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Crown-of-thorns starfish

Condition

The crown-of-thorns starfish is one of only a few animals that feed on living coral tissue. The starfish is named for the dense covering of long, sharp spines on its upper surface. At low densities the crown-of-thorns starfish is a 'normal' part of the reef's ecology. However, when the numbers of crown-of-thorns starfish on a reef increase to the point where they consume coral faster than it can grow, the starfish can dramatically reduce coral cover, resulting in a major disturbance to the whole system (see *Environmental status - corals*). This situation is commonly known as a crown-of-thorns starfish 'outbreak'. Outbreaks of crown-of-thorns starfish have been a concern on the Great Barrier Reef for more than 40 years. Research suggests that the outbreak 'trigger point' is around 30 mature crown-of-thorns starfish per hectare of coral reef that has average levels of coral cover. Once crown-of-thorns starfish densities exceed this threshold, the population will begin to consume coral faster than it can grow and is considered to be an outbreak population.

Patterns of crown-of-thorns outbreaks on the Great Barrier Reef

There have been three recorded series of crown-of-thorns starfish outbreaks on the Great Barrier Reef. However, since underwater exploration of the Great Barrier Reef only began in earnest with the advent of SCUBA equipment, it is possible that previous outbreaks have occurred but have not been recorded. The three observed series of outbreaks have followed the same general pattern, with outbreaks first recorded in the northern section of the Great Barrier Reef near Cairns. Over the following ten to fifteen years, the series of outbreaks slowly moved south with an increasing number of reefs affected by crown-of-thorns starfish outbreaks in successive years. Outbreaks tend to occur on mid-shelf reefs but can also occur on inner and outer shelf reefs. Previous series of outbreaks have dissipated in the Mackay region and outbreaks have not been reported in the Keppel Islands or Capricorn Bunker group reefs in the southern Great Barrier Reef. It is thought that the north to south spread of outbreak series is due to crown-of-thorns starfish larvae being transported from one reef to another by the south flowing East Australian Current.

Crown-of-thorns starfish outbreaks can cause large reductions in coral cover.

There have also been crown-of-thorns starfish outbreaks observed on offshore reefs in the Swains region in the southern Great Barrier Reef. While these outbreaks do not appear to be directly linked to the north-south wave pattern observed in series of outbreaks in the northern Great Barrier Reef, the relationship between the two outbreak patterns is still unclear.

History of crown-of-thorns starfish outbreaks

There are varying amounts of information available on each of the three series of outbreaks, with the most complete monitoring records kept by the Australian Institute of Marine Science Long Term Monitoring Program (AIMS LTMP). A brief account of each outbreak follows, but more detailed accounts are summarised in Moran, 1986, and on the AIMS LTMP website.

1962 to 1976
The first 'outbreak scale' populations of crown-of-thorns starfish to be noticed and described were at Green Island and nearby reefs offshore from Cairns in 1962. By 1970, the series of outbreaks had reached reefs off Townsville, and by the mid 1970's, had spread to reefs in the Whitsunday and Mackay region where it gradually petered out.

1979 to 1991
A second series of outbreaks, starting to the north of Cairns and spreading southwards, occurred between 1979 and 1991 (Moran, 1986; Sweatman *et al*, 1997, 2000, 2001). The second outbreak series affected approximately 17% of the coral reefs in the Great Barrier Reef, with 5% of reefs having severe outbreaks. Approximately 57% of reefs that experienced an outbreak suffered 30% to over 50% coral mortality over at least one-third of their perimeters. On average, this outbreak series caused a 3 to 4 fold increase in the amount of dead coral on affected reefs.

1993 to present
In 1993, the first stages of a third series of outbreaks was detected, once again in the region north of Cairns. Surveys of reefs offshore from Cairns during 1994-95 found that only two out of 27 surveyed reefs (7.4%) had reef-wide outbreaks. However, by 1996-97, seven out of 28 (25%) reefs had reef wide outbreaks, while another thirteen of these reefs had smaller outbreaks over part of their area (spot outbreaks), leaving only eight that were completely free from outbreaks. In addition, the proportion of observed crown-of-thorns starfish that were sexually mature increased every year, suggesting that the series of outbreaks could increase in severity and geographic range.

By 2001-2002, the series of outbreaks had moved further south with numbers of crown-of-thorns starfish decreasing on reefs off Cairns, but increasing in the central Great Barrier Reef. By 2003, the AIMS LTMP and divers conducting crown-of-thorns starfish control programs (see *Response*) were recording the highest numbers of starfish on reefs in the Townsville region. In the most recent surveys (February – March 2004) conducted by the AIMS LTMP, new outbreaks have been detected in the Cape Upstart sector and small numbers of crown-of-thorns starfish (below outbreak levels) have been recorded on two reefs in the Whitsunday sector. These observations represent a rise in the number of crown-of-thorns starfish observed in this sector compared with surveys in the past decade and indicate the continued southward spread of the current series of outbreaks. While there have been isolated, anecdotal reports of localised increases in crown-of-thorns starfish numbers at specific sites in the northern Great Barrier Reef, there are no indications of widespread increase in crown-of-thorns numbers in this region.

The 2003 LTMP surveys showed that 15% of the surveyed reefs had outbreaks of crown-of-thorns starfish. This is higher than the number of reefs affected in the 1988 series, which resulted in widespread declines in coral cover on reefs in the central Great Barrier Reef (Figure 1). An updated list of the reefs with active outbreaks and more information on the north-south outbreak patterns can be found on the AIMS LTMP website.

Recovery from crown-of-thorns starfish outbreaks
While crown-of-thorns starfish outbreaks can cause dramatic declines in coral cover, coral reefs can and do recover from outbreaks. The rate of recovery will depend on factors such as the extent of coral decline, the type of coral remaining, coral larval supply and recruitment, and the influence of subsequent disturbance events such as storms. Affected reefs have been

observed to recover to pre-outbreak levels of coral cover within 10-15 years after the outbreak, although recovery may take longer if slower growing corals have been depleted. For more information about coral reef recovery, see *Environmental status – corals: variation on coral reefs*.

While three series of outbreaks have been documented on the Great Barrier Reef, the absence of historical information on the timing of outbreaks prior to 1960 makes it difficult to assess whether the pattern and intensity of outbreaks has changed (Engelhardt *et al*, 2001). It is also difficult to determine if the length of time between series of outbreaks is changing, which would affect the extent of coral recovery between outbreaks. Nevertheless, if the frequency of outbreaks has increased due to human activities, it is possible that this could lead to a gradual decline in coral abundance and diversity, especially if slower growing corals are consumed, or reef recovery is hampered by events such as coral bleaching or poor water quality. Broad-scale monitoring of the Great Barrier Reef needs to be maintained in order to document the frequency and patterns of crown-of-thorns starfish outbreaks, and detect possible changes in coral condition and community structure (see *Response*).

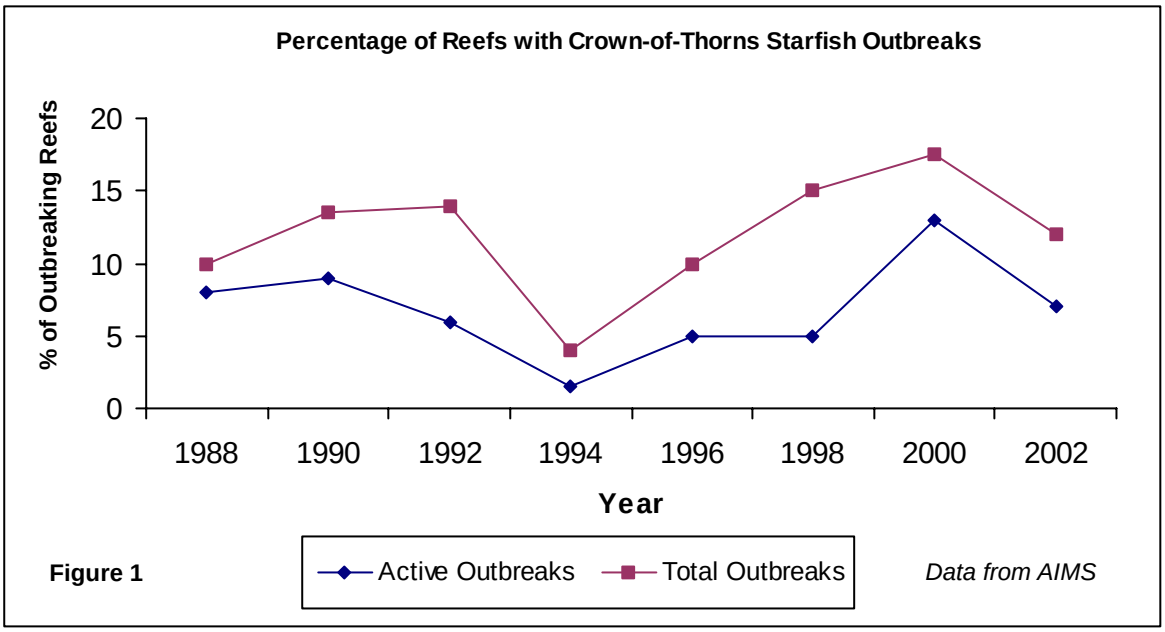

Figure 1

Reproductive characteristics and links to outbreaks

The crown-of-thorns starfish has a very high reproductive capacity. Each female can produce millions of eggs in a breeding season which means that a very small increase in fertilisation success or larval survival rates can result in a great increase in the number of juvenile starfish settling on the reef after the spawning event. As a result, outbreaks can theoretically arise from situations where fertilisation success or larval survival is increased.

Spawning and fertilisation

Crown-of-thorns starfish are dioecious, with males and females reproducing sexually through broadcast spawning with peak spawning activity recorded during December in the central Great Barrier Reef (Babcock and Mundy 1993). The exact timing of spawning is not predictable and spawning has been observed during the day and at night, and at various stages of the tidal and lunar cycles.

As well as producing large numbers of eggs and despite being broadcast spawners, the eggs themselves have high fertilisation rates. Studies have demonstrated fertilisation rates of more than 70% at a distance as great as 8m downstream from a single spawning male and successful fertilisation has been observed between spawning adults up to 100m apart. The large volumes of sperm released by male starfish are the primary cause of the high rates of fertilisation derived from widely spaced individuals. Under natural conditions this means that fertilisation rates can be quite high even though individuals may be spaced quite widely apart.

Crown-of –thorns starfish have a very high reproductive output.

Reproductive output is also related to the availability of food. When there is little food available, adult females reabsorb their body wall and skeletal tissues, which reduces their size, lifespan and overall reproductive capacity (Stump 1993). However, when food is plentiful, females are able to take advantage of the favourable conditions and produce more eggs (Stump 1993).

Larval development

Larval development may be influenced by environmental factors, and small variations in temperature and salinity may have significant effects on larval development and recruitment success (Lucas, 1982; Johnson and Babcock, 1994). This implies that crown-of-thorns starfish populations may be influenced by climatic events. Research has also demonstrated that the survival of crown-of-thorns starfish larvae may be closely linked to the availability of food and thus may be correlated with the amount of phytoplankton in the water (Lucas, 1982).

Spawning, recruitment and outbreaks

Another important factor to consider is whether outbreaks arise from a single spawning event, or the combination of several consecutive spawning seasons. Unfortunately, counting the numbers of crown-of-thorns starfish of a specific size present in a population cannot be used to identify recruitment pulses from previous years as starfish size may be dependant on the quantity and quality of the available food (Stump 1993).

Nevertheless, analysis of annual pigment bands in the starfish spines can be reliably used to determine the age of sexually mature crown-of-thorns starfish (Stump and Lucas 1990; Stump 1993). These studies suggest that outbreaks arise from several consecutive recruitment events and not from one single pulse. Research has also found no evidence of genetic differentiation between age classes present in outbreak populations. This suggests that outbreak populations are derived from one genetic source, with no change in the source of recruits (Benzie and Wakeford, 1997).

Loss of coral cover caused by crown-of thorns starfish may affect other reef organisms, which rely on the coral for a habitat and food.

The crown-of-thorns starfish is an organism that can be viewed from two different perspectives. Firstly, that it is a component of the natural coral reef ecosystem and should be considered using the condition, pressure and response model as it relates to the starfish itself. Secondly, the crown-of-thorns starfish can be considered as a direct pressure on hard corals (because it feeds on them) and an indirect pressure on other reef organisms (such as many fishes and invertebrates) that are reliant on hard corals for food or shelter (see *Environmental status – corals* and *Environmental status – fishes*).

Pressure

Crown-of-thorns starfish outbreaks may be caused by the interaction of many factors, all of which may vary in both space and time. Outbreaks have a significant impact on coral reefs, killing corals, which are subsequently colonised by algae. There may also be flow on effects to other reef organisms, such as obligate coral feeders and animals that rely on the coral structure for food, shelter and nesting. While research has provided important information on the biology of the starfish and the effects of outbreaks on coral reefs, the exact cause of crown-of-thorns starfish is unknown and there are several theories as to why outbreaks occur.

Natural event hypothesis

The natural event theory proposes that series of crown-of-thorns starfish outbreaks are a part of the natural ecological cycle of the reef ecosystem. Crown-of-thorns starfish have a number of unique adaptations that lend themselves to large fluctuations in numbers (i.e. they are predisposed to form outbreaks). These are:

- A high fecundity: an average female crown-of-thorns starfish produces 12-24 million eggs (a single large individual can produce up to 60 million eggs)
- A larval dispersal phase that enables crown-of-thorns starfish to "migrate" from their natal reef via prevailing water currents
- Rapid growth reaching reproductive maturity within two years of settling on a reef
- No equivalent coral predator, freeing crown-of-thorns starfish from inter-specific competition
- A large stomach that allows crown-of-thorns starfish to feed on an abundant high energy food source
- A preference for feeding on relatively fast growing *Acropora spp.* corals
- Relatively long-lived (probably more than 8 years) allowing successive breeding seasons over a number of years.

Protection of corals by crabs:

A study by Pratchett et al. (2000) has found that the presence of small crabs within coral colonies may defend the coral against the crown-of-thorns starfish. Crabs of the genera *Trapezia* and *Tetralia* (Family Trapeziidae) are often associated with hard corals. Trapezia crabs occupy pocilloporid corals and defend the coral by attacking the spines of the starfish by breaking them at the base. Crabs of the genus *Tetralia* occupy only Acropora corals and protect the coral by attacking the tube feet of the starfish.

Experiments also showed that corals that had the crabs removed were eaten by crown-of-thorns starfish. In contrast, the crown-of-thorns starfish avoided all pocilloporid corals with *Trapezia* crabs in them. However the acroporid corals with the *Tetralia* crabs in them were still eaten, suggesting that the presence of crabs is not a complete defence.

Photo by P.Parks

The natural event theory proposes that at certain times, when environmental conditions become favourable, the naturally high reproductive capacity of the animal allows the crown-of-thorns starfish to capitalise on these conditions and produce especially large numbers of juveniles that results in an outbreak. There is some geological evidence to suggest that crown-of-thorns starfish have been present on the Great Barrier Reef for the last 3000 to 7000 years, and some historical records imply that large numbers of the starfish have been seen in the past. However, as with most aspects of the crown-of-thorns starfish issue, this evidence is not unequivocal and there are those who disagree with the conclusions drawn from it. Alternative hypotheses propose that human activities are responsible for at least making outbreaks worse and/or more frequent, if not actually causing them. These hypotheses are described below.

Larval survival hypothesis

The larval survival hypothesis is based on the principle that a small increase in the survival rate of crown-of-thorns starfish larvae can result in a massive influx of juvenile starfish on 'downstream' reefs. It is proposed that increased runoff of nutrients from coastal areas causes coastal waters to become nutrient rich, resulting in a phytoplankton bloom that provides more food for crown-of-thorns larvae. This increases larval survival rates that subsequently cause outbreaks to develop (see Moran 1988 for review).

Recent research indicates that changing land use patterns have caused nutrient availability to increase in the Great Barrier Reef lagoon (see *Environmental status – water quality*). These studies also suggest that the parts of the Great Barrier Reef that are exposed to agricultural terrestrial runoff have Chlorophyll levels (an index of the amount of phytoplankton present) 2.04 times higher than 'pristine' areas. Laboratory studies have demonstrated the link between increased phytoplankton abundance and increased larval survival, with experiments showing that doubling the concentration of phytoplankton results in an almost ten-fold increase in larval development, growth and survival (De'ath *et al*, 2004). Computer model simulations using these data produced outbreak patterns similar to those observed on the Great Barrier Reef. Considered together, these lines of evidence provide compelling evidence that declining water quality, and the associated rise in Chlorophyll levels, can lead to an increase in the frequency and severity of outbreaks of the crown-of-thorns starfish on the Great Barrier Reef (De'ath *et al*, 2004).

Predator removal hypothesis

The predator removal hypothesis proposes that fishing and shell collecting have led to decreased numbers of predators of the crown-of-thorns starfish, thereby allowing starfish populations to increase beyond natural levels. A few predators such as the giant triton snail, humphead Maori wrasse, sweetlip emperor and starry puffer fish feed to some extent on crown-of-thorns starfish. However none of these predators appear to feed exclusively on the starfish, and predation rates of many of these species on crown-of-thorns starfish are unknown.

Predators of the crown-of-thorns starfish, from left to right: humphead Maori wrasse, Giant Triton snail, sweetlip emperor and starry puffer fish

Predation by the giant triton
Several studies have been conducted on the role of the giant triton as a crown-of-thorns starfish predator. Field studies suggest that on average, the giant triton consumes less than one starfish a week (Pearson and Endean, 1969). Other studies indicate that attacks by giant tritons on crown-of-thorns starfish are not always successful, with the starfish escaping and regenerating damaged body parts. Generally speaking, the predation rate of giant triton on the crown-of-thorns starfish is very low, and given the reproductive capacity of the crown-of-thorns starfish and the sheer number of starfish present in outbreak populations, it seems unlikely that predation by giant triton could exert sufficient pressure to regulate crown-of-thorns starfish populations.

Predation by fishes
Juvenile crown-of-thorns starfish are more prone to predation as they have less developed spines and external armour. Field studies have shown that juvenile starfish are preyed upon by a variety of benthic organisms including crabs, shrimp and fish (Keesing and Halford 1992). A study by Sweatman (1995) placed laboratory reared juvenile crown-of-thorns starfish on small habitat units in a reef lagoon to test whether commercially exploited fishes could regulate populations. Predator exclusion experiments revealed that losses were low and that there was no statistically significant difference between the number of starfish in units accessible to predators and units where predators were excluded. Juvenile starfish were then presented to emperor fish at two reefs. Only thirteen percent of juvenile crown-of-thorns starfish presented at one reef were eaten. Nevertheless, these experiments were limited to a small number of reefs and there are no studies that have addressed the role of fishes in controlling crown-of-thorns starfish during pre-outbreak conditions.

The starry puffer fish is one of the few species known to feed on adult crown-of-thorns starfish.
Photo courtesy of Reef Monitoring Services

While there is currently insufficient evidence to definitively state that fishes play a major role in regulating crown-of-thorns starfish numbers, this possibility cannot be discounted.

While there is information to support each of the above hypotheses, there is currently no scientific consensus as to which is the most likely or plausible. Emerging evidence appears to support the larval survival hypotheses over the alternatives, however this research requires further scrutiny and review by the scientific community. In the meantime, the causes and factors giving rise to crown-of-thorns starfish outbreaks remain unresolved.

Response

The Great Barrier Reef Marine Park Authority's (GBRMPA) approach to the management of crown-of-thorns starfish on the Great Barrier Reef is to address the human activities that potentially cause or exacerbate outbreaks, rather than attempting widespread eradication of populations of the species. This is preferable for a number of reasons:

- The human activities most likely to lead to crown-of-thorns starfish outbreaks (declining water quality leading to increased larval survival and/or over-fishing which reduces numbers of starfish predators) constitute significant threats to the Great Barrier Reef in their own right, and need to be addressed irrespective of their potential roles in crown-of-

thorns starfish outbreaks (see *Environmental status – water quality* and *Environmental status – fishes*).

- Widescale eradication is difficult to justify in the absence of definitive information about the extent to which crown-of-thorns starfish outbreaks are natural events or induced by human pressures.
- While localised controls at select sites can be successful, previous attempts to eradicate outbreak populations at reef-wide scales have been largely unsuccessful, in that they were unable to remove enough starfish to prevent further coral damage from occurring. Large-scale eradication programs also proved too costly and labour intensive to sustain.

Response: crown-of-thorns starfish control at key sites

While the GBRMPA does not support the widespread eradication of the crown-of-thorns starfish, the GBRMPA grants permits for localised, small scale crown-of-thorns starfish control programs at key tourism or research sites. These programs are restricted to specific parts of a reef where consistent control efforts may keep the area relatively free from crown-of-thorns starfish. Considerable research has been conducted on the most effective methods for localised crown-of-thorns starfish control (see box: *Controlling crown-of-thorns starfish*). Experiments have shown that sodium bisulphate (also known as 'dry acid') is an effective, environmentally acceptable chemical that can be used to kill crown-of-thorns starfish on a local scale. It is biodegradable and does not affect other plants and animals on the reef. The chemical is applied by direct injection into the tissues of the crown-of-thorns starfish.

While widespread eradication programs are not supported, the GBRMPA issues permits to tourism operators to conduct localised control programs at key sites

Recognising the value of the tourism industry and the extent of the damage at key tourism sites that has occurred during the current outbreak, the Australian Government has provided funding to support crown-of-thorns starfish control programs at key tourism sites. A total of $2.4 million has been committed to starfish control from 2002 to 2007. The funds are used by the Association of Marine Park Tourism Operators to supply vessels and divers to supplement crown-of-thorns starfish control programs run by

Controlling crown-of-thorns starfish:

At specific high value sites, tourism operators may apply to the GBRMPA for a permit to control crown-of-thorns starfish at their site. The recommended control technique includes the use of:

- trained divers to inject the starfish with sodium bisulphate solution;
- sodium bisulphate or 'dry acid', which is widely available, inexpensive, and breaks down in seawater to completely benign components; and
- injector guns ('drench guns' commonly used by the pastoral industry) to inject the starfish with dry acid.

Click here for more information on controlling crown-of-thorns starfish

Cutting up starfish into a number of pieces was one of the first control methods attempted. However, this method is controversial as there are concerns that starfish are able to regenerate from fragments and subsequently, this increases starfish numbers. While regeneration of entire starfish seems unlikely, a significant drawback to this method is that the starfish have to be extracted form the coral. This often results in physical damage to the coral as the starfish can be entwined around branches and wedged into small crevices. Over time, divers were also found to become increasingly sensitive to the toxin in the starfish spines and could become quite ill if accidentally 'spiked' while handling the starfish. Consequently, cutting is not a preferred control option.

individual tourism operators at key sites. By December 2003, divers involved in the program had removed some 48,000 starfish across 51 reefs and had helped to significantly reduce starfish numbers at key sites.

Response: research and monitoring

Without a clear understanding of the exact causes behind crown-of-thorns starfish outbreaks it is especially important to monitor the dynamics of crown-of-thorns starfish populations and their effects on the Great Barrier Reef. This will provide more information on outbreak patterns and the environmental factors associated with outbreaks. Over the last ten years, there have been two major monitoring programs of crown-of-thorns starfish populations.

Broadscale surveys are carried out by the AIMS LTMP on some 100 reefs every year, using observers towed on manta boards and scuba divers surveying permanent transects. The LTMP is designed to detect broadscale ecological changes on coral reefs across the entire Great Barrier Reef, and provides information about the extent of crown-of-thorns starfish outbreaks, effects on coral cover and subsequent reef recovery. These surveys have been carried out every year since 1985-86 on reefs spread throughout the Great Barrier Reef Marine Park (GBRMP).

Fine-scale surveys have also been carried out by the Cooperative Research Centre for the Great Barrier Reef World Heritage Area (CRC Reef). These intensive surveys use scuba divers to closely inspect the reef surface, allowing detection of much smaller sizes and numbers of crown-of-thorns starfish than the broadscale surveys. These surveys provided detailed information that could potentially be used to predict future outbreaks. Fine-scale surveys were carried out between 1994-1995 and 2000-2001, but have been restricted to reefs off Cairns, Lizard Island and Townsville.

Response: addressing the possible causes of outbreaks

While there is no consensus as to the cause of crown-of-thorns starfish outbreaks, the larval survival and predator removal theories provide some evidence of links between human activities and crown-of-thorns starfish outbreaks. If outbreaks are indeed caused or exacerbated by human activities, the most effective strategy to address the issue is to directly address those activities suspected of contributing to outbreaks. The two most plausible theories linking human activities to crown-of-thorns starfish outbreaks involve the over-fishing of predators, and nutrient runoff into the Great Barrier Reef. Both fishing pressure and declining water quality are significant issues for the Great Barrier Reef Marine Park regardless of the potential linkages with crown-of-thorns starfish outbreaks, and are currently being addressed.

Reducing overfishing

The giant triton is a protected species under the *Great Barrier Reef Marine Park Act (1975)* and collection of this species is prohibited. Fisheries management is the responsibility of the Queensland Department of Primary Industries and Fisheries. In December 2003, the Queensland government's *Coral Reef Finfish Management Plan* came into effect which included measures to reduce commercial fishing effort, introduced revised size and bag limits for a suite of fish species and listed species such as the Maori wrasse as protected species. For more information, see *Environmental status - Fishes* and *Management status: Fisheries*.

Addressing declining water quality

In October 2003, the Queensland and Australian Governments released the *Reef Water Quality Protection Plan*, which aims to halt and reverse declining water quality in the Great Barrier Reef within ten years. This includes measures to address land use practices and the runoff of sediment, nutrients and pollution into the Great Barrier Reef from coastal areas. For more information on water quality and the *Reef Water Quality Protection Plan*, see *Environmental status - Water quality*.

Protecting biodiversity and ecosystem function

The GBRMPA has recently rezoned the Great Barrier Reef Marine Park through the Representative Areas Program. The program is designed to provide the various habitat types of the Great Barrier Reef with adequate levels of protection to maintain ecological balance and preserve biodiversity. This will help to ensure that habitats such as coral reefs are able to recover from major disturbance events such as crown-of-thorns starfish outbreaks. The new *Great Barrier Reef Marine Park Zoning Plan 2003* came into effect on 1 July 2004. More information on the scientific basis for the Representative Areas Program, and the rezoning of the Great Barrier Reef can be found at:

- http://www.gbrmpa.gov.au/corp_site/management/zoning/index.html
- http://www.gbrmpa.gov.au/corp_site/key_issues/conservation/rep_areas/index.html

Summary

- Crown-of-thorns starfish outbreaks cause significant disturbance to coral reefs over a wide geographic area.
- It is possible that the observed frequency of crown-of-thorns starfish outbreaks could have a long term detrimental effect on the abundance and community dynamics of corals on the Great Barrier Reef, especially when considering the effects of other major pressures, such as coral bleaching and declining water quality.
- At present, the Great Barrier Reef is experiencing its third major series of outbreaks, which is following a similar pattern to that recorded during the previous two series of outbreaks.
- Despite considerable scientific research, the cause of crown-of-thorns starfish outbreaks and the role of human activities as a causal factor are still uncertain.
- The two most plausible linkages between outbreaks and human activities involve the removal of predators and declining water quality. Recent research has provided additional evidence that increased nutrient runoff from coastal areas is linked to outbreak events.
- Irrespective of their role in crown-of-thorns starfish outbreaks, over-fishing and declining water quality are major issues for the Great Barrier Reef. These issues are currently being addressed via the *Reef Water Quality Protection Plan*, new fisheries management initiatives and the *GBRMP Zoning Plan 2003*.
- The widespread eradication of crown-of-thorns starfish outbreaks is not supported, nor does it appear to be technically feasible. However the GBRMPA grants permits for localised starfish control activities at key tourism and research sites, and the Australian Government has provided a significant amount of funding to aid control programs undertaken by the tourism industry.
- The GBRMPA is involved in research and monitoring programs to assess the extent and intensity of outbreaks, and provides advice on crown-of-thorns starfish control measures.

Further Reading

About the crown-of-thorns starfish

- Crown-of-thorns starfish (general information)
- CRC Reef Brochure: Crown-of-thorns starfish on the Great Barrier Reef: Current state of knowledge November 2003 (revised edition).
- AIMS Reef Monitoring website: Reef Issues: crown-of-thorns starfish
- Reef ED, Great Barrier Reef Explorer: *Crown-of-thorns starfish*

Publications:

- *Crown-of-thorns starfish: questions and answers*
- GBRMPA workshop series and technical publications (including crown-of-thorns starfish)
- Publications by the CRC Reef (including crown-of-thorns starfish)

Recommended reading

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