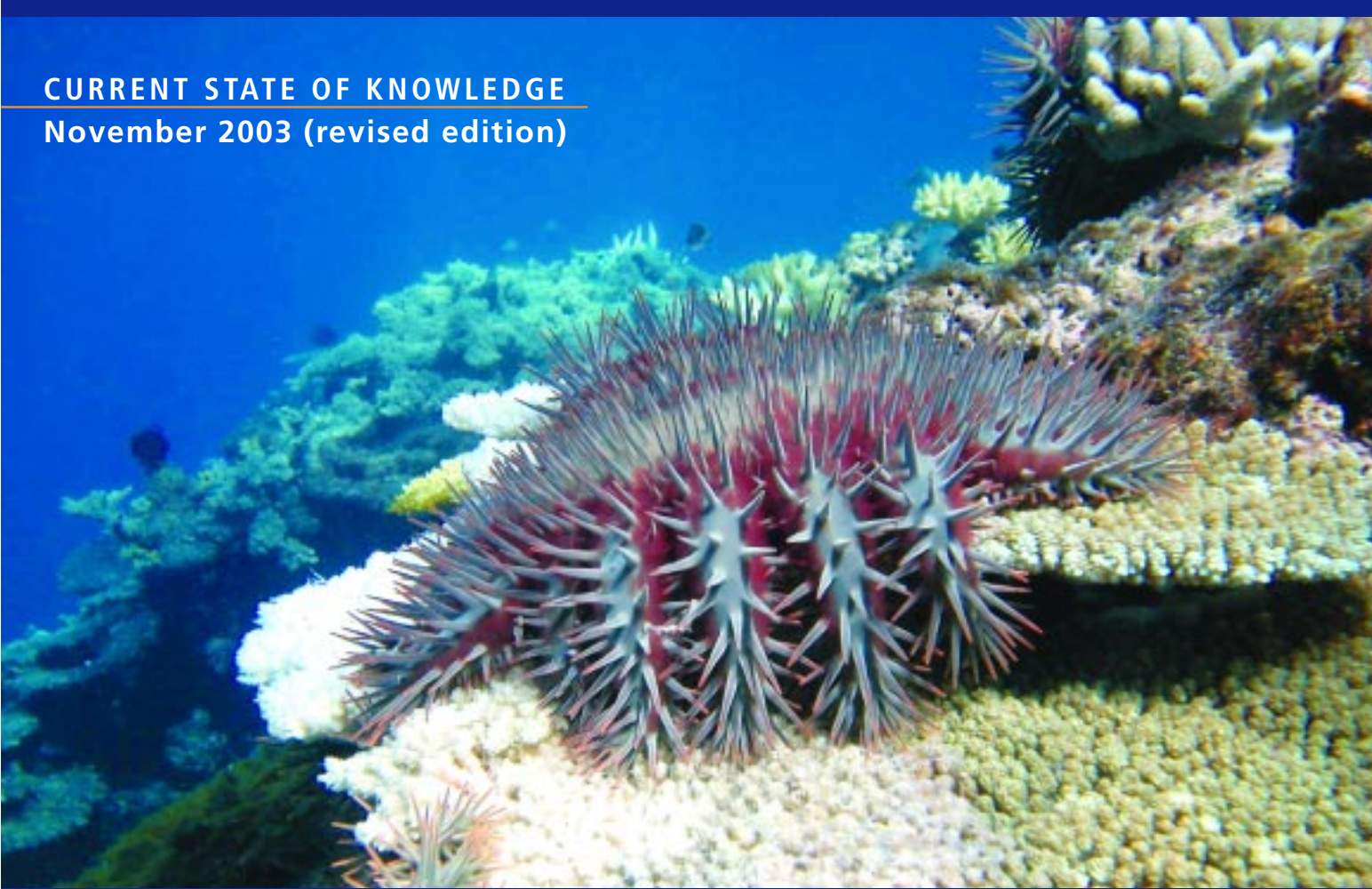


Crown-of-thorns starfish

on the Great Barrier Reef

CURRENT STATE OF KNOWLEDGE

November 2003 (revised edition)



Outbreaks of crown-of-thorns starfish *Acanthaster planci* have been a major issue on the Great Barrier Reef and other Indo-Pacific reefs for nearly 40 years. The outbreaks have generated great concern among the community and considerable debate among scientists.

Outbreaks generally occur at regular intervals with coral cover returning to pre-outbreak levels in the intervening years. In 2003, there is an outbreak on reefs between Cairns and the Whitsundays which is costing tourism

operators, and the Queensland and Commonwealth Governments about \$3 million a year for control measures.

Despite more than 30 years of research on this very complex problem, and the commitment of millions of dollars on research over the last 17 years, the ultimate causes of the outbreaks are still not clear. However, there is now a much greater understanding of the biology of the starfish, the nature of the outbreaks, and the pattern of recovery of the reefs.

Biology of crown-of-thorns starfish

The crown-of-thorns starfish is an unusually large starfish and can grow to more than 1 m in diameter. It has up to 21 arms, with the entire upper surface of its body covered in long venomous spines. The starfish can move up to 20 m in an hour.

Breeding

Crown-of-thorns starfish spawn from December to April when water temperature is about 28°C. The starfish release eggs and sperm into the water through pores on the top of their central disc. When the eggs are fertilised, they develop into larvae which spend from two to four weeks drifting as plankton in ocean currents. The juveniles settle (or recruit) onto the reef when they are about 1-2 mm across. They live among rocks and rubble on the reef and are almost invisible until they are about six months old.

A crown-of-thorns starfish first breeds when it is 2-3 years old and breeds for five to seven years. Each female can produce up to 60 million eggs during a single spawning season. The starfish tend to gather together to spawn which increases the chance of fertilising the eggs. Indeed, fertilisation rates in the field for crown-of-thorns starfish are the highest measured for any invertebrate. Therefore, a small population of crown-of-thorns starfish could potentially produce a very large number of offspring.

Feeding and growth

Young crown-of-thorns starfish eat encrusting (coralline) algae which are common among rocks and rubble on the reef. At about six months of age, they start to eat coral and begin to grow more rapidly. During the next two years, the starfish grow from about 1 cm to about 25 cm in diameter.

Crown-of-thorns starfish spend about half their time feeding. When there are few crown-of-thorns starfish, they are very cryptic and tend to hide in the reef and under corals during the day. Larger starfish (more than 40 cm) usually feed during the day while smaller starfish (less than 20 cm) usually feed at night. Crown-of-thorns starfish feed mainly on tabular coral species particularly *Acropora* spp. and may only eat a portion of the entire coral colony. As a result, the reef can recover quite rapidly from low levels of predation by crown-of-thorns starfish. Some reefs seem to support small populations of crown-of-thorns starfish for many years, with only a small reduction in coral cover. Scientists estimate that a healthy coral reef with about 40-50% coral cover can support about 20-30 crown-of-thorns starfish per hectare (10,000 square metres).

But when starfish are in large numbers, there is intense competition for food and most types of corals will be eaten, including species such as *Porites* spp. that are not usually eaten by the starfish. During a severe outbreak, there can be many crown-of-thorns starfish per square metre, even piling on top of each other. They can eat so much that they can kill most of the living coral in that part of the reef, reducing hard coral cover from the usual 25 - 40% of the reef surface to less than 1%. Such a reef can take 10 years or more to recover its coral cover. Results from fine-scale surveys indicate that coral cover of more than 10% is needed for juvenile starfish to survive and grow.

History of crown-of-thorns starfish outbreaks

Spicules from crown-of-thorns starfish skeletons have been found in old reef sediments which suggests that starfish have occurred on the Great Barrier Reef during the past 3,000 to 7,000 years. However, because the sediments become mixed over time and the spicules are difficult to date accurately, it is unclear whether starfish outbreaks are a new phenomenon or not.



Photo by Vicki Harriott

Crown-of-thorns starfish are one of the few starfish that eat living coral.

The first documented case of large numbers of crown-of-thorns starfish on the Great Barrier Reef was at Green Island off Cairns in 1962. It is possible that starfish outbreaks are more likely to be noticed now than in the past because of increased tourism and the popularity of SCUBA diving.

Starfish outbreaks generally have started in the north of the Great Barrier Reef and moved southward. This pattern is believed to result from the starfish larvae being carried with the southerly flowing ocean currents in the area. For example, reefs off Townsville were affected in 1970 and by the mid-1970s, the starfish had reached reefs north of the Whitsundays, more than 300 km further south. This southward progression of outbreaks has been a consistent pattern in subsequent events in the Great Barrier Reef.

During the first outbreak in the 1960s, only a few reefs in each region carried large populations of crown-of-thorns starfish. As with the following outbreaks, mid-shelf reefs were the most likely to be affected. On some reefs, only sections around the perimeter were affected. This outbreak on the Great Barrier Reef ended about 1975, with subsequent good recovery of corals on most of the affected reefs.



Photo by GBRMPA

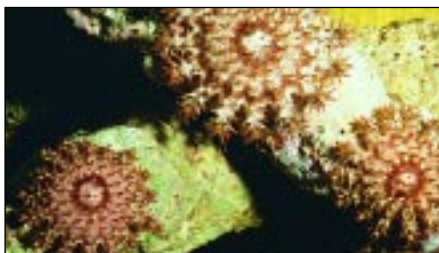


Photo by GBRMPA

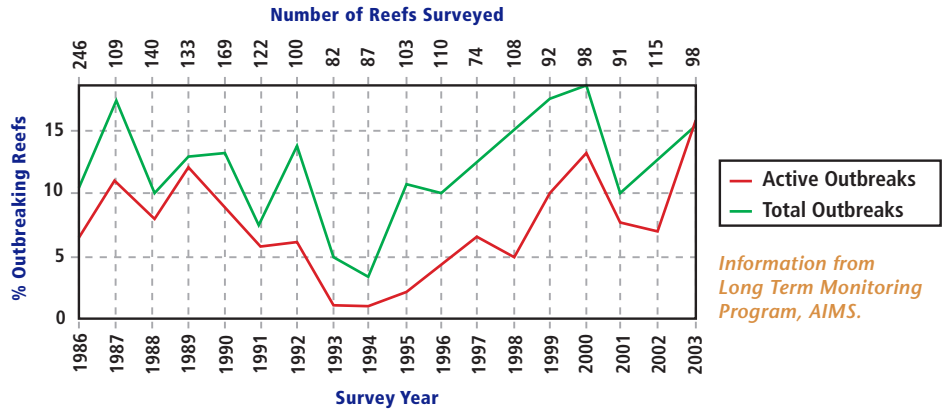
Young crown-of-thorns starfish feed on coralline algae.

A new outbreak was recorded in 1979, again starting in the Green Island region. Large *Porites* corals that were metres across and hundreds of years old, were eaten by the starfish, even though this type of coral is not usually preferred as food. Once again, this outbreak took about a decade to move south to the Swains Reefs, but largely missing the Whitsunday and Pompey regions. About 17% of reefs were affected by crown-of-thorns starfish during this outbreak.

In 1994, about 15 years after the start of the previous outbreak, large numbers of crown-of-thorns starfish were found in the Cooktown region. As expected, this was followed by reports of large populations further south along the Great Barrier Reef. By 2003, the highest densities of starfish were recorded in the area northeast of Townsville.

There have been persistent outbreaks on reefs in the Swains area. These starfish populations are genetically similar to northern populations but do not follow the pattern of southward spread of crown-of-thorns starfish outbreaks. In 2002-03, four of the seven reefs surveyed in the Swains sector by the Long-Term Monitoring Program had active outbreaks.

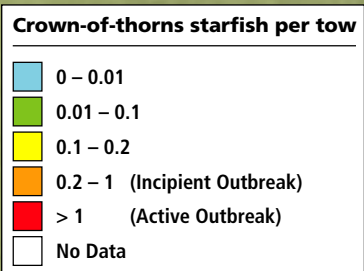
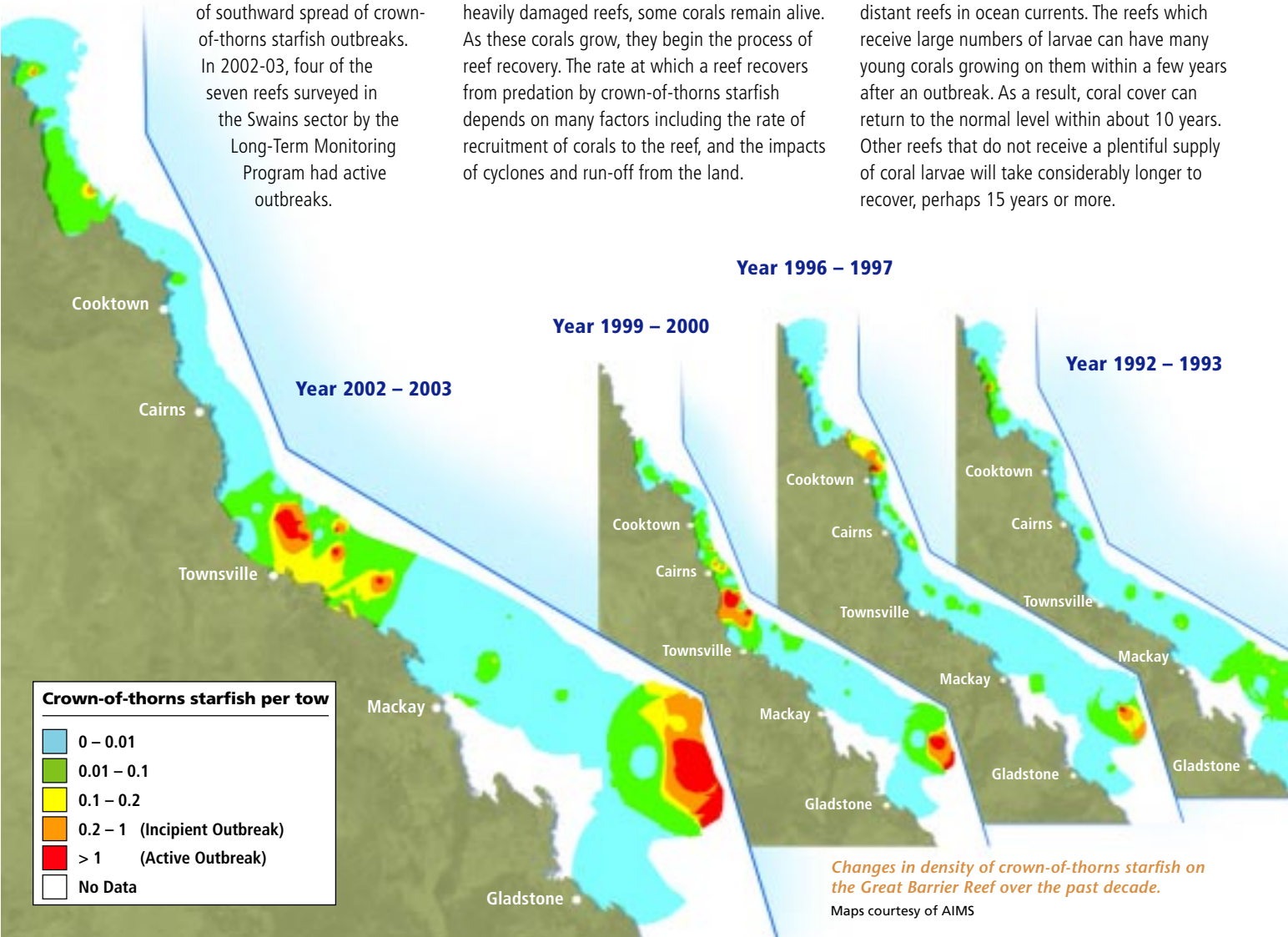
Percentage of reefs with crown-of-thorns starfish outbreaks



Recovery of reefs from crown-of-thorns starfish outbreaks

Coral reefs recover from outbreaks of crown-of-thorns starfish in a similar way to their recovery from other impacts that reduce coral cover, such as cyclones or coral bleaching. Even on the most heavily damaged reefs, some corals remain alive. As these corals grow, they begin the process of reef recovery. The rate at which a reef recovers from predation by crown-of-thorns starfish depends on many factors including the rate of recruitment of corals to the reef, and the impacts of cyclones and run-off from the land.

Many coral species spawn only once a year in a mass spawning in spring or early summer (October to December). Eggs and sperm are released into the water where they combine and eggs are fertilised. Coral larvae can be carried long distances from the parent colonies by currents and tides. Recent research has shown that some reefs are more likely than others to receive large numbers of coral larvae from distant reefs in ocean currents. The reefs which receive large numbers of larvae can have many young corals growing on them within a few years after an outbreak. As a result, coral cover can return to the normal level within about 10 years. Other reefs that do not receive a plentiful supply of coral larvae will take considerably longer to recover, perhaps 15 years or more.



Changes in density of crown-of-thorns starfish on the Great Barrier Reef over the past decade. Maps courtesy of AIMS



A diver using a manta board is towed behind a small boat to survey a reef for crown-of-thorns starfish.

Although coral cover on an individual reef can reach levels that are considered normal on the Great Barrier Reef, the same combination of coral species may not be present as existed before the outbreak. Some species appear quickly after a reef is damaged and grow rapidly. Other species are slower to appear and slower growing. These corals may not reach previous levels on the reefs for some decades. This change in species diversity is one of the concerns if the interval between outbreaks becomes shorter than the time required for the coral community to completely recover. In this situation, reefs might lose some biodiversity and be dominated by a small number of those coral species that can recover rapidly.

What causes outbreaks of crown-of-thorns starfish?

While there have been many theories on the causes of outbreaks of the crown-of-thorns starfish, there are three theories that are supported by scientists. These theories have neither been proved nor disproved. The theories are:

- Fluctuations in crown-of-thorns starfish population are a natural phenomenon.
- Removal of natural predators of the crown-of-thorns starfish has allowed populations to expand.
- Human use of the coastal zone has increased the nutrients flowing to the sea and resulted in an increase in planktonic food for larvae of crown-of-thorns starfish. The improved survival of larvae has led to an increase in the number of adult starfish which results in outbreaks.

Natural fluctuations

Like many marine invertebrates, crown-of-thorns starfish produce large numbers of eggs - potentially 1,000 million eggs in the lifetime of a single female. Fluctuations in the environment can change the survival rate of the larvae. If larval survival is improved from one larva in 100 million, to one larva in 10 million, there would be a 10-fold increase in the population of crown-of-thorns starfish within one generation. Once there is a small increase in the starfish population, the success of subsequent spawning aggregations would ensure that even more larvae could survive in successive generations.

Natural fluctuations in temperature, salinity or availability of planktonic food could all contribute to improving the survival of crown-of-thorns starfish larvae. There has been some suggestion that outbreaks of the crown-of-thorns starfish are linked to the timing of the El Niño-Southern Oscillation (ENSO) system which can cause dramatic shifts in local climate around the Pacific Ocean.

Removal of predators

Although crown-of-thorns starfish have few predators, one theory suggests that they play an important role in keeping starfish populations in check. Predators of adult crown-of-thorns starfish include the giant triton snail, the humphead maori wrasse, starry pufferfish and titan triggerfish.



The giant triton snail is one of the few predators of adult crown-of-thorns starfish.

The giant triton snail was highly prized and heavily collected prior to its protection in 1969. Numbers of triton snails on the Reef remain low. However, the triton shell can eat only about one crown-of-thorns starfish per week so its capacity to prevent starfish outbreaks seems limited.

Humphead maori wrasse are reputed to be active crown-of-thorns starfish predators. Whilst maori wrasse have historically been taken in the Great Barrier Reef line fishery – and more recently in the live fish fishery – from December 2003, it became illegal under Queensland fisheries legislation to fish for, or keep this species.

Predation by other reef fish on juvenile starfish might also limit crown-of-thorns starfish populations. Juvenile starfish are most likely to be eaten by fish about six months after settling when they start to feed on coral. If numbers of the predator fish were depleted by fishing activities this might allow an abnormally large number of starfish to survive to maturity. There is no substantial evidence at this time to show that commercially exploited fish eat significant numbers of juvenile crown-of-thorns starfish.

Because the numbers of starfish larvae that usually survive and then settle is unknown and it is difficult to estimate feeding rates of predators in the field, it is unclear what is the minimum predation rate that would be needed to prevent outbreaks.

Human influence on water quality

Many reports from around the world have suggested that there is a relationship between periods of high rainfall and the beginning of crown-of-thorns starfish outbreaks. Periods of high rainfall after drought or extended dry periods cause water with low salinity, high sediment and high nutrient loads to be washed into the waters of the Great Barrier Reef.

High nutrient levels can cause an increase in microscopic algae in the water, providing food for the developing crown-of-thorns starfish larvae. This can increase the number of larvae that survive and lead to larger adult starfish populations. Low salinity also increases the survival of crown-of-thorns starfish larvae.

Therefore, flood events could be a natural cause of outbreaks. However, the amount of nutrients reaching the Great Barrier Reef lagoon from the adjacent rivers has increased several-fold since European settlement. This increased nutrient load could improve survival of larvae which could possibly cause outbreaks or increase the frequency or intensity of outbreaks. Recent mathematical models that mimic a 10-fold increase in larval survival shows that this would lead to more frequent outbreaks of crown-of-thorns starfish over 200 years.

Managing crown-of-thorns starfish outbreaks

Crown-of-thorns starfish are a natural part of the Great Barrier Reef ecosystem. Outbreaks of the starfish may also be a natural part of the reef ecosystem. So, even if it were possible to eliminate crown-of-thorns starfish, would it be appropriate?

To develop the best control measures, it is important to understand the distribution of crown-of-thorns starfish. Therefore, the Great Barrier Reef Marine Park Authority (GBRMPA) has supported the development of several survey techniques to monitor starfish distribution and numbers (see Survey Methods on next page).

There are few options to manage outbreaks of crown-of-thorns starfish. Several techniques have been developed to control starfish numbers. However, they are labour-intensive and expensive, and are only practical in small areas, for example, areas that are visited frequently by tourists who expect a high cover of hard coral.

Some human influences, such as overfishing and poor water quality, have been suggested as playing a role in crown-of-thorns outbreaks. Regardless of whether such factors cause outbreaks, they are already being addressed by management responses because they are important issues in the Great Barrier Reef.



Photo by AIMS

During a severe outbreak, crown-of-thorns starfish can be so dense they pile on top of each other.

Controlling crown-of-thorns starfish populations

Natural controls

Natural controls on starfish populations include high mortality of the larvae, predation of small starfish and diseases. Adult starfish have few predators because of their tough and toxic 'skin' and long spines. There is little evidence of any major diseases in crown-of-thorns starfish.

Other control methods

Considerable effort has gone into developing methods to control large numbers of crown-of-thorns starfish in small areas by the Great Barrier Reef Marine Park Authority (GBRMPA), CRC Reef researchers and the marine tourism industry.

It is impossible to eradicate crown-of-thorns starfish from reefs where they are in outbreak densities. However, with sufficient effort, small areas can be protected. Because starfish can quickly move from one area to another, control of a specific area must be an ongoing effort and may be required on a daily basis.

The recommended control method involves trained divers injecting sodium bisulfate (dry acid) solution into the starfish, which kills them within a few days. This chemical is non-toxic to other marine life.



Photo by GBRMPA

Crown-of-thorns starfish are killed by injecting with sodium bisulfate solution.

This control method is extremely costly. Some tourism operators in the Cairns region spend up to \$300,000 each per year in crown-of-thorns starfish control. During active outbreaks, operators may need to inject 200 to 500 starfish every day in an effort to keep selected sites free of starfish. In 2001, the Commonwealth and Queensland Governments committed \$2 million to a two-year, industry-run crown-of-thorns starfish control program that services the Cairns, Townsville and Whitsunday areas. This program is supported by the Great Barrier Reef Research Foundation.

Future research

Scientists will continue to search for the cause or causes of crown-of-thorns starfish outbreaks. They will also:

- Continue to monitor crown-of-thorns populations.
- Investigate links between terrestrial run-off and crown-of-thorns starfish outbreaks.
- Investigate more cost-effective methods to control crown-of-thorns starfish.



Photo by David Wachenfeld, Triggerfish Images

Crown-of-thorns starfish can grow to 1 m in diameter.

Survey methods for crown-of-thorns starfish

The distribution of crown-of-thorns starfish on the Great Barrier Reef has been monitored regularly using two different and complementary methods: broad-scale reef surveys by the Long-Term Monitoring Program supported by the Australian Institute of Marine Science (AIMS) and CRC Reef; and the fine-scale reef surveys carried out by Reefwatch Australia, funded by CRC Reef.

LONG-TERM MONITORING PROGRAM

The Long-Term Monitoring Program is designed to monitor broad-scale changes in several parameters that are indicators of reef health across the Great Barrier Reef. The program is undertaken by scientists from the Australian Institute of Marine Science (AIMS) who have been conducting surveys since 1985.

Each year, the team uses manta tows to survey the perimeters of about 100 reefs. During a manta tow, a diver using a 'manta board' is towed behind a small boat around each reef. The boat stops every two minutes so the diver can record evidence of crown-of-thorns starfish (sightings or feeding scars) and estimates of reef-wide coral cover. During the Long-Term Monitoring Program, sites on 48 of these reefs are surveyed more intensively for coral cover and resident fish populations.

Divers using manta tows can see adult crown-of-thorns starfish that are bigger than about 15 cm in diameter. The numbers of starfish seen during two-minute tows are used to estimate the status of the crown-of-thorns starfish populations. An 'incipient' outbreak is the density of starfish at which coral damage is likely: 0.22 starfish per two-minute tow. During an 'active' outbreak, densities reach >1.0 starfish per two-minute tow which would certainly damage reefs. It is interesting to note that some reefs have been unaffected by crown-of-thorns starfish since the beginning of the monitoring program in 1985.

Information about the current status of crown-of-thorns starfish on the Great Barrier Reef from the Long-Term Monitoring Program is available on the AIMS website at: www.aims.gov.au/monmap/COTSPage/COTSPage.html.

FINE-SCALE SURVEYS

Since 1994, up to 21 reefs between Cooktown and Townsville have been surveyed each year using the fine-scale survey method. As the name suggests, the fine-scale surveys look in detail at small areas of reef and reveal the structure of the crown-of-thorns starfish populations.

At each reef that is surveyed, SCUBA divers search for crown-of-thorns starfish in 40 transects (50 m long x 5 m wide) at 20 different places on the reef. The divers count all the starfish in each transect, including juveniles (up to 13 cm diameter, estimated to be one year old), sub-adults (14-25 cm diameter, estimated to be about two years old) and adults (more than 26 cm diameter, estimated to be three years old or more). The smaller starfish cannot be seen during manta tow surveys.

Incipient outbreaks are recorded when sub-adult and adult densities together reach more than 30 per hectare (10,000 square metres). Active outbreaks are defined when there are more than 30 adult crown-of-thorns starfish per hectare (10,000 square metres).

COMPARING LONG-TERM MONITORING AND FINE-SCALE SURVEYS

An analysis of the difference between manta tows and fine-scale surveys showed that:

- Manta tow surveys underestimate the numbers (densities) of crown-of-thorns starfish compared with fine-scale surveys on the same reef.
- Both techniques show a similar progression of the outbreak and rate of southerly drift of the outbreak.

Therefore, the fine-scale surveys are most useful to calculate densities of crown-of-thorns starfish on a small-scale. Manta tows are better for following broad-scale changes in crown-of-thorns starfish density across the entire Great Barrier Reef.



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is a knowledge-based partnership of coral reef researchers, managers and industry. Its mission is to plan, fund and manage world-leading science for the sustainable use of the Great Barrier Reef World Heritage Area.

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