally requested. A short series of tests to compare the relative effectiveness of a Sonicator and a mechanical homogenizer (using the sonicator on loan from the Botany Department and an Ultra-Turrax homogenizer) will be required to confirm that mechanical homogenizers can adequately disrupt cellular membranes.

Future Research

It is anticipated that this will be the final year of research on the time-course of physiological parameters of Acanthaster in the population on Helix Reef. Starfish numbers have declined to the point where it is envisaged that only two collections will be made this year. One of these was completed in January. The second trip of the year has been postponed due to problems with the University research vessel, but is currently being rescheduled for mid-April. This trip will be the tenth (and the last) regular field trip of the program.

It is anticipated that aspects (i) to (iii) of this work will cease at the end of 1987. Final presentation of the data analyses and Mr B. Kettle's Ph.D. thesis, based on these studies, are expected by the end of December 1987.

Studies of ageing Crown-of-Thorns starfish (aspect iv.) are expected to extend through 1988. With the availability of sufficient suitable specimens, the testing of the biochemical ageing technique could be completed by December, 1987. Additional funding will be necessary to continue with microscopy for both the skeletal components and the age pigments. A budget for this Project, covering the 1987/88 fiscal year, is given in Table 1.

References

Kettle, B. and Lucas, J.S. (in press) Biometric relationships between organ indices, fecundity, oxygen consumption and body size in Acanthaster planci (L.) (Echinodermata; Asteroidea).

The Crown-of-Thorns Study Reports (1986) Progress report on research. Australian Institute of Marine Science, Townsville. September, 1986, 25 p.

Table 1 Project 6(A): 1987/88 budget.

Item		Cost ($)
Salaries:		
Research Assistant (Mr R. Stump)	14,459	
Allowances	985	
CPI wage increases	1,500	
		16,944
Consumables:		
Chemicals	420	
Glassware	1,600	
SEM and TEM user time	350	
		2,370
Travelling and subsistence:		
Vehicle usage		600
Hire of aircraft and ships:		
Vessel charter (13 days x $450/day R.V. James Kirby)		5,850
TOTAL		**25,764**

PROJECT 6(B) A STUDY OF THE TEMPORAL AND SPATIAL DISTRIBUTIONS OF ACANTHASTER LARVAE, IN RELATION TO SURVIVAL AND DISPERSAL.

Chief Investigator(s) Dr R.F. Hartwick, James Cook University of North Queensland

Research Objectives

This project was funded as a pilot study to determine the feasibility of tracking the dispersal of Acanthaster larvae from the immediate area of a natural spawning population using appropriate net sampling techniques. Questions to be considered include:

1. Can a population of Acanthaster larvae be identified and associated with spawning adults by an appropriate transect sampling scheme across the inferred downstream plume?
2. What is the vertical, horizontal and temporal distribution of larvae in the downstream plume?
3. What is the developmental age distribution of larvae within the plume over time and does this permit inferences about the source reef and estimates of natural rates of growth and mortality?
4. To what extent do distribution patterns reflect purely passive advection or influences from the locomotion (vertically) of the larvae?
5. To what extent can other more common constituents of the plankton be used as indicators of the downstream plume?
6. What can be learned about sources of nutrition and predation on the larvae?

Research Plan

Briefly stated, the plan entailed the location of an actively spawning massed population of adult Acanthaster among those known to be present on inner reefs of the Central Great Barrier Reef. Underwater visual surveys by divers using a towed 'manta board' were the primary means of detection of an appropriate population. The inferred dispersal plume was to be marked by a series of three curtain-drogue buoys released near the spawning adults at regular intervals. The plume was to be sampled over time in a series of horizontal transects and vertically-stratified profiles designed ad hoc according to the observed scale of the spawning event (and the inferred density and distribution of larvae) and to the availability of ship time. If possible, macrozooplankton samples were to be taken concurrently, in the hope that major predators could be identified by gut content analysis.

Progress and Results

Sampling was carried out during the cruise of the R.V. Lady Basten between 2 and 11 January 1987, a period deemed of high likelihood to include spawning events. Diver surveys of Wheeler and Bowden reefs were conducted from 2 to 5 January. Moderately-dense populations of Acanthaster were observed between the western and south-eastern corners of the face of Wheeler Reef, but no spawning was observed until the afternoon of 5 January, when a population near the west side of the sand cay was found to be spawning when inspected at 1520. Spawning males and females were observed continuously until 1640, over a reef area of at least 2000 m^2 between depths of 3 and 8 m. The three drogues were released at twenty minute intervals beginning at 1805 at the nearest point (clear of the reef) downstream (SE) from the spawning population. Because spawning had largely ceased by this time and because the spawning population was not apparently very abundant or widespread (perhaps no more than 100 synchronously spawning individuals), large volume horizontal net tows were taken along transects downstream from the first drogue and perpendicular to the axis of the plume (inferred from the distribution of the 3 drogues and the net drift).

Between 5 and 8 January, 31 net tows were taken along 5 transect lines across the inferred plume. In the 72 hours since spawning the larval cohort had been transported 104 km to the southeast, parallel to the inner margin of the barrier reef matrix. Practical considerations of ship-board navigation and other cruise priorities required termination of sampling at that point.

To date 20 of the samples have undergone preliminary sorting for asteroid larvae, and 81 specimens have been found which are tentatively identified as Acanthaster. Since the earliest transects are yet to be sorted, increasing abundances within a more clearly defined dispersal plume may yet be found, assuming that the majority of larvae represent the Wheeler Reef cohort. Some larvae are evidently too mature to be so ascribed, and must represent prior spawnings, presumably from more northerly populations. Detailed analyses of age-frequency and spatial patterns will follow completion of the sorting (as will quantification of other plankton constituents, manpower permitting).

Problems Experienced

Apart from the small initial budget, which inevitably restricted the sampling program to pilot-project status, a number of other difficulties further hampered its scope and rigour:

1. Available ship time was severely restricted due to the priorities of other research activities. This limited the sampling to a maximum of two transects per day (totalling less than 90 minutes each) and terminated the sampling after 3 days.
2. The spawning event, though a rare phenomenon in the best of circumstances, was less extensive than hoped for. Density of spawning adults was substantially less than reports had anticipated, and the extent of the population was apparently restricted to a small area of the one small reef. This necessitated larger sample sizes, by means of horizontal tows, in place of the vertical drop-net samples originally favoured for their spatial definition.
3. For technical reasons the main oceanographic winch was unavailable for use during the cruise. This entirely precluded vertical profile and macrozooplankton sampling, and restricted horizontal tows (retrieved largely by hand) to the upper 8 metres of the water column.

Future Research

Given the inherent difficulties of the identification of asteroid larvae and the as yet poorly understood and unpredictable nature of spawning, it is not yet possible to predict the feasibility of larval ecology studies on Acanthaster. If detailed analysis of the samples reveals coherent patterns of cohort development in a dispersal plume, it may follow that similar sampling on a suitable scale of time and space, with adequate replication and resolution, may reveal important information on the dispersal, survivorship and recruitment potential of the species.

PROJECT 6(C) SIMULATION OF THE LARGE-SCALE POPULATION DYNAMICS OF CROWN OF THORNS STARFISH IN THE GREAT BARRIER REEF SYSTEM

Chief Investigator(s) Dr M.K. James, Dr L. Bode
Prof K.P. Stark and Mr L. Marsh
James Cook University of North Queensland
(Report prepared by I. Dight)

Research Objectives

The research objectives presently remain unchanged from those expressed in the original proposal (December, 1985), these being:

1. The development of numerical models of the spread of *A. planci* populations between reefs; and
2. The application of the models to investigate the large-scale population dynamics of the starfish.

We remain convinced that an assessment of the *Acanthaster* phenomenon can only be gained through an understanding of the impact of dispersal processes and the application of this knowledge to recruitment at the relevant spatial and temporal scales.

Research Plan

Phase 1 of the original proposal, preliminary modelling and the development of appropriate numerical techniques for the major processes involved, is substantially complete. Phase 2, their application to the Great Barrier Reef system, is in progress.

The simulation model being developed to investigate the large-scale population dynamics of *A. planci* is designed in a modular format. This is viewed as a necessary design characteristic resulting from the diversity of components, the immense data-sets generated at various stages, the need to maintain tractability and the ease with which smaller units can be manipulated during the developmental stage. The ease with which modular units can be adapted and applied to other ecological problems of a general and fundamental nature is a further advantage of this design.

A primary split in the modular design is viewed between what is in essence the hydrodynamic component versus the population component. The hydrodynamic component, while essentially deterministic given a specific set of forcing parameters, runs under time-dependent tidal flow and a randomly varying wind field. The final output will be in the form of a probability matrix of values which describe the interrelationships among reefs with respect to the advection of larvae and the likelihood of a larval cloud, or proportion thereof, encountering a suitable habitat within the time constraints of larval life. The population component shall be the simulation model which will be used to investigate the dynamics of *A. planci* populations. This component will be stochastic in nature and based around the probability matrix resulting from the hydrodynamic component. The population model will describe the principal life-history characteristics of *A. planci* including survivorship during the different developmental stages, growth, reproduction and predator/prey interactions. A schematic representation of the model design is presented in Figure 1.

Emphasis to date has been given to the hydrodynamic component of the project which provides essential input into the population component and is potentially the most complex and innovative of the two components. Consequently, discussion in this report will place an emphasis on detailing progress in this area.

Progress and Results

The numerical hydrodynamic model being developed is based on the software SURGE of Sobey et al. (1977) which has since been modified and further developed with the purpose of making it more relevant to the study of tidal and wind-driven flows by Bode et al. (1981). The existing software, already successfully tested (Frith and Mason, 1986., Andrews and Bode, 1987., Bode, Mason and Middleton, 1987, 3 papers in prep.), has been further developed for the present purpose. The hydrodynamic model of this study consists of three components in its own right, each generating its own output through SURGE, and each corresponding to one of the major determinants of water motion within the Great Barrier Reef region: the astronomical tides, wind stress and the East Australian Current.

The hydrodynamic model SURGE

This numerical hydrodynamic model is based on the principles of mass and momentum conservation in the form of the Navier-Stokes equations. The equations of motion are solved by an explicit finite-difference technique on a uniform grid that is staggered both spatially and temporally. SURGE was designed to model tropical cyclone induced storm surge along the coast of Queensland. As such, it accounts for the physical characteristics of the continental shelf including bathymetry, coastal details such as bays, headlands and offshore islands, and coral reefs which are all represented on this grid. The three-dimensional equations are reduced to two spatial dimensions, the two components of horizontal momentum transport, and sea surface elevation by integrating throughout the water depth. This two-dimensional vertically integrated form - the Long Wave Equations - represents the conservation of mass and momentum in the X and Y spatial directions.

SURGE is designed to be neither site nor resolution specific. By use of a system of codes to represent land, sea, full or partial barriers to flow, the full non-linear equations may be solved, or alternatively the advective terms omitted when close to a boundary and flow directed in either the X or Y directions. The area of specific interest in the present study was deemed to be from the level of Princess Charlotte Bay in the north to below the Whitsunday Islands in the south, covering six degrees of latitude. The orientation of the North Queensland coast required, for reasons related to savings in computer costs, that two grids rather than a single grid be set up with a suitable area of overlap in the region of Hinchinbrook Island. Choice of an appropriate grid scale is particularly important where velocity and direction can vary over relatively short distances as a response to changing bathymetry and the obstruction of currents by barriers such as coral reefs. The grid scale selected, five nautical miles, represents a compromise between that required to resolve adequately the physical features of the continental shelf, the time step, and limitations imposed by computer speed and storage. The physical characteristics of the southern grid, corresponding to the Central Section of the Great Barrier Reef Marine Park, are presented in Figure 2.

The astronomical tides

Tidal flow is time-dependent and therefore more complicated to describe adequately than flow resulting from wind stress or the effect of the East Australian Current, both of which are treated as essentially steady-state. Andrews and Bode (1986) have demonstrated that a subset of seven tidal constituents, the M2, S2, N2, K2, O1, P1 and K1, are sufficient to describe accurately the tidally induced water motion in both the reef matrix and lagoonal zones of the Central section of the Great Barrier Reef. These seven constituents have been analyzed separately using SURGE. The output are data-sets of amplitude and phase for each constituent over the entire grid.

Of primary concern is the ability of the model to reproduce adequately physical phenomena. With this in mind, the process of calibration and validation by which the accuracy of a model is established is most important. Validation was conducted by comparing the model output with published data derived from field studies. Close agreement has been obtained, thus providing a good test of the means by which model parameters are effective. Displayed in Figures 3a and b are the amplitude and phase respectively of the M2 tidal constituent for the northern grid. This area corresponds closely to the Cairns Section of the Great Barrier Reef Marine Park.

Wind stress

The forcing of appreciable water motion by wind shear is depth dependent and therefore largely restricted to the shallower waters of the continental shelf. A non-linear relationship between surface wind velocity and shear stress results in the need for multiple data-sets of output. These correspond to the range of wind velocities and directions characteristic of the period when the larvae of A. planci disperse. While the hydrodynamic component is derived from what are deterministic processes, some input variables are considered to be stochastic. They include the occurrence of wind velocity and direction. A probabilistic interpretation of the wind field has therefore been adopted through the use of Monte-carlo simulation techniques.

The East Australian Current

The third major mechanism contributing to flow within the reef matrix and lagoon is the effect of an East Australian Current, presumably driven by an oceanic pressure gradient in the Coral Sea. The southerly drift of surface waters off the edge of the shelf are assumed to be quasi steady-state. Flow has been forced by the application of a pressure gradient along the deep-water open boundary by setting a constant sea-level gradient running north to south. The output is mass-transport over the entire gird.

Advection/Dispersion

The advection of the centroid of each larval cloud is being effected by using a 'marker and cell' technique on a staggered grid. At each timestep the current position is recalculated from a summation of output from the three models determining flow in the surrounding region. The longitudinal and lateral concentration distributions of larvae are to be determined by means of a separate two-dimensional mass transport calculation driven by the velocity field.

Population Component

Disease related mortality has been recorded for many Echinoderms, most recently by Dr Leon Zann (GBRMPA), who observed a severe epidemic which caused apparent mortality in excess of 98% to a population of juvenile *A. planci* on Suva reef. Assessment of the likely role of disease in the regulation of *Acanthaster* populations has been carried out using the general epidemic model of Kermack and McKendrick (1927) with data supplied by Dr Zann. A good fit to the data was provided by the model and has led to a number of predictions which are to be incorporated into the population component of the project. These include:

1. That large populations of juvenile *A. planci* will be subjected to high mortality resulting from disease if they are stressed due to the unavailability of a suitable diet, either due to settlement in a zone devoid of live coral or because previous infestations had drastically reduced live coral cover.
2. That a threshold population of around 300,000 starfish is required before an epidemic will result causing significant mortality. A further prediction of the model is that the pathogen was unlikely to have been a virus.

Problems Experienced

No major problems have been experienced. However, it should be noted that the sometimes total absence of bathymetric recordings from substantial areas within the reef matrix and shelf edge places a limit on the accuracy of numerical hydrodynamic models. Similarly, the paucity of offshore information relating to tidal amplitude and phase has resulted in a substantial cost during the process of calibration both in accuracy and time.

Future Research

Completion of the project is anticipated towards the end of February, 1988. During the intervening period research will concentrate on finalizing the hydrodynamic component of the project, the probability matrix having yet to be produced, and design of the population component. The final simulation experiments are expected to shed light on the population dynamics of *A. planci* with respect to the principal hypotheses suggested to account for the large populations that have been observed within the Great Barrier Reef since the early 1960s. The funds required to complete this Project are given in Table 1.

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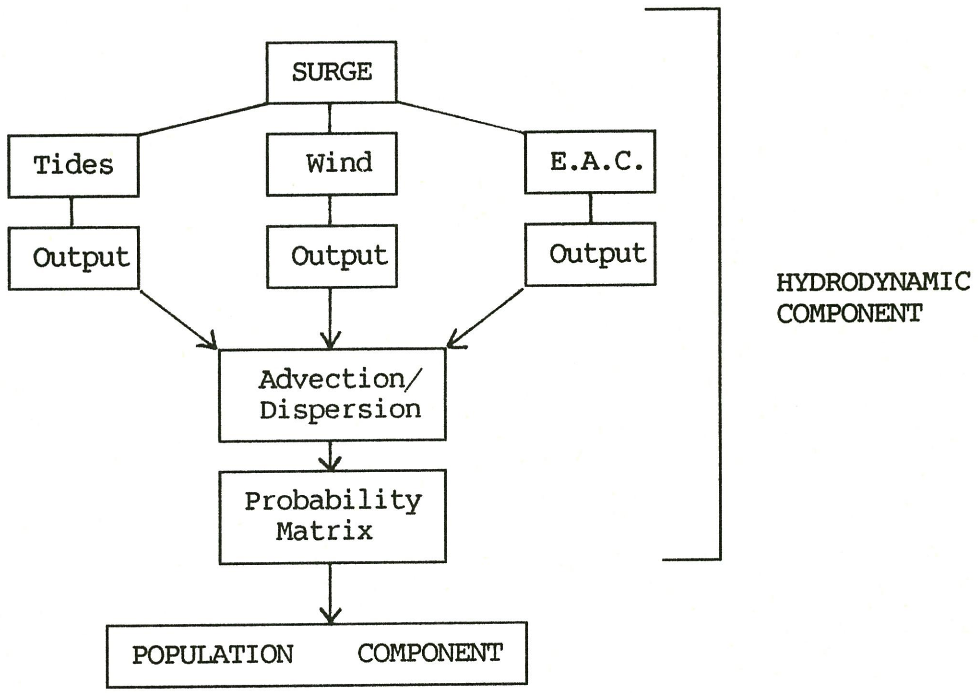

Figure 1. A schematic representation of the model design.

SOUTHERN GREAT BARRIER REEF
BATHYMETRY CONTOURS

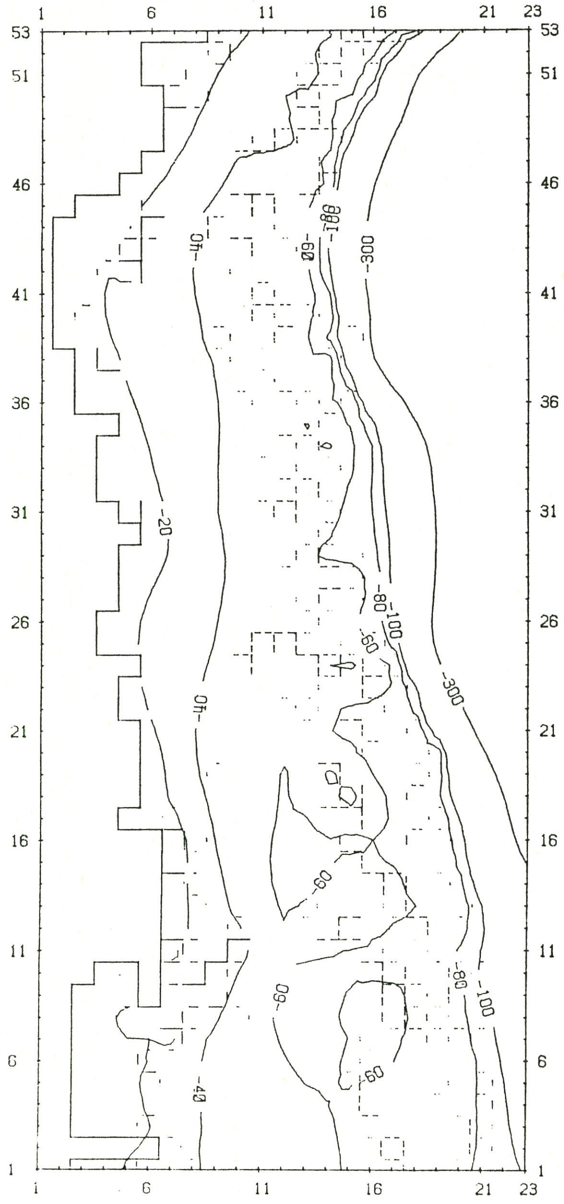

Figure 2. Physical characteristics of the southern grid. Land barriers are indicated with a solid line while reefs are shown as dashed lines.

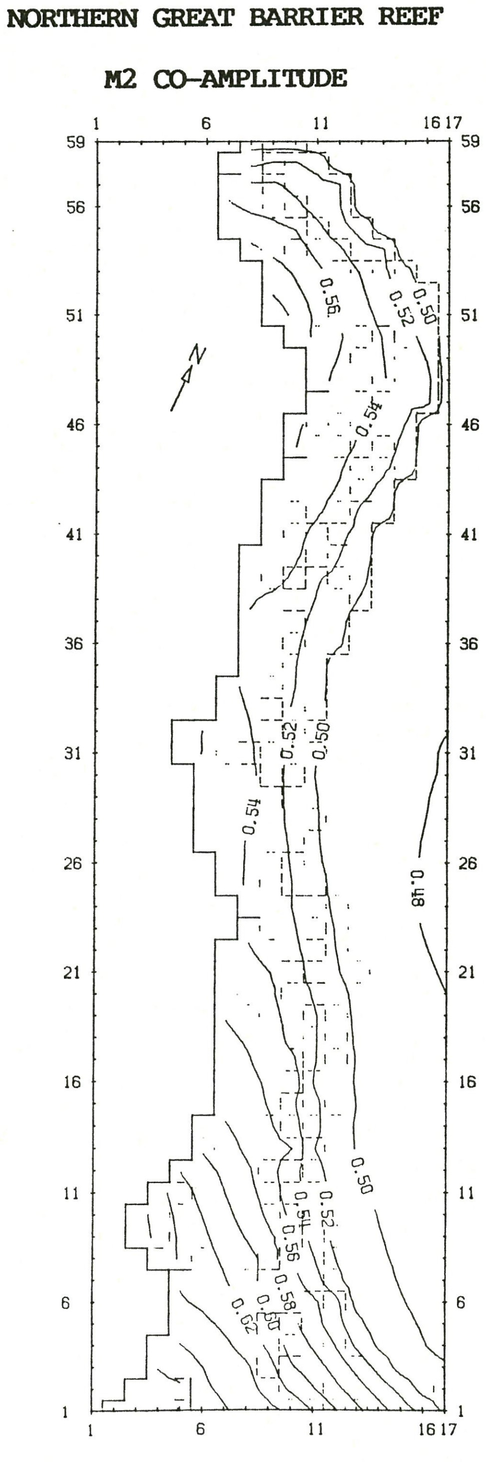

Figure 3a. Tidal co-amplitudes for the M2 constituent over the northern grid.

NORTHERN GREAT BARRIER REEF

M2 CO-PHASE

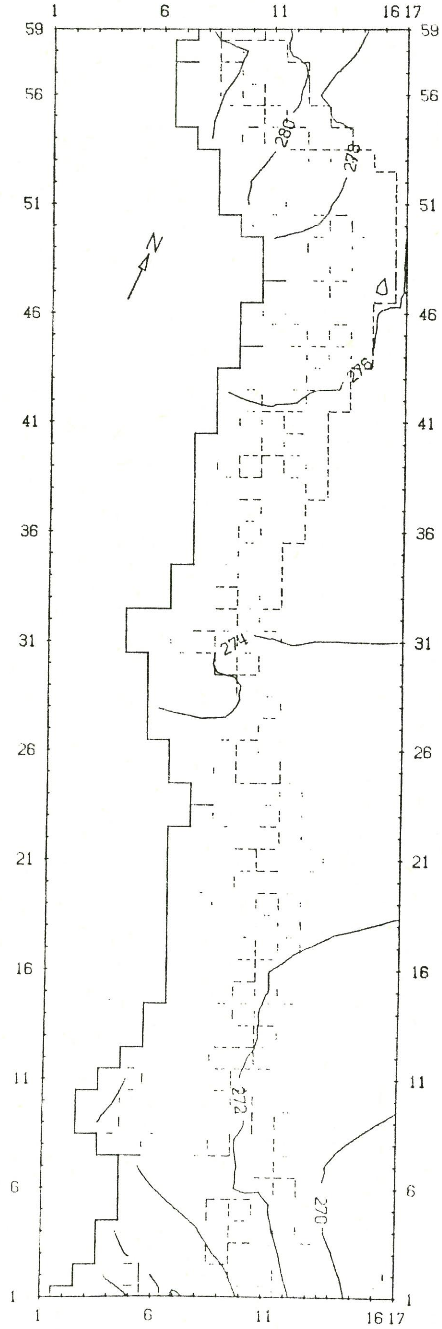

Figure 3b. Tidal co-phase for the M2 constituent over the northern grid.

Table 1. Project 6(C): 1987/88 budget (to February 1988).

Item	Cost ($)
Salaries:	
Research Officer (Mr I. Dight)	4,683
Consumables:	
Computing accessories	500
TOTAL	**5,183**

PROJECT 6(D) FIELD STUDIES ON ASPECTS OF THE ECOLOGY OF ACANTHASTER PLANCI

Chief Investigator(s) A/Prof. R. Endean and Dr A. Cameron
University of Queensland

Research Objectives

We have proposed (Cameron and Endean, 1985, Endean and Cameron, in press) that it is primarily the persisters (as opposed to the opportunists) among the coral species present that are responsible for structuring complex coral communities. If this is so, extensive predation on persisters (which, by definition are relatively longer lived than are opportunists) will lead to impoverishment of coral reef communities (Endean and Cameron, 1985).

When present at normal population density Acanthaster planci appears to feed primarily on opportunistic corals. If the normal mean population density of 0.06 adults/ha of reef increases to approximately 140/ha a population outbreak occurs (Endean, 1974). The outbreaking A. planci adults aggregate and move openly across the reef eating most species of coral encountered including some of the species we regard as persisters. The bulk of the hard coral cover of a reef of average size in Great Barrier Reef waters is usually destroyed within 1-3 years. Most A. planci then disappear but residual populations have been detected on some reefs. These residual populations appear to engage in a type of mopping-up operation directed against the corals that have survived the initial outbreak. Species of corals regarded as persisters appear to be attacked frequently by these residual A. planci populations. We postulate that destruction of persistent corals will have far-reaching implications for recovery of the basic structure of complex communities by slowing that recovery.

We intend to test the above hypothesis by determining the structure of the coral community and the structures of populations of the constituent coral species on sectors of 14 reefs in conjunction with determinations of the density and structure of populations of Acanthaster planci on these reefs. The reefs selected include some that are currently experiencing A. planci outbreaks, some that have experienced an A. planci outbreak during the last ten years and some that have not experienced outbreaks during the last 30 years.

Research Plan

The structure of coral communities and population structures of constituent coral species.

Data will be obtained by making synoptic belt transects and by examination of permanent mapped sites.

Synoptic belt transects

After a perimeter survey of each reef, 3 areas will be selected. Within each area 3 belt transects each of 300 m^2 (30 m down slope and 10 m wide) will be surveyed. All persistent species of corals present will be assigned to size categories and to degree of damage categories. Photographic records will be obtained.

Permanent mapped sites

On a mapped area of approximately 400 m^2 on each reef the position of each coral colony will be defined in a three dimensional matrix and its size (circumference, maximum and minimum diameters and height) measured. The sizes of dead areas on the surfaces of each colony will be determined. Mapped sites will be monitored every six months. Photographic records will be obtained.

A. planci population densities and population structures

Specimens of *A. planci* will be located on each reef during perimeter surveys. At three selected locations 300 m^2 belt transects will be made so as to include *A. planci* specimens. The number of *A. planci* in each transect will be counted. Each individual will then be measured (overall diameter), assessed for arm injury and arm regeneration and its prey recorded if it is feeding. Some of these transects will coincide with the synoptic belt transects. Also the numbers of *A. planci* present and their population structure will be determined for *A. planci* encountered on each visit to the permanent mapped sites.

Data processing

Computer processing

Data will be put into the "Ecopa k" database of the AIMS computer for analysis using the "NTA" suite of programmes.

Comparison with baseline data

Wherever relevant, comparisons of results obtained will be made with results obtained using baseline data gathered during earlier surveys of coral community structure made by Endean and Cameron and with earlier surveys of *Acanthaster planci* population densities and population structure made by these authors.

Progress and Results

Coral community structure and population structure of persistent corals.

Substantial differences at generic and family level exist in the size frequency distributions of surviving corals and in the levels of damage arising from *A. planci* predation on persistent corals on the reefs surveyed. On the basis of extent of damage to the hard coral cover exhibited the reefs examined may be placed in one of three categories.

Severely perturbed reefs

On Green Island Reef, Potter Reef, John Brewer Reef and Rib Reef isolated populations of *Porites* spp. and to a lesser extent *Diploastrea* sp. comprise the bulk of the remnant populations of persistent corals. Comparatively low numbers (compared with the normal situation) of live persistent corals belonging to a few other genera were found. The degree of damage displayed by most surviving colonies in all size classes was in excess of 2/3 mortality of total surface area. However, some very large colonies of *Porites* spp. and *Diploastrea* sp. at John Brewer Reef and Rib Reef exhibited less damage. Although some regeneration by opportunistic species of branching and tabulate *Acropora* has occurred at Green Island Reef there is a lack of recolonization by persistent species.

Moderately damaged reefs

On Holbourne Island Reef, Beaver Reef (A. planci capture area near cay) Lizard Island Reef and Normanby Island Reef there were, compared with the situation on severely damaged reefs, higher numbers of live massive corals belonging to a greater number of genera particularly in the smaller size classes (< 60 cm) and extent of surface mortality exhibited by individual colonies is of the order of 1/3 to 2/3 total surface area. There is noticeable regeneration from surviving surfaces of partially killed colonies of Porites spp.

Least damaged reefs

On Brook Island Reef, Fitzroy Island Reef and Low Isles Reef there were relatively high numbers of persistent species of coral belonging to many genera and to a wide range of sizes. Most of the colonies were either undamaged or exhibited < 1/3 mortality.

A. planci populations

An A. planci outbreak is in progress on Holbourne Island Reef but data obtained have not yet been analysed. Residual populations of A. planci were found on John Brewer Reef and on Rib Reef. The population on John Brewer Reef is widely scattered along the back reef slope but that on Rib Reef appears clumped towards the S.W. back reef area. Both populations are preying on remnant Acropora formosa, A. robusta, A. florida, Porites spp. and Pavona sp. As a result the remnant live coral cover is decreasing and to date there is little coral settlement visible and little regeneration was observed. When present at normal population density A. planci appears to feed almost exclusively on opportunistic species of coral.

Significance

It is apparent that there is a general decline in species diversity and in numbers of colonies of persistent species of corals on reefs that are carrying or have recently carried outbreaks of *A. planci*. It is also apparent that large specimens of *Porites* spp. and *Acanthastrea* sp. are sometimes bypassed by *A. planci* even when the starfish is present in outbreak numbers. To date there has been negligible recolonization by persistent species of coral at Green Island Reef.

Problems Experienced

The funds allocated to this project fell far short of those requested and this underfunding has restricted the number and duration of research trips made to reef localities. Our Research Assistant (Mr L. DeVantier) has been forced to deviate from the planned timing of field trips in order to accompany other reef workers who could act as his diving partners. We are grateful to AIMS and GBRMPA personnel who have assisted in this way. However, it is an unsatisfactory state of affairs as the collection of field data is dependent to a large extent on the timing of trips made by other workers. We have therefore requested increased personnel funds (see Table 1).

Future Research

Work began in April, 1986 and should finish in June, 1989. It is planned that the belt transect sampling and the surveys of *A. planci* populations will be completed by June, 1988. The detailed mapping of permanent sites (5 have already been completed) will be completed by December, 1988. This timetable allows 6 months (to June, 1989) for comprehensive analysis of the data and for preparation of papers reporting the overall results and significance of the project. A budget for this project is given in Table 1.

Analysis of data obtained should enable comparisons to be made of the community structure of corals on different reefs and of the effects of *Acanthaster* predation on community structure. Additional information will be obtained that will enable the decline in species diversity and in the numbers of colonies of persistent species of corals on reefs that are carrying or have recently carried outbreaks of *A. planci* to be quantified and correlated with numbers of *A. planci* present. As data from permanent quadrats are analysed information will be obtained that will indicate the extent and nature of recolonization and regeneration by persistent coral species, the extent of overgrowth of coral skeletons by soft corals etc. on reef areas that have suffered different degrees of damage caused by *A. planci*.

Analysis of data on *A. planci* population numbers and prey preferences on each reef studied should reveal any changes in the feeding preferences of *A. planci* as its population numbers increase and the amount of coral prey available decreases.

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Table 1. Project 6(D): 1987/88 budget.

Item		Cost ($)
Salaries:		
Research Assistant (Grade 1.1)	22,634	
Research Assistant (Grade 2.1)	19,777	
		42,411
Travelling and subsistence:		
Domestic travel	1,000	
Field travel	5,452	
		6,452
Consumables:		
Film, telephone, stationary	2,000	
Contingencies	1,000	
		3,000
Hire of aircraft and ships:		
Vessel charter (2 trips @ $3,000 each)		6,000
Capital equipment:		
Underwater video (Sony Handicam and flash)		4,000
TOTAL		**61,863**

PROJECT 6(E) DYNAMICS OF RECRUITMENT AND THE DENSITIES OF JUVENILE CROWN-OF-THORNS STARFISH BETWEEN 15°S AND 20°S ON THE GREAT BARRIER REEF

Chief Investigator(s) Dr P.J. Doherty, Griffith University

Research Objectives

The aims of this project are to:

1. Measure the densities of small *Acanthaster planci* on selected reefs south of Townsville.
2. Investigate the influence of relative exposure, water-column depth and substratum quality on the densities of small starfish.
3. Establish background levels for the natural occurrence of small *Acanthaster* in the vicinity and downstream of breeding aggregations.
4. Hindcast the spatial patterns and relative strength of previous larval recruitment(s).
5. Test the hypothesis that outbreaks of *Acanthaster planci* are the result of intense recruitment from larval sources.

Research Plan

Because small *Acanthaster* conceal themselves, their densities had to be established by destructive sampling of measured transects. The size and number of transects reflected a compromise between the competing needs to characterise natural variability in starfish populations among and within reefs. On economic grounds, it was decided to spend a maximum of two days sampling each reef. Working within this restriction, it was possible to sample 24 transects of 10 x 1 m on each of 18 coral reefs during 1986.

Transects were allocated to three depth zones (Base, Crest, Flat) and two orthogonal exposures (Windward, Leeward). Within each of these six locations, transects were replicated at each of two arbitrarily chosen sites separated by at least 0.5 km. "Base" sites were located up to 5 m from the bottom of the reef slope or at a maximum depth of 15 m below the top of the reef. "Crest" sites were located 2-5 m below the top of the reef and "Flat" sites were located behind the reef crest. Where local choice was possible, transects were located on heterogeneous substratum containing a mixture of live corals and rubble.

Individual elements of the surface cover were mapped with a resolution of 15 cm. All the surface cover was removed, broken into small pieces and searched underwater for the presence of starfishes. The position of each animal encountered was recorded on the substratum map and the specimen retained for subsequent identification and measurement. Sampling of a transect ceased when bedrock was encountered or a maximum depth of 30 cm was reached.

During 1986, 16 reefs between $18^{\circ}S$ and $21^{\circ}S$ were surveyed during cruises in July, September and November. In order to reduce potential variation due to cross-shelf influences, all of these reefs were chosen from the inside edge of the reef tract (Figure 1). The reef with the highest densities observed on the first cruise was resurveyed twice more during subsequent cruises to determine the precision of the sampling method. In addition, four reefs were surveyed at night to check on the accuracy of the daytime sampling. This was done by marking out six undisturbed transects adjacent to six from which the coral had been removed at one leeward site. The undisturbed transects were searched without destruction after 2100 h.

Data pertaining to each starfish (identity, size, substratum, depth, exposure, reef) was entered into a micro-computer database (dBase III) and linked to a second database containing details of the major lifeforms on each transect (number of colonies, percent cover). To maintain compatibility with previous studies, life-forms were described following a protocol developed at the Australian Institute of Marine Science for this type of work (DeVantier *et al*. 1985).

Results

The 432 destructive samples (single surveys of 15 reefs and three surveys of Stanley Reef) and 24 nocturnal samples yielded a total of 819 starfish (30 species) of which *Acanthaster planci* was the second most common species (Table 1). The smallest individual collected was 9 mm (*Bunaster uniserialis*).

Several points can be made regarding the size-distributions of all *A. planci* recovered during the three cruises of 1986. First, the three collections were each dominated by survivors from the 1985 year-class; average size of 70 mm (n = 20) in July, 85 mm (n = 37) in September and 98 mm (n = 37) in November. Secondly, only three individuals from the 1986 spawnings were detected; all from the November cruise. Thirdly, a small number of sub-adult and adult starfish (>18 cm) were encountered but have been excluded from the following analyses.

A total of 97 small *Acanthaster planci* were recovered from the destructive sampling of 16 reefs but only one of these individuals was taken from the five reefs south of 20^{o}S (Table 2). It is unlikely that this pattern reflected changing reef quality since neither the numbers of other starfish nor the numbers of transects without starfish showed any similar pattern

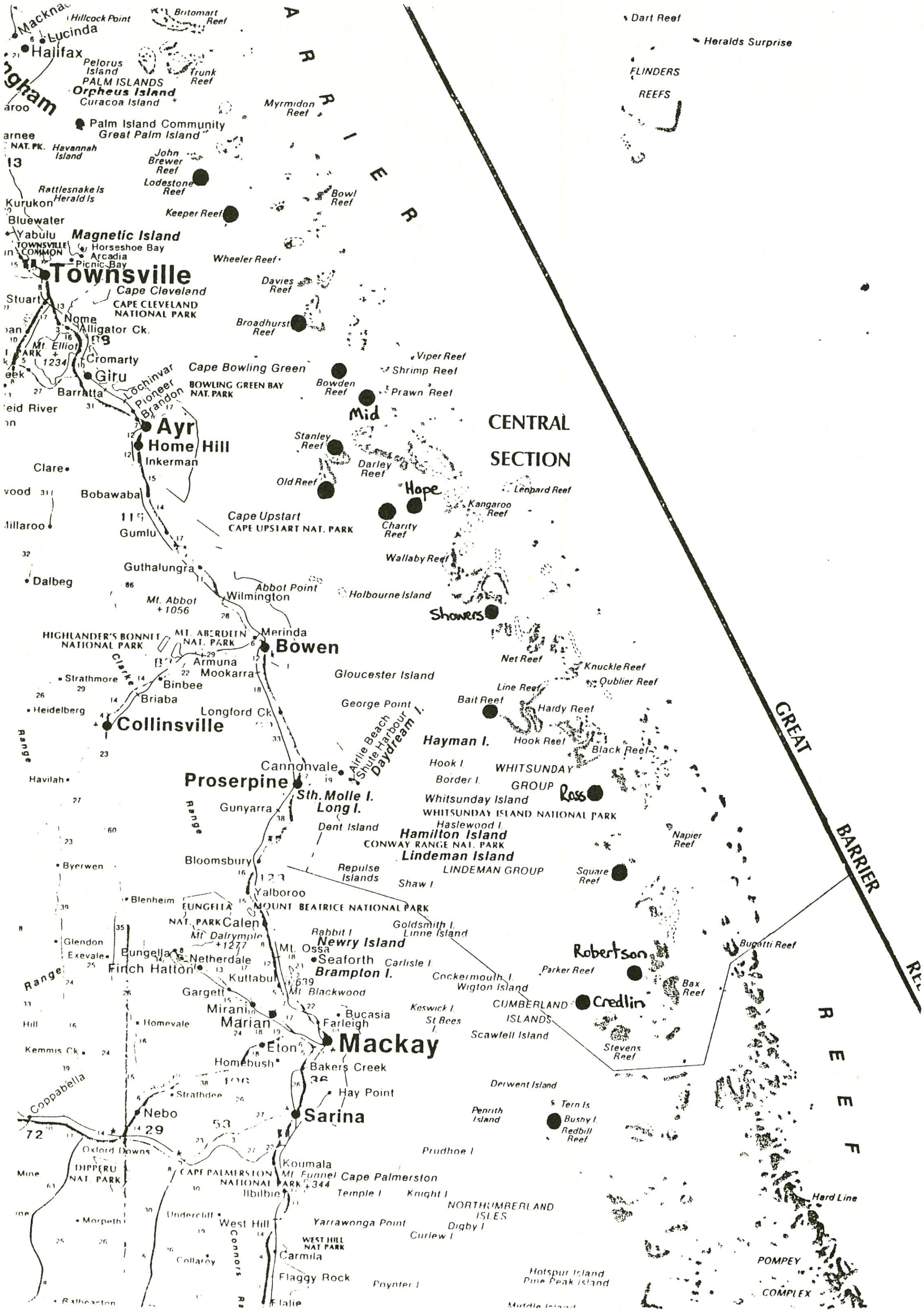

Figure 1. Map showing the locations of reefs sampled in 1986.

with latitude (Spearman Rank Correlation tests, 16 degrees of freedom, $P > 0.05$). The implication is that settlement of Acanthaster planci from the 1985 year-class was more intense on reefs north of 20°S.

Table 3 shows the results of three independent surveys of Stanley Reef where the greatest densities of small Acanthaster were detected. Although the total number of starfish encountered in each trial varied from 12 to 21, the three surveys gave qualitatively similar results each showing that there were significantly more starfish detected at leeward sites (Chi-square tests, 1 degree of freedom, $P < 0.005$). Approximately 90% of all small Acanthaster observed on Stanley Reef were found at the Crest and Base sites on the leeward reef slope.

Table 4 shows the same breakdown for small A. planci on the other ten reefs north of 20°S. These reefs showed an opposite result to Stanley Reef with significantly more small starfish on windward sites (Two-factor ANOVA, Interaction $F(1,4) = 1240$, $P < 0.001$).

Table 5a shows that densities of small Acanthaster on the leeward slope sites of Stanley Reef stand out from all other localities sampled on the reefs north of 20°S. These are approximately five times higher than the regional average and suggest enhanced recruitment. The only other conclusions suggested by this comparison are the latitudinal shift towards lower densities on reefs south of 20°S and the consistently low ranking of transects on the reef flat indicating greater settlement and/or survival in deeper habitats. None of these trends can be easily explained as changes in habitat quality since the densities of other starfishes (species pooled) do not show any consistent trends with latitude, exposure or depth (Table 5b). Direct evidence with which to test this claim will be available when the analysis of the substratum maps is completed (currently in progress).

Table 6 contrasts the results obtained from the destructive and nocturnal sampling. The latter was not more efficient than the daytime sampling and is likely to be greatly influenced by the age-dependent mobility of the starfish.

Problems Experienced

Although not a problem, the focus of the study was shifted a few degrees south of the original proposal in order to track the downstream influence of spawnings from aggregations in the Townsville region.

The greatest problem was the failure to find large numbers of individuals from the 1986 spawnings. In repeated sampling of Stanley Reef, none were encountered until November. None were seen on other reefs sampled in November but these reefs were totally lacking in juveniles. While it is likely that the method of in situ inspection was the reason for the failure to find more small starfish, a general failure of recruitment cannot be ruled out and this has implications for future sampling (see below).

Future Research

In 1987, I propose to resample the 16 reefs examined last year. This represents a departure from the original protocol of only resurveying a small proportion of the same reefs. I justify this change by the need to obtain information on the 1986 spawnings over the region already surveyed. The surveys will be done as late in the year as practicable in order to maximise the chance of detecting juveniles from the 1987 spawnings.

It is most important that this Project be continued for another year given the likelihood of detecting inter-annual variations in spatial patterns. A budget is given in Table 7 which is based on the 1987 costs and adjusted for inflation.

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DeVantier, L.M., Barnes, G.R., Daniel, P.A. and Johnson, D.B. (1985) Studies in the assessment of coral reef ecosystems. I. Assessment protocol. Technical Report, Australian Institute of Marine Science.

Table 1. The relative abundance of all starfishes collected in 1986.

Species	Number detected	Size range (mm)
Linkia multifora	136	14 - 85
Acanthaster planci	114	13 - 520
Fromia indica	104	14 - 70
Gomophia watsoni	88	19 - 140
Ophidiaster hemprichi	80	13 - 153
Linkia laevigata	70	45 - 220
Fromia milleporella	51	12 - 66
Ophidiaster cribrarius	46	24 - 55
Dactylosaster cylindricus	20	24 - 149
Asterina cephia	13	15 - 64
Neoferdina cummingi	13	24 - 87
Fromia monolis	12	18 - 81
Nardoa novaecaledoniae	12	42 - 232
Fromia japonicus	10	20 - 68
Bunaster uniserialis	9	9 - 17
Ophidiaster grannifer	6	21 - 72
Asteropsis carinofera	5	91 - 189
Cistina columbiae	2	48 - 73
Ophidiaster sp. nov.	4	40 - 52
Asterina anomola	3	12 - 14
Echinaster luzonicus	3	32 - 40
Tosia queenslandensus	3	23 - 40
Ophidaster lioderma	3	84 - 153
Asterina sarasini	2	17 - 19
Euretaster insignus	4	30 - 34
Nardoa pauciforis	2	115 - 145
Celerina heffernani	1	75
Culcita noveginia	1	40
Disasterina leptalacantha	1	30
Laeaster spesionis	1	148
Total	**819**	

Table 2. **Abundance patterns by latitude revealed by destructive sampling.**

Reef name	Small *Acanthaster*	Other Asteroids	Empty transects
Lodestone	7	100	4
Keeper	3	38	10
Little Broadhurst	8	37	6
Bowden	1	21	8
Mid	1	18	11
Stanley (1)	12	42	8
Stanley (2)	21	36	6
Stanley (3)	14	47	6
Old	4	41	6
Charity	6	50	6
Hope	5	26	10
Showers	9	25	10
Bait	5	33	9
Ross	0	18	11
Square	0	15	14
Robertson	0	38	4
Credlin	0	35	10
Bushy	1	82	6
Totals	**97**	**702**	**145**

Table 3. The numbers of small *Acanthaster planci* revealed by independent samplings of Stanley Reef. Sites and replicates have been pooled so that each value represents 40 m^2 of destructive sampling.

	Windward sites			Leeward sites			
	Base	Crest	Flat	Base	Crest	Flat	Totals
	1	0	0	1	2	8	12
	1	1	0	1	12	6	21
	0	0	0	0	5	9	14
Totals	**2**	**1**	**0**	**2**	**19**	**23**	**47**

Table 4. Comparison of numbers of small *Acanthaster* revealed by three samplings of Stanley Reef and single samplings of 15 other reefs.

Source	Windward sites		Leeward sites		Totals
	Site 1	Site 2	Site 1	Site 2	
Stanley	2	1	22	22	47
Others	17	18	8	7	50
Totals	**19**	**19**	**30**	**29**	**97**

Table 5a. Comparison of densities of small Acanthaster on Stanley Reef, ten other reefs above 20°S (Group A) and five reefs below 20°S (Group B). Each site on each reef was characterised from 40 m^2 of destructive sampling.

	Windward sites			Leeward sites			
	Base	Crest	Flat	Base	Crest	Flat	Totals
Stanley	0.017	0.008	0.000	0.017	0.158	0.192	0.065
Group A	0.030	0.040	0.015	0.015	0.003	0.020	0.020
Group B	0.000	0.005	0.000	0.000	0.000	0.000	0.001
Totals	**0.019**	**0.025**	**0.008**	**0.011**	**0.028**	**0.043**	**0.022**

Table 5b. As above for other species of starfish.

	Windward sites			Leeward sites			
	Base	Crest	Flat	Base	Crest	Flat	Totals
Stanley	0.22	0.16	0.08	0.17	0.27	0.16	0.17
Group A	0.19	0.18	0.06	0.16	0.21	0.07	0.15
Group B	0.18	0.27	0.19	0.19	0.17	0.15	0.19
Totals	**0.19**	**0.20**	**0.10**	**0.17**	**0.21**	**0.11**	**0.16**

Table 6. The number of small *Acanthaster planci* located during day and night searches of the same leeward site (60 m^2) on each of four reefs.

Reef name	Number of destructive samples	Number seen at night
Stanley	11	2
Hope	0	0
Showers	0	0
Bait	0	1

Table 7. Project 6(E): 1987/88 budget.

Item	Cost ($)
Salaries:	
Research Assistant (Grade 1.2)	21,603
Travelling and subsistence:	
Field travel	1,200
Consumables:	
Outboard fuel, tools etc.	600
Hire of aircraft and ships:	
Vessel charter	23,000
TOTAL	**46,403**

PROJECT 6(F) ANALYSIS OF PHYSICAL MECHANISMS CONTROLLING PLANKTON PATCHINESS ON THE GREAT BARRIER REEF

Chief Investigator(s) Dr J. Parslow and Dr A. Gabric, Griffith University.

Research Objectives

The research goals of this project have been to:

1. Investigate the effects of physical transport processes on plankton patchiness and larval recruitment on the Great Barrier Reef.
2. Look for evidence of patches at the predicted length scales in remotely sensed water properties.

This research was prompted by recent advances in understanding the stirring and mixing effects of turbulent advection on a passive tracer. For a tracer released in a 2D turbulent field, Garrett (1983) distinguished 3 statistical domains: the domain of occupation, the particle domain and the tracer domain. The domain of occupation is the region within which the tracer may be found over many realizations or releases. It is determined by spatial and temporal fluctuations at the largest scales. A good discussion of these large scale motions on the GBR is given by Williams et al (1984). The particle domain summarizes the mean dispersal of the tracer about its centre mass, and is related to the mean square separation of particles released in the initial patch. The tracer domain is the actual area occupied by the tracer in any one realization. Depending on the balance between meso-scale stirring motions and small-scale diffusive turbulence, the tracer may be smeared over the particle domain, or concentrated in narrow streaks of isolated patches within the particle domain. The degree of patchiness developed in this way may profoundly affect the statistical distribution of larval recruitment to individual reefs. Garrett (1983) presented an approximate theory for the development of patchiness in open-ocean geostrophic turbulence. The present study aims to extend this approach to the different mixing regime on the GBR.

Research Plan

The study has had two components; a theoretical analysis of advection and dispersal on the GBR, and a preliminary survey of satellite images for evidence of patchiness in water colour, or temperature, on scales from 1-100 km. The theoretical analysis has been carried out in three stages:

1. A review of the physical oceanography of the GBR to identify relevant physical processes, coupled with a review of the turbulence literature to identify appropriate model formulations.
2. An attempt to apply Garrett's approximate theory to the GBR.
3. The development of a numerical model of advection through a section of the GBR reef matrix to simulate directly the development of larval patches.

Progress and Results

The September, 1986 progress report (The Crown-of-Thorns Study Reports, 1986) contained a review of relevant results from general turbulence theory. The distinction between Lagrangian and Eulerian formulations, and the results from both idealized 2D turbulence and residual eddies in shallow flows over complex topography were discussed.

A preliminary application of Garrett's approximate theory was presented to the Annual Meeting of the Coral Reef Society in November 1986. Garrett's theory requires 3 parameters: a small-scale diffusivity, K_s; a large-scale eddy diffusivity, K_h; and a strain rate. For the GBR, a value for K_s based on shear dispersion associated with vertical shear is $0(4m^2.s^{-1})$ (Fisher et al., 1979). The large scale eddy diffusivity, K_h, based on mixing of the Burdekin River plume, has been reported to be 1000 $m^2.s^{-1}$ (Wolanski and Van Senden, 1983). If an associated length scale of 10 km is assumed, the corresponding strain rate is $0(1\ d^{-1})$. Insertion of these values in Garrett's formulae yields a streak width of 0(0.5 km) and a time for streak persistence of 0(15 d).

There is a considerable degree of uncertainty in the selection of these parameter values. There is also a rather dubious extrapolation involved in applying results for ideal geostrophic turbulence, characterized by a single strain rate over the entire enstrophy cascade, to the shallow, topographically-dominated flow around the GBR. A numerical model has been developed to test this extrapolation. The model predicts particle displacements based on a constant long-shelf drift and an alternating cross-shelf tidal current interacting with a 300 km section of reef matrix in the central region of the GBR. The model does not attempt a detailed solution of the equations of motion; at the spatial resolution required, this would involve several million spatial elements and an enormous amount of computation. Instead, an approximate flow pattern is constructed, based partly on[A analytic solutions for flow around individual obstacles, and partly on empirical observations. Three processes are represented: horizontal shear due to flow around reefs, trapping in eddies behind reefs (Wolanski et al., 1984) and diffusion due to vertical shear dispersion. A detailed account of the model assumptions is presented in a manuscript currently in preparation.

The initial Lagrangian version has been used to predict the mean square separation of ensembles of particle pairs; that is, the growth of the particle domain. Growth of the particle domain was dominated by trapping: in the absence of trapping, the effects of horizontal shear were small even compared with vertical shear dispersion. After 15 days, the mean square separation increased to 0(200 km^2). It increased cubically rather than linearly with time, a result consistent with many observations of dye and float releases in geophysical flow fields on a variety of scales (Csanady, 1973). (Garrett's theory assumes an exponential increase in both particle and tracer domains.)

A second version of the model has been developed to predict tracer distribution, based on a marked-cell technique. Cells containing tracer are displaced according to the flow field, and replicated where necessary to allow for horizontal shear. Renormalization is used to avoid an explosion in cell numbers, and the cell size is chosen so that the numerical diffusion associated with renormalization matches the assumed vertical shear dispersion. Figure 1a shows the distribution of tracer 15 days after an initial patch, 1.6 km square, with unit concentration, was released. Tracer occupies a large fraction of the particle domain, but the distribution is still patchy, with the highest concentrations (>0.01) occupying several small scattered regions. Small scale variations were analysed by considering departures of the tracer concentration from a Gaussian field with the same total content and covariance matrix. These departures had a coefficient of variation of ca 1 near the patch centre, increasing to 2 near the periphery. The intermittency (frequency of zero values) increased from 0.07 at the centre to 0.5 at the periphery. A lag-correlation analysis suggests a small-scale patch radius of 2-3 km.

The results suggest a close balance between stirring and smearing. Patchiness is predicted to decline after 15 days: the coefficient of variation and the intermittency near the patch centre are lower at 20 days. If the small scale diffusivity is lowered by a factor of 4, the predicted tracer distribution is more patchy (Fig. 1b), with higher coefficient of variation and higher intermittency.

To sum up, the model predicts that larvae released from one reef will, 15 days later, be spread over an area ca 30 x 40 km, concentrated near the centre, but subject to order of magnitude fluctuations in density of length scales of 2-3 km. The significance of these results for larval recruitment will depend on larval settlement strategies.

Problems Experienced

The remote-sensing component is presently lagging behind the modelling. Researchers at GBRMPA have generously offered access to archived CZCS images, once these arrive from the U.S.

Future Research

Aside from the remote-sensing, several extensions to the model are being considered. Specific hypotheses concerning larval settlement can be incorporated and corresponding statistical patterns of larval recruitment predicted. It may be possible to incorporate results from recent detailed numerical studies of flow around individual reefs (Black, 1987), after suitable approximation, to improve the model's dynamics. These studies have suggested long trapping times for some particles in the vicinity of reefs: this can certainly be incorporated. It should also be possible to

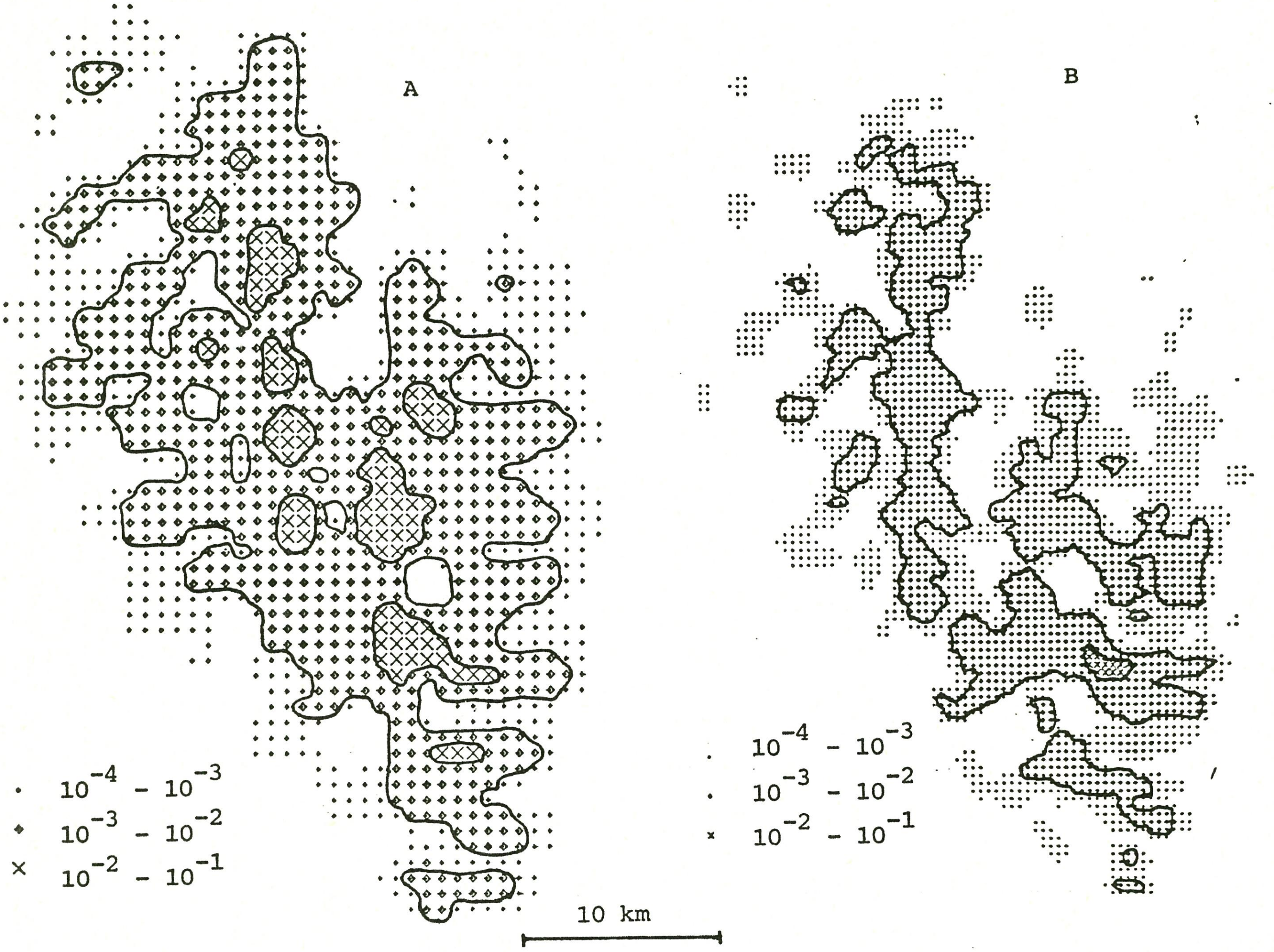

Figure 1. Predicted tracer distribution after 15 days for element widths of A) 0.8 km ($K_s = 4 m^2 s^{-1}$) and B) 0.4 km ($K_s = 1 m^2 s^{-1}$).

look at the implications for stirring of broad cross-shelf gradients in plankton communities (Sammarco and Crenshaw, 1984). As funds have been carried over from 1986 no additional funds are requested for 1987.

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PROGRAM 6(G) DEVELOPMENT OF MONOCLONAL ANTIBODIES AGAINST LARVAE OF ACANTHASTER PLANCI: A PILOT STUDY TO DETECT AND CHARACTERIZE LARVAL MEMBRANE MARKER(S) FOR THIS SPECIES

Chief Investigator(s) Dr P.J. Hanna, Dr V.W.K. Lee and Dr B. Richardson, Deakin University

Research Objectives

The major aim of the project is to produce monoclonal antibodies (mAb's) against surface antigens of the larvae of *A. planci*. These mAb's can then be used to identify and characterize surface antigens following labelling of larvae with radioactive iodine, solubilization, separation on gels by electrophoresis, electro-transfer to membranes, autoradiography and enzyme linked immunosorbent assays (ELISA). Further characterization of antigens can be obtained from immunofluorescence microscopy in which the mAb's are used to locate surface antigens on larval external structures.

Research Plan

The basic research plan outlining the methods, and experimental design to meet the objectives, have not altered since the original proposal of December, 1985.

Progress and Results

Larvae of *A. planci* were collected at AIMS and sent to Deakin University in late 1986. They were 9 day old brachiolaria (probably from 2 adults) from Grub reef which were washed in filtered seawater and then either fixed in 5% formalin or frozen at -20^{o}C.

At Deakin University samples of the fixed larvae were given 3 x 10 min washes in sterile saline prior to immunising female Balb/c mice by i.p. injections. Blood samples, taken from eye-bleeds of mice prior to and following a course of immunization, were used to obtain serum for monitoring immunological responses. Two methods were used to monitor the responses: ELISA and fluorescence microscopy. Both methods utilized mouse antibodies reacting with larval surface antigens and secondary enzyme- or fluorescein-tagged (goat)-anti-mouse immunoglobulins to detect the presence of the mouse antibodies. Both methods gave positive responses for post-immunisation bleeds.

Fusions of antibody producing spleen cells with mouse myeloma cells have taken place. Hybridoma clones are currently being grown, recloned, and tested for antibody production against homogenised larvae by ELISA techniques.

Larval surfaces have been radioactively labelled with ^{125}I using lactoperoxidase enzyme bound beads. These larvae were then solubilised and subjected to polyacrylamide electrophoresis (PAGE). The gels were then Coomassie blue stained, dried and autoradiographs prepared. Four present major surface proteins have been identified with molecular weights:

1. >130,000
2. >130,000
3. 113,000
4. <17,000

Experiments are in progress to examine for the presence of minor proteins by using:

1. Increased concentrations of sample loaded on gels.
2. Gradient gels with 4 to 20 per cent acrylamide.
3. Silver staining of gels rather than Coomassie blue staining.
4. Variation in autoradiograph exposures.

Electro-transfer of surface components to nitrocellulose membranes and subsequent ELISA using monoclonals will be carried out after electrophoresis conditions are optimized.

Problems Experienced

Several factors have affected the progress of the project. The project was delayed in starting due to larval supplies arriving in late 1986 and Dr Hanna returning in January. In addition, it was found that the amount of larvae requested was insufficient to complete and extend the experiments which involves injection, homogenizing for ELISA screening assays and electrophoretic studies of surface components. Additional larvae have been requested from Dr Moran at AIMS and further samples are expected to arrive within a couple of months.

Future Research

It is anticipated that mAb's directed against surface antigens of *A. planci* could have several uses in future research. However, cross-screening of mAb's against closely related echinoderm larvae would be *a priori* before the future work is undertaken. Dr Moran has arranged for sand-dollar larvae to be collected and sent for cross-screening but larvae of more closely-related species would need to be tested.

Extensions of the current research into 1988 would include studies of:

1. Surface-antigen changes during A. planci development,
2. Stock discrimination of A. planci using mAb's to detect differences between surface-antigens on larvae from different stocks,
3. Predation of A. planci larvae by analysing the gut contents of suspected prey with aid of the mAb's, and
4. Larval dispersion using mAb's and ELISA assays to detect A. planci in plankton samples.

The relevance of these four studies in relation to the overall Crown-of-Thorn Study is self-evident (see also Project 6(B)). Studies 1 and 2 should give definite results in a shorter time than for studies 3 and 4.

All of the studies (1-4) are labour intensive and require competence in various biochemical techniques. In this regard, funding is therefore sought for a full-time Research Assistant (Grade 1.3) to perform and extend the current research into cross-screening mAb's against larvae of related echinoderm species, obtain data on studies 1 and 2, and proceed into evaluation of studies 3 and 4. A budget for this project, covering the 1987/88 fiscal period, is given in Table 1.

Table 1. Project 6(G): 1987/88 budget.

Item	Cost ($)
Salaries:	
Research Assistant (Grade 1.3)	20,795
On-costs (8%)	1,664
Consumables:	
Chemicals, laboratory supplies	7,500
TOTAL	**29,959**

PROJECT 6(H) DYNAMICS OF THE ACANTHASTER/HARD CORAL INTERACTION

Chief Investigator(s) Mr D. Fisk

(Reef Research and Information Services,

P.O. Box 5348, Townsville 4810).

Research Objectives

The aims of this project have been:

1. To monitor the recruitment, survival and growth of juvenile *A. planci* at Green Island reef, and to undertake further ecological studies if large juvenile populations are found.

2. To continue current monitoring of regrowth of corals at Green Island using line transect techniques. This section of the study will provide information on recovery rates on reefs affected by *A. planci* and will produce base-line data in the event of future *A. planci* infestations.

3. To continue current studies on comparative recruitment of coral larvae onto settlement plates in the forereef and backreef of 3 reefs in the region (Green, Michaelmas, and Upolo reefs), and to expand the number of sites on each reef.

4. To continue mapping of juvenile corals on natural substrate in order to determine their mortality, recruitment and growth rates, and their role in determining community structure.

Research Plan

Abundance and distribution of *A. planci* at Green Island

Broad scale searches for *A. planci* have taken two forms.

1. Searches for coral scars, large juveniles and adults.
   Two divers search for a timed 5 minute period at each study site, looking for patches of recently dead coral that might be the result of a feeding starfish, and for any visible starfish. Any crown-of-thorns found are measured and their prey type noted.

2. Searches in the rubble.
   At selected sites in the rubble bommy field (which extends for approximately 5 kilometers from the eastern crest at Green Island) four quadrats, each 0.5 m x 0.5 m, are searched for year 0+ starfish. The rubble is removed piece by piece to a depth of approximately 0.5 m, using a hammer and chisel when necessary, and each piece is searched for small starfish (1 cm+).

Coral regrowth

A set of 15 sites around Green Island are being sampled using line transects in 1985 and 1986. An additional census was made following Cyclone Winifred in early 1986. The sites will be resurveyed annually to determine changes in coral cover and community structure.

<u>Recruitment onto settlement plates</u>

Racks of settlement plates are placed in 4 sites each in the forereef and backreef of Green, Michaelmas and Upolo Reefs. The summer and winter recruitment rates give information on the degree of dispersal of Ocoral recruits and on whether recovery of reefs damaged by <u>Acanthaster planci</u> is recruitment-limited.

<u>Population dynamics of juvenile corals</u>

The majority of corals at Green Island at present are juveniles (here we define as colonies <20 cm mean diameter) and these colonies are under represented, and the dynamics poorly described, by line transect methods. Abundance, recruitment, mortality, and growth of juvenile corals in replicated quadrats at 3 m and 6 m, forereef and backreef, on solid limestone and dead plates, are being studied at Green Island.

Progress and Results

<u>A. planci at Green Island</u>

A total of 46 sites around Green Island were surveyed using timed swims, as shown in Figure 1. A total of 47 <u>A. planci</u> were found during the initial surveys of the 46 sites during the timed swims. A subset of 12 sites forming a grid in the central areas of the bommy field, were sampled by an additional 2 timed swims at each site to determine the repeatability of the sampling technique, and 14 starfish were found in those swims. An additional 6 starfish were found during the course of other activities in the same time period. Starfish found during timed swims were distributed as shown in Figure 1. Starfish appeared to be randomly distributed across the reef area surveyed, with the possible exception that very few starfish were found along the seaward margin of the reef. The number of starfish per swim is represented graphically in Figure 2, showing that the majority of sites (43/70) had no starfish.

Abundance of starfish in the replicated grid were analysed using a two way analysis of variance to determine whether mean abundance differed with distance from the reef crest or distance in a north-south direction. Neither factor had a significant effect on mean abundance.

The relationship between the number of scars counted in a 5 minute swim, and the number of starfish recorded, showed a significant positive correlation ($r = 0.81$, $n = 71$). Feeding starfish or feeding scars were found in 85% of cases on branching Acropora (including arborescent, caespitose, and corymbose colonies), and on 3% of cases on tabulate or plate Acropora.

The size distribution of the starfish is shown in Figure 3. The histogram is indicative of a single year class, with the possible exception of the specimens with diameters of 27 and 36 cm. The size range is consistent with those published by Zann (1986) for 18 month old animals. Replicated searches of the rubble were completed at 15 sites in the eastern bommy field. Only one starfish was found during these searches, in September 1986 at site 33. The starfish was 2 cm in diameter and was almost certainly less than 1 year old, probably approx. 9 months old given the summer spawning pattern of A. planci on the Great Barrier Reef.

Coral regrowth

Results for the work on coral regrowth indicated that juvenile coral populations are well established at Green Island, but coral cover measured in line transects did not increase significantly between 1985 and 1986. Regenerating corals are dominated by *Acropora* sp. The passage of Cyclone Winifred close to Green island in February 1986 significantly reduced coral cover in only one of six sites sampled. Details of results for this section of the project are contained in a report to GBRMPA on the coral transplantation work carried out at Green Island (to be submitted shortly) and in a paper in the GBRMPA workshop on the effects of Cyclone Winifred.

Coral recruitment

Results of the recruitment study of the 18 months prior to November 1986 show the expected summer dominance of recruitment that has been reported in previous studies. The most interesting result was that recruitment was much higher at Green Island than at Michaelmas or Upolo Reefs, despite the relatively depauperate coral fauna at Green Island compared to the other reefs. Since the majority of recruits almost certainly came from outside Green Island Reef, the study is evidence that coral planulae are capable of moving between reefs in the interval between spawning and settlement, and the recruitment pattern is largely dependent on the strength and direction of the currents for a very limited period each year. Settlement plates were placed in the field at an increased number of sites in November 1986 to sample the 1986/87 season and to determine the inter-annual variation in recruitment patterns.

Juvenile coral dynamics

Preliminary results of the study of juvenile corals in mapped quadrats show that 35% of juvenile corals recorded are in the genus *Acropora*, the favoured diet species of *A. planci*. Corals of the genus *Pocillopora*, generally considered as an opportunistic species and early colonizer, comprise only 4% of the juvenile corals. The abundance of juvenile corals was greater on the backreef than forereef areas, and this is consistent with the findings for coral spat on settlement plates in this study. Mortality rates of coral juveniles appeared to be dependent on whether they were on dead *Acropora* plates or solid substrate, but did not differ between depths and forereef and backreef sites.

Problems Experienced

Through Dr Moran, we learned that the Green Island work was viewed as being more significant than the comparative work at nearby reefs, so when the start of the grant was delayed in 1986, we eliminated the section on comparative line transect and juvenile population dynamics at Michaelmas and Upolo Reefs, and adjusted the budget accordingly. The section on comparative recruitment on settlement plates requires data from the other reefs so was retained. Otherwise no problems were encountered in the programme.

Future Research

Results from the first year of this study show a significant population of juvenile starfish probably recruited from the summer of 1984/85, as well as smaller numbers of older and younger starfish (though the scale of sampling of the 0 + year class prevents direct comparisons). By following the distribution, growth and mortality of this population, as well as determining the periodicity of recruitment to Green Island Reef, we will greatly increase knowledge of the dynamics of *A. planci* at this important site. Combined with measurements of the rate of recovery of the coral populations at the same site, and a study of the larval and juvenile coral stages, this gives a community approach to the problem, and any rapid changes in the dynamics of the system will be detected while the study continues. A budget for this Project is given in Table 1. The costs given in this Table are dependent on permission being given to use the 5 m boat, diving gear, microscope and planimeter previously used for this grant.

Table 1. Project 6(H): 1987/88 budget.

Project Component	Days required	Costs ($)
1. Line transects *	7	2,450
2. Coral spat recruitment *	6	2,100
3. Juvenile coral dynamics *	4	1,400
4. Juvenile COT searches *	18	6,300
5. Analysis and reports **	60	13,200
TOTAL		**25,450**

* Field work (@ $350/day)
** Office work (@ $220/day)

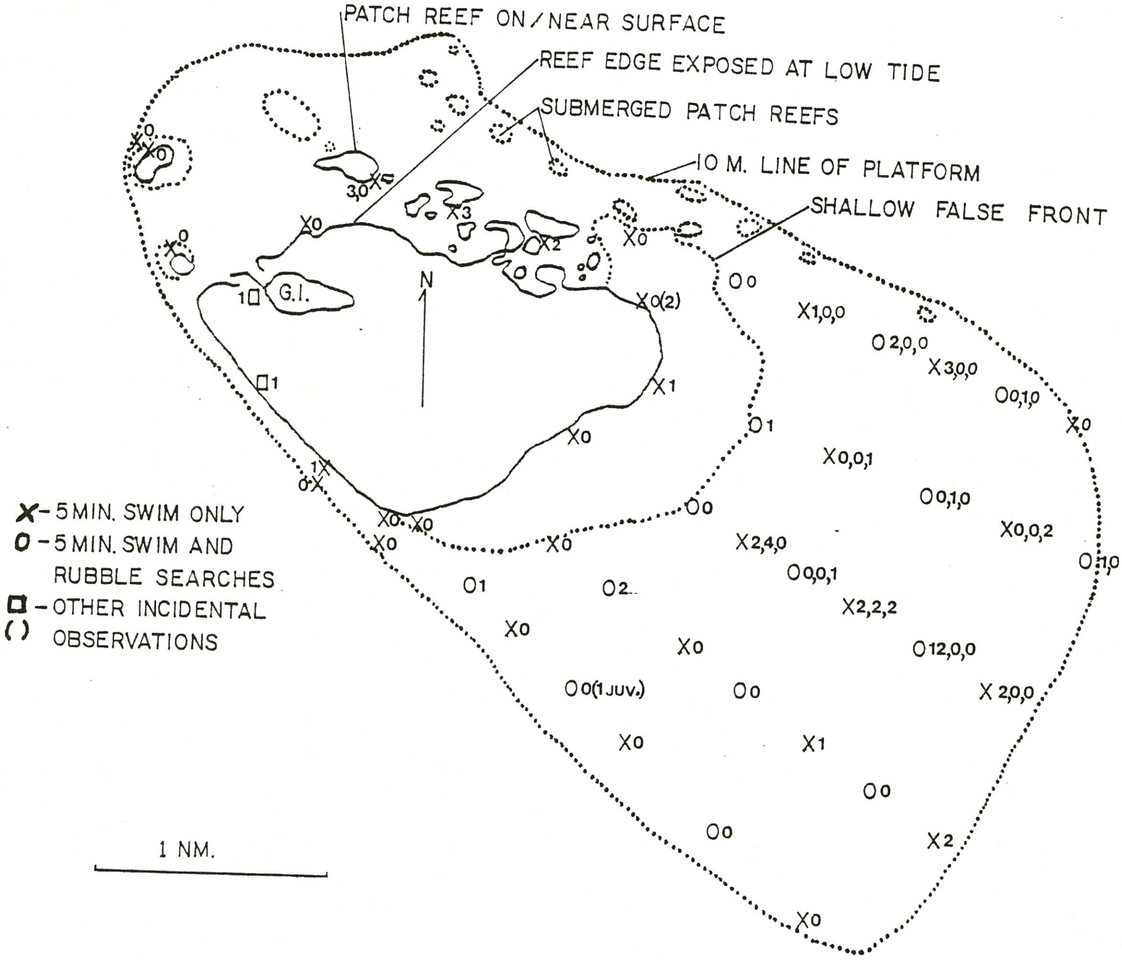

Figure 1. The distribution of surveyed sites on the reef and bommy field at Green Island. The number of crown-of-thorns starfish seen on each 5 minute swim is indicated next to each site. The crosses represent sites where only timed swims were done; the circles are sites where both timed swims and rubble searches were done.

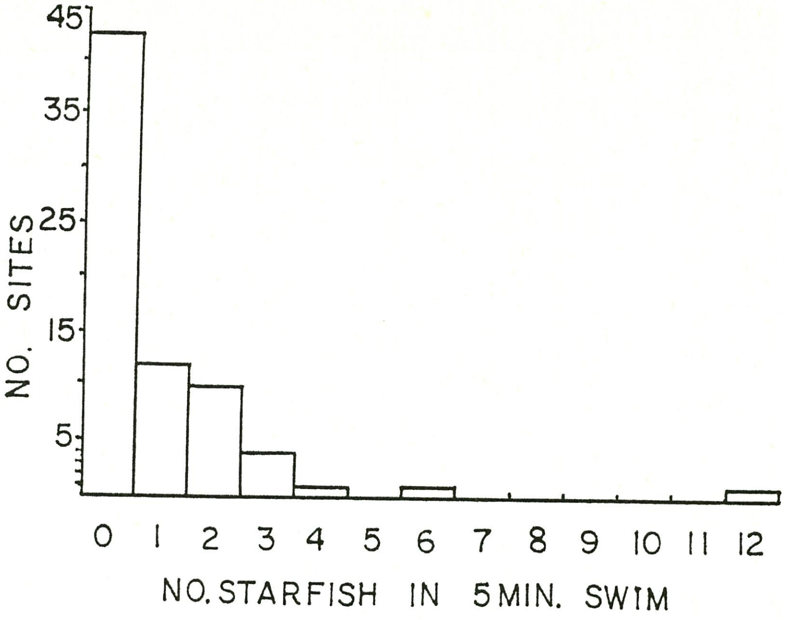

Figure 2. The number of starfish seen per 5 minute swim in 70 sample sites at Green Island Reef.

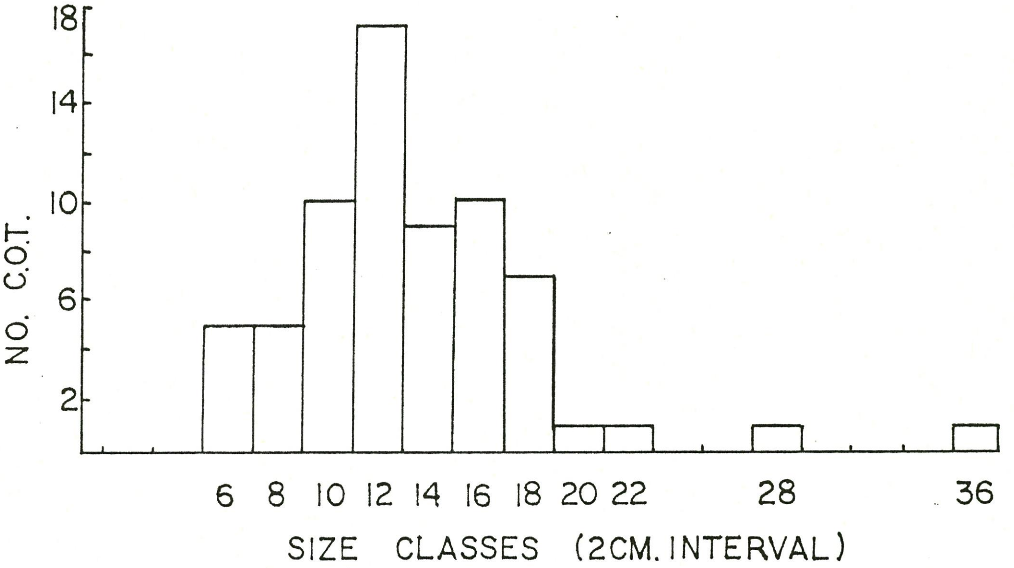

Figure 3. The frequency distribution of diameter of the starfish measured at Green Island Reef in July and August, 1986.

NEW RESEARCH PROPOSALS

PROJECT TITLE: INVESTIGATIONS OF REEF-TO-REEF CONNECTIVITY USING LABORATORY-HYDRAULICS

Chief Investigator(s) Dr E. Wolanski (AIMS)

Introduction

The processes of advection and dispersion of suspended matter, such as crown-of-thorns larvae and coral planulae, in inter-reefal waters are strongly controlled by the prevailing scales of motion. In the absence of reefs, these processes can be calculated numerically using the advective-diffusion equation (e.g. Fischer et al., 1979). In this equation, the vertical and horizontal eddy diffusion coefficients must be specified. Various turbulence closure models have been proposed. One commonly accepted technique is to parameterize the vertical eddy diffusion as a function of the local water depth and currents, and to make the horizontal eddy diffusion coefficient vary with the size of the 'cloud' of matter (Okubo, 1973). It is however not obvious that Okubo's model is valid in shallow shelf waters for horizontal scales or order kilometres. These various models require in any case the accurate knowledge of the velocity field. Here, considerable uncertainty arises from the presence of coral reefs. The currents are strongly modified by the reefs as was first reported in some detail by Wolanski et al. (1984a). Jets, eddies, convergences and divergences are generated and these motions are now known to control the dispersion of inter-reefal waters of coral planulae, as was shown by the findings of the very successful 1986 Coral Spawning Experiment.

The numerical modelling of reef-induced circulation in the barotropic case has progressed greatly the last few years as a result of research at AIMS. Falconer _et al_. (1986) were able to reproduce with a very high accuracy the detailed field observations of the wake behind Rattray Island as reported by Wolanski _et al_. (1984b).

More recently, Wolanski _et al_. (1986) were able to reproduce numerically, using the Falconer _et al_. (1986) model, the detailed observations of the tidal jet (two reef system) off the Ribbon Reefs. These authors showed the importance of free shear layers, i.e. layers in the lee of obstacles where the horizontal gradients of horizontal velocities occur over a length scale much smaller than the usual horizontal scale of the model (typically 100-200 metres). It must be pointed out here that Dr K. Black (personal communication) has proposed the concept that free shear layers are not important in unsteady flows around reefs. It is interesting to point out that Black's model yields no island wake at Rattray Island at steady state, while Falconer's _et al_. (1986) model does yield a very strong eddy at steady state, the reason for this discrepancy being that in the latter model free shear layers effects are included.

These free shear layers are not a mathematical articraft or an invention. Free shear layers have indeed been observed in the field by Wolanski _et al_. (1984b) and Wolanski _et al_. (1986). The presence of these free shear layers is important in the vertical vorticity balance of reef-induced circulation. As a result of this vorticity shedding, a secondary circulation exists with a self-generating Ekman pumping. Flows in the lee of reefs are simply quite similar to the flow in a stirred tea cup where the tea leaves are entrained towards the centre. Without this Ekman suction, flow in a tea cup would be brought to rest after stirring stops in a minute or so as a result of viscosity effects. With this Ekman suction effect, the flow in a tea cup is brought to rest in a few seconds. This is conceptually exactly similar to what happens in an island's wake when the currents are strong enough to generate flow separation. As a result, a number of secondary circulation effects develop and have been reported from field observations by Wolanski et al. (1984b) and Wolanski et al. (1986) and Wolanski (1986), such as

1. Upwelling near the eddy centre.
2. Strong downwelling near the free shear layers.
3. Sorting out of fine sediment from the eddy centre.
4. Concentration of floating material near the free shear layers. This was made apparent in a visually spectacular manner by aerial observations in December 1985 by Ms B. Willis (personal communication) of coral planulae slicks around the Palm Islands and near Rib Reef. Spectacular colour slides show this phenomenon.

As a result, Wolanski et al. (1984b) proposed that the island wake is controlled by an island wake parameter

$$P = Re\ (H/W)^2 \qquad (1)$$

where Re is the Reynolds number of the reef based on the vertical eddy diffusion coefficient and H is the depth and W the reef width. For typical reefs, Re = 1000 to 10000. However, H/W is much smaller than 1 (H is typically 40 m while W is typically 2000 m). As a result, P can take values of order 1. Wolanski (1986) has shown field evidence of increasing complex wake flows for increasing values of P. It is extremely encouraging that as long ago as 1983, Riegels (1938) carried out laboratory investigations of island wakes using a Hele-Shaw cell. He arrived at exactly equation (1). It is also extremely encouraging that very recently Pattiaratchi, James and Collins (1987) have also shown, from an examination of Landsat and Airborne Thematic Mapper Images in a dozen situations of currents around islands in the Bristol and English Channel, that equation (1) is indeed the most appropriate way to describe current-reef (island) features in coastal waters.

Research Plan

Thus equation (1) is that obtained also in laboratory studies of island wakes in coastal waters (when H/W is much less than 1). It is thus proposed to use a Hele-Shaw cell to model the reef-current interaction in areas where the currents are strong enough to generate flow separation. Satellite images of such areas, (eg. the Whitsundays; Wolanski et al., 1984a), show that the flows are even more complex than simple island wakes and jets. This added complication is brought upon by the closeness of reefs one from the other so that their reef-induced currents interfere one with the other. Conceptually such an interaction could be studied numerically but the area to be covered would need to include at least a dozen reefs. The area becomes so large that with typical mesh sizes of order 100-200 m computer storage and running costs and problems would become insurmountable. Further, these depth-average models neglect the important secondary circulation processes. A Hele-Shaw cell enables one to include these effects and to study the water circulation in a very large area with strong currents and a complex network of reefs.

For eventual reviewers of this proposal more familiar with Hele-Shaw cells studies run at small values of Re, it must be pointed out here that the proposed experiments would be run at high values of Re so that flow separation occurs as in the field.

This study will test the hypothesis that mass outbreaks of the crown-of-thorns starfish are, on physical grounds, unlikely to occur in areas with strong tidal currents and high reefal density. The basic reason for this hypothesis is that in such areas the island wake-tidal jet effects generate horizontal patchiness at scales equal to the reef dimensions. In tidally reversing flows, such enhanced patchiness increases the horizontal diffusion processes so much that the probability of massive reef-to-reef connection is becoming extremely small. Analytically, this finding results directly from the fact that island wakes create trapped patches so that the effective horizontal diffusion coefficient becomes (Okubo, 1973)

$$K = \frac{K'}{1+r} (r U_0^2 / 2k(1+r+F/k)(1+r)^2 \qquad (2)$$

where r is the ratio of trapped to non-trapped fluid, k^{-1} is the exchange time between the trapped fluid and the main flow, F is the tidal frequency, U_0 is the maximum tidal velocity and K′ the normal diffusion coefficient without reefs. The second term on the right-hand side of equation (2) is the contribution from the wake effect. Assuming for the Swain Reefs area or the Whitsundays area, r = 0.025, k = F = 4, 3 x 10^4 sec, U_0 = 0.6 m s^{-1}, one obtains K = 90 m^2 s^{-1}, compared to values of K of order 1 m^2 s^{-1}. The values of K are thus an order of magnitude larger than would be expected for motions of scale of reefs (1 to 3 km say).

The assumption that the eddy exchanges water (and crown-of-thorns larvae) at the rate of the tidal frequency is not very critical to the above estimate at very long time scales (say 1 week, much larger than the tidal period; Wolanski et al., 1984b). This is an important finding because the Hele-Shaw cell cannot reproduce the increase of K with increasing 'cloud' size as in Okubo's model (1973); however, as shown above, this effect is of secondary importance. What happens is that the first term in equation (2) is always much smaller than the second term. Since the latter is due to the trapping by jets and eddies, which the Hele-Shaw cell can reproduce, the correct order or magnitude of dispersion processes is reproduced in the Hele-Shaw cell.

The Hele-Shaw cell will first be used to assess the 'error bars' in reproducing the detailed barotropic current observations at Rattray Island (Wolanski et al., 1984b), the Ribbon Reefs (Wolanski et al., 1986) and if possible at Bowden Reef in the second period of CORSPEX 1986.

The Hele-Shaw cell will then be used to simulate the effect of the superimposition of both unidirectional external currents and rotating tidal currents. The model will be used with variable 'reef density' from widely scattered reefs to dense arrays of reefs (e.g. the Swain Reefs area and the Whitsundays area).

The ultimate aim will be to arrive at a criterion for reef density (i.e. the horizontal density or coverage of the reef network) at which horizontal dispersion is so enhanced that the probability of massive seeding of crown-of-thorns larvae from one reef to another one, becomes negligible. An effort will be made to arrive at an analytical formula to link probability of massive cross-seeding of reefs with reef density and current patterns.

Significance

This work will thus directly benefit the Crown-of-thorns Study in that a better understanding of the physics controlling reef-to-reef connection and seeding of crown-of-thorn larvae, will emerge. This knowledge should find use in mapping the likelihood of crown-of-thorn outbreaks (based on physical criteria) in various areas of the Great Barrier Reef, and may well explain why the outbreaks appear to be more intensive in the central and central-northern regions of the Great Barrier Reef than in the southern and far northern regions. Based on equation (2) and on what we know about the tidal currents in these various regions, such gradients of outbreak intensity are indeed expected on physical grounds. This knowledge should also provide an estimate of likely rates of spread of outbreaks once a source (an outbreaking reef) is established. Again, on physical grounds, one expects these rates to vary from region to region.

Organisation and budget

I can supervise this laboratory study, having had experience in other laboratory studies, namely of mixing across density interfaces (my Ph.D. study at the Johns Hopkins University, U.S.A.), of mixing in California coastal waters of heated water from nuclear power plants (my post-doc at Caltech), of buoyant jets in reversing tidal currents (my work at U.N.S.W. with Dr Banner, published by A.S.C.E. J. Hydr. Division), and of boundary mixing on sloping surfaces (at ANU). The duration of the study is 18 months. A room (air-conditioned) will be needed at AIMS to undertake this research. A budget for this Project is given in Table 1.

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Table 1. Project budget for 1987/88.

Item	Cost ($)
Salaries:	
Research Officer	25,000
Capital Equipment:	
Hele Shaw cells, pumps etc...	10,000
Flow visualization and measurement techniques (This includes running costs for the last 6 months evaluated at $1500)	10,000
TOTAL	**45,000**

PROJECT TITLE: ASSESSMENT OF THE ACANTHASTER PHENOMENON THROUGH A CONSIDERATION OF THE LIFE-HISTORY STRATEGY OF A. PLANCI

Chief Investigator(s) Dr M.K. James, Mr I.J. Dight, Prof. R. Jones, Dr L. Bode and Prof. K.P. Stark (James Cook University of North Queensland)

Objectives

1. To further develop existing hydrodynamic/population models in order to provide an appropriate and flexible tool for examining the life-history strategy of *A. planci*.
2. To assess the *Acanthaster* phenomenon in light of model results and life-history theory.

Research Plan

Research is currently proceeding on the development of a numerical model to simulate the population dynamics of *Acanthaster planci* within the Cairns and Central Sections of the Great Barrier Reef Marine Park. The simulation model is modular in design so that the units can be easily adapted and applied to other ecological problems.

A primary split in the design of the model is the separation into a hydrodynamic component and a population component. The hydrodynamic component, while essentially deterministic given a specific set of forcing parameters, runs under time-dependent tidal flow and a randomly varying wind field. The final output will be in the form of a probability matrix of values which describe the interrelationships among reefs with respect to the advection of larvae and the likelihood of a larval cloud, or proportion thereof, encountering a suitable habitat within the time constraints of larval life. The population component of the model will be used to investigate the dynamics of A. planci populations. This component will be stochastic and based around the probability matrix resulting from the hydrodynamic component. The population model will describe the principal life-history characteristics of A. planci including developmental rates, growth and reproduction, as well as survivorship and predator/prey interactions.

The current project should be completed by the end of February, 1988. During the intervening period research will concentrate on finalizing the hydrodynamic component of the project, the probability matrix having yet to be produced, and the design of the population component. On completion, it will be expected to have established:

1. The connectivity between reefs.
2. The rate and pattern of spread of larvae.
3. The feasibility of chronic infestation.

The final simulation runs are expected to shed light on the population dynamics of A. planci, however, this model is descriptive and should be viewed as a tool with which the implications of appropriate hypotheses can be investigated. Also, the model is tailored to meet the specific objectives of the original research proposal. These were; first, the development of numerical models of the spread of A. planci between reefs and secondly, the application of the models to investigate the large-scale population dynamics of the starfish. Thus, biological parameters which are unnecessary to fulfill these objectives will not be included. However, such parameters will need to be incorporated into the model if it is to provide a versatile tool for future research.

This new proposal aims to assess the Acanthaster phenomenon through a consideration of life-history theory. This will require, as a first step, that further development of the hydrodynamic/population model be conducted. The goal is to identify what patterns of survivorship and abundance A. planci appears best adapted to. In particular, whether its life history strategy shows evidence of adaptation to 'outbreak' population dynamics.

The Great Barrier Reef system consists of isolated patches of reef with large inter-reefal areas. This, together with the variable pattern of water currents in time, makes successful pelagic dispersal between reefs likely to be highly unpredictable. A. planci, like other reef organisms with pelagic dispersal, can be expected to possess life-history attributes which are adapted to this type of unpredictability. The critical question for A. planci is whether it also possesses attributes which are adaptations to high variability in its own population density. This distinction is a crucial one, and has not been clearly recognized in arguments about the species' life-history strategy. Two alternative hypotheses will be investigated:

1. That the life-history characteristics of A. planci are those of a species adapted to a system where population densities are normally low as a result of predation on both juveniles and adults, or alternatively,

2. That the life-history characteristics of A. planci are consistent with the recently observed population fluctuations and the exploitation of habitats.

This will be achieved by maintaining the life-history characteristics of A. planci constant while varying the context within which they operate. Values for the various life-history traits (including reproductive pattern, fecundity, longevity, developmental rate and duration of larval life) appear sufficiently well established to justify their use as constant parameters. By varying the context, such as the patterns of survivorship, reproductive success and abundance, it should be possible to identify the population dynamics for which the life-history traits of A. planci are best adapted. Thus it may be possible to determine whether a low-density, predator-regulated population regime can be maintained, or alternatively if high-density, food- or disease-limited outbreaks are necessary to ensure reproductive success and persistence of the species.

Proposed Research

Debate surrounding the causes of outbreaks of Acanthaster planci that have been observed within the Great Barrier Reef since the early 1960's has, by and large, been centred around the issue of whether they are natural or unnatural phenomena. This emotive issue still continues to divide the community (e.g. The Australian, 1/4/87) and the limited research funding that has been made available. Hypotheses proposed in support of the two viewpoints advocate contradictory life-history strategies. Proponents of the view that humans have triggered the outbreaks by overcollecting the predators of A. planci argue that outbreaks are abnormal and unprecedented, that populations are normally held at a level well below the carrying capacity of the environment with respect to resources by predators of both juveniles and adults, and that the life-history characteristics of A. planci correspond to those from a biologically accommodated, stable and predictable system (Endean, 1977, Cameron and Endean, 1982). In contrast, proponents of the view that the observed population fluctuations are a normal component of the dynamics of coral reef communities argue that the life-history characteristics of A. planci are of a type consistent with such outbreaks and the exploitation of habitats in a system where recruitment is unpredictable and dominated by stochastic events (Moore, 1978, Birkeland, 1982).

Interest in the theory of life-history strategies has developed because of the predictive nature of its primary objective: to explain the range of life-history patterns that are observed in nature in terms of their selective pressures. It is assumed that strategies evolve as sets of co-adapted traits designed to solve particular ecological problems (Stearns, 1976). The components of a life-history strategy are many and include: the degree of iteroparity (in contrast to semelparity), age at maturity, clutch size and frequency, adult longevity, body size, and egg size. In addition, for those many marine organisms with an obligate larval dispersive phase to their life cycle, the patterns and characteristics of larval development are an important component of their life-history strategy. Selective pressures postulated to act upon the components of a life-history strategy include population density with respect to resources and the carrying capacity of the environment (MacArthur and Wilson, 1967), age specific mortality (Schaffer, 1974), trophic position (Wilbur et al., 1974) and the degree of environmental stability and predictability (Murphy, 1968).

Other Applications

The modular design of the original model and the further developments proposed will provide a flexible tool which can be applied to future research and hypothesis testing as more information on the ecology of *A. planci* becomes available. An area of research that could be addressed is that of a more general approach to the life-history theory of coral reef invertebrates and fish which looks at the adaptive significance of life-history traits themselves. Furthermore, other ecological problems of general and fundamental relevance to the management of the Great Barrier Reef Marine Park can be addressed after the proposed developments are in place. Such a concern which could be addressed is the inter-dependence of reefs or groups of reefs and thus the appropriate size and location of replenishment areas. This would be of particular advantage in the event of an oil spill or other disturbance to any particular area of the Great Barrier Reef.

Schedule

It is anticipated that a full 12 months funding will be required to complete the project which will proceed in three phases. Work would commence in March 1988, following completion of the present project.

Phase 1: Further Development.

This first phase, with an anticipated duration of six months, will be aimed at further developing the existing models in order to provide an appropriate and flexible tool for hypothesis testing.

This phase will result in a model which will not only serve the present purpose, but also that of future research on A. planci as well as other management related projects.

Phase 2: Hypothesis Testing.

The second phase of the project will focus on the formulation and testing of hypotheses related to the life-history strategy of A. planci. Extensive simulation runs will be required during this phase as will the development of appropriate means of output presentation.

It is anticipated that four months will be required to complete this phase.

Phase 3: Synthesis and Final Report.

This final phase, with an anticipated duration of two months, will include a synthesis of both the experimental and comparative approaches and the production of a final report.

Budget

Salary

It is anticipated that Mr Ian J. Dight, presently employed as Research Officer on the current project, will continue in the same capacity for a further 12 months. Appointment at the level of Research Officer Grade II would be justified.

Contingencies

These will include regular maintenance expenses such as photocopying, telecommunications, local transport, library use (incl. inter-library loans and on-line literature searches), computer materials (printing and plotting paper) and the production of a final report.

No expenditure on capital equipment is anticipated on the basis that equipment bought under the terms of the previous grant will be retained for the duration of the project. A budget for the Project is given in Table 1.

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Table 1. Project budget for 1987/88.

Item	Cost ($)
Salaries:	
Research Officer (Grade 2)	24,013
On-costs and inflation	4,082
Contingencies:	1,000
TOTAL	**29,095**