Abstract

This report summarises the small-scale local control measures implemented by the Ministry of Marine Resources, in response to large numbers of adult crown-of-thorns starfish (*Acanthaster planci*; known locally as *Taramea*) on the outer reef of Rarotonga, Cook Islands. A total of 15 control trips were conducted, across 4 sites, over the period 11 August to 1 December 2000. More than 8500 adult *A. planci* were injected with sodium bi-sulphate during the control operation. The results indicate the control measures are effective in reducing local populations of *A. planci*. The number of animals injected per trip declined, over time, between 50-85% from previously recorded levels of peak abundance (for sites where such comparisons were possible). The long-term success of this operation requires an ongoing commitment to local control measures at these sites. Opportunities to incorporate new objectives into the programme, including i) increased data collection, ii) the determination of local population age structure, and iii) mapping the distribution and relative abundance of *A. planci* in relation to sites of major terrestrial runoff, and patterns of water movement around Rarotonga, are also briefly discussed.

Introduction

The crown-of-thorns starfish (*Acanthaster planci*; known locally as *Taramea*) is a large predatory asteroid, which feeds preferentially on species of hard coral (scleractinia) within the family Acroporidae (Keesing & Lucas, 1992; Lassig, 1995). It is also known to attack other species of coral and invertebrates, depending on the availability of prey items (see Moran, 1987a). The species is widely distributed and a natural inhabitant of coral reef systems throughout the tropical Indo-Pacific (Moran, 1987a; Lassig, 1995).

Acanthaster planci is usually present at low densities on the reef (between 1-15 animals per hectare (Lassig, 1995)), and the coral communities are able to withstand and sustain this level of predation pressure. However, large, irregular and sudden increases in adult *A. planci* abundance (believed to be due to the occasional, very high settlement of larvae (Zann, 1987a)), often results in spectacular and extensive coral mortality, which may, in turn, bring about changes in the community structure of the reef.

These events (popularly termed 'outbreaks') have attracted a great deal of research interest, and *A. planci* is now possibly the most intensively studied animal in Australian waters (Moran, 1987b). Many surveys have been conducted throughout the Indo-Pacific region (Moran, 1987c), and these have given rise to a large volume of scientific literature about this animal (Keesing & Lucas, 1992; Moran, 1987b).

In July 2000, the Ministry of Marine Resources (MMR) received reports from *Cook Island Divers*, as well as members of the local fishing community, about the presence of large numbers of adult *A. planci* on the outer reef around Rarotonga. Preliminary observations by the MMR established that the density of adult *A. planci* at the sites surveyed constituted a population outbreak (i.e., > 30 animals per hectare; GBRMPA, 1997), and some form of control operation would be necessary.

In defining the scope of the control operation, the MMR took into account the following:

1) No large-scale control programmes have successfully protected corals, or eradicated starfish populations (Zann, 1987b; Lassig, 1995).

2) Although uncertainty remains as to whether their frequency and/or intensity is higher as a result of certain human activities (GBRMPA, 1997), population outbreaks of *A. planci* are now widely accepted within the scientific community as being natural events. Furthermore, it is thought that these outbreaks may be important in maintaining high diversity within coral communities.

It was therefore decided that the control operation would be restricted to realistic (in terms of available resources), small-scale measures, aimed at minimising the destructive impact of *A. planci* at sites of special importance to dive tourism. In addition to this, the number, size and depth of all animals targeted would be recorded. The reason for doing this was to 1) gauge the effectiveness of the control operation in reducing local populations of *A. planci*, and 2) provide a valuable point of reference against which future control programmes can be compared.

Materials and methods

The Ministry of Marine Resources (MMR) conducted a total of 15 control trips over the period 11 August to 1 December 2000 [see Table 1]. Small-scale local control efforts were spread over 4 sites, namely 1) Black Rock/Edgewater (north-west Rarotonga), 2) Tupapa (north Rarotonga), 3) Arorangi/Papana (south-west Rarotonga) and 4) Rutaki Passage/Papua (south Rarotonga) [see Figure 1]. Site selection was made in consultation with Greg Wilson of *Cook Island Divers*, and based on a high abundance of *Acanthaster planci* in areas of importance to dive tourism.

Control trips were undertaken using the MMR vessel *Te Rama*. Each trip consisted of a team of between 5-12 dive personnel (made up of SCUBA-certified MMR employees and volunteers). Between 10-12 air cylinders were used on each control trip. Where necessary divers were required to make repetitive dives.

In addition to full SCUBA gear, divers were equipped with a Chemagrow forestry spot injector gun and recording slate. Each gun was set to deliver a 10ml dose of sodium bi-sulphate solution from the supply unit attached to the divers air cylinder. Divers were instructed to inject individual *A. planci* in their central disc 1-3 times (depending on the size of the animal), and record the size (diameter) and depth of each animal encountered. The barrel of each injector gun was marked at 10cm intervals to aid animal size measurements. Data from individual recording slates were subsequently collated and entered into the MMR database.

Results

More than 8500 *Taramea* (crown-of-thorns starfish; *Acanthaster planci*) were injected with sodium bi-sulphate, across 4 control sites, during the period 11 August to 1 December 2000. A detailed breakdown of this figure is given below (by site and for each trip), and a summary provided in Table 1.

Site 1: Black Rock/Edgewater [north-west coast]

Trip 1 (11 August 2000): No data were recorded.

Trip 2 (16 August 2000): A total of 239 *A. planci* were injected at depths of between 20-80 feet. Figure 2A describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 50-60 feet (Figure 2B). Sixty-four percent of the total number of animals injected measured between 20-40 cm in diameter (Figure 2C).

Trip 3 (21 September 2000): A total of 471 *A. planci* were injected at depths of between 0-70 feet. Figure 2D describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 10-20 feet (Figure 2E). Eighty-four percent of the total number of animals injected measured between 10-30 cm in diameter (Figure 2F).

Trip 4 (21 November 2000): A total of 521 *A. planci* were injected at depths of between 20-70 feet. Figure 2G describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 40-50 feet (Figure 2H). Seventy-eight percent of the total number of animals injected measured between 20-40 cm in diameter (Figure 2I).

Trip 5 (23 November 2000): A total of 704 *A. planci* were injected at depths of between 30-80 feet. Figure 2J describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 40-50 feet (Figure 2K). Eighty-two percent of the total number of animals injected measured between 10-40 cm in diameter (Figure 2L).

Trip 6 (25 November 2000): A total of 91 *A. planci* were injected at depths of between 30-80 feet. Figure 2M describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 30-40 feet (Figure 2N). Eighty-nine percent of the total number of animals injected measured between 20-40 cm in diameter (Figure 2O).

Trip 7 (1 December 2000): A total of 139 *A. planci* were injected at depths of between 30-80 feet. Figure 2P describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 40-50 feet (Figure 2Q). Eighty-seven percent of the total number of animals injected measured between 20-40 cm in diameter (Figure 2R).

Site 2: Tupapa [north coast]

Trip 1 (18 August 2000): A total of 434 *A. planci* were injected at depths of between 10-50 feet. Figure 3A describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 20-30 feet (Figure 3B). Eighty-nine percent of the total number of animals injected measured between 10-40 cm in diameter (Figure 3C).

Trip 2 (6 September 2000): A total of 224 *A. planci* were injected at depths of between 10-50 feet. Figure 3D describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 30-40 feet (Figure 3E). Seventy-seven percent of the total number of animals injected measured between 20-40 cm in diameter (Figure 3F).

Site 3: Arorangi/Papana [south-west coast]

Trip 1 (1 September 2000): A total of 782 *A. planci* were injected at depths of between 20-80 feet. Figure 4A describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 50-60 feet (Figure 4B). Eighty-two percent of the total number of animals injected measured between 20-40 cm in diameter (Figure 4C).

Trip 2 (14 September 2000): A total of 1457 *A. planci* were injected at depths of between 10-70 feet. Figure 4D describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 10-20 feet (Figure 4E). Eighty-five percent of the total number of animals injected measured between 20-40 cm in diameter (Figure 4F).

Trip 3 (20 September 2000): A total of 1079 *A. planci* were injected at depths of between 10-50 feet. Figure 4G describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 10-30 feet (Figure 4H). Eighty-five percent of the total number of animals injected measured between 20-40 cm in diameter (Figure 4I).

Trip 4 (9 November 2000): A total of 1345 *A. planci* were injected at depths of between 10-30 feet. Figure 4J describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 10-20 feet (Figure 4K). Eighty-seven percent of the total number of animals injected measured between 10-30 cm in diameter (Figure 4L).

Trip 5 (17 November 2000): A total of 211 *A. planci* were injected at depths of between 10-80 feet. Figure 4M describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 50-60 feet (Figure 4N). Eighty-eight percent of the total number of animals injected measured between 10-30 cm in diameter (Figure 4O).

Site 4: Rutaki Passage/Papua [south coast]

Trip 1 (28 November 2000): A total of 927 *A. planci* were injected at depths of between 40-60 feet. Figure 5A describes the size-frequency distribution of *A. planci* injected, for each depth range at which they were encountered. Peak abundance of animals occurred within a depth range of 50-60 feet (Figure 5B). Seventy-seven percent of the total number of animals injected measured between 10-30 cm in diameter (Figure 5C).

Discussion

Although labour-intensive and potentially expensive over the long term, it seems the most cost-effective means of reducing large local populations of adult *Acanthaster planci* is by injecting individual animals with a lethal solution. Small-scale local control measures of this nature have been successful in Guam (Australian Academy of Science, 1970), and applied extensively on the Australian Great Barrier Reef, where some form of control measure has been deemed necessary; namely in areas of special importance to science or tourism. The benefits of this type of control approach ahead of alternatives are well documented (Lassig, 1995), and its efficacy supported by the data collected during this control operation.

At both the Black Rock/Edgewater and Arorangi/Papana sites (sites 1 and 3, respectively; refer to Figure 1), a reduction in the adult *A. planci* population size was observed over time (see Table 1, and Figures 2 & 4). Put another way, and given the similar diver effort applied to each control trip (between 10-12 dives), the number of *A. planci* injected declined by 80% and 85% (sites 1 and 3, respectively) from previously recorded levels of peak abundance.

It is interesting to note the observed shift in size-class data recorded from control trips 4 and 5 at site 3 (Arorangi/Papana), compared with those of earlier trips. That is, the proportional increase in the number of individuals measuring 11-20cm in diameter, and concurrent decline, of similar magnitude (between 30-40%), of individuals measuring 31-40cm (Table 1; Figures 4C, 4F, 4I, 4L & 4O). This shift, together with the overall decline in the total count/trip over time, suggests the larger size-class was sufficiently reduced in abundance during earlier control trips, necessitating divers shift the focus of their search on to the less visible smaller size-class.

Given the limited control effort so far applied at site 2 (Tupapa - 2 trips) and site 4 (Rutaki Passage/Papua – 1 trip), it is not possible to infer much from the data collected at these sites. However, it is perhaps worth highlighting, once again, the decline in numbers injected (c.50%) between the 2 trips made to the Tupapa site (Table 1; Figure 2).

These early results are encouraging and imply the control operation has been effective in reducing local populations of *A. planci*. It is important to recognise, however, that the long-term success of small-scale control measures demands a sustained commitment of effort and resources. To this end, Lassig (1995) provides a concise outline of how such operations might be managed.

Consideration should now be given to how available resources can be maximised. For example, 2 of the 3 recreational dive operators on Rarotonga are known to be conducting periodic control measures of their own, in an effort to reduce adult *A.*

planci abundance around other popular dive sites. Encouraging these operators to collect and submit basic data, that is, the number, size and depth at which animals are present, would enhance our knowledge of the distribution and abundance of adult *A. planci* on the outer reef around Rarotonga.

Further Research

There is much scope for additional research to be incorporated as part of the ongoing control programme. While the size data collected so far indicates a wide size range of adult *A. planci* on the reef (which in turn might suggest the presence of several age-classes and successive years of high larval recruitment), adult size is not a reliable indicator of age (Moran, 1987c; Mead, 1900). It is, however, possible to determine the age of individual animals from the spines on their aboral (or upper) surface. This information would allow us to establish whether the local populations of *A. planci* are made up of a single year class (cohort) or in fact several year classes. This type of assessment of population age structure could form the basis for estimating, firstly, how long the outbreak may persist, and secondly, how severe it may become over time. Obviously local control efforts may benefit from having this type of information to hand. It would be timely to approach the Australian Institute of Marine Science and/or the Great Barrier Reef Marine Park Authority, not only to ascertain the recommended approach for ageing spines (and whether it can be undertaken in Rarotonga), but also to establish a direct line of communication between the MMR and their researchers.

A great deal of research on the Australian Great Barrier Reef has been devoted to understanding more about the larval stages of *A. planci*, and factors influencing recruitment success (see Moran, 1987c). Reduced salinity, elevated water temperature, increased phytoplankton productivity and favourable currents are all implicated in contributing to increased larval recruitment (Fisk, 1987; Lucas, 1987; Zann, 1987c). It may be useful to map the distribution and relative abundance of adult *A. planci* on the outer reef of Rarotonga, in relation to 1) sites of major terrestrial runoff and freshwater input, and 2) the net direction of water movement around Rarotonga during their spawning season (December/January). Indeed this is fundamental to our understanding the ecology of this animal in the waters around

Rarotonga. Once again, augmenting our data and observations with those from the other dive operators would greatly assist this exercise.

Summary

The results derived from this operation suggest the small-scale local control measures employed are effective in reducing the abundance of adult *A. planci*, at the sites targeted. To ensure the long-term success of these control measures, an ongoing commitment of effort and resources to the operation is required. Without this, a return to high levels of *A. planci* abundance at these sites could be anticipated. Nevertheless, the interim results are encouraging and, furthermore, provide 1) a reference against which future control operations can be compared and 2) a platform from which further research opportunities can be pursued.

Acknowledgements

The Ministry of Marine Resources (MMR) gratefully acknowledges the generous and ongoing assistance of Greg Wilson (*Cook Islands Divers*), for supplying the injector guns, sodium bi-sulphate solution and compressed air.

The MMR also wishes to acknowledge the support of the volunteer dive personnel associated with this control operation.

References

Australian Academy of Science (1970) Acanthaster *planci* *(crown-of-thorns starfish) and the Great Barrier Reef*. Reports of the Australian Academy of Science Number 11.

Fisk, D. (1987) *Coral recovery after crown-of-thorns infestation*. In: The Crown-of-Thorns Starfish; Zann, L. & Eager, E. (eds). Aust. Sci. Mag. Issue 3, 1987. Great Barrier Reef Marine Park Authority, Queensland. pp 55.

Great Barrier Reef Marine Park Authority (1997) *Crown-of-thorns starfish on the Great Barrier Reef: the facts (update March 1997).* Great Barrier Reef Marine Park Authority, Queensland. Public information pamphlet.

Keesing, J. K., and Lucas, J. S. (1992) *Field measurement of feeding and movement rates of the crown-of-thorns starfish* Acanthaster planci (L.). J. Exp. Mar. Biol. Ecol. 156: 89-104.

Lassig, B. (1995) *Controlling Crown-of-thorns starfish.* Great Barrier Reef Marine Park Authority, Queensland. 11pp.

Lucas, J. (1987) *Life history.* In: The Crown-of-Thorns Starfish; Zann, L. & Eager, E. (eds). Aust. Sci. Mag. Issue 3, 1987. Great Barrier Reef Marine Park Authority, Queensland. pp 55.

Mead, A. D. (1900) *On the correlation between growth and food supply in starfish.* Am. Nat. 34: 17-23.

Moran, P. (1987a) *A close look: the crown-of-thorns starfish.* In: The Crown-of-Thorns Starfish; Zann, L. & Eager, E. (eds). Aust. Sci. Mag. Issue 3, 1987. Great Barrier Reef Marine Park Authority, Queensland. pp 55.

Moran, P. (1987b) *Answers lie in research.* In: The Crown-of-Thorns Starfish; Zann, L. & Eager, E. (eds). Aust. Sci. Mag. Issue 3, 1987. Great Barrier Reef Marine Park Authority, Queensland. pp 55.

Moran, P. (1987c) *The starfish and its environment.* In: The Crown-of-Thorns Starfish; Zann, L. & Eager, E. (eds). Aust. Sci. Mag. Issue 3, 1987. Great Barrier Reef Marine Park Authority, Queensland. pp 55.

Zann, L. (1987a) *Juveniles – a new direction for research.* In: The Crown-of-Thorns Starfish; Zann, L. & Eager, E. (eds). Aust. Sci. Mag. Issue 3, 1987. Great Barrier Reef Marine Park Authority, Queensland. pp 55.

Zann, L. (1987b) *Can the crown-of-thorns be controlled.* In: The Crown-of-Thorns Starfish; Zann, L. & Eager, E. (eds). Aust. Sci. Mag. Issue 3, 1987. Great Barrier Reef Marine Park Authority, Queensland. pp 55.

Zann, L. (1987c) *Possible reasons for outbreaks.* In: The Crown-of-Thorns Starfish; Zann, L. & Eager, E. (eds). Aust. Sci. Mag. Issue 3, 1987. Great Barrier Reef Marine Park Authority, Queensland. pp 55.