THE STATUS OF THE CORAL REEF COMMUNITY AT THE COCOS (KEELING) ISLANDS, EASTERN INDIAN OCEAN, 1997–2005.

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EXECUTIVE SUMMARY

The Cocos (Keeling) Islands are a remote coral reef atoll located in the eastern Indian Ocean. The marine community is largely comprised of 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. These disturbances, and the remoteness of the 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 have 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 was collected on important indicator, keystone and harvested marine fish and invertebrate species as well habitat composition.

Based on the underwater surveys at 11 sites from 1997 to 2005 is appears that the coral reef community at Cocos (Keeling) Islands is very healthy and in a stable period with little anthropogenic impacts. Live coral cover is high and there is minimal impact from coral damage, bleaching, and disease. 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 abundance were found to have similar abundance levels throughout the survey period at all sites. A small number of significant changes occurred in the abundances of some study taxa, however these changes were usually the exception and represented short-term fluctuations in abundance. 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 in the abundance data were a very high abundance of sea cucumbers and a relatively low abundance of snappers. Further monitoring will determine whether these exceptions are typical for Cocos (Keeling) Islands or just a short-term occurrence that was observed during the 1997-2005 survey period.

With the exception of crown-of thorns starfish, disturbance events that have been reported previously for Cocos were generally lacking during the study period, however these are likely to occur in the near future and may even increase in frequency and intensity (e.g. coral bleaching). Given that isolated islands have the highest extinction rates, generally low recovery rates, and the history of disturbance events that have occurred at Cocos, it is of utmost importance that monitoring continue as disturbance events are likely to occur in the near future and assessing the impact and recovery of the reef community and identifying susceptible species is fundamental to management. Expanding the monitoring program into the southern lagoon, where mass die-off events have been reported previously, would be beneficial to determining the impacts of such die-offs on the reef community.

1. INTRODUCTION

The Cocos (Keeling) Islands (12º 12' S, 96º 54' E) are an external Australian territory situated in the eastern Indian Ocean approximately 2700km northwest of Perth, 900km WSW of Christmas Island and 1000km SW 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 is comprised mainly of species from Indo-West Pacific, with only a small number of West Indian Ocean species (Woodroffe and Berry, 1994). Endemism is very low at Cocos, which is thought to be related to the geological development of the atoll (Woodroffe and Berry, 1994). The only known endemic marine species is the angelfish *Centropyge joculator*, which also occurs at neighbouring Christmas Island.

The Cocos (Keeling) Islands are comprised of 27 islands of which 2 are inhabited comprising a total population of around 600 people. The islands have been inhabited since 1826 and the environment has been modified accordingly. The most notable changes have been on land where vegetation was once cleared to make way for coconut plantations for a copra industry that has since ceased (Bunce, 1988). The marine environment has received very little anthropogenic impacts with subsistence fishing accounting for a relatively small harvest of fish and invertebrates. Although small-scale changes may have occurred through inhabitation and the subsistent needs of the small population, the remoteness of the islands has resulted in very little commercial exploitation of valuable marine species.

Although isolation has been a barrier to commercial exploitation, the remoteness and relatively small size of islands typically results in a species poor community with a high proportion of endemics but also relatively high rates of extinction (Whittaker, 1998). In addition, marine species on isolated islands are largely relying on the self-recruitment of larvae. Consequently if a disturbance event, such as coral bleaching or crown-of-thorns starfish outbreak, were severe enough to significantly reduce the abundance of a species at Cocos (Keeling) Islands then recovery is expected to be slow because species would be relying on the 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 of self-recruitment, species inhabiting isolated islands, such as the Cocos (Keeling) 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, crowns-of-thorns starfish outbreaks and mass die-offs of corals and fishes (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 health of coral reefs in order to document long-term trends in abundance and community structure, as well identifying destructive processes, describing their impacts, and identifying the species that are most susceptible. Ongoing monitoring is also important to 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 health of the coral reef community at Cocos (Keeling) Islands and identify any significant changes in abundance or community structure from 1997 to 2005.

2. METHODS

2.1 Data collection

To determine the health of 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 that involves the collection of field data on an annual basis at 11 representative sites around the atoll. Ten 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. Data was 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) parrotfishes (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 *Diadema* (sea urchins), pencil urchin, giant clams (*Tridacna*), sea cucumbers (Holothurians), crown-of-thorns starfish (*Acanthaster planci*) and lobsters (*Panulirus*). Internationally recognised underwater visual surveys methods were used to census the marine environment according to Reefcheck protocol. Reefcheck is an international organization that is assembling the world's largest international database on coral reef health. By collecting data in a standardised format Reefcheck is able to detect spatial and temporal trends in reef health 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 4 permanent 20 x 5 metre belt transects at each site. Transects were conducted at a depth of 10m for 10 of the 11 sites, and at 3m depth at one Cabbage Patch site. Habitat composition was determined using 4 replicate 20m line intercept transects, with substrate type noted under every 50cm increment.

2.2 Statistical analyses

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 3 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 was graphical represented rather than analysed statistically due to the nature of the data.

3. RESULTS

3.1 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 around 75% and the lowest live coral cover (25 – 40%) was recorded at Horsburgh, Prison Island and Cabbage Patch 3m. The three most relatively 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. Most sites remained relatively similar in benthic composition throughout the survey period. The most notable changes were increase in soft coral coverage at Two Trees from 33% in 2002 to 50% in 2005, an increase in hard coral at 100th site from 21% in 2002 to 37% in 2004, an increase 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%).

The abundance of crown-of-thorns starfish (*Acanthaster planci*) at 10 of the 11 sites averaged less than 1 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 4 years of surveys (conducted from 1999 to 2004) *A.planci* density dropped with only 2 individuals recorded in total over the 4 survey years. *A. planci* was not observed in surveys at Prison Island and Pulu Chepelok.

Coral damage, presence of rubbish, coral bleaching and disease were all generally 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 8 of the 11 sites across the entire survey period, and was very low at the Two Trees, Cabbage Patch 3m and 10m. Coral Bleaching (across all years) was also very low, with no records of bleaching at 4 sites and less than 1% of bleaching at the remaining 7 sites. Coral disease (across all years) was almost non-existent with no records at 9 sites and less than 1% of corals affected at the other 2 sites.

3.2 Fish status

The abundance of butterflyfishes (Chaetodontidae) remained similar across years for 8 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 6 fish per 100m square).

Parrotfish (Scaridae) abundance was generally consistent through the surveyed years at 9 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 0 fish per 100m

square in 1999 to 11.25 fish in 2001 and then decreased to 5 fish in 2002. Cabbage Patch 10m exhibited a similar trend increasing from 0 fish per 100m square in 1999 to 11.25 fish in 2001 and then decreased 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 1 fish per 100m square.

The abundance of groupers (Serranidae) remained similar 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 3 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 1 individual per 100m square were observed on only 2 occasions across all sites. Groupers were not observed at Bunya Coral site and Two Trees in 3 and 4 years of surveys respectively.

Densities of less then 1 individual per 100m square at all 11 sites during the entire survey period were recorded for humphead wrasse (*Cheilinus undulatus*), bumphead parrotfish (*Bolbometapon muricatum*), sweetlips (Haemulidae), snappers (Lutjanidae), barramundi cod (*Cromileptes altivelis*) and moray eels (Muraenidae) (Table 2). For all years bumphead parrotfish and Lutjanids were not recorded at 9 of the 11 sites, moray eels were not recorded at 7 sites, humphead wrasses were not recorded at 5 sites, sweetlips were not recorded at 4 sites and barramundi cod was not recorded at any of the 11 sites.

3.3 Invertebrate status

Pencil urchin densities remained relatively consistent through the survey period for 8 of the 11 sites (Figure 3d). Significant changes in abundance through time were observed at Cabbage Patch 3m, Horsburgh and Prison Island (Appendix D). The mean density per 100m square of pencil urchins at Cabbage Patch 3m 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 form 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 1 individual per 100m square for all surveys).

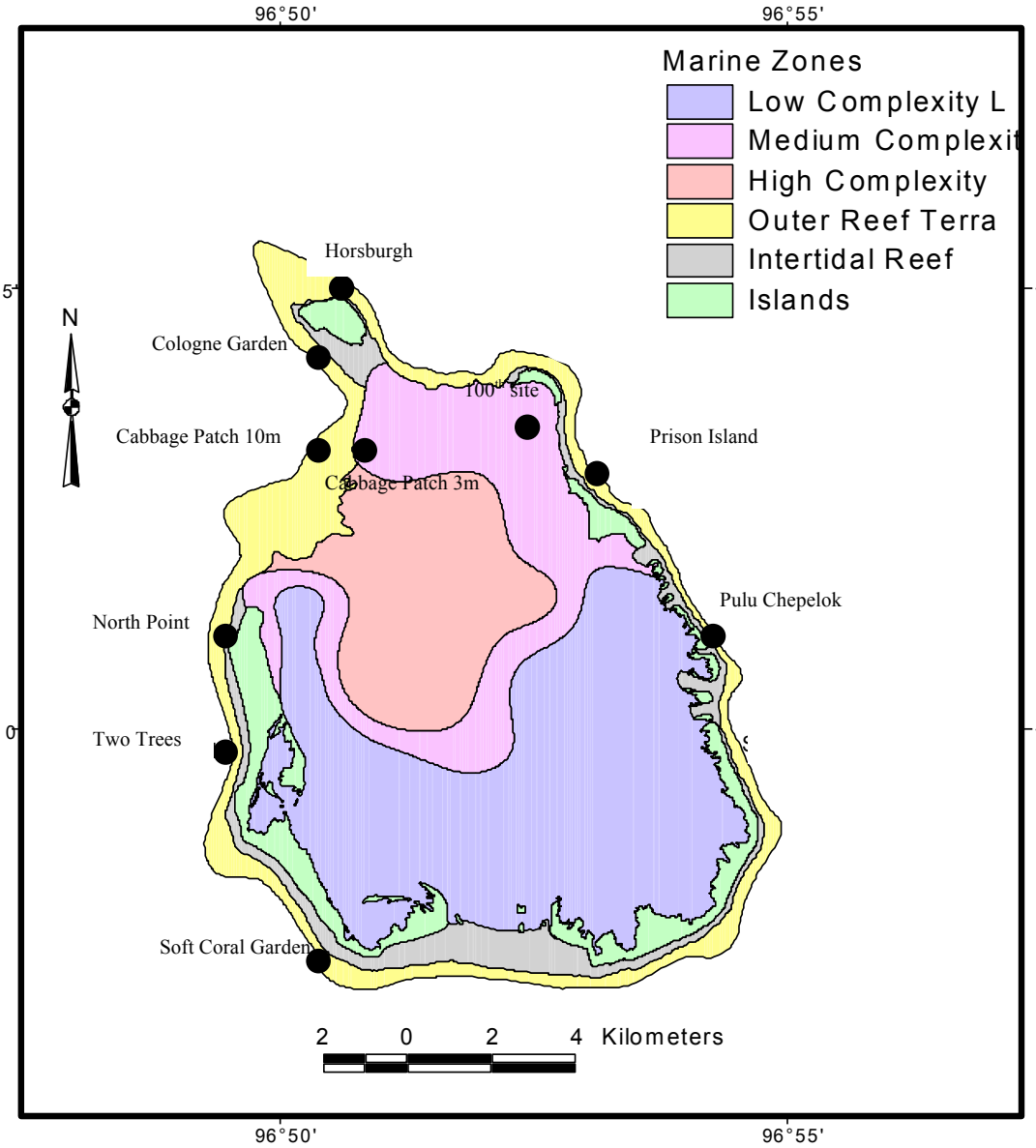
Giant clams (*Tridacna*) remained relatively stable in abundance at most sites with significant changes in abundance being observed at 2 of the 11 sites (Figure 3e, Appendix E). Cabbage Patch 10m exhibited considerable fluctuation in abundance with mean density per 100m square varying from zero in 2000 and 2003, to 15, 8 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 1 individual per 100m square for all surveys) and Horsburgh had no giant clams recorded in 3 years of surveys.

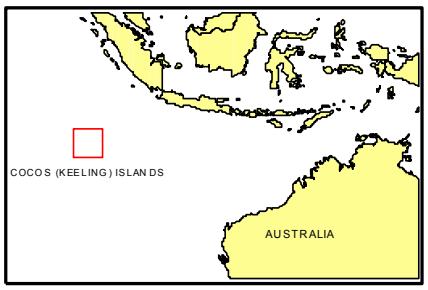
Surveys of edible sea cucumbers (Holothurians) revealed considerable changes in abundance across years at 4 of the 11 sites (Figure 3f, Appendix F). The mean density per 100m square of cucumbers increased significantly at Prison Island from 1.7 individuals in 2002 to 5 individuals in 2004 ($p<0.05$). 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, cucumber density dropped considerably from 14.5 individuals per 100m square in 1997 to zero in 2001 and then increasing rapidly to 26.5 individuals in 2004. The sharpest increase in cucumber abundance was recorded at 100th site where cucumber 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 with densities ranging 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 5 of the 11 sites (Appendix G). *Diadema* density increased significantly over 2-3 years at Bunya Coral, Cabbage Patch 3m, Horsburgh and Soft Coral Garden ($p<0.05$). At Two Trees, *Diadema* 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.

Lobsters were low in abundance with no records at 7 sites, and less than 1 individual per 100m square (averaged across all years) observed in the remaining 4 sites (Table 2).

Figure 1: Marine zone map of the Cocos (Keeling) Islands, showing the reef check sample sites surveyed by Parks Australia from 1997 to 2005, excluding Bunya Coral site which is located at North Keeling.





WARNING: Not for navigational use.
Sources: -Cocos (Keeling) Islands Administration
Cocos GIS
- Hender *at al.* 2001
Date Surveyed: June-September 2001

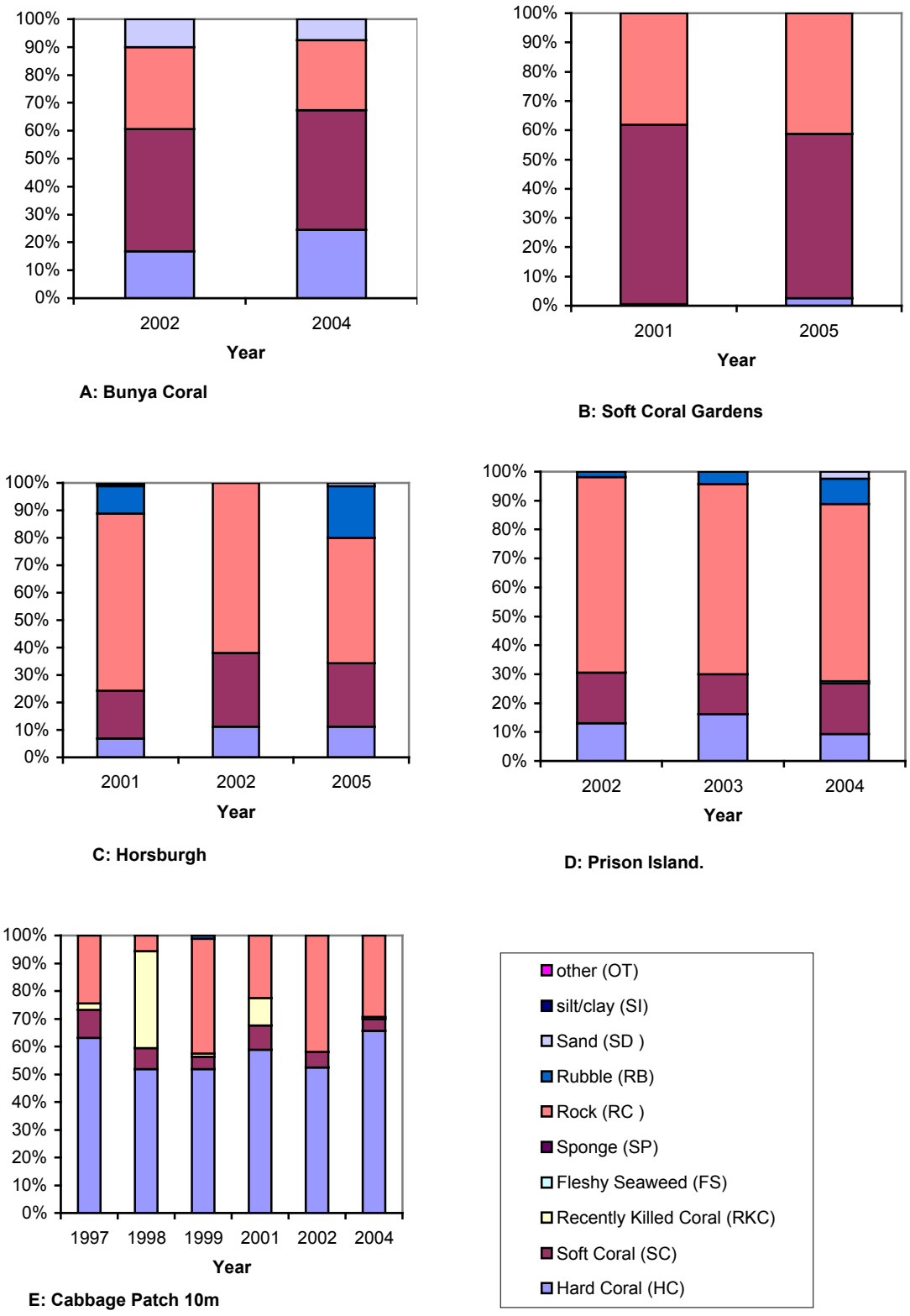
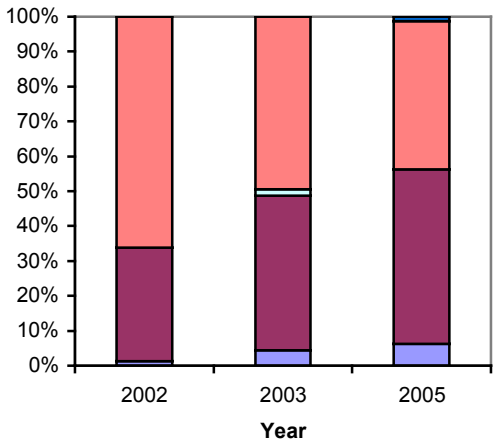
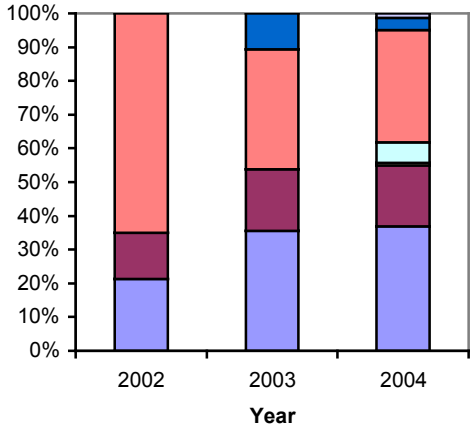


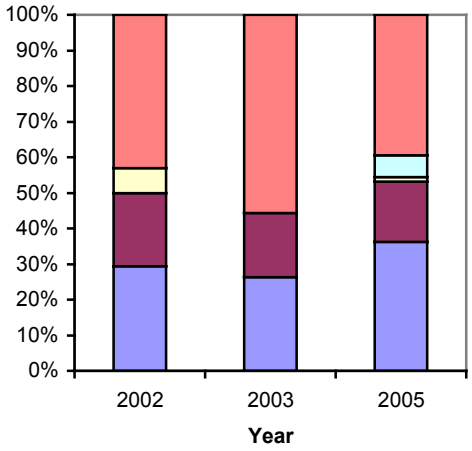
Figure 2: Substrate composition at 11 sites at the Cocos (Keeling) Islands, Indian Ocean between 1997 and 2005.



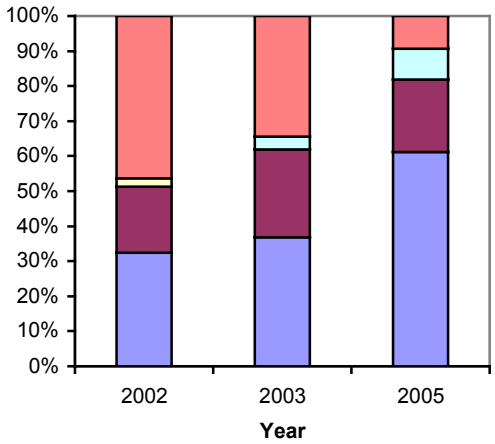
F: Two Trees



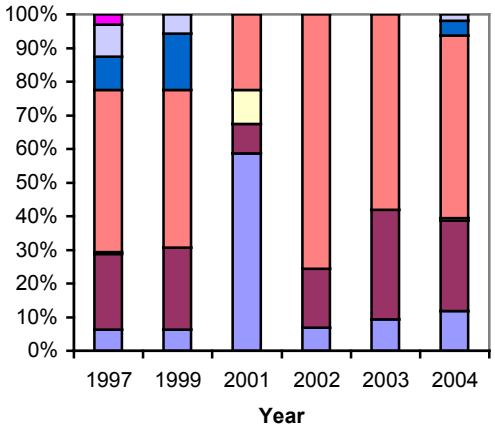
G: 100th site



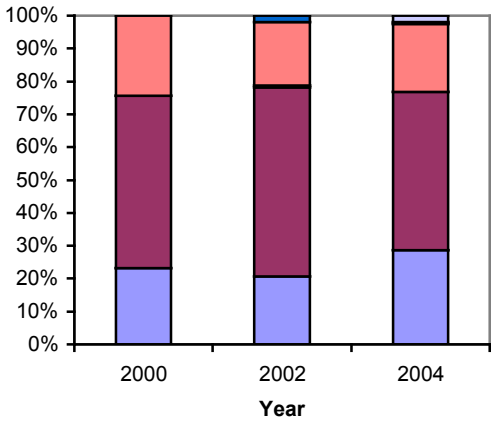
H: North Point



I: Cologne Garden



J: Cabbage Patch 3m.



K: Pulu Chepelok

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

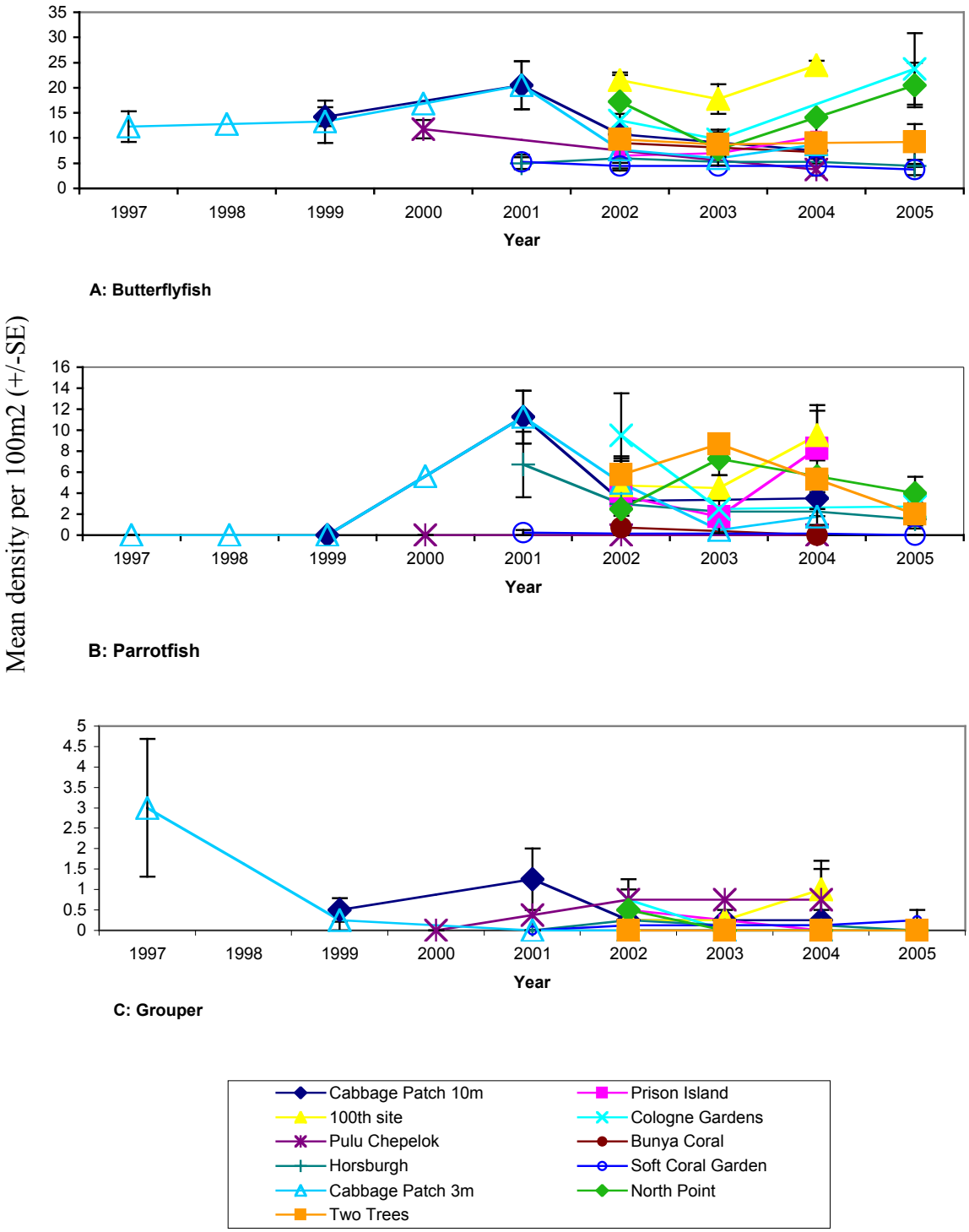


Figure 3: Mean densities (+/- SE) per 100m2 of fish and invertebrate groups at 11 sites, Cocos (Keeling) Islands, Indian Ocean between 1997 and 2005.

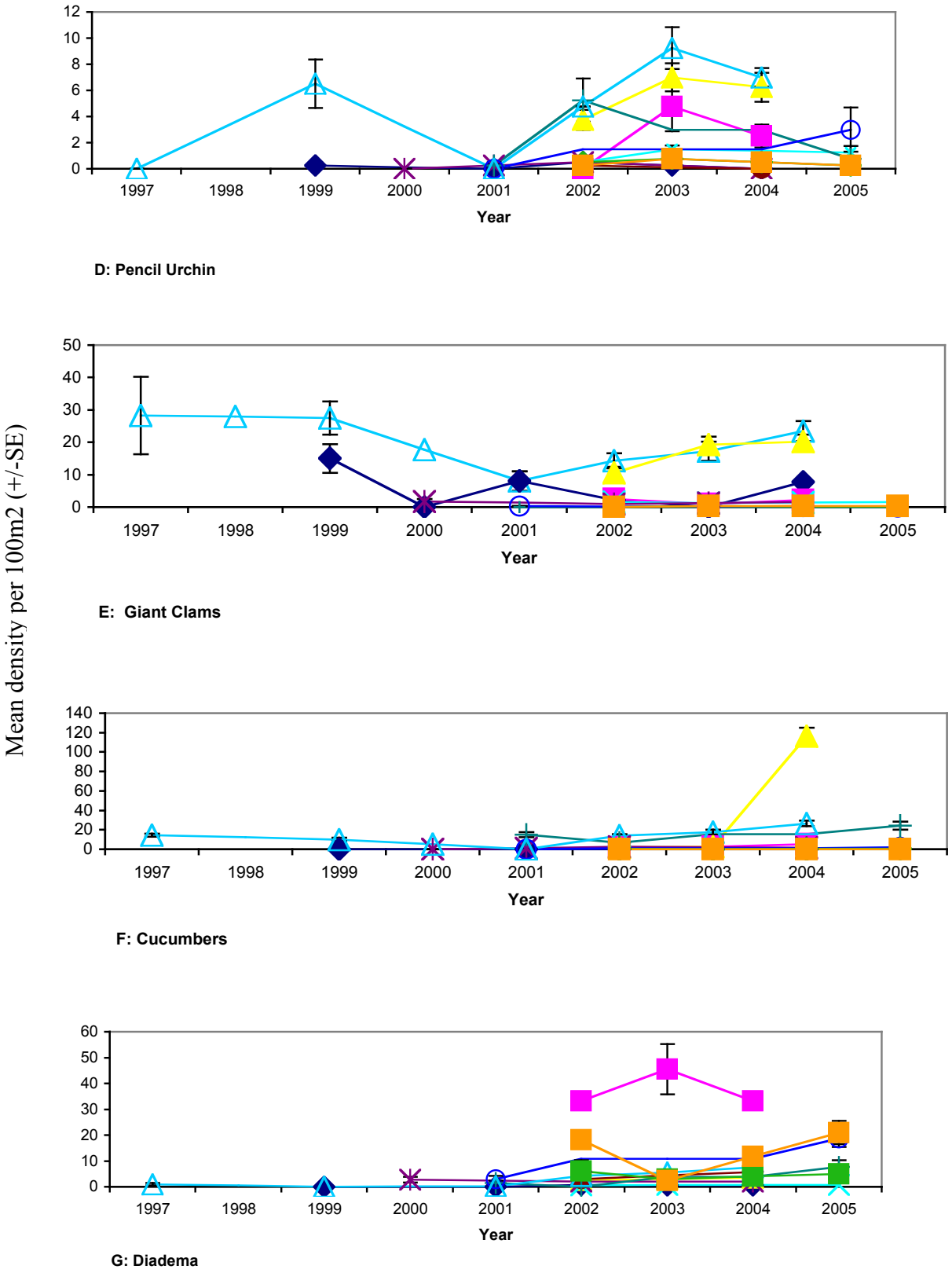


Figure 3 (cont): Mean densities (+/- SE) per 100m2 of fish and invertebrate groups at 11 sites, Cocos (Keeling) Islands, Indian Ocean between 1997 and 2005.

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 square. Values for coral bleaching and disease are mean percentages of coral population. Values for coral damage and trash are mean category values where 0=none, 1=low, 2=medium and 3=high.

Site	Crown-of-thorns starfish	Coral damage	Trash	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 Garden	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 fishes 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 Garden	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

4. 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.

4.1 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 has increased at some sites during the survey period. Only small amounts of recently killed coral or fleshy macroalgae 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.

4.2 Fish status

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

The abundance 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, is similar to the survey at the Cocos atoll by Hender *et al*. (2001), which estimated a density 36.63/ha in similar habitats. The abundance of groupers was much lower than 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 will be required to determine if the decrease in density is a result of different survey designs or changes in grouper abundance. Mean densities of groupers at Cocos (Keeling) Islands are also comparable to the Sumilion Islands, Philippines (45.2/ha, Russ & Alcala, 1989) and reefs in Kenya (42.8 – 68.8/ha, Samoilys, 1988).

Densities of less then 10 individuals per hectare at all sites during the entire survey period were recorded for humphead wrasse (*Cheilinus undulates*), bumphead parrotfish (*Bolbometapon muricatum*), sweetlips (Haemulidae), snappers (Lutjanidae) and moray eels (Muraenidae). Comparable mean densities of sweetlips, bumphead parrot fish and humphead wrasse have been estimated at the Cocos (Keeling) Islands and MOU74 Box while the estimated abundance of snappers was substantially lower than that estimated by Hender *et al*., (2001) and Skews *et al*., (1999) respectively. More detailed surveys should be completed to investigate the low abundance estimates of snappers.

4.3 Invertebrate status

Most sites were relatively constant in invertebrate abundance through time. A significant increase in abundance of *Diadema* was recorded at 4 of 11 sites. This could have been a response to increases in algae, or due to gregarious behaviour, or may reflect changes in the ability to locate these cryptic species. The abundance of cucumbers and pencil urchins did not change significantly through time at most sites, and the few recorded differences in abundance were mainly due to short-term fluctuations and could be a response to an increase in food or suitable habitat or may reflect changes associated with the study organisms' behaviour and movement between censuses or changes in the observers ability to detect these species. The abundance of giant clams did not differ considerably through time for most sites indicating that traditional harvesting is not currently reducing densities at these sites.

Crown-of-thorns starfish (*Acanthaster planci*) densities varied during the survey period. *A.planci* densities ranged from 0 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), determined densities of *A.planci* in similar habitats to be 63.2/ha 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, which he attributed to *A. planci*. Colin (1977), observed densities of approximately 25-50/ha *A.planci* between 15-30 metres depth. According to Moran and De'ath, 1992 outbreak classed densities are those greater than 15/ha. Therefore, Cocos (Keeling) Islands have experienced several outbreak episodes. In the current study four sites had mean densities (averaged over all years) that were greater than 15/ha during the survey period. 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 6 of the 11 sites and increasing at the remaining 5 sites. During the surveys between 1997 and 2005 *Diadema* densities varied substantially between sites from 0 to 4550/ha with an average across all sites over the entire survey period of 623.56/ha. The variability in *Diadema* estimates may be due to short-term fluctuations, a shift in the marine community, and deficiencies in the survey design and/or observer bias. Pencil urchin densities appeared stable at the majority of sites and fluctuated at the remaining sites. Pencil urchin density varied between sites from 0 to 925/ha with an average across all sites over the survey period of 177.75/ha.

The Cocos (Keeling) Islands represents a high biomass of sea cucumbers. Sea cucumbers have received very little harvesting in the last 50 years, although anecdotal reports indicate some harvesting occurred in the 1950's. The Parks Australia surveys between 1997 and 2005 show considerable variation in cucumber densities over time at the Cocos (Keeling) Islands. Cucumber densities ranged over the survey period from 0 to 11625/ha with an average across all sites over the entire survey period of 645.57/ha. The mean density of holothurians is similar to the density estimated by a survey in similar habitats of the Cocos (Keeling) Island, 539.47/ha (Hender *et al*. 2001). The densities at Cocos (Keeling) Islands are over 20 times greater than the fished sea cucumber populations of the MOU 74 Box around Ashmore Reef with an estimated density of 26.8/ha (Skews et al., 1999). Sea cucumber fisheries are prone to over exploitation (Uthicke, 1996), with proposed commercial fishing licenses it is important careful management and monitoring policies are implemented.

Giant clam densities appear to be stable over time, although densities differed between sites ranging from 0 to 2825/ha. The density averaged across all sites over the entire survey period was 535.5/ha. The average density is similar to the other estimate from the Cocos (Keeling) Islands (361/ha), although the current estimate is 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; Munroe, 1998; Hender *et al*., 2001).

4.4 Conclusion

Based on the underwater surveys at 11 sites from 1997 to 2005 is appears that the coral reef community at Cocos (Keeling) Islands is very healthy and in a stable period with little anthropogenic impacts. Live coral cover is high and there is minimal impact from coral damage, bleaching and disease. Crown-of-thorns starfish were recorded at high densities at 4 sites and have been recorded previously at high densities at Cocos (Keeling) Islands, however in this current study there did not seem to be a clear impact of the starfish on hard coral cover. Continued monitoring of crown-of-thorns abundance is necessary to understanding patterns in starfish abundance and their impact on the reef community, particularly hard corals.

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

Disturbance events were generally lacking during the study period, although high densities of *A. planci* were present, their effect on the coral community was not clear. 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. These events are likely to continue, and may even increase in frequency and intensity (e.g. coral bleaching: Hoegh-Guldberg, 1999). Given that isolated islands have the highest extinction rates, generally low recovery rates (Whittaker, 1998) and 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 continue as disturbance events are likely to occur in the near future and assessing the impact and recovery of the reef community and identifying susceptible species is fundamental to management. Expanding 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 determining the impacts of such die-offs on the reef community.

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Appendix A: Statistical analyses 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 analyses 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 analyses 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 analyses 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 analyses of giant clams 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 analyses of sea cucumbers 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 analyses 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