Australian Government
Department of the Environment and Heritage

Status of the Coral Reefs at the Cocos (Keeling) Islands

A report on the status of the marine community at Cocos (Keeling) Islands, East Indian Ocean, 1997–2005

PARKS AUSTRALIA
COCOS (KEELING) ISLANDS

ISBN 0642551944

Printed on recycled paper

Photography Credits

Front Cover

Cabbage Coral and Green Turtle - Robert Thorn
Lobophyllia Coral - Wendy Murray

Other Images

Cocos (Keeling) Islands - Robert Thorn
Cocos (Keeling) Islands - Robert Thorn
Gorgonian Fan Coral - Robert Thorn
Wendy Murray conducting reefcheck - Robert Thorn
Cabbage Coral at Cabbage Patch - Robert Thorn
Wendy Murray conducting quadrat survey at Cologne Gardens - Robert Thorn
Giant Claim - Robert Thorn
Indian Steephead Parrotfish - Robert Thorn
Moray Eel - Robert Thorn
Titon Triggerfish - Robert Thorn
Racoon Butterflyfish - Robert Thorn
Green Turtle - Robert Thorn
Soft Coral - Wendy Murray
The wall of the drop off - Robert Thorn

Contents

Executive Summary

The Cocos (Keeling) Islands are a remote coral reef atoll located in the eastern Indian Ocean. The marine community comprises largely Indo-West Pacific species, with little endemism. A range of disturbances have impacted on the Cocos marine community including subsistence fishing, cyclones, coral bleaching, crown-of-thorns starfish outbreaks, and mass die-off events. Disturbances such as these on remote islands have the potential to cause drastic changes in the marine community. To determine the status of coral reefs at Cocos and document changes in community composition and species abundances, Parks Australia has developed an extensive monitoring program using internationally recognised Reefcheck survey methods. Underwater censuses were conducted by Parks staff at 11 representative sites from 1997 to 2005. Data were collected on important indicator, keystone and harvested marine fish and invertebrate species as well as on habitat composition.

Evidence from the underwater surveys at 11 sites from 1997 to 2005 indicates that the coral reef community at Cocos (Keeling) Islands is very healthy and in a stable period with little impact from anthropogenic activities. Live coral cover is high and there is minimal impact from coral damage, bleaching, and disease although some coral cancers are present. Crown-of-thorns starfish were found at high densities at some sites and further monitoring is required to determine the impact of these starfish on the coral community. Overall, fish and invertebrate abundances were found to be relatively constant throughout the survey period at all sites. A small number of significant changes occurred in the abundance of some study taxa, but these changes were usually the exception, involving only short-term fluctuations. Densities of fish and invertebrates calculated in this study were comparable with previous studies at Cocos (Keeling) Islands and similar to other coral reef locations. Two notable exceptions were the very high densities of small sea cucumbers and relatively low densities of snappers. Further monitoring will determine whether these levels are typical for Cocos (Keeling) Islands or just short-term phenomena observed during the 1997–2005 survey period.

With the exception of the presence of crown-of thorns starfish, disturbance events that have been reported previously for Cocos were generally lacking during the study period. Given that isolated islands generally have high extinction rates and low recovery rates, and given the history of disturbance events that have occurred at Cocos, it is of utmost importance that monitoring be continued. Disturbance events are likely to occur in the near future and assessing their impact on the reef community and its subsequent recovery, and identifying susceptible species, is fundamental to effective management. Expansion of the monitoring program into the southern lagoon, where mass die-off events have been reported previously, would be beneficial to determining adverse impacts on the reef community.

Introduction

The Cocos (Keeling) Islands (12°12'S, 96°54'E) are an Australian external territory situated in the eastern Indian Ocean approximately 2950km north-west of Perth, 950km west-south-west of Christmas Island and 1000km south-west of Java (Indonesia). Although situated in the Indian Ocean, this remote coral atoll represents the western edge of the Western Pacific marine biogeographic province (Woodroffe and Berry, 1994). Consequently, the marine community of the islands comprises mainly species from the Indo-West Pacific, with only a small number of West Indian Ocean species (Woodroffe and Berry, 1994). At Cocos, endemism is very low , and this is thought to be related to the geological development of the atoll (Woodroffe and Berry, 1994). The angelfish, *Centropyge joculator*, is known only from Cocos and neighbouring Christmas Island.

The Cocos (Keeling) Islands comprise 27 islands of which two are inhabited by a total of around 600 people. The islands have been inhabited since 1826 and the environment has been modified considerably. The most notable changes have been on land where native vegetation was cleared to make way for coconut plantations for a copra industry that has since ceased (Bunce, 1988). The marine environment, however, has been affected very little by anthropogenic activities, with subsistence fishing taking only relatively small harvests of fish and invertebrates. Although small-scale changes may have occurred through habitation and subsistence fishing, the remoteness of the islands has meant there has been very little commercial exploitation of valuable marine species, and thus none of the more usual deleterious impacts on the marine community have occurred.

Small, remote islands such as the Cocos (Keeling) group typically exhibit species-poor communities with high proportions of endemics, coupled with high rates of extinction (Whittaker, 1998). In addition, marine species on isolated islands rely largely upon self-recruitment of larvae. Consequently, if a disturbance event such as coral bleaching or a crown-of-thorns starfish outbreak were severe enough to reduce significantly the

abundance of a species at Cocos (Keeling) Islands then recovery is expected to be slow. Species would have to rely on survival of a few individuals to replenish the population. Furthermore, if the disturbance event eliminated a species it would take considerable time for larvae from another location, for example Christmas Island or Indonesia, to recolonise the reefs of Cocos (Keeling) Islands. Due to remoteness and reliance on self-recruitment, species inhabiting such isolated islands are therefore expected to have slow recoveries from any significant disturbance.

The marine communities at Cocos (Keeling) Islands have experienced a range of disturbances including coral bleaching, cyclones, outbreaks of crowns-of-thorns starfish and mass die-offs of corals and fish due to deoxygenation events (Colin, 1977; Berry and Woodroffe, 1994; Marsh, 1994; Bunce, 1988; Hender *et al*, 2001). Some of these disturbances are expected to increase in intensity and frequency in the future (e.g. coral bleaching: Hoegh-Guldberg, 1999). It is important to monitor the status of coral reefs in order to document long-term trends in abundance of species and changes in community structure, as well identifying destructive processes, describing their impacts, and identifying the species that are most susceptible. Ongoing monitoring is also important for assessing recovery of particular species and the coral reef community as a whole, in addition to evaluating the effectiveness of management strategies. The aim of this report is to determine the current status of the coral reef community at Cocos (Keeling) Islands and to identify any significant changes in abundance of species or in community structure from 1997 to 2005.

Methods

Data collection

To determine the status of the Cocos (Keeling) coral reef community and identify any significant changes in community structure, Robert Thorn and Wendy Murray from Parks Australia initiated and continue to develop a monitoring program. The program involves the collection of field data on an annual basis at 11 representative sites around the atoll. Ten of these sites are located on the South Keeling atoll (Figure 1) and an additional site (Bunya Coral site) is located on the more remote North Keeling atoll (within Pulu Keeling National Park). Data were collected from 1997 to 2005 on habitat composition and important indicator, keystone and harvested marine fish and invertebrate species. Fish taxa included in the surveys were butterflyfish (Chaetodontidae) groupers (Serranidae) parrotfish (Scaridae), humphead wrasse (*Cheilinus undulatus*), bumphead parrotfish (*Bolbometapon muricatum*), sweetlips (Haemulidae), snappers (Lutjanidae), barramundi cod (*Cromileptes altivelis*) and moray eels (Muraenidae). Invertebrate species included in the surveys were sea urchins (*Diadema*), pencil urchins, giant clams (*Tridacna*), sea cucumbers (Holothurians), crown-of-thorns starfish (*Acanthaster planci*) and lobsters (*Panulirus*). Internationally recognised underwater visual survey methods were used to perform a census of the marine environment according to Reefcheck protocol. Reefcheck is an international organisation that is assembling the world's largest international database on coral reef status. By collecting data in a standardised format, Reefcheck is able to detect spatial and temporal trends in reef status across the globe and make comparisons on the status of coral reefs all around the world, including the Cocos (Keeling) Islands. Underwater visual censuses of fish and invertebrate species were conducted using four permanent 20 x 5 metre belt transects at each site. Transects were surveyed at a depth of 10m for 9 of the 11 sites, and at 3m depth at two sites within the lagoon. Habitat composition was determined using four replicate 20m line intercept transects, with substrate type noted under every 50cm increment.

Statistical analysis

To detect any significant changes in abundance statistical analyses were conducted on fish and invertebrate taxa. Only those taxa that were relatively common were analysed because species with low abundances typically have limited analysis power, high variances and provide little information. For common species, abundances were compared between years at each site using One-way ANOVAs where there were three or more years and when the assumptions of this analysis were met. If the assumptions were not met then the Kruskal Wallis non-parametric test was used. For sites with only two years of observations, between-years comparisons were conducted using a two-tailed T-test and if the assumption of homogeneity of variances was not met than a T-test assuming unequal variances was conducted. Homogeneity of variances was calculated using Levene's test with alpha set at $p = 0.05$. It was not possible to conduct statistical analyses for some sites due to zero abundance. Statistical analyses were conducted in SPSS (version 8.0) and Excel. To determine trends in substrate composition, data were represented graphically rather than analysed statistically (due to the descriptive nature of the data).

Results

Reef status

Live coral cover (soft and hard coral) was typically high, between 50–75%, for 8–11 sites (Figure 2). Pulu Chepelok had the highest live coral cover at around 75%. The lowest figures for live coral cover, 25–40%, were recorded at Horsburgh, Prison Island and Cabbage Patch 3 m depth. Relatively, the three most abundant substrate types were hard coral, soft coral and rock, which collectively accounted for more than 65% of the substrate composition across all sites and all years. Soft coral dominated the benthic composition at Bunya Coral, Soft Coral Gardens and Pulu Chepelok, whereas rock formed the major substrate type at Horsburgh, North Point and Prison Island, and hard coral was relatively abundant at Cologne Garden and Cabbage Patch 10m. Benthic composition at most sites varied little throughout the survey period. The most notable changes were increases in soft coral coverage at Two Trees from 33% in 2002 to 50% in 2005, in hard coral at 100th site from 21% in 2002 to 37% in 2004, in hard coral at Cologne Gardens from 33% in 2002 to 61% in 2005, and a spike in the abundance of hard coral at Cabbage Patch 3m in 2001 (59%).

Changes in substrate can be attributed to the movement of the transect line because, although the start and end points are fixed, the tape measure moves with the current. Photo points of 1 square metre are being installed in each transect to more accurately measure colonization rates and changes in substrate structure.

The abundance of crown-of-thorns starfish (*Acanthaster planci*) at 10 of the 11 sites averaged less than one individual per 100m square across all years (Table 1). Cabbage Patch 10m had the greatest average density of *A. planci* across all years (1.417 per 100m square), largely due to high densities in 1997 and 1998. In the following four years of surveys (conducted from 1999 to 2004) *A. planci* density dropped with only two individuals recorded in total over the four survey years. *A. planci* was not observed in surveys at Prison Island and Pulu Chepelok.

Coral damage, presence of rubbish, coral bleaching and disease generally were all very low across all sites over the entire survey period (Table 1). Coral damage was very low at most sites, with minor damage at Bunya Coral site and a small amount of anchor damage at Cabbage Patch 10m. Rubbish was not observed on eight of the 11 sites across the entire survey period, and was very low at Two

Trees, and at Cabbage Patch 3m and 10m. Coral bleaching (across all years) was also very low, with no records of bleaching at four sites and less than 1% of bleaching at the remaining seven sites. Coral disease (across all years) was almost non-existent with no records at nine sites and less than 1% of corals affected at the other two sites.

Fish status

The abundance of butterflyfish (Chaetodontidae) varied little across years for eight of the 11 sites (Figure 3a). There was a significant decrease ($p < 0.05$) in mean density per 100m square at Cabbage Patch 10m from 20.5 fish in 2001 to 7.5 fish in 2004, and Pulu Chepelok decreased significantly from 11.75 fish in 2000 to 3.75 in 2004 (Appendix A). Butterflyfish mean density increased significantly ($p < 0.05$) at Cologne Gardens from 9.75 fish per 100m square in 2003 to 23.75 in 2005. Butterflyfish mean density was consistently highest at 100th site, ranging from 17.75 to 24.5 fish per 100m square, and lowest at Soft Coral Garden and Horsburgh (3.75 to six fish per 100m square).

Parrotfish (Scaridae) abundance was generally consistent throughout the surveyed years at nine of the 11 sites (Figure 3b). There was a significant change ($p < 0.05$) in parrotfish density at Cabbage Patch 3m and 10m with both sites exhibiting a similar spike in abundance during 2001 (Appendix B). At Cabbage Patch 3m parrotfish density increased from zero fish per 100m square in 1999 to 11.25 fish in 2001 and then decreased to five fish in 2002. Cabbage Patch 10m exhibited a similar trend, increasing from zero fish per 100m square in 1999 to 11.25 fish in 2001, and then decreasing to 3.25 fish in 2002. Parrotfish abundance was consistently low at Bunya Coral site, Soft Coral Garden and Pulu Chepelok with densities less than one fish per 100m square.

The abundance of groupers (Serranidae) was consistent throughout the surveyed years for 10 of the 11 sites (Figure 3c). The only significant change in grouper density occurred at Cabbage Patch 3m, where mean density per 100m square was three fish in 1999 decreasing to 0.25 fish in 1999 (Appendix C). For most sites grouper density was variable between years, with no site having consistently high abundance. Grouper mean densities greater than one individual per 100m square were observed on only two occasions across all sites. Groupers were not observed at Bunya Coral site and Two Trees in three and four years of surveys respectively.

For humphead wrasse (*Cheilinus undulatus*), bumphead parrotfish (*Bolbometapon muricatum*), sweetlips (Haemulidae), snappers (Lutjanidae), barramundi cod (*Cromileptes altivelis*) and moray eels (Muraenidae) densities of less than one individual per 100m square were recorded at all 11 sites during the entire survey period (Table 2). For all years bumphead parrotfish and lutjanids were not recorded at nine of the 11 sites, moray eels were not recorded at seven sites, humphead wrasses were not recorded at five sites, sweetlips were not recorded at four sites and no barramundi cod were recorded at any of the 11 sites.

Invertebrate status

Pencil urchin densities were relatively consistent throughout the survey period for eight of the 11 sites (Figure 3d), but significant changes in abundance were observed at Cabbage Patch 3m, Horsburgh and Prison Island (Appendix D). At Cabbage Patch 3m, the mean density of pencil urchins per 100m square decreased from 6.5 individuals in 1999 to zero in 2001 and then increased to 9.25 individuals in 2003. At Horsburgh, the mean density of pencil urchins increased initially from 0.25 individuals per 100m square to 5.25 individuals in 2002 and then decreased considerably to 0.75 individuals in 2005. Pencil urchin mean density at Prison Island increased sharply from zero individuals per 100m square in 2002 to 4.75 individuals in 2003 and then dropped to 2.5 individuals in 2004. Pencil urchin density was consistently high at 100th site (density ranging from 3.75 – 6.25 individuals per 100m square) and lowest at North Point, Pulu Chepelok, Bunya Coral and Two Trees (less than one individual per 100m square for all surveys).

Numbers of giant clams (*Tridacna maxima*) were relatively stable at most sites with significant changes in abundance being observed at only two of the 11 sites (Figure 3e, Appendix E). Considerable fluctuations in abundance were recorded for Cabbage Patch 10m, the mean density per 100m square varying from zero in 2000 and 2003, to 15, eight and 7.75 in 1999, 2001 and 2004 respectively. Giant clam density increased significantly at 100th site from 10.5 individuals per 100m square in 2002 to 20.25 individuals in 2004. Cabbage Patch 3m and 100th site had consistently high densities of giant clams (8–28.25 individuals per 100m square), whereas North Point, Soft Coral Garden and Two Trees had very low abundances (less than one individual per 100m square for all surveys) and, in three surveys years, no giant clams were recorded in Horsburgh. The most likely reason the two sites within the Cocos lagoon (Cabbage Patch 3m and 100th sites) have higher densities of clams is because the water is calmer, which allows the clam larvae to settle. Constant water flow at the more exposed sites inhibits settlement.

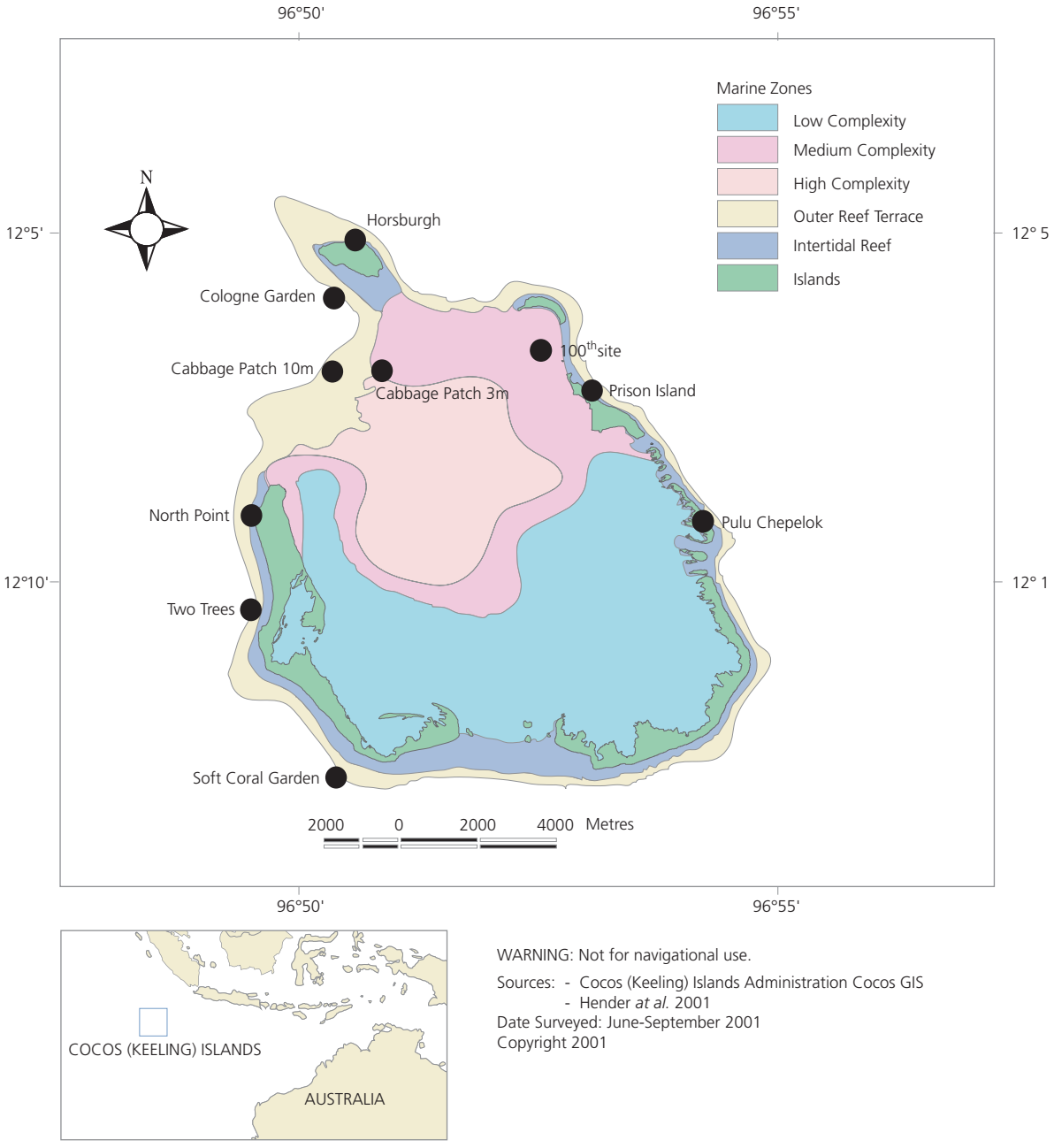
Surveys of edible sea cucumbers (holothurians) revealed considerable changes in abundance across years at four of the 11 sites (Figure 3f, Appendix F). The mean density of sea cucumbers per 100m square increased significantly at Prison Island from 1.7 individuals in 2002 to five individuals in 2004 ($p < 0.05$). Sea cucumber density at Horsburgh was approximately 15 individuals per 100m square in 2001, 2003 and 2004, but decreased to 6.5 individuals in 2002 and increased sharply to 24.25 in 2005. At Cabbage Patch 3m, sea cucumber density dropped considerably from 14.5 individuals per 100m square in 1997 to zero in 2001 and then increased sharply to 26.5 individuals in 2004. The sharpest increase in sea cucumber abundance was recorded at 100th site where density increased dramatically from 2.8 individuals per 100m square in 2003 to 116.25 individuals in 2004.

Diadema (sea urchins) density was greatest at Prison Island in the north-eastern section of the atoll. There densities ranged from 33.5 individuals per 100m square to 45 individuals from 2002 to 2004 (Figure 3g). The abundance of *Diadema* varied significantly through time at five of the 11 sites (Appendix G). At Bunya Coral, Cabbage Patch 3m, Horsburgh and Soft Coral Garden density increased significantly over 2–3 years ($p < 0.05$). At Two Trees, density decreased sharply from 18.25 individuals per 100m square in 2002 to 2.3 individuals in 2003 and then increased considerably to 21 individuals in 2005.

Lobster numbers were low. None were recorded at seven sites, and less than one individual per 100m square (averaged across all years) observed at the remaining four sites (Table 2).

Graphical representation of data

Figure 1: Marine zone map of the Cocos (Keeling) Islands, showing the Parks Australia reefcheck sites surveyed from 1997 to 2005. Bunya Coral site, located at North Keeling Island, is off the map.



WARNING: Not for navigational use.

Sources: - Cocos (Keeling) Islands Administration Cocos GIS
- Hender *at al.* 2001

Date Surveyed: June-September 2001

Figure 2: Substrate composition at 11 sites at the Cocos (Keeling) Islands, Indian Ocean between 1997 and 2005.

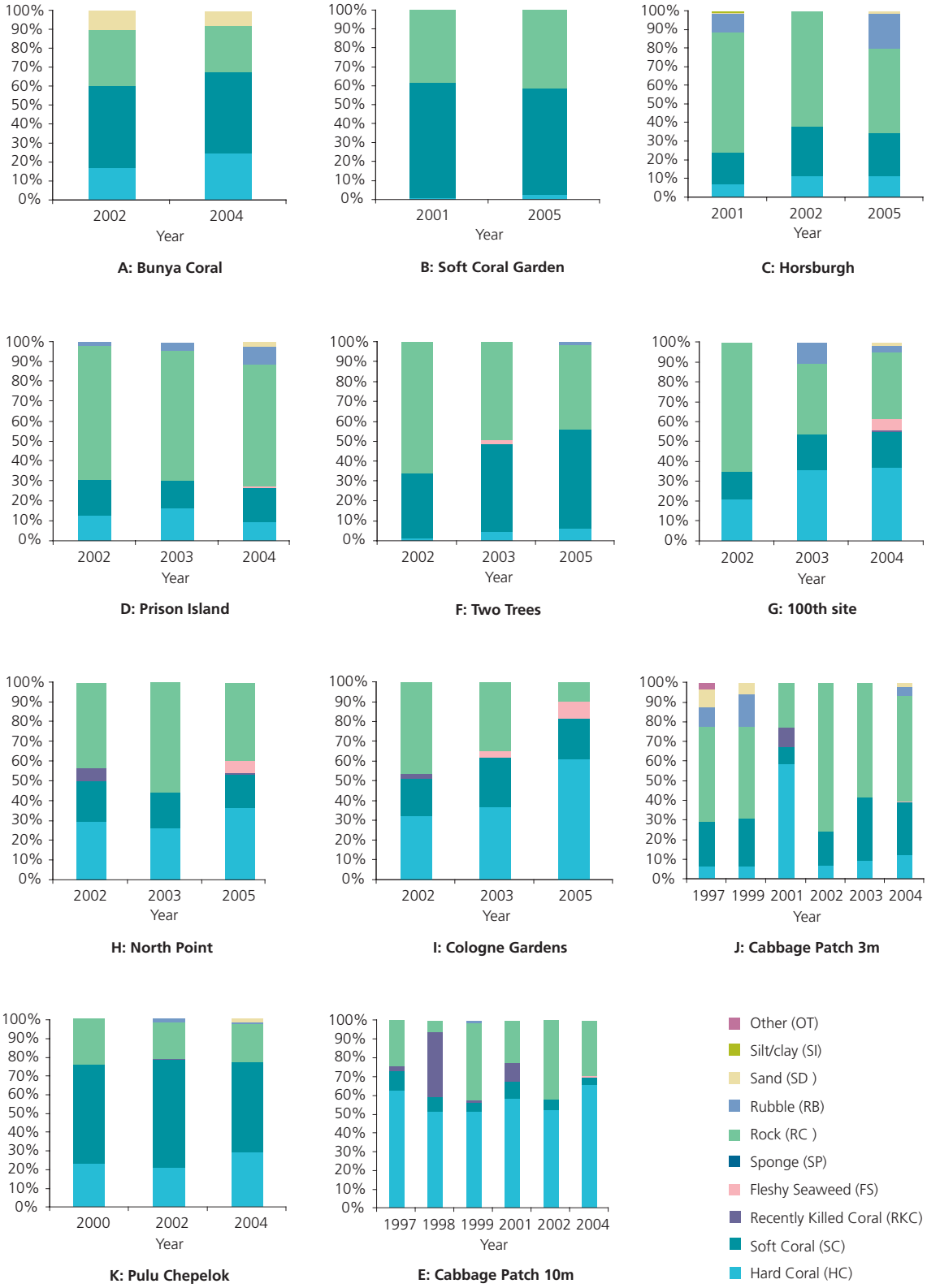
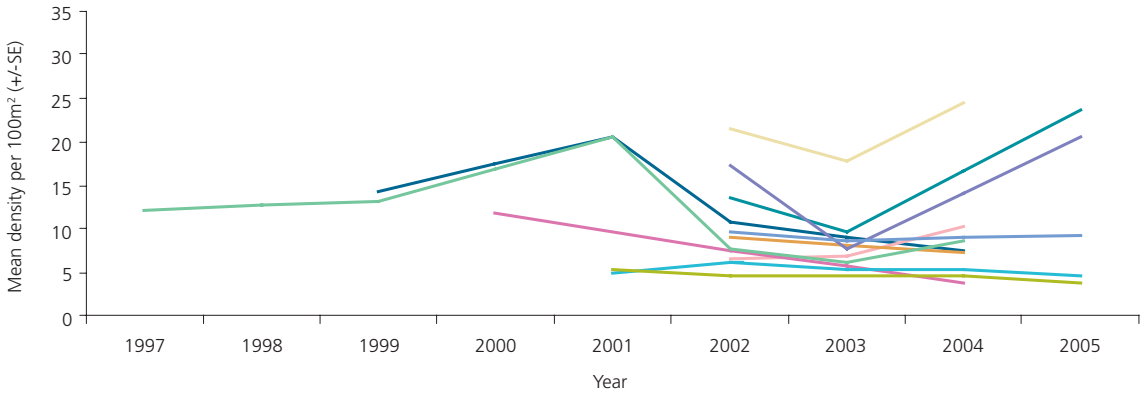
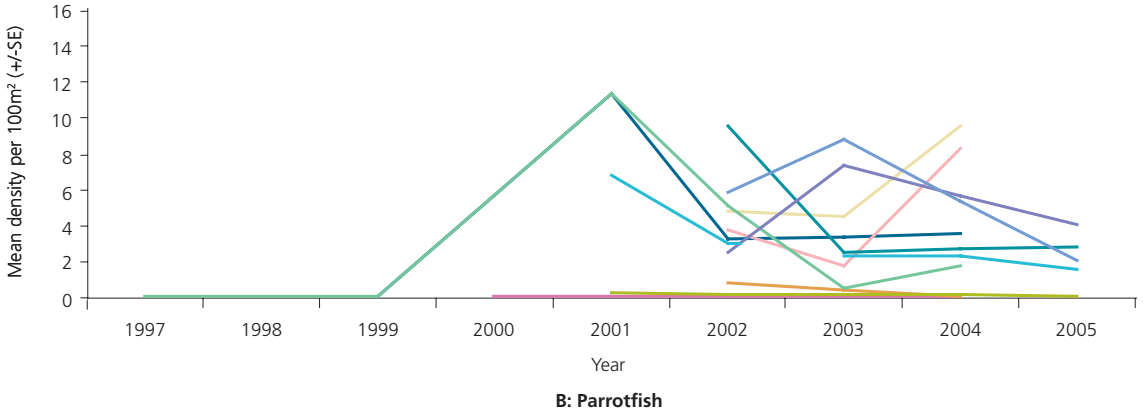


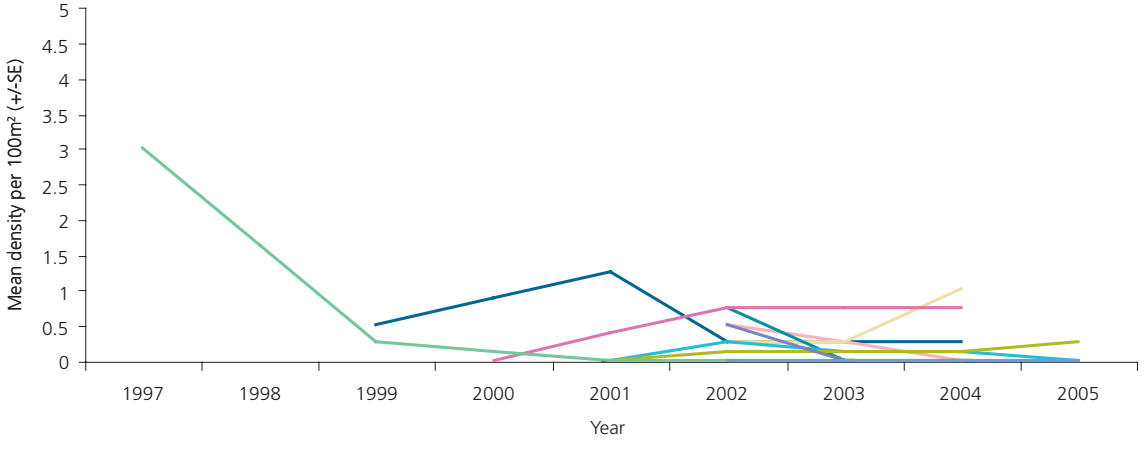
Figure 3: Mean densities (+/- SE) per 100m² of selected fish and invertebrate groups at 11 sites, Cocos (Keeling) Islands, Indian Ocean between 1997 and 2005.



A: Butterflyfish



B: Parrotfish



C: Grouper

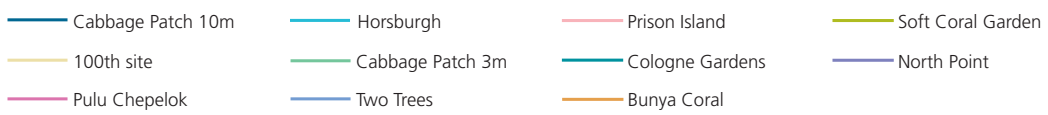


Figure 3 (cont): Mean densities (+/- SE) per 100m² of selected fish and invertebrate groups at 11 sites, Cocos (Keeling) Islands, Indian Ocean between 1997 and 2005.

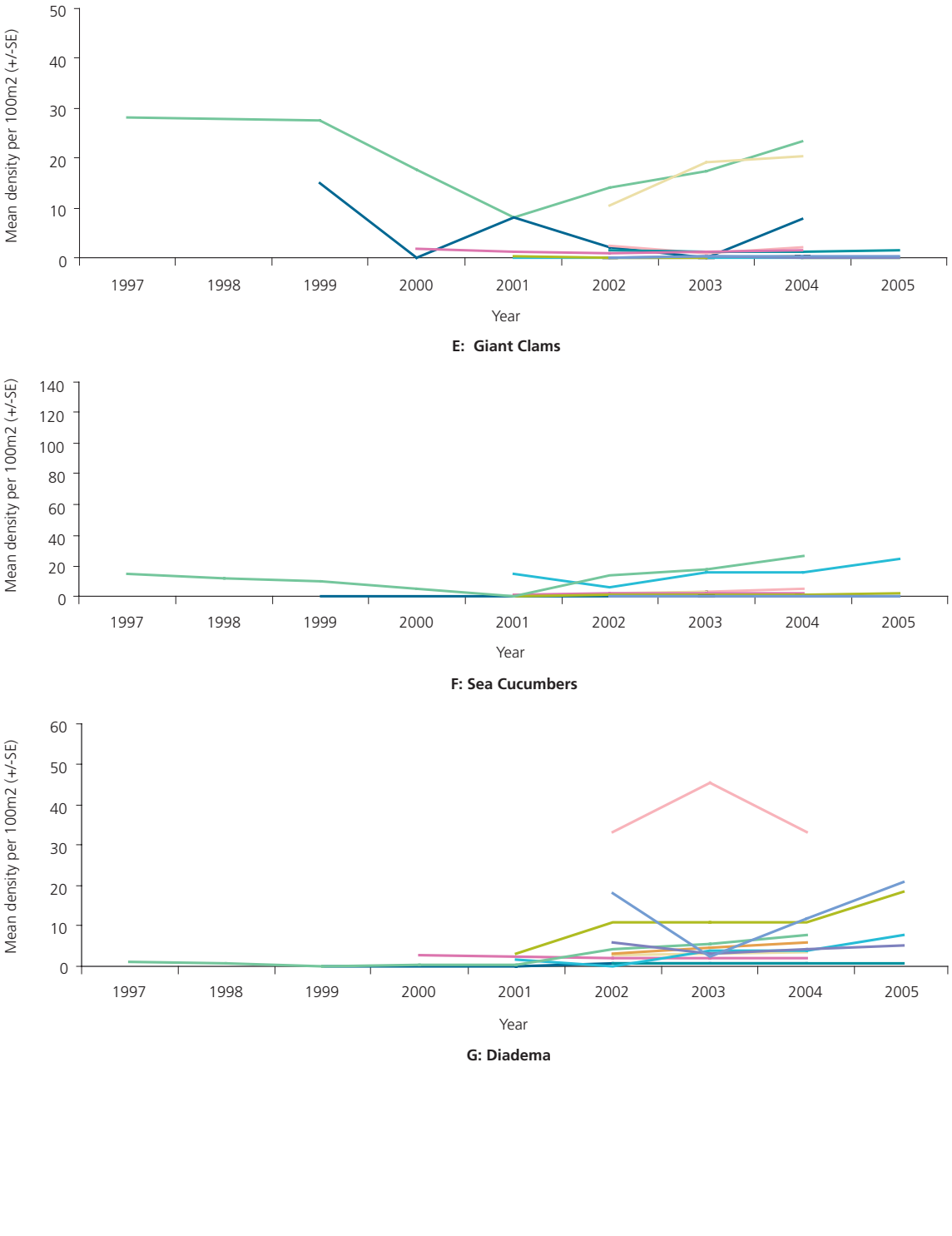


Table 1: Indicators of coral health, averaged over all years, for 11 sites surveyed at Cocos (Keeling) Islands, 1997–2005. Values for crown-of-thorns starfish are mean density per 100m^2. Values for coral bleaching and disease are mean percentages of coral population. Values for coral damage and rubbish are mean category values where 0=none, 1=low, 2=medium and 3=high.

Site	Crown-of-thorns starfish	Coral damage	Rubbish	Bleaching	Disease	Number of years
100th Site	0.167	0.278	0	0.333	0.833	3
Bunya Coral Site	0.375	1.167	0	0	0	2
Cabbage Patch 3m	0.083	0.125	0.125	0	0	6
Cabbage Patch 10m	1.417	0.764	0.208	0.901	0	6
Cologne Gardens	0.083	0.111	0	0.555	0	3
Horsburgh	0.083	0.111	0	0	0	3
North Point	0.083	0.25	0	0.667	0.333	3
Prison Island	0	0.055	0	0.333	0	3
Pulu Chepelok	0	0.055	0	0	0	3
Soft Coral Garden	0.125	0	0	0.5	0	2
Two Trees	0.167	0.111	0.208	0.667	0	3

Table 2: Mean density (per 100m square) of selected fish and lobsters, averaged over all years, surveyed at 11 sites at Cocos (Keeling) Islands, 1997–2005.

Site	Humphead Wrasse	Bumphead Parrotfish	Sweetlips	Snappers	Barramundi Cod	Moray Eel	Lobster	Number of years
100th Site	0.083	0	0.25	0	0	0	0.083	3
Bunya Coral Site	0	0.05	0	0.9	0	0.1	0	2
Cabbage Patch 3m	0.208	0	0.042	0	0	0.167	0	6
Cabbage Patch 10m	0.042	0	0.417	0	0	0	0	6
Cologne Gardens	0.083	0	0	0	0	0	0.083	3
Horsburgh	0.083	0	0.833	0	0	0	0	3
North Point	0.083	0.167	0.167	0.417	0	0	0.083	3
Prison Island	0	0	0	0	0	0.083	0	3
Pulu Chepelok	0	0	0.75	0	0	0.5	0	3
Soft Coral Garden	0	0	0	0	0	0	0	2
Two Trees	0	0	0.083	0	0	0	0.083	3

Discussion

Overall, there was little change in the marine community at the 11 surveyed sites at Cocos (Keeling) Islands from 1997–2005. The small number of significant changes in abundance that were observed were mainly due to short-term fluctuations occurring within the eight-year survey period.

Reef status

The coral reefs at Cocos appear to be very healthy. Live coral cover at most sites ranges between 50–75% ('good' category: Gomez and Alcala, 1979; Gomez *et al.*, 1981) and increased at some sites during the survey period. Only small amounts of recently killed coral or fleshy macro-algae were observed. Crown-of-thorns starfish were in relatively high densities at some sites, and have been consistently reported at high densities previously at Cocos (Keeling) Islands (Colin, 1977; Woodroffe and Berry, 1994; Hender et al., 2001). Coral damage, bleaching and disease were all very low and almost non-existent across all sites for the entire survey period. No mass die-offs were reported by the public during the 1997–2005 survey period.

Fish status

As a whole, the fish community of the Cocos (Keeling) Islands appears to have been stable through time, with only a small number of minor exceptions. Non-target fish species, including groupers, parrotfish and butterflyfish, were generally stable indicating overall healthy reefs with minimal impact from harvesting at the survey sites during the monitoring period. The few observed changes in fish abundance over time are most likely to have been natural fluctuations. Butterflyfish and parrotfish were recorded in densities similar to those previously reported at Cocos (Keeling) Islands (Hender *et al.*, 2001).

The density of groupers (Serranidae) at the 11 sites surveyed between 1997 and 2005 ranged from 0 to 300/ha with an average across all sites during the entire survey period of 31.25/ha. The mean densities of groupers estimated by Parks Australia, are close to that found in the survey at the Cocos atoll by Hender *et al*. (2001), which estimated a density of 36.63/ha in similar habitats. The abundance of groupers was much lower than recorded in an earlier study at the Cocos (Keeling) Islands by Lincoln Smith *et al*. (1993), which estimated a density of 128/ha. More detailed surveys separating individual species are required to determine if the decrease in density is a result of different survey design or true changes in grouper abundance. Mean densities of groupers at Cocos (Keeling) Islands are comparable to those reported for the Sumilion Islands in the Philippines (45.2/ha: Russ & Alcala, 1989) and reefs in Kenya (42.8–68.8/ha: Samoilys, 1988).

Densities of fewer than 10 individuals per hectare were recorded at all sites over the entire survey period for humphead wrasse (*Cheilinus undulates*), bumphead parrotfish (*Bolbometapon muricatum*), sweetlips (Haemulidae), snappers (Lutjanidae) and moray eels (Muraenidae). Comparable mean densities for sweetlips, bumphead parrotfish and humphead wrasse were estimated at the Cocos (Keeling) Islands and MOU74 Box, while the estimated density of snappers was substantially lower than those of Hender *et al*., (2001) and Skewes *et al*., (1999), respectively. More detailed surveys are required to investigate the apparent low abundance of snappers.

Invertebrate status

At most sites densities of the selected invertebrates were relatively constant through time, although a significant increase in abundance of *Diadema* was recorded at four of 11 sites. This could have been a response to increases in algae, or due to gregarious behaviour. *Diadema* counts were only added to the Reefcheck surveys in 2001. The abundance of sea cucumbers and pencil urchins did not vary significantly through time at most sites. The few recorded differences in density were mainly due to short-term fluctuations and could have been responses to increased availability of food or suitable habitat or may reflect changes associated with the study organisms' behaviour and movements between censuses. Giant clam densities fluctuated little through time for most sites indicating that, currently, traditional harvesting is not reducing densities at these sites.

Crown-of-thorns starfish (*Acanthaster planci*) densities varied during the survey period, ranging from zero at a number of sites, to 600/ha in 1997 at the Cabbage Patch 10m site. The average density of *A. planci* across all sites over the 1997 to 2005 survey period was 23.48/ha. Hender *et al*. (2001) reported densities of *A. planci* of 63.2/ha in similar habitats at Cocos (Keeling) Islands. Estimates from the current study and Hender *et al*. (2001) appear to be consistent taking into account the mix of outer reef terrace and lagoon sites. Colin (1977) reported extensive areas of dead hard coral at the Cocos (Keeling) Islands on the outer reef slope to a depth of 45m. He attributed these to predation by *A. planci*. In the same study, Colin observed densities of *A. planci* of approximately 25–50/ha between 15–30 metres depth. According to Moran and De'ath (1992), densities greater than 15/ha are considered to be of outbreak class. Thus, Cocos (Keeling) Islands have experienced several outbreak episodes. Over the current survey period, four sites had mean densities (averaged over all years) that were greater than 15/ha. There appeared to be no relationship between hard coral cover and *A. planci* abundance, as evident at Cabbage Patch 10m, which had the highest hard coral cover and also the greatest density of *A. planci*.

The abundance of *Diadema* was stable at six of the 11 sites and increased at the remaining five sites. Between 1997 and 2005, *Diadema* densities varied substantially between sites from 0 to 4550/ha with an average of 623.56/ha across all sites over the entire survey period. The variability in *Diadema* estimates is due to the fact that *Diadema* counts were only added to the Reefcheck surveys in 2001. Pencil urchin densities appeared stable at the majority of sites and fluctuated at the remaining sites. Densities varied between sites from 0 to 925/ha, averaging 177.75/ha across all sites over the survey period.

Waters of the Cocos (Keeling) Islands support a high biomass of sea cucumbers. Little harvesting of sea cucumbers has taken place over the last 50 years, although anecdotal accounts indicate that heavy harvesting occurred in the 1950s. The Parks Australia surveys between 1997 and 2005 show considerable variation in sea cucumber densities over time, ranging from 0 to 11625/ha, with an average of 645.57/ha across all sites over the entire survey period. The mean density of holothurians is similar to the density of 539.47/ha estimated in a survey in similar habitats of the Cocos (Keeling) Islands (Hender *et al.*, 2001). These Cocos (Keeling) Islands densities are over 20 times greater than the estimated density of 26.8/ha reported for the fished sea cucumber populations of the MOU 74 Box around Ashmore Reef (Skewes et al., 1999), although the Cocos sea cucumbers are considered very small in size (Hender et al. 2001). Sea cucumber fisheries are prone to over exploitation (Uthicke, 1996) and, with commercial fishing licenses proposed for Cocos (Keeling) Islands, it is important that careful management and monitoring policies are implemented.

Giant clam densities appear to be stable over time, although densities between sites ranged from 0 to 2825/ha. The density averaged across all sites over the entire survey period was 535.5/ha, which is similar to the earlier estimate for the Cocos (Keeling) Islands (361/ha), but low when compared to One Tree Island on the Great Barrier Reef (8000/ha) and high when compared to surveys of Kiribati (100/ha) and Tuvalu (63–101/ha) (McMichael, 1975; Braley, 1988; Munro, 1988; Hender *et al.*, 2001). Clam densities are greater in the more protected waters, where conditions are calm enough for clam larvae to settle.

Conclusion

Based on the underwater surveys at 11 sites from 1997 to 2005 it appears that the coral reef community at Cocos (Keeling) Islands is very healthy and experiencing a stable period with low anthropogenic impacts. Live coral cover is high and there is minimal evidence of coral damage, bleaching and disease. Crown-of-thorns starfish were recorded at high densities at four sites. They have been recorded previously at high densities at Cocos (Keeling) Islands, so these levels may not be unusual and in this current study there seemed to be no clear deleterious impact of starfish on hard coral cover. Continued monitoring of crown-of-thorns numbers is necessary for understanding patterns in starfish abundance and their impact on the reef community, particularly on hard corals.

Overall, fish and invertebrate densities were at constant levels throughout the survey period and comparable to those recorded in previous studies at Cocos (Keeling) Islands and also at other locations. Notable exceptions include the very high abundance of small sea cucumbers and the relatively low abundance of snappers. A small number of significant changes occurred in the densities of some study taxa during the survey period, but these changes were usually the exception and represented short-term fluctuations.

Disturbance events generally appeared to be lacking during the study period. Although high densities of *A. planci* were recorded, no clear impact of these starfish on the coral community was noted. The marine community at Cocos (Keeling) Islands has experienced severe disturbance events in the past (e.g. mass die-offs as recent as 1983: Bunce, 1988) and these are likely to have had a significant impact on the reef community. Such events (e.g. coral bleaching: Hoegh-Guldberg, 1999) are likely to recur, and may even increase in frequency and intensity. Given that isolated islands can be expected to have high extinction rates and, generally, low recovery rates (Whittaker, 1998) and in view of the history of disturbance events that have occurred at Cocos (Colin, 1977; Bunce, 1988; Woodroffe and Berry, 1994), it is of utmost importance that monitoring be continued. Assessment of the impact of disturbances and the rate of recovery of the reef community, and identification of susceptible species, are fundamental to effective management. Expansion of the monitoring program into the southern lagoon where mass die-off events have been reported previously (Bunce, 1988; Woodroffe and Berry, 1994), would be beneficial to ensuring sustainability of the Cocos (Keeling) Islands reef community.

References

Braley, R.D. (1988). The status of giant clam stocks and potential of mariculture in Tuvalu. Report prepared for Fisheries Division. Funafuti, Tuvalu, FAO South Pacific Aquaculture Development Project, Fiji, 38pp.

Bunce, P. (1988). *The Cocos (Keeling) Islands, Australian Atolls in the Indian Ocean*. The Jacaranda Press, Australia. 144pp.

Colin, P.L. (1977). The reefs of Cocos (Keeling) Atoll, Eastern Indian Ocean. *Proceedings, 3rd International Coral Reef Symposium.* University of Miami

Gomez, E.D. and Alcala, A.C. (1979). Status of Philippine Coral reefs. *Proceedings of the International Symposium on Marine Biogeography and Evolution in the Southern Hemisphere* 2: 163–669

Gomez, E.D., Alcala, A.C. and San Diego, A.C. (1981). States of Philippine coral reefs. *Proceedings of the 4th International Coral Reef Symposium*, pp. 275–282

Hender, J., McDonald, C.A. and Gilligan, J.J. (2001). Baseline surveys of the marine environments and stock size estimates of marine resources of the south Cocos (Keeling) Atoll (0–15m), eastern Indian Ocean. Draft Report to Fisheries Resources Research Fund. Canberra

Hoegh-Guldberg, O. (1999). Coral bleaching, climate change and the future of the world's Coral Reefs. *Marine and Freshwater Research* 50: 839–866

Lincoln-Smith M. P., Skilleter G. A., Underwood A.J., Smith A. K., Hawes P. M. H., Howitt L., Stark J. and Chapman, M. G. (1993) Study of the impact of harvesting marine invertebrates and fish on the marine ecosystems of the Cocos (Keeling) Islands, Indian Ocean - final report. Unpublished report to the Australian Nature Conservation Agency, Darwin.

Marsh, L.M. (1994). Echinoderms of the Cocos (Keeling) Islands. *Atoll Research Bulletin* no. 406

McMichael, D.F. (1975). Growth rate, population size and mantle colouration in the small giant clam Tridacna maxima (Roding) at One Tree Island, Capricorn Group, Queensland. *Proceedings of the 2nd International Coral Reef Symposium* 1: 242–254

Moran, P.J. and De'ath, G. (1992). Estimates of the abundance of the crown-of-thorns starfish *Acanthaster planci* in outbreaking populations and non-outbreaking populations on reefs within the Great Barrier Reef. *Marine Biology* 113: 509–515

Munro, J.L. (1988). Status of giant clam stocks in the central Gilbert Islands group of the Republic of Kiribati. South Pacific Commission, Inshore Fisheries Research Workshop Background Paper. 54, 13 pp.

Russ, G.R. and Alcala, A.C. (1989). Effects of intense fishing pressure on an assemblage of coral reef fish. *Marine Ecology Progress Series* 56: 13–27

Samoilys, M.A. (1988). Abundance and Species Richness of Coral Reef Fish on the Kenyan Coast. *Proceedings of the 6th International Coral Reef Symposium.*

Skewes, T.D., Dennis, D.M., Jacobs, D.R., Gordon, S.R., Taranto, T.J., Haywood, M., Pitcher, C.R., Smith, G.P., Milton, D. and Poiner, I.R. (1999). Survey and stock size estimates of the shallow reef (0–15m deep) and shoal area (15–50m deep) marine resources and habitat mapping within the Timor Sea MOU74 Box. Unpublished report to the Fisheries Resources Research Fund

Uthicke, S. (1996). Beche-de-Mer: A Literature Review on Holothurian Fishery and Ecology. Final report. Unpublished report to Cape York Land Council

Whittaker, R.J. (1998). *Island Biogeography: Ecology, Evolution and Conservation.* Oxford University Press, New York

Woodroffe, C.D. and Berry, P.F. (1994). Scientific studies of the Cocos (Keeling) Islands: An introduction. *Atoll Research Bulletin* no. 406

Appendices

Appendix A: Statistical analysis of butterflyfish abundance from 1997–2005 at 11 sites at Cocos (Keeling) Islands.

Site	Test	Chi-Square/ F stat/ T stat	d.f.	Sig	p <0.05
100th site	One-way ANOVA	3.010968921	2	0.09973	No
Bunya Coral	T-test	0.484200125	6	0.64541	No
Cabbage Patch 3m	One-way ANOVA	2.437965261	5	0.074457	No
Cabbage Patch 10m	One-way ANOVA	4.203677511	3	0.030026	Yes
Cologne Gardens	Kruskal-Wallis	7.362280369	2	0.025194	Yes
Horsburgh	Kruskal-Wallis	1.490842462	2	0.474534	No
North Point	One-way ANOVA	2.658116064	2	0.12384	No
Prison	One-way ANOVA	0.417190776	2	0.671011	No
Pulu Chepelok	One-way ANOVA	5.855329949	2	0.023508	Yes
Soft Coral Garden	T-test	0.826767382	6	0.440002	No
Two Trees	One-way ANOVA	0.039430449	2	0.961502	No

Appendix B: Statistical analysis of parrotfish abundance from 1997–2005 at 11 sites at Cocos (Keeling) Islands.

Site	Test	Chi-Square/ F stat/ T stat	d.f.	Sig	p <0.05
100th site	One-way ANOVA	1.755760369	2	0.22709	No
Bunya Coral	Not applicable				
Cabbage Patch 3m	Kruskal-Wallis	16.65151978	5	0.00521	Yes
Cabbage Patch 10m	One-way ANOVA	5.388807069	3	0.01396	Yes
Cologne Gardens	One-way ANOVA	2.300911854	2	0.15592	No
Horsburgh	Kruskal-Wallis	1.974107146	2	0.37267	No
North Point	One-way ANOVA	3.329411765	2	0.08273	No
Prison	One-way ANOVA	1.795275591	2	0.22074	No
Pulu Chepelok	Not applicable				
Soft Coral Garden	T-test assuming unequal variances	1	3	0.391	No
Two Trees	One-way ANOVA	1.872483221	2	0.20896	No

Appendix C: Statistical analysis of grouper abundance from 1997–2005 at 11 sites at Cocos (Keeling) Islands.

Site	Test	Chi-Square/ F stat/ T stat	d.f.	Sig	p <0.05
100th site	One-way ANOVA	0.9	2	0.440235	No
Bunya Coral	Not applicable				
Cabbage Patch 3m	Kruskal-Wallis	19.12024117	5	0.001825	Yes
Cabbage Patch 10m	Kruskal-Wallis	1.752475381	3	0.625331	No
Cologne Gardens	Kruskal-Wallis	2.000000238	2	0.367879	No
Horsburgh	Kruskal-Wallis	2.000000238	2	0.367879	No
North Point	Kruskal-Wallis	4.400000095	2	0.110803	No
Prison	Kruskal-Wallis	2.444444418	2	0.294575	No
Pulu Chepelok	Kruskal-Wallis	3.791666746	2	0.150193	No
Soft Coral Garden	T-test assuming unequal variances	-1	3	0.391002	No
Two Trees	Not applicable				

Appendix D: Statistical analysis of pencil urchin abundance from 1997–2005 at 11 sites at Cocos (Keeling) Islands.

Site	Test	Chi-Square/ F stat/ T stat	d.f.	Sig	p <0.05
100th site	One-way ANOVA	2.936619718	2	0.104296	No
Bunya Coral	T-test	-1.414213562	6	0.207031	No
Cabbage Patch 3m	Kruskal-Wallis	17.83204651	6	0.003164	Yes
Cabbage Patch 10m	Kruskal-Wallis	4.230769157	3	0.237599	No
Cologne Gardens	One-way ANOVA	2.052631579	2	0.184326	No
Horsburgh	Kruskal-Wallis	8.601503372	2	0.013558	Yes
North Point	One-way ANOVA	0.346153846	2	0.716422	No
Prison	Kruskal-Wallis	8.478302002	2	0.01442	Yes
Pulu Chepelok	Kruskal-Wallis	2.000000238	2	0.367879	No
Soft Coral Garden	T-test assuming unequal variances	-1.782265577	3	0.172724	No
Two Trees	One-way ANOVA	0.705882353	2	0.519077	No

Appendix E: Statistical analysis of giant clam abundance from 1997–2005 at 11 sites at Cocos (Keeling) Islands.

Site	Test	Chi-Square/ F stat/ T stat	d.f.	Sig	p <0.05
100th site	One-way ANOVA	5.868271955	2	0.02338	Yes
Bunya Coral	Not applicable				
Cabbage Patch 3m	Kruskal-Wallis	1.906300918	5	0.14323	No
Cabbage Patch 10m	One-way ANOVA	3.526244953	3	0.04868	yes
Cologne Gardens	One-way ANOVA	0.058823529	2	0.94323	No
Horsburgh	Not applicable				
North Point	Kruskal-Wallis	2.000000238	2	0.36788	No
Prison	One-way ANOVA	1.016129032	2	0.40004	No
Pulu Chepelok	One-way ANOVA	0.382	2	0.693	No
Soft Coral Garden	T-test assuming unequal variances	1	3	0.391	No
Two Trees	Kruskal-Wallis	1.100000024	2	0.57695	No

Appendix F: Statistical analysis of sea cucumber abundance from 1997–2005 at 11 sites at Cocos (Keeling) Islands.

Site	Test	Chi-Square/ F stat/ T stat	d.f.	Sig	p <0.05
100th site	One-way ANOVA	5.29962565	2	0.03013	Yes
Bunya Coral	Not applicable				
Cabbage Patch 3m	One-way ANOVA	20.00493151	5	8.8E-07	Yes
Cabbage Patch 10m	One-way ANOVA	0.333333333	3	0.80151	No
Cologne Gardens	Not applicable				
Horsburgh	One-way ANOVA	7.432220039	2	0.01242	Yes
North Point	One-way ANOVA	0.157894737	2	0.85625	No
Prison	One-way ANOVA	4.663636364	2	0.04075	Yes
Pulu Chepelok	Kruskal-Wallis	3.710698605	2	0.1564	No
Soft Coral Garden	T-Test	-2.049390153	6	0.08631	No
Two Trees	Not applicable				

Appendix G: Statistical analysis of *Diadema* abundance from 1997–2005 at 11 sites at Cocos (Keeling) Islands.

Site	Test	Chi-Square/ F stat/ T stat	d.f.	Sig	p <0.05
100th site	One-way ANOVA	0.513513514	2	0.61492	No
Bunya Coral	T-test assuming unequal variances	7.071067812	4	0.00211	Yes
Cabbage Patch 3m	Kruskal-Wallis	20.45372009	5	0.00103	Yes
Cabbage Patch 10m	Kruskal-Wallis	4.011904716	3	0.26018	No
Cologne Gardens	One-way ANOVA	0.115384615	2	0.89232	No
Horsburgh	Kruskal-Wallis	9.115537643	2	0.01049	Yes
North Point	Kruskal-Wallis	3.05109477	2	0.2175	No
Prison	One-way ANOVA	1.44002399	2	0.28669	No
Pulu Chepelok	One-way ANOVA	0.272727273	2	0.76737	No
Soft Coral Garden	T-test	-4.473451096	6	0.00422	Yes
Two Trees	One-way ANOVA	14.16424682	2	0.00166	Yes