| Indicator Organism | Indicator for: | | | | | |
|---|---|---|---|---|---|---|
| | OF | BF | PF | AF | NP | CC |
| **Global** | | | | | | |
| Banded coral shrimp (***Stenopus hispidus***) | | | | X | | |
| Butterfly fish (***Chaetodon*** spp.) | X | | X | X | | |
| Crown of thorns starfish (***Acanthaster planci***) | X | | | | | |
| Fleshy algae | | | | | X | |
| Grouper (>30 cm) (Serranidae) | X | X | X | | | |
| Hard coral | | X | X | | X | |
| Lobster | X | | | | | |
| Long-spined black sea urchins (***Diadema*** spp.) | X | | | | X | |
| Moray eel (Muraenidae) | X | | | X | | |
| Parrotfish (>20cm) (Scaridae) | X | X | X | X | | |
| Pencil urchin | | | | | | X |
| Recently killed coral | | X | X | | X | |
| Snapper (Lutjanidae) | X | X | | | | |
| Sponge | | | | | X | |
| Sweetlips – (Haemulidae) | X | X | X | X | | |
| Triton (***Charonia*** spp.) | X | | | | | X |
| | | | | | | |
| **Indo-pacific region only** | | | | | | |
| Barramundi cod (***Cromileptes altivelis***) | X | X | X | X | | |
| Bumphead parrot (***Bolbometopon muricatum***) | X | X | X | X | | |
| Giant clams (***Tridacna*** spp.) | X | | | | | X |
| Humphead wrasse (***Cheilinus undulatus***) | X | X | X | X | | |
| Sea Cucumber (***Thelenota ananas, Stichopus chloronotus***) | X | | | | | |
| | | | | | | |
| **Atlantic region only** | | | | | | |
| Gorgonia | | | | | X | |
| Flamingo Tongue (***Cyphoma gibbosum***) | | | | | | X |
| Nassau grouper (***Epinephelus striatus***) | X | | | | | |

Table 3.1: Reef Check Indicator organisms for overfishing (OF), blast fishing (BF), poison fishing (PF), aquarium fish collecting (AF), nutrient pollution (NP) and curio collection (CC).

## Ordination Analyses

Non-metric multidimensional scaling was applied to the Reef Check global database to represent the similarities and/or dissimilarities between differing countries and/or geographic regions in two-dimensional space. This ordination technique constructs a "map" of samples based on a rank (dis)similarity matrix where all the conditions imposed by a rank similarity are taken into account (Clarke and Warwick 2001). The MDS computation is an iterative procedure where the distances between points within the MDS plot have the same rank order as the corresponding dissimilarities between samples. The orientation of the ordination plot is arbitrary because the distance between points is the only factor of concern, so the plots can be rotated or inverted when viewed on the computer without influencing the interpretation.


Scientists and other volunteers from Cambodia, China, Japan, Thailand, and the United States prepare to begin a Reef Check survey on reefs in the Andaman Sea as part of a regional training program in Thailand. Photo by Jennifer Liebeler.

The global indicators butterfly fish, ***Diadema***, grouper, haemulids, lobster and live coral index (percent live coral/(percent dead coral + percent live coral)) were selected for analysis. Samples with missing data for any of these indicators were removed from all multivariate analyses as similarity matrices cannot be constructed if missing values are present in the data. Data were averaged by geographic area (Indo-Pacific, Atlantic, and Red Sea) by year. Data were standardized to control for the different scale of the coral index and root transformed to add more weight to the less abundant species indicators. The Bray-Curtis coefficient was utilized to construct a similarity matrix and the MDS algorithm was applied to this matrix to produce the MDS plots.

The SIMPER procedure (Clarke and Warwick, 2001) was utilized to determine the individual indicators principally responsible for sample groupings in the ordination analyses. The similarity between reefs in analogous geographic regions (Indo-Pacific, Atlantic, and Red Sea) and the dissimilarity between groups of reefs in differing geographic regions was calculated to determine the percent contribution of individual species to the grouping patterns in the MDS ordination plots. All multivariate analyses were performed with PRIMER version 5 (Clarke and Gorley, 2001).

# Chapter 4 GLOBAL TRENDS IN CORAL REEF HEALTH

courtesy of Coral Reef Adventure, MacGillivray Freeman Films

Over the five-year period from 1997 to 2001, Reef Check monitoring was carried out at approximately 1500 coral reefs. After quality assurance procedures, data from 1,107 surveys were accepted for analysis. The most common reasons why data sets were rejected were: incomplete site description, non-standard protocol, and incomplete survey. Some of the surveys were carried out with strictly educational goals in mind, and these were not included in the analysis. The monitoring was carried out on coral reefs in 55 countries and territories (Table 4.1). For biogeographic reasons, political boundaries were sometimes ignored and some locations within one political entity were treated separately – for example, the three locations within the United States are treated as separate locations: Guam, Florida and Hawaii. The list represents about half of the 101 coral reef countries listed in the ***World Atlas of Coral Reefs***. The distribution of survey sites includes sites in all the major coral reef regions in the Indo-pacific and the Caribbean. Several remote and/or previously unsurveyed areas were surveyed by Reef Check teams e.g. Cocos Keeling, Australia, San Andreas World Heritage Site in Colombia and the Mergui Archipelago in Myanmar.

Since Reef Check is a volunteer program, there is no way to guarantee that a given site or country will be resurveyed every year. There was an obvious burst of enthusiasm during the 1997 International Year of the Reef, followed by a reduction in the number of sites surveyed for the next few years. However, with the establishment of the program headquarters in the United States, the number of sites has steadily grown. When there are a large number of surveys in one particular country in a given year, this can bias the regional and global analyses.

Reef Check encourages long-term monitoring using permanent transects, however, many teams resurvey reefs using haphazardly placed transects. Of the total surveys, 21% were surveyed two or more times over the five year period.

In this chapter, a rationale is given for the choice of each indicator followed by a presentation of results and interpretation. As explained previously in the methods section, Reef Check surveys include a Site Description that provides information on the perceived level of human impacts such as fishing on a given reef. Unless otherwise noted there was no consistent relationship between the rating of anthropogenic impacts and the number of indicator species found. All organism abundance maps depict total number of indicator organisms per transect at each site.

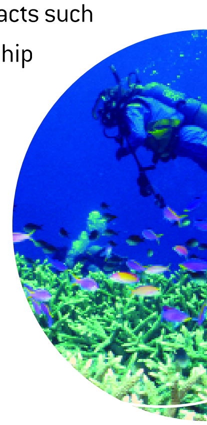
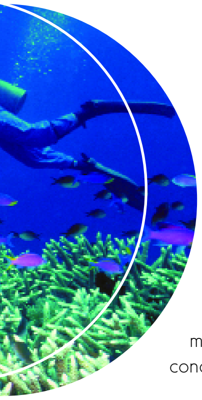


Table 4.1: Number of reefs surveyed in each location and accepted for analysis (1997-2001).

| Country | 1997 | 1998 | 1999 | 2000 | 2001 | TOTAL |
|---|---|---|---|---|---|---|
| American Samoa | 1 | | | | | 1 |
| Australia | 14 | 7 | 9 | 1 | 10 | 41 |
| Bahamas | | | 2 | 1 | | 3 |
| Bahrain | 1 | 5 | 4 | 4 | | 14 |
| Barbados | 5 | | | | 8 | 13 |
| Belize | 2 | | | | 1 | 3 |
| Bonaire | 2 | 2 | | 1 | 2 | 7 |
| Brunei | 1 | | | | | 1 |
| BVI | 3 | 1 | 3 | | 4 | 11 |
| Cambodia | | 1 | | | 1 | 2 |
| China | | | | 5 | 17 | 22 |
| China - Hong Kong | 7 | 9 | | | | 16 |
| China - Taiwan | 3 | 7 | | | | 10 |
| CNMI | | | 2 | 3 | 1 | 6 |
| Colombia | 2 | 13 | 9 | 10 | 2 | 36 |
| Cuba | | | | | 2 | 2 |
| Egypt | 49 | | | 10 | 12 | 71 |
| Eritrea | | | | 2 | | 2 |
| Fiji | 6 | | 6 | 8 | 8 | 28 |
| French Polynesia | | | 2 | | | 2 |
| FSM | | | | 10 | 13 | 23 |
| Grand Cayman Island | 1 | 1 | | | | 2 |
| Honduras | 1 | | 2 | | | 3 |
| India | | 1 | | | | 1 |
| Indonesia | 25 | 1 | 18 | 38 | 85 | 167 |
| Iran | | | 1 | 2 | 2 | 5 |
| Israel | 1 | 3 | | | 2 | 6 |
| Jamaica | | 1 | | 2 | 3 | 6 |
| Japan | 2 | 5 | 8 | 16 | 21 | 52 |
| Madagascar | | | | | 3 | 3 |
| Malaysia | 39 | 31 | 7 | 28 | | 105 |
| Maldives | 30 | | | | 8 | 38 |
| Mauritius | | | 6 | 2 | 2 | 10 |
| Mexico | 8 | | | 4 | 1 | 13 |
| Mozambique | 1 | | | 1 | 2 | 4 |
| Myanmar | | | | | 5 | 5 |
| Netherlands Antilles | | 4 | | 4 | | 8 |
| New Caledonia | 5 | 24 | | | 6 | 35 |
| Palau | 2 | | | 4 | 2 | 8 |
| Panama | 1 | 1 | | | | 2 |
| Philippines | 3 | 11 | 6 | 5 | 9 | 34 |
| PNG | | 4 | 14 | 5 | 1 | 24 |
| Saudi Arabia | | | 17 | | | 17 |
| Seychelles | 6 | | | | 1 | 7 |
| South Africa | | | | 1 | 5 | 6 |
| St. Lucia | | | 4 | 2 | 2 | 8 |
| Tanzania | 2 | 3 | 1 | | | 6 |
| Thailand | | 2 | 10 | 7 | 55 | 74 |
| USA - FL | 31 | 19 | 6 | 1 | 12 | 69 |
| USA - GUAM | 1 | 3 | 3 | | 4 | 11 |
| USA - HI | 1 | 5 | 2 | 1 | 7 | 16 |
| Vietnam | | 8 | 10 | 11 | 16 | 45 |
| Yemen | | 1 | | | 2 | 3 |
| **Total** | **256** | **173** | **152** | **189** | **337** | **1107** |



The reef slope below 12 m depth is not monitored by Reef Check due to safety concerns. Photo by Jeff Jeffords.

# INVERTEBRATES

## GLOBAL INDICATORS

### Spiny Lobster

*(Panulirus spp.)*

Spiny lobsters were chosen as a Reef Check indicator because they are universally prized as a seafood item. Many different species are harvested commercially in the Pacific and Atlantic Oceans for the global market. The five major species are ***P. argus*** in the Caribbean, ***P. cygnus*** in W. Australia, ***P. marginatus*** in Hawaii and ***P. pencillatus*** in the Pacific. In 2000, almost 36,000 metric tons were exported from the Caribbean and Central Western Pacific regions alone (FAO, 2002). Although lobster are nocturnal feeders and tend to stay in caves and crevices during the day, they are easily caught using nets, traps and spears and so are typically fished out very quickly from coral reefs. The absence of lobster on the shallow reefs monitored for Reef Check is thus a good indicator of human predation.

Of the 1,068 reefs surveyed for lobster, none were recorded on 83%; regionally the percentage of sites with zero lobster was 90% in the Indo-pacific and 49% in the Atlantic region. Only 168 lobsters were recorded during 888 Reef Check surveys in the Indo-pacific, an average of 0.05 ± 0.26 lobster per 100 m². When averaged over five years, lobster were approximately eight times more abundant in the Caribbean than in the Indo-pacific, with an average of 0.39 lobster ± 0.64 per 100 m² ($p \leq 0.01$) (Figure 4.2). The maximum density of lobster recorded was 5.25 per 100 m² on a reef in the Abrolhos Islands, Australia in 1998. This area supports the famous Western Australian lobster fishery, which brings in about A$200 million per year from an annual catch of between 8 and 15 thousand tons of ***Panulirus cygnus***. The fishery is unusually productive for a coral reef area due to periodic nutrient rich upwelling and the Leeuwin Current. The maximum abundance of lobster in the Atlantic was 3.25 per 100 m², recorded at Hens and Chickens reef in the Florida Keys in 1999.

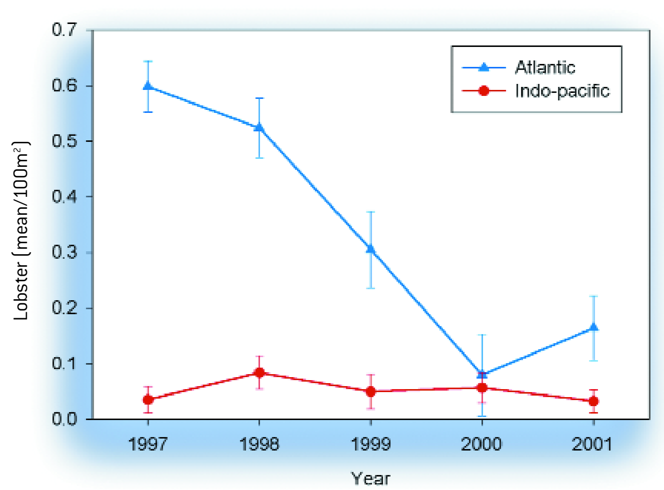
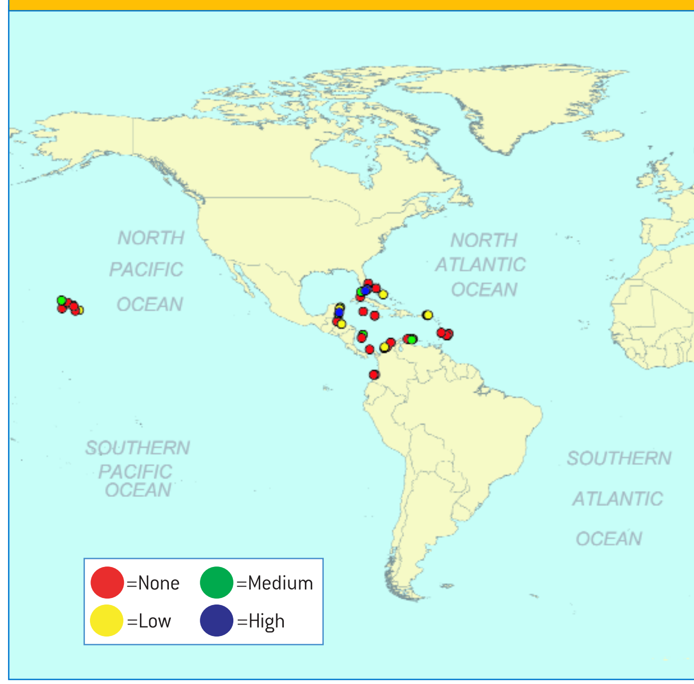



Figure 4.1: Mean abundance of lobster per 100 m² (1997-2001) on Indo-pacific and Atlantic reefs.

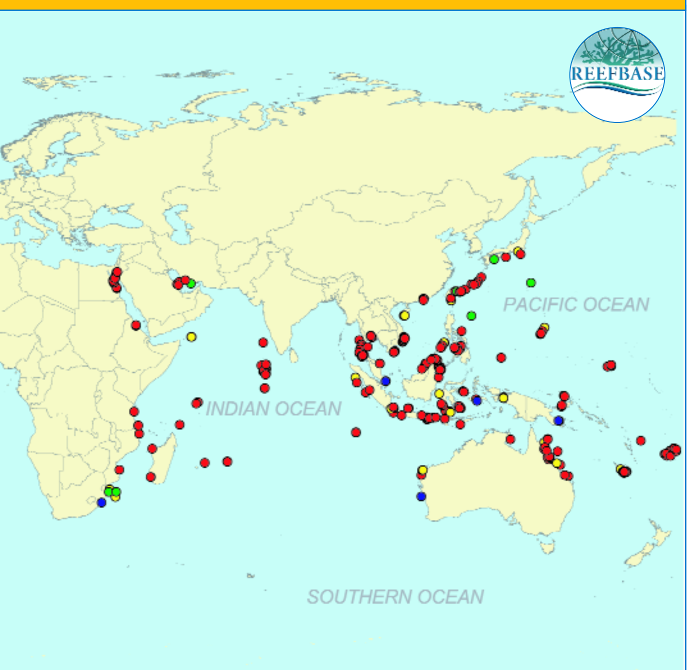
**Figure 4.2: Relative abundance of lobster (1997-**




During the time period 1997-2001, the abundance of lobsters remained fairly constant in the Indo-pacific, whereas numbers of lobster in the Atlantic declined from a mean of 0.60 per 100 m² ± 0.69 in 1997 to a mean of 0.08 ± 0.72 ($p \leq 0.01$) in 2000 and 0.16 in 2001 ($p=0.01$) (Figure 4.1). This significant decline indicates a major change in regional lobster abundance, and is exactly the type of change that Reef Check was designed to detect. This decline occurred at the same time as an increase in lobster exports from the Caribbean from 29,226 mt in 1997 to 35,204 mt in 2000 (FAO, 2002). Fisheries managers in Atlantic countries should try to obtain more detailed independent assessments as to whether their reefs have experienced a similar trend. It should be noted that this decline was only measured on shallow reefs monitored by Reef Check.

Information on abundance of spiny lobster is rare. In Bermuda,

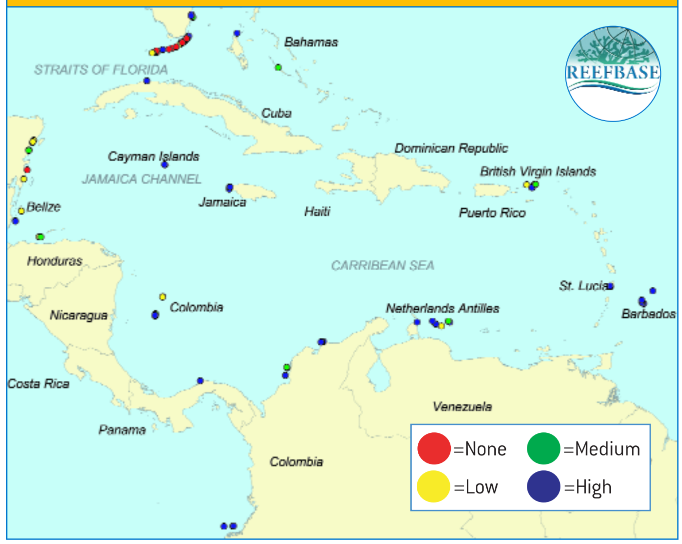
2001). None = 0; Low=1; Medium= 2-3; High>3




Evans and Evans (1996) measured 6.0 post-recruits per ha (0.06 per 100 m$^2$) near the reef crest and 97 under sized lobsters per ha on the outermost terraces of the platform edge.

Two studies made by Prescott (1980) in the Solomon Islands, and three by Ebert and Ford (1986) at Eniwetak for ***Panulirus penicillatus*** derived estimates of approximately 0.5 lobster per 100 m$^2$. This is ten times the mean obtained by Reef Check teams from a wide variety of reefs. In an article entitled, "Pacific Island Lobster Fisheries: Bonanza or Bankruptcy?" Tim Adams and Paul Dalzell (1993) hypothesized that the lack of broad continental shelves around Pacific Islands limits the amount of shallow water habitat for lobsters. This combined with the lack of nutrient inputs from

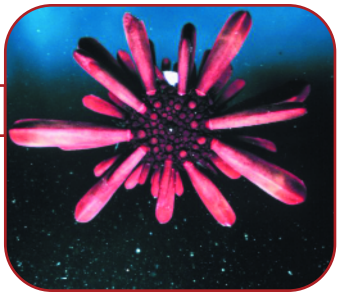
Figure 4.3: Caribbean Inset of Figure 4.2




land and upwelling limits productivity such that a sustainable catch rate is estimated to be 20 kg per kilometer of reef face per year. In considering advice for investors in this fishery, they stated:

> "Most Pacific Island lobster stocks are already subject to a certain level of local exploitation: catch-rates will thus not be very high..... Only very remote reefs have the possibility of supporting "virgin" stocks with densities high enough to support the expenses of a trip by a large vessel, and all of these have been prospected at least once already. The average recovery rate of these isolated reefs after being hit is unknown, but would be several years."

As with many other fisheries, overfishing has eliminated spiny lobsters from shallow reefs throughout the world. Although the explanation is obvious, this dramatic decline has not been documented prior to Reef Check. The fishermen simply shifted to new areas and deeper water. An interesting research question is why the density of lobsters is lower on Pacific than on comparable Atlantic reefs?



## Pencil Urchins

*(Heterocentrotus mammilatus and Eucidaris spp.)*

Although many sea urchins are collected from reefs for their edible roe, pencil urchins are only prized as a curio. Their attractive thick and smooth spines are often used in decorative seashell arrangements or as wind chimes. They are also used in jewelry and sold in the marine ornamental trade. On the reef, these organisms are found in shallow water and are easily collected by free divers.

Of the 818 reefs surveyed for this indicator over the five-year period, there was a significantly higher number ($p \leq 0.01$) of pencil urchins in the Atlantic, represented by ***Eucidaris*** spp. (1.17 ± 3.0 per 100 $m^2$) than in the Indo-pacific, represented by ***Heterocentrotus mammilatus*** (0.40 ± 3.1 per 100 $m^2$). However, the greatest abundance of pencil urchins was found on two reefs in the Hawaiian Islands. A reef surveyed off Palauea Beach in Maui in 2001 had 120.7 pencil urchins per 100 $m^2$. Kahalu'u Beach in windward Oahu, an area with restrictions on fish feeding and collection for the aquarium trade, had an abundance of 29.25 urchins per 100 $m^2$ when it was surveyed in 1998.

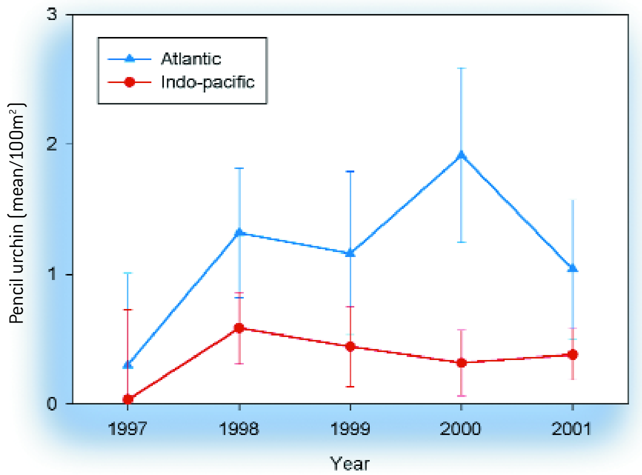
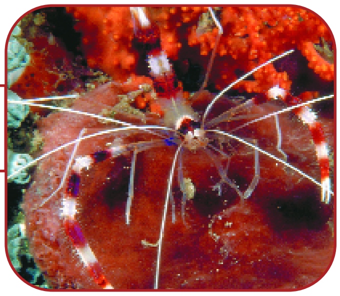



Figure 4.4: Mean abundance of pencil urchins per 100 $m^2$ (1997-2001) on Indo-Pacific and Atlantic reefs.

The number of pencil urchins in the Indo-pacific and Atlantic did not change significantly over time (Figure 4.4).



## Banded Coral Shrimp

*(Stenopus hispidus)*

The banded coral shrimp was chosen as an indicator of aquarium fish collecting. The shrimp is collected in both the Atlantic and the Pacific Oceans, and currently sells for approximately US$20 per pair in United States pet shops.

Of the 820 sites surveyed for banded coral shrimp, a mean of 1.2 ± 3.3 per 100 $m^2$ was found in the Atlantic region during the period 1997-2001, a significantly higher number ($p \leq 0.01$) than in the Indo-pacific (0.09 ± 0.42 per 100 $m^2$). This order of magnitude difference in coral shrimp populations is likely a natural difference between the two oceans, however, in high collection areas such as the Philippines, Fiji and Indonesia, this may be due to much higher extraction rates. There were no obvious trends in abundance over time (Figure 4.5). The maximum number of banded coral shrimp recorded during any one survey was 46.3 per 100 $m^2$ in the Karpata Marine Reserve in Bonaire in 2000.

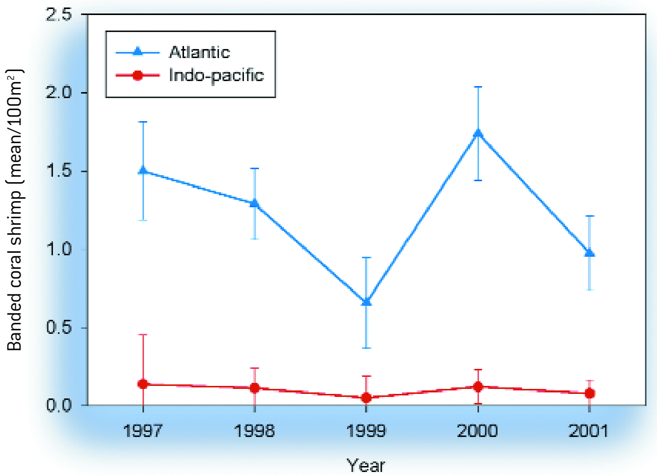
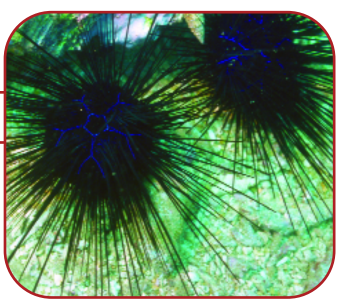



Figure 4.5: Mean abundance of banded coral shrimp per 100 $m^2$ (1997-2001) on Indo-pacific and Atlantic reefs.

should not be taken as an indication that the species is on the verge of extinction. During the day when Reef Check surveys are carried out, the banded coral shrimp hides in cracks and holes under rocks. Therefore, the animals counted are those that venture near to the opening of such cracks and crevices where they can be observed. In fact, the aquarium fishermen turn over large coral heads to locate and collect these organisms.

The mean abundance of banded coral shrimp was ten times lower at sites with high perceived impacts from the aquarium trade than at sites with no perceived impacts from these activities. None of these differences were statistically significant due to the relatively low sample size of reefs rated as high for aquarium fishing impacts.

According to the GMAD database of ornamental trade maintained by WCMC/UNEP, 16,248 banded coral shrimp were exported by five companies in the Philippines in 2001. Of these, 14,805 were exported to the United States. The total exports from the Philippines and Indonesia are undoubtedly much higher. Reef Check is working closely with the Marine Aquarium Council to set up sustainable collection systems in countries where this potentially sustainable trade occurs. (See Chapter 7).



## Diadema

*(Diadema spp.)*

The six species of long-spined black sea urchins in the genus ***Diadema*** serve as global indicators and their abundance levels indicate different problems in the two major oceans. ***Diadema*** are nocturnal grazing herbivores that decrease algal cover on reefs through their feeding activities. They feed by scraping algae from the surface of the reef. ***Diadema*** populations contribute to net reef erosion. For example, a normal population of ***Diadema*** can produce as much as 5 kg of carbonate sediment per square meter per year by scraping the carbonate rock surfaces. This corresponds to about 1 cm of reef erosion per year (Ogden and Carpenter, 1987). When ***Diadema*** population densities are high, and the urchins graze around the bases of large colonies, this bioeroding activity can destabilize coral heads, increasing their susceptibility to getting knocked over by storm waves.

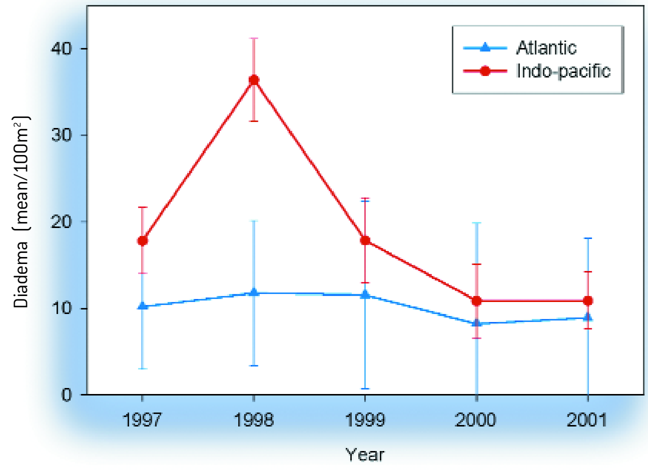



Figure 4.6: Mean abundance of ***Diadema*** per 100 $m^2$ (1997-2001) on Indo-pacific and Atlantic reefs.

On overfished reefs in the Atlantic or Pacific, where there is a lack of predators on all life stages of ***Diadema***, populations can reach high levels that tip the balance towards bioerosion and make it difficult for new coral recruits to become established (Vo and Hodgson, 1997). Prior to 1983, this problem was commonly observed on reefs in both oceans.

In 1983, a species-specific pathogen hit the Caribbean, resulting in a mass die-off of up to 99% of the existing ***Diadema*** populations in some areas (Lessios, 1995). In areas where overfishing had severely reduced both predators and herbivores, such as in Jamaica, the loss of grazers led to an exponential increase in macroalgae. Reef corals, particularly those in shallow water, were overgrown by algae. Living coral cover on these reefs declined from about 30 to 70% to a mere 1 to 10% (Hughes, 1994).

Therefore, while moderate ***Diadema*** populations are critical to maintaining the natural balance between algae and coral in a

FIGURE 4.7: RELATIVE ABUNDANCE OF DIADEMA (1997-2001). NONE = 0; LOW=1-4; MEDIUM= 5-19; HIGH>19


healthy reef system, high-density populations are considered a negative indicator in all oceans. In areas where overfishing has reduced herbivore populations, a low population of ***Diadema*** is also considered to be a negative indictor. This is the present situation in most of the Caribbean.

During the period 1997-2001, 1,066 reefs were surveyed for ***Diadema*** urchins. The mean number of ***Diadema*** in the Atlantic (10.3 ± 30.9 per 100 m$^2$) was lower than the mean number in the Indo-pacific (17.1 ± 58.3 per 100 m$^2$) (p=0.07). In the Atlantic, ***Diadema*** abundance remained consistently low throughout the five-year sampling period (Figure 4.6). Mean numbers of ***Diadema*** were generally higher in the southern Caribbean when compared to the northern Caribbean and Florida Keys area (Figure 4.7). The abundance of ***Diadema*** in the Indo-pacific significantly increased from 17.82 ± 48.9 per 100 m$^2$ in 1997 to 36.41 ± 103.1 per 100 m$^2$ in 1998 (p=0.04) and then significantly decreased (p = 0.01) to 10.9 ± 42.1 per 100 m$^2$ in 2000 (Figure 4.6). From an ecological standpoint, the reduction in ***Diadema*** abundance on Indo-pacific reefs to the same level as the Atlantic is cause for concern that should be investigated in more detail.

The mean number of ***Diadema*** per 100 m$^2$ was higher (24.5 ± 68.1) at sites where anthropogenic impacts were judged high than at those judged to have no impacts (11.8 ± 29.5), although these differences were not statistically significant at a 95% confidence level.

Previously, surveys in Jamaica have recorded densities of 0.1 to 12 ***Diadema*** per m$^2$ (Edmunds and Carpenter, 2001; Miller and Gersner, 2002). Much lower numbers, 0.004-0.379 ***Diadema*** per m$^2$ were recorded in Singapore (Grignard et al., 1996). The high variation of estimates in the Caribbean may reflect different methods and scales of sampling.

### Triton

*(Charonia spp.)*

The triton was chosen as a global reef health indicator because it has a beautiful shell that it is very desirable and easy to collect as a curio. Like the pencil urchins, the triton is represented by a different species in the Atlantic (***Charonia variegata***) and Pacific (***Charonia tritonis***). In contrast to smaller mollusks, the triton grows so large (50 cm long) that it cannot hide in small crevices, and so is visible to the collector. Saville-Kent (1893, plate XLII-III) provided two photos and remarked, "Either singly or in artistically arranged groups, these coral-mounted shells lend themselves with remarkable suitability to the purposes of table decoration." He also correctly described how native Australians collected the shells for use as a trumpet. The triton is now protected on the Great Barrier Reef. A survey of about 1 ha of John Brewer Reef in 1988 by Chesher (1988) yielded 7 triton (equivalent to 0.07 triton/100 $m^2$).

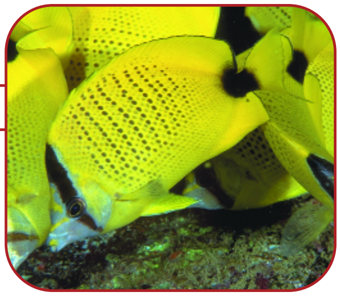
In the Indo-pacific, the triton is a predator of the crown-of-thorns sea star that, in turn, preys on corals. According to Sap (1999), estimates of the harvest of triton from the Great Barrier Reef during the 1960s were 10,000 per year, potentially reducing predation on the crown of thorns.

Only 60 of the 1101 sites surveyed had at least one triton. There was a total of 101 triton found over the five year sampling period. The mean abundance of triton was $0.03 \pm 0.32$ per 100 $m^2$ in the Indo-pacific and $0.05 \pm 0.24$ in the Atlantic.

Unfortunately, the triton is now extremely rare, and it is difficult to know what the "normal" baseline should be for a natural population anywhere. Given the success of giant clam aquaculture and the high price of triton shells (approximately US$30-50 each), triton would be a good candidate for aquaculture research.

# FISH

## GLOBAL INDICATORS



### Butterfly Fish

*(Chaetodon spp.)*

Butterfly fish of the family Chaetodontidae were selected as an indicator of the ornamental fish trade. At least 30 species of butterfly fish are actively collected for the aquarium trade, despite the fact that most of the 114 species are notoriously difficult to maintain in home aquaria due to special feeding preferences. They are a medium to high-priced fish (US$15 to $300 each) depending on the species and size. It is also worth noting that butterfly fish, despite their small size, are frequently caught and eaten by people from Hawaii to the Philippines. They are caught in gill nets, traps and by spear fishermen for consumption.

During the five-year monitoring period, 98% of all reefs monitored worldwide had at least one butterfly fish. The mean abundance of butterfly fish in the Atlantic ($0.2 \pm 6.4$ butterfly fish per 100 $m^2$ ) was significantly less ($p \leq 0.01$) than in the Indo-pacific ($10.0 \pm 10.0$ fish per 100 $m^2$ reef ) (Figures 4.8 and 4.9). This is believed to be a natural biological difference that defines reef fish

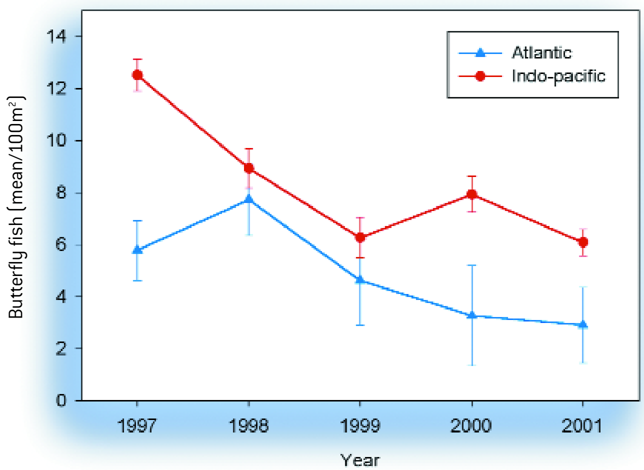
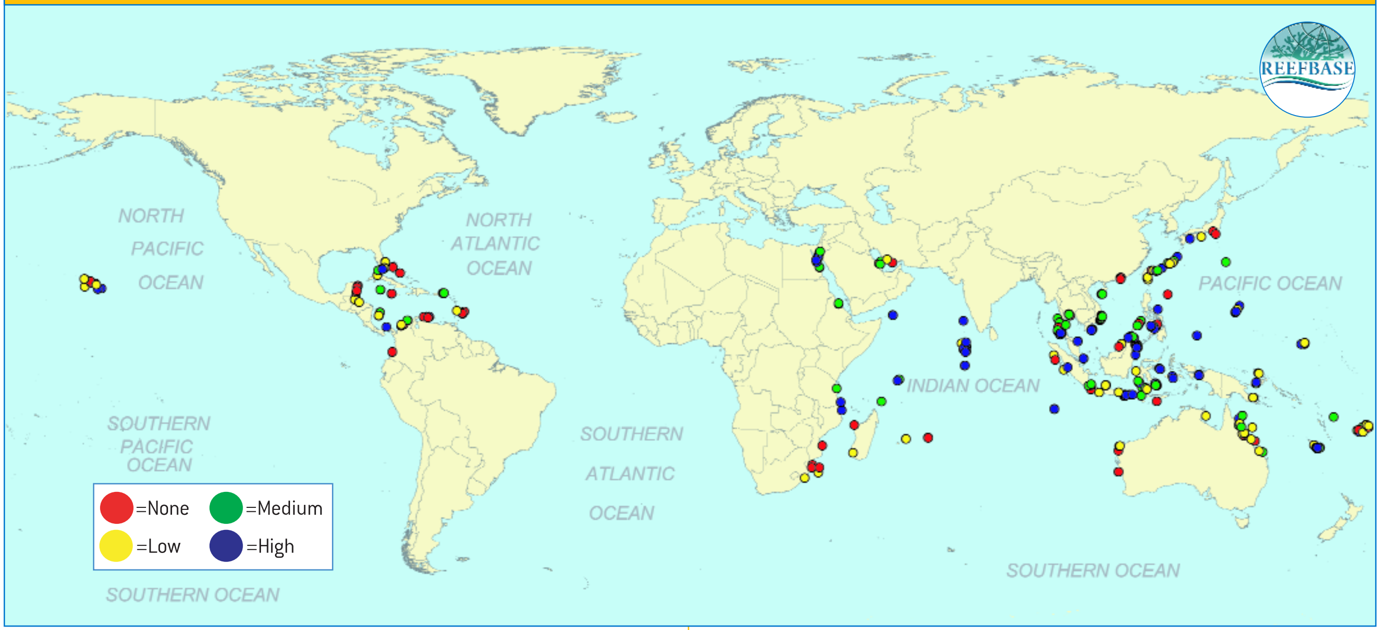



Figure 4.8: Mean abundance of butterfly fish per 100 $m^2$ (1997-2001) on Indo-pacific and Atlantic reefs.

**Figure 4.9: Relative abundance of butterfly fish (1997-2001). None = 0; Low=1-16; Medium= 17-44; High>44**




communities in the two oceans, and may be related to the fact that there is a ten times higher species diversity in the Pacific than in the Atlantic. This hypothesis is supported by multidimensional scaling analyses followed by the SIMPER test that indicated butterfly fish were responsible for 42% of the similarity among Indo-pacific sites (See Multivariate Analyses).

There was a significant decrease in the global mean number of butterfly fish in all oceans from 1997 (11.0 ± 10.6 per 100 $m^2$) to 2001 (5.7 ± 5.8 per 100 $m^2$ reef) ($p \leq 0.01$) (Figure 4.8). This decrease is primarily due to the decline in butterfly fish in the Indo-pacific. In 1997, the mean number of butterfly fish on an Indo-pacific reef was 12.5 ± 10.4 per 100 $m^2$. Five years later, the mean had decreased to half that number (6.1 ± 5.3). This significant decrease ($p \leq 0.01$) could be an indication of overfishing and destructive fishing methods.

Since 2000, Reef Check has been working with the Marine Aquarium Council to help test and establish a certification system to promote a sustainable marine ornamentals trade. The initial intensive surveys using the MAQTRAC method indicate that butterfly fish such as ***Chaetodon baronessa*** and ***C. octofasciatus*** have been severely overfished in two areas of the Philippines (Ochavillo et al., in prep). Additionally, Tissot and Hallacher (1999) demonstrated that aquarium collection significantly reduced the abundance of butterfly fish in Hawaii.

## Grouper

*(Serranidae)*

Grouper of any species with a length greater than 30 cm were selected to serve as an indicator for over fishing of all types. Grouper are some of the easiest fish for divers to spear because of their size and territorial habits. Grouper also aggregate during spawning, making them vulnerable to many forms of fishing. Grouper are fished using spears, nets, hook and line and various types of traps. Grouper larger than 30 cm are a very useful indicator of fishing pressure because they are one of the higher priced food fish and most easily fished out due to their reproductive traits. Grouper may take several years to reach sexual maturity and typically change sex. Fisheries that remove large individuals can easily wipe out all sexually mature fish and/or create a highly skewed sex ratio making reproduction unlikely (Sadovy, 1997).

In detailed multi-year studies of overfishing in locations including Jamaica, Australia and the Philippines, Serranidae initially show a decrease in mean size followed by local extinction (Craik, 1981; Munro, 1983; Koslow et al., 1988; Russ et al., 1989). When a new grouper fishery was opened on Boult Reef in the Great Barrier Reef, 25% of the grouper were removed in the first 14 days of fishing (Beinssen, 1988).

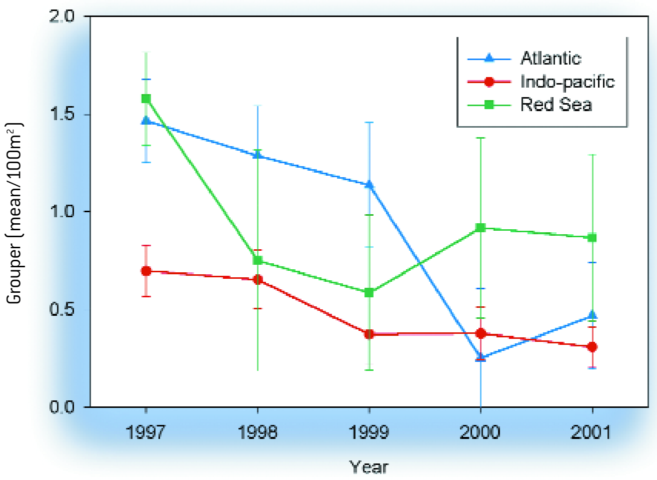


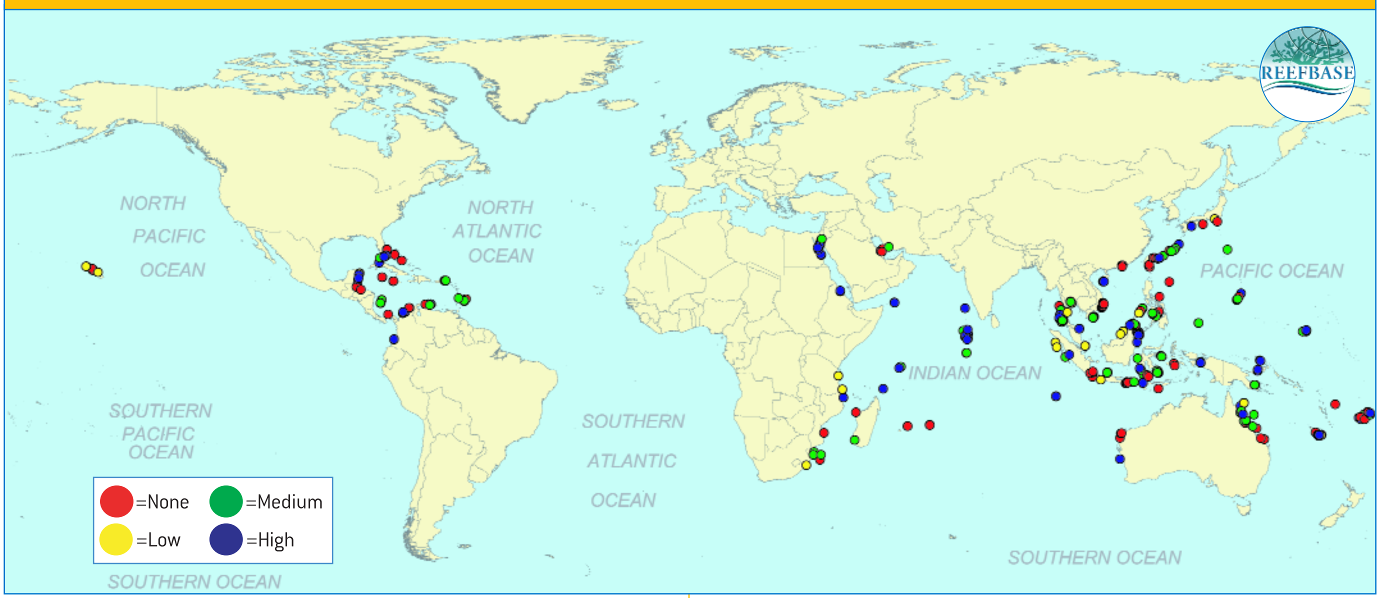

Figure 4.10: Mean abundance of grouper > 30 cm per 100 m$^2$ (1997-2001) on Indo-pacific and Atlantic reefs.

Reef Check results indicate grouper have been fished out from most shallow reefs throughout the world (Figure 4.11). There were zero grouper larger than 30 cm recorded at 48% of 1,022 reefs surveyed during the period 1997 to 2001. In contrast, the highest numbers of grouper were found on Tennessee Reef in Florida in 1997. This reef is part of the Florida Keys National Marine Sanctuary and had an abundance of over 24 grouper per 100 m$^2$. Reefs surveyed in Ras Mohamed National Park in Egypt during 1997 and 2001 also had a high abundance, with a mean of over five grouper per 100 m$^2$.

The mean number of grouper found on Indo-pacific reefs during the period 1997 to 2001 was 0.54 ± 1.04. The mean number of grouper in the Red Sea during this period was 1.15 ± 1.3, while the mean number of grouper in the Indo-pacific (minus the Red Sea) was 0.45 ± 0.98 (Figure 4.10).

The mean number of grouper per 100 m$^2$ in the Indo-pacific decreased by a factor of two between 1997 and 2001 (Figure 4.10) from a mean of 0.69 ± 1.4 in 1997 to 0.31 ± 0.51 in 2001 ($p \leq 0.01$).

FIGURE 4.11: RELATIVE ABUNDANCE OF GROUPER > 30CM (1997-2001). NONE = 0; LOW=1; MEDIUM= 2-4; HIGH>4



| Species | Location | Effects |
|---|---|---|
| *Cepalopholis miniata, C. hemistiktos, Variola louti* | Red Sea | About 30 to 300% increase in mean weight of species in un(der)fished relative to other areas (Roberts and Polunin 1993) |
| Serranids, mainly *Cephalopolis spp*. | Sumilon Island, Philippines | Average weight twice as large and density and biomass 3-30 times greater than controls (Russ 1985). |
| *Plectropomus leopardus* | Great Barrier Reef, Australia | Average lengths greater, and density higher on unfished than on fished reefs (Beinssen 1989, Craik 1981) |
| *Epinephelus fulvus* | Saba Marine Park, Belize | Unfished biomass, sizes and abundance greater in unfished than in fished zone (Polunin and Roberts 1993, Roberts 1995). |
| *Epinephelus striatus* | Marine Park, Bahamas | Eggs per area greater inside (due to greater parental sizes and abundance) than outside park (Sluka et al. 1997) |
| Serranids | Looe Key Reef, Florida, USA | Abundance increased after two years of protection from spearfishing (Bohnsack and Bannerot 1986) |
| Serranids, mainly young *Plectropomus leopardus* | New Caledonia | Significant increase of biomass and density in protected areas (Wantiez et al. 1997) |

Table 4.2: Examples of the positive effects of Marine Protected Areas on grouper populations (Sadovy, 1999).

In the Atlantic region, grouper abundance (including Nassau grouper) declined from 1999 (1.13 grouper ± 3.2 per 100 m$^2$) to 2000 (0.25 ± 0.54 per 100 m$^2$). Although non-significant, this decline should be investigated in more detail.

Similar to the results of Sadovy (1999), the numbers of grouper counted by Reef Check were significantly higher inside than outside MPAs. Ferreira and Russ (1995), did not detect this trend.

## Haemulidae

Haemulidae are represented in the Indo-pacific by sweetlips and grunts, and in the Atlantic region by margates and grunts. The 150 species of fish that make up this family were chosen as reef health indicators because they are a highly popular food fish in both oceans. Many species grow to a large size and thus are subject to all major forms of fishing. Some of the haemulids also have behavioral traits that make them particularly susceptible to spearfishing. In areas where spearfishing is common, many fish become "skittish" around divers. But haemulids such as ***Diagramma*** seem oblivious to past history and typically swim close to divers. Hence they tend to be the first to get shot out of a reef.

There was a mean of less than one haemulid per 100 m$^2$ in the Indo-pacific over the five-year period (Figure 4.12). In contrast to relative abundance of butterfly fish in each ocean, there were fifty times more haemulids in the Atlantic than in the Indo-pacific (p≤ 0.01)(Figure 4.13).

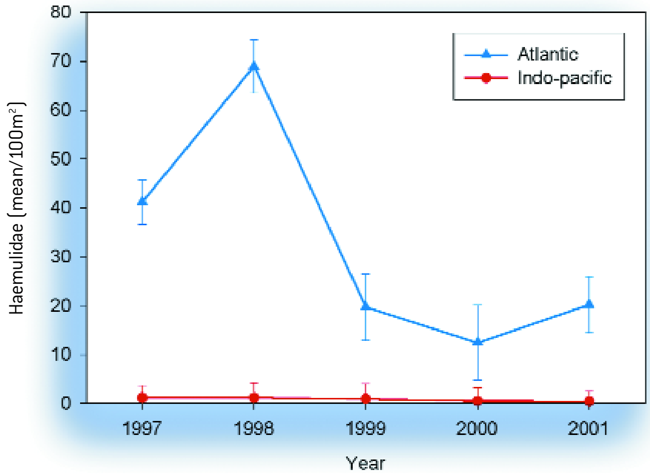



Figure 4.12: Mean abundance of Haemulidae per 100 m$^2$ (1997-2001) on Indo-pacific and Atlantic reefs.

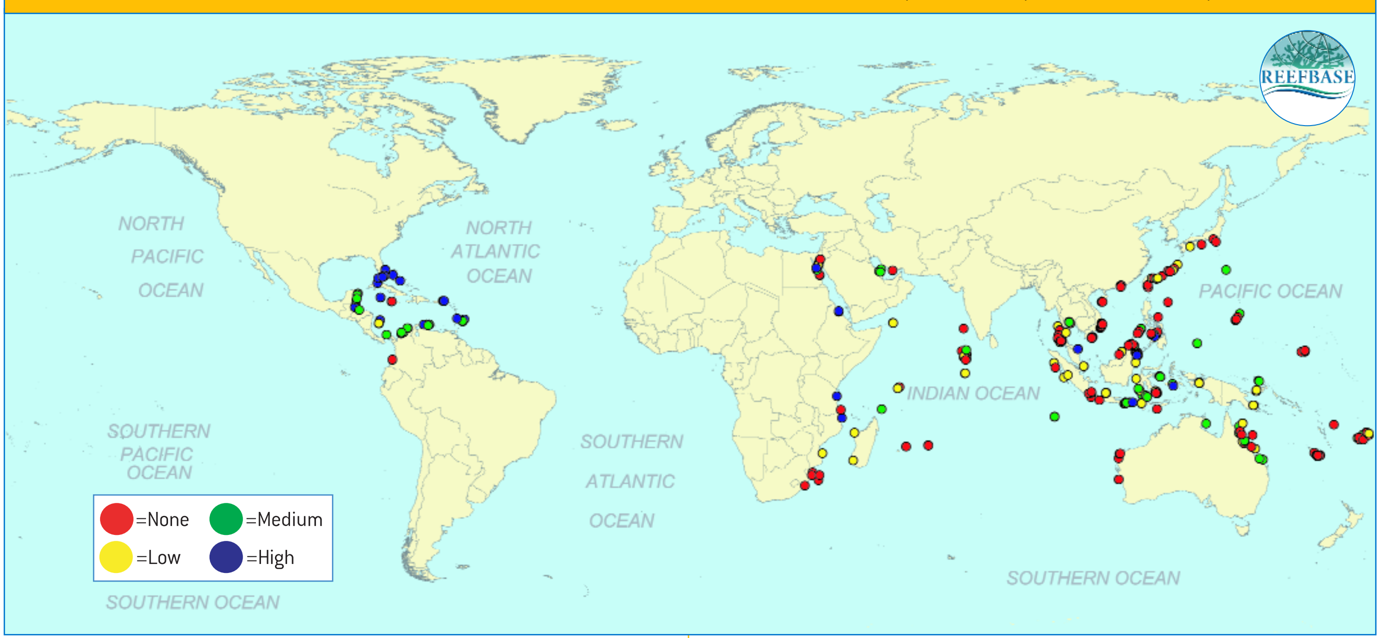
Consequently, two fundamental differences between reefs in the two oceans are the relative predominance of the family Haemulidae on Atlantic reefs and the predominance of the family Chaeodontidae on Indo-pacific reefs.

Between 1998 and 2001, there was a decrease in the number of Haemulidae in the Atlantic region. The mean density of Haemulidae decreased from 68.8 ± 142.6 per 100 $m^2$ to 20.1 ± 46.8 per 100 $m^2$ in 2001 ($p=0.08$). At least one haemulid was found on 98% of all reefs surveyed in the Atlantic region, with a record 797.5 fish per 100 $m^2$ found on Alligator Reef in Florida in 1998. This reef lies within the Florida Keys National Marine Sanctuary. When analyzed on an ocean wide basis, there was no significant difference in abundance of haemulids inside and outside of MPAs. Overall, 57% of all reefs surveyed in the Indo-pacific had zero Haemulidae, with the greatest number (25) seen on a reef in Ras Mohamed National Park in Egypt in 1997.

The number of Haemulidae was negatively correlated with increasing levels of blast fishing. The higher the level of perceived blast fishing, the lower the numbers of Haemulidae ($p=0.04$). In the Indo-pacific, the mean number of Haemulidae on reefs with no perceived blast fishing was 0.83 ± 2.2 per 100 $m^2$, whereas reefs with a high rating for blast fishing had a mean of 0.29 ± 0.73 fish per 100 $m^2$, however, this was not significant.

In detailed studies of reefs where overfishing has reached the ecosystem level, large Haemulidae are usually missing (Munro, 1983; Koslow et al., 1988). Reef Check results indicate that more than half the reefs have been fished so heavily that haemulids are missing. In the Atlantic, instead of seeing hundreds of grunts and margates, there are only a dozen per reef. The haemulid data clearly indicate that the level of overfishing has reached a damaging level.

FIGURE 4.13: RELATIVE ABUNDANCE OF HAEMULIDAE (1997-2001). NONE = 0; LOW=1-2; MEDIUM= 3-20; HIGH>20



## Parrotfish

*(Scaridae)*

Parrotfish were selected as an indicator of over fishing of various kinds. The 80-odd species of parrotfish play a critical role in the ecological balance of a coral reef because they are the largest herbivorous reef fish and they scrape large quantities of turf algae from the reef, ingesting live and dead coral, and creating sand in the process. Without parrotfish, algae would have an advantage in the competition for space with coral. The Indo-pacific bumphead parrot ***Bolbometapon muricatum*** is counted separately because it is a large, enigmatic, and easily identified schooling fish, and it feeds directly on live coral. Because of their wandering lifestyle, off-transect records are allowed for this species. Parrotfish are easily caught using nets, spears and traps. They form a significant part of the reef fish biomass. When reefs are subject to heavy fishing, the normal pattern is for predators to be fished out first, followed by the herbivores such as the parrotfish (Munro, 1983; Koslow et al., 1988).

In the Indo-pacific, 55% of all reefs surveyed were devoid of all parrotfish greater than 20 cm or bumphead parrotfish of any size

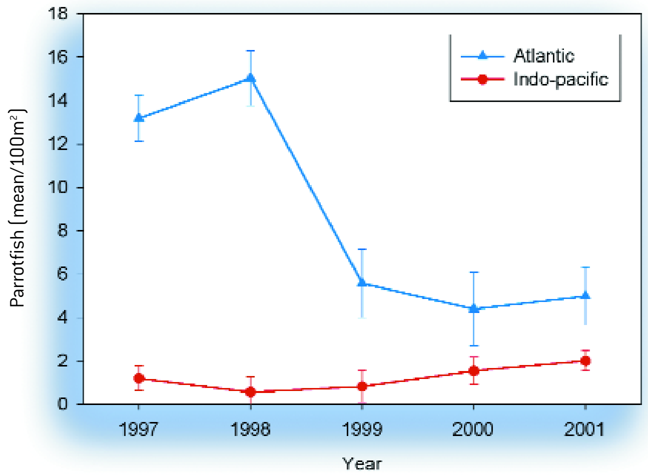
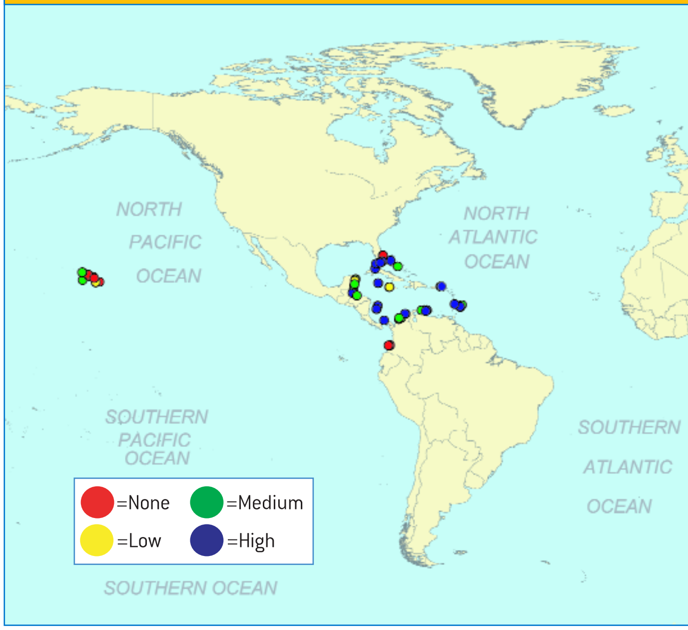



Figure 4.14: Mean abundance of Parrotfish > 20 cm and all bumphead parrofish per 100 m² (1997-2001) on Indo-pacific and Atlantic reefs.

FIGURE 4.15: RELATIVE ABUNDANCE OF PARROTFISH (1997-2001). NONE = 0; LOW=1; MEDIUM= 2-4; HIGH>4



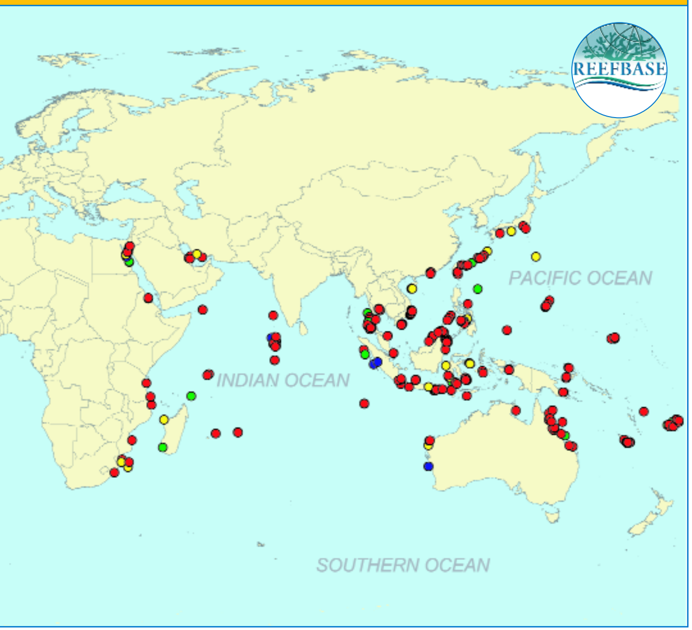

(hereafter defined as total parrotfish). Numbers of parrotfish in the Atlantic region ranged from four to six times higher than in the Indo-pacific – another defining difference between the two oceans (Figure 4.14). In addition, 96% of all reefs surveyed in the Atlantic region had at least one parrotfish > 20cm. (Figure 4.15).

Overall, total parrotfish in the Indo-pacific increased significantly ($p=0.01$) from 1997 to 2001 from 1.2 ± 2.5 per 100 $m^2$ to 2.0 ± 2.9 per 100 $m^2$ reef.

Parrotfish abundance in the Atlantic region decreased significantly over the same period from a high of 13.2 ± 24.0 per 100 $m^2$ in 1998 to a low of 5.1 ± 4.3 per 100 $m^2$ in 2001 ($p=0.05$). Despite this decrease, the density of parrotfish was greater inside MPAs (11.38 ± 21.7 per 100 $m^2$) than outside MPAs (5.5 ± 5.0 per 100 $m^2$), although this difference was not significant at the 95% confidence level.

In the Indo-pacific, the abundance of total parrotfish significantly decreased with higher ratings for blast fishing ($p \leq 0.01$). The mean number of total parrotfish was 1.6 ± 2.89 per 100 $m^2$ in the absence of any perceived blast fishing and dropped to 0.46 ± 1.2 per 100 $m^2$ where blast fishing was rated as high.

> 20CM AND BUMPHEAD PARROTFISH OF ALL SIZES




## Moray eels

*(Muraenidae)*

Moray eels were added to the Reef Check protocol in 2001 as another global indicator for fishing impacts. There are over 100 species ranging in length from a few centimeters to 2 m. While moray eels have a lot of small bones that make them difficult for people to eat, they are an easy spear fishing target for those in search of a meal because of their large size and territorial behavior. Each fish lives in a defined hole and is visible at close range. Morays are nocturnal predators. No moray eels were detected on 81% of the 302 reefs surveyed.

## Snapper

*(Lutjanidae)*

Atlantic snapper were selected as a reef health indicator because of their importance as a food fish. Pacific snapper were then added to the protocol in 1999 to allow comparison between population levels in the two oceans. Snapper are medium to large-sized predators made up of over 100 species.

A total of 644 reefs were surveyed for snapper during the period 1997-2001. The mean number of snapper on an Atlantic reef (10.4 ± 23.2 per 100 $m^2$) was ten times higher than on an Indo-pacific reef (1.7 ± 5.2 per 100 $m^2$). This difference is largely due to the higher abundance of snapper found in 1997 and 1998 in the Atlantic (Figure 4.16) (p=0.02). In the Atlantic, 84% of all reefs surveyed had at least one snapper per reef. The abundance of snapper in the Atlantic declined from 15.5 ± 29.0 per 100 $m^2$ in 1997 to 3.5 ± 8.1 per 100 $m^2$ in 2001 (p=0.10). The greatest abundance of snapper, 169 per 100 $m^2$ reef, was recorded at Davis and Tennessee reefs in the Florida Keys National Marine Sanctuary in 1997 and 1998. No data are available from 1999-2001 from these reefs.

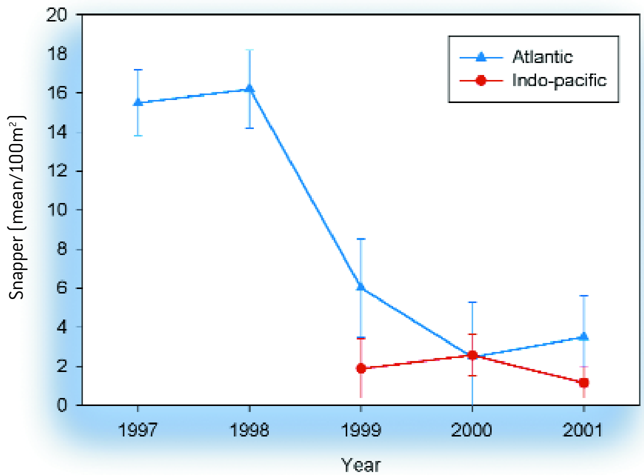



Figure 4.16: Mean abundance of snapper per 100 $m^2$ on Indo-pacific (1999-2001) and Atlantic reefs (1997-2001).

The numbers of snapper in the Indo-pacific did not change significantly between 1999 and 2001. However, there was a significant reduction between 2000 and 2001, the mean number of snapper per 100 $m^2$ reef dropped from 2.6 ± 7.8 to 1.1 ± 3.4. Snapper were not recorded on 45% of the 468 surveys conducted in the Indo-pacific.

In the Indo-pacific, more snapper were found on reefs inside MPAs (2.0 ± 6.2 per 100 $m^2$) than on reefs outside MPAs (1.2 ± 2.8 per 100 $m^2$) ($p$=0.15), although these differences were not significant. Biomass estimates made by Hawkins et al., (1999) at the Caribbean island of Bonaire showed a similar situation with 2.5 ± 0.7 kg inside the MPA and 1.1 ± 0.7 kg outside.

## Multivariate Analyses

Six global indicators (butterfly fish, ***Diadema***, grouper, haemulids, lobster and live coral index [% live coral/(recently killed coral + live coral]) were selected for ordination analysis. The MDS plot of the global indicators, averaged yearly by geographic region, is displayed in Figure 4.17. The Atlantic reef annual means are clearly separated from those of the Indo-pacific and Red Sea. The stress level of 0.03 corresponds to an excellent representation with no prospect of misinterpretation (Clarke and Warwick, 2001). ***Diadema*** and butterfly fish accounted for 44% and 30% of the similarity between Indo-pacific years, respectively. Haemulids and ***Diadema*** accounted for 42% and 24% of the similarity between Atlantic years, respectively. The mean dissimilarity of all pairwise coefficients between Indo-pacific and Atlantic regions was 34%. Of this, haemulids, ***Diadema***, and butterfly fish contributed 49%, 24% and 18% of the total value, respectively.

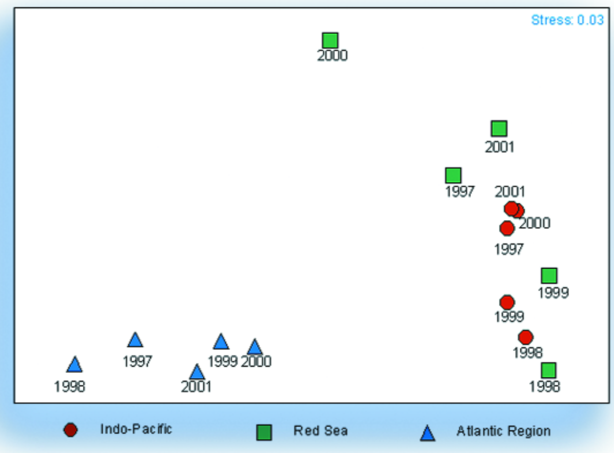



Figure 4.17: MDS plot of global indicators (butterfly fish, ***Diadema***, grouper, haemulids, lobster and live coral index) averaged yearly by geographic region.

The mean of the global indicators in 2000 for the Red Sea reefs was quite different from all other yearly averages on the plot. The low average abundance of ***Diadema*** (1.9 per 100 $m^2$) accounted for approximately 40% of the dissimilarity with all other years in the Red Sea. The density of ***Diadema*** increased in 2001 and was not a major factor differentiating 2001 from other years.

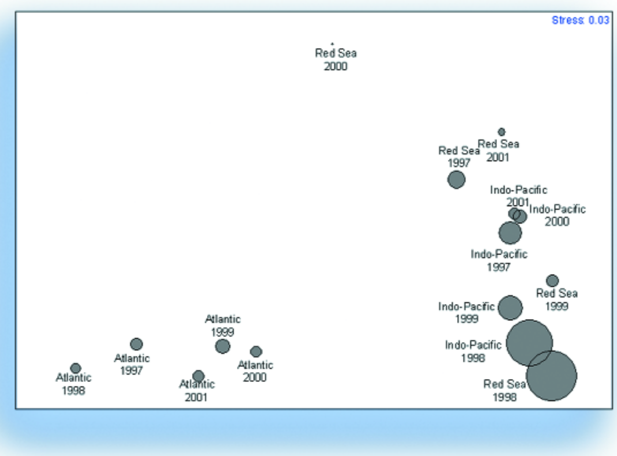



Figure 4.18: MDS plot of global indicators (butterfly fish, ***Diadema***, grouper, haemulids, lobster and live coral index) averaged yearly by geographic region. Circles represent the relative density of ***Diadema***.

Figure 4.18 is a replicate MDS plot of Figure 4.17, however the relative abundance of ***Diadema*** is represented by the size of the circles on the ordination plot. It is apparent that the differential densities of ***Diadema*** in the Indo-pacific and Atlantic Regions may play an important role in the overall multivariate pattern. For example, in both the Red Sea and the Indo-pacific in 1998, a high abundance of ***Diadema*** (compared to other years) may have been important in placing these samples close to each other. The SIMPER routine was used to assess numerical values of these relationships, i.e. the effect of ***Diadema*** on both the mean similarity within distinct geographic regions and the dissimilarity between geographic regions. ***Diadema*** contributed 44%, 37%, and 24% to the similarity between years in the Indo-pacific, Red Sea, and Atlantic, respectively. ***Diadema*** contributed 24% to the dissimilarity between annual means in the Indo-pacific and Atlantic and 20% to the dissimilarity between Red Sea and Atlantic yearly averages.

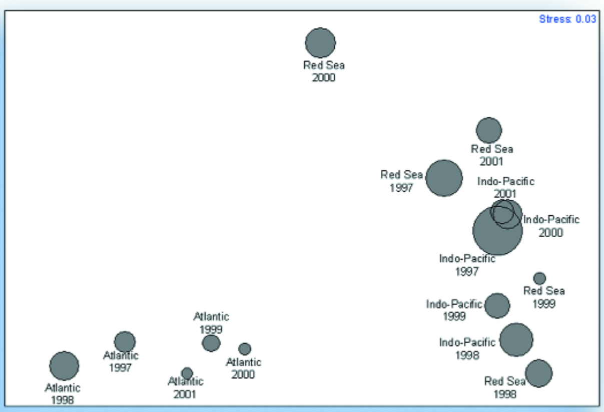



Figure 4.19: MDS plot of global indicators (butterfly fish, ***Diadema***, grouper, haemulids, lobster and live coral index) averaged yearly by geographic region. Circles represent the relative density of butterfly fish.

The relative abundance of butterfly fish represented by the size of the circles on the ordination plot is shown in Figure 4.19, a replicate of Figure 4.17. The differential densities of butterfly fish in the Indo-pacific and Atlantic may play an important role in the overall multivariate pattern shown on the MDS. The contribution of butterfly fish was 30%, 31%, and 18% to the similarity between years in the Indo-pacific, Red Sea, and Atlantic, respectively. Additionally, butterfly fish contributed 18% to the dissimilarity between Indo-pacific and Atlantic and 19% to the dissimilarity between Red Sea and Atlantic yearly averages.

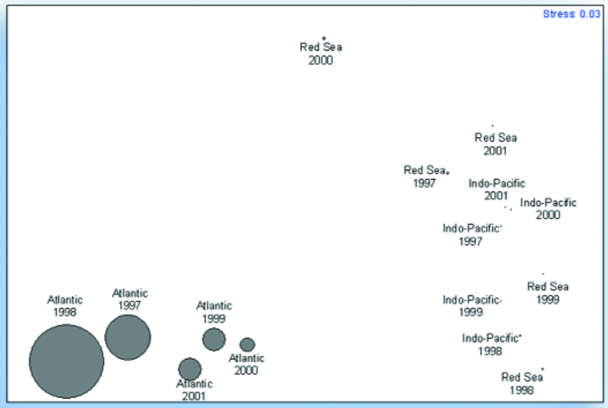



Figure 4.20: MDS plot of global indicators (butterfly fish, ***Diadema***, grouper, haemulids, lobster and live coral index) averaged yearly by geographic region. Circles represent the relative density of haemulidae.

Figure 4.20 is a replicate MDS plot of Figure 4.17 with the relative density of haemulids represented by the size of the circles on the ordination plot. The relatively high abundance of haemulids in the Atlantic compared to the other regions plays an important role in the overall multivariate pattern shown on the MDS. The contribution of haemulids was 9%, 10%, and 42% to the similarity between years in the Indo-pacific, Red Sea, and Atlantic, respectively. Additionally, haemulids contributed 50% to the dissimilarity between Indo-pacific and Atlantic annual means and 49% to the dissimilarity between Red Sea and Atlantic annual means.

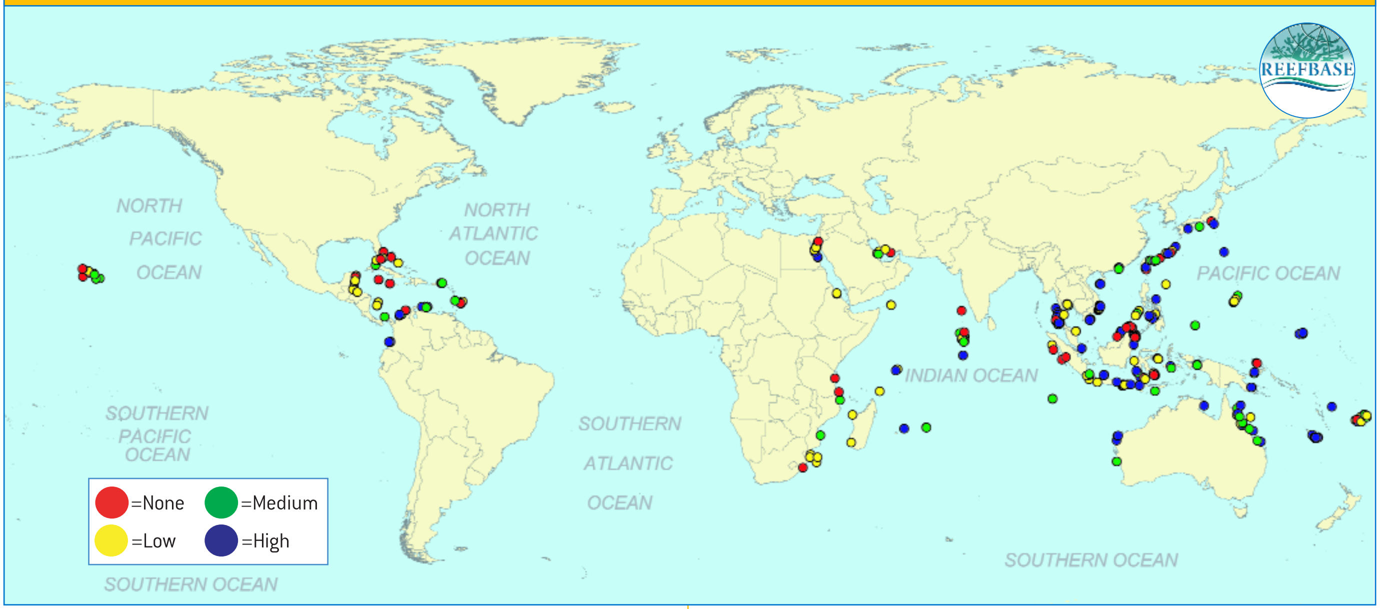
## CORAL COVER

### GLOBAL INDICATOR

#### Percent Hard Coral Cover.

The results of five years' monitoring show the percentage of the seabed covered by live coral at many of the world's best reefs is 32% (Figures 4.21 and 4.22). This number is important because previous characterization of reef health based on coral cover used very high percentages for good or excellent reefs e.g. (Gomez, 1981). Coral cover is greatly affected by the distribution of hard substratum on a reef as well as by the health of the corals living there. Out of over 1000 reefs monitored, only 34 had more than

**FIGURE 4.21: GLOBAL RELATIVE PERCENT HARD CORAL COVER (1997-2001).**




70% hard coral cover and none had higher than 85% cover (Figure 4.21). Many of the healthiest reefs in the world have probably never had more than about 30% coral cover.

However, coral cover by itself may not be a very useful indicator of reef health unless permanent transects are resampled over time, or unless very large sample sizes are available such as in the above global analysis. Without permanent transects, it is possible that a subsequent sample of reef will hit a large patch of e.g. sand or rubble, biasing the results. The large number of samples provides evidence of a true 10% difference between the Atlantic and Indo-pacific reefs.

A more meaningful indicator of reef health is the ratio of live coral cover to total coral cover (hard coral index), where total coral cover is defined as live coral cover plus recently killed coral. In Figure 4.23 we see no significant change in the hard coral index between years in the Atlantic region.

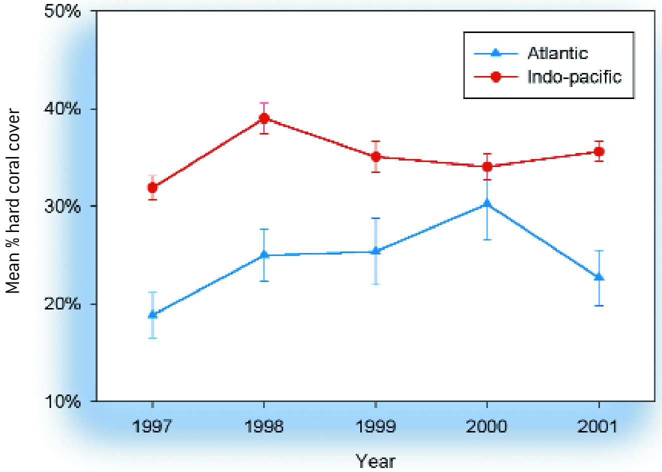



Figure 4.22: Mean percent coral cover (1997-2001) on Indo-pacific and Atlantic reefs.

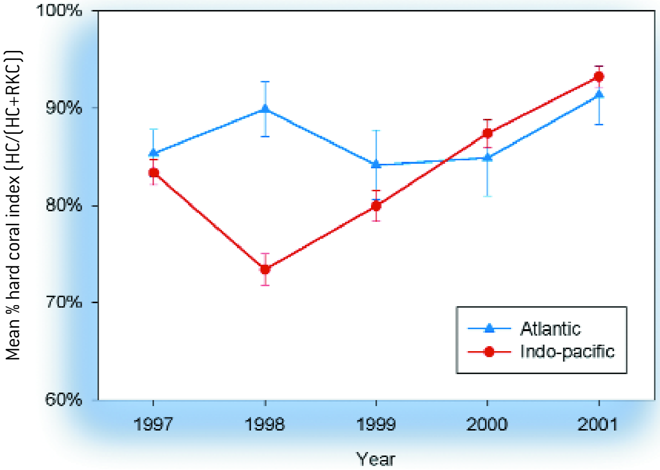



Figure 4.23: Mean percent hard coral index (hard coral/(hard coral + recently killed coral))(1997-2001) on Indo-pacific and Atlantic reefs.

However, the hard coral index drops significantly from 1997 to 1998 ($p \leq 0.01$) in the Indo-pacific as a result of the increase in recently killed coral cover in 1998, a consequence of the 1997-1998 bleaching event. The hard coral index increased significantly ($p \leq 0.01$) from 1998 to 2001, while at the same time the percentage of substrate classified as rock decreased. Figure 4.24 shows the relationship between recently killed coral cover and rock cover. This could be explained by the recently killed coral (RKC) category shifting into the rock category after one year. This is because the RKC category is defined only to include coral killed within the past year.

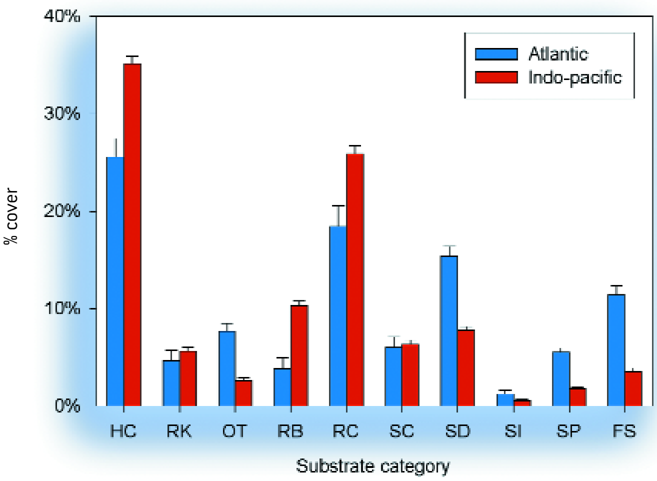



Figure 4.24: Mean percent cover of substrate categories in the Indo-pacific and Atlantic. HC= Hard coral; RK= Recently killed coral; OT= Other; RB= Rubble; RC= Rock; SC= Soft coral; SI= Silt; SP= Sponge; FS= Fleshy seaweed.

Globally, reefs are predominantly composed of hard coral, followed by rock (Figure 4.24). Indo-pacific reefs have a relatively higher proportion of hard coral and rock than Atlantic reefs. Indo-pacific reefs have approximately three times the amount of rubble than the Atlantic reefs. One explanation for some reefs would be that there are more than double the number of typhoons in the Pacific (mean 25) than there are hurricanes in the Atlantic each year (mean 9), and the mean wave height is higher (Pielke and Pielke, 1997). The average Atlantic reef has twice the percentage cover of sand as the average Indo-pacific reef. There was no significant difference in the percent cover of the "soft coral" category between the two oceans (NB: zooanthids are lumped into this category in the Atlantic).

## Perceived impacts

The mean percent hard coral cover was related most closely to the perceived level of sewage pollution. Hard coral cover on reefs with no perceived sewage pollution (Figure 4.25) was 35 ± 18% whereas reefs with perceived heavy levels of sewage pollution had significantly lower hard coral cover, 28 ± 14% ($p=0.04$). In the Indo-pacific, the percentage of hard coral cover was significantly related to the perceived level of blast fishing. 99% of all perceived blast fishing occurred in SE Asia (Figure 4.26). Reefs rated as having no blast fishing had a mean hard coral cover of 35 ± 18%, whereas reefs rated as having a high level of blast fishing had a hard coral cover of 25 ± 19% ($p \leq 0.01$). Also in the Indo-

**Figure 4.25: Human impact rating for sewage pollution (1997-2001).**

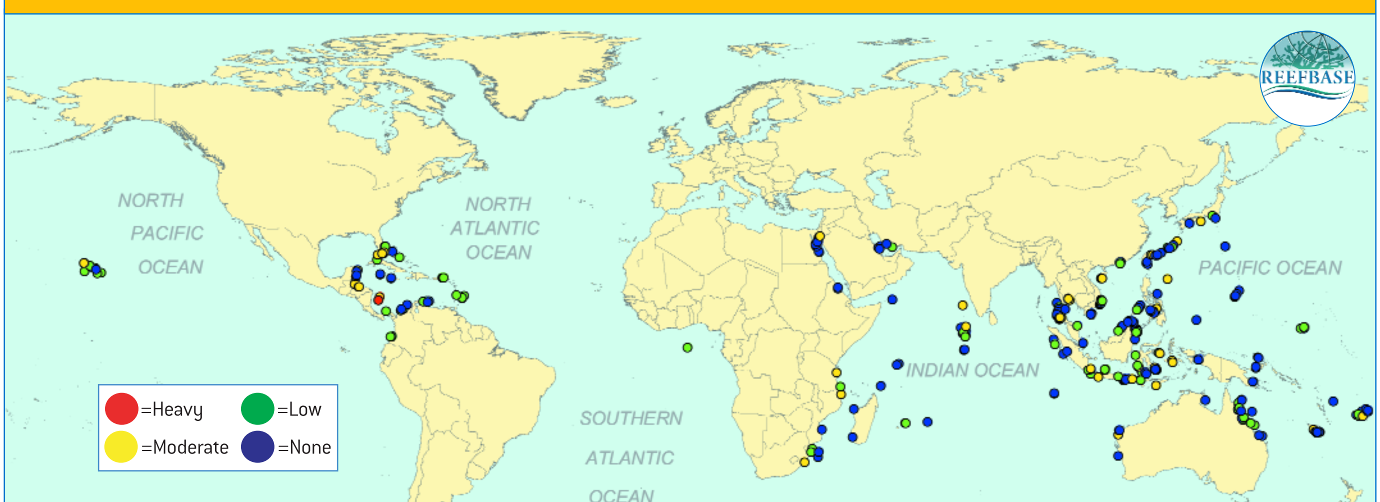
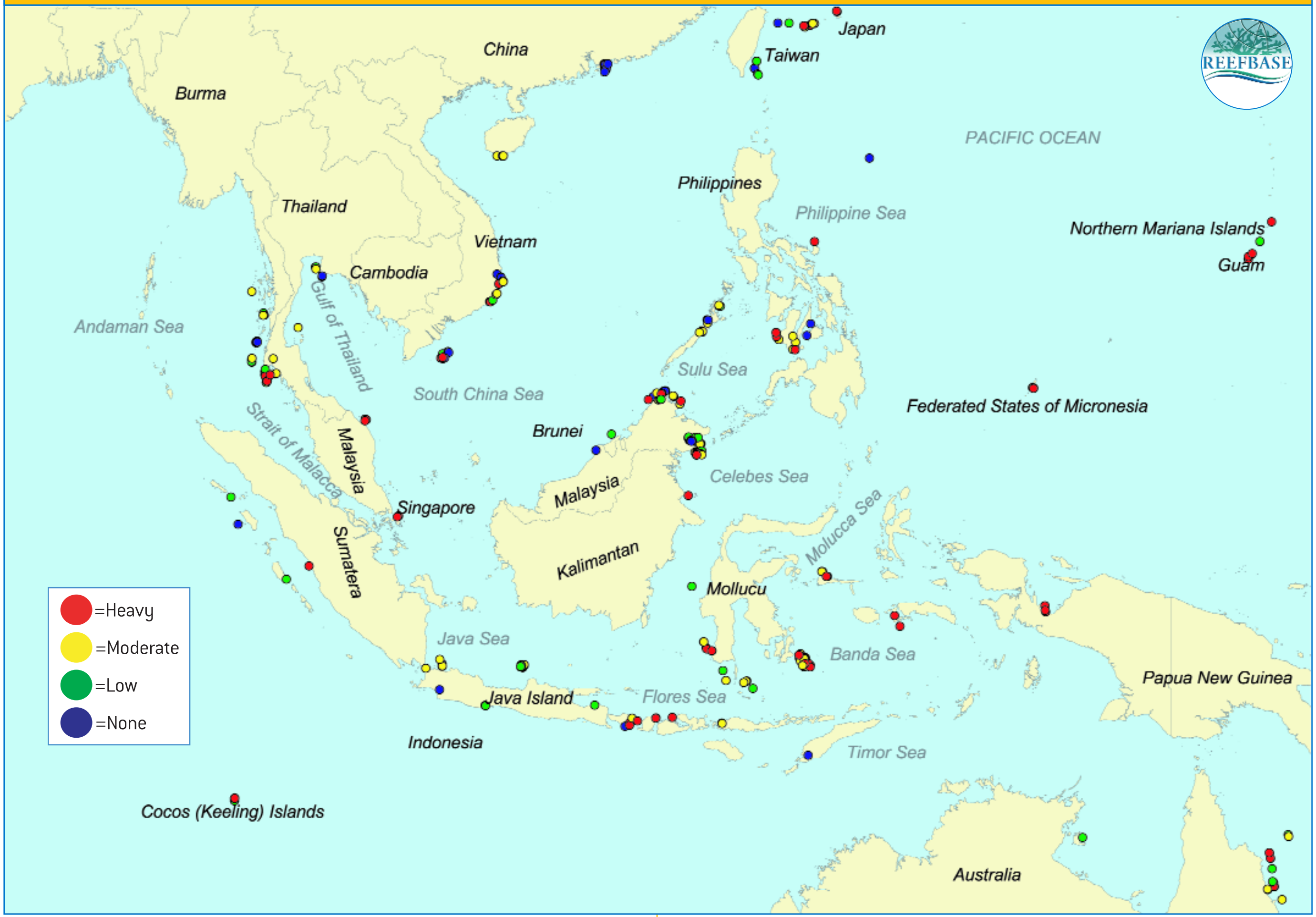


**Figure 4.26: Human impact rating for blast fishing (1997-2001).**




pacific, reefs rated with a high level of poison fishing had a significantly lower hard coral cover of 21 ± 19%, than reefs rated as having no poison fishing, 32 ± 18% ($p \leq 0.01$).

Worldwide, hard coral cover on reefs rated as having no anthropogenic impacts was significantly higher 39 ± 19%, than on reefs with a high rating for overall anthropogenic impacts (coral cover 23 ± 18%) ($p = 0.02$).

High ratings for sewage pollution, blast and poison fishing, and overall anthropogenic impact had the opposite effect on the percentage of dead coral. On reefs in the Indo-pacific without any perceived blast fishing, recently killed coral cover was 6 ± 11% of the total substrate. However, on reefs with heavy levels of perceived blast fishing, recently killed coral covered 11 ± 16% of the total substrate.

## Fleshy (Nutrient Indicator) Seaweed

Fleshy seaweed is a substratum category that was introduced to the Reef Check survey protocols in 1999 as a way to measure impacts of high nutrient inputs from sources such as fertilizer and sewage pollution. The types of seaweed in this category include the lettuce-like ***Ulva*** spp., slimy filamentous blue-green algae, and the fleshy green species such as the bubble-alga ***Dictyosphaeria cavernosa***. The fleshy seaweed category does not include natural seasonal reef flora such as ***Sargassum***.