FUTURE PROGRAM DIRECTIONS

The COTSREC and the Authority have used three mechanisms to review COTS research and to recommend on future research directions:

- workshops;
- ad hoc working groups; and
- reviews by individuals with expertise in particular areas.

There have been three major COTSREC workshops (A Geological Perspective on the *Acanthaster* Phenomenon in May 1990; Reproduction, Recruitment and Hydrodynamics in the Crown-of-thorns Phenomenon held in May 1991; The Possible Causes and Consequences of Outbreaks of the Crown-of-thorns Starfish held in June 1992) and four working groups (Geological Working Group; COTS and Water Quality Working Group; Predator Working Group; Massive Coral Working Group).

The COTS Program has four primary objectives:

1. to monitor COTS and their effects on the GBR;
2. to establish the causes of COTS outbreaks and, in particular, to establish the role of human activities in causing or exacerbating them;
3. to develop policy in relation to the COTS issue and advise on appropriate management responses; and
4. to inform the public of the results of COTS research and monitoring of the GBR.

This chapter addresses these objectives and presents new and continued initiatives required to meet them. Specific directions will evolve as the status of COTS populations on the GBR change and as more knowledge is acquired. Many of the objectives are long-term by virtue of the complexity of the issue and the apparent cyclicity of outbreaks. Missed opportunities to study initial causes of outbreaks, for example, may result in delays of up to twenty years (based on the interval between the previous two outbreak episodes).

Monitoring COTS and their effects on the Great Barrier Reef

Three main forms of monitoring have been used to provide information on the distribution of COTS on the GBR:

- Reef-user COTS sighting schemes;
- Broad-scale surveys; and
- Fine-scale COTS surveys.

The Reef-user COTS sighting scheme (COTSWATCH) was originally implemented in the early 1980s because low levels of funding precluded the implementation of formal broad-scale scientific surveys. COTSWATCH has been particularly successful (in terms of questionnaire return rates) over the last two to three years, largely because of efforts to regularly promote the scheme and to disseminate information resulting from responses. Information provided by respondents, although qualitative, was responsible for detecting recent increases in COTS numbers on reefs between Cairns and Cooktown. The scheme has also been successful in providing a platform for keeping the public informed of the status of COTS outbreaks and the results of research.

Future Direction 1: *Because of the success of COTSWATCH in providing detailed site information on COTS abundances and its role in providing a platform for extension activities, the scheme should be continued.*

Annual broad-scale surveys of the GBR have been conducted by AIMS since 1985. Over that time there has been a substantial increase in our understanding of the extent and dynamics of the COTS phenomenon. The surveys have provided information on the origins, patterns and rates of movements of outbreaks as well as the general status of surveyed reefs. Since 1992 the broad-scale surveys have acted as a basis for more detailed monitoring of benthos, fish and water quality at selected sites on around eighty reefs each year.

Results of the broad-scale surveys confirmed the increase in COTS numbers on reefs in the northern GBR detected through the COTSWATCH scheme.

Future Direction 2: *Because of the long-term value of broad-scale surveys, the 'big picture' information they provide, and the basis for more detailed monitoring they serve, these surveys should be continued.*

At the same time there is a critical need for detailed information on COTS population dynamics prior to large-scale outbreaks. Because monitoring programs were not in place before the previous two outbreak episodes, the dynamics leading to such episodes are unknown. Because of increasing numbers of (particularly juvenile) COTS on reefs in the suspected source area of outbreaks on the GBR, fine-scale surveys based on the belt transect method were implemented in 1994-95. These surveys have provided detailed information on the status of COTS populations on mid-shelf reefs in the area, including starfish densities and population structure. With this information it is possible to hindcast the timing and extent of recruitment events and to make projections on likely changes to COTS populations. At even finer scales, detailed studies of COTS populations on particular reefs can provide necessary information on critical parameters such as recruitment, migration and mortality rates. A combination of these three scales of information is critical to understanding the causes of outbreaks and for the development of appropriate management responses. The combination of broad- and fine-scale surveys, as well as local COTS population dynamics studies, provides detailed information for key areas while maintaining the necessary wider perspectives.

Future Direction 3: *The fine-scale surveys of COTS on selected mid-shelf reefs between Cairns and Cooktown and detailed studies of COTS population dynamics on particular reefs should be continued to record the status of reefs in the area and to monitor changes in COTS populations over time.*

The effects of major COTS outbreaks on massive coral communities have been used to support the argument that outbreaks in recent times are novel events or, alternatively, evidence of increased outbreak frequency. A concurrence with increased human activity has led some scientists to conclude that human activities are therefore responsible for outbreaks. Measurements of the effects of outbreaks of different intensities on massive coral communities have recently provided evidence that conflicts with this extrapolation. Further information on the dynamics of massive coral communities before and during outbreaks (on a large number of reefs) is needed to resolve the frequency with which particular communities are affected.

Future Direction 4: *Further monitoring of massive coral communities on a reasonably large number of reefs to provide information on population dynamics before and during outbreaks is needed.*

The Origins and Causes of Outbreaks

Both of the two previous outbreaks and the recent increase in COTS populations originated in the Cairns Section of the GBR Marine Park. While other independent outbreaks have occurred outside of this area on the GBR, this consistency raises the question of whether or not the Cairns Section has some characteristics that pre-dispose it to primary outbreaks. Although some models suggest that the northern origin and southward progression of outbreaks is imposed by coral cover (i.e. food) limitations following the first outbreak, the patchiness of coral mortality and variability in outbreaks weakens this argument.

Future Direction 5: *A desktop study to investigate the possible 'uniqueness' of the Cairns Section of the GBR Marine Park should be conducted to provide insights into why COTS outbreaks are initiated in this area. The study should include the following components:*

- *hydrodynamic characteristics;*
- *geomorphology;*
- *recent history of episodic events that have affected the area (e.g. cyclones and floods);*
- *nutrient sources;*
- *nutrient distribution in space and time;*
- *phytoplankton community composition;*
- *anecdotal information; and*
- *commonalities with other areas that have experienced periodic outbreaks.*

While it is known that two previous outbreaks and the recent increases in COTS populations originated in the Cairns Section, the dynamics leading up to these situations is unknown. Large-scale hydrodynamic models point to an outbreak epicentre behind the Ribbon Reefs at around 16°S, but there is no information on the scale of the epicentre (single reef, reef cluster or larger area). Modelling by Dr Kerry Black of VIMS and the results of the fine-scale surveys suggest that the origin may cover up to two degrees of latitude. Knowledge of the scale is critical in understanding outbreak causality and the spread of outbreaks as well as in developing appropriate management responses.

Future Direction 6: *Genetic studies to determine the degree of connectivity among currently increasing COTS populations in the Cairns Section should be conducted, together with field measurement of hydrodynamic conditions.*

It is likely that outbreaks are caused by a variety of factors, and it is possible that these differ in both space and time. On the GBR many factors contributing to outbreaks may be operating concurrently. The situation is further complicated by the relatively high degree of connectedness between reefs making it difficult to differentiate primary and secondary outbreaks. Knowledge of the status of COTS populations in other areas, together with information on key environmental parameters, could provide useful insights into the causes of outbreaks and the degree of connectivity between geographically spread reef systems.

Future Direction 7: *An international COTS information network should be established to gather and collate details of the status of COTS populations throughout the Indo-Pacific region.*

Acanthaster planci is a very specialised animal, but it shares many of its biological and ecological characteristics with other reef species. For example, many reef species produce planktonic larvae that feed on phytoplankton and settle after similar lengths of time in the plankton to *A. planci*. There are many species (including other species of starfish) that feed on coral. These similarities with other species raises the question of whether or not other species undergo similar substantial population

fluctuations to COTS. It may be that other species do 'outbreak', but because the species have a lower profile than COTS they go unreported, or their significance is not realised. If 'outbreaks' of other species have occurred and coincided with those of *A. planci*, the shared biological/ecological characteristics could shed light on causative factors.

Future Direction 8: *A desktop study to review existing data on recruitment of other coral reef organisms over the past thirty years to determine whether or not 'outbreaks' have occurred.*

From a management perspective it is imperative to determine whether or not there is a connection between human activities and COTS outbreaks. If such a connection exists, managers have a responsibility to attempt to regulate that activity or at least ameliorate its effects.

There is general agreement among scientists and managers that two primary mechanisms for human activities causing or exacerbating COTS outbreaks exist:

- increased survival of COTS larvae through elevated nutrient levels caused by coastal and catchment modification resulting in higher food availability for larvae; and
- over-fishing or over-collecting of predators.

Water Quality

Water quality has been implicated as both a natural and human-influenced cause of COTS outbreaks. In a recent survey of researchers and managers familiar with COTS research, most regarded factors associated with water quality as being the most likely causes of outbreaks.

Gaps in our knowledge identified by working groups, workshops and individual reviews provide the following questions that need to be addressed by research into connections between COTS outbreaks and water quality:

- Has human activity (coastal development, catchment modification etc.) increased nutrient inputs into GBR waters over the last fifty years?

Research to date (e.g. Moss et al. 1992) indicates that there have been three to five fold increases or more in sediment and nutrient exports from Queensland coastal catchments since European settlement. Further research in this area is being conducted through the Authority's Water Quality Program. At this stage there is compelling evidence to answer this question in the affirmative, at least for short-term events. While it is probable that nutrient loadings have been increased through human activities, there is very limited data to substantiate claims by some scientists that levels of nutrients are chronically elevated (e.g. Bell and Elmetri 1995). Short-term increases in nutrients associated with substantial run-off events are probable. Other natural events, such as upwelling of Coral Sea waters, contributes significant amounts of nutrients (phosphorus) to GBR waters in some areas at certain times.

- Does the level of nutrient increase result in increased food supplies for COTS larvae? (i.e. are the right sizes and species of phytoplankton affected?)

Laboratory work by Mr Ken Okaji at the AIMS suggests that increased nutrients favour disproportionate increases in the abundance of nanoplankton (> 2 μm) which is a critical component of larval COTS diets. However, in the field, phytoplankton blooms associated with major run-off events are generally only short-lived (lasting only two to three days) and the levels of nitrogen and phosphorus required to shift phytoplankton community structure is unknown.

Future Direction 9: *Further research is needed to confirm the food sources (in particular the sizes of phytoplankton) and dietary requirements of COTS larvae and to determine whether or not realistic elevated nutrient levels (i.e. those likely to be encountered in GBR waters) positively affect these in the field.*

- Do these increased nutrients (and their effects on food availability) extend to mid-shelf waters where COTS larval 'clouds' occur, and at times when the larvae are likely to be in the water column?

A number of research projects and direct observations of river plumes have confirmed the occasional extension of coastal influences to mid-shelf regions in the northern areas of the GBR. Evidence suggests that rainfall, current and winds affect the cross-shelf extent of river plumes. The timing and frequency of such major run-off events are unpredictable, as are COTS spawning events (although December appears to be the peak of effective spawning activity).

Future Direction 10: *Further research to determine the timing of peak COTS spawning and the environmental triggers responsible for initiating spawning activity is needed.*

Future Direction 11: *Monitoring and modelling (including hindcasting) the offshore extent of river and coastal runoff around COTS spawning times (December - January) as well as continued monitoring in the Cairns Section of the Marine Park to determine spatial and temporal fluctuations in key water quality parameters (including size-fractionated phytoplankton densities) is needed.*

- Does an increase in larval food supply result in significant increases in larval survival, shortening of larval life (which may translate into higher survival through shorter exposure to predation in the plankton) and/or more successful settlement of larvae?

Research by Mr Ken Okaji of AIMS has produced results opposed to earlier work conducted by Dr Randolf Olson who concluded that under normal conditions COTS larvae are unlikely to be food limited (Olson 1987). Additional laboratory experiments and measurement of chlorophyll concentrations in the field indicated that the growth and development of COTS larvae were food-limited under natural conditions. Most successful settlement of COTS larvae generally occurred when mean chlorophyll *a* levels were > 0.5-0.8 $\mu g\ l^{-1}$. Okaji also noted considerable inter-annual variability in development rates and survival of COTS larvae in some experiments.

Future Direction 12: *Further research to establish whether or not larvae are normally food limited in the field is required. Additional studies are needed to establish whether or not short-term increases in food sources significantly enhance COTS larval survival and development.*

Future Direction 13: *Monitoring of size-fractionated chlorophyll concentrations in the suspected source area to assess the probability of COTS larvae encountering favourable conditions (where concentrations exceed the critical levels) should be continued.*

Unsuccessful attempts to rear COTS larvae and juveniles over the last few years have highlighted the inadequate status of knowledge on factors affecting reproduction and larval survival. Factors other than nutrition may play critical roles in larval development, survival and settlement. Information in this area is useful not only for understanding these key processes, but also as a precursor to developing efficient rearing techniques for the production of juveniles necessary for further predation studies.

Future Direction 14: *Further research into factors (other than nutrition) affecting reproduction, larval development, survival and settlement is required.*

- Are outbreaks of COTS the result of enhanced survival of larvae?

There is a substantial difference between larval settlement and recruitment to the population. Small juvenile COTS have been shown to be exposed to intense predation pressure (Keesing and Halford 1992).

Future Direction 15: *Research to establish the relative roles of pre- and post-settlement processes in limiting adult population densities is needed* (see next section on predation).

Results from research in a number of these areas will also provide information on possible connections between water quality and COTS outbreaks in the context of natural causes (e.g. Birkeland's 'terrestrial runoff hypothesis').

Predation

An answer to the question of whether or not human exploitation of the fish predators of COTS has caused or exacerbated recent outbreaks on the GBR requires the resolution of three primary questions:

(1) what are the COTS predators that may have been affected by fishing or collecting?
(2) has fishing or collecting by humans caused a significant decline in the abundance of these predators?
(3) has this reduction caused or exacerbated COTS outbreaks?

A study of the gut contents of putative fish predators of adult COTS on an outbreaking reef failed to find evidence of significant predation on COTS. Predation on juvenile COTS has been measured at one location but problems with rearing juveniles for these experiments resulted in the research being discontinued. As there are good reasons why predation on juvenile COTS should be more significant than at later stages, this work must be repeated when juveniles become available.

Future Direction 16: *Larval and juvenile COTS rearing should be continued with a view to continuing research into predation on juvenile COTS. This research should focus on identifying principal predators and measuring predation rates on juvenile COTS in the field. Predation studies should be initiated as a matter of high priority if substantial populations of small juvenile COTS are detected in the field.*

One problematic area of predation on COTS involves the role of the giant triton (*Charonia tritonis*). Views on the significance of this known predator are diametrically opposed. Although giant tritons are the most frequently observed predator of large juveniles and adults, they are slow in consuming their prey (hence there is more opportunity for observations). Consumption rates of COTS by tritons (based on observations in artificial situations) suggest that they could be a significant predator. Population densities are unknown because of the cryptic nature of the species and their apparent rareness. The impact of collecting tritons from the GBR (prior to the banning of this activity in 1969) on population densities is also unknown. There is some evidence to suggest that tritons are attracted to aggregations of COTS and if this is so, this behaviour could be utilised to improve the cost-effectiveness of triton research.

Future Direction 17: *Research to establish the possible correlation between COTS and triton densities should be conducted when appropriate densities of COTS are located. If sufficient numbers of tritons are found, basic research (population densities, feeding preferences and rates, movements etc.) should be conducted.*

Analysis of historical information to address the question of fishing pressure proved fruitless because of inadequate and confused record keeping. The Authority's Effects of Fishing Program and research being conducted through the CRC Reef Research Centre are currently investigating the effects of line and inter-reef trawl fishing on target species and associated reef communities. Results of this research should provide information relevant to understanding the impacts of fishing on COTS predators in recent times but the historical trends will never be unravelled.

This part of the question hinges on understanding what is a significant reduction in predator densities. On the basis of modelling predation on COTS, Dr Hamish McCallum concluded that it was not possible to establish a minimum level that predation must reach to be of importance in preventing outbreaks. He also concluded that any increase in starfish mortality may decrease the intensity or frequency of outbreaks and any predator capable of increasing mortality by 0.01% per day was important. Such mortality estimates can be tested by experimental manipulations noted above (Direction 11).

Future Direction 18: *Close collaboration between the COTS Program and Effects of Fishing Programs should be maintained to ensure that information derived from research is relevant (where possible) to addressing the question of human impacts on COTS predators.*

Management Responses: Controls and Planning

Recent research into local COTS control techniques found chemicals that were effective in killing starfish but were more environmentally friendly than copper sulphate (the poison previously recommended). The alternative (100% sodium bisulphate or *Dry Acid*) is now being used in locally controlling COTS numbers in some areas of high tourism use on the GBR and overseas. A variety of control strategies based on the injection of poison and removal have been employed in the past. These have ranged from low-level (involving one or two divers) but frequent (daily or weekly) controls through to highly intensive operations (using teams of ten or more divers) months or years apart. The implementation of particular strategies has been based on convenience rather than an appreciation of effectiveness.

Future Direction 19: *Research to determine the most cost-effective strategies for locally controlling COTS outbreaks using injection of sodium bisulphate should be conducted.*

The conduct of effective local controls relies heavily on the early detection of outbreaks and the existence of established plans of action. Monitoring as described above should facilitate achievement of the former objective. A COTS Contingency Plan has been developed to provide guidelines for a rapid response to any future major outbreaks. However, the Plan focuses on the need to establish the extent of suspected outbreaks and aspects of communication between tourism operators and Reef management agencies. It doesn't describe detailed research initiatives required to take advantage of the early detection of outbreaks.

Future Direction 20: *A COTS Research Contingency Plan should be developed to provide a prioritised program of research to be initiated in the event of early detection of outbreaks. Priority should be given to work that needs to be done prior to, during and after outbreaks. Collection of surface sediments should be considered in this context.*

Public Information

The Reef-user survey scheme (COTSWATCH)

The COTSWATCH survey scheme is already proving highly successful. Since November 1993, GBRMPA have received an unprecedented number of completed survey forms. Indeed the Reef-user surveys have been instrumental in identifying the current increase in the number of COTS on some reefs between Cairns and Lizard Island. The feedback given to all contributors through public lectures and presentations as well as through the R&M Section's newsletter *Reef Research* is largely responsible for the high proportion of contributors to the COTSWATCH scheme now reporting their observations on a regular basis. This is particularly encouraging, because this kind of information will potentially provide important long-term data on the dynamics of COTS populations.

Future Direction 21: *Maintenance of the current high level of active promotion of the COTSWATCH scheme is crucial. The provision of training to particular tourist operators and QDEH would assist in the quality of information received and an ability to confirm unusually large populations would be beneficial.* [see #1 also]

Media Component

The COTSREC and the Authority recognise the important role the media plays in forming public opinion on the COTS issue. A comprehensive media strategy aiming to provide a balanced and factually correct view of the COTS phenomenon has been prepared.

Future Direction 22: *The effectiveness of the COTS media strategy should be monitored and modified as circumstances change or if deficiencies are found.*

Educational Materials

The production of quality educational materials for distribution to schools and the general public is a highly desirable yet often expensive means of keeping a potentially large audience informed. Currently available materials (i.e. booklet and video) will need to be updated in the near future.

Future Direction 23: *The production of new updated educational materials may need to be given a fairly high priority, particularly if the status of COTS on the GBR changes in the near future. Any such materials should consider the particular requirements and guidelines of educational institutions as identified during informal discussions with teachers and librarians. This should ensure that a highly professional and effective product is available.*

Displays at Aquaria and Zoos

The development and setting up of modern interactive displays in both aquaria and zoos have the potential of reaching very large audiences. However, development costs are typically very high.

Future Direction 24: *The high costs involved do not allow the Authority to fully fund any such ventures. However, the COTS Program should continue to encourage interested parties to consider development of such displays and offer assistance where appropriate.*

Other Areas

At its November 1993 meeting the COTSREC recommended three additional priority areas for research:

- development of an assay based on the monoclonal antibody technique aimed at field identification of COTS larvae;
- development of scientific standards for testing of hydrodynamic models; and
- modelling of COTS, corals and fish population dynamics and the effects of management action.

The first two of these are currently being addressed by research projects funded through the Program. The COTSREC has recommended a workshop be held to review relevant aspects of population modelling.

Future Direction 25: *A workshop be held to review modelling of COTS and coral interactions; COTS and potential predator population dynamics and coral recovery. The workshop should identify priorities in the area of modelling and information needs.*