# THE CROWN OF THORNS STARFISH

A SPECIAL FEATURE OF AUSTRALIAN SCIENCE MAG
EDITED BY LEON ZANN AND ELAINE EAGER

Great Barrier Reef Marine Park Authority

# FOREWORD

*The damage to coral reefs caused by outbreaks of the crown of thorns starfish is one of the most serious scientific and management issues on the Great Barrier Reef. This large starfish, known to scientists as Acanthaster planci, eats the living part of corals leaving the skeleton behind. It is usually an uncommon animal on coral reefs and the damage is negligible but sometimes, and for reasons unknown, populations explode and damage to reefs may become very great.*

*In recent years there have been two distinct waves of outbreaks on the Great Barrier Reef, the first beginning in the early 1960s and the second in the late 1970s. There may have been others before tourists and scientists began to explore the reefs for, despite the impressions given by the media, the starfish is not a new creature nor is the problem confined to the Great Barrier Reef.*

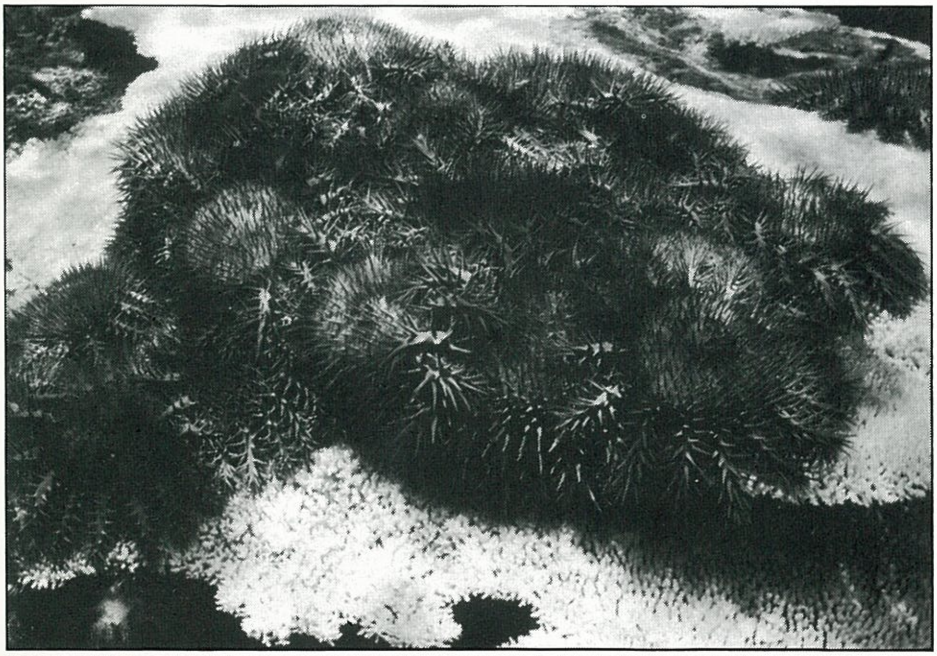
*The Great Barrier Reef Marine Park Authority (GBRMPA), the agency responsible for the management of the area, is very concerned about the phenomenon of crown of thorns starfish outbreaks. Opinion on the causes of the outbreaks and on the extent of the damage is divided, and the phenomenon has generated heated debate among scientists and the public alike. For almost 25 years now Australians have been subjected to emotional reports telling of the destruction of the entire Great Barrier Reef.*

*What, then, is the truth of the crown of thorns starfish phenomenon?*

*What is being done about it?*

*Attempts to eradicate the starfish on a wide scale have proven futile. The GBRMPA has therefore channelled its efforts into research to find out more about the starfish, and particularly whether the outbreaks are a natural event or are in some way the result of man's activities. Following GBRMPA's recommendations in 1985, the Commonwealth Government has granted the Authority about $800,000 per year for an intensive, four to five year coordinated research program on the starfish. Today scores of marine scientists from many research institutions around Australia are investigating different aspects of the starfish, using equipment ranging from electron microscopes to experimental satellites, and SCUBA diving to monoclonal antibodies. The following pages describe some of what is now known about the crown of thorns phenomenon and some of the research which is now underway.*

*Graeme Kelleher*
*Chairman, GBRMPA*



*Crown of thorns starfish aggregate several layers deep to feed at Green Island. Researchers have demonstrated that starfish release chemicals during the digestion of coral which attract other starfish into the feeding group.*

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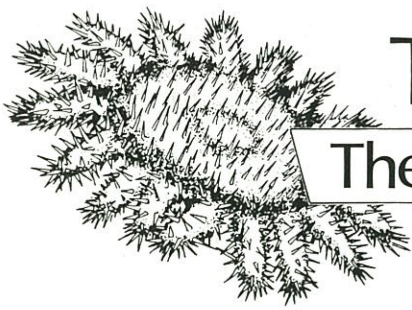
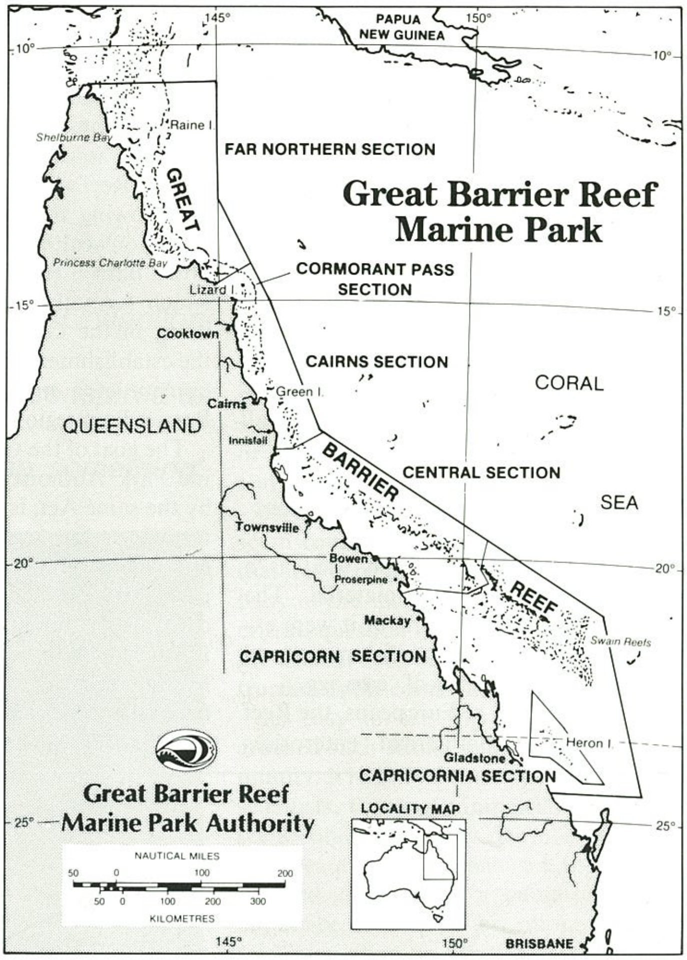


# THE SETTING:

## The Great Barrier Reef and the Marine Park

THE GREAT BARRIER REEF is the largest system of coral reefs in the world, stretching more than 2,000 km from off Gladstone in the south to the Gulf of Papua opposite Port Moresby. It is not a continuous barrier, but a scattering of about 2,900 individual reefs. Because of its large size and great diversity of life forms, the Reef has been inscribed on the UNESCO World Heritage List. Almost all of the Reef in Australian waters now lies within the world's biggest Marine Park. The Great Barrier Reef Marine Park has an area of 349,000 square kilometres, bigger than the combined areas of Victoria and Tasmania.

A warm climate, sandy beaches, colourful reef life, tropical islands and ideal conditions for water sports make the Reef region an increasingly popular tourist destination. It also supports amateur and commercial reef fisheries, whilst prawns are trawled in open waters.




All the reefs that make up the Great Barrier Reef system lie on Australia's continental shelf. This area of relatively shallow seas (around 40 metres deep) is broad off southern Queensland but narrows considerably further north. Consequently the reefs located on the edge of the continental shelf are over 250 kilometres offshore in the south (in the vicinity of Mackay) but less than 50 kilometres offshore in many places further north.

Experts suggest that parts of the Reef could be as much as 18 million years old. However most of the structures visible today have developed over the last 2 million years. The topmost layers of reefs now at sea level are all geologically young, only a few thousand years old, but most are built upon older reefs.

### Marine Life

Coral reefs are built up by billions of tiny animals (coral polyps) and plants (coralline algae) that deposit limestone. Dead corals, bound together by their own limestone and that of the skeletons of coralline algae, make up a reef. Over thousands of years, coral growth, death and cementing built a reef many metres thick, with a veneer of living corals and a myriad of associated plants and animals. The corals that build reefs grow best where conditions provide sunlight, stable temperatures of 20°C or above, good aeration (mixing of air and water) and a good supply of nutrients (food). These conditons are usually found from mid-tide level down to about 40 metres. A few coral species grow in waters up to 120 metres deep, but they are not important reef builders.

A coral reef includes many different species of corals. Some of the common forms are staghorn coral, brain coral, honeycomb coral, and mound coral.

The colour of reef building corals comes from pigments in the tissues of the polyps. When a coral colony dies or is eaten by a crown of thorns starfish only its white limestone skeleton remains. This is soon covered by algae but may eventually be colonized by new corals.

The success of corals as reef builders is due in part to tiny single-celled plants called zooxanthellae which live in the cells of the polyps' tissues. Zooxanthellae, like other plants, harness energy from sunlight ▶

to manufacture materials used in their own nutrition and reproduction. In doing so they make use of carbon dioxide produced by the coral, and in return they pass some materials back to the coral. Their presence greatly enhances the rate at which polyps create their limestone skeletons.

Coral reefs harbour more kinds of fish than any other marine environment. From a total of about 3,000 fish known from the seas around Australia, almost 1,500 have been recorded from the Reef. Angelfish, cod, manta rays, mackerel, butterfly fish, and surgeon fish all live and breed in Reef waters. Of 10,000 Australian species of shellfish, 400 occur on or around coral reefs.

There are many hundreds of species of crabs, shrimps, crayfish, sea urchins, sea stars, sea cucumbers, soft corals, sea fans, sponges, sea anemones, and worms, all living in their own reef habitats.

## Conservation of the Great Barrier Reef

The Reef region has been used as a source of food and raw material. The Great Barrier Reef or parts of it were explored and used by native fishermen and hunters many thousands of years ago.

Since the arrival of Europeans, the Reef has supported commercial enterprises based on harvesting its natural resources: beche de mer, turtles, scallops, prawns and pelagic and demersal fishes.

During the late 1960s public concern for the future of the Great Barrier Reef grew and began to be expressed in the media. Awareness that the Reef was under threat from oil drilling and mineral exploitation drew people together and gave them a single, strong voice. In 1970 joint Commonwealth and Queensland Royal Commissions were established to investigate the issue of oil drilling in Great Barrier Reef waters.

Following that important inquiry, the Commonwealth Parliament passed the Great Barrier Reef Marine Park Act 1975, which formally ensured the future well-being of the Great Barrier Reef through the establishment, control, care and development of a marine park in the Great Barrier Reef region.

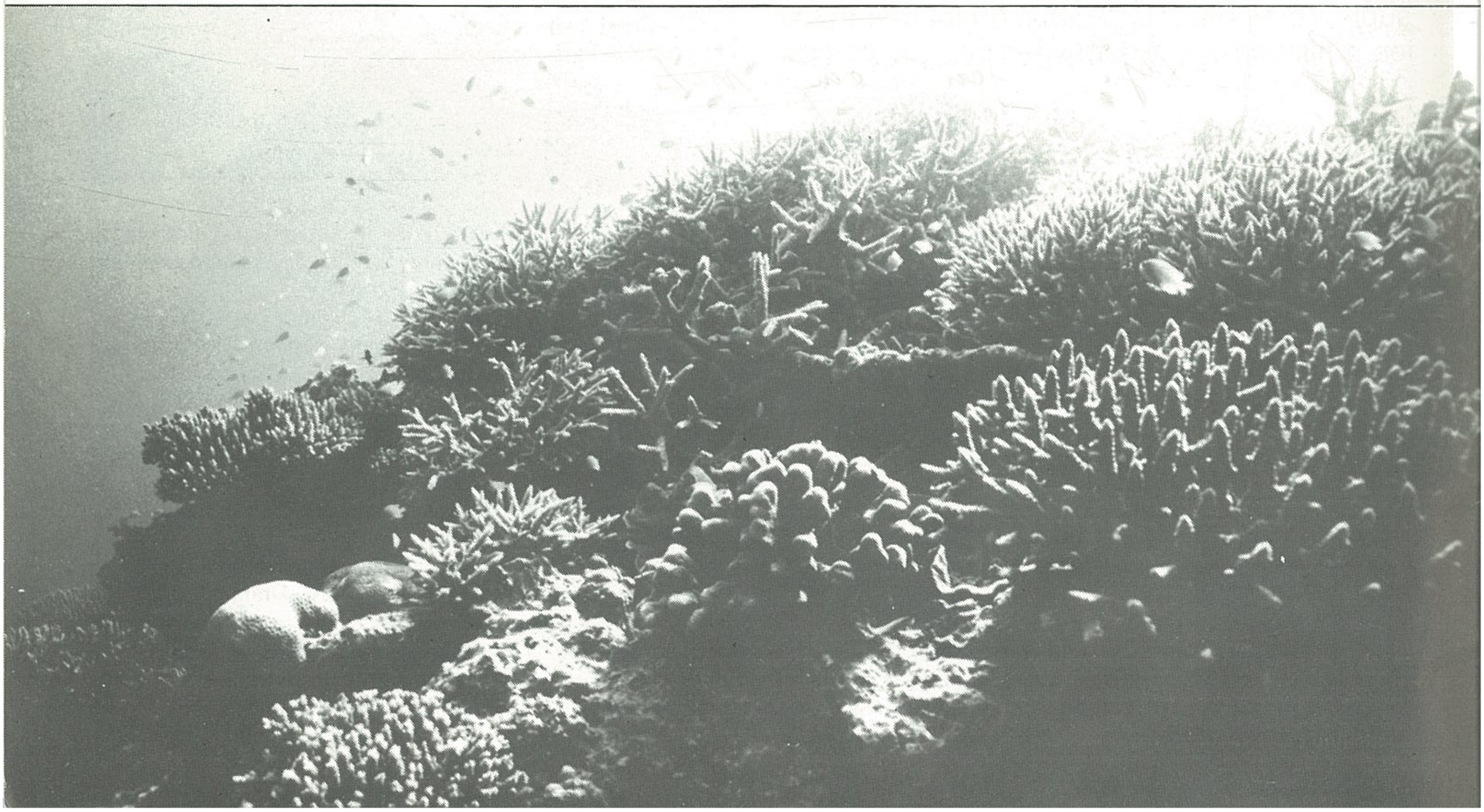
The goal of the Great Barrier Reef Marine Park Authority (GBRMPA), created by the same Act, is to provide for the protection, wise use, understanding and enjoyment of the Great Barrier Reef in perpetuity through the development and care of the Great Barrier Reef Marine Park. The day-to-day management of the Marine Park is undertaken by officers from the Maritime Estate Management Branch of the Queensland National Parks and Wildlife Service (Q.NPWS).

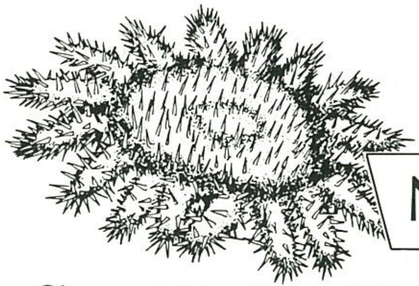
Apart from the purposes of scientific research, mineral extraction is no longer allowed within the Marine Park, and oil drilling is prohibited anywhere within the Great Barrier Reef region.

## Zoning

The main tool used in managing the Reef is zoning. Zoning separates uses that might conflict with each other, while allowing space for any reasonable activity and still ensuring the protection of the Reef. The Authority depends on public input when developing zoning plans. The area to be zoned is advertised and Reef users are invited to give their opinions on how zoning should be undertaken, and to provide information about their use of the Reef. This information is put together, conflicts in usage are resolved, and a draft zoning plan is prepared. This draft zoning plan is then advertised and the public is again invited to comment. Changes may then be made in the draft zoning plan before the final steps are taken to make it a legal document.

Zoning plans for every section of the Marine Park will be completed in Australia's bicentenary year, 1988. □





# THE CONTROVERSY:
## Natural Cycle or Not?

*by Leon Zann*

*Since aggregations of the coral-eating starfish were first noticed on the reef at Green Island in 1962, the crown of thorns starfish has been the subject of intense controversy in Australia. Is the entire Great Barrier Reef at risk? Or only parts?*

*Is it a cycle that will soon be over?*

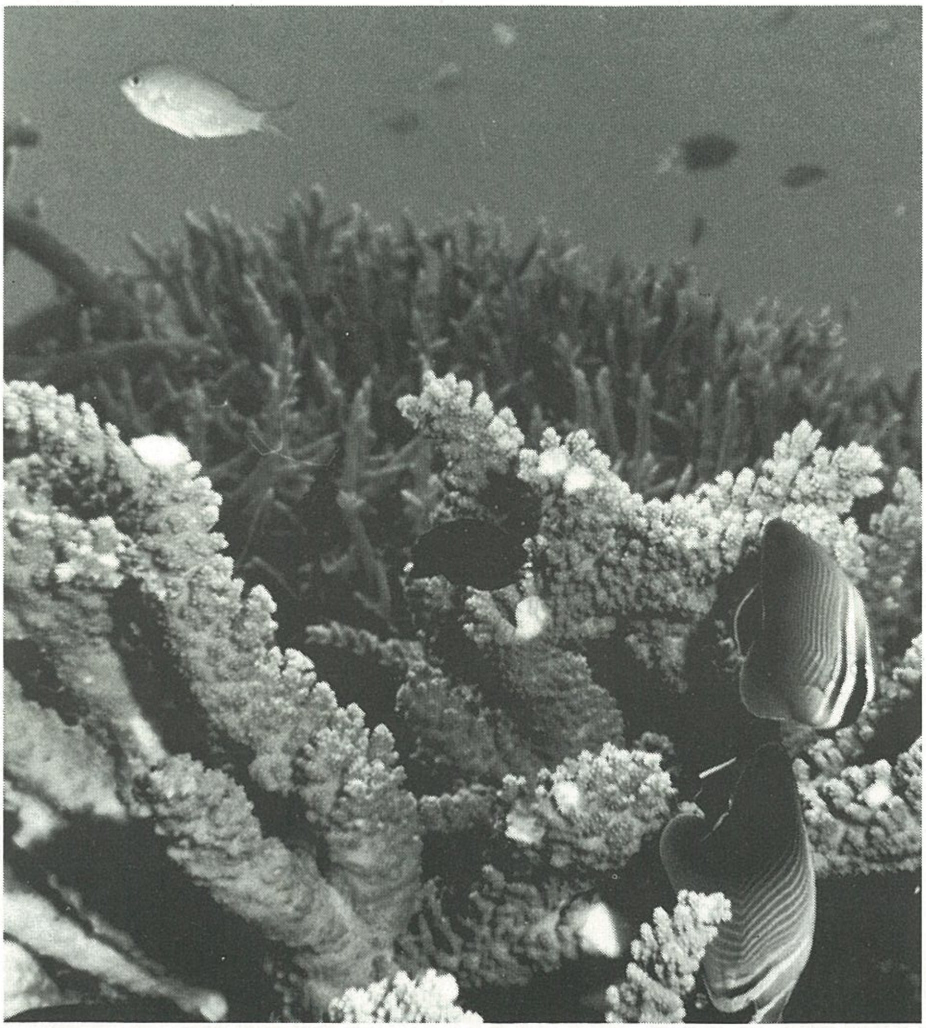
*Is it a natural event or the result of human activity?*

*If it is natural, should man attempt to control the starfish?*

*If it is not, what is the cause? Pollution? Overfishing? Collection of the triton shell?*

*Have some scientists, bureaucrats and politicians conspired to keep the terrible reality from the Australian public?*

*Why aren't the Reef's managers out there 'doing something' about this threat?*



It seems that almost everyone, scientist and member of the general public alike, has a strong opinion on the starfish. And the debate is as heated now as it was 25 years ago.

Unlike the quaint little five-armed seastars found around our shorelines, the crown of thorns is big and ugly, its many arms bristle with venomous spines ... and it eats the beautiful coral which is the builder of the reef. Normally an uncommon animal, it may appear suddenly and mysteriously on a reef in its thousands or millions, devastate much of the coral, and then depart as quickly and mysteriously as it arrived, leaving a barren, scum-covered landscape. It is little wonder that it is depicted as a 'villain', in the company of the sharks and box jellyfish. The critical question is, **'Is it as much a part of the natural cycle of reef building and destruction as the corals themselves?**

It's easy to see why this seastar has aroused such strong reaction in the community. It is difficult for anyone, including scientists, to remain impartial when they see a coral reef, surely the most complex and beautiful ecosystem on the planet, reduced to a grey, apparently lifeless landscape within a few months. Even scientists often use emotive terms such as *'plagues'*, *'outbreaks'* and *'infestations'* to describe clusters or aggregations of the seastars while affected reefs are generally *'devastated'*. Some even talk about *'ecocastrophy'* — the collapse of a whole ecosystem — on a vast scale.

### The Media Controversy

The media have fuelled the public's appetite for a horror story. Countless newspaper and magazine articles, and several books and television specials have been produced on the crown of thorns starfish phenomenon. Dramatic headlines tell of plagues of the pests, controversy amongst scientists, and even the death of the entire Great Barrier Reef. Letters to the Editor reflect differing opinions of newspaper readers on the phenomenon. ▶

The 'letters to the editor' that follow present some of the various arguments and schools of though surrounding the crown of thorns issue. We have selected 'letters to the editor' to tell the crown of thorns story because they most accurately present the theories, thoughts and feelings of the participants in this controversial debate.

THE COURIER MAIL 7/5/84

## *Starfish risk on Barrier Reef 'small'*

*DURING the last six months, there has been substantial media attention on a renewed Crown-of-Thorns "threat" to the Great Barrier Reef.*

*As well as being members of the Council of the Australian Coral Reef Society, we are all scientists active in ... the Great Barrier Reef, ... summary of the ... Great Barrier ... thority detailing ... starfish during*

*... also seen large ... starfish causing ... ever, sighting of ... of starfish does ... te that the Great ... risk, or even that ... rfish have risen*

*... there has been ... ias, and exaggera- ... the reef caused by ... present starfish populations.*

*... minority of scientists ... is seriously at risk ... dation. This is the ... which has raised ... mes since the mid- ... dictions have not ... past, yet the media ... redibility to their ... ensive coverage.*

*... ntly dense aggrega- ... Thorns starfish on ... on these reefs, sub- ... s being done to cor- ... a whole, the Great ... ll a place where this ... ng coral predator is ... date operated very responsibly with respect to the Crown-of-Thorns "problem". It has managed an extensive monitoring program and has released the results of that program to public view.*

*It has made great efforts to inform the media, and through them, the public, concerning the true state of affairs. Based on scientific data available, the most appropriate summary statement is that there are at present dense aggregations (40 or more starfish) on 14 percent of the reefs, but few starfish on the remaining area of the Great Barrier Reef.*

*The reasons why this animal sometimes occurs in large numbers are not fully understood, but there is no evidence whatever that man's activities have caused an increase in the frequency of such events.*

*Such fluctuations in numbers are a common feature of many starfish and other echinoderms, and present evidence suggests that in this regard, the Crown-of-Thorns is a typical echinoderm. To argue that massive funds and manpower must be used to eradicate starfish is irresponsible, not supported by available scientific data, and impractical.*

*It could also be undesirable as a form of reef management if periodic cutting back of coral by this predator was important to sustaining the rich diversity of the coral community. Removal of predators is not always best for prey species.*

*Like members of the Marine Park Authority, we recognise that the population dynamics of the starfish are not fully known, and we advocate an ... eased research effort.*

*We believe that research directed at the Crown-of-Thorns starfish must be well designed, and competently carried out. It would be most unfortunate if the current "crisis" atmosphere resulted in massive amounts of research funds being poured into poorly designed, or impractical projects, simply because they dealt with the starfish. —*

***Peter F. Sale, president, Australian Coral Reef Society, and Associate Professor of Biology, University of Sydney — signing on behalf of the following: Dr J.E.N. Veron, vice-president, ACRS, Australian Institute of Marine Science, Townsville; Dr P.G. Flood, secretary, ACRS, Department of Geology, University of New England, Armidale; Mr M. Chalupka, treasurer, ACRS, Marine Unit, Queensland National Parks and Wildlife Service, Brisbane; Associate Professor H. Heatwole, past president, ACRS. Department of Zoology, University of New England, Armidale; Dr J.T. Baker, council member, ACRS, director, Sir George Fisher Centre for Tropical Biology, James Cook University, Townsville; Dr M.A. Borowitzka, council member, ACRS, Department of Environmental and Life Sciences, Murdoch University, Perth; Dr D.J.G. Griffin, council member, ACRS, director, Australian Museum, Sydney; Dr P. Hutchings, council member, ACRS, senior research scientist, Australian Museum, Sydney; Dr B.C. Russell, council member, ACRS, Curator of Fishes, Northern Territory Museum, Darwin; Dr P. Saenger, council member, ACRS, scientific chairman, Australian Underwater Federation, Brisbane; Dr C.C. Wallace, council member, ACRS, Department of Marine Biology, James Cook University Townsville.***

## Fencing out the crown of thorns

• Pictured — right — Crown of thorns lifted off coral on which it was feeding. Note extruded stomach which wraps over and digests living tissue off coral skeleton.

...EKEND AUSTRALIAN. SATURDAY/SUNDAY, 17/18TH DECEMBER 1983

## Time to tackle 'thorny' issue

SIR — How the present crown of ...orns starfish controversy could ...volve and so divide the scientific ...ommunity must be difficult for the ...verage reader to comprehend, and ... am in complete agreement with this aspect of Dr John Lucas's letter (*The Australian, 29/11*).

The reason may involve what has been called "anomaly anxiety," a term coined at the University of Pittsburg.

The conventional researcher, trained in a specific area of expertise, tends to experience this reaction when faced with new evidence that doesn't fit the prescribed parameters of his, or her, knowledge.

The crown of thorns infestations throughout the Indo-Pacific region should never have occurred.

The starfish population explosions were contrary to all past documented knowledge and teachings in marine science.

Unable to accept the issue as fact, some academics initially rejected the existence of the crown of thorns infestations.

In late 1969, I was slated as a liar by unnamed academics when I first recorded these along parts of the Great Barrier Reef.

However, when faced with the overwhelming evidence of coral reef destruction, and perhaps out of sheer desperation, the opposing academic group spawned the natural cycle hypothesis to explain away the phenomenon.

### Cancer

Although the weight of evidence gathered over the past 15 odd years clearly indicates that the starfish population explosions are man-induced, and as such control measures are essential to protect the Reef, their introduction has been vetoed on the pretext that the agency responsible must firstly be ascertained regardless of the long-term consequences associated with the problem.

One could draw a parallel to the situation where a doctor, having diagnosed that a patient is suffering from cancer, sets about trying to establish the cause of the illness rather than attempt any cure. Naturally the patient dies.

Contributing factors which may have triggered the starfish ... breaks could include marine p... tion, the over-collecting by hu... of known predators of the cro... thorns like the giant triton... helmet shells, together wit... over exploitation of some spe... reef fish.

While agreeing that more re... is needed, there no longer ex... valid argument to delay th... duction of starfish control... sure the protection, pres... and conservation of the Gr... rier Reef.

**THEO W...**
Director, Australi...
World Life Researc...
Newport ...

## Warning: No reef by 2000

## Crown of thorns moves in for kill on the reef

NOVEMBER 1983

## Scientists at sea over starfish

ONCE more the public is being treated to controversy between marine biologists and other marine experts over the crown-of-thorns starfish (Letters 25/10, 14/11, *The Weekend Australian 5/11*).

This must lead lay people to wonder what is wrong with marine biologists.

The problem is the current state of our knowledge of coral-reef ecosys...ems, of which the crown-of-thorns ...arfish is part.

We do not yet properly under...nd the factors producing changes ...nimal populations on coral reefs. ...ithout adequate knowledge, the "experts" have had to adopt hypotheses about the dramatic changes in abundance of crown-of-thorns starfish.

One is that the large populations are an unprecedented event caused by the recent level of human interference in the marine environment — thus the starfish has become a pest through human activity (which activity?) and should be treated as a pest.

The alternative hypothesis sees the crown-of-thorns starfish as a ... processes of the coral-reef ecosystem.

There is no compelling evidence for either hypothesis. Should we try, anyway, to control the crown-of-thorns starfish where it is consuming large areas of coral?

I am aware of major control programs, costing tens or hundreds of thousands of dollars, that have been attempted in the southern islands of Japan, in the Micronesian islands and in American Samoa.

### Declined

None of the biologists associated with these programs has indicated to me that they were clearly successful.

Starfish remained after the money ran out and, in time, the large populations declined, whether they were attacked or not.

These control programs were directed at starfish on accessible fringing reefs, the logistics of tracking large populations on the offshore patch reefs of the Great Barrier Reef are much more daunting.

I am not against keeping particular areas of coral free of crown-of-... rently in the central region of the Great Barrier Reef would be extremely expensive, while having absolutely no guarantee of success.

I am not arguing for complacency about the crown of thorns starfish. Clearly much more research is needed on this species, particularly field studies of its population dynamics.

There is need for patience in waiting for the answers from research. It should be noted that the current level of research on coral reefs is far greater than even five years ago.

As an example of increasing knowledge, when the crown of thorns starfish first gained notoriety in the 1960s it was possible for biologists to claim:

That we may be witnessing the extinction of hard corals in the Pacific region;

It might take many decades for reefs to recover from starfish predation.

These claims would not now be made in the light of the acquired knowledge of coral reefs.

**(Dr) JOHN LUCAS**
Zoology Department
James Cook University

## Coral-killer is raping the reef

By RUTH YOUNGBLOOD

## The peril of the Great Barrier Rubble

## Common Questions, Popular Misconceptions

While much remains to be learnt about the crown of thorns starfish phenomenon some of those questions which are frequently asked can be at least partially answered at this time, and some popular misconceptions can be corrected.

*Is the entire Great Barrier Reef in danger? Will it eventually be eroded and will the coastline be threatened?*

No. The infestations have mainly been confined to the central third of the Great Barrier Reef, between Lizard Island off Cooktown and Townsville, although minor outbreaks have occurred elsewhere. Surveys along the entire Great Barrier Reef in 1985 indicated that 28% of reefs sampled had been affected by the starfish, and that damage ranged from slight to great.

Although it was suggested in the 1960s that the entire Great Barrier Reef would be eroded away within 20 years and waves would threaten the coastline this has definitely not been the case. (For details on the reefs affected by the starfish, see page 31.)

*The Great Barrier Reef will take many decades, perhaps even centuries to recover*

False. The faster growing staghorn corals which are the main food for the crown of thorns regrow quickly, between 5 cm and 20 cm in a year. After five to fifteen years they will have completely recovered. The slower growing giant or massive corals may be centuries old but are not a favoured food. If they are attacked some patches often survive to recolonize the coral or grow into new head. (For detailed information about the recovery of coral reefs, see page 38)

*Pollution, over fishing of reef fish, or over collection of the triton shell have been responsible for the outbreaks.*

Unproven. Pollution along the Great Barrier Reef is as low as any place in the world. Observations of reef fish eating crown of thorns are very rare on the Great Barrier Reef and there are no confirmed reports of crown of thorns fragments in fish gut contents. Although the triton is a confirmed predator of the seastars, it is naturally uncommon even on remote reefs which are not visited by collectors. Most scientists think that most of the natural mortality in the starfish takes place in the more vulnerable larval stage. (Read about the theories on the causes of the outbreaks, and how they are being tested on page 44.)

*Is the phenomenon therefore a recurring natural cycle?*

Not known. Some scientists have suggested that it is entirely natural and even necessary for reef growth, rather like a bushfire is necessary for the germination of seeds in the Australian bush. Geological studies indicate that crown of thorns remains are common in sediments as old as 8,000 years on some reefs, suggesting that outbreaks did occur in the past. However a few scientists strongly believe that human activities have caused the phenomenon. (Read about how geologists are trying to answer this important question on page 47.)

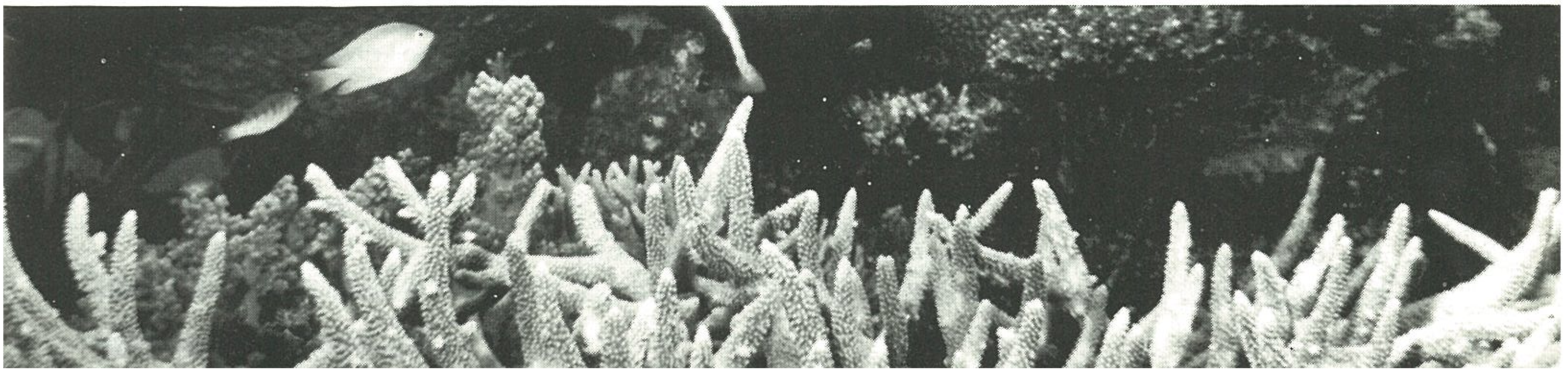
*Has there been a conspiracy among many scientists and others to hide the truth about the extent of the damage on the Great Barrier Reef?*

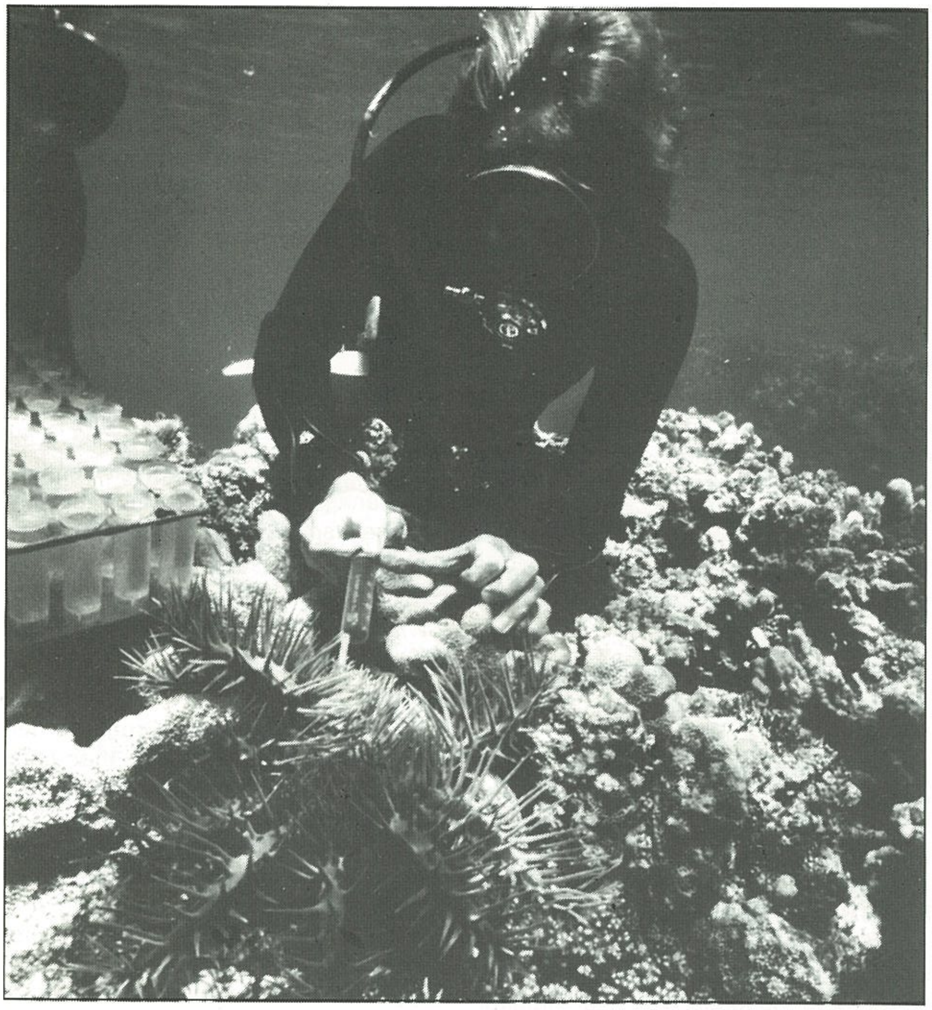
No. Scientists have been reluctant to talk to the media, but for other reasons. The crown of thorns issue is considered so controversial that most scientists are reluctant to become involved in the debate or give interviews for fear of being misquoted. In addition, most scientists are very cautious about making categoric statements unless they have solid evidence concerning a particular matter. Professional ethics have been interpreted as a 'conspiracy of silence' by some sensation-seeking journalists.

As the Reef managers are relying on firm evidence from the scientists, their own caution has been criticised as 'inactivity'. These criticisms do illustrate a common problem between scientists and managers, and a common inability amongst specialists to communicate with the public.

*Why doesn't someone do something about the outbreaks?*

The managers of the Great Barrier Reef Marine Park consider that until most scientists who are experts on the crown of thorns starfish are sure that the infestations are not a natural event, but the result of man's activity, they should not intervene to eradicate the starfish on a large scale. Controls have therefore only been undertaken on reefs of special importance to science and tourism. In reality, large-scale attempts to eradicate the starfish in other countries have proven unsuccessful and a complete waste of money. The GBRMPA has therefore channelled its efforts into science to try to find out more about the starfish, while funding research on potential biological controls if these should ever be considered necessary. A $3m, four to five year study is currently underway on the management and ecology of the starfish. (The scientific research program, the eradication programs and biological controls are discussed in detail on pages 20 and 39.) □





*Marine scientist takes samples in a study of breeding patterns of crown of thorns starfish.*

# Answers Lie in Research

The crown of thorns starfish phenomenon is a complex one and it is apparent that it can only be clarified by painstaking scientific research. To date over 300 scientific papers have been written on the starfish, most of which have been published since 1969. While many of these are simply reviews of the phenomenon, or reports of occurrences of the starfish, some have contributed important information, adding a piece or two to a giant jigsaw puzzle. But the picture still remains far from clear and each of the five official committees which have investigated the problems over the years has been unanimous in recommending more research.

When the first outbreaks occurred in the 1960s, very little was known about the starfish or coral reefs, but when the second episode was reported in 1979 the situation was different. The Australian Institute of Marine Science (AIMS) and the James Cook University, both situated in Townsville, had become world recognised centres of coral reef studies, and the Great Barrier Reef had been declared a Marine Park.

The Great Barrier Reef Marine Park Authority spent $638,000, a large proportion of its research budget, on surveys and studies of the starfish between 1979 and 1985. Since 1981, the Marine Science and Technology Grants Scheme has also awarded $600,000 for various studies on the starfish. Then in 1985 AIMS undertook a comprehensive survey of 228 reefs along the entire Great Barrier Reef using a $1m grant from the Commonwealth Community Employment Program. This gave, for the first time, a general view of the infestations.

### Major Research Program Now Underway on Starfish

In 1985 the Crown of Thorns Starfish Advisory Committee, a group of experts convened by GBRMPA to advise on the problem, recommended that a coordinated research program be undertaken on the starfish over four to five years and requested funding of about $3m from the Commonwealth. This research program is currently underway.

The research program — probably the most intensive study of a marine animal ever conducted in Australian waters — now includes 58 distinct research projects on the crown of thorns starfish and related subjects. Of these, 25 are in the field of management and the remainder are ecological. About 20 Australian and overseas research institutions, including the Australian Institute of Marine Science (AIMS) and most eastern Australian universities, are involved in the program.

The GBRMPA undertakes the general coordination of the program and supervises the management-related research while AIMS supervises the ecological studies. The progress of research is regularly reviewed by an independent body of Australian and overseas experts chaired by Professor John Swan, an eminent Australian scientist.

The problem is a very complex one. At this stage we are not even sure whether the starfish should even be classed as a pest, except in relation to specific reefal areas that are important for tourism or science. Professor Swan has warned that we should not expect simple answers. He has likened the situation to that of the plague locusts of Africa and spruce worms of North America which are prone to similar population explosions and cause great damage to crops and trees. In those cases the causes of the outbreaks are only now just beginning to be understood after several decades of intensive research. And a coral reef is a far more complicated ecosystem than those in which these animals are found!

### Research to Provide Answers for the Reef Managers

The most important areas of GBRMPA's research include:

*(1) Studies of geological sediments to determine if outbreaks occurred in the past.*

Whether similar outbreaks occurred

in the past is the key question in the crown of thorns starfish phenomenon. The characteristic minute parts of the skeleton of the starfish have now been distinguished in the surface sands of recently affected reefs and in similar concentrations well below the surface in drill cores of sand suggesting that outbreaks have also occurred in the past. The fragments of the skeleton are being dated using accelerator mass spectrometry, a recently developed dating technique for small particles. The studies require painstaking grain-by-grain searches of the sand samples and the dating technique is very expensive.

*(2) Testing the theories on the causes of the outbreaks*

While there have been many theories on the causes of the outbreaks (both natural and human), there is no concrete evidence to date. Studies on the development and food of the larvae, of the adults' predators, examination of the gut contents of reef fish, baseline studies on pollution, and research to map the productivity of the Great Barrier Reef shelf are all addressing the theories on the causes. Many scientists now feel that there may be many reasons for the outbreaks — perhpas even a combination of natural and man-induced factors.

*(3) Biological controls*

Preliminary studies of the natural diseases of the crown of thorns are proceeding at the same time in case a biological control might be needed. Such a control would only be used if it is definitely proven that the outbreaks are the result of man's activity, and only if they were specific to this starfish.

The GBRMPA is also undertaking trial **eradication programs** on selected reefs of importance to science and tourism.

Other study areas include **socio-economics** (i.e. the effect of the outbreaks on the tourist and other Reef industries), and an **analysis of risk** to determine when controls might be used.

**Public education** is also an important part of the program. The crown of thorns starfish has attracted sensationalised press and television coverage in the past and it is the GBRMPA's responsibility to keep the Australian public informed on the problem — and what the Government is doing about it — through regular press, radio and television news releases, and feature articles such as this booklet. □

## Current Ecological Research

Researchers now mostly agree that the crown of thorns starfish phenomenon cannot be explained by a simple cause-effect relationship, alluring though this solution may be. Hence, research on the starfish needs to address a range of related ecological questions rather than putting all of our 'research eggs into the one ecological basket'.

The current program of ecological research which is being co ordinated by the Australian Institute of Marine Science has been designed so that the results from different studies can be compared and placed in context. The first studies began at the end of 1985.

The program involves the collaboration of almost 50 scientists, from 15 different institutions, in 33 projects. This extensive manpower input, plus research time at sea, means the program is expensive. Over $1m was spent in the first 18 months from special Commonwealth funds with AIMS providing support in the form of personnel, shiptime and equipment, making an estimated additional allocation of $600,000 towards this program.

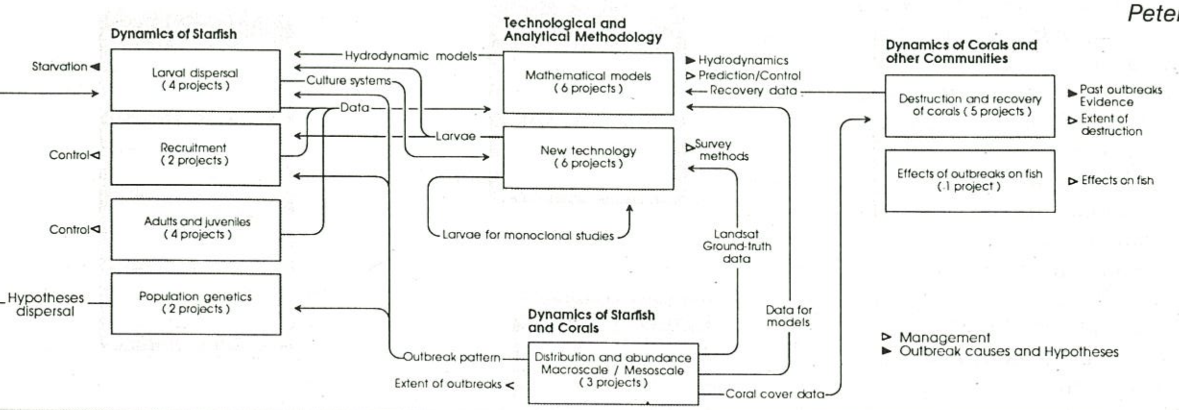
Four different aspects of the crown of thorns are being investigated:

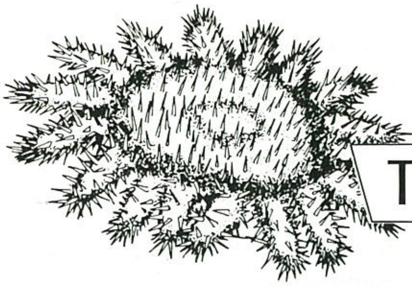
1. Population dynamics of the predator (ie, studies relating to particular aspects of the starfish itself)
2. Dynamics of the prey and associated organisms (ie, studies of the effects of outbreaks on corals and other reefal communities)
3. Interaction between the predator and its prey (ie, studies of the change in distribution and abundance of both the predator starfish and its coral prey)
4. Technological and analytical methodology (ie, the development of technology which has potential for the study of the phenomenon).

Good progress has been made in all ecological projects and many of the results from this program will be drawn together over the next 12 months. The extent of the interconnections of the ecological processes is illustrated below.

The overall aim of this program is to determine what causes outbreaks of the crown of thorns starfish, in particular, whether they are natural events or the result of man's intervention. However, a more immediate goal is to ascertain which ecological questions are most likely to bring this about. Much of science involves formulating theories, testing them and, if they are wrong, formulating new theories.

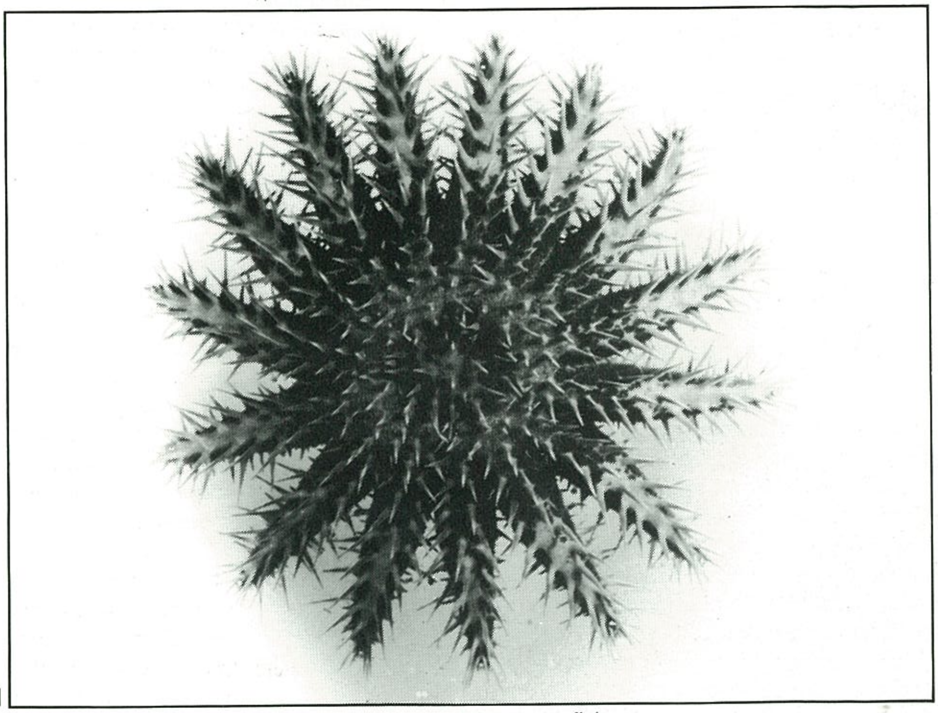
*Peter Moran*





# A CLOSE LOOK:
## The Crown of Thorns Starfish

*by Peter Moran*



*A close look at the upper surface of the crown of thorns starfish.*

We have learnt much about the biology of the crown of thorns starfish in the past 15 years. You can get an idea of just how far our knowledge of this starfish has advanced, if you consider that it was first thought that the white patches of coral observed on the reef surrounding Green Island in 1962 were caused by the starfish 'smothering' the corals. This was the first recorded outbreak of crown of thorns on the Great Barrier Reef.

Much of the data we have obtained, particularly in relation to the life history and reproduction of this animal, have come from studies in the laboratory. This information has provided a strong base of knowledge which is now being used by researchers in their studies of the crown of thorns phenomenon.

### Thousands of Spines

A glance at the crown of thorns starfish explains how this animal got its name, for it is covered by thousands of spines (Photograph 1). Those on its uppermost or aboral surface are the longest, reaching a length of between 3 cm and 5 cm. Not only are these spines extremely sharp in having three raised cutting edges on the tip, but they also are known to produce a toxic reaction, often severe, in humans. Studies have demonstrated that the chemical responsible for producing these reactions can be found in the tissues covering the spines. It is now known that this compound, and perhaps several others, are responsible for causing allergic responses in some victims. The range of reactions recorded to date in patients who have been wounded by this starfish include nausea, vomiting and extensive swelling of tissues. There is one report from the Cook Islands of a man having his lower leg amputated as a result of stepping on a crown of thorns starfish. Consequently, care must be taken at all times when handling or undertaking activities near this animal.

Not only does this animal have big spines, but it is also one of the largest starfish in the world. Individuals as large as 700 mm in diameter from arm tip to arm tip have been reported, although the normal size range recorded for individuals in outbreak populations is between 250 mm and 350 mm. Despite its somewhat sinister appearance, this starfish is quite beautiful when it is seen in its natural environment as it is multi-coloured ranging from purplish blue with red tipped spines to having a green body with yellow tipped spines.

Like most other starfish or seastars, the crown of thorns starfish has a number of arms or rays which project from its body. However, unlike many other animals, it does not possess a set number of arms, and fully grown individuals may have between 6 and 23 arms. If attacked by a predator, the crown of thorns starfish may shed several of its arms which it will regrow over a period of between three and four months. Such an ability is extremely useful in the event of being caught by a predator. Unfortunately for researchers, it also means that it is very difficult to tag or put external markers on starfish to track their movements in the field. While the crown of thorns starfish has the ability to shed part of its body, it is unable to regrow a whole new body from just one or two arms. Studies conducted in the past have demonstrated that starfish cut into halves will generally not survive.

### Hundreds of Feet

If you turn a starfish over and examine its under or oral surface, you will notice a number of features (Photograph 2). Firstly, in the centre is the starfish's mouth which is surrounded by short, blunt spines. If you look carefully inside, the starfish's stomach may be seen as a yellow, membranous structure. Apart from the mouth and stomach, hundreds of small feet may be seen projecting from under each arm of the starfish, running in pairs in a line from the tip of the arm to the beginning of the mouth. These structures, called tube feet, are used for movement, feeding, holding and sensing. It is difficult to comprehend how starfish are able to undertake such well coordinated activities given the large number of individual tube

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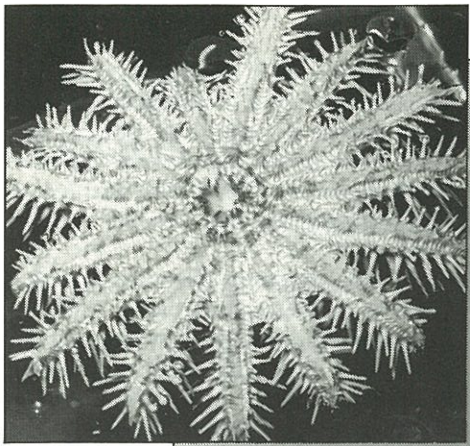

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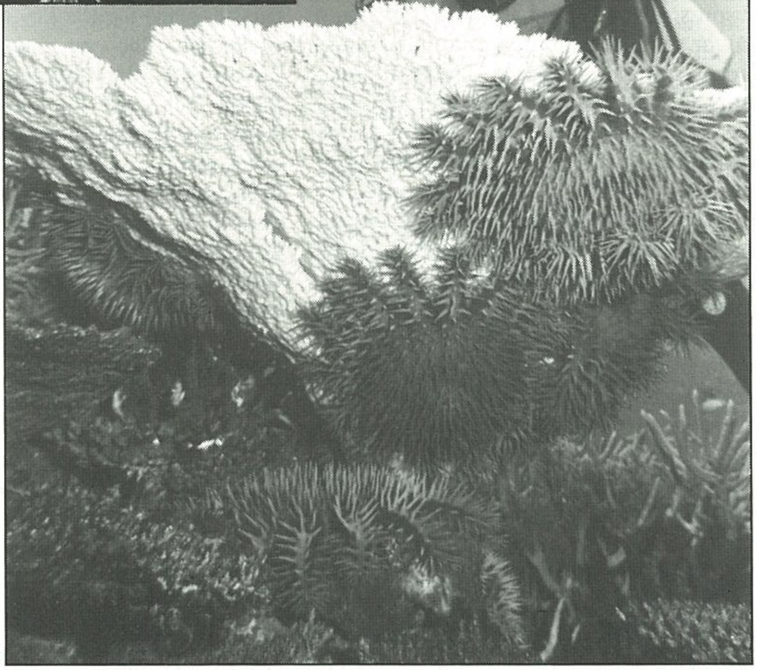


*The whitened coral skeleton left after these starfish have finished feeding is called a 'feeding scar'.*

feet that they possess and their relatively simple nervous system.

### An Indo-Pacific Creature

Contrary to popular opinion, the crown of thorns starfish was discovered many years before the first series of outbreaks were reported in the world. It was first described by a biologist called Rumphius in 1705 and was given a scientific name (*Acanthaster planci*) by Linnaeus in 1758. Clearly, the crown of thorns starfish has been recognised for at least 280 years. What is unclear, at this stage, is whether this starfish has occurred in large populations or outbreaks prior to the first recorded outbreak in the Ryukyu Islands of Japan in the 1950s. This question is central to the current debates on the crown of thorns phenomenon. If outbreaks have occurred for hundreds, if not thousands of years, then it is likely that they are a natural event and part of the normal fluctuations which can occur in marine systems. On the other hand, if they have occurred only recently, then it could be argued strongly that they are likely to be a result of man's influence.

Over the years since the crown of thorns starfish was first recorded, it has been reported in a variety of places in the Indo-Pacific region.

### Sheltered Habitats Preferred

Field studies show that the crown of thorns starfish prefers to live in particular habitats on reefs. For example, it prefers to live in relatively sheltered environments where it is not so likely to be injured by strong waves or forced off corals by strong currents. For this reason, they tend to be found in deeper water on the fronts of reefs, in lagoons, and along the leeward slopes of reefs. Starfish tend to avoid shallow or exposed environments and the corals in these types of areas are often not eaten. The deepest recording of a starfish on the Great Barrier Reef is 64 m.

### A Diet of Corals

While the crown of thorns starfish feeds on corals, and is thus regarded as a carnivore (or more specifically a corallivore), observations in the field, and in the laboratory, have shown that it will feed on other organisms. These foods range from soft corals and gorgonians (sea whips) to echinoids (sea urchins), clams and algae. In the laboratory, starfish have also been observed to eat each other. It is doubtful whether this would take place in the field. Further, it appears that these additional sources of food are generally consumed only when there is very little coral available, as observed during the declining phase of an outbreak.

Without a doubt the crown of thorns starfish is geared for eating corals. Like some other starfish, it is an extraoral feeder. The starfish everts its stomach through its mouth and spreads it over the coral surface using its tube feet (page 33). This is a specialised process as the starfish secretes chemicals, or enzymes, which break down the tissues of the corals and unlock their reserves of energy which are stored in the form of waxes (cetyl palmitate). The process is so efficient that only a whitened coral skeleton survives after the starfish has finished feeding which usually takes between four and six hours. This is referred to as a feeding scar (Photograph 3). The crown of thorns starfish is capable of going for relatively long periods of time without food — as long as six to nine months in the laboratory. □

**Summary**

The crown of thorns starfish is both an interesting and formidable animal. Interesting, because it possesses biological features which make it an exciting animal to study, such as the ability to produce large numbers of gametes; synchronised spawning; and extraoral feeding. Formidable because it is well armoured. It can regenerate parts of its body; it has the ability to endure long periods when little food is available; and it has the potential to produce enormous numbers of progeny. Such features make it well equipped to not only survive, but do exceedingly well in a coral reef environment. Perhaps it is not surprising that, from time to time, it does!

▶

# Life History

*by John Lucas*

There are male and female crown of thorns starfish, but there is no way to tell them apart by just looking at them. How then do the starfish themselves know which is which and when to breed? The answer is that crown of thorns starfish breed like many other marine animals: they release their eggs and sperm (gametes) freely into suspension in the water, through fine pores in their upper surface. The important thing is to synchronise this spawning activity, so that eggs get fertilized, and this is achieved by chemical messages. As one starfish spawns, it releases chemical messages with its eggs or sperm and adjacent starfish 'smell' the chemicals in the water and also release their eggs or sperm to join the milling throng of gametes.

The fertilized eggs are only 0.2 mm in diameter, smaller than the dot on this 'i'. They hatch after a day as a tiny transparent bag which gradually develops into a simple larva, called a bipinnaria larva, showing absolutely no resemblance to a starfish. The larva consists of little more than a simple gut and some bands of beating hairs (cilia) for swimming and feeding. These larvae feed on microscopic algae floating in the sea and they drift along in the ocean currents.

After several weeks the larvae may have developed into another stage, the brachiolaria larva. This is really two animals: the front part is the swimming/feeding larva, the hind part is an embryonic starfish. If the brachiolaria is lucky, it will be carried over a coral reef where it attaches to the reef surface. Then the embryonic starfish absorbs all the remains of the larva in a day or so, and, behold, a minute crown of thorns starfish is present. This is a metamorphosis that is far more dramatic than even the caterpillar to butterfly transformation. The new starfish, half a millimetre in diameter and having only five arms, is too small to feed on coral; in fact, the coral polyps can eat **it**. So it feeds on algae. It grows and adds arms until it is about a centimetre across at six months of age and then it takes the big step to coral feeding. The little starfish is still very inconspicuous and food for any predator that spots it. It is not until it is two years old and about twenty centimetres across that it can live at all conspicuously on the reef. The large starfish's more open habits, and the rapidly increasing amounts of coral that it eats each day, makes it seem as though large crown of thorns starfish suddenly appear on coral reefs, whereas they have been present for several years as small juveniles. The starfish matures at two years of age and the life cycle is completed.

Because the crown of thorns is such a large starfish it produces tens of millions of eggs each summer spawning season. Thus, when I began research on the crown of thorns, it seemed to me that we should look to the early, very abundant stages of the life cycle for the key to the outbreaks of starfish. The vast majority of the eggs, larvae and little starfish perish, and any factor that even slightly improves their survival will cause a great increase in the subsequent numbers of adult crown of thorns starfish on nearby coral reefs. Our decade of research along these lines has found that a number of environmental factors: salinity, temperature, algae and predators, strongly influence the survival of these early stages. We now need more observations of how these factors vary in the waters of the Great Barrier Reef. □

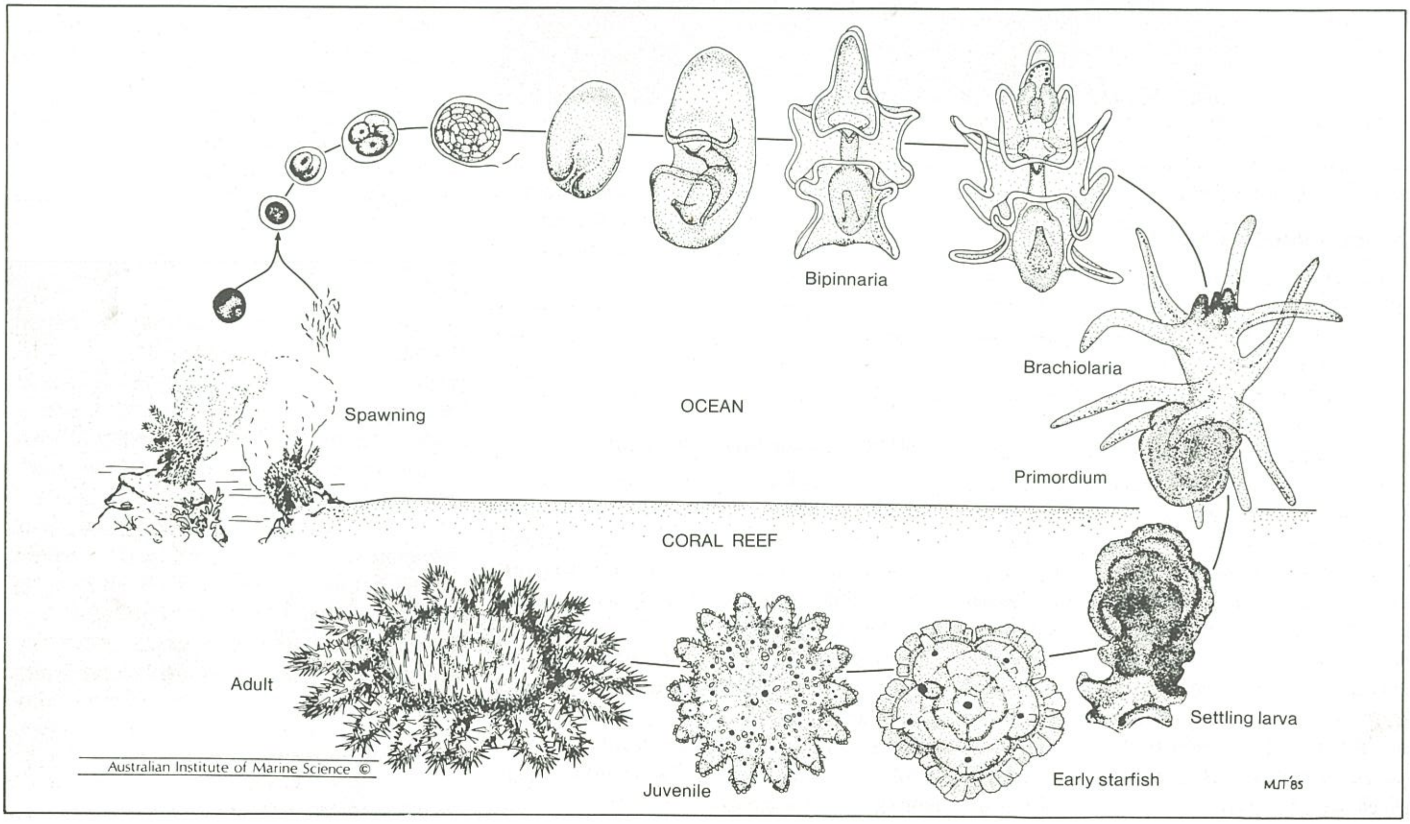



Figure by courtesy of AIMS

# Starfish Physiology

*by Brett Kettle*

Typically, when an outbreak is first noticed, it consists of quite large starfish. The coral on the reef is usually luxuriant and the starfish prosper. The more they eat, the less there is, and so the starfish begin to starve. By the time the coral is sparse, so too the crown of thorns have disappeared.

This leaves us with many interesting questions.

- What processes occur in the starfish's body as it begins to starve?
- How can you identify a healthy or starving crown of thorns?
- Is it possible to predict the fate of a population from the health of the starfish?
- Are the starfish that suddenly appear on a reef healthy or starving? If they are starving, they may have walked (without food) from a nearby reef, but if they are healthy, then they may have been there all along and only recently become easy to see.
- How much coral is needed to maintain the population, and at what point is there insufficient food to prevent starvation?

## Starfish Starvation

The data from my study are still being analysed but several observations are worth reporting. During enforced starvation, the first noticeable change was in the food storage organ, the pyloric caeca. This organ, usually fawn-brown in colour, became blotchy brown, sometimes almost red, and began to shrivel in size. As starvation continued, the starfish's skin became soft and weak, and the spines began to droop. Presumably, the starfish were trying to maintain their health by reabsorbing nutrients. To my surprise, some starving females still produced healthy looking eggs. Most starfish survived total starvation for almost six months.

At the beginning of the outbreak, most starfish were healthy and robust. They didn't look as though they had walked (without food) from another reef. They had most probably settled as juveniles on that same reef two years earlier and had passed unnoticed because of their small size and tendency to hide.

Starfish numbers did not drop noticeably until coral cover was greatly depleted. Before this decline, the starfish showed signs of starvation. As coral cover decreased even further, so too did starfish health and starfish numbers. It seems that, rather than walking on to the next reef, most starfish simply 'starved to death' at the end of an outbreak.

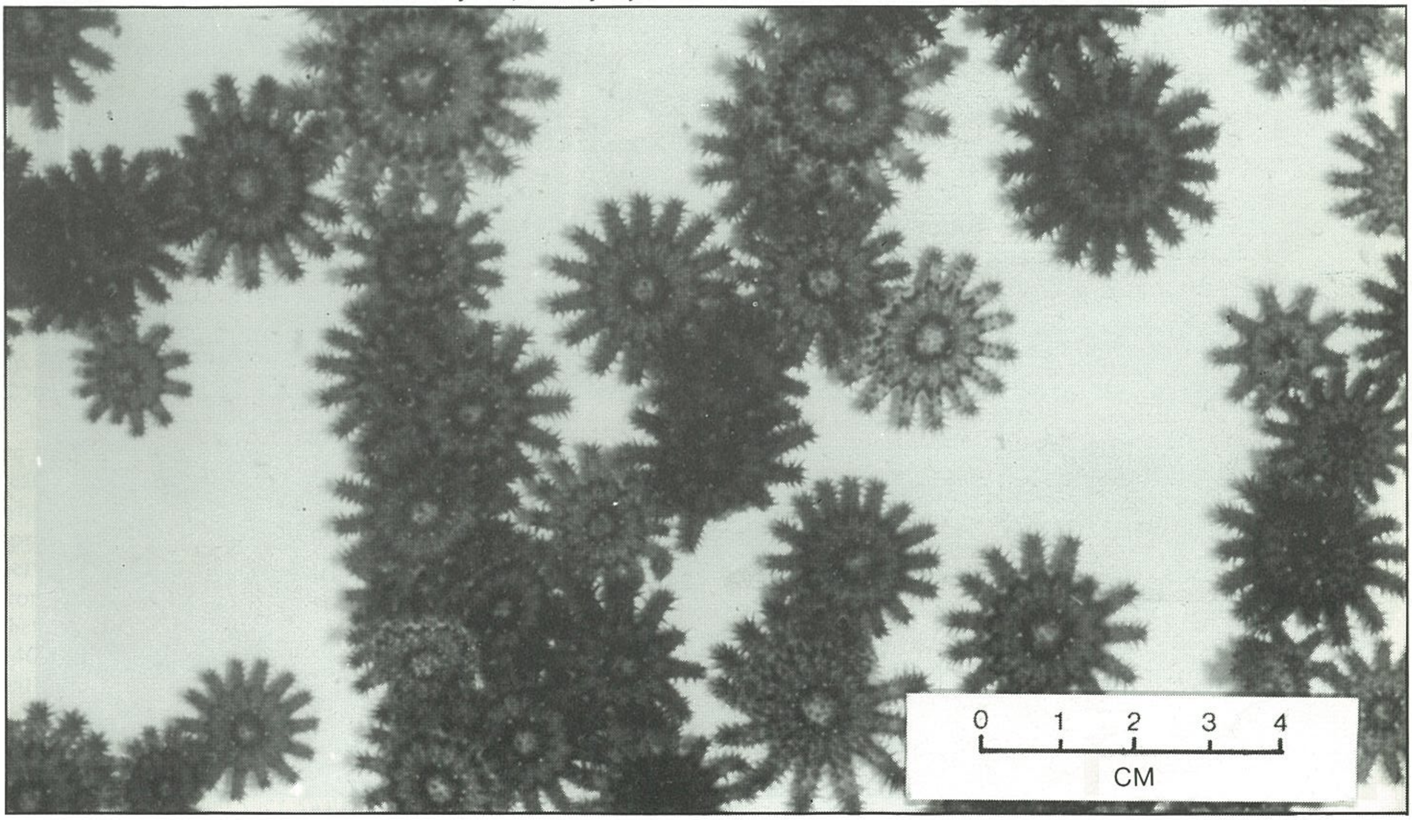
## Outcomes

With the completion of this project, we will have a number of useful skills:

- we will be able to quickly recognise 'healthy' and 'starving' starfish in the field;
- we will be better able to judge whether a population will grow or decline from a quick estimate of coral cover; and
- we may be able to judge whether starfish arriving on a reef have walked in or simply 'become obvious'.

These indicators may help us to predict the likely outcome of future outbreaks with a little more reliability. □

*An old fashioned clock mechanism? A kiddies toy? No, an array of juvenile starfish.*



## Larval Starvation?

For many years, researchers have given much attention to starvation as this process is likely to be very important in determining the numbers of larvae which ultimately settle on a reef. Starvation may affect the survivorship of larvae either directly or indirectly; directly by death through malnutrition; indirectly by prolonging development. Longer-lived larvae may suffer greater levels of predation.

That larvae of the crown of thorns starfish starve in the field is central to one of the main theories concerning the cause of outbreaks of this animal, namely, the terrestrial run off theory. This theory is based on information obtained from laboratory studies which measured the development and survival of starfish larvae in relation to the density of phytoplankton in the form of a single species of unicellular alga.

Two important arguments have been raised against the larval starvation theory.

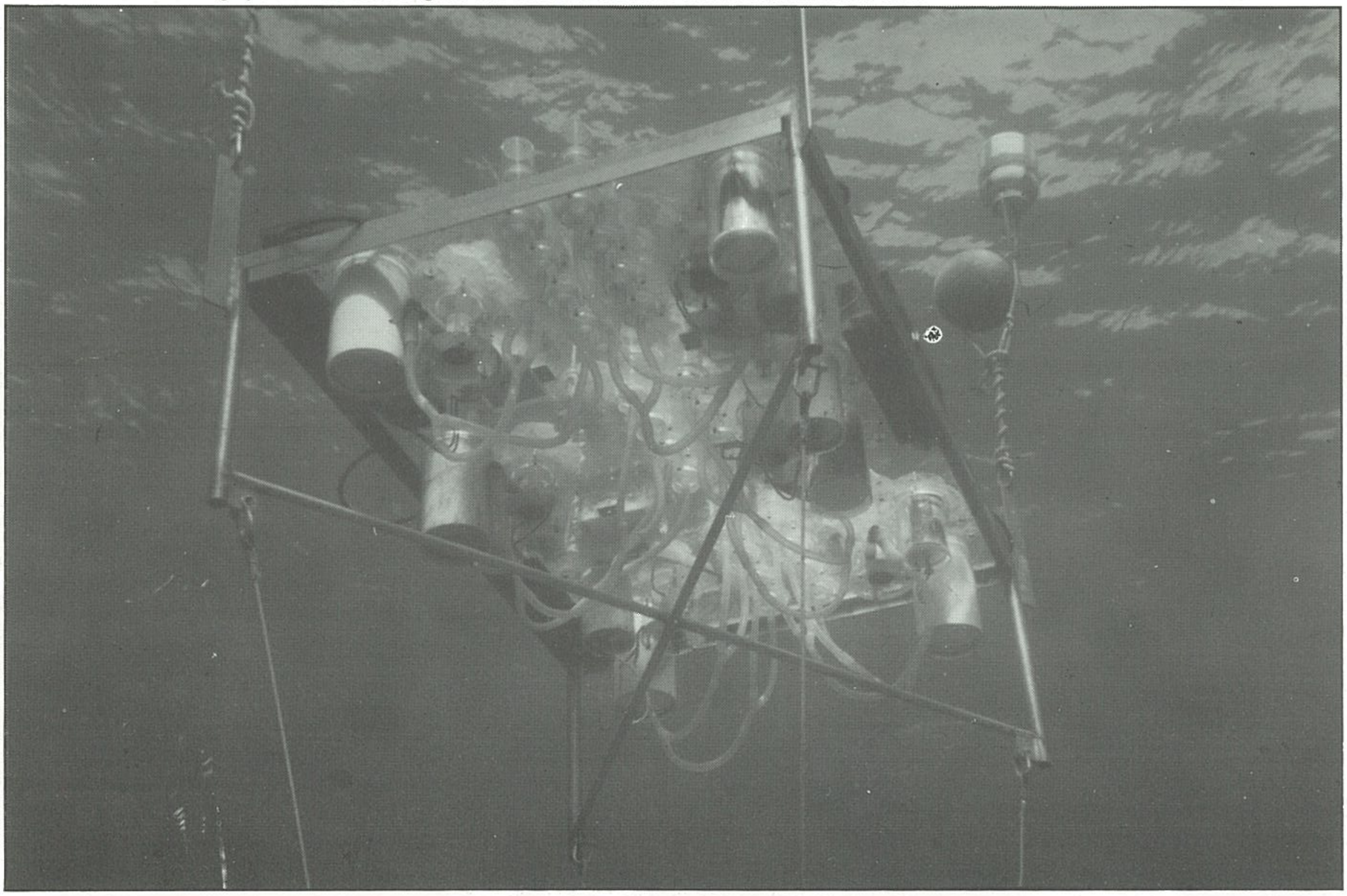
1. Although the amount of phytoplankton may be low in the field compared with that required to support larval development in the laboratory, the effects of this may be compensated for by the nutritional benefits of a diet of mixed phytoplankton.

2. Phytoplankton may not be the only source of nutrients for the larvae of the crown of thorns starfish. For example, recent studies have shown that dissolved organic matter may be an important source of energy for the embryos of echinoids (sea urchins).

A relatively simple way of determining whether the larvae of the crown of thorns starfish ever starve on the Great Barrier Reef is to grow them in the field rather than in the laboratory. While this may seem an obvious thing to do, it is not as simple as it sounds, primarily because the larvae are very small and take a reasonably long time to develop. For studies in the field, it is necessary to devise a means of being able to keep the larvae in enclosures which prevent them from escaping, but which allow the surrounding water to move in and out. In a recent AIMS study, this was carried out successfully using submersible culture systems which enabled groups of crown of thorns larvae to develop in a coral reef environment. Development of the culturing systems took almost two years during which time many problems were overcome. The major conclusion from this study is that the development of the larvae of the crown of thorns starfish may be food-limited, but that the extent of this food limitation does not appear to be sufficient to cause large variations in the survivorship of larvae of this starfish. This has important biological and ecological implications for the study of not only the crown of thorns starfish but also many other marine invertebrates.

*by Peter Moran*

*A submersible culturing system was used to grow larvae of the crown of thorns starfish in the field.*



# Juveniles~ A New Direction for Research

*by Leon Zann*

The lack of information on the early life history is perhaps the main reason why the crown of thorns phenomenon is so poorly understood. Typically, large feeding aggregations — sometimes comprising thousands or millions of adult starfish — appear suddenly on a coral reef but where they come from has been a mystery. Some researchers felt that they result from larvae which settled close by while others considered that they might have marched from an infested reef.

The smallest individuals seen in an outbreak are usually not less than 140 mm in diameter. Although starfish have been raised from eggs to adults a number of times in the laboratory, the juveniles were virtually unknown in nature; juveniles less than 20 mm in diameter have been reported on only two occasions on the Great Barrier Reef prior to 1986.

Studies which I have undertaken in the Fiji Islands have now established details of the habitats of the juveniles, and traced growth, migration and mortality in their first two years of life.

During the first five years of my study I found very few juvenile crown of thorns starfish, but in 1984 I found many thousands in my study area. The juveniles, smaller than a one cent coin in size and estimated to be about 6 months of age, were located under coral boulders, on the dead bases of staghorn coral and in cracks and fissures in shallow water on the windward reef front. Densities were very high, up to 25 individuals per square metre (250,000/ha).

The food of these juveniles was found to be encrusting coralline algae until they reached an age of about 12 months, after which they gradually switched to live coral. They grew much faster on this diet; between 6 and 18 months of age they grew from about 20 mm to 100 mm in diameter. By 24 months they were about 140 mm in diameter and becoming sexually mature.

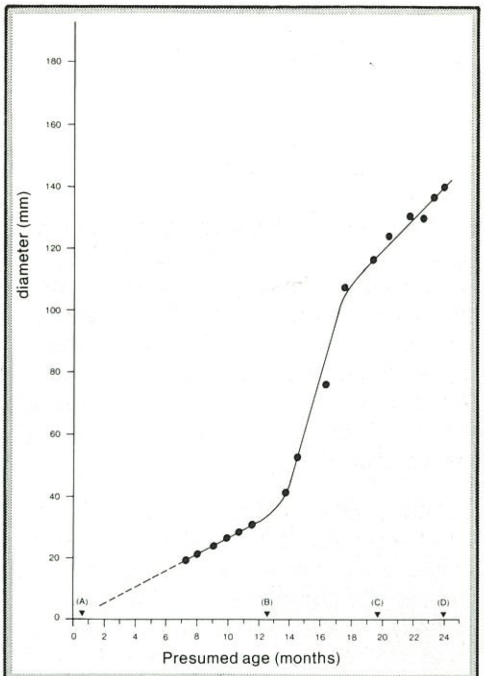
During their first year the early juveniles were well camouflaged and remained hidden deep in their refuges in the reef by day and night. When they switched to a diet of coral, they became active by night but remained well hidden by day. Then, at an age of around 18 months, they began to feed during the daytime and form the well known clusters or aggregations. During their first 18 months they moved no more than about 30 m, indicating that the 'sudden' appearance of an outbreak on a reef is probably just due to a change in behaviour and it is likely that they grew up very close by on that reef!

## Outbreaks From Occasional, Massive Settlement

The area where the juveniles were located has now been sampled each year for eight years, but a massive settlement occurred only once during this period. During two of the other years a small number of juveniles was located while very few or none at all were found in the remainder. This seems to be the 'normal' situation when the starfish are uncommon on the reef. An outbreak therefore appears to result from an occasional, very high settlement of larvae.

## Disease May Lead to Biological Control

I also found that an epidemic caused high mortality amongst these juveniles between 9 to 13 months of age. About 10% of all starfish I sampled during this period had an open wound or necrosis on their upper surfaces and when some of these specimens were placed in an aquarium they died within several days. Although mortality from this and other causes was estimated to be about 99% between the ages of 8 months and 23 months, sufficient starfish reached maturity to constitute an outbreak. Bacterial cultures and tissue specimens from the diseased Fijian starfish are currently being studied in Australia in the hope that they may lead to a biological control.

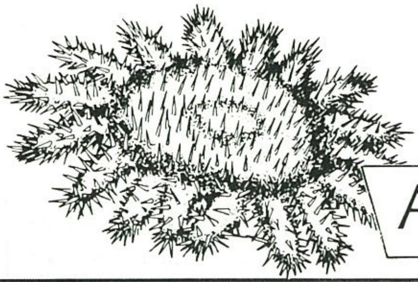



*Average growth of a year-group of crown of thorns starfish in Fiji. Circles show the average size of 50 to 100 of the group each month. Gradual growth occurred while on a diet of algae for the first year after settlement (A). Rapid growth followed the switch to a coral diet (B). After an age of about 20 months (C), they left shelter to feed during the daytime and form aggregations. They approached sexual maturity at age two years (D).*

## Juveniles on the Great Barrier Reef

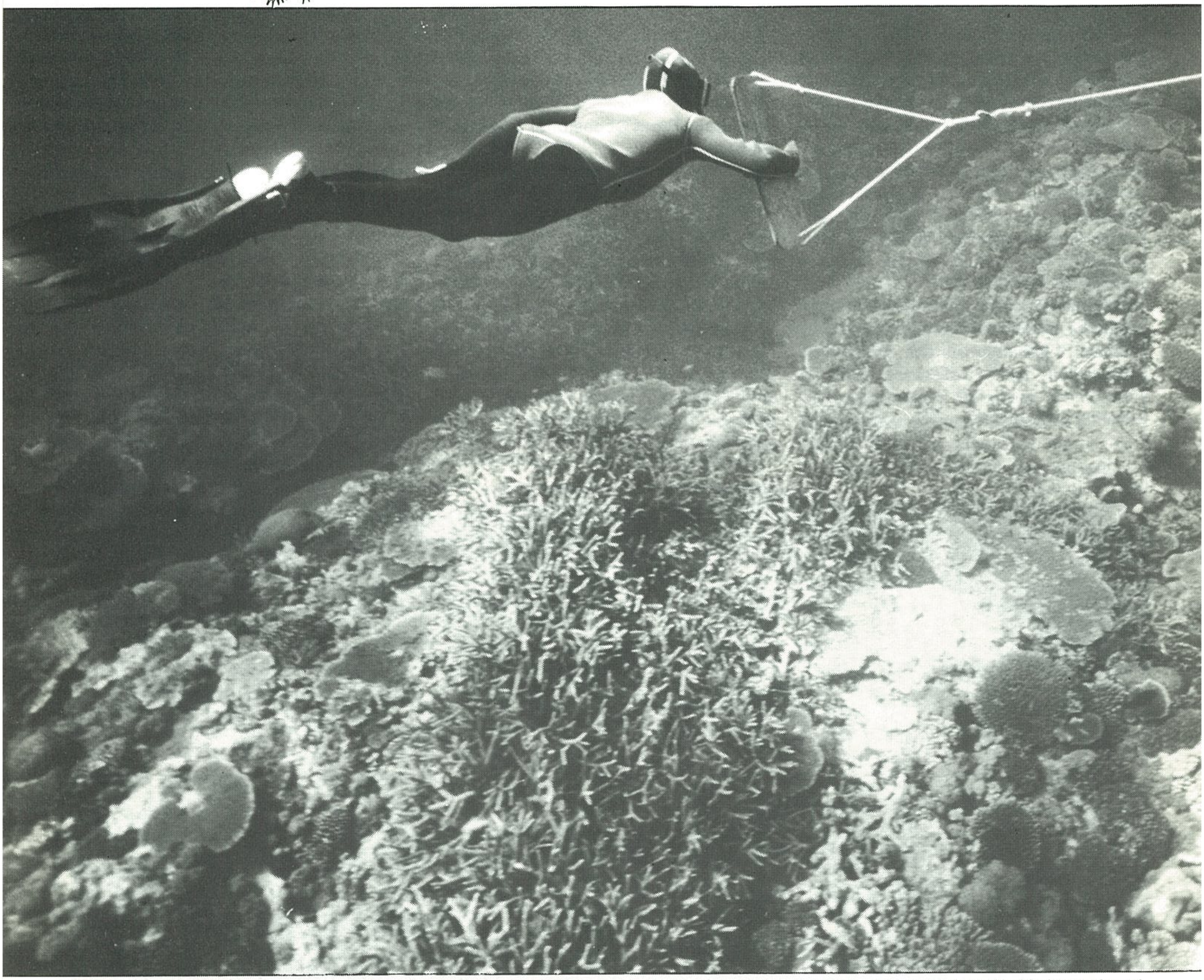
The discovery of the 'nursery' of the early juveniles in Fiji is already paying dividends on the Great Barrier Reef; in 1986 one-year-old juveniles were located on several reefs off Townsville, allowing new outbreaks to be predicted. □

*The secretive early juveniles of the crown of thorns are rarely seen by scientists. (Above) Three six-month-old juveniles the size of a one cent coin are attached to the underside of a coral rock encrusted by coralline algae. The lighter patches are algae recently eaten by the starfish. (Left) Juveniles collected from the undersides of the coral rubble in the background.*



# THE STARFISH:
## And its Environment

by Peter Moran



*Surveys for crown of thorns starfish are undertaken by 'manta tow'. Holding effortlessly to a steering board, the observer is towed behind an outboard-powered dinghy, enabling him to search many kilometres of reef in one day.*

Currently, we know much less about the ecology of the crown of thorns starfish than we do about its biology for three reasons.

- Research on the larvae and juveniles is difficult as they are hard to find in sufficient numbers in the field.
- Conducting studies on large populations of adult starfish is hampered by the current inability to tag and follow individual starfish for relatively long periods. The importance of undertaking such research is outlined in the following section.
- As a consequence of 1 and 2, most field research over the past 20 years has concentrated on determining the extent of activity of adult starfish and their effects on the coral communities of reefs.

To the uninitiated, conducting surveys may seem to be a low priority task given the many important ecological questions which need scientific attention. However, these surveys are vital because the data they provide, when integrated with other biological and ecological information, allow scientists to gain a better understanding of the crown of thorns starfish phenomenon. This type of approach has been successful in the study of several similar ecological interactions, e.g., the spruce—budworm problem in North America.

Surveys of the Great Barrier Reef have mainly determined the distribution and abundance of starfish and corals. However, more recently collected data have been used to investigate the pattern of spread of outbreaks over the entire Reef which is directly relevant to recruitment processes; the pattern of development of outbreaks on individual reefs that is useful in modelling and management studies; and the nature of the interaction which occurs between the starfish predator and its coral prey. Of course, the data that are collected have many other potential uses. For example, data describing outbreaks of crown of thorns starfish in different geographical regions of the Reef may help to highlight anomalies in the current set of theories for the occurrence of outbreaks of this starfish.

The systematic collection of data over long periods is needed if the phenomenon is to be studied using mathematical models. While such models are often simple representations of the real world, they nonetheless help scientists to predict how the system will behave given a certain set of conditions. Mathematical models serve two other useful functions. Firstly, they indicate which processes or mechanisms in the system are likely to be important. Secondly, they help to define more accurately the research questions and put them into a proper context. In so doing, they help to establish priorities for future research.

### Population Dynamics

A feature common to all populations of organisms, whether it be a population of bacteria or a herd of elephants, is that their numbers fluctuate over time. In order to understand the fluctuations, scientists frequently obtain data on several different parameters which define the population being studied. These parameters include population density, birth and death rates, dispersion, movement, longevity, immigration and emigration, age distribution of the population, and sex ratio. Such information is useful for predicting future fluctuations of populations.

Unfortunately, much of this type of information on the crown of thorns starfish is lacking, primarily because individual starfish cannot be recognised or followed over long periods in the field. Many of the population parameters (e.g. longevity) require data on individual starfish over several years. Despite numerous attempts, scientists have been unable to devise a method which will enable them to recognise starfish for periods greater than two or three days. This is because the starfish can shed external tags or markers, or that part of its body to which the tag is attached, very quickly. Other methods involving dyes, branding, spine clipping and noting physical features (e.g. colour, number of arms) have all proven unsuccessful in long term studies. Despite this problem, information about certain parameters has been obtained from short-term tagging studies, from starfish kept in captivity, and also from measurements taken over entire populations of starfish in the field. Here is a summary of this information:

1. Adult starfish move at speeds of up to 20 m per hour over certain substrates. Smaller starfish, between 20 mm and 70 mm diameter, move at rates of between 1 m and 4 m per hour. It is not known how long starfish can maintain these speeds and therefore how far they can move. It has been suggested that in complex reef systems, such as the Great Barrier Reef, they may move from one reef to the next once the food runs out, but the evidence for this is largely circumstantial.

2. The sex ratio of starfish in different populations is normally 1:1.

3. Starfish may live for as long as eight years, the longest period they have survived in captivity. However, we must interpret such information carefully as it does not take into account processes such as starvation and predation which no doubt occur in the field.

4. In the laboratory, starfish grow at different rates during particular stages of their life cycle. Initially growth is slow as the juvenile starfish feeds on epiphytic and encrusting algae. Growth becomes more rapid once the starfish begins to feed on coral. During this time, a starfish may grow as much as 100 mm in a year. In the laboratory, ▶

*This photograph shows how aptly named is the crown of thorns starfish, Acanthaster planci.*

once a starfish reaches sexual maturity towards the end of its second year, its growth rate declines and it reaches a phase of little or no growth sometime after three years of age (about 350 mm in diameter). This has lead to an interesting debate whether or not crown of thorns starfish grow continually throughout their life. Laboratory studies indicate that the growth of starfish is determinate. Supporters of the opposing view suggest that growth must be indeterminate as it is possible to find very large starfish in the field (up to 700 mm in diameter). This issue will not be resolved until the growth rate of individual starfish can be measured for long periods in the field. Obviously, we must devise an effective tagging method before this can be achieved.

5. The age of a starfish cannot be accurately determined from its size. This is because the size of a starfish is likely to depend on a number of factors:
   - diet — starfish fed on different foods for the same period may vary greatly in size
   - reproductive state — individuals increase in size during the spawning season
   - population density — aggregated starfish are, on average, smaller than those in sparsely distributed populations.

   The inability of scientists to determine the age of a starfish from its size is a major obstacle to understanding the recruitment patterns of this animal as well as the patterns associated with the change in its distribution and abundance.

Clearly, we must give high priority to improving our understanding of the population dynamics of the crown of thorns starfish. We need to overcome technical problems which are a barrier to progress in several areas of research. Currently, we are working on this as part of an extensive program of ecological research being coordinated by the Australian Institute of Marine Science.

## Outbreaks

When does a population of starfish become an 'outbreak'? This is a difficult question to answer.

Many surveys have been undertaken in the Indo-Pacific region over the past 20 years, but few of these have attempted to accurately determine the numbers of starfish on reefs for two main reasons. Firstly, it is difficult to get reliable estimates of abundance for 'normal' populations as the starfish are usually uncommon and they tend to hide. Secondly, the numbers of starfish in outbreaks may be so great that it is an almost impossible task to obtain reliable estimates of such populations.

Perhaps the most accurate information we have to date is from areas where control programs have been carried out. For example, 500,000 starfish were killed in one year as a result of such a program in American Samoa. Subsequent surveys of the area indicated that this exercise had little effect on the overall numbers of starfish in the population! Outbreaks in some areas may consist of hundreds of thousands, if not millions, of starfish. However, if an outbreak is reported on a reef, it doesn't necessarily mean that such large numbers are involved.

Recently, populations of starfish which contain only between 50 and 100 individuals, have been found in the Swain Reefs group on the Great Barrier Reef. For several years, we have received reports of even smaller, more isolated populations in the Capricorn-Bunker group. These latter populations have had little effect on the coral populations and are considered to be 'stable'. At present, we are unsure whether the starfish observed in the Swain Reefs represent normal populations or outbreaks. If the populations are normal, then the question arises as to whether the starfish are sufficiently dense to give rise to outbreaks. Clearly, this is an important issue which requires further intensive investigations of a wide range of population types.

When discussing outbreaks of starfish, scientists usually differentiate between those which have arisen as a result of changes associated with certain local factors and those which have arisen from nearby populations either by larval recruitment or adult migration. The former type is referred to as a primary outbreak; the latter a secondary outbreak. We have considered most of the outbreaks on the Great Barrier Reef to be secondary, resulting from the dispersal of larvae from an area of primary outbreaks to the north of Cairns (see next section). Unfortunately, there is little evidence to substantiate this belief. An important step towards understanding the origin of outbreaks is therefore to find areas of primary outbreaks.

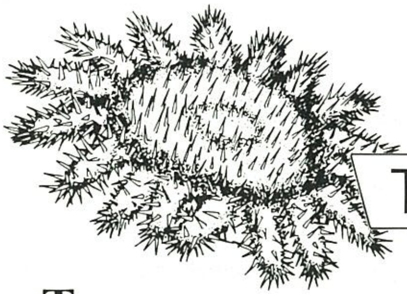
## Recruitment

One of the most important, yet poorly understood of all ecological processes concerning the crown of thorns phenomenon, involves the recruitment of larvae. Recruitment is a scientific term to describe the processes which are responsible for the introduction of new individuals to a population. Such an event can occur as a result of the immigration of individuals or by reproduction. We must investigate this process to understand why populations of the crown of thorns starfish fluctuate so wildly.

Most research has concentrated on larval dispersal because immigration is not likely to be an important source of new individuals for reefs separated by relatively extensive areas of deep water. However, past studies to determine the distribution and abundance of crown of thorns larvae in the field have generally failed because larvae are difficult to catch and, when caught, they cannot be positively identified. They look very similar to those of other species of starfish. Researchers at Deakin University are currently working to overcome this problem by developing an immunological marker using monoclonal antibodies.

As the larval phase may last for up to four weeks, it is likely larvae may be dispersed over large distances. This has led to the suggestion that, during the past 25 years, larval recruitment on the Great Barrier Reef has occurred in waves, moving southwards from an area of primary outbreaks just to the north of Cairns (see page 31). This belief is supported by computer studies of the current patterns of the central region of the Great Barrier Reef. These patterns show that during the summer, the most likely spawning time, the currents in this region of the Reef move in a net southerly direction. Researchers have proposed larval dispersal over long distance to explain extensive outbreaks on coral reefs in other parts of the world, e.g. Ryukyu Islands and Panama.

There is an urgent need to develop techniques for identifying larvae in the field so we can investigate these theories further. □



# STARFISH OUTBREAKS:

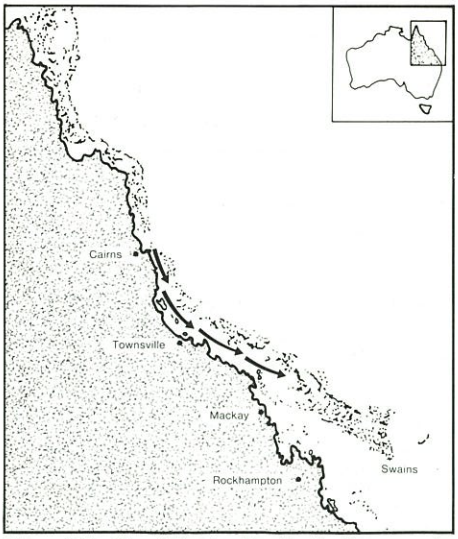
## The Great Barrier Reef

by Peter Moran

The outbreaks of starfish on the Great Barrier Reef probably have been the most extensive of those recorded in the Indo-Pacific region. Over the past 25 years they have occurred on a number of the reefs stretching from the Swain Reefs group in the south, to the Princess Charlotte Bay region in the north (a distance of some 1200 km). We consider two series of outbreaks have occurred. Outbreaks in the first series were first reported on reefs off Cairns in 1962. During the next 15 years they were recorded on a variety of reefs further to the north and south. After 1977 no outbreaks were reported for about two years and then the second series of outbreaks began on reefs near Cairns in 1979 and continues to spread. Since 1979, a variety of scientific surveys have been undertaken to try to determine the extent of activity of the starfish and its effects on the coral communities of the Great Barrier Reef.

### 1962—1977

Large numbers of crown of thorns starfish were first recorded on the Great Barrier Reef at Green Island in 1962. Surveys were undertaken to investigate whether similar outbreaks were present on reefs nearby. Over the next decade the surveys moved further southwards as reports of more outbreaks came to hand. By 1967, large populations of starfish were recorded on reefs off Innisfail, and some three years later, they were reported on reefs near Townsville. At about the same time, those off Innisfail were in decline. Although no repeat surveys were undertaken on the reefs near Cairns, we believe that the outbreaks of starfish there had disappeared by about 1967. Around this time, outbreaks were also recorded on reefs just to the south of Cooktown. By 1971, the populations of starfish on the reefs near Townsville had begun to decline. New populations were reported on reefs still further to the south, between Ayr and Proserpine, in 1973-1974. Around this time, unofficial reports were also received of outbreaks on reefs much further to the south, in the Swain Reefs. Surveys in the southern part of the Reef subsequently confirmed these reports. They also indicated that reefs immediately to the north, in the Pompey Complex, appeared to be free of starfish outbreaks. From 1975 to 1977, outbreaks of starfish appeared to be restricted to those in the Swain Reefs. Surveys undertaken at that time on reefs to the north of Princess Charlotte Bay and in the Capricorn-Bunker Group failed to find any evidence of starfish outbreaks. Those in the Swain Reefs had disappeared by 1977, after which time, no further outbreaks were recorded on the Great Barrier Reef for two years.




*Map of the Great Barrier Reef with diagram of the apparent sequence of colonisation by the crown of thorns starfish.*

### 1979—1986

The outbreak on Green Island had died out around 1967 and, during the next 10 years, people became optimistic that coral communities on this reef would recover. But, in 1979, another outbreak of starfish appeared and subsequently caused as much damage as the first outbreak. Again, surveys were undertaken to determine the extent of the activity of these new populations. By 1982 they were reported on reefs off Innisfail and, about 2 years later, they began appearing on reefs off Townsville and on reefs near Lizard Island.

During 1985 and 1986 an extensive survey of 228 reefs on the Great Barrier Reef was undertaken by the Australian Institute of Marine Science (AIMS) using funds allocated under the Commonwealth Community Employment Program. The aim of this survey program was to determine the extent of activity of the crown of thorns starfish and its effects on the coral communities of the Reef. This program was extremely important as it was the first to survey a significant number of reefs (approximately 10% of the total number of reefs) scattered throughout the entire Great Barrier Reef Region in only one year. The 228 reefs that were chosen for survey ranged as far north as Whyborn Reef (just south of the tip of Cape York) and as far south as Lady Musgrave Island (somewhat south of Gladstone). During the surveys active outbreaks of starfish were reported on a large proportion of reefs off Townsville (approximately 78%) and on several reefs in the Swain Complex. Extensive areas of dead coral, which were thought to be associated with the activities of the crown of thorns starfish were recorded on a high proportion of reefs (about 65%) between Townsville and Lizard Island. About 90 of the reefs that were studied during this extensive program are currently being re-surveyed as part of the ecological research being coordinated by AIMS (discussed in a previous section). To date these surveys have identified outbreaks on several reefs between Ayr and Bowen and on two additional reefs in the Swain Reef Complex.

### Pattern of Outbreaks

Results from the surveys conducted over the past 20 years reveal a pattern of outbreaks on the Great Barrier Reef which is similar for both the first and second series of outbreaks. This pattern has several features:

1. Outbreaks of starfish appear to first arise in the area of reefs just to the north of Cairns. ▶

### The Present Situation

The AIMS/CCEP surveys of 228 reefs during 1985-86 indicated that 28% of those reefs investigated were either experiencing an outbreak or had experienced one. On these reefs effects were variable, ranging from slight to very severe. The outbreaks were largely confined to the central third of the Great Barrier Reef.

*Northern third:*
3 of 42 reefs affected (7.1%)
*Central third:*
29 of 84 reefs affected seriously (35%); 25 affected (30%); 29 not affected (35%)
*Southern third:*
4 of 102 reefs affected (5.8%)

2. After outbreaks have developed in the region off Cairns they begin to spread in a southerly direction, first occurring on reefs off Innisfail (between 3 and 5 years later), then on those off Townsville (between 5 and 8 years later) and finally on reefs between Ayr and Proserpine (between 10 and 12 years later).
3. Outbreaks have not occurred on reefs to the north of Princess Charlotte Bay nor have they occurred in the Pompey Complex or the Capricorn-Bunker Group. (However, recently outbreaks on reefs in the Torres Strait have been reported.)
4. Generally, outbreaks have not been recorded on reefs located within a few kilometres of the coast.
5. The incidence of outbreaks on reefs on the outer edge of the Great Barrier Reef (outer-shelf reefs) appears to be lower than that on the main body of the reef (mid-shelf reefs).
6. On both occasions outbreaks of starfish occurred in the Swain Reefs at about the same time that they were being recorded much further north on reefs between Townsville and Bowen. The reason for this is unclear, although a possible explanation is that the outbreaks in the Swain Reefs region are taking place independently of those occurring on the rest of the Reef. If this is the case, then a study which attempts to define the independence of, or the links between, such outbreaks may yield important information concerning the possible cause of outbreaks.

It could be argued that some aspects of the pattern are really related to likelihood of sighting. There has been debate about whether or not outbreaks actually spread southwards during the 1960s and 1970s, because the surveys themselves also tended to move in this direction. However, to the present time, this pattern has been repeated during the second series of outbreaks. If it continues, then outbreaks of starfish may start to appear on reefs south of Townsville over the next few years.

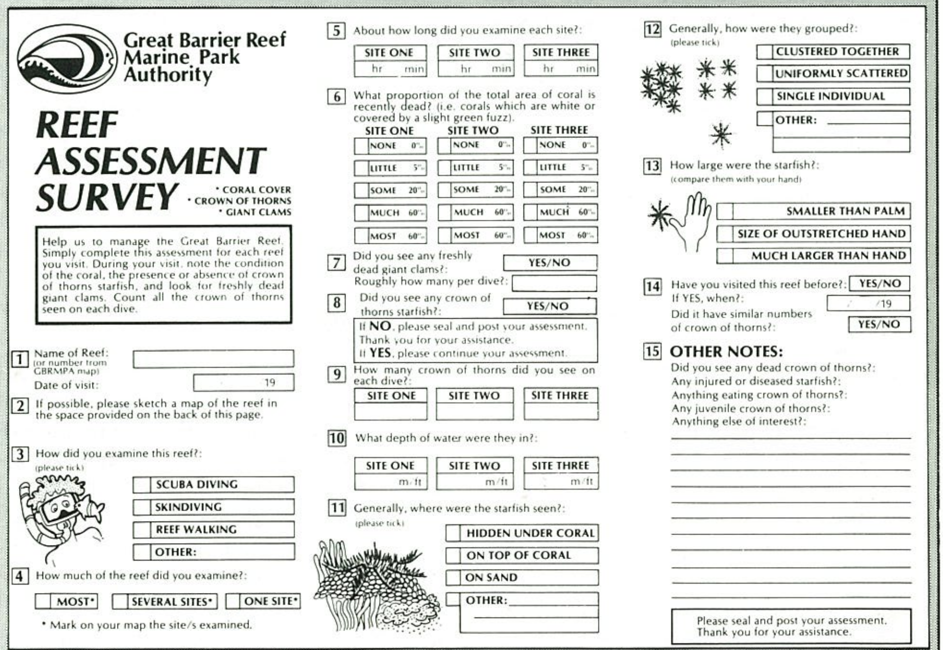
From the information given above it becomes clear that future surveys are needed to fill in many of the missing parts of the starfish puzzle. It is important that surveys are conducted during times where no outbreaks are present as negative results for starfish abundance are just as important as positive ones. In the future this type of strategy may be instrumental in gaining a better appreciation of the dispersal of crown of thorns larvae and the factors which affect this process as well as determining where primary outbreaks occur on the Reef.

### GBRMPA Follows Spread of Starfish from Users' Reports

Because surveys for crown of thorns are very time consuming and expensive, in 1982 GBRMPA implemented a scheme to involve the users of the Marine Park in reporting on the state of reefs and numbers of starfish. A simple, reply-paid form has been widely circulated amongst diver clubs, charter boat operators, scientists and sports divers along the Reef. As it is also important that GBRMPA knows where there are *no* crown of thorns, divers are urged to send in a report on all reefs they visit. The form also requests divers to report areas of dead coral, dead giant clams (an epidemic has affected clams on several reefs between Cairns and Lizard Island) and coral bleaching (loss of colour in corals sometimes resulting in their death).

The scheme has been very successful; each year many hundreds of forms are returned to GBRMPA and entered into a computerised database. The database was used to plan the detailed AIMS/CCEP surveys, and by AIMS researchers to study the patterns of the outbreaks.

So if you are fortunate enough to snorkel or dive on the Great Barrier Reef, don't forget to get your reporting forms from GBRMPA's office in Townsville.


Great Barrier Reef Marine Park Authority

**REEF ASSESSMENT SURVEY**
• CORAL COVER
• CROWN OF THORNS
• GIANT CLAMS

Help us to manage the Great Barrier Reef. Simply complete this assessment for each reef you visit. During your visit, note the condition of the coral, the presence or absence of crown of thorns starfish, and look for freshly dead giant clams. Count all the crown of thorns seen on each dive.

1 Name of Reef: (or number from GBRMPA map)
Date of visit: 19

2 If possible, please sketch a map of the reef in the space provided on the back of this page.

3 How did you examine this reef?: (please tick)
SCUBA DIVING
SKINDIVING
REEF WALKING
OTHER:

4 How much of the reef did you examine?:
MOST* SEVERAL SITES* ONE SITE*
* Mark on your map the site/s examined.

5 About how long did you examine each site?:

| SITE ONE | SITE TWO | SITE THREE |
|---|---|---|
| hr min | hr min | hr min |

6 What proportion of the total area of coral is recently dead? (i.e. corals which are white or covered by a slight green fuzz).

| SITE ONE | SITE TWO | SITE THREE |
|---|---|---|
| NONE 0% | NONE 0% | NONE 0% |
| LITTLE 5% | LITTLE 5% | LITTLE 5% |
| SOME 20% | SOME 20% | SOME 20% |
| MUCH 60% | MUCH 60% | MUCH 60% |
| MOST 60% | MOST 60% | MOST 60% |

7 Did you see any freshly dead giant clams?: YES/NO
Roughly how many per dive?:

8 Did you see any crown of thorns starfish?: YES/NO
If **NO**, please seal and post your assessment. Thank you for your assistance.
If **YES**, please continue your assessment.

9 How many crown of thorns did you see on each dive?:

| SITE ONE | SITE TWO | SITE THREE |
|---|---|---|
| | | |

10 What depth of water were they in?:

| SITE ONE | SITE TWO | SITE THREE |
|---|---|---|
| m/ft | m/ft | m/ft |

11 Generally, where were the starfish seen?: (please tick)
HIDDEN UNDER CORAL
ON TOP OF CORAL
ON SAND
OTHER:

12 Generally, how were they grouped?: (please tick)
CLUSTERED TOGETHER
UNIFORMLY SCATTERED
SINGLE INDIVIDUAL
OTHER:

13 How large were the starfish?: (compare them with your hand)
SMALLER THAN PALM
SIZE OF OUTSTRETCHED HAND
MUCH LARGER THAN HAND

14 Have you visited this reef before?: YES/NO
If YES, when?: / /19
Did it have similar numbers of crown of thorns?: YES/NO

15 **OTHER NOTES:**
Did you see any dead crown of thorns?:
Any injured or diseased starfish?:
Anything eating crown of thorns?:
Any juvenile crown of thorns?:
Anything else of interest?:

Please seal and post your assessment. Thank you for your assistance.

## The crown of thorns starfish: man-induced pest or important natural part of reef processes?

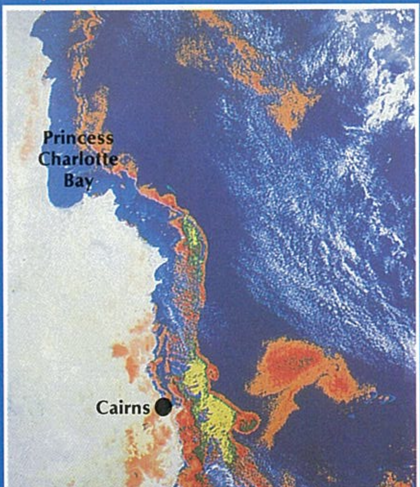
The crown of thorns starfish is a predator of the stony corals which form reefs. It attaches itself to a coral using its suckered 'tube feet' and protudes its yellow stomach from its mouth, covering an area of its prey. Digestive juices from the stomach break down the coral animals' tissues which are then absorbed, leaving the coral skeleton. A white 'feeding scar' is visible on the branch at the left. While damage from a low density of the starfish is slight, outbreaks have occurred in many parts of the Indian and Pacific Oceans, including the Great Barrier Reef, causing great damage to corals. ⇨

An aggregation of crown of thorns starfish in staghorn coral *(Acropora)* off Green Island in 1981. The white skeletons left by the starfish are quickly overgrown by drab seaweeds like those covering the bases of these branches.

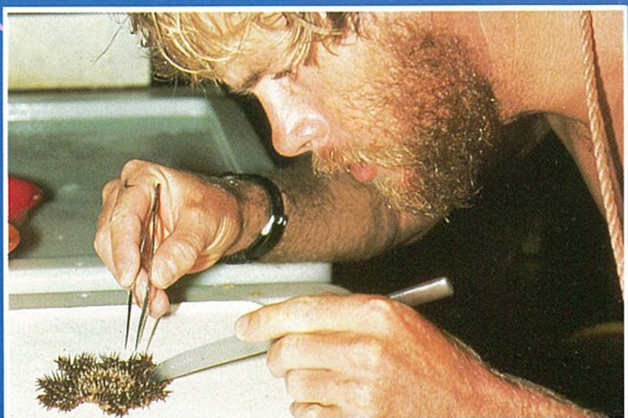
⇩

# Research – the key to the crown of thorns phenomenon

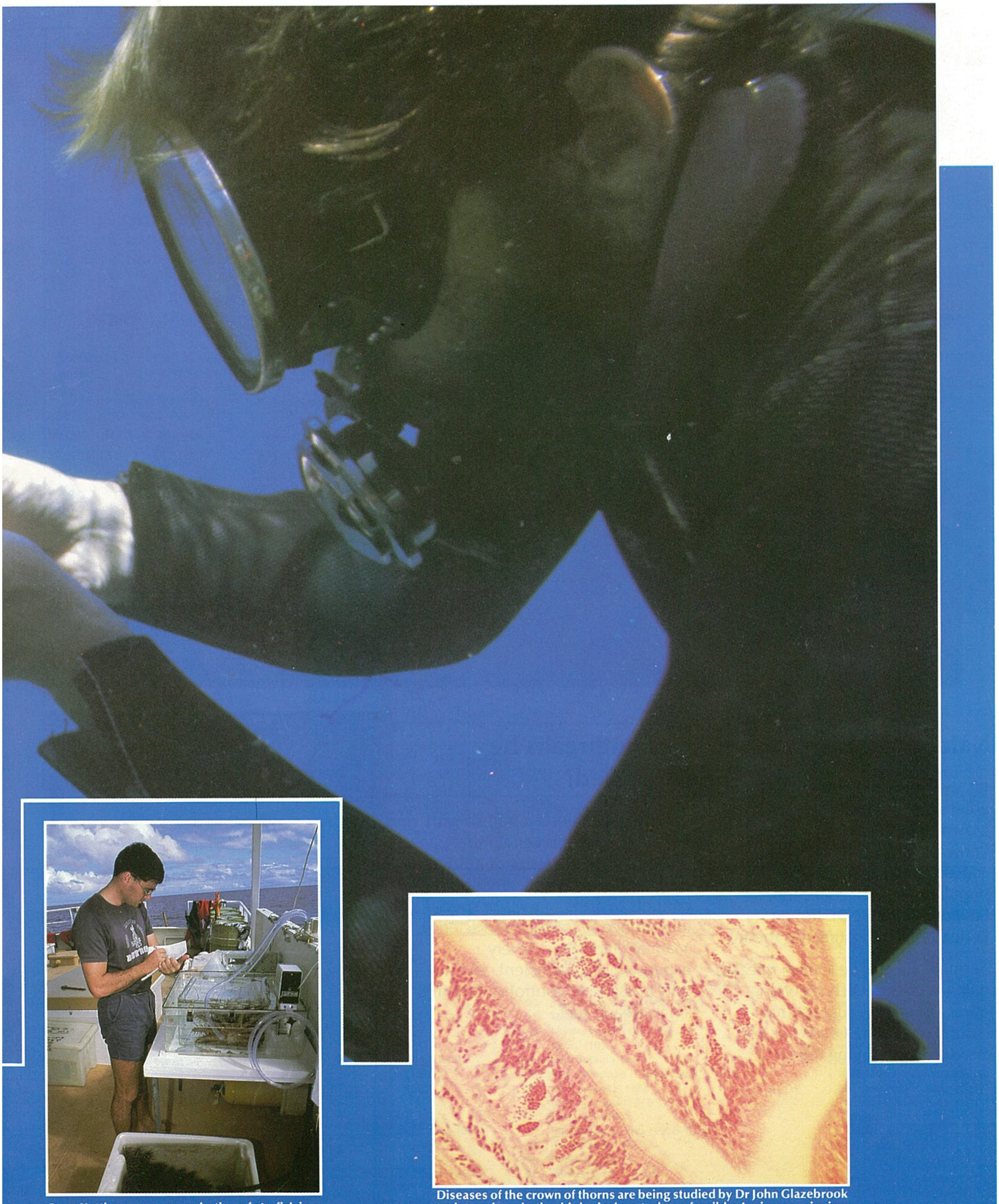
Diver collects samples from the reproductive organs of a starfis




Is there a relationship between plankton levels and crown of thorns outbreaks? A satellite image of the northern part of the Great Barrier Reef shows that some areas have high concentrations of plankton. Yellow-green-red-orange-blue show high to low levels of chlorophyll 'a', the green pigment in plants.



Researcher examines the internal organs of a juvenile crown of thorns starfish.



Brett Kettle measures respiration of starfish in a study of its physiology.

Diseases of the crown of thorns are being studied by Dr John Glazebrook to determine whether biological controls are feasible. A microscopic view of a thin section through the stomach of a diseased starfish shows the micro-organisms (dark red dots) responsible.

⇧

## Natural controls

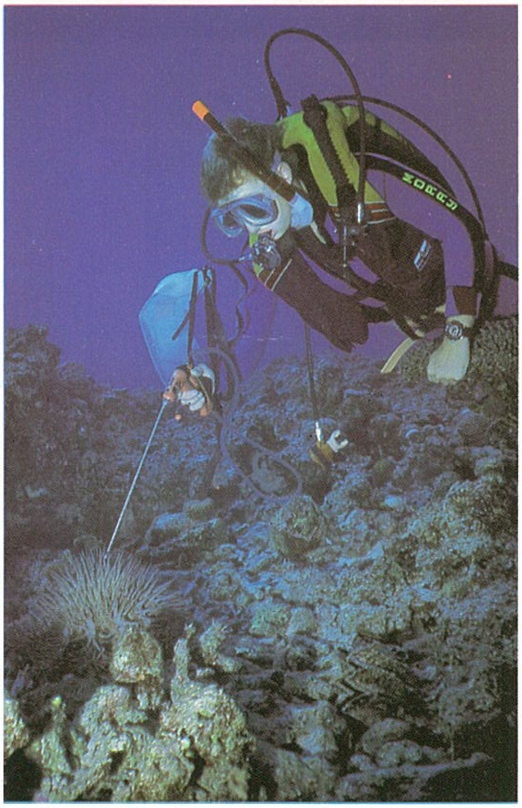
It's well known that tritons eat adult starfish but their role in the crown of thorns ecology is less well known. Are starfish outbreaks caused by declining triton populations (shell collection, trawler by-catch)? Dr. Robert Endean is investigating this theory.

Because the female starfish releases millions of eggs each spawning, other researchers suspect that natural controls act earlier in the development, during the larval stage.

⇨

## Can outbreaks be controlled?

A Navy diver injects a starfish with a poison. Until it is certain that outbreaks are the result of human activity, GBRMPA will confine its controls to areas of reefs of special importance to tourism and science. Manual eradication is very expensive and inefficient, and it is only possible to control starfish in a small area of reef.



## Outbreaks Affect Other Areas in the Indo-Pacific

The crown of thorns starfish has been recorded from coral reefs in the Indian and Pacific Oceans from Africa in the west to Panama in the east. It is not present in the Atlantic. Though it is usually present in small numbers, reefs in widely separated areas have also experienced infestations similar to those on the Great Barrier Reef.

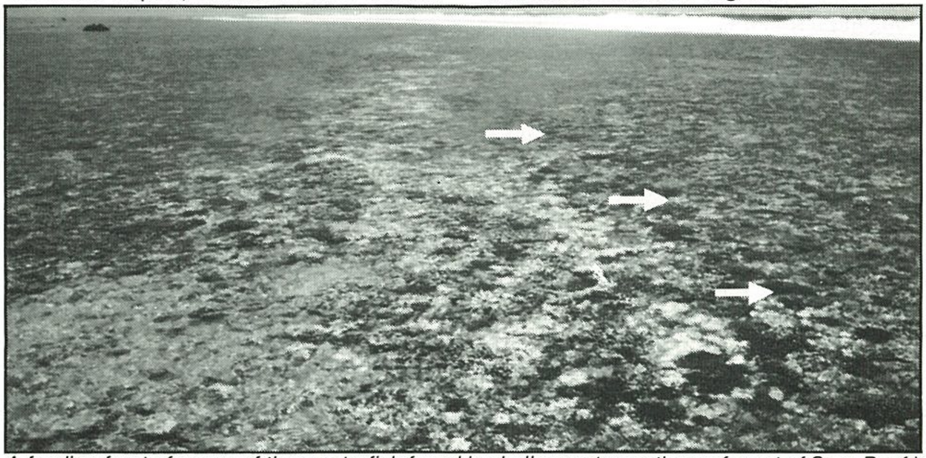
In the Pacific, reefs in Southern Japan, Taiwan, the Marianas Islands, the Caroline Islands, Malaysia, Philippines, Papua NG, New Caledonia, Solomons, Fiji, Tonga, Samoa, Cook Islands, Tahiti, Tuamotu Archipelago, Hawaii, Panama and other places have been affected. As on the Great Barrier Reef, most of these outbreaks occurred in the late 1960s and early 1970s while there have also been more recent reports in the 1980s on some reefs. Particularly extensive damage has been caused in Japan and the Carolines, while that in most of the other places has been patchy.

Outbreaks have also occurred in the Indian Ocean, in Thailand, Vietnam, Maldives, Sri Lanka, Cocos-Keeling Atoll, the Red Sea, and Mauritius.

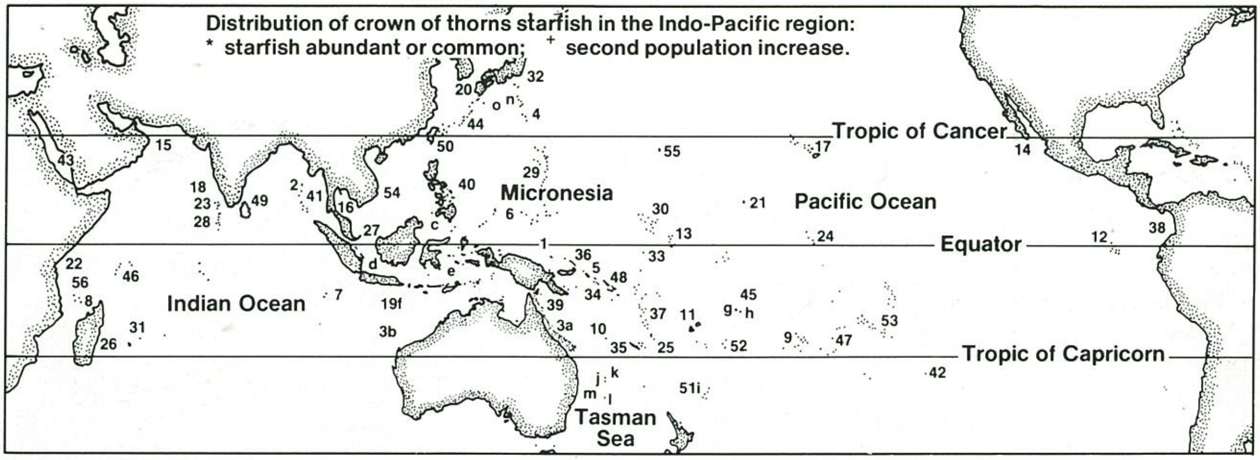
The most serious outbreaks have generally been off the continental land masses and high islands, though isolated oceanic reefs such as Cocos-Keeling, Wake, Elizabeth and Middleton Reefs have been affected. They have therefore occurred over vast areas of ocean, from the equator to the coolest waters where reefs are to be found (e.g. southern Japan, Elizabeth and Middleton Reefs in the Tasman Sea off NSW).

Interestingly too, the period of the recorded outbreaks are similar in most areas: the first episode in the early 1960s with a second outbreak in many places in the late 1970s.

A careful examination of the characteristics of the places which have experienced outbreaks may yield clues to their cause or causes; such a study is now underway in the Crown of Thorns Starfish Research Program.



*A feeding front of crown of thorns starfish found in shallow water on the reef crest of Suva Reef in Fiji, two years after their settlement. Note the ragged line of starfish (advancing in the direction of the arrows) leaving white, recently eaten coral immediately behind, and the overgrown dead corals at the left.*




| Map No. | Location |
|---|---|
| 1. | Admiralty Islands (1969*) |
| 2. | Andaman Islands (1953) |
| 3. | Australia: |
| | a. Great Barrier Reef (1962-1977*, 1979+) |
| | b. Western Australia (1971-1974*) |
| 4. | Bonin Islands |
| 5. | Buka (1968*) |
| 6. | Caroline Islands (1969-1972*) |
| 7. | Cocos-Keeling Islands (1949, 1976*) |
| 8. | Comoro Islands (1973*) |
| 9. | Cook Islands (1969-1970*) |
| 10. | Coral Sea: |
| | Chesterfield Reef (1970) |
| 11. | Fiji (1969*, 1979+) |
| 12. | Galapagos Islands (1889) |
| 13. | Gilbert Islands (1969*) |
| 14. | Gulf of California (1970*) |
| 15. | Gulf of Oman (1982) |
| 16. | Gulf of Thailand (1973*) |
| 17. | Hawaiian Islands (1969*) |
| 18. | India: |
| | Goa (1743) |
| 19. | Indonesia: |
| | c. Sabah (1967*) |
| | d. Pulau Pari Islands (1975*) |
| | e. Ambon Island (1973*) |
| | f. Bali (1982) |
| 20. | Japan: |
| | n. Kushimoto (1973*) |
| | o. Ashizuri-Uwakai (1972-1983*) |
| 21. | Johnston Islands (1969*) |
| 22. | Kenya (1972) |
| 23. | Laccadive Islands (1976-1979) |
| 24. | Line Islands (1933) |
| 25. | Loyalty Islands (1983) |
| 26. | Madagascar (1958) |
| 27. | Malaysia (1968*) |
| 28. | Maldive Islands (1963) |
| 29. | Mariana Islands (1967-1972*, 1979+) |
| 30. | Marshall Islands (1969-1970*) |
| 31. | Mauritius (1972*) |
| 32. | Miyake Island (1977-1980*) |
| 33. | Nauru (1971) |
| 34. | New Britain (1968*) |
| 35. | New Caledonia (1969*, 1982) |
| 36. | New Hanover (1968*) |
| 37. | New Hebrides (1970*) |
| 38. | Panama (1970*) |
| 39. | Papua New Guinea (1968-1970*) |
| 40. | Philippines (1972*) |
| 41. | Phuket (1969*) |
| 42. | Pitcairn Group (1970) |
| 43. | Red Sea (1968-1970*) |
| 44. | Ryukyu Islands (1957-1958*) (1969-1985*) |
| 45. | Samoa: |
| | g. Western (1969-1970*) |
| | h. American (1977-1979*) |
| 46. | Seychelles (1972) |
| 47. | Society Islands (1969-1971*) |
| 48. | Solomon Islands (1969-1971*) |
| 49. | Sri Lanka (1971*) |
| 50. | Taiwan (1971*) |
| 51. | Tasman Sea: |
| | i. Kermadec Islands (1978) |
| | j. Elizabeth Reef (1979, 1981*) |
| | k. Middleton Reef (1981*) |
| | l. Lord Howe Island |
| | m. Solitary Islands |
| 52. | Tonga (1969*, 1976) |
| 53. | Tuamotu Archipelago (1970) |
| 54. | Vietnam (1981) |
| 55. | Wake Island (1969*) |
| 56. | Zanzibar (1921) |

# Coral Recovery after Crown of Thorns Infestation

*by David Fisk*

Do corals and reefs recover from the effects of a crown of thorns starfish infestation, and if so, how?

Large aggregations of starfish will drastically alter the amount and composition of hard corals on a reef. Most hard corals will be eaten, though remnants of these corals will be left behind and a few species may be avoided altogether. Our study of Green Island Reef looked at the recovery process and concentrated on three scales: the microscopic scale, looking at newly settled coral recruits (coral spat) under a microscope; the medium scale, looking at the survival and growth of small juvenile corals up to 20 cm diameter; and on the largest scale of hundreds of metres of reef slope, looking for broader general patterns of recovery.

## Settlement of Larvae

As the majority of adult corals at Green Island were killed, where would new larval recruits come from? Which species or groups (Families) are most abundant in the available pool of planulae? We are finding out by using standardised settlement blocks of the same size and material, so we can accurately compare settlement rates at different parts of Green Island Reef, and at two other nearby reefs for comparison with Green Island.

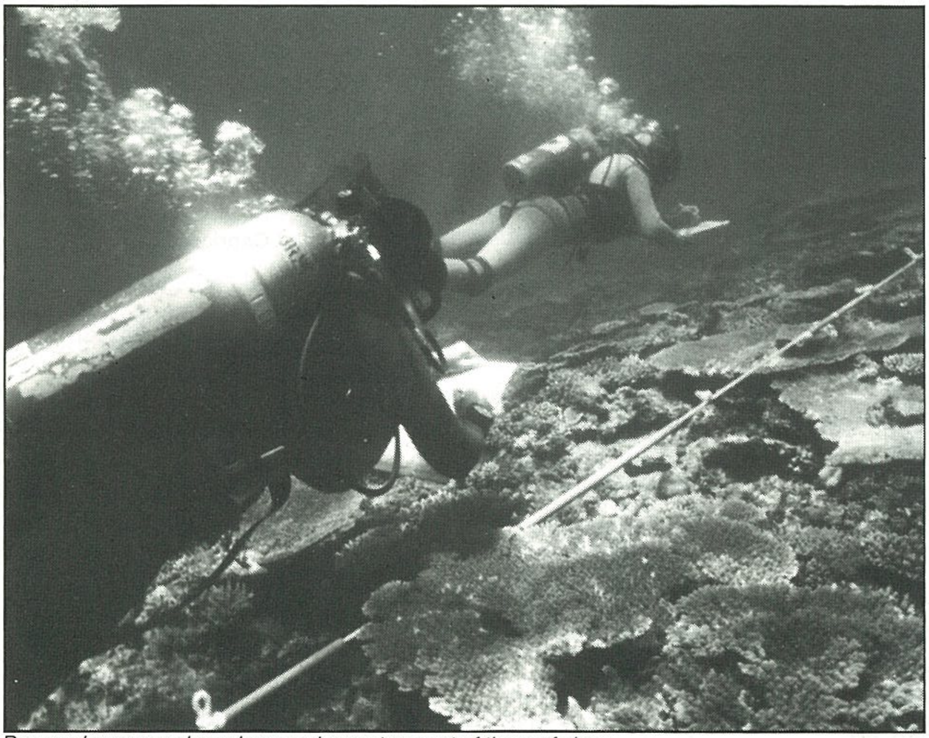
The settlement of larvae is showing some clear patterns: most settle over summer following the mass spawning of high numbers of species during brief periods in October and November; more spat are settling in back reef areas than fore reef areas; spat from the staghorns and tabletop corals (family Acroporidae) dominate the summer settlement, and other branching corals commonly known as needle and knobby corals (family Pocilloporidae) dominate the winter settlement. The relative abundance of coral families in the newly settled corals is similar to the established juveniles at Green Island. This suggests that larval recruitment is the most important process determining the composition of a recovering reef. The strength and direction of surface currents influence recruitment. Green Island differed from the other reefs which have been studied in that the family Pocilloporidae are less abundant in spat and are not abundant in the juvenile corals, suggesting some selection against this group.

## Survival and Growth of Juveniles

About 60% of juvenile corals survive per year at Green Island and a net increase in colony members is occurring. Juveniles in the fore reef are growing faster than those in the back reef, although there are more juvenile colonies in the back reef than the reef front. The relatively fast growing staghorns and tabletop corals (Acroporidae) are dominating the reef slopes and will continue to do so. This coral family is the preferred prey of the crown of thorns starfish. In the next three to five years Green Island Reef should have good coral cover again with a dominance of this coral group. This will be about 10 years after the last outbreak. The less preferred prey groups, the massive or framework corals, will be present in large numbers but have only small sizes, and will take much longer to grow into large colonies. Competition from the faster growing corals for space and especially light will slow down the normal intrinsically slow growth in the massive corals.

## General Pattern of Recovery

The overall result of the crown of thorns infestation of a reef appears to be one of favouring the fast growing corals which recruit well from larvae. Many of these also happen to be the preferred prey of the starfish. □



*Researchers record coral cover along a transect of the reef slope.*

*Monitoring newly settled coral colony.*

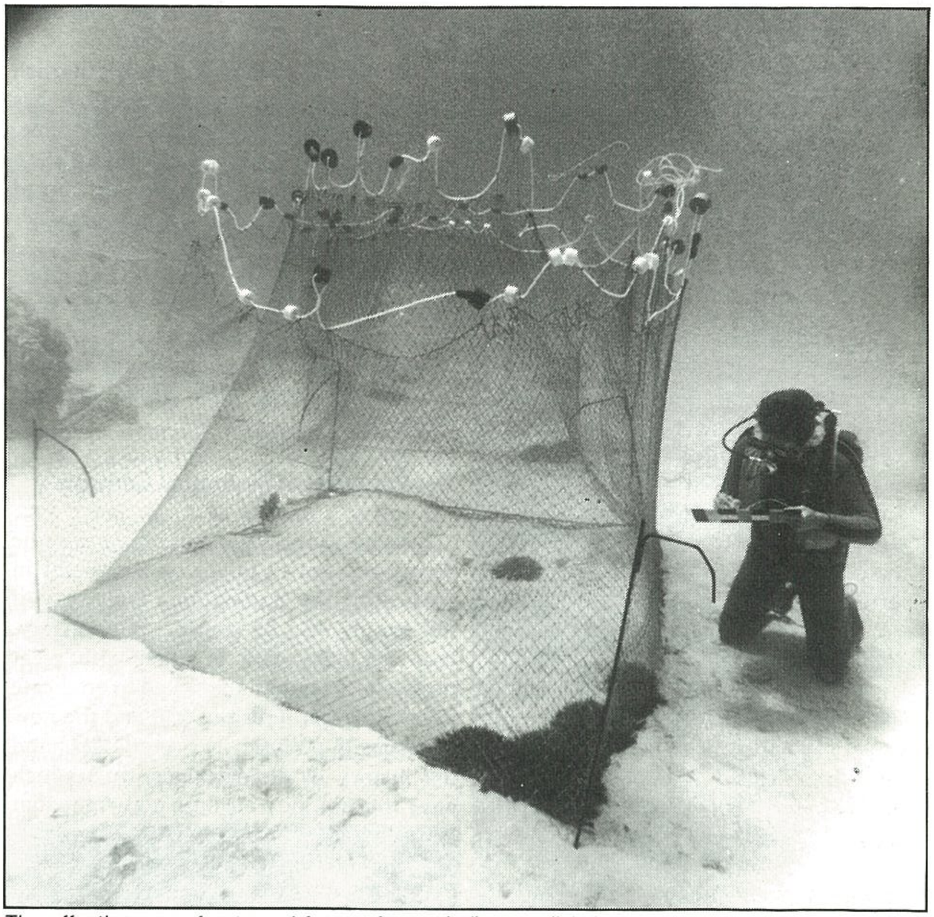
# Can the Crown of Thorns be controlled?

*by Leon Zann*

As scientists do not know whether the outbreaks are a natural or man-induced event, the GBRMPA has limited its controls to small-scale tactical programs on reefs of special importance to science and tourism. However, attempts to eradicate the starfish have generally proven difficult and most have had very doubtful value.

A number of attempts have been made in Australia and overseas over the past twenty years to use divers to eradicate outbreaks of the crown of thorns. When the starfish invaded Green Island in the 1960s, divers attempted to kill them by cutting them into pieces until it was realised that they might be able to regenerate from parts like other starfish. Hooks were then used to collect the starfish which were brought ashore and buried. The injection of copper sulphate, using agricultural injector guns, was later found to be more efficient. In trials conducted on Green Island divers were able to inject over 130 starfish per hour, resulting in a 95% mortality rate. But even divers with guns could not keep a small coral viewing area on Green Island Reef free from the starfish, estimated in 1980 to number in the millions.

Tourist operators on Beaver Reef and John Brewer Reef managed to save small areas of coral from the starfish while Authority divers were able to preserve a small area of reef at the well known 'Cod Hole' (in the Cormorant Pass Section of the Marine Park north of Cairns). But, in general, attempts to defend any more than a few hectares of reef have proven futile.



*The effectiveness of nets and fences for excluding starfish from coral-viewing areas has been assessed by the GBRMPA. The diver is recording the responses of the starfish when they encounter barriers.*

## Lessons from Japan's Attempts

Overseas, larger scale efforts have met with very limited success. Over 600,000 starfish were removed from a number of reefs in Micronesia but the results were not conclusive. In Japan, some 13,200,000 were killed between 1973 and 1983 at the cost of \$A6m, but the program was considered a failure. By the time funds were made available for a control, the outbreaks were very well established and coral damage was great. In addition, as fishermen were paid a bounty on each crown of thorns collected, they stopped collecting in an area when it became uneconomic and not when they had removed all the starfish. Sufficient starfish were left in these areas to eventually eat the remaining corals. The situation has been similar in Fiji, Samoa and elsewhere where controls have been attempted.

It has been suggested by some scientists that partial controls may actually be harmful. Normally a major outbreak exhausts its food supply in two or three years and then disappears. But if a smaller number of starfish are left on a reef with ample food they will live much longer and continue breeding. This may result in a longer-term or chronic problem in the area.

## GBRMPA's Starfish Controls on the Great Barrier Reef

Because of the high cost of professional divers, it has been suggested that GBRMPA use volunteer divers for control of the starfish on the Great Barrier Reef.

In 1986 the GBRMPA undertook trial controls using 15 Royal Australian Navy divers from the training school HMAS *Creswell* to eradicate starfish threatening a popular diving site on Grub Reef off Townsville. During the two week exercise each diver undertook three or four SCUBA dives per day in depths from 2 to 20 m of water. Although about 3,000 starfish were injected, starfish from neighbouring areas moved in and within a few weeks the area was again infested.

## Underwater Fences an Aid for Local Control

Underwater fences might be used to prevent reinfestation of a cleared area of coral reef. To evaluate the effectiveness of underwater barriers, researchers erected a range of enclosures of different mesh size and construction on John Brewer Reef in late 1986 and placed starfish inside. Each hour for almost a week, the responses of the captive starfish were carefully moni- ▶

tored. While they proved masters of escape (capable of squeezing their bodies up to pass through surprisingly small spaces), one design of barrier, a low wire net with the top bent over, was found to be very successful. Each time the starfish reached the overhang they fell off because they could not gain sufficient grip on the wire.

While the fences were found to be effective, there was some concern that they may become less so as they are fouled by marine growth. However a repetition of the experiment after the fences had been fouled for six months indicated that they remained efficient in excluding the starfish.

Such barriers might be very useful for enclosing coral viewing and diving sites on a reef, but they are certainly not the equivalent of the rabbit and dingo fences used on land because the microscopic larvae of the starfish could pass easily through any barrier. However, used in combination with injection, these barriers could be very effective in small-scale management of the starfish.

In 1987 the GBRMPA arranged for Army and Navy divers (transported in an Airforce boat on one occasion) in an attempt to eradicate an outbreak at Holbourne Island off Bowen. This is the first attempt to eradicate an infestation at the whole-reef level. Holbourne's reef is very small (about 1 km long) and isolated, and the starfish were aggregated thus making eradication easier. Service divers have so far injected over 8,000 starfish during two expeditions to the island but many starfish remain on the reef. This year the GBRMPA has also assisted the tourist operators at Credlin Reef, off Mackay, to eradicate an outbreak in their coral viewing area.

## Cost-Effectiveness of Controls

The major problem with these control techniques is that each starfish has to be located, and then injected or collected by a diver, a time consuming and very expensive operation. Support vessels are very expensive, about $1,000 per day for a vessel carrying 10 to 12 divers, and divers are very expensive to employ.

Even though the GBRMPA did not have to pay the divers in the Grub Reef exercise, the total ship costs for two weeks were $23,000, i.e. $7.42 per starfish injected. And, if the costs of the divers and scientists were also included, the cost would be two or three times that!

Techniques for mass killing the starfish are inefficient and expensive and it has been suggested that granulated quicklime, a corrosive chemical used to kill starfish in oyster beds in the US, might be spread over the reefs, possibly using cropduster aircraft. However, experiments conducted by GBRMPA indicate that the technique has limited usefulness as most of the starfish are at least partially hidden and escape fatal burns. Corals and other animals and plants were also killed by the chemical.

## The Potential of Biological Controls

It seems at this time that only a specific biological control might be successful in eradicating the starfish on a large scale if this should ever be considered necessary. However, this path is filled with great problems. Man has attempted to eradicate many different pests on land and the now widespread pollution by pesticides, and the history of biological controls which have run riot, provide ample warning that they will have to be very carefully screened before they might be used in the marine environment.

## Manual Eradication Not a Solution

Manual eradication of the crown of thorns starfish on all the 2,900 reefs which make up the Great Barrier Reef may be biologically undesirable. It is, in any case, quite impossible. If it were possible to completely eradicate an outbreak on a **single reef** (and this remains to be demonstrated) the cost, even using volunteer divers, would probably be many hundreds of thousands of dollars. The cost for the entire Great Barrier Reef would therefore be hundreds of millions, or possibly billions, of dollars. And this would not stop the outbreaks from recommencing.

According to a leading Japanese scientist, his country's attempts at manual eradication were a waste of money and it would have been far better to channel the funds into scientific studies of the causes of the outbreaks as we are now attempting in Australia. □

*Royal Australian Navy divers from the training base HMAS Creswell have assisted the GBRMPA in control programs at Grub Reef and at Holbourne Island.*

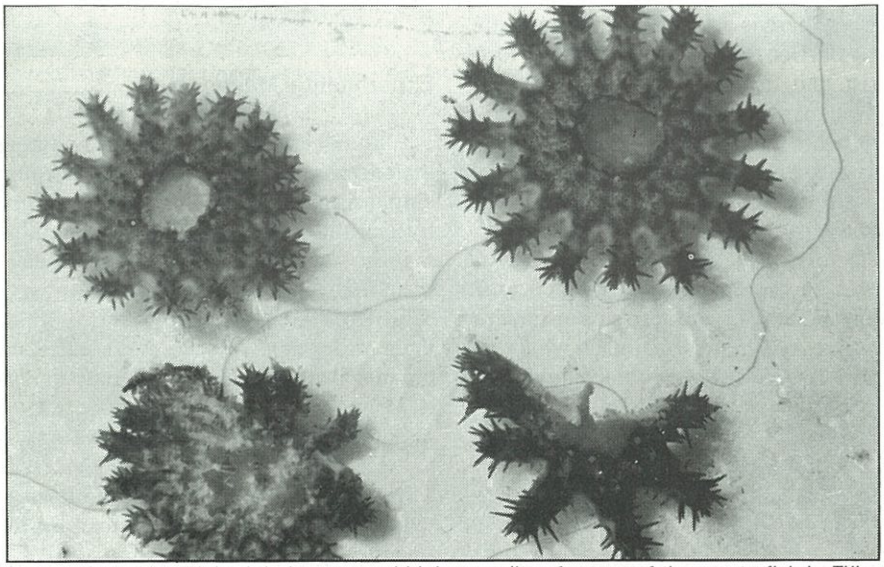
**Biological Control**

Traditional methods of pest control, e.g. chemical agents, have been used throughout the world for many years. However, the immense damage caused by some of these compounds, e.g. DDT and Polychlorinated Biphenyls (PCBs), has led to the promotion of biological agents as an alternative means of pest control. Ideally, these agents either consist of micro-organisms capable of producing fatal disease in the target species, or they are predators intent on killing or devouring them.

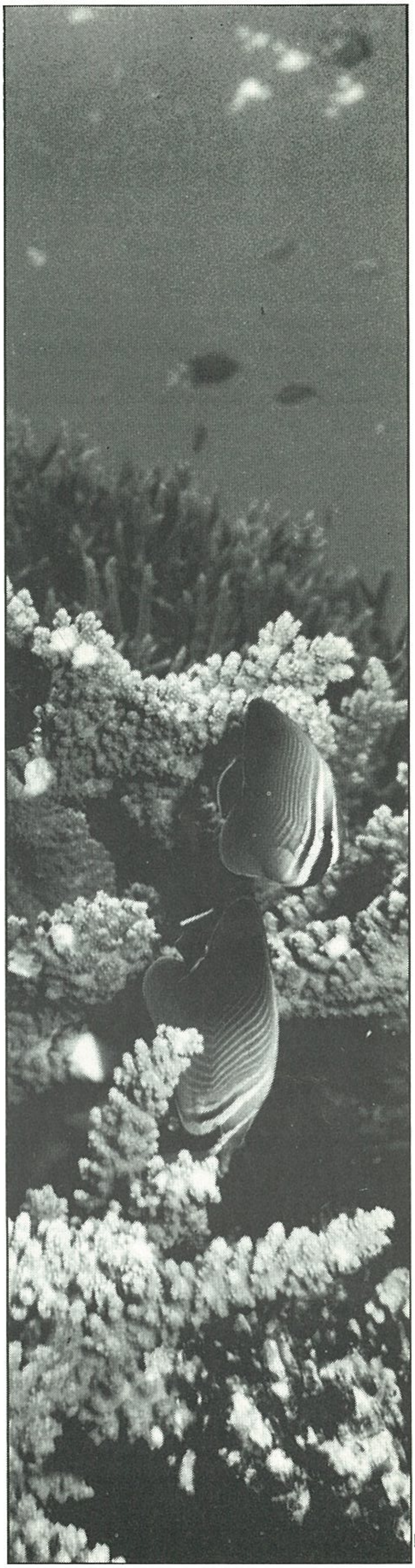
With regard to biological control, Australia has seen several important precedents. The cactoblastis moth which devoured the prickly pear and the myxomatosis virus which destroyed millions of rabbits by flea tranmission within the burrow were two great success stories. The introduction of the latter however, was not without controversy. Sir McFarlane Burnett, the winner of the 1960 Nobel Prize for medicine, had to publicly inject himself with the virus to prove that it was not related to the mosquito borne human pathogen, Murray Valley Encephalitis. In South East Queensland local people have shown their gratitude after the eradication of prickly pear by erecting a 'Cactoblastis Memorial Hall'. A notable failure, of course, has been the introduction of the cane toad (*Bufo marinus*) to control the cane beetle. This animal has not only done the job required of it but continues to decimate native species.

Work presently being carried out at James Cook University in Townsville indicates that the biological control of large crown of thorns (*Acanthaster planci*) populations on the Great Barrier Reef is a distinct rather than remote possibility. Scientists at the Graduate School of Tropical Veterinary Science and Sir George Fisher Centre for Marine Studies are investigating a disease outbreak amongst juvenile crown of thorns on Suva Reef in Fiji during the summer of 1984-85. The disease, now known to be infectious, resulted in a mortality rate of about 99% over a period of several months and was characterized by severe erosion of the central disc area. Efforts are being made to identify the organism responsible and culture it in the laboratory. If this can be achieved, the Great Barrier Reef Marine Park will have an effective means of controlling crown of thorns starfish numbers in selected areas on the Great Barrier Reef, e.g. popular tourist spots. However, the scientists must first be sure that the crown of thorns agent will not decimate natural populations of other marine invertebrates.

*S. Hall and J. Glazebrook*



*An epidemic of microbial origin has caused high mortality of crown of thorns starfish in Fiji and may have potential as a biological control on the Great Barrier Reef. These diseased juveniles collected from Suva Reef show progressive damage or necrosis on the upper side.*



# Crown of Thorns Risk Analysis

*by John Parslow and Tor Hundloe*

What is risk analysis?

Risk analysis refers to a set of techniques for choosing between management policies which have uncertain outcomes.

A risk analysis for crown of thorns starfish involves:

1. the assignment of probabilities or likelihoods to each of a set of possible outcomes, for each of a set of management actions;
2. the assignment of economic or other values to alternative outcomes and actions;
3. a decision analysis based on probabilities and values and management objectives.

## Identifying Management Objectives

The GBRMPA has the responsibility for protecting the national heritage of the Great Barrier Reef and maintaining it as a base for economic activities such as tourism and fishing. If starfish outbreaks threaten these goals, then the objectives should be to reduce or eliminate outbreaks. However, some reef ecologists have argued that the outbreaks are a natural phenomenon, perhaps essential to reef structure.

## Identifying Management Actions

Most proposed actions have been concerned with reducing starfish numbers and/or protecting corals. They include the removal or killing of starfish by divers, or by broadcasting quicklime, and the exclusion of starfish using fences. Biological control, using disease organisms or predators, has been suggested but not tested.

## System Analysis

In the case of crown of thorns, there is a natural division between an analysis at a local level, and an analysis at the regional level.

## Local Analysis

At the local level, one can consider the problem from the point of view of tourist operators who take tourists to view coral on particular reefs. If an outbreak occurs, the operators must decide how much money to spend on local control. The cost and effectiveness of local control will depend on the size of the outbreak and the area of coral they seek to protect. Present control methods are very expensive and their effectiveness has varied widely.

An operator making long-term investment decisions must assess the expected costs of future starfish outbreaks. One way to predict the probabilities of future outbreaks is to extrapolate from statistical analyses of past outbreaks. The operator must also attempt to forecast the effects of coral damage on tourist numbers. Recent studies suggest that the effects so far have been relatively small. Numbers of tourists on the Great Barrier Reef have grown rapidly, and first-time visitors have been uncritical of damaged coral. This may change if tourists become better educated about coral quality. To this point, tourist operators have spent relatively little on local control, and this behaviour is consistent with the absence of a strong economic incentive.

## Regional Analysis

A risk analysis at the regional level is more appropriate to the management problem facing GBRMPA. It must decide whether there is a long-term threat to the Great Barrier Reef, or a problem for local tourist and fishing industries which can best be managed by action at a regional level. The uncertainties at this level of analysis are greater and the problem is less well-defined. The use of statistical extrapolation from previous observations is not satisfactory: it is precisely the prospect of changes in system behaviour which must be considered. Under these circumstances, one must rely more on models which incorporate some scientific understanding of the key biological and physical processes.

The complete Great Barrier Reef ecosystem is far too large and complex to model in its entirety, but so are most ecosystems. Other successful pest-management models have been based on the population dynamics of the pest, its principal food resources, and a few other interacting species (often predators).

There are still considerable gaps in our knowledge of crown of thorns population dynamics, arising in part from the difficulty of studying the widely dispersed larvae and the secretive early juvenile stages. Some of these gaps are being filled by current research. We know enough to characterise crown of thorns as a typical outbreaking pest. Analogies can be drawn with terrestrial pests such as locusts and temperate forest insects.

Theoretical studies and observations of crown of thorns and similar pests suggest three general states for the coral-starfish interaction:

(i) a cyclic state, with intense outbreaks and high coral damage, followed by a long period of low starfish densities and good coral recovery;

(ii) an endemic state, with outbreaks occurring frequently, if sporadically, and coral recovery poor;

(iii) a possible state with high coral cover and starfish regulated at low densities by predators.

Over the past 25 years, the Great Barrier Reef, or at least the central part, seems to have been in state (i). There is still debate over whether it was in state (iii) prior to that time. The major concern must be that a transition could occur to state (ii). Ironically, theoretical studies and the Japanese experience suggest that the simplest large-scale management action, widespread harvesting of crown of thorns, could produce a transition from state (i) to state (ii).

## Experimental Management

With uncertainty as high as in the large-scale (regional) analysis, the management emphasis must switch from meeting objectives in the short term, to acquiring information which will allow better management in the long term.

GBRMPA has recognised this by funding a wide range of scientific studies and broad crown of thorns and coral surveys. It is important that these activities are maintained and that their implications for management are constantly reassessed. The question of whether crown of thorns represents a threat to the Great Barrier Reef will surely be answered in time. The challenge is to ensure that all management options have not closed by the time the answer is clear. □

## Value of the Reef

The Great Barrier Reef is one of the great natural wonders of the world. As such it is a very valuable tourist attraction. It is also a valuable commercial and recreational fishery.

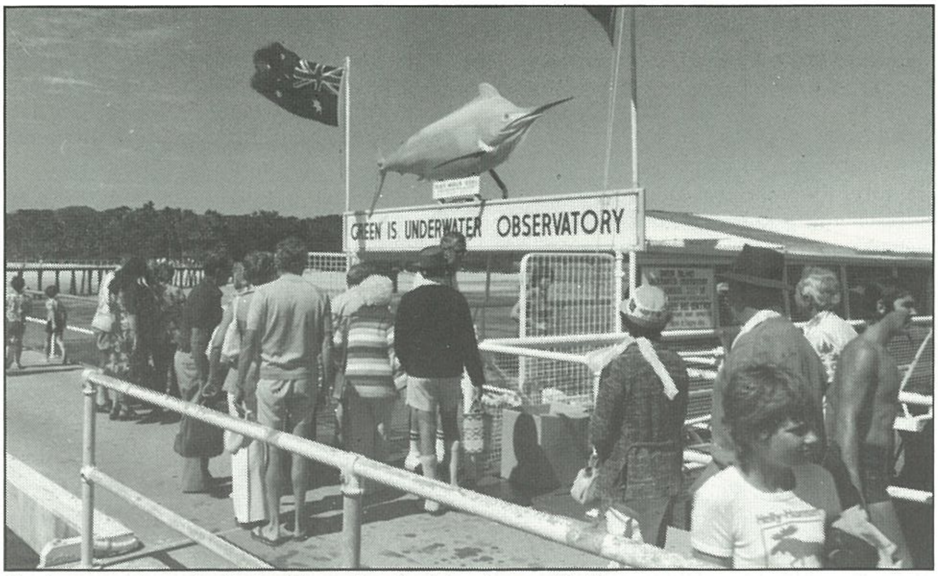
Between two-thirds and one million people visit the Reef annually. Not all of them go specifically to view coral and other marine life. At least one-third of a million do that, by snorkelling, diving, taking trips in glass-bottom boats and coral-viewing from semi-submersible vessels. Those who do not visit specifically to experience the underwater environment, go for the pleasure of resort holidays. There are 22 major island-based resorts in the Reef area, but only three coral cays have resorts on them. There are about 200 tourist boats, ranging from very small ferries through to huge catamarans, plying their trade in Reef waters. These few facts suggest the importance of the Reef as a tourist destination.

There are approximately 2,000 commercial fishermen who largely depend on the Reef waters for their livelihood. Approximately half of these are skippers and crew on prawn trawlers, the remainder fish for reef fish (such as coral trout and sweetlip), mackerel, crayfish, scallops, and various other species. In addition to the commerical fishing fleet, there are nearly 15,000 privately-owned recreational fishing boats which are used in Reef waters. These facts illustrate the importance of the Reef as a fishery resource.

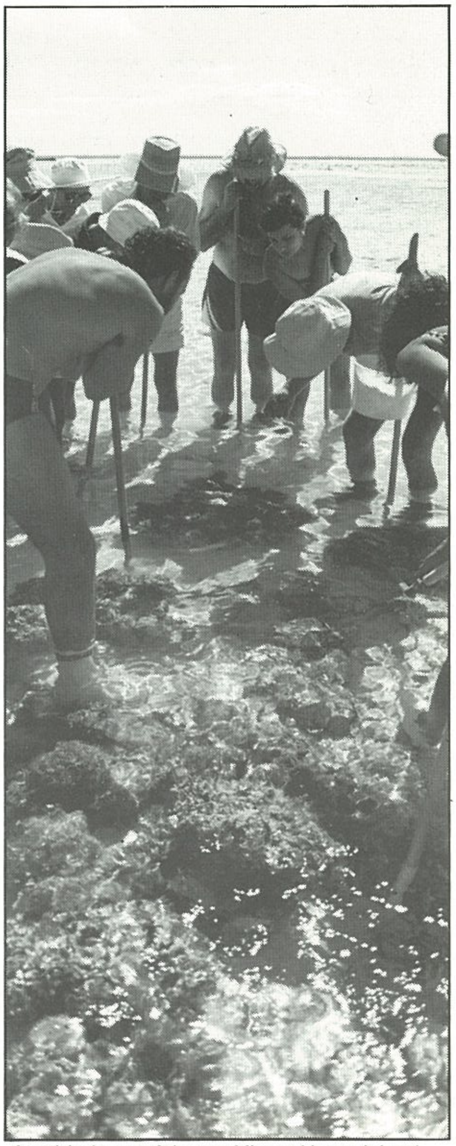
In addition to the value to direct users, the Reef is a valued resource by the Australian and international public — even though the vast majority will never visit it.

One of the important research projects being undertaken is the estimation of the economic value of the Reef: it has to be derived by complicated analytical techniques because there is no market as such for the amenity and productive value of the Reef, as there is, for example, for agricultural land. It is that value which is being threatened by the crown of thorns starfish.

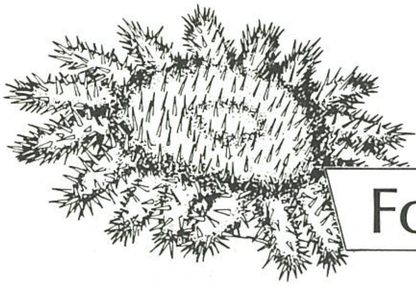
*Tor Hundloe*




*The two most important industries on the Reef: tourism and fishing.*



*A guided tour of the reef flat at Heron Island.*



# POSSIBLE REASONS

## For Outbreaks

*by Leon Zann*

There have been many theories on the causes of the outbreaks and despite frequent reports in the press that they are due to overfishing, collection of tritons or something else, *at this time scientists simply do not know the reason* (or reasons, for more than one factor may be responsible).

Are the outbreaks natural? Or are they unnatural, the result of man's activities? This is the key question in the crown of thorns phenomenon and all the theories on the causes of outbreaks fall into these two main areas.

### THE THEORIES ON NATURAL CAUSES

These theories propose that the outbreaks are a natural phenomenon which affect reefs periodically and they had not been previousy reported simply because there was no one around to see them; recreation diving and the study of coral reefs are only recent activities of man.

Coral mortality through predation, heavy rainfall and siltation, high temperatures and desiccation during unusually low tides and climatic events such as the El Nino/Southern Oscillation, rough seas and cyclones, is a natural process necessary for reef building to occur. The crown of thorns starfish is an important natural predator of corals and may play a vital role in selectively removing the faster growing species such as *Acropora* allowing slower growing massives to proliferate. The 'outbreaks' of crown of thorns may therefore be the result of normal, but unusually successful spawning, high survival of the planktonic larvae, favourable currents depositing them back on a reef, high survival of the juvenile stage, and good coral cover for the adults.

The starfish have an enormous reproductive potential and a single female may release over 20 million eggs at the annual spawning. As spawning aggregations may consist of many hundreds of individuals, possibly billions of larvae may be produced from a successful spawning of a population. If conditions in the open sea happen to be favourable (e.g. appropriate temperature, salinity, food supply) many larvae might survive and if they are carried onto a reef at the right time it is easy to imagine thousands or millions of starfish resulting. But if conditions are less favourable, or the larvae do not reach a reef, few if any might survive.

Many scientists consider that populations can be expected to fluctuate widely, quite independently of man's influence. Populations of other animals which produce large numbers of eggs (described by biologists as 'r-strategists', as opposed to the 'K-strategists' which produce few young) may also fluctuate greatly from year to year.

Because variable survival of the planktonic larvae is suspected, this theory (which is favoured by many coral reef researchers) has been termed the 'larval recruitment hypothesis'. Studies by Professor John Lucas of laboratory-raised larvae indicate that lowered salinities, elevated temperatures and a higher than normal level of plant plankton (phytoplankton) increases the survival of the larvae. However, as recent studies by Dr. Randy Olson of larvae raised in cages in the sea have indicated that survival is just as high in water with a 'normal' level of phytoplankton as that with artifically enhanced levels, and that the situation may be more complex (see page 26).

Overseas, Professor Charles Birkeland of the University of Guam has attempted to test this theory by relating starfish outbreaks with unusually heavy rains occurring at the spawning season three years before the outbreaks were observed. The three year time lag was the period the juveniles were thought to remain hidden in their unknown nursery. Heavy rains after a dry period would flush nutrients from the land increasing phytoplankton growth offshore. Though the correlations generally apppeared positive, there has been criticism of some of the examples and scientists generally do not regard the case as proven.

Researchers at the GBRMPA are using satellites to determine whether patches of high productivity (from concentrations of phytoplankton) do exist, how they might be distributed, and whether this is related to the crown of thorns starfish outbreaks (see page 50).

#### Geological Evidence

The only way to really determine whether infestations ocurred in the past would be travel back in time. Geologists have attempted to do this by searching amongst the sands beneath the surface for starfish remains.

A study in the 1970s provided some evidence of past infestations but marine scientists are critical of the methods used and the study is now being repeated. The results of the new surveys do suggest that large numbers of crown of thorns were found on Green Island and John Brewer Reefs in the past (see page 47).

A more recent record of crown of thorns damage may be found in the growth of the massive corals, some of which may be thousands of years old. Interruptions of growth resulting from the partial death of the colony which are sometimes evident in the shape of the coral do suggest that outbreaks occurred before the 1960s on the Great Barrier Reef. However, as these do not tell the cause of death, it provides only circumstantial evidence of outbreaks.

## Historical Reports and Traditional Knowledge

Another way of finding out whether outbreaks occurred before the 1960s is to question the surviving trochus and pearl divers who worked the Great Barrier Reef before and after the Second World War. Though they were not trained biologists, many were keen observers of nature and knew the Reef long before any researchers arrived. These interviews suggest that the starfish were common at times in the 1930s and 1950s (see page 49).

The Pacific Islanders are also a great ▶

*Green Island off Cairns is one of the best known tourist attractions on the Great Barrier Reef. The crown of thorns were first seen here in large numbers in 1962, and again in 1979. The dark patches off the wharf are seagrasses, possibly abundant here because of the nearby sewage discharge.*

source of information on coral reefs, a source of food for thousands of years. The crown of thorns is particularly well known amongst the inhabitants of the high islands (e.g. Fiji, Samoa, Southern Cook Islands) and some old fishermen in Samoa did recall outbreaks over 50 years ago. However, it has been pointed out that a large, venomous starfish would be well known for reasons other than its occasional outbreaks.

### Structure of Coral Communities

There are hundreds of different types of corals on a reef, from the branching staghorns which may grow up to 30 cm a year to the massive 'bommies' ten or more metres in diameter which grow only a few centimetres each year. The structure of a coral community, whether it is largely constituted by slow or fast growing species, or a mixture, may tell researchers what disturbances have occurred in the past, rather like the types of trees dominating a forest indicate past disturbances. Scientists from AIMS, having investigated growth rates of established corals and the recruitment of new corals, have simulated different outbreaks of starfish using computers to determine whether reefs can sustain present rates of damage. The results are inconclusive but do suggest that the present composition of large, old coral species might be sustained at the present level of outbreaks.

## THE THEORIES ON HUMAN CAUSES

These assume that outbreaks did not occur in the past and that coral reefs are stable ecosystems which do not experience fluctuations of populations. The main scientists proposing this, Drs. Robert Endean and Ann Cameron, from the University of Queensland, argue that the crown of thorns starfish is a naturally rare, relatively long-lived, specialized predator of corals with few predators and parasites and the removal of natural predators of the starfish and other disturbances to a reef may trigger a population explosion in the crown of thorns. This primary outbreak would trigger secondary outbreaks as the spawn of the initial outbreak are carried to other reefs.

### The Stability of the Coral Reef Ecosystem

Some researchers maintain that coral reefs are biologically stable and predictable because of their large numbers of different species, and the outbreaks are therefore unnatural. However growing information on reef fish and echinoderms (the group to which the starfish belong) indicates that annual recruitment is variable from year to year for those species which have been studied.

### Correlation with Man-Induced Disturbances

Some scientists argue that many of the primary outbreaks occur on reefs which have been disturbed by pollution, dredging and blasting, and heavy fishing pressure. However others point out that the outbreaks are reported mainly from centres of human population because this is where people are to see them!

Details on the distribution of the outbreaks, and where they have not occurred, are being gathered in the Crown of Thorns Starfish Research Program.

### Pollution

Although it has been suggested that outbreaks are linked with pollution (e.g. from farms and cities) there is no direct evidence to support this. Some scientists argue that the Great Barrier Reef has very low levels of pollution, probably as low as any place in the world, and that other starfish and reef inhabitants seem to be unaffected.

Other scientists point out that some localised pollution does exist. Green Island, which is at or near the origin of the two Great Barrier Reef outbreaks, has been affected by human activities. Since the first aerial photographs were taken about 40 years ago, the seagrass beds on the reef have grown from a fraction of a hectare to over 50 hectares, probably due to increased sewage discharges.

Detailed studies of changes in land use in North Queensland, of the use of fertilizers and pesticides, their effects on corals and the levels of chemical pollutants on the Great Barrier Reef off Cairns are now underway in the Research Program.

### Removal of Predators

The theory, proposed by Drs. Endean and Cameron, that the outbreaks have occurred because of the removal of the natural predators of the starfish by man has received the widest coverage in the media.

The giant triton shell, *Charonia tritonis*, is the major predator of the adult crown of thorns starfish and other reef starfish. It has a very attractive shell and Endean and Cameron have argued that its overcollection by shell collectors has allowed the starfish to explode in numbers. The triton has been protected in Queensland since 1969.

This theory has achieved little acceptance amongst other scientists because the tritons are naturally uncommon on reefs seldom visited by man, and because it is argued that they could never be in sufficient numbers to eat the millions of adult starfish which might make up an outbreak on a reef. A triton may eat only one or two starfish per week, and feeds on species of starfish in addition to crown of thorns. Why don't the other starfish also form outbreaks?

Endean and Cameron also argue that overfishing of reef fish, especially the gropers, has contributed to the outbreaks. Although there have been occasional reports of pufferfish and triggerfish eating the adult crown of thorns, these species are not fished on the Great Barrier Reef. Other scientists point out that there are no confirmed scientific reports of gropers eating crown of thorns.

Most scientists consider that predation on the adult starfish cannot be crucial in regulating its numbers. As a mature female may produce many millions of eggs per year, they reason that population regulation **must** occur at the larval stage.

The GBRMPA Research Program includes studies by Drs. Endean and Cameron on the identity of predators of the adults, and studies by other scientists on the gut contents of fish caught on infested reefs and on the collection of tritons.

### A Single Cause, or Many?

Some of the explanations sound logical and it is easy to speculate on the causes of the outbreaks, but none of the theories advanced can be easily tested. In addition some scientists are now suggesting that we have been seeking a simple answer to something which is obviously very complicated and that many factors may individually or collectively trigger an outbreak. □

# A Clue to the Present from the Past

*by P.D. Walbran*

An answer to the question 'what causes outbreaks?' perhaps may be provided by delving into the geologic past to see if evidence of previous infestations is preserved in the sedimentary record. It stands to reason that, when a coral reef is invaded by hundreds of thousands, or even millions of starfish, some parts of their skeleton will be deposited on the sea floor, either through the animals shedding portions of their bodies or as a result of death and subsequent decay. Over many years this skeletal material becomes buried in the sediment pile by the continual influx of new sediment from shallower parts of the reef and the action of organisms such as crustaceans, molluscs and worms that live in the sediment. In this way, pieces of skeleton or ossicles which were once on the surface will, in due course, become buried beneath several metres of sediment.

Researchers at the James Cook University in Townsville are attempting to determine if the crown of thorns starfish has left a record of its presence in the sediment. If so, does this record indicate the occurrence of population outbreaks on the Great Barrier Reef prior to European settlement of the central and north Queensland coast?

## Identifying Skeletal Fragments

First of all, we need to be able to identify crown of thorns skeletal fragments (ossicles) and be able to distinguish them from the skeletal elements of other reef-dwelling organisms whose hard parts are also present in reef sediment. We are fortunate that the skeletal elements of the crown of thorns starfish are easily distinguished by their shape and generally light to medium mauve coloration. A variety of ossicles from the crown of thorns starfish are shown in Figure 1.

The second phase of the study is to determine if starfish infestations leave significantly more ossicles in the sediment of reefs which we know have been invaded than on unaffected reefs. To do this, we must examine sediment samples from both these groups of reefs.

## Survey Areas

Three reefs were selected for this purpose. John Brewer Reef, north-east of Townsville, and Green Island Reef, east of Cairns, have both suffered two starfish population outbreaks since the early 1960s resulting in very extensive destruction of living hard coral on both occasions. If large numbers of marauding starfish **do** leave a signature of their presence, it will be evident in the surface sediment of these two reefs.

Heron Island Reef, north-east of Gladstone, has maintained a constant population of starfish for many years without any large fluctuation in numbers. Thus, the abundance of crown of thorns skeletal material in the surface sediment of Heron Island Reef represents a 'normal' starfish population on a 'healthy' reef.

Surface sediment is collected using a grab sampler, a jawed device that bites into the sediment. Subsurface sediment is collected in cores, using a vibrocorer (see Figure 2) which pushes lengths of aluminium tubing into the sediment. Four to five metres of sediment can be retrieved in this manner, brought back to the laboratory and examined under a binocular microscope for crown of thorns ossicles.

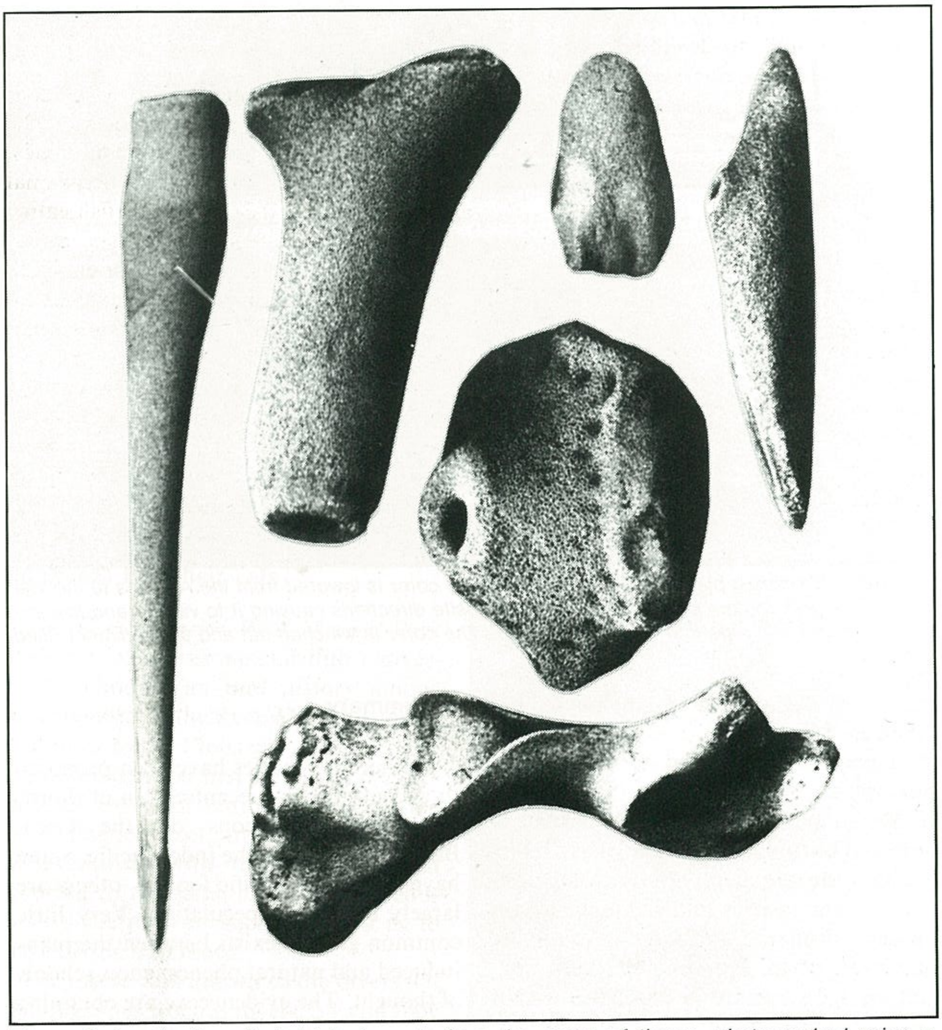


*Figure 1. A selection of skeletal elements from the crown of thorns, photographed using a scanning electron microscope. The size ranges from about 2 mm to 25 mm. Individual elements have been aged using experimental accelerator mass spectrometry.*

## Survey Results

The results of this work are very interesting. Two skeletal elements were recovered from a total of 54 x 1 kg surface samples collected on Heron Island Reef. In contrast, John Brewer Reef (59 x 1 kg samples) and Green Island Reef (46 x 1 kg samples) produced many more elements, up to 135 per sample in the sur- ▶

face sediment. Clearly, large numbers of starfish leave behind an abundance of elements as evidence of their presence.

The distribution of ossicles in the sediment cores from John Brewer Reef and Green Island Reef suggests that large numbers of starfish were also present in the past. If the outbreaks are a recent phenomenon, we should expect to find a comparable number of skeletal elements in the subsurface sediment as are present in the surface sediment of Heron Island Reef, that is, virtually zero. This was not the case.

### An Uncertainty Arises ...

An abundance of ossicles in the subsurface does not, by itself, provide proof that outbreaks of crown of thorns starfish have been occurring on the reefs of the Great Barrier Reef for hundreds, or thousands of years. Whilst sediment is laid down with the oldest material at the bottom and the youngest at the top, the activity of crustaceans, molluscs and worms churns up the sediment as they build burrows and search for food. Their activities may completely redistribute a sedimentary sequence. Grains may be transported vertically up or down within the sediment pile. With a continuous input of fresh material and subsequent increase in the depth of sediment, these animals are forced to migrate upwards to avoid burial and maintain their position relative to the surface of the sediment.

### ... and is Being Resolved

To assess the problems posed by the burrowing organisms, the relative age of the sediment is determined by a process known as carbon-14 dating or C-14 dating for short. All living organisms (animals and plants) continuously accumulate C-14 in their bodies. When they die, this accumulation ceases and C-14 starts to undergo radioactive decay, breaking down to nitrogen-14. Carbon-14 has a half-life of 5730 years. In other words, after 5730 years the remains of an organism contain half the amount of C-14 which was present in that organism at the time of death. Thus, it is possible to determine the age of organic material by measuring the amount of residual C-14 in a sample.

We are using the C-14 dating method in association with the Australian National University in Canberra and the Institute of Nuclear Science in Lower Hutt, New Zealand. We must date starfish ossicles plus the sediment from which they were recovered in order to determine the extent to which burrowing organisms have redistributed the sediment. Ideally, dates obtained from ossicles and sediment would be very similar, indicating little mixing has taken place. Preliminary results suggest an age structure **is** preserved within the sediment, despite the influence of burrowing organisms, but further dating is needed before we can be sure.

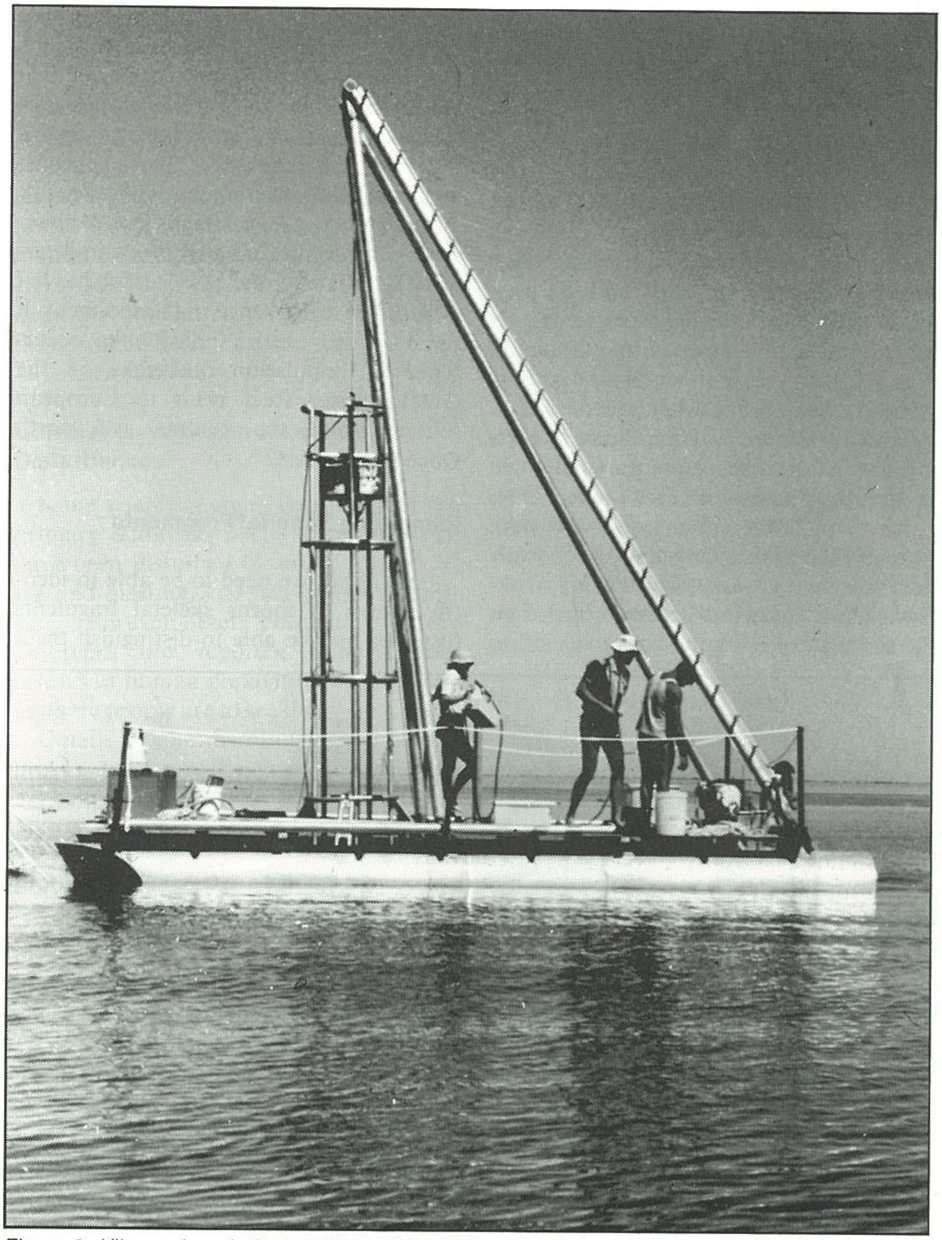


*Figure 2. Vibrocoring platform at Green Island. The corer is lowered from the A-frame to the sea floor of the reef. Motors in the head spin in opposite directions causing it to vibrate and thereby push an aluminium pipe into the sandy bottom. The corer is winched out and the sediment-filled core removed.*

### In Summary

Numerous theories have been proposed to account for the recent crown of thorns population explosions on the Great Barrier Reef and in the Indo-Pacific. Some have a sound scientific footing, others are largely based on speculation. Very little common ground exists between the man-induced and natural phenomenon schools of thought. The evidence we are obtaining from the sediment record will be crucial in resolving this debate. □

# Long-known Hazard for Trochus Divers

*by Regina Ganter*

Before the proliferation of SCUBA diving equipment and outboard motors in the 1960s, relatively few people were familiar with the underwater world and many marine organisms of the Great Barrier Reef were not even named. The recency of popular use of the Reef makes it difficult to determine whether major populations of crown of thorns starfish are a natural, and perhaps cyclical, phenomenon, or whether they present a recent anomaly which may entail long-term damage to the Barrier Reef.

One group of people had an intimate knowledge of the Reef Province, its currents, its resources and its dangers. They were the young men involved in the pearl-shell, trochus and beche-de-mer fishery which was, from the 1860s to the 1950s a major industry in far north Queensland. Torres Strait Islanders and coastal Aborigines were prominently involved in this fishery which involved sailing across isolated reefs for weeks or months until the boat was loaded with shell or trepang, or until water supplies were exhausted. On trochus and beche-de-mer boats each crew member was a 'swimming diver' spending all day in the shallow reef waters with self-fabricated goggles, unprotected by diving suits or shoes from the marine organisms which inhabit the reefs.

## Old Divers Tell Their Tale

The Great Barrier Reef Marine Park Authority commissioned Griffith University to conduct an oral history among these pioneers of the Reef. My study found that, prior to the 1960s when popular and scientific attention first turned to the presence of crown of thorns starfish on the Great Barrier Reef, trochus divers were quite familiar with this animal which occurred in the same habitats as trochus shell, sometimes in such numbers as to make diving hazardous.

They were well known to the divers. Of 38 indigenous trochus divers, 34 said they had seen crown of thorns starfish before 1960. Divers sometimes accidentally stepped on the starfish, or touched them when they attempted to pick up shells. The sting was extremely painful, incapacitating divers for days, and the spines which broke off in the wound were difficult to extract. Usually divers attempted to remove the spines by applying heat. Sometimes methylated spirits, potassium permanganate, or the milk from ti-trees were applied. Other treatments recommended by Japanese skippers were burnt rice infused with hot water, 'Bluo' diluted in hot water, or grass ashes mixed with hot water.

## Starfish Were Numerous

Sometimes the large numbers of crown of thorns starfish led divers to abandon a rich patch of shell, but other than that they were never concerned about the presence of the starfish, which were accepted as a natural part of the reef environment, with a distribution from the eastern Torres Straits to the Swain Reefs. Normally only a few specimens were found on a reef, but two divers reported aggregations. Douglas Pitt skippered the *Wondai* in the 1950s when he found 'mats' of crown of thorns starfish of up to an acre in the Whitsunday area (Hook Reef and Black Reef); and Jack Kennell had heard of an infestation in the Howick group in January 1951.

The ethnic group most familiar with the crown of thorns starfish were Torres Strait Islanders from the Eastern Group of Islands — Murray, Darnley and Stephen Islands — which are situated on the northern extremes of the Barrier Reef. Nine out of 11 Meriam-speaking divers had been familiar with crown of thorns starfish before the 1960s and referred to it as *urmemeg*. Murray Islanders sometimes killed crown of thorns starfish, sea urchins and other dangerous creatures on their home reefs to keep them safe for gathering activities. Trochus and pearl-shell divers from the Western and Central Islands, which are not situated on the Reef, were less familiar with crown of thorns starfish (9 out of 18), and although they have a common language with regional variations, there was no agreement in the indigenous names suggested for the crown of thorns starfish.

It has not been possible to cross-substantiate sightings of aggregations. The accounts of former trochus divers confirm that crown of thorns starfish have been present on the Great Barrier Reef since at least before World War II. □

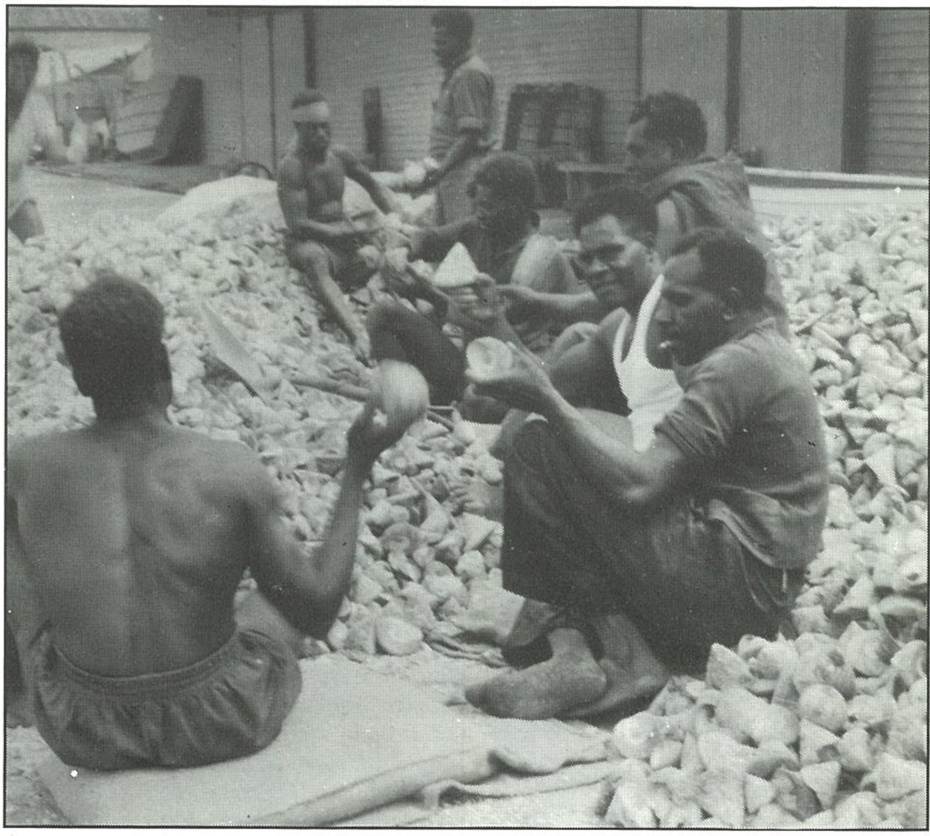


Photo: Courtesy of Mrs. W. Kilpatrick.

*Crew of the 'Australia' from the Eastern Torres Strait Islands grade trochus shell in Townsville, 1954.*

# A Link with Ocean Productivity

*by Dan Claasen*

As with terrestrial ecosystems, the primary productivity of a marine area is an important determinant of the abundance and diversity of its flora and fauna. The distribution of phytoplankton and knowledge of the rate of photosynthesis are therefore useful aids in studying the ecology, food chains and location of fisheries resources of the oceans. If we can obtain this information and map yearly and seasonal variation for the Great Barrier Reef, it will provide an important basis for more exhaustive research into population distributions such as those of the crown of thorns starfish.

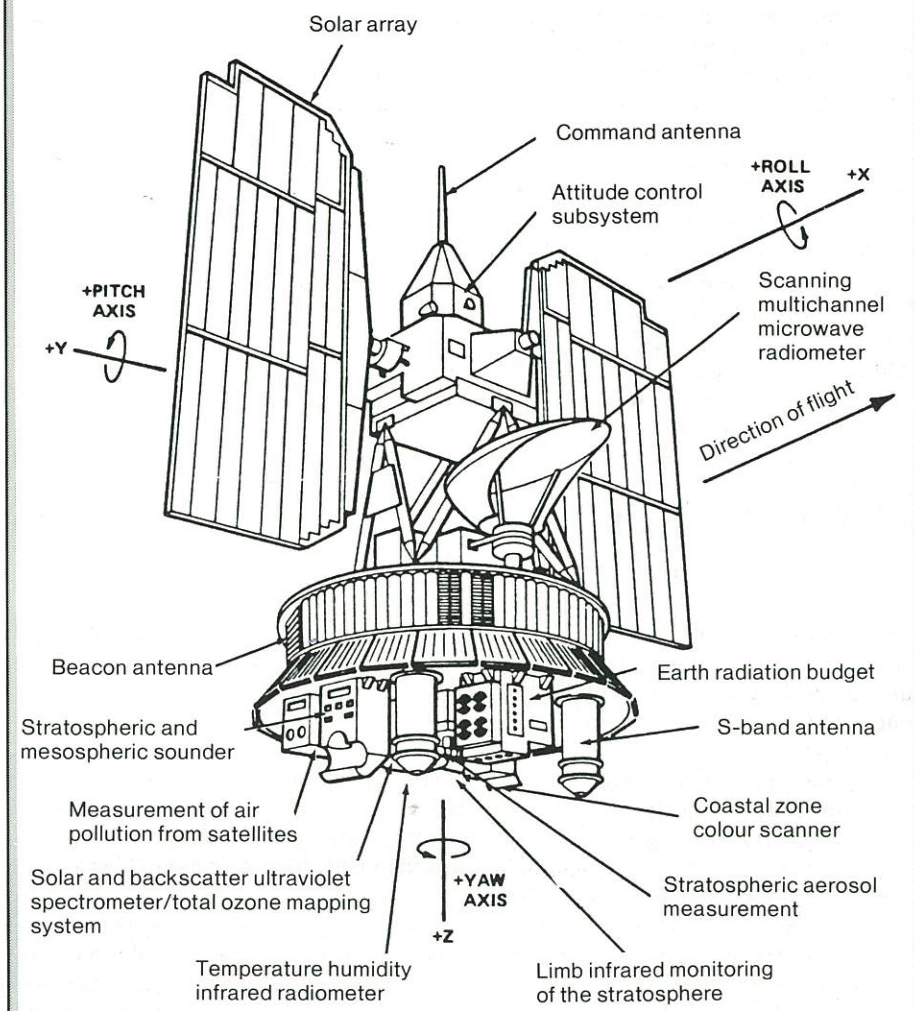
It has been suggested that starfish larvae may disperse in or with patches of phytoplankton upon which they feed. Being able to compare the regional distribution of phytoplankton with the annual distribution of crown of thorns outbreaks may point the way for further investigations.

One of the best ways to map an area of this size is to use images provided by instruments carried on board satellites. Remote sensing allows the regular collection of data from inaccessbile areas at a fraction of the cost of other methods. This is attractive to marine scientists because ships, the traditional vehicles for collecting data, are expensive to run and therefore limit the area and time over which data can be collected.

The lofty viewpoint of the satellite yields data that essentially complement the more detailed and precise data collected by ships. Unfortunately only certain physical processes can be sensed remotely and there are severe technological limitations which further restrict the possibilities. However, satellite remote sensing provides two reliable techniques for our purposes at present: the radiometric sensing of temperature and the radiometric sensing of colour.

Both forms of sensing are passive, meaning they use an external energy, the sun, and its interaction with the target, the ocean. Both methods use multispectral scanning radiometers and rely on computerised digital image processing to produce useful final results. Multispectral scan-

### *Mapping Ocean Colour and Sea Surface Temperature of The Great Barrier Reef from Satellites*




**NIMBUS-7 Satellite with Coastal Zone Colour Scanner**

| | | | |
|---|---|---|---|
| Satellite Launch | : | 21 October 1978 | |
| Orbit Altitude | : | 954 kilometres | |
| Orbit Frequency | : | 6 days or 83 orbits | |
| North-bound Equatorial crossing | : | within 10 minutes of local noon | |
| Resolution at Nadir (sub-satellite) | : | 825 metre pixel | |
| Swath Width | : | 1636 kilometres | |
| Present Status | : | no longer operational | |
| Spectral Channels | : | 1. Blue | 443—453 nm |
| | | 2. Green | 510—530 nm |
| | | 3. Green | 540—560 nm |
| | | 4. Red | 660—680 nm |
| | | 5. Near Infra-red | 700—800 nm |
| | | 6. Thermal Infra-red | 10.5—12.5 µm |

ning takes measurements in a number of different parts of the electro-magnetic spectrum.

In marine applications, multispectral scanning radiometers can be used to sense ocean colour by measuring the reflected sunlight from the ocean. The sensors in the case of the Coastal Zone Colour Scanner (CZCS) are sensitive to visible light in the range 400 nm (blue) to 700 nm (red). The surface temperature of the ocean may also be measured remotely using radiometers sensitive to radiated thermal energy in the infrared region, 10 $\mu$m to 14 $\mu$m. In both cases corrections must be made to the data to compensate the effects of the atmosphere.

Although ocean colour and surface temperature constitute a restricted set of oceanographic parameters they are particularly useful, giving insight into biological activity, water depth, water movement and circulation.

## Ocean colour and water type

Studies have shown that ocean colour measured at the sea surface can be reliably related to levels of near surface planktonic pigment and is a useful indicator of oceanic water type.

The penetration of daylight into the ocean varies with wavelength and the concentrations of absorbing and scattering material. The colour of the emergent light depends on the integrated effects experienced by the light throughout the water on the downward and return path. On leaving the ocean surface it is transmitted through the atmosphere where more changes are effected by atmospheric absorption and scattering. These effects are most influential in the important blue region of the spectrum. The removal of these effects can be computed and allows the further calculation of quantitative estimates for ocean pigments by remote sensing of ocean colour.

## Sea currents from surface temperatures

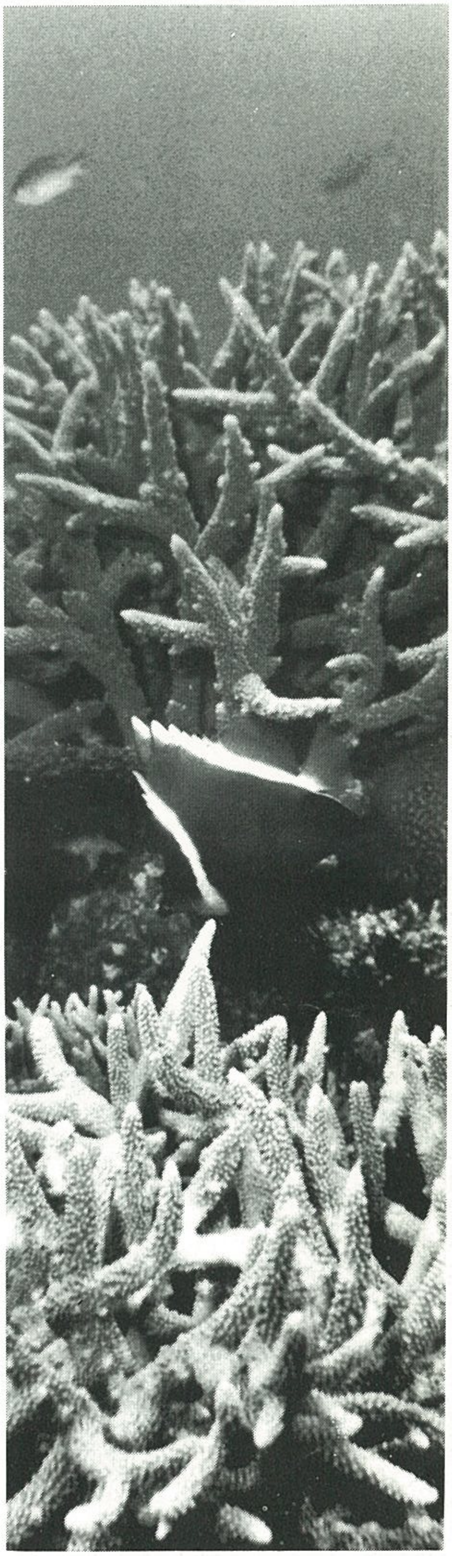
The remote sensing of sea surface temperature can be accomplished using a single radiometer although the potential precision is then limited by a lack of knowledge of the effect of the atmosphere. The use of more than one channel allows some correction to be made for the air mass and allows the calculation of absolute values. The measurement is based on the thermal energy radiated by the sea surface and is restricted to only the top few millimetres of water. This can be a cause of concern since this thin layer may be affected by local heating or cooling or even transport, and so not reflect accurately the temperature of the bulk of the water below it. In general however, the ocean features displayed in thermal imagery are of such a scale and duration that it is clear that they do represent real circulation patterns.

## Coastal Zone Colour and Plankton

The Coastal Zone Colour Scanner (CZCS) is a six channel multispectral scanning radiometer carried on the NIMBUS-7 satellite (see box). It was developed to allow the estimation of near-surface oceanic planktonic pigment concentrations. The term 'coastal' has proven to be something of a misnomer since it has been found that suspended material and 'green stuff' in near shore waters reduce the accuracy of the estimates and the best performance has come from the open ocean. Although there is no way to distinguish between the effects of chlorophyll and the pheopigments from such data, the quantity estimated is usually referred to as chlorophyll because the levels of the pheopigments are typically less than 10% of the chlorophyll levels.

A sample photo-image is included in the colour plates. It shows the relative distribution of near surface planktonic pigment on the Great Barrier Reef from Cape Grenville in the north to Dunk Island. The uncoloured oceanic blue areas are those with very little phytoplankton concentrations. The various coloured themes depict high to low levels of chlorophyll content waters. These levels have not been quantified.

The present major problem with the coastal zone colour scanner is that of data supply. Because the satellite used a lot of power, the scanner could only be operated for up to two hours per orbit. A set of target areas were defined pre-launch in conjunction with overseas collaborators and it is possible that the area of interest has not been imaged. Furthermore, cloudy conditions at the time of overpass may mean useful data was not collected on many orbits. Only data specifically requested is processed. Unfortunately, the satellite system has now degenerated to the degree that it can no longer be classed as operational. Further use of ocean colour measurements to monitor phytoplankton distribution and possibly predict crown of thorns outbreaks will have to await a follow-on instrument on a future satellite. □



# What is Your Verdict? A Summary of the Evidence

The evidence in the crown of thorns story reads like a 'whodunnit' detective story. The 'evidence' is all circumstantial and much of it is contradictory; each important clue seems to be refuted by another and the plot is filled with red herrings. Little wonder the crown of thorns starfish has been in the headlines for 25 years.

**The Evidence For and Against Natural Causes:**

(1) The great reproductive potential of the starfish suggests that population controls must occur in the planktonic phase rather than the adult stage. *(This is logical argument and is favoured by the majority of scientists but there is no scientific evidence to support it.)*

(2) Geological studies indicate that starfish have been common in the past. *(This is strong but not conclusive evidence as it is not proven that these represent past infestations.)*

(3) Observations of the starfish in the 1930s by trochus divers suggest that outbreaks may have occurred in the past. *(But are these equivalent to the current outbreaks? How reliable are their memories? This may only be a red herring, pushing back the first records of outbreaks by a couple of decades.)*

(4) The starfish is well known to Pacific Islanders. *(But this may be so solely because it is large and venomous!)*

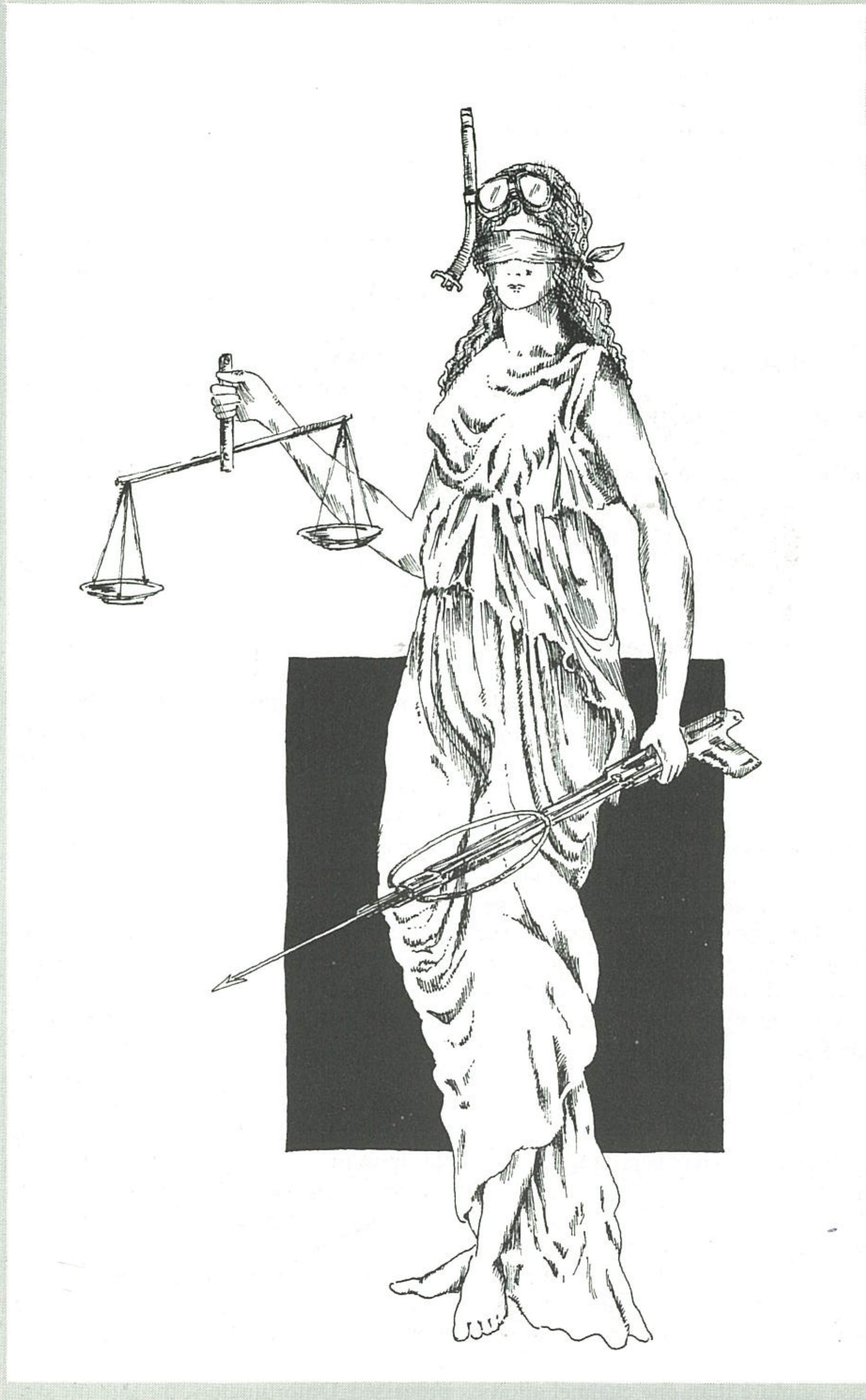
**The Evidence For and Against Human Causes:**

(1) The removal of the natural predators, tritons and reef fish, are responsible for the population explosions. *(A concept disputed by most sicentists. Reports of predation (other than by tritons) are exceedingly rare. Tritons are very rare on remote reefs.)*

(2) Outbreaks seem to be more common in areas disturbed by fishing, port works etc. *(But there are more people around these areas to report them!)*

(3) Predation of large, very old massive corals indicate that they could not have sustained this level of mortality in the past. *(Computer modelling indicates that they may sustain this predation.)*

**What Do You Think?**



Leon Zann

## Further Information

Many scientific papers and a number of books have been written about the crown of thorns starfish. Most of the 300 or so scientific papers on the starfish are much too technical for the average reader. On the other hand, the books and many of the newspaper stories have grossly sensationalized the story to increase sales and do not give an impartial view of the phenomenon. Unfortunately the scientific papers are not generally available in school and public libraries, but efforts should be made where possible to balance the views presented in the popular press.

The most up-to-date, comprehensive scientific review of the crown of thorns is:

Moran, P. (1986) The *Acanthaster* phenomenon. *Oceanog. Mar. Biol. Ann. Rev.* **24**: 379-480.

Papers on the proposed causes of the outbreaks include:

Birkeland, C. (1982). Terrestrial runoff as a cause of outbreaks of *Acanthaster planci* (Echinodermata: Asteroidea). *Marine Biology* **69**: 175-185.
Endean, R. (1982). *Acanthaster planci* on the Great Barrier Reef. *Endeavour* **6**: 10-14.
Potts, D.C. (1981). Crown-of-Thorns Starfish: man-induced pest or natural phenomenon? in: *The Ecology of Pests: Some Australian Case Histories.* (Kitching, R.L. and Jones, R.E. Eds.) Melbourne, CSIRO, pp 55-86.
Rowe, F.W.E. and Vail, L. (1984). Crown-of-Thorns: GBR *not* under threat. *Search* **15**: 211-213.

VIDEOTAPE: "THE CROWN OF THORNS STORY"

A 26 min tape on the subjects included in this booklet has been produced as an educational aid by

The Great Barrier Reef Marine Park Authority,
Box 1379,
Townsville.
Q. 4810.
(Price on application) ▶

*The GBRMPA's Chairman, Mr. Graeme Kelleher, being interviewed for the educational videotape 'The Crown of Thorns Story'. The GBRMPA aims to keep the Australian public informed on the situation regarding the starfish and the progress of the research program through regular news releases and educational features.*

# Contributors

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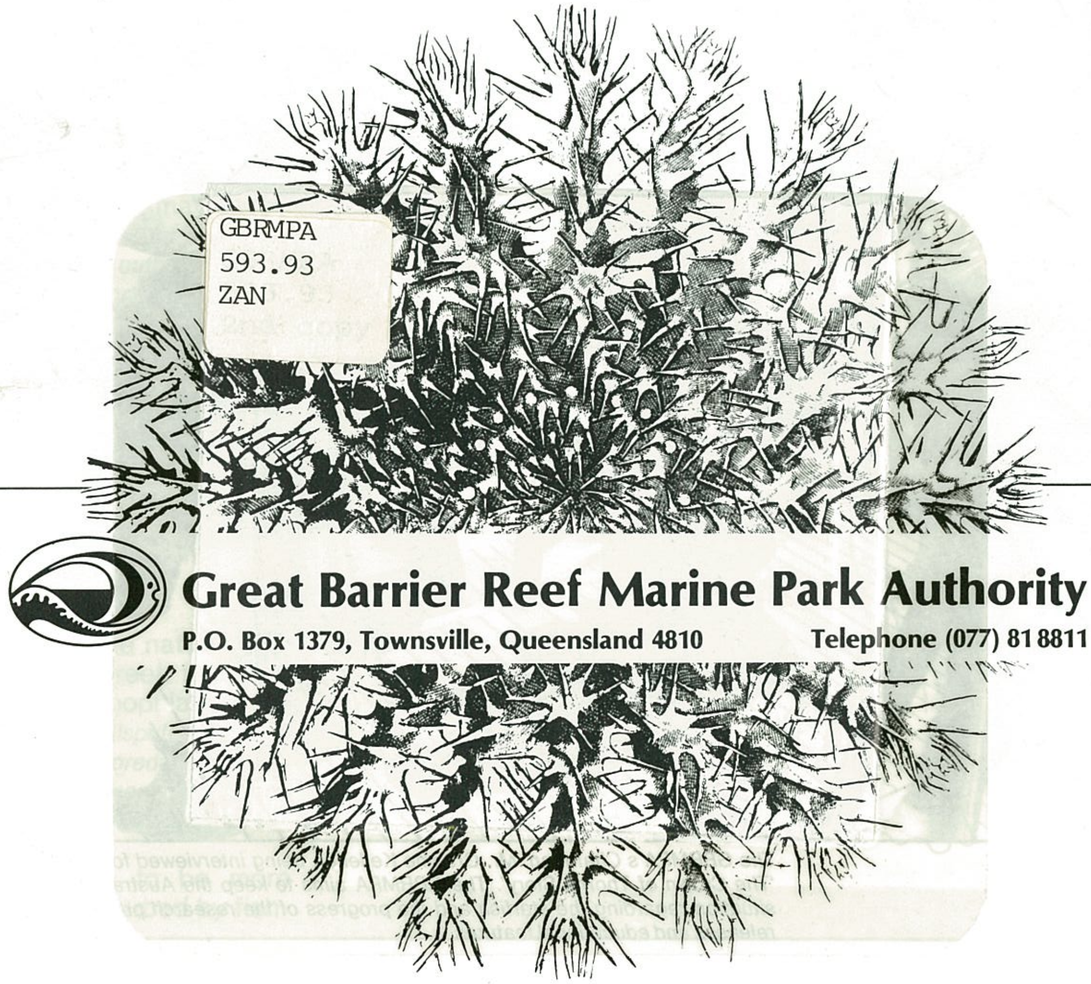
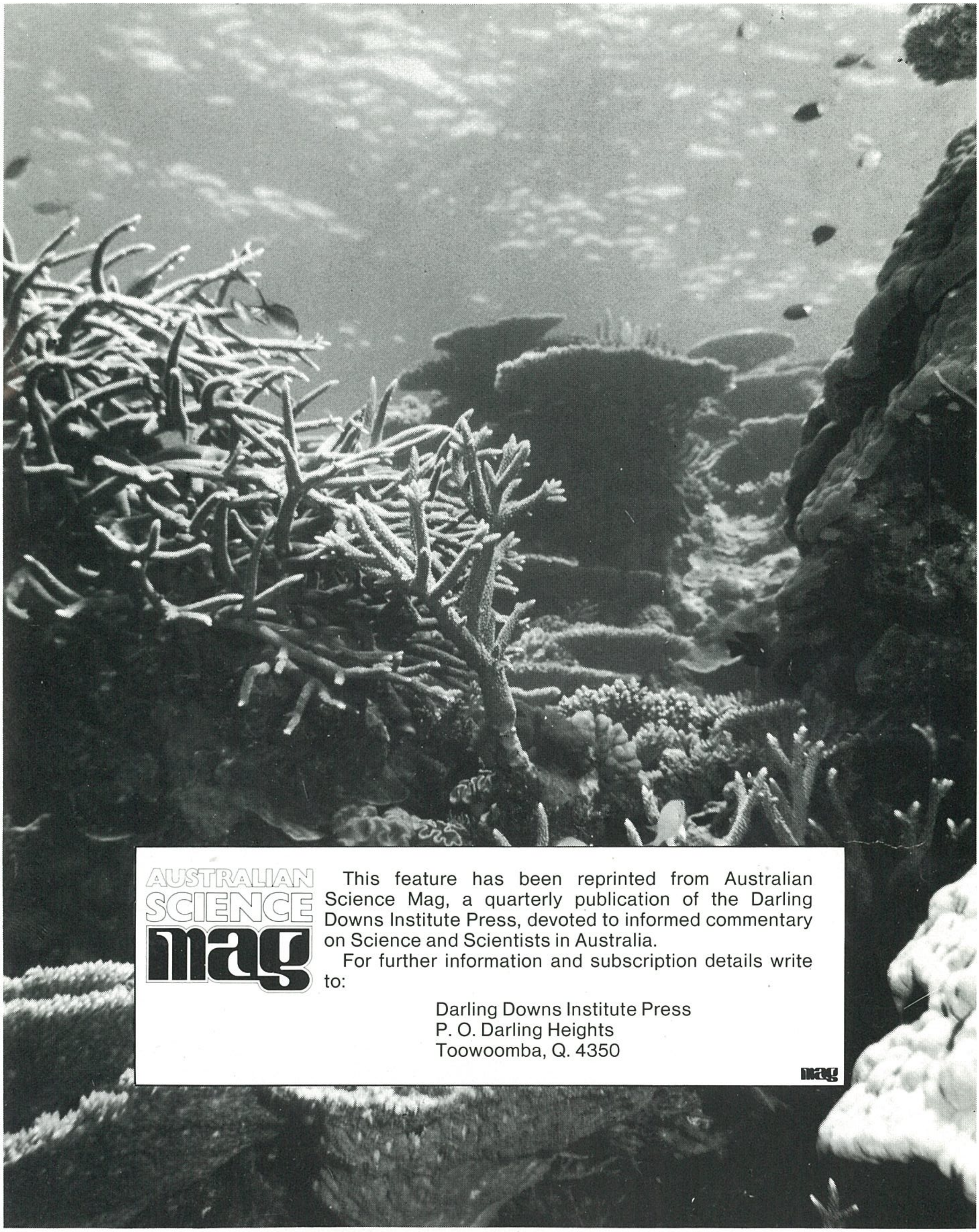
**David Fisk** is a consultant marine biologist who investigated the recovery of hard corals on damaged reefs for the Great Barrier Reef Marine Park Authority.

**Dan Claasen** is a Senior Planning Officer in the Great Barrier Reef Marine Park Authority which is using data collected by remote sensing in the management of this vast marine area.

**Brett Kettle** is a PhD student in the Department of Zoology at the James Cook University.





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THE CROWN OF THORNS STARFISH – A special feature of Australian Science Mag