

Status of coral reefs of the world: summary of threats and remedial action

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INTRODUCTION

While the history of active coral reef research stretches back over 100 years, the concern for the declining status of coral reefs is relatively recent, probably less than 25 years. The first major attempt to alert the global coral reef science community to the threats posed to coral reefs was in 1981 by Edgardo Gomez, who subtitled the 4th International Coral Reef Symposium in Manila, May 1981, as *The Reef and Man* (Gomez, 1982). Similarly Bernard Salvat and David Stoddart raised the alarm in 1982 (Salvat, 1980, 1982; Stoddart, 1982). At this time, most coral reef researchers worked from field stations during vacations; field stations specifically chosen that were adjacent to healthy and flourishing coral reefs seemingly not affected by human impacts. There was a small group of coral reef scientists who were working in developing countries, however, who were aware of an impending crisis for coral reefs.

Since that 1981 Symposium, there has been a steady increase in the involvement of coral reef scientists in the applied aspects of coral reef management (summarized in Knowlton, this volume). A paper published by Don Kinsey in 1988 succinctly summarized the stresses to coral reefs (Kinsey, 1988). Similarly there were other reports of localized damage to coral reefs by coral reef scientists (Brown, 1987; Gomez, 1988; Pauly and Chua, 1988; Grigg and Dollar, 1990), but it was not until 1992 that global attention was alerted to the threats facing coral reefs. That was the year of

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the United Nations Conference on Environment and Development in Rio de Janeiro and the 7th International Coral Reef Symposium in Guam. The two plenary addresses in Guam focused on the threats facing coral reefs, with alarming predictions of a bleak future if remedial action was not taken (Bud-demeier, 1993; Wilkinson, 1993). Immediately following this symposium, Bob Ginsburg organized a landmark conference in Miami that recognized the apparent crisis facing coral reefs, although there was insufficient information for a full assessment (Ginsburg, 1993). One of the reports of decline was the collapse of the Discovery Bay coral reefs of Jamaica, a 'model' coral reef studied by many coral reef scientists (Goreau, 1959; Hughes, 1989, 1994). These conferences all acted as catalysts to initiate the International Coral Reef Initiative (ICRI) in 1995, the Global Coral Reef Monitoring Network (GCRMN) in 1996, and Reef Check in 1998 (Hodgson, 1999). The decline of coral reefs was confirmed with 14 reports presented at the 8th International Coral Reef Symposium in Panama, 1996, the findings of which were used to produce the first *Status of Coral Reefs of the World: 1998* report by the GCRMN (Wilkinson, 1998).

There is indeed a crisis facing coral reefs with a range of stresses acting sometimes in isolation, but usually in concert, in many parts of the world. This chapter is a summary of the *Status of Coral Reefs of the World: 2004* report that was finalized in early December 2004 based on more than 240 contributors from 96 countries (Wilkinson, 2004). The report was published by the Australian Institute of Marine Science and the Global Coral Reef Monitoring Network and is available online at www.aims.gov.au or www.gcrmn.org.

CORAL REEFS IN A HISTORICAL PERSPECTIVE

It is instructive to review the recent history of coral reefs during the last 10 000 years of human activities. Much of this overview is derived from the research of Jeremy Jackson and colleagues (Jackson, 1997; Jackson *et al.*, 2001; Pandolfi *et al.*, 2003). Additional historical information is presented by Precht and Aronson (this volume).

10 000 years ago

The history of modern coral reefs can be traced readily back about 10 000 years when sea levels were rising as the ice melted to end the Pleistocene. Over a period of about 5000 years, sea levels rose 110 to 120 m (approximately 240 cm per 100 years compared to the current predicted rate of

approximately 50 cm per 100 years). The early Holocene was a period of rapid coral reef growth as corals settled on limestone and other hard substrata in tropical and subtropical regions. The Pleistocene also facilitated human migrations during low sea level. These early human populations undoubtedly exploited coral reef resources, seen in archaeological evidence of major harvesting of fishes, molluscs, dugongs, manatees and especially turtles in most areas. That rate of exploitation most probably increased as human populations grew and technology increased (Jackson *et al.*, 2001).

1000 years ago

Human populations had occupied most available land adjacent to coral reefs, including the vast expanses of the Pacific Ocean, with the exception of some Indian Ocean islands and very remote islands and atolls. These peoples continued to exploit coral reef resources for food and building materials. By current standards, most of these reefs would have been regarded as predominantly pristine with healthy corals, and large, well-structured fish and invertebrate communities. The available human technology allowed the exploitation of some of the larger fauna (turtles, dugongs and giant clams) in shallow water, but there was little capacity to harvest organisms in deeper water. These indigenous populations remained relatively small and some small island populations were developing traditional management of coral reef resources to ensure sustainability.

100 years ago

The consensus opinion of authors from the 94 countries included in the 2004 report (Wilkinson, 2004) is that reefs were generally 'healthy' 100 years ago with high coral cover and relatively 'natural' fish populations. Exploitation was increasing, but the harvesting of fishes and many invertebrates was within sustainable limits for the reefs. The exceptions again were the large fauna: dugong, manatee, turtles and giant clams. Pollution was not regarded as a problem and sediment damage was limited, although the land clearing in the tropics for agriculture was increasing. There was no concept of a 'coral reef problem' and little consideration was given to the need for management of the resources, except possibly pearl shell in the Pacific.

Since 1992

The first global assessment of coral reefs produced by Sue Wells and colleagues in 1988 contained many references to degraded reefs (Wells, 1988).

The World Environment Summit at Rio in 1992 set an agenda for global marine conservation with Chapter 17 of Agenda 21; then there were alarming predictions about the future of coral reefs (Wilkinson, 1993). There followed a landmark conference in Miami which concluded that, while there was insufficient information to assess the status of the world's coral reefs, there was an apparent crisis facing coral reefs (Ginsburg, 1993). The ICRI started in 1995 as a means of stimulating diplomatic and international agency focus on coral reefs, especially because of their considerable strategic and economic importance. The GCRMN and Reef Check followed soon after to document this apparent global decline in coral reef status.

2004

The collective opinions of the 240 authors who contributed to the *Status of Coral Reefs of the World: 2004* report (Wilkinson, 2004) are summarized in Table 1.1. The estimates are:

- that 20% of the world's coral reefs have been effectively destroyed and show no immediate prospects of recovery;
- approximately 40% of the 16% of the world's reefs seriously damaged by coral bleaching in 1998 are either recovering well or have recovered;
- approximately 24% of the remaining reefs in the world are under imminent risk of collapse through human pressures; and
- a further 26% of the remaining reefs are under a longer-term threat of collapse.

The losses of the reefs are attributed to direct damage from human activities on coral reefs: poor land management practices that result in the release of sediments, nutrients and other pollutants; over-fishing and particularly fishing with destructive methods; coral predators such as the crown-of-thorns starfish and coral diseases; and increasing water temperatures that result in lethal coral bleaching and exacerbated coral diseases.

A similar assessment of global reef status was obtained by Reef Check, a predominantly volunteer monitoring programme that has obtained data from more than 750 coral reefs in 70 coral reef countries in 2003. They report that the living coral cover lost during the 1998 bleaching event has been largely replaced by new growth, although often very variable in extent and location. Reef Check reports that many key human impact indicators, such as food fish, continue to decline, with the number of sites not reporting medium- to large-sized serranids and a key target species in the Indo-Pacific, the humphead wrasse (*Cheilinus undulatus*), having

Table 1.1. A summary of the current status of coral reefs in 17 regions of the world designated as Nodes within the GCRMN. These estimates were developed by the authors of the chapters in Wilkinson (2004), and from the Reefs at Risk analyses (Bryant *et al.*, 1998; Burke *et al.*, 2002; Burke and Maidens, 2004). These assessments should be regarded as indicative, because there are insufficient coral reef monitoring data for many regions to make definitive statements on losses and authoritative predictions for the future. The proportion of reefs in column 3 has increased from 11% reported in Wilkinson (2000), with the addition of more damaged reefs and those that have not recovered from 1998 (column 4)

Chapter number and region of the world	Reef area (km ² × 1000)	Destroyed reefs (%)	Reefs recovered / reefs destroyed in 1998 (% / %)	Reefs at critical stage (%)	Reefs at threatened stage (%)
4. Red Sea	17.64	4	2 / 4	2	10
5. The Gulfs	3.80	65	2 / 15	15	15
6. East Africa	6.80	12	22 / 31	23	25
7. SW Indian Ocean	5.27	22	20 / 41	36	31
8. South Asia	19.21	45	13 / 65	10	25
9. SE Asia	91.70	38	8 / 18	28	29
10. E and N Asia	5.40	14	3 / 10	23	12
11. Australia, PNG	62.80	2	1 / 3	3	15
12. SW Pacific Islands	27.06	3	8 / 10	18	40
13. Polynesian Islands	6.73	2	1 / 1	2	3
14. Micronesian Islands	12.70	8	1 / 2	3	5
15. Hawaiian Islands	1.18	1	NA	2	5
16. US Caribbean	3.04	16	NA	56	13

(cont.)

Table 1.1. (*cont.*)

Chapter number and region of the world	Reef area (km ² × 1000)	Destroyed reefs (%)	Reefs recovered / reefs destroyed in 1998 (% / %)	Reefs at critical stage (%)	Reefs at threatened stage (%)
17. North Caribbean	9.80	5	3 / 4	9	30
18. Central America	4.63	10	NA	24	19
19. East Antilles	1.92	12	NA	67	17
20. S Tropical America	5.12	15	NA	38	15
Total	284.30	20	6.4 / 16	24	26

Notes:

Column 1: The countries in each region are listed in Wilkinson (2004).

Column 2: Coral reef area from the *World Atlas of Coral Reefs* (Spalding *et al.*, 2001).

Column 3: Reefs 'destroyed' with 90% of the corals lost and unlikely to recover soon.

Column 4: Proportion of reefs recovered of the losses in 1998 from global coral bleaching (% / %).

Column 5: Reefs at a critical stage with 50% to 90% loss of corals, likely to join those in the Destroyed reefs column in 10 to 20 years.

Column 6: Reefs threatened with moderate signs of damage, 20% to 50% loss of corals and likely to be added to the Destroyed reefs column in 20–40 years.

NA. Not applicable, as there were no climate change related losses in 1998.

Columns 4 and 5 are based on the very high to high risk (combined), and the medium risk categories of the *Reefs at Risk* process (Burke and Maidens, 2004).

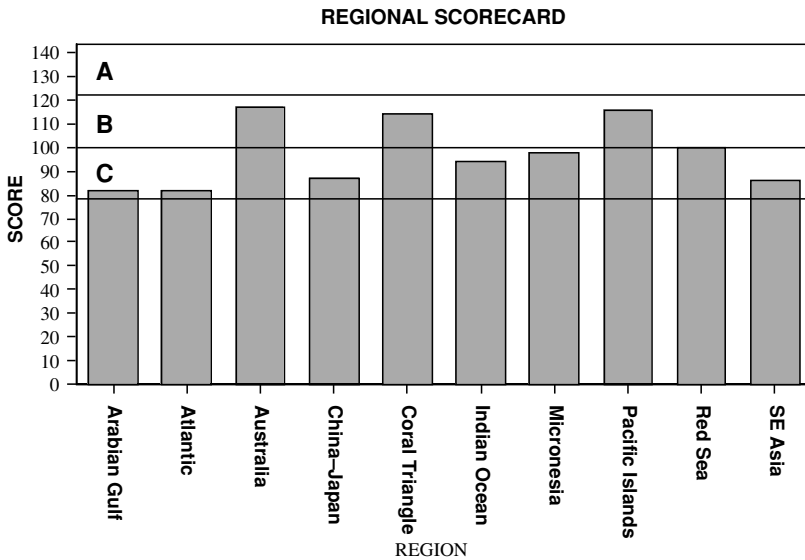


Figure 1.1 Sum of the 18 indicator grades (A = 4, B = 3, etc.) in each region from Reef Check surveys in 2002–2003; a perfect score would be 144. (Source: Gregor Hodgson, Reef Check.)

increased from 90% to 95% from 1997 to 2003 (Hodgson and Liebler, 2002; www.ReefCheck.org). A regional scorecard based on the 18 categories of data recorded by Reef Check shows variation among regions of the world in the health of coral reefs (Fig. 1.1). This shows that Australia, the Pacific Islands and Coral Triangle (between Indonesia, the Philippines and Papua New Guinea) had the least damaged reefs in 2003, whereas the Arabian Gulf and Atlantic reefs were in the worst condition.

STATUS OF CORAL REEFS OF THE WORLD BY REGIONS

The following sections are summaries of the more detailed chapters in the *Status of Coral Reefs of the World: 2004* report (Wilkinson, 2004). The information on damage from the major tsunami of 26 December 2004 is derived from reports received after these chapters were written.

The Red Sea and Gulf of Aden (Kotb *et al.*, 2004)

The Red Sea reefs continue to be in relatively good health, because there are few direct anthropogenic threats. There is virtually no runoff from the land, fishing is at a relatively low level, although key target species like sharks are

being removed, and tourism is largely concentrated in a few areas. Shipping, over-development of tourism without sufficient controls on sewage pollution and sediment runoff, coral bleaching and the crown-of-thorns starfish are the major future problems. The political awareness and will for conservation are not widespread, and monitoring and management capacity remain weak. Damage from coral bleaching in 1998 has been largely reversed in many areas.

Arabian/Persian Gulf region (Regional Organization for the Protection of the Marine Environment Sea Area) (Rezai *et al.*, 2004)

The reefs off the Arabian Peninsula have shown little recovery after they were largely destroyed during severe coral bleaching events in 1996 and 1998. The only recovery is larvae recruiting from reefs in deeper water that were less affected; however, there is an apparent shift in the recruiting coral species to lower-profile, slow-growing and more resistant species (e.g. species of *Porites*, *Favia* and *Cyphastrea*). Prior oil exploitation, shipping activities, and military conflicts that had resulted in some major oil spills have caused minimal previous damage. Near-shore reefs on the Iranian coast have also been affected by bleaching, but at a low level, whereas some of the offshore reefs in deeper water retain healthy corals. Awareness is increasing in this region; however, there are some major development projects that are destroying coral reefs. A monitoring network was formed in late 2003 with Iran as the host country.

East Africa (Obura *et al.*, 2004)

There has been significant, but very patchy, recovery of reefs devastated in 1998, with better recovery on reefs that are well managed. Coral regrowth is estimated at about 30–50%. The growing coastal population of 22 million people poses the largest threat to the reefs, with land-based activities and over-fishing increasing. There have been significant improvements in the management of coral reef marine protected areas (MPAs) in the last two to four years, due to national and regional initiatives, and greater commitments to increase the area of MPAs and improve fisheries management (see McClanahan, this volume). Regional and international NGOs are assisting communities in developing their own co-management places for MPAs, often based around tourist destinations. Ecological and socio-economic monitoring and research on coral reefs is expanding in the region due to local and international efforts. Damage to the coral reefs from the tsunami was relatively minor (D. Obura, pers. comm.).

South West Indian Ocean islands (Ahamada *et al.*, 2004)

There has been some recovery of the coral reefs damaged in 1998. However, recent bleaching damage to the new coral recruits is slowing recovery (see also Sheppard, this volume). There are some exceptional sites that were highly resilient to the bleaching damage, but human stresses and natural disturbances pose a constant threat to these reefs. Coral reefs on the Southern Islands (Madagascar, Mauritius, Réunion) suffered less damage in 1998, but natural disturbances have caused some coral mortality. There has been a marked increase in awareness of the need for coral reef management and conservation, and all countries have active monitoring programmes to assist in environmental decision-making. There are more monitoring sites, including remote reefs like Tromelin, Juan da Nova, Europa (France) and Cosmoledo, Assumption and Aldabra (Seychelles). The Global Environment Facility has just announced a continuation of funding for monitoring activities, which are expanding and providing information for governments. Damage to the coral reefs from the tsunami was relatively minor (D. Obura, pers. comm.).

South Asia (Rajasuriya *et al.*, 2004)

While there has been encouraging coral reef recovery in the Maldives, Chagos, Sri Lanka and Lakshadweep (India) after the massive coral bleaching mortalities in 1998, there has not been a parallel rise in awareness about the importance of coral reefs and the need for effective conservation. The possible exception is India, where there have been great advances in coral reef science with the publication of several major coral guidebooks and the formation of senior government committees and some stakeholder groups. Monitoring in the Maldives has assumed a lower priority, although there is high economic dependence on coral reef resources; insufficient national funds are allocated for monitoring or management, with the tourism sector filling the gaps. Management capacity continues to be weak in most countries with the drive for development taking priority over environmental conservation. There are, however, some excellent examples of effective management and successes in reef protection through community control. Many of the MPAs in the Maldives are managed by tourist resorts to protect their resources. Poverty continues to drive over-exploitation of fishes, invertebrates and coral rock. There was massive damage in India, the Maldives and Sri Lanka from the tsunami, but damage to the reefs was less important than damage to shorelines and coral islands. Some reefs

were virtually destroyed; however, the majority escaped major damage and should recover rapidly once debris is removed (A. Rajasuriya, pers. comm.). Some reefs of the Andaman Islands have been uplifted and exposed to the air (K. Venkataraman, pers. comm.).

Southeast Asia (Tun *et al.*, 2004)

There has been a continual decline in reef condition across the region, with some signs of coral recovery in Indonesia and possibly Burma. Continued reef decline in the Philippines, Vietnam, Thailand and Singapore is occurring within the area of highest coral reef diversity. Direct human pressures remain high, dominated by over-fishing and damaging fishing, pollution from the land, excess sediment flow onto the reefs from coastal development, dredging and deforestation; and reclamation of coral reef areas continues for industries, airports and marinas. However, there are more active management initiatives throughout the region, and monitoring programmes have improved and expanded, after a decade of little progress. Some countries lack the expertise and resources for monitoring and there is a critical lack of effective coordination. Several major projects are starting to address the issues with assistance from United Nations and non-governmental organization (NGO) agencies, but there is a major need for regional coordination and cooperation, and a sharing of resources for coral reef monitoring and management. Damage from the tsunami along the Andaman Sea and Indian Ocean coastlines of Burma, Indonesia, Malaysia and Thailand was severe in some places, but generally far less than damage on land. Some shallow reefs were destroyed in Northern Sumatra as they were uplifted 2 to 3 m out of the water (G. Hodgson, pers. comm.).

East Asia (Kimura *et al.*, 2004)

Pressures from human activities remain the major threats to coral reefs in East and North Asia. These have been exacerbated by coral bleaching and some severe, recent typhoons. Sediment runoff is a major problem in many areas and rapid development is threatening reefs. Fishing pressures remain at extreme levels in most areas. Coral reefs continue to decline in areas of high human activity, whereas remote reefs are recovering from the bleaching losses of 1998. All countries are developing coral conservation and management programmes, and it is anticipated that these programmes could be effective in conserving coral reefs in the future, provided that there

are no repeat bleaching episodes and that growing human populations do not increase pressures on coral reefs. Mariculture is supplementing stocks of coral reef fishes and invertebrates, but also resulting in local pollution. Coral bleaching has occurred since 2002, but most corals recovered.

Australia and Papua New Guinea (Miller and Sweatman, 2004)

Coral reefs in this region remain in relatively good condition, despite some recent setbacks. However, the level of resource monitoring and management is markedly different in both countries. Papua New Guinea has few trained people, minimal resources and low political will for coral reef conservation in a country where human pressures on the reefs are relatively low, but increasing rapidly. The only potentially effective model for conservation in Papua New Guinea is a decentralized, community-based system for reef resource management driven largely by NGOs. Australia has set an example for the world in coral reef conservation by declaring 33% of the whole Great Barrier Reef area as a highly protected zone; similarly 34% of the Ningaloo Reef tract of Western Australia has also been given protection. Good central planning, legislation, enforcement, research and monitoring support these activities. The reefs of the Great Barrier Reef show highly dynamic patterns of short periods of decline from disturbances, followed by longer periods of recovery. There is an apparent, longer-term trend of gradual decline, especially on inshore reefs affected by coastal pollution. The other major threats are coral bleaching and crown-of-thorns starfish outbreaks. There was a major bleaching event in 2002 and an outbreak of coral disease, but the mortality caused localized declines in coral cover, and many of the areas are recovering.

Southwest Pacific (Lovell *et al.*, 2004)

Coral reefs in the Southwest Pacific are generally in good condition, although there was extensive coral bleaching during 2000–2002. Some coral reefs have shown full recovery of live coral cover, whereas others have not recovered. The greatest threats to reefs continue to be human activities and cyclones, with reefs of New Caledonia, Samoa, Solomon Islands and Vanuatu having been damaged by cyclones since 2002. Other threats are crown-of-thorns starfish plagues and disease. The human pressures of over-exploitation and pollution are concentrated around the cities and towns, and in lagoons. There is increased participation of governments, NGOs, scientists, volunteers and local communities in coral reef protection and

conservation, with more plans for sustainable management of resources. Monitoring training and field surveys have increased; however, there is a lack of sustainable funding and support, and political will for the necessary conservation measures is weak.

Southeast Pacific (Vieux *et al.*, 2004)

The coral reefs of Polynesia Mana are predominantly healthy and under a low risk of damage in the immediate future. The reefs are probably the least degraded in the world as they are remote from large land masses and human influences; however, predicted global climate change, threats of more cyclones and coral bleaching are the major concern. Monitoring is developing, with some countries having ongoing programmes, whereas others are starting. Local populations are reviving cultures and traditions for sustainable reef management. Political awareness and will for coral reef conservation are increasing, but more effort is needed to combat the threats of increased sedimentation, over-fishing, dredging and nutrient pollution. If governments fail to implement coral reef resource management and do not remedy the causes of human stresses to the reefs around the heavily populated islands, these reefs will continue to decline, especially with lower fish stocks.

Micronesia (Kelty and Kuartei, 2004)

Micronesia contains some of the most diverse and pristine reefs in the world, but the cumulative impacts of sedimentation, increasing population demands, commercial fisheries, coastal pollution, ship groundings and recreational activities are apparent on many reefs. Human population growth is the main factor behind increasing disturbance. Isolated reefs are in good condition, but many reefs near population centres, and around the high islands, are declining with decreases in coral cover, reduced fish abundance, increased sediment damage and poor resilience to disease and bleaching. Coral reef monitoring and management continue to improve, with significant regulations banning scuba fishing, 'live rock' collection, and hunting of turtles and marine mammals. Monitoring activities have been boosted by increased support for the Palau International Coral Reef Center and more awareness in Micronesian countries. Governments and NGOs are developing more MPAs, and combining these into networks to conserve biodiversity.

Northeast (American) Pacific (Friedlander *et al.*, 2004)

The Hawaiian archipelago is one of the most isolated in the world, with many endemic species. The northwestern Hawaiian Islands are mostly uninhabited atolls and banks and generally in excellent condition with the only potential threats being coral bleaching and marine debris. The main Hawaiian Islands have 1.2 million residents and receive 7 million tourists each year who use the heavily developed tourism infrastructure; coral reefs are estimated to be worth US\$10 billion per year to the economy. The major pressures are from land-based sources of pollution, over-fishing, recreational overuse and alien species. Fishing pressures vary considerably between the islands, with the remote reefs having large populations of apex predators, whereas there are very few remaining on the main volcanic islands. US government funding and expanded partnerships amongst organizations have resulted in more monitoring, mapping and research efforts to guide management decisions.

The American Caribbean (Kelty *et al.*, 2004)

There were massive losses in coral cover in the 1980s and 1990s from coral diseases, bleaching and human damage. However, the losses appear to have stabilized at much lower levels of coral cover, with evidence of coral recovery. Fishing pressures continue in both the economically depressed regions of Puerto Rico, and also along the coastlines of Florida and US Virgin Islands. The major recent change has been multinational fishing on the isolated and uninhabited Navassa reef, where the once healthy populations of major target fishes have been severely depleted in the last two years. Monitoring is demonstrating negative trends in reef community health, especially in existing MPAs. This is providing a stimulus for better management to protect coastal resources by reducing anthropogenic stresses. An essential need is to strengthen cross-boundary and cross-jurisdictional agreements to facilitate ecosystem-based management and information and technology transfer. Mapping, monitoring and management of coral reefs of Florida, Flower Garden Banks, Puerto Rico, US Virgin Islands and Navassa have all improved, with increased government awareness and funding.

Northern Caribbean and western Atlantic (Jones *et al.*, 2004)

Coral cover in the northern Caribbean remains low, averaging 20% cover, compared to what existed in the 1960s. There are a few sites in most countries with 30–50% coral cover; however, most sites have 3–10% cover. There

has been little recovery of the formerly abundant *Acropora* spp. coral cover, and diseases, bleaching and pollution are still resulting in coral loss. Patchy recovery of the *Diadema* sea urchin is occurring, but algae still dominate on many reefs. Fishing is still intense, and many grouper populations are virtually extinct, such that it is rare to see large fishes on the reefs. All countries report significant threats to coral reefs, including over-fishing, land-based sources of pollution, and regional or global factors such as coral bleaching and disease. Over-fishing of algal grazing fishes is the major cause of macroalgal overgrowth of corals. National capacity to implement and enforce fisheries regulations is inversely proportional to fishing intensity. Most countries have adequate legislation, but enforcement is inadequate or lacking, and many MPAs lack effective management. Although progress in coastal management is being made in most countries, poor financial resources often impede the implementation of laws and policies.

Central or Mesoamerica (Arrivillaga and Garcia, 2004)

Natural disturbances, such as hurricanes, coral diseases, *Diadema* mortality and coral bleaching, combined with anthropogenic stresses, such as nutrient enrichment, sedimentation, over-fishing and direct damage of the corals, all threaten the coral reefs of this region. A new regional initiative between Belize, Guatemala, Honduras and Mexico has gathered considerable support for public and private conservation efforts, and resulted in coordinated environmental monitoring of coral reefs, which is producing substantial trend data. NGOs are active in the region and assisting communities with co-management of their resources to reverse major declines in fisheries stocks. Tourism is expanding very rapidly and will have positive effects in providing alternative uses for coral reefs and employment for communities, but the rapid and often uncontrolled pace of development is damaging coastal lands and increasing demand for quality seafood, e.g. lobsters and groupers.

The eastern Antilles (Bouchon *et al.*, 2004)

The coral reefs of the French West Indies and nearby islands have steadily declined since the early 1980s. This has stimulated long-term monitoring on the French islands and increased Reef Check activities in the other island states with the support of the United Nations Environment Programme (UNEP) Regional Coordinating Unit in Jamaica. Reef Check rapid assessments are filling gaps where there were no current data, and training local

fisheries and dive operator staff. All reefs face a common set of threats: high rates of sedimentation, due to deforestation and bad land management, which affect mainly the reefs in the enclosed bays; algal proliferation due to an overload of nutrients in the coastal waters from excessive use of fertilizers and poor wastewater treatment; and chronic over-fishing and harvesting of reef resources. More MPAs have been declared, but many remain without adequate management. Many of these islands were damaged by a series of major hurricanes in mid-2004. There are no available data on the fate of the reefs; however, it is anticipated that many sustained wave and sediment damage.

Southern tropical America (Garzón-Ferreira *et al.*, 2004)

Most coral reefs in this region have undergone major changes in the last 30 years, but particularly during the 1980s. There have been considerable losses of live coral cover in many reef areas, while algae have become dominant. However, some areas of high coral cover occur on both the Caribbean (means between 20% and 40%) and Pacific (means above 40%) coasts. The coral reefs are strongly influenced by continental runoff containing large amounts of sediments and high concentrations of nutrients from large rivers on the South American mainland. The other major threats are coral bleaching, disease outbreaks and phytoplankton blooms, and direct human pressures from deforestation, increased sedimentation, coastal development, sewage pollution and over-fishing. An additional threat is the demands of a strongly developing tourism industry for seafood. There are major gaps in financial support for coral reef monitoring and management, and governments are not fully aware of or concerned about the fate of their coral reefs.

THREATS AND STRESSES TO CORAL REEFS

The authors of the *Status of Coral Reefs of the World: 2004* report (Wilkinson, 2004) identified the major threats and stresses to coral reefs around the world (Table 1.2). These frequently occur simultaneously, and will result in varying degrees of damage to specific coral reefs. For example, on reefs close to human populations, pollution is a greater threat in some areas, whereas over-fishing is more destructive in others. By contrast, on remote reefs global climate change poses the major threat. However, poor awareness of the problem and insufficient political will are usually causal agents behind damage to coral reefs and threats to their future survival (Table 1.2).

Table 1.2. Summary of threats and stresses affecting coral reefs

General category	Specific threat	Description
Global change	Coral bleaching	Loss of photosynthetic zooxanthellae from coral tissues caused by elevated sea surface temperatures due to global climate change
	Rising levels of CO ₂	Increased concentrations of CO ₂ in sea water due to increasing water temperatures, resulting in decreased calcification rates in coral reef organisms
	Diseases, plagues and invasives	Increases in frequency of diseases and plagues of coral predators; increasingly linked to human disturbances in the environment
Direct human pressures	Over-fishing (and global market pressures)	The harvesting of fishes and invertebrates beyond sustainable yields, including the use of damaging practices (bomb and cyanide fishing)
	Sedimentation	Increased rate of sediments and mud deposited on coral reefs, stemming from poor land use, deforestation, and dredging
	Nutrients and chemical pollution	Both organic and inorganic chemicals carried with sediments, in untreated sewage, wastes from agriculture, animal husbandry and industry; includes complex organics and heavy metals
	Development of coastal areas	Modification of coral reefs for urban, industrial, transport and tourism developments, including reclamation and the mining of coral reef rock and sand beyond sustainable limits
Governance, awareness and political will	Rising poverty, increasing populations, alienation from the land	Increasing numbers of poor and dispossessed people relying on coral reef resources for subsistence and exploiting them beyond sustainable limits
	Poor capacity for management and lack of resources	Lack of trained personnel for coral reef management, raising awareness, enforcement and monitoring; lack of adequate funding and logistic resources to implement effective conservation
	Poor political will, and oceans governance	Political ignorance, indifference or inertia; corruption in governance of resources at global and regional levels

True natural threats are not considered in this chapter, as coral reefs generally have strong potential to recover from tropical cyclonic storms, freshwater inundation, geological events such as earthquakes, volcanoes or tsunamis, and low levels of plagues and diseases. The caveat about recovery is that additional anthropogenic stresses are not imposed on the reefs, and the level of these natural disturbances does not increase in future. Such an increase, however, is one of the predicted scenarios of global climate change (Kleypas *et al.*, 1999; Bellwood *et al.*, 2004; Hoegh-Guldberg, 2004). It is predicted that tropical storms could increase in frequency and severity, and the major global ocean currents may change (Intergovernmental Panel on Climate Change Working Group I, 2001; Intergovernmental Panel on Climate Change Working Group II, 2001; Timmermann, 1999).

Pressures on reefs are increasing as human populations and economies increase (Wilkinson, 1993; Birkeland, 2004), resulting in direct damage to coral reefs, either inadvertently via pollution or directly through the extraction of resources, e.g. fishes, rock, sand. There is another category for which the direct cause is not obvious. These are stresses that are natural in origin, but are probably exacerbated by human activities. This category includes: stresses arising from global climate change, with increased coral bleaching (Hoegh-Guldberg, 1999; Wilkinson, 1999, 2002); diseases of corals and other reef organisms (Harvell *et al.*, 2002); plagues of coral predators and other damaging animals; and invasive species that threaten to disturb the ecological balance on coral reefs by out-competing local species (Table 1.2). All these stresses have increased markedly in the past 30 years.

Global change threats

Coral bleaching

The major emerging threat to coral reefs in the last decade has been coral bleaching and mortality associated with global climate change, especially major El Niño–La Niña events. The 1998 global coral bleaching event effectively destroyed 16% of the world's coral reefs, with most damage throughout the Indian Ocean and the western Pacific (Wilkinson *et al.*, 1999; Wilkinson, 2000). The damage appeared to be a 1-in-1000-year event in many regions based on the past history of coral reefs (Fig. 1.1). Very old corals (around 1000 years old) died from bleaching during 1998 and there is no record or memory of similar bleaching mortality in official government records or in the memories of traditional cultures. What is uncertain is whether the major climate shifts of 1998 will prove to be a 1-in-1000-year event in the future. The evidence is strongly against that assumption, with

predictions that coral bleaching like that seen in 1998 will become a regular event in approximately 50 years time (Hoegh-Guldberg, 1999, 2004; see also Sheppard, this volume), although by then most of the susceptible corals may have been lost from many coral reefs. There is a strong probability that some rare and restricted corals may become totally extinct. There has been no recurrence of the major coral bleaching episodes of 1998, although there have been some more localized bleaching events in 2000 and 2003 causing damage to reefs.

The other major predicted threats from global climate change are: an increase in the frequency and intensity of tropical storms; more frequent and severe switches in global climate, such as El Niño – La Niña changes; a rise in sea level; a potential shift in ocean currents; and an increase in the dissolved concentration of the greenhouse gas carbon dioxide in sea water (Wilkinson and Buddemeier, 1994). There are suggestions that the first effect of more frequent and severe storms has already happened, but clusters of severe storms such as that which happened in the Caribbean in 2004 are known from historical records and no definitive trend has emerged so far. It is apparent that the interval between El Niño events has shortened from about 12 years to less than seven years, but the record is too short for confirmation. It is also too early to assess whether the large ocean currents will change (Timmerman, 1999). Sea level rise will not threaten coral reefs, but will have potentially disastrous consequences for low-lying coral islands, especially atoll countries like the Maldives, Tuvalu, Marshall Islands and Kiribati (Wilkinson and Buddemeier, 1994). Sheppard (this volume) covers many of these longer-term impacts of global climate change.

Rising levels of carbon dioxide

The threat of increasing concentrations of atmospheric CO₂ dissolving in sea water and altering the carbonate–bicarbonate balance (lower pH, lower carbonate ion concentration) is becoming more likely as greenhouse gas concentrations continue to increase. The oceans are sequestering about one-third of all human-induced CO₂ emissions (Feely *et al.*, 2004). Increased dissolved CO₂ has the potential to decrease rates of calcification in tropical and cold-water corals, molluscs, calcifying algae and foraminifera. All of these organisms make major contributions of calcium carbonate in many marine ecosystems. The potential was reported by Smith and Buddemeier (1992), and has since been confirmed in experiments on reef-building organisms in the laboratory and in large coral mesocosms with calcification rates declining significantly under higher CO₂ concentrations (Kleypas *et al.*, 1999). There was a 10–40% reduction in coral calcification

under doubled CO₂ concentrations, the scenario that is predicted to occur within 50 years (Kleypas *et al.*, 1999; Feely *et al.*, 2004). The increasing atmospheric CO₂ concentrations may result in synergistic pressures, possibly increasing already acute coral reef stresses like bleaching and diseases by reducing coral resilience.

Diseases, plagues and invasives

The other major global threat to coral reefs is through an apparent proliferation of coral reef diseases and plagues of destructive organisms. These threats are increasing in incidence and severity, with strong correlations with damaging human activities, whether through pollution from poorly managed watersheds, heat stress to corals, or through over-fishing of the organisms that control plagues (Jackson *et al.*, 2001).

Coral diseases are reported to affect more than 150 species of Caribbean and Indo-Pacific corals, and new examples continue to be added to the 29 described diseases (Harvell *et al.*, 2002; Rosenberg and Ben-Haim, 2002; Willis *et al.*, 2004). Diseases have caused more damage to the coral reefs in the wider Caribbean than in the Indo-Pacific region; however, the recent increases in marine diseases worldwide emphasizes the need for more research and also points to potential linkages to other stresses on corals as possible instigators of disease (Harvell *et al.*, 2002; Rosenberg and Ben-Haim, 2002).

It is apparent that plagues of predators, such as crown-of-thorns starfish (*Acanthaster planci*), are increasingly reported around areas of human activities, with the possibility that either the plagues are initiated or exacerbated by over-fishing and/or that increases in nutrients from the land favour the planktonic stages of the starfish (Birkeland, 1982; Jackson *et al.*, 2001). Unfortunately, definitive explanations for the outbreaks do not exist after decades of intensive research, although the best explanation for current outbreaks is through a removal of fishes that consume juvenile starfish (Jackson *et al.*, 2001). There have been widespread, large-scale losses of coral cover and biodiversity on many reefs and these plagues can be added as another large-scale threat to the integrity of coral reefs. The highest densities of crown-of-thorns starfish in recent years have been in Tanzania, Kenya and on the Great Barrier Reef.

The potential threats from invasive species have largely been ignored until recently. While there is the likelihood that such invasives could disrupt the ecological balance of coral reefs, there is little evidence of significant deleterious effects on ecosystem processes or biodiversity. The most serious

incidence was the suspected introduction through the Panama Canal of a disease that killed the sea urchin *Diadema antillarum* in the Caribbean in the early 1980s (Lessios, 1995). There is now evidence of invasive species causing damage in Hawaii and parts of the Caribbean. The most likely causes of invasive introductions are through ballast-water or the hulls of cargo ships, or through the release of aquarium specimens in the wrong habitat (Davis, 2005).

Direct human pressures

Direct human pressures continue to rise in almost all coral reef areas of the world, as human populations grow and increase their demand for more resources, e.g. human activities on land result in more pollution of reefs, and over-fishing disrupts the ecological balance. These are the stresses that are most amenable to intervention by resource managers and governments, acting in concert with local user communities. Coral reefs remote from land influences or managed to reduce human pressures have the greatest recovery potential and resilience to other pressures, like global climate change bleaching and disease.

Over-fishing

As human populations increase and regional economies grow, there is a parallel increase in the demand for seafood. Most coral reefs within range of small fishing boats, including motor-powered aluminium boats, are now over-fished with the key target species being those that are closely associated with coral reefs, i.e. the groupers, snappers and large wrasses (Pauly and Chua, 1988; Pauly *et al.*, 1998). As catches decrease, fishers target all fish species, using more efficient methods of traps, fine-mesh nets and spears; the final resort is to use bombs and cyanide to catch the few remaining fish. This fishing down the food chain from the predators, to omnivores, to herbivores, and eventually to planktivores has multiple effects on a coral reef (Hughes, 1994; Pauly *et al.*, 1998). Coral reefs with reduced fish populations are more susceptible to overgrowth by macroalgae, plagues of coral predators, and probable increases in disease (McClanahan *et al.*, 2000; McClanahan, this volume). In addition, fishing results in direct physical damage to the reef framework, thereby further exacerbating the effects of over-fishing. Damage results from anchors, nets and traps and especially the use of explosives to stun fish hiding in the corals (Burke *et al.*, 2002).

One of the most effective measures to protect biodiversity, including fishes, is the establishment and enforcement of no-take MPAs (Roberts *et al.*, this volume). However, many national and international fisheries

management authorities contend that improvement in fish abundance in areas near MPAs has to be demonstrated before more MPAs are implemented. This suggests that no-take MPAs are experiments in managing fish stocks and must be scientifically validated. The inverse is the reality. No-take MPAs on coral reefs do conserve biodiversity and retain natural ecosystems, and constitute the 'control' in the 'experiment', which is to determine whether fishing or selectively removing one component (fish) from an ecosystem causes an ecological imbalance. Thus, the hypothesis should be: 'Does fishing remove fish from an ecosystem and does over-fishing affect the biodiversity and ecological balances on a coral reef?' The no-take zone then becomes the control for this experiment as an un-fished ecosystem.

Unless fishing pressures can be reduced through the provision of alternative livelihoods and employment for fishers, through sustainable aquaculture and through establishing more no-take MPAs, it is predicted that there will be more collapses in fisheries stocks. Daniel Pauly and colleagues have a pessimistic view on the possibility of managing coral reef fisheries in developing countries and suggest that current approaches towards establishing sustainable coral reef fisheries are unlikely to yield success (Pauly *et al.*, 2002), whereas the International Society for Reef Studies (2004) and others recommend the essential measures needed to achieve sustainability in coral reef fisheries, although with some pessimism (see also McClanahan, this volume).

Destructive fishing

Over-fishing is often accompanied by damaging practices to compensate for the depletion of fish stocks and to feed the demand for high-priced species for Asian restaurants and the aquarium trade. Bomb fishing is largely restricted to Southeast and East Asia, although it has occurred in eastern Africa and parts of the Pacific. Bombs are used when fish stocks drop, making hook-and-line, net and trap fishing unprofitable. Cyanide was first used to catch small aquarium fish, but its use has expanded to capture live fish for the restaurant trade (Vincent, this volume). The fish can be resuscitated after being stunned, although there is usually permanent liver damage. The use of cyanide, however, usually results in death of corals and other reef organisms, producing a wasteland (Johannes and Riepen, 1995; Barber and Pratt, 1997; Sadovy and Vincent, 2002).

Sediment pollution

Most developments within reef catchment areas increase sediment flow onto coral reefs. This results in reduced photosynthesis in corals, increased

rates of disease and bioerosion, and eventual burial of corals. The rate of sediment release into the oceans is increasing, as more coastal lands are developed to accommodate rising urban populations and increases in agriculture (Fabricius, 2005). One of the major increases is through tropical deforestation, often by clear-felling for tropical timbers and agriculture, such as oil palm plantations in Southeast Asia and the western Pacific. These impacts are clearly being felt in Indonesia, Papua New Guinea, the Solomon Islands and throughout the wider Caribbean. In parts of Micronesia, steep upland forest areas are being cleared to grow the root crop 'sakau', a type of mildly intoxicating 'kava'.

Nutrient pollution

Nutrient pollution has been studied extensively on many coral reefs, e.g. the Kaneohe Bay story (Hunter and Evans, 1995). Excess nutrients favour the growth of macroalgae when the populations of grazing fishes and sea urchins are reduced. They increase phytoplankton growth in sea water, thereby reducing light energy penetration to the light-dependent corals. They also favour the growth of other competitors of corals, especially those that bore into coral skeletons, such as sponges, molluscs, worms and burrowing algae, and probably make corals more susceptible to disease. All reefs near human populations or adjacent to large land masses suffer some degradation from nutrient pollution. The control of catchment pollution through an extensive water-quality programme is seen as one of the major issues for the management of the Great Barrier Reef (Haynes and Schaffelke, 2004).

Development on coral reefs

As populations increase on the coast, so do the pressures to alienate land from the sea as 'development'. There are currently large plans to 'reclaim' coral reef areas in the Persian/Arabian Gulf, especially in United Arab Emirates, in the Red Sea along the coast of Saudi Arabia, in Singapore and recently in peninsular Malaysia and southern Japan to build airports on coral reefs to attract tourists. Virtually all coastal developments result in sediment damage to fragile corals; however, some activities have long-lasting effects. The building of marinas, groynes and causeways around coral reefs disrupts currents and often causes major displacements of sediment. Causeways on some Pacific islands have resulted in considerable coral death and reduced fisheries in coral lagoons.

Many countries have prohibited the mining of coral rock and sand from sensitive areas on and around coral reefs. This ban was in recognition of the

damage that excessive mining caused to reefs and their potential to provide other goods and services, such as fish productivity, shoreline protection and attracting tourists. Mining is still practised in some countries where there are limited sources of sand and limestone on land, or where governments do not enforce the regulations, such as in South Asia.

Governance, awareness and political will

The human component of poor governance and low political will in many coral reef countries, combined with occasional unintended consequences of actions by international agencies, is resulting in collateral damage to coral reefs (see Brown, this volume). Many countries reported that there was inadequate governance capacity and a lack of awareness of the problems facing coral reefs

Rising poverty, increasing populations, alienation from the land

Many tropical countries have rapidly increasing coastal populations and consequent rising levels of poverty, which put increasing pressures on coral reefs to provide food and other resources, usually beyond sustainable limits (Wilkinson, 1993; Birkeland, 2004). There is a global trend towards a migration of populations to coastal areas in search of work, as agricultural lands lose fertility or are divided into smaller parcels for family members. These increased pressures have caused, and will cause, collapses of coral reefs and phase shifts towards algal-dominated reefs at the expense of corals. Moreover, the increases in populations and the associated increases in pollution and resource exploitation will undermine attempts at conserving coastal resources. These three problems have to be faced in order to implement sustainable management of coral reef resources.

Poor capacity for management and lack of resources

Of the 100 coral reef countries and states reported in Wilkinson (2004), 21 have populations under 100 000, and a further 23 have populations under 1 million. These countries must establish the full range of government and be represented on United Nations (UN) bodies and multilateral environmental agreements. In addition, they are responsible for the management of a large component of global biodiversity. These governments have often declared MPAs and passed well-drafted legislation to protect coral reefs, but there is little follow-up action to manage the MPAs and enforce the regulations, principally because they lack the capacity and financial and logistic resources for the task. There is also often insufficient awareness

of the threats facing coral reefs and the potential solutions. For example, the many small to large states in the Wider Caribbean have declared 285 MPAs, but only 16 are regarded as effectively managed (Burke and Maidens, 2004). Similarly in Southeast Asia, only 10% to 20% of more than 630 MPAs are effectively managed, with well-prepared management plans that are enforced (Tun *et al.*, 2004).

Low political will and oceans governance

Many developing country governments focus on solving the immediate needs of providing health, housing, education and nutrition for their populations, and postpone action on the longer-term, and potentially more difficult problems of ensuring that environmental goods and services are conserved for the future. The resources needed to build management capacity by training young graduates in environmental management, and providing the funding and logistic resources to implement effective conservation, are low on the priority list; authors report that some governments consider that the environmental problems can be solved after the immediate problems. Conservation efforts are often taken on by the multilateral environmental agreements and NGOs, working at the local government level.

Inter-sectoral disputes and poor coordination are contributing factors towards poor environmental management. The 'traditional' management approach was consensus-based or 'integrated coastal management', often with the whole or large sections of the community involved in discussions before decisions were made about resource use. The resources were considered as the 'common property' of the community. Most developing countries have now adopted 'Western' or 'modern' methods of governance, with a cash economy, the concept of free access to all marine areas, and a sectoral government approach, e.g. a fisheries department seeking to maximize fish harvests, a forestry department aiming to maximize returns from trees, and an environment department tasked with conserving resources and ecosystems. Moreover, many of these governments must simultaneously consider the potential impacts of global climate change throughout the economy and on particular ecosystems.

The critical issues to improve coral reef (and oceans) governance are: a firm basis of local, national and international environmental policies and regulations to ensure the sustainable use of coral reef resources; effective mechanisms to implement and enforce those policies and regulations, including reviews of the effectiveness of the mechanisms in conserving resources; and improved capacity for coral reef management in these countries and the provision of resources for actions to avert the potential collapse in coral reef resources.

International agencies assisting coral reef countries

Many international agencies, including organizations of the UN, national donors and NGOs, assist countries with activities to conserve coral reef biodiversity, reduce threats, introduce integrated coastal management, and assist communities to develop alternative and sustainable livelihoods. These efforts are achieving considerable successes. However, many international agencies are inadvertently exacerbating the problem of poor capacity in many developing countries.

For example, the major multilateral environmental agreements concerned with coral reefs – the Convention on Biological Diversity, the Framework Convention on Climate Change, the World Heritage Convention, as well as the CITES, Ramsar and Migratory Species conventions which focus on protecting biodiversity – all seek to assist countries with natural resource conservation and environmental management. However, this assistance often depends on the production of regular reports to convention secretariats and the need to attend annual or biannual meetings in distant lands. Unfortunately, these reporting and meeting requirements and some training programmes divert the few trained environmental staff from direct activities aimed at conserving coral reef resources. Thus, there would be considerable benefits if the meeting and reporting requirements of the multilateral environmental agreements and other UN agencies could be rationalized to ensure that more time and resources are spent on activities directly related to resource conservation.

The Kyoto protocol to reduce the flow of greenhouse gases into the atmosphere and slow the accelerating rate of global climate change was drafted in Japan in 1997 (www.unfccc.int/essential_background/convention/items/2627.php). This protocol, which is minimalist in its ambitions to slow climate change, has only come into force as a UN-ratified convention in late 2004, with 84 parties signing and 124 either ratifying or acceding to the convention; some major greenhouse gas emitting countries, such as the USA, are not included. Thus, seven years have potentially been lost in reducing the threats to the world's ecosystems, including coral reefs. These delays result in cynicism amongst the smaller coral reef countries that are likely to be adversely affected by climate change but are not major emitters of greenhouse gases.

TWO EXAMPLES OF DAMAGE AND CONSERVATION

Two regions of the world illustrate variations in both the damage to coral reefs and activities aimed at conserving them. The Great Barrier Reef (GBR) of Australia is an example of particularly active conservation, supported

by a strong scientific base and supportive local community. In mid-2004, 33% of the whole province of the GBR (the GBR World Heritage Area) was given highly protected status (or no-take zones) by the Parliament of Australia (www.gbrmpa.gov.au). This is an increase from 5% of the GBR with the focus on the coral reefs that were zoned for protection in 1981. The heightened protection was considered necessary by the single management agency, the Great Barrier Reef Marine Park Authority, following increasing evidence that existing multiple-use zoning was inadequate to conserve biodiversity. For example, dugong populations have declined by 97% since the 1960s; nesting loggerhead turtles declined by 50–80% over four decades; commercial and recreational fishing have doubled since 1990; populations of major target species of fishes have been reduced and are now composed of smaller individuals; the annual flow of sediments and nutrients into the GBR has increased fourfold; and the reefs have suffered from severe coral bleaching, a series of cyclones and outbreaks of crown-of-thorns starfish. Many marine organisms rely on several adjacent ecosystems, thus the planning process focused on conserving a representative sample of all ecosystems ('ecoregions' or 'bioregions'), including seagrass beds, sandy and muddy bottoms and deep continental shelf slopes.

The process for reviewing the zoning of the Great Barrier Reef Marine Park started with the collation of all available scientific information, followed by community involvement, which together led to the identification of 70 bioregions within the Marine Park. There were a number of guiding principles to achieve the overall goal, including extending no-take protection to at least 20% of each bioregion. There was strong community involvement throughout the review process, with more than 31 000 public submissions received. The resulting new zoning includes the world's largest network of no-take areas (114 530 km²).

Support for the rezoning was helped by the government offering assistance to affected parties such as commercial fishers, who might have reduced earning potential from the reduction in line-fishing and trawling areas.

In contrast, there has been a significant and catastrophic degradation of coral reef status in the Wider Caribbean (including the nearby Atlantic coral reefs), accompanied by largely ineffective attempts at removing the human stresses and implementing effective resource conservation. Coral cover has declined by approximately 80% over 25 years, from about 50% cover on many reefs to approximately 10% now (Gardner *et al.*, 2003; Côté *et al.*, this volume). These declines are attributed to coral bleaching and disease,

hurricanes, and chronic problems of over-fishing, nutrient and sediment pollution and coastal modification (Burke and Maidens, 2004). The decline is particularly evident with the formerly dominant and major reef-building corals, *Acropora cervicornis* and related species and hybrids, and *A. palmata* (Precht and Aronson, this volume). These were severely affected by coral diseases and bleaching in the 1980s and 1990s, such that they have now been listed under the Endangered Species Act (ESA) of the USA (B. Plater, pers. comm.).

There has been some recent recovery in the major reef-building coral species in parts of the Wider Caribbean (Precht and Aronson, this volume), with fewer reported incidences of disease and major bleaching events. However, this should be treated with caution as the long-term trend is for an increase in the severity and extent of coral bleaching (McWilliams *et al.*, 2005). The long-term prognosis for Caribbean reefs is also discouraging as human pressures continue to mount with increasing populations. There are currently 116 million people living within 100 km of a Caribbean coast, which is a 20% increase in the past 10 years (Burke and Maidens, 2004).

The *Reefs at Risk* analysis for the Caribbean in 2004 (Burke and Maidens, 2004) and the report on impacts of climate change on Caribbean coral reefs from the Pew Center for Global Climate Change (Buddemeier *et al.*, 2004) found that:

- In the Caribbean, 64% of coral reefs are threatened by high levels of human activities, especially the eastern and southern Caribbean, Greater Antilles, Florida Keys, Yucatan and the Mesoamerican Barrier Reef.
- Coastal development threatens 33% of the region's reefs. The threat is greatest in the Lesser and Greater Antilles, Bay Islands of Honduras, Florida Keys, Yucatan and southern Caribbean.
- Land-based sources of pollution and sediments threaten 35% of Caribbean coral reefs, most notably in Jamaica, Hispaniola, Puerto Rico, the high islands of the Lesser Antilles, Belize, Costa Rica and Panama. Pollution and damage from ships threaten 15% of coral reefs, especially around large ports and cruise tourism centres.
- Over-fishing threatens more than 60% of Caribbean coral reefs, particularly on narrow coastal shelves near human population centres.
- Diseases and rising sea surface temperatures threaten reefs across the Caribbean.
- Ineffective MPA management threatens Caribbean coral reefs, with only 6% of 285 MPAs rated as effectively managed.

- There will be large economic losses if coral reef degradation continues, with a predicted loss of US\$350–870 million per year by 2015 of the US\$3100–4600 million of current annual benefits from fisheries, dive tourism and shoreline protection services.

These pressures and the threats of global climate change pose major threats for future recovery of Caribbean reefs. Many of these reefs are within the territorial waters of small developing states, with little capacity and few resources to implement effective management. Most reefs continue to be damaged by over-fishing such that surveys, especially by Reef Check (www.ReefCheck.org) and AGRRA (www.agrra.org), show that some fish stocks are close to collapse throughout, with very few reefs having populations of breeding fish. Moreover, there are very few areas with highly protected MPAs and most of those that do exist are not enforced.

RECOMMENDATIONS FOR THE FUTURE OF CORAL REEFS

The authors of the chapters in Wilkinson (2004) made a series of recommendations to reduce the stresses on coral reefs so as to reverse their declining status in their regions. These recommendations have many features in common with the 'Okinawa Declaration' and the Action Statement from the 2nd International Tropical Marine Ecosystems Management Symposium, as well as the statements from *Reefs at Risk* (Burke and Maidens, 2004), the Pew Center for Global Climate Change (Buddemeier *et al.*, 2004) and elsewhere (Birkeland, 2004).

Action to conserve coral reefs

These recommendations focus on:

- reducing and, where possible, removing the direct pressures on coral reefs through integrated catchment and coastal management to minimize the inflow of polluting sediments and nutrients into reef waters;
- managing coral reef fisheries in an attempt to make them sustainable and prohibit damaging fishing practices;
- improving fisheries yields by protecting breeding stocks in no-take MPAs, protecting spawning sites, and also in selective breeding programmes to satisfy the Asian restaurant market for live reef fish;

- involving local communities in the design and management of MPAs and enforcement of regulations;
- developing networks of MPAs that are larger, contain the most resistant and resilient coral and other organism populations, and are connected to ensure a free transfer of new larvae to restock the reefs and repair damage; and
- acting locally and globally to reduce the emissions of greenhouse gases that are driving global climate change inexorably towards massive destruction of coral reefs and the possible extinction of many coral reef species.

Action to improve oceans governance

Many countries reported there was insufficient capacity to implement actions to conserve natural resources. The main issues are for countries to have: environmental policies and regulations for effective conservation; implementation mechanisms for policies and regulations to improve coral reef management and conservation; and the capacity for coral reef management and resources for direct action with communities.

Environmental policies and regulations

There are many international policies and regulations, with the Law of the Sea Convention, the Climate Change Convention and the multilateral environmental agreements (e.g. World Heritage, CITES, Ramsar and Migratory Species). Most governments have developed strong national legislation, thus the urgent issue is not to develop more of these, but ensure that they are implemented. There is a need is to:

- ensure that local user communities and the private sector are aware of these environmental policies and regulations and have access to their provisions to manage environments on the ground;
- ensure that the international community provides incentives for communities and governments to manage their resources sustainably. Market-based incentives are an effective mechanism to assist communities;
- increase recognition in national and international policy development that sustainable development and poverty reduction in many countries are not achievable without integrated watershed and marine ecosystem management;

- recognize the role that effective management of coral reef resources can play in sustainable development and poverty alleviation.

Implementation mechanisms for policies and regulations

Implementation is where most effort is required. There is an urgent need to develop effective mechanisms to convert the legal instruments into effective implementation in the natural environment, and to:

- develop integrated oceans, integrated natural resource and integrated catchment management groups that include all stakeholders, especially local communities and the private sector, supported by governments, that can make decisions across all sectors of government;
- devolve sufficient authority to communities to develop and run their own no-take MPAs and implement enforcement (all well supported by state and national governments);
- develop joint enforcement mechanisms with government and communities acting in concert to enforce environmental laws aimed at conserving resources;
- strengthen jurisdiction and the imposition of penalties under existing laws to demonstrate to communities that their actions are supported and that infringements are treated seriously in the courts;
- reduce the reporting and meeting requirements of UN agencies and multilateral environmental agreements and make them more relevant to small countries, possibly through developing regional meetings that combine several international marine environmental instruments with more attention to practical issues;
- facilitate the access of small countries to international conventions and instruments as collaborating blocks and reduce their meeting and reporting requirements by forming groups of states with similar cultures, problems and resources;
- review the effectiveness of implementation of international conventions and instruments to ensure that they are assisting in conserving the marine resources;
- undertake an objective appraisal of the performance of current international and regional environmental agencies to ensure that their current activities meet the stated objective of conserving environmental resources.

Capacity for coral reef management

Most coral reef countries lack trained personnel for coral reef management, awareness raising, enforcement and monitoring. Moreover, they lack the

necessary resources to implement effective management. Thus there is a need to:

- assist in the training of environmental resource managers and ensuring that they are provided with in-country employment;
- assist countries in the development of alternative livelihoods to combat poverty and reduce the need to over-exploit coral reef resources;
- assist developing countries in the design, implementation and management of networks of MPAs to conserve their resources;
- consolidate the training provided by UN agencies and multilateral environmental agreements to ensure that they are targeted on resources, issues and problems relevant to conserving national resources;
- provide adequate and long-term financial and logistic resources for developing countries to undertake environmental planning for the longer term, rather than the three- to five-year funding cycle of projects;
- assist in the recognition of appropriate traditional knowledge and methods of environmental management and help governments harmonize these with state and national laws;
- develop the 'capacity to build capacity' and use 'train-the-trainers' and peer-to-peer exchanges as low-cost mechanisms to ensure that capacity building is a self-sustaining mechanism.

CONCLUSIONS

Coral reefs of the world continue to decline under a mix of predominantly human stresses arising from increasing exploitation of resources and developments on the land, fuelled by increasing populations. Coral reefs in the Indian Ocean and western Pacific are recovering after the 1998 El Niño–La Niña global coral bleaching event, with stronger recovery in well-managed and remote reefs; however, there is not uniform recovery and many reefs damaged in 1998 show few signs of recovery, because there are inadequate supplies of new coral larvae.

Action will be required at local, national and international scales to implement better management practices, to make fisheries more sustainable and improve yields by protecting breeding stocks, to protect reefs from direct damage and to integrate conflicting approaches to management in the watersheds and adjacent waters around coral reefs. It is widely recognized that one of the better methods of protecting coral reefs is through

MPAs and affording them the highest level of protection possible. The declaration of 33% of the Great Barrier Reef World Heritage Area with highly protected status is an example for other governments. Many MPAs have been declared recently by governments around the world; however, few MPAs have effective management and most are ignored by local populations. There is strong recognition amongst international agencies that developing countries need scientific, logistic and financial support to designate and manage coral reef MPAs to safeguard biodiversity of global importance.

Fundamental to supporting these actions is a wider involvement of the public and stakeholders in management processes, as well as an improved understanding of the importance of coral reefs, especially the economic value of coastal ecosystems. Understanding the linkages between human activities and changes in coral reef condition is critical for implementing the necessary changes in management, and strengthening political will and community support for these changes. Stronger partnerships will need to be developed between all sectors involved in coral reef exploitation and conservation. The World Summit on Sustainable Development in 2002 called for the establishment of networks of larger MPAs and a major international effort to reduce losses in biodiversity, including the biodiversity on coral reefs. This call lies at the heart of efforts to conserve coral reefs for future generations.

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