Increased Coral Cover in Komodo National Park, Indonesia: Monitoring for Management Relevance

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Abstract

Komodo National Park (KNP), a World Heritage site in eastern Indonesia, has been seriously threatened by destructive fishing practices. This paper presents the design and results from the first two surveys (1996 and 1998) of a long-term coral reef monitoring program initiated and conducted by The Nature Conservancy (TNC). The objective of the monitoring program is to examine changes in coral cover, which can inform a recently-implemented management plan for the marine component of KNP. To this end, we broadly assessed the benthic cover of a large reef area. Timed survey swims at 3 depths (4, 8, and 12 m) were conducted at 185 sites in 10 regions throughout the Park, as well as in areas outside Park borders. Percent cover of live scleractinian coral, dead scleractinian coral, soft coral, and other cover was recorded, and an index of hard coral mortality calculated [% dead *100 / (% dead + % live)]. Although there is extensive coral mortality in many areas of KNP, there has been a significant increase in live coral cover in some regions, primarily those with the largest initial damage and located close to the center of Park management and protective activity. In six areas most likely to have had the highest protective activity, hard coral mortality decreased significantly. This monitoring program provides information relevant to Park managers on the kilometer-scale variability in coral cover within KNP.

Introduction

Pressures from rapid population and economic growth in Southeast Asia severely threaten many reef ecosystems in this region. It is estimated that less than 3% of the reefs in Indonesia remain in excellent condition (>75% live coral cover) and these are being rapidly degraded, as few of the marine protected areas that exist on paper are effectively managed (Chou 1997; Wilkinson et al. 1994). The need for effective management of marine protected areas and of monitoring programs to determine the success of management actions is widely recognized (Allison et al. 1998; Kelleher et al. 1995; McClanahan 1999; McNeill 1994).

A marine park that is being actively managed is Komodo National Park (KNP), in eastern Indonesia. KNP is a large (>170,000 ha), tremendously diverse park and a premier dive tourism destination. However, the coral reefs in KNP remain seriously threatened (Pet and Djohani 1998; Pet 1999). The main threat is unsustainable resource use, practiced both by local inhabitants and by fishermen from other areas in Indonesia. An early survey conducted by The Nature Conservancy (TNC) in 1995 showed that more than 50% of the coral reefs inside the Park had suffered damage from destructive fishing practices (DFPs), primarily blast fishing (Holthus 1995). Other DFPs include the use of cyanide to catch fish and the harvesting of organisms that hide between corals (reef gleaning or "meting") (Pet 1997). Destructive fishing practices not only remove the resource itself (fish and invertebrate stocks) but also destroy the habitat (coral reefs) (Pauly et al. 1989).

Perhaps the most damaging of DFPs is dynamite or "blast" fishing (Mous et al. 2000). Blast fishing in Indonesia originated with excess munitions from World War II, and today consists of home-made kerosene and fertilizer bombs packed in glass or plastic bottles (Pet-Soede and Erdmann 1998). The detonated bomb's shock waves not only kill fish and other organisms within the 1-5 m blast radius, but also pulverize the coral skeletons themselves (Alcala and Gomez 1987; McManus et al. 1997).

This study is different than many other studies of disturbance and recovery (reviewed in Connell 1997) in that no pre-disturbance baseline coral cover data exists. However, data from patrols, oral histories, and eyewitness accounts suggest that the damage reported is due to DFPs, rather than other causes. Furthermore, KNP is not within a hurricane belt, and is generally well-protected from major storm damage. Observers familiar with blast damage concur that the vast rubble fields point to chronic blast fishing in the past. The threatened status of the coral reefs in KNP necessitates the implementation of an active conservation program. We therefore are using the 1996 survey results as baseline "damaged" data, and are attempting to document any trends in live coral coverage now that an active marine management plan is in place. There are no "control sites," as enforcement patrols attempt to protect the entire park, so we are examining long-term trends. Finally, the large number of study sites covers a wide area, which should add statistical robustness.

There is good potential to protect the marine waters of the Park, since there is an existing terrestrial management infrastructure and low human population pressure (Alpert 1995). To combat the multiple threats to the marine resources of KNP, a management plan was drafted in 1996 by the Park service and TNC (Pet and Djohani 1996). This management plan has recently been updated and incorporated into Indonesian law (Pet and Yeager 2000a-c). The primary goals of the management plan are to stop destructive harvesting of marine resources in KNP and to involve local communities in conservation decision making, implementation, and enforcement. Monitoring and research programs were developed to assess fish stocks, resource utilization, and coral reef condition.

Objectives of the long-term coral reef monitoring program are to assess the current state of coral reefs and track subsequent changes of live and dead coral cover. This information is needed to assess the success of enforcement and conservation programs. Crucial to any long-term monitoring program is cost-effectiveness and ability to detect significant change in the resources in question. To this end we sample a large area to determine the status of corals throughout the Park (Pet and Mous 1999). The methodology does not require extensive education or training. It can and has been taught to local rangers and Park management staff with little formal marine biology background. The design of the coral reef monitoring program and results from the first two years (1996 and 1998) are presented here.

Materials and Methods

Study area

Komodo National Park (KNP) is located between the islands of Sumbawa and Flores in eastern Indonesia (Figure 1). The Park encompasses 41,000 ha of land area and 132,000 ha of marine waters. The three major islands are Komodo, Rinca, and Padar, and there are many smaller islands. The Park was established in 1980, and was declared a Man and Biosphere Reserve and a World Heritage Site in 1986. Famous as the habitat of the world's largest lizard, the Komodo dragon *Varanus komodoensis*, KNP is also one of the world's richest areas for marine biodiversity. In 1994 the government of Indonesia requested The Nature Conservancy Asia/Pacific Program to conduct a Rapid Ecological Assessment (REA) of the marine environment of KNP, with a focus on coral reefs, to provide a basis for conservation management planning. From this REA conducted in 1995, it was estimated that ~260 species of reef-building corals and ~1000 species of fish are found in the Park. This high diversity of marine life is sustained by a wide range of habitats: coral reefs, mangroves, sea grass beds, rocky shores, sheltered bays, and narrow sea straits with strong currents (Holthus 1995). Several areas within KNP are designated as multiple use zones, in which subsistence fishing and some mariculture is allowed. There is also a buffer zone to the northeast of the Park, to which several communities have limited fishing rights (Pet and Djohani 1996).

Coral Reef Monitoring Program

The objective of the KNP coral reef monitoring program is to obtain information on spatial and temporal patterns of coral cover inside and outside the Park (Pet and Mous 1999). The monitoring program was designed to be relevant to managers, rather than to acquire general knowledge on coral reef ecology. The program is conducted by 2-3 trained SCUBA divers, for a total of approximately 60 speedboat days every other year. Finally, since the monitoring team frequently changes, ease of training is important.

Sites were chosen throughout KNP, inside the buffer zone, and outside the Park (Figure 2). Sites were selected for extensive spatial coverage, and the large number of sites (185) helps ensure statistical robustness. To compare different regions within the Park, the monitoring area was divided into ten geographically contiguous regions, each with similar sample size, surface area, and habitat characteristics (Figure 2). The northwestern regions (Labuan Bajo, Misa, and Siaba areas) in general have wide reef flats, with many islands and patch reefs. Some islands are populated and fishing effort is much higher than in the regions inside the National Park. Komodo North and Banta have narrower reef flats and a steep slope. The northern areas are influenced more by the Flores Sea, which tends to be warm and calm. Rinca North is dominated by 2 large bays. The narrow straits between Rinca and Flores, and between Rinca and Padar, cause extremely strong currents. The southern coasts of Komodo, Padar, and Rinca are steep and rugged, with a rocky volcanic foundation. These areas are influenced more by the Indian Ocean, experience upwelling, and are colder with strong currents and more wave action. Different regions have different environmental conditions and different levels of impact from the fisheries (Pet 1999).

Monitoring sites were positioned approximately every 1 to 5 km of shallow fringing reef. The GPS location of each site was recorded to enable subsequent expeditions to monitor approximately the same sites each year. At each site, 3 depths were surveyed: 4, 8, and 12 m (one observer at each depth). Five consecutive swims (4 minutes each) were conducted at each depth, using snorkel for 4 m depths and SCUBA for 8 and 12 m. The swimming speed was ~0.33 m/s, so ~80 m were covered per observation swim, for a total distance covered at each depth of ~400 m. At the end of each observation swim, the observer recorded the visually estimated percentages to the nearest 5% of four habitat categories: "live hard (scleractinian) coral"; "dead hard coral" (dead portions of colonies or coral rubble); "soft coral"; and "other," including rock, sand, algae, sponges, tunicates, anemones, echinoderms, etc. Other studies have shown that visual estimates can be accurate in manta tows (Miller and Müller, 1999) and quadrats (Dethier et al. 1993). All observers participated in a training program until all observers could estimate the percent cover by habitat categories within 5% of each other as recommended by English et al. (1994). Standard underwater data sheets were designed for recording of date, site number, GPS location, depth, and name of observer. The survey is conducted every 2 years, and the 60 total survey days are spread over 8-9 months. The first survey was conducted in 1996, the year in which enforcement patrols began.

Data analysis

For each of the 185 sites, coverage data from the five swims at each depth were averaged, yielding 3 samples per site. These means were then used to compute averages of the percent cover of four benthic categories (live hard coral, dead hard coral, soft coral, and other), for each region at each depth. A hard coral mortality (HCM) index, a unitless ratio of dead coral cover to the sum of live and dead coral cover, was calculated for each site with HCM = [% dead * 100 / (% live + % dead)] (Gomez et al. 1994). The higher the hard coral mortality, the smaller the proportion of live coral. This mortality index was used in addition to the more common parameter of percent live coral cover, since it may be a better gauge of reef health than live coral cover, which can be low even in pristine reefs (Gomez et al. 1994). SAS version 6.11 was used for all statistical analyses. To normalize the data, the ARCSIN(SQRT(x)) transformation was applied to the mean HCM/100 per sample data (Sokal and Rohlf 1995). To test differences between years, the difference in transformed HCM values between 1996 and 1998 was calculated. Two-way analyses of variance (ANOVAs) were performed with survey depth, geographical region, and the interaction term as explaining variables. Depth explained only 0.09% of the total variance; consequently the different depths were pooled within sites, and depth was not included in subsequent models. Residual analyses were carried out to confirm that the assumptions of ANOVA were approximately met. For all ANOVAs, the residuals were approximately normally distributed (Wilk-Shapiro test, $p>0.05$). A t-test was used to test the hypothesis that there was a difference in mean HCM of each region between survey years.

The Mean Square Error (MSE) from the ANOVA was used as a measure of within-region variance (Cochran 1977). This measure was used to evaluate the minimum sample size required to detect meaningful differences in HCM values, using the critical values for t at $\alpha=0.05$. It is assumed the Mean Square Error measures the variance typically found within a relatively homogeneous area. Although KNP overall is very diverse, the habitat is similar within the 10 sub-regions.

Results

The 1996 survey showed that many of the coral reefs in KNP have been extensively damaged in nearly all regions. However, in 1998 there were increases in the living proportion of hard coral in a majority of regions. The cover of soft coral and other benthos remained basically unchanged between the two surveys (changing from 22% to 24% and 35 to 34%, respectively).

In 1996 45% of monitoring sites had at least 30% dead hard coral coverage; two years later only 31% had similar levels of dead coral.

The changes in live and dead coral cover differed markedly between the ten regions (Figure 2). Figure 3 shows the average percent cover of each habitat category at each depth in each region. Live coral coverage increased in 6 of the 10 regions, from 11-14% in 1996 to 15-21% in 1998. The most prominent increases in live coral cover and decreases in dead coral cover were in areas near the center of Park management and protective activity: average live hard coral cover increased by 10, 4, and 6% in Labuan Bajo, Misa, and Siaba, respectively, and average dead hard coral cover decreased by 15, 14, and 10%, respectively. Banta and Komodo North had the highest average cover of live coral in 1996 (28% and 23%, respectively); live coral cover did not increase significantly in these areas. In most regions, soft coral and other habitat cover did not change dramatically, although in Misa and Banta soft coral increased while dead hard coral decreased, suggesting that soft coral, in addition to live hard coral, is growing over the dead hard coral.

Figure 4 summarizes the hard coral mortality (HCM) data. The results from the one-way ANOVA on the difference between years of the arcsine transformed HCM of each region indicate that there are significant regional differences (F value=7.60, $p<0.0001$). Variance corrected for area and survey year was 0.064. In 1996, HCM was 57 overall; the most damaged regions were Labuan Bajo, Misa, and Siaba (77, 70, and 73 HCM, respectively). These are the closest regions to the large town of Labuan Bajo, just outside the Park. In 1998, HCM decreased to 49 overall, and all 3 of the most damaged regions had experienced a statistically significant reduction (to 56, 55, and 59, respectively; $p < 0.0001$ in all cases). HCM also decreased in the regions of Rinca North, Komodo North, and Komodo Southeast ($p<0.05$). The area with the least hard coral mortality was the remote Komodo Southwest area (HCM=26), although this increased in 1998 (to 32; $p<0.05$). There was no statistically significant change in the other 3 regions (Figure 4).

The average HCM at each of the 185 sites in 1996 and 1998 is shown in Figure 5. Note the overall shift from higher coral mortality (darker circles) to lower coral mortality (lighter circles), especially in the northeastern regions.

The results from the analysis of the minimum sample size required to detect meaningful differences in HCM values indicated that ~50 samples are sufficient to detect differences in HCM of ~10. The number of samples in each region ranges from 48 to 63, except for Banta, which has 39 samples.

Discussion

The initial increase in live coral cover already detected with this long-term coral monitoring program is encouraging, although coral recovery differs markedly in the different regions. In four areas (Labuan Bajo, Siaba, Rinca South and Komodo Southeast), average live coral cover in 1998 had increased by over 40% of 1996 levels. Decrease in hard coral mortality (HCM) is most pronounced in the Labuan Bajo, Misa, and Siaba areas, with decreases in HCM of 15-20 (Figure 4). Those regions are nearest the center of protective activity (The Nature Conservancy field office, Police Station, and National Park office are all located in Labuan Bajo) and thus receive the most surveillance time. There were lower, but still significant, levels of recovery in Komodo North, Komodo Southeast and Rinca North, with decreases in HCM of 8-11 (Figure 4). These increases in coral cover are comparable to other studies in the literature (reviewed in Connell 1997). In 46 cases of coral that had declined from disturbance (defined as an event that damages or kills the corals), significant coral recovery occurred in 41%. Most of those recoveries (11) were from acute disturbances with indirect effects on the environment (Connell 1997). Blast fishing, however, tends to be a chronic disturbance with direct effects on the physical substrate, shattering the coral skeletons and leaving a shifting, unstable rubble field (Alcala and Gomez 1987). Considering the extent of dead coral, the increase in cover seen in some of the most damaged regions is encouraging.

Areas in which there was no natural recovery of hard corals between 1996 and 1998 include Banta Island, Komodo Southwest, Rinca South, and the Padar area. Several possible reasons might explain the lack of recovery. Banta Island and parts of Rinca South are outside Park boundaries and not covered by enforcement patrols. Komodo Southwest and Rinca South are more remote areas at the edge of the umbrella of protective activities. In addition, Banta and Komodo Southwest are easily accessible by blast fishing communities from eastern Sumbawa, although some of the former dynamite fishing communities have changed their practices due to clashes with enforcement patrols. Although the Padar area is in the middle of the presently protected area, it is one of the most extensively damaged locations. It is easily reached by several communities and had been subject to blast fishing for several decades prior to the start of patrols in 1996. The habitat has been almost entirely leveled, so there is little three-dimensional, complex, stable substrate left (Pet and Mous 1999). A topographically complex substrate greatly facilitates new coral growth (Clark and Edwards 1995). Additionally, the area is swept by strong currents, which, combined with the lack of habitat complexity and few nearby live "source" corals in the immediate area, might inhibit the settlement of coral larvae (Fox et al. 1999). This might be an area where active rehabilitation would be necessary to enhance recovery.

The variation in coral reef community structure varies over a scale of kilometers, necessitating sampling programs that will identify the variability on this spatial scale (Edmunds and Bruno 1996). The area covered per swim and benthic categories recorded in this monitoring program are comparable to those for a manta tow survey (~80 m covered in a 4 min swim, compared to ~65 m covered in a 2 min tow at 2 km/hr). Manta tows have been shown to be particularly useful for assessing broad changes in coral cover, especially when the unit of interest is a large reef area (Miller and Müller 1999; Pernetta 1993). Although this study is less detailed than other long-term transect- or quadrat-based coral monitoring studies (e.g. Bythell et al. 1993; Connell et al. 1997; Edinger 2000; Hughes 1994) and does not provide information on species abundance and overall diversity, it is nonetheless valuable for a number of reasons. First, this monitoring program covers a much larger area than most other studies and can be used to detect relatively small changes in coral cover in KNP. Second, the methodology is simple and appropriate for training Park rangers and management staff without formal education in marine biology. Third, habitat complexity and the overall cover of hard coral is likely to be more important for fish populations than the specific taxonomic makeup of the community (Lewis 1997). Finally, since an inventory of biodiversity is not a management goal, the additional training and effort needed to separate hard corals into more detailed life form or taxonomic divisions would not be cost-effective.

In order to evaluate the cost-effectiveness and usefulness of a monitoring program, it is important for managers of a park to decide the level of change they hope to be able to detect. The analysis of the minimum sample size required to detect differences in hard coral mortality (~50 sites per region to detect HCM differences of >10) can be used to determine the number of sampling sites in a monitoring program to avoid over-and under-sampling (Hughes 1992).

There are several potential management responses to our coral monitoring results. For example, it seems clear that the areas at the edge of the protective umbrella (Banta, Komodo Southwest, and Rinca South) are in need of further protection, so enforcement patrols should increase their presence in those areas. A proposal to include Banta within KNP has been approved. Although this has not yet happened, the inclusion would provide further protection to the reefs of Banta if combined with increased enforcement. In some areas, reef regrowth appears to occur naturally and rapidly, whereas in other areas, such as Padar, little or no recovery is observed at all. A research project is currently underway to investigate environmental influences on coral recovery and to explore methods to enhance reef rehabilitation (Fox et al. 1999).

The increase in live coral cover is correlated with increased enforcement patrols. Based on resource use surveys counting encounters with blast-fishing boats, dynamite fishing in the Park decreased by 75% in 1996, the year regular patrolling began (Pet 1999). This reflects increased law enforcement and community awareness as well as a shift from low-income fishing for local markets (dynamited fish) to high-income fishing for export markets (live reef fish and fresh chilled pelagics) (Cesar 1996; Pet 1999). Considering that dynamite fishing has been calculated to cause a net loss of between US$33,900 and US$306,800 per km^2 of coral reef over a 20 year period, programs that successfully decrease this destructive fishing practice are well worth the effort (Pet-Soede et al. 1999). We anticipate that this monitoring program will continue to provide management-relevant information on damage and recovery from anthropogenic impacts or natural disturbances.

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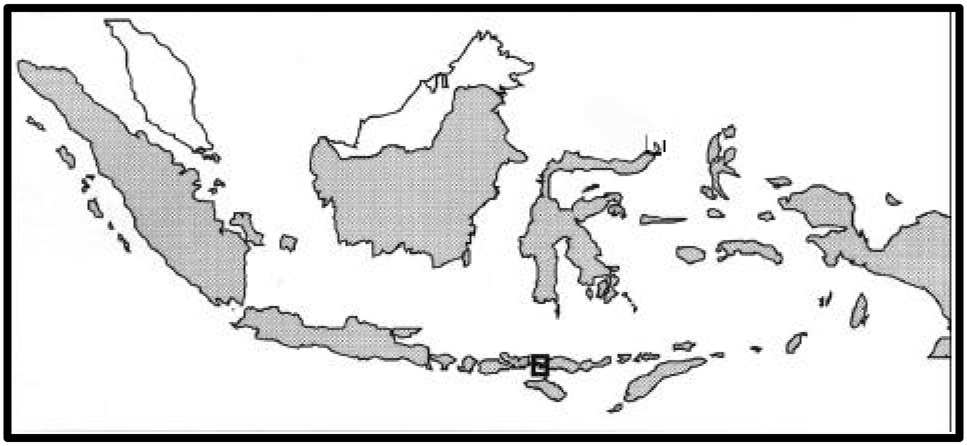

Figure 1. Map of Indonesia, showing the study site, Komodo National Park, boxed. KNP is located between the islands of Sumbawa and Flores in Eastern Indonesia.

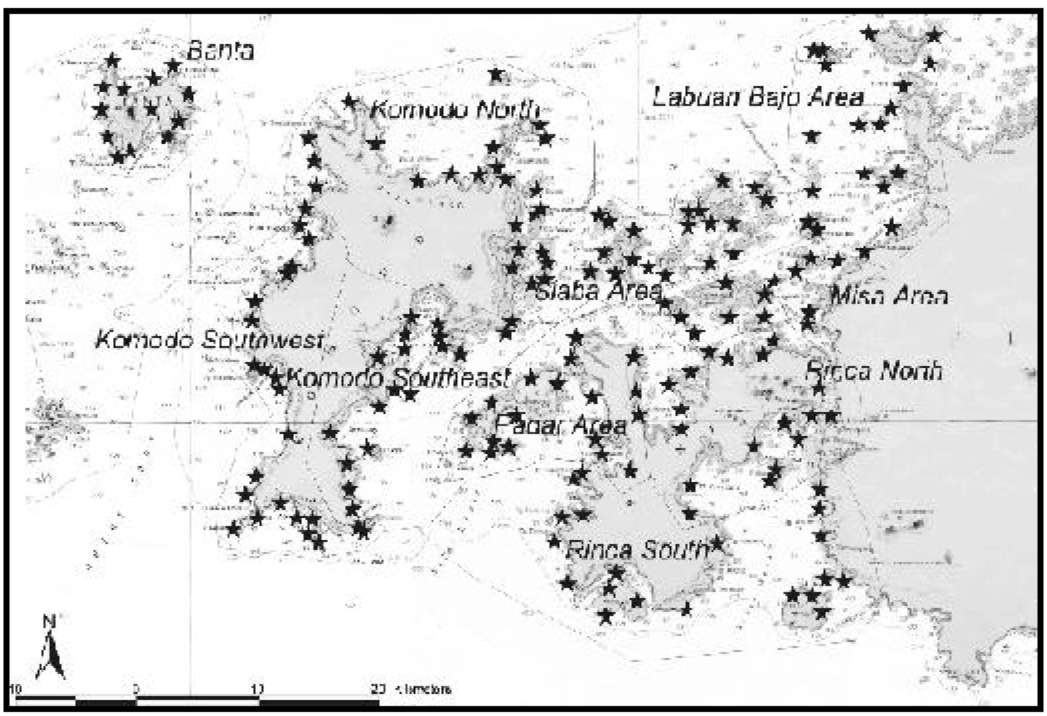

Figure 2. Map of Komodo National Park (KNP), the 185 sampling sites, and ten sub-regions, with regional borders shown in solid line.

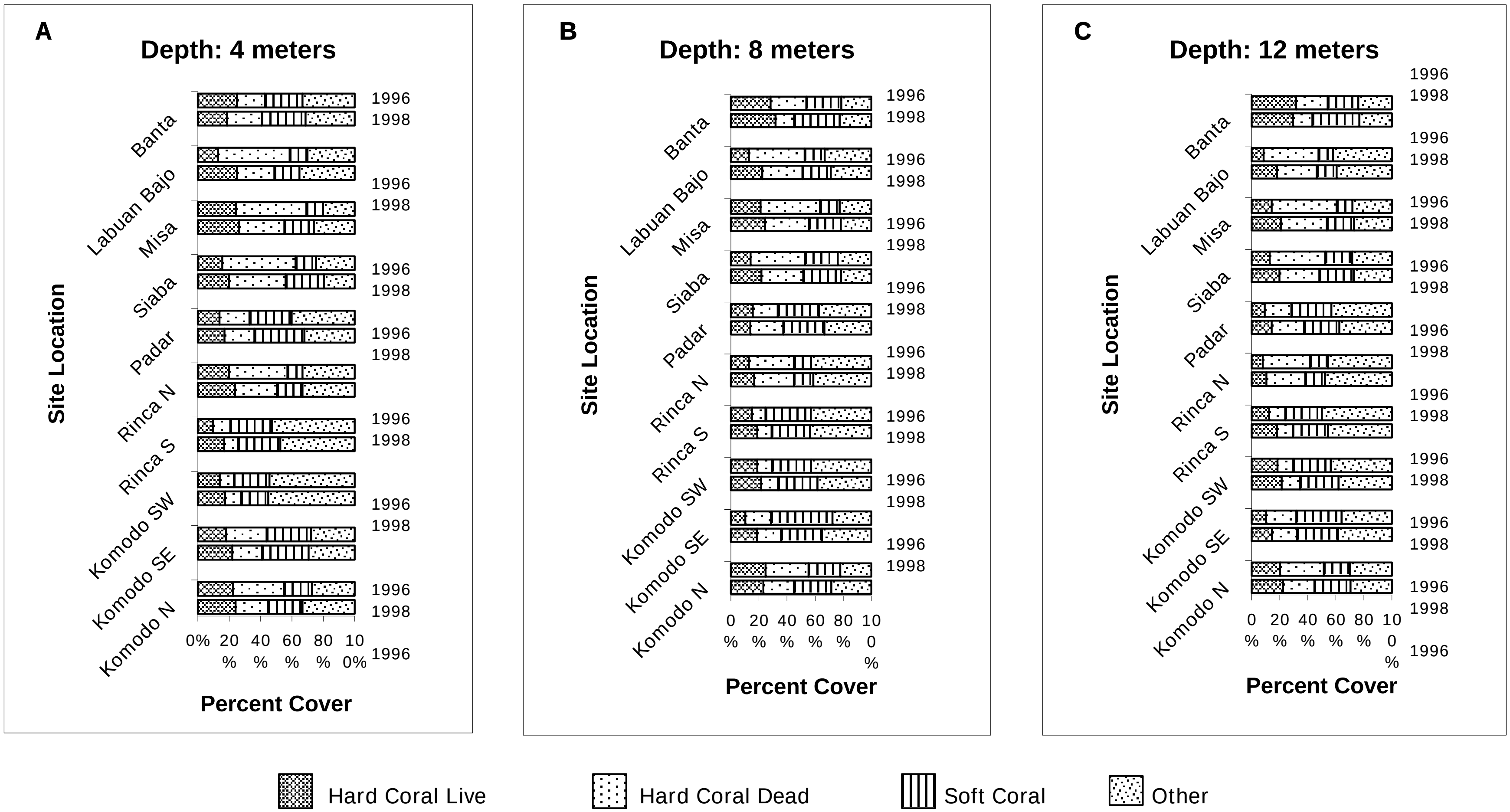

Figure 3 Percent cover of each benthic habitat category in each region for 1996 (top) and 1998 (bottom) at A) 4 m, B) 8 m, C) 12 M.

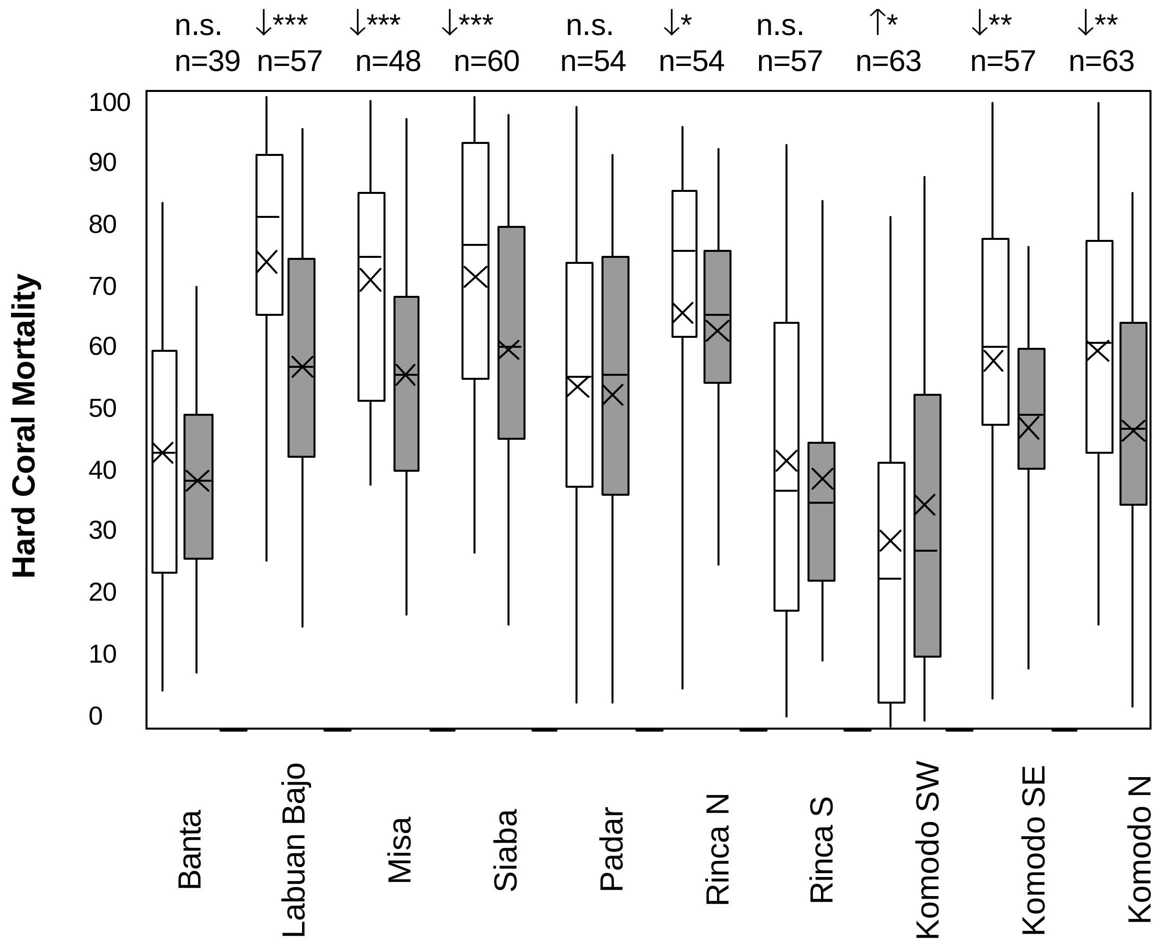

Figure 4. Boxplot and whiskers showing the average hard coral mortality (X) in each region for 1996 (open) and 1998 (shaded). Also shown are the maximum, minimum, and 25%, 50%, and 75% quartiles. (HCM = [% dead/ (% live +% dead) * 100]). Statistical results of t-test on the arcsine-transformed HCM data and sample size are shown above the boxplots (↓= decrease in coral mortality, ↑= increase in coral mortality; *=p<0.05, **=p<0.002, ***=p<0.0001).

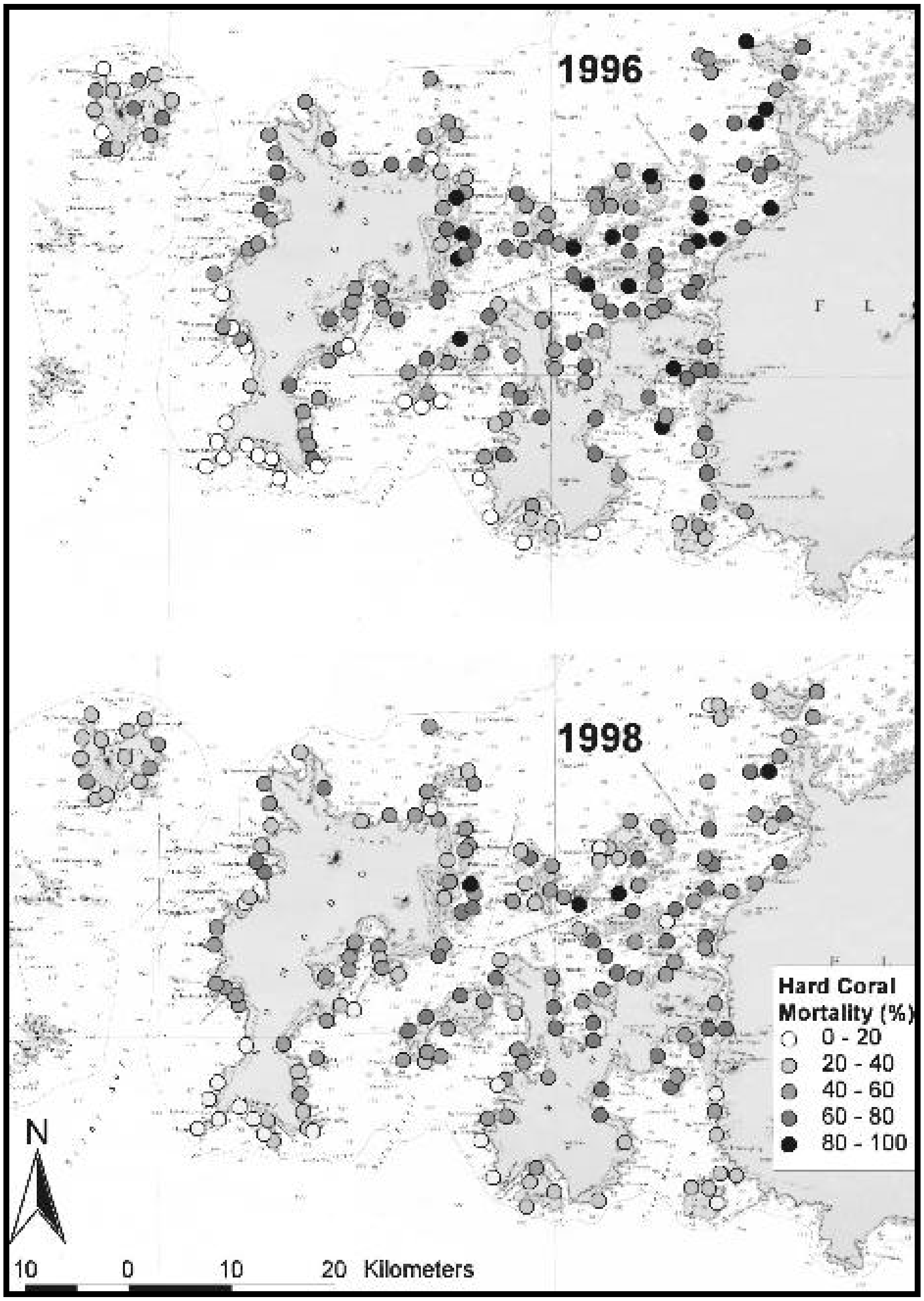

Figure 5. The average hard coral mortality (HCM) at each of the 185 sites in 1996 (top) and 1998 (bottom). HCM = [% dead * 100 / (% live + % dead)]. Note the overall decrease in HCM in 1998 (lighter circles rather than darker circles).