The history of crown-of-thorns starfish controls on the Great Barrier Reef and an assessment of future needs for controls

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Abstract

The Authority is planning for the next series of outbreaks of crown-of-thorns starfish by developing a Contingency Plan. Part of the Plan is devoted to the feasibility and desirability of primary controls aimed at preventing the southwards spread of outbreaks. This paper reviews the history of the Authority's policy on controls, the results of past and present controls and reasons for their success or failure. The arguments likely to be raised for widespread controls in the event of another outbreak (including the causes of outbreaks, recovery since the last outbreak, usage of reefs) will be discussed. The feasibility of such controls will be examined in terms of costs, possible effectiveness, side effects and alternatives.

Background

Providing for the protection, wise use, understanding and enjoyment of the Great Barrier Reef in perpetuity through the care and development of the Great Barrier Reef Marine Park is the goal of the Great Barrier Reef Marine Park Authority (GBRMPA). Achievement of this goal necessitates the management of problems and their effects. Included in this is the management of the crown-of-thorns starfish phenomenon, which in two outbreak episodes on the Great Barrier Reef has caused considerable damage to coral communities. The current policy of GBRMPA's regarding crown-of-thorns starfish and their control is that, unless it can be proven that outbreaks are either caused or exacerbated by human activity, controls should be limited to small-scale tactical measures in areas important to tourism and science. This policy has evolved from many government enquires and the recommendations of researchers.

The second series of outbreaks of crown-of-thorns starfish on the Great Barrier Reef is coming to an end. However, it is possible that outbreaks will occur in the future. To prepare for this the Great Barrier Reef Marine Park Authority has developed a Contingency Plan to be consulted and activated at the start of the next outbreak episode (Lassig *et al., in press*). The Contingency Plan involves options for monitoring, research and controls. There are likely to be calls for widespread controls of the starfish at the start of the next outbreak, as occurred in both previous outbreaks. Already arguments have been presented for the early eradication of starfish to prevent the coral mortality associated with the southward-progressing waves of secondary outbreaks. Research in the next few years may also suggest a link between human activities and outbreaks. It is therefore timely to re-examine widespread controls, in terms of their desirability, usefulness and effectiveness. In this paper I present a history of the controls issue, a discussion of the likely calls for widespread or primary controls, and an examination of the costs, effectiveness and possible side effects of such measures.

A History of Thoughts about Controls on the Great Barrier Reef

The first recorded outbreak of crown-of-thorns starfish on the Great Barrier Reef was seen on Green Island reef in 1962. High coral mortality and a lack of knowledge about the long term consequences for the Reef led to the popular media and some scientists demanding widespread eradication of the starfish. The impossibility of such measures was recognised early in the history of the crown-of-thorns phenomenon. In the earliest official report on crown-of-thorns starfish in 1965, state fisheries biologist NM Haysom advised that controls would only be practical in very restricted areas. Haysom also recommended control techniques other than "hand harvesting" be investigated and a program of research of the starfish be instigated. The recommended research included distribution and abundance, reproduction, feeding ecology and means of controls.

In the first report of these investigations Endean (1969) recommended widespread controls by hand harvesting and the use of one of the starfish's predators, the giant triton shell (*Charonia tritonis*), as a control agent. In particular, Endean (1969) recommended breeding and release of large numbers of tritons. In a report of the other main areas of research Pearson and Endean (1969) provided data on the feeding ecology of the giant triton shell suggesting that each triton consumed less than one crown-of-thorns starfish per week. To this day there is little extra information available on the feeding ecology of the giant triton, although popular scientific consensus is that control by tritons is not feasible.

Controlling outbreaks in small areas, such as around tourist sites, has been seen as desirable in all government reviews of the crown-of-thorns starfish phenomenon. The issue of more widespread controls has been an evolving one. In the early years of the phenomenon arguments against widespread controls were utilitarian ie widespread controls were desirable but impractical. A joint conference of Commonwealth and Queensland government officers in 1969 concluded that controls were desirable but should not be undertaken until the methods were evaluated. Research into the giant triton was also recommended. A 1970 report of a committee established by the Australian Academy of Sciences concluded that controls should be confined to small areas around established tourist sites, because practical methods were unavailable to undertake widespread or long-term controls (Walsh *et al.* 1971).

A shift in thinking about widespread controls occurred in 1971. A Committee of Queensland and Commonwealth experts was established in 1970 in response to conflicting expert opinions of the phenomenon. The Committee considered evidence from many experts and also from a growing body of research. The 1971 report of the Committee concluded that the starfish did not threaten the entire Great Barrier Reef, that coral recovery was occurring, and that damage was restricted to reefs between Cairns and Townsville. Importantly, the Committee concluded that the starfish outbreaks may be a natural part of the destructive processes of coral reefs. Eradication of starfish on reefs of "social or commercial importance" was regarded as feasible; however, widespread controls were "unwarranted" (Walsh *et al.* 1971). The scale and success of control programs undertaken during the first outbreak episode has been reviewed by Zann and Weaver (1988).

In 1976 the Great Barrier Reef Marine Park Authority was established and as the government agency responsible for managing the GBR Marine Park, issues related to crown-of-thorns starfish were also its responsibility. GBRMPA's policy on controlling crown-of-thorns starfish appears to have grown from the recommendations of the 1971 Walsh report.

The second episode of outbreaks on the GBR was first reported around Green Island reef in 1979. A number of expert committees were convened by GBRMPA to advise it on the crown-of-thorns starfish problem. The Crown of Thorns Committee (1980) recommended research directions but not controls (Lassig 1991). The 1985 report of the Crown-of-Thorns Starfish Advisory Committee (COTSAC) supported the GBRMPA controls policy and also recommended a program of research into controls. Between 1985/86 and 1989/90 six research projects were funded for a total of $193,210 and covered the costs and effectiveness of copper sulphate injections as controls, underwater fencing to protect small areas of reefs, and the diseases of crown-of-thorns starfish. Results of these programs were summarised by Lassig (1991) and Zann and Weaver (1988). COTSAC also reviewed the available evidence on the results of macro-scale control operations and concluded they were of "limited value in controlling major populations".

GBRMPA's management of the crown-of-thorns phenomenon was again reviewed in 1989 (Anderson 1989) following adverse publicity in the media. The controls policy of GBRMPA was supported and research into biological controls recommended. After serious consideration of the use of biological controls, including costs and risks, the new advisory body to GBRMPA on crown-of-thorns starfish, the Crown-of-Thorns Starfish Research Committee (COTSREC), advised against funding for biological controls research.

A condition of the Federal government funded COTSREC research program was for a mid-term independent review. The report (Johannes 1991) made no mention of controls but recommended a Contingency Plan to be initiated at the start of the next series of crown-of-thorns starfish outbreaks. An important component of the Contingency Plan (described in detail by Lassig *et al., in press*) is an assessment of the possible needs, and options, for controls at the start of the next outbreak episode.

In summary, discussion to date on the desirability of widespread controls has focussed on the impracticalities and costs, the unresolved issue of whether outbreaks are natural

or human-influenced, and the damage caused by outbreaks. There is general agreement about the desirability of limited controls around small, important areas. In the next outbreak episode these discussions may be more focussed on the long-term consequences of further outbreaks and the threat to the amenity value of the Reef.

Preparing for the next Outbreak Episode

There were considerable public calls for large-scale controls of COTS at the start of both outbreak episodes on the GBR (Raymond 1986), even in the absence of evidence for human influences in outbreaks. It is anticipated that these calls will be repeated at the start of the next outbreak episode. It is therefore an opportune time for GBRMPA, as a management agency, to begin to prepare for another controls debate by reviewing the scope of controls that may be called for.

The term "primary controls" will be used here to describe controls designed to eradicate COTS on primary outbreak reefs. The aim would be to prevent the southward progression of secondary outbreaks along the GBR.

Calls for Controls

GBRMPA's current policy on controls indicates that larger scales of controls would be considered if evidence suggests that outbreaks are influenced by human activities. At present, no such evidence is available.

During the current outbreak an estimated 17% ± 4% of reefs have been affected, about one-fifth of these (ie. about 3-4% of all reefs) seriously. Given this scale of damage, major ecosystem-wide effects seem unlikely. However, geographic regions, in particular the central section of the GBR, suffered more intense damage (about three-quarters of all surveyed reefs affected) and reefs in this area may not recover fully from another outbreak should one occur in the next 15-20 years.

There have been recent calls for primary controls (Lucas 1990). Lucas (1990) argues that another outbreak in the next few years may fundamentally alter the composition of reefs from highly diverse coral communities to communities dominated by faster growing species. In the past two outbreaks on the GBR many massive corals on affected reefs were eaten (Endean *et al.* 1988; Done and DeVantier 1990). Time for these corals to be replaced, it is predicted, may vary from 9 to more than 100 years (Done 1988). Lucas (1990) has called for primary controls, if the next outbreak occurs within a few years, to prevent further degradation of the reefs.

Calls for primary controls could also come from the tourist industry. The GBR is Australia's most popular tourist destination and generates about A$ 1 b per annum (WS Cummings Economic Research Services 1991). The most popular part of the GBR is the reefs and islands offshore from Cairns on the far northern coast of Queensland. Coincidentally, this is also near to the hypothesised primary outbreak area for COTS on the GBR (Dight *et al.* 1990). Coral reefs are an important commercial resource and their value is expected to grow rapidly. In 1984/85 there were 934,000 visits made to the reefs and islands near Cairns; it is predicted that by 1997/98 this will have risen to 2,608,000 and by 2002/03 it could be 3,310,000 (Thomas 1992). In 1989/90 the value of tourism in the Cairns area was $500 m (WS Cummings Economic Research Services 1991).

If coral reefs were affected by another outbreak of COTS there would be no alternative sites for tourist operators. Suitable sites for either moored pontoons or roving boats are limited, owing to needs for good coral cover, low currents, and a safe anchorage. All suitable sites in the Cairns region are currently utilised. There could be considerable lobbying for primary controls at the start of the next outbreak, by the tourist industry around Cairns and also further south on the GBR, to prevent any damage to reefs.

In conclusion, even without evidence for human influence in COTS outbreaks, it is expected that there will be public demands for primary controls at the start of the next outbreak episode on the GBR. If human influence is proven there needs to be an assessment of the possibility of success of primary controls using current control technology.

The Option of Primary Controls

The aim of primary controls would be to eradicate all COTS in a primary outbreak to prevent the southward progression of secondary outbreaks. This would rely on the primary outbreak being detected as early as possible. COTS become more visible to observers, and reproductively mature, at around two years of age; however fecundity is low until they reach age three years (Birkeland and Lucas 1990). Primary controls would have to be done in that interval between ages two and three. COTS are currently eradicated manually by divers injecting a concentrated solution of copper sulphate. The feasibility of primary controls can be examined in terms of costs, the likelihood of success, possible side effects, and alternatives to current control technology.

Costs

Estimated costs of eradicating all COTS on a reef would vary with such factors as the size of the primary outbreak, the injection rate, distance of the primary outbreak reef from shore-based facilities and the number of reefs with primary outbreaks. Costs have been estimated for primary outbreaks of several sizes: 2 m, 1 m, 0.5 m, 100,000 and 50,000 starfish. The maximum injection rate is around 130 starfish per hour (Birkeland and Lucas 1990) for large outbreaks; for smaller outbreaks the injection rate varies from 10 to 80 per hr (Zann and Weaver 1988; Johnson *et al.* 1990). The cost model assumes that as starfish numbers decline the injection rate also declines because of the additional time spent searching for starfish. The model also assumes the following: time spent diving of 4 hours per day (which takes into account time lost due to poor conditions); a salary of A$ 150 per day per person; a minimum diving team of three (two divers and one boat person); ship charter costs of A$1200 per day; supervisors' salaries; dive equipment costs and services; chemicals; and follow-up surveys of reefs.

Predicted costs for controlling primary outbreaks of each size are:

2m COTS	A$ 3.51m
1m COTS	A$ 1.57m
0.5m COTS	A$ 1.37m
100,000 COTS	A$ 0.50m
50,000 COTS	A$ 0.47m

The high cost of hiring staff to undertake control programs could be offset by the use of volunteer divers. There are a number of problems with using volunteers, including numbers available and their effectiveness. This would be difficult to guarantee, and even more difficult if a large number of reefs had to be controlled. The supply of volunteers would also be subject to the weather, time of year, number of paid jobs available in a nearby centre, the incentive of the individuals, and their success rate in the field (interest would likely to be high when COTS are abundant but decline substantially when there are few).

The number of volunteers would have to be greater than the salaried divers because of the need to continually train personnel in locating and injecting COTS, and the associated longer time to search and find COTS. In a series of control programs in the Whitsundays between 1988 and 1990 the injection rates for experienced local divers were 30.4 $\pm$ 10.06 per hr (Mean $\pm$ SE) compared with 2.3 $\pm$ 0.74 per hr for inexperienced volunteers. The costs of using volunteers for other reefs with different sized outbreaks would be around 40% of those if personnel were paid for the control action, but the costs are still substantial.

There is no information on the possible size of a primary outbreak on the GBR, nor on the number of reefs that might simultaneously experience primary outbreaks. It is therefore difficult to predict total costs. It is feasible that the waves of secondary outbreaks could be generated by a primary outbreak on a single reef. Primary controls would probably need to be done several times on each reef in order to locate cryptic starfish and to kill those recruiting to the adult population. The above costs may therefore represent annual costs, rather than one-off costs. Owing to the high fecundity and fertilisation success of COTS, the prevention of secondary outbreak would depend on the eradication of all COTS from a primary outbreak. If an aggregation of even a few starfish were missed, the control operation would possibly fail.

Likelihood of Success

The effectiveness of past control programs have been reviewed by Zann and Weaver (1988), Birkeland and Lucas (1990), and Johnson *et al.* (1990). Results from these reviews show that controls were successful when there was adequate warning of an approaching outbreak; the COTS were aggregated in small accessible areas; the population was small; there was a rapid response; there were sufficient, dedicated personnel for the job and the controls were repeated. Controls failed when there were too many COTS for the resources available; when there was migration of COTS into the cleared area; and when COTS were difficult to detect owing to reef topography, crypticity and weather.

The most critical factor appears to be early detection of outbreaks. Small primary outbreaks could feasibly be eradicated, however, they would need to be detected at an early stage before they spawn and produce the larger secondary outbreaks. Then, widespread controls would be impossible: none of the above success factors, and all of the above failure factors, would be applicable at this stage.

Possible Side Effects

Eradicating large numbers of COTS with copper sulphate injections risks copper contamination of other organisms. The background level of dissolved copper in GBR waters is around 0.11-0.24 g/L seawater (Denton and Burdon-Jones 1986). About 1 kg of copper sulphate is required to kill 1000 COTS. Outbreaks of the sizes modelled above would add, respectively, 0.40, 0.21, 0.10, 0.02, and 0.01 g dissolved copper / L seawater / day (modelled on the volume of water above the reef at Green Island) to background levels over 6 months.

Zann and Weaver (1988) reported elevated levels of copper in a tridacnid clam and an alga after controls were attempted on a relatively small outbreak (8019 COTS) at Holbourne Island.

In conclusion, there is the possibility of contamination of other reef organisms, and possibly of the divers administering the copper sulphate, if current control measures are used to eradicate large outbreaks.

Alternatives to Copper Sulphate Injections

No alternatives currently exist for eradicating large numbers of COTS. Underwater fences have been successfully trialed (Birkeland and Lucas 1990), but they are only capable of protecting small areas of reef eg. around tourist sites.

Conclusions

The history of the crown-of-thorns starfish phenomenon on the Great Barrier Reef suggests the issue of controls will be raised again at the start of the next outbreak episode. In the absence of any evidence to the contrary current policy allows for limited controls. Other measures may need to be considered if research indicates a link between human activities and outbreaks or if evidence suggests long-term damage to the GBR. The type of evidence indicative of human involvement in the generation of primary outbreaks and/or the prolongation of secondary outbreaks needs to be clarified and agreed to by managers and the scientific community. There is also a need to decide upon the most appropriate management actions available to control large populations of starfish before it becomes necessary to undertake such actions. This is important because of the long time needed to organise operations and the high fecundity of the starfish. One option could be primary controls on a primary outbreaking reef(s) to prevent the southward progression of outbreaks. With current control technology eradication of all starfish on a primary outbreak reef will be uncertain and therefore not guaranteed of preventing secondary outbreaks. Primary outbreaks need to be detected as early as possible to allow for all management options to be considered and any intervention to be instigated quickly.

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