1. Global Threats to Coral Reefs: Coral Bleaching, Global Climate Change, Disease, Predator Plagues, and Invasive Species

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A series of new and emerging threats to coral reefs has become a focus of attention in recent decades with clear evidence of widespread and even global damage. This chapter focuses on these threats:

- coral bleaching and global climate change;
- diseases of corals and other reef organisms;
- plagues of predators like the crown-of-thorns starfish (COTS – *Acanthaster planci*) and other damaging organisms such as the sea urchin *Echinometra mathei*; and
- invasive species which have been introduced onto new coral reefs.

These threats are in addition to natural stresses that have always existed on coral reefs such as storms, freshwater inundation and seismic and volcanic events. Direct human pressures on reefs have, until recently, been the dominant factors damaging coral reefs through a range of stresses, many of the which can co-occur:

- the delivery of 'pollution' from unsustainable land-based human activities such as deforestation, poorly regulated agriculture, and urban and industrial development resulting in the release of excess amounts of sediments and nutrients. This is exacerbated by the release of nutrients and other pollutants from untreated or poorly treated sewage and industrial and agricultural wastes;
- over-fishing and over-exploitation of coral reef fisheries and coral rock and sand resources. Within the last 2 decades there has been an alarming increase in damaging fishing activities involving the use of home made bombs, cyanide and damaging practices such as *muro ami* that involves dropping weighted rocks onto corals to drive fish into set nets; and
- modification and engineering practices such as building of ports, airports and groynes on coral reefs, including the practice of 'reclamation', which pours sediments onto shallow areas, displacing sea area in exchange for increased terrestrial amenity.

Coral reefs managers and scientists now suspect that these apparently newer global threats (bleaching, disease and predators) are increasing rapidly in frequency and severity, coincidentally with direct human disturbances. Predator plagues like COTS are increasingly reported around areas of human activities with 2 strong hypotheses advanced: the plagues may be initiated and certainly exacerbated by either over-fishing of key starfish predators; and/or increases in nutrient runoff from the land favours the planktonic stages of the starfish. Coral disease has caused major disruptions to coral reefs in the Caribbean with a range of human disturbances potentially implicated, and there are now increasing reports of similar disturbances from the Indo-Pacific region. Evidence linking severe coral bleaching and mortality to increasing rates of global climate change attributed to rising levels of anthropogenic greenhouse emissions is growing stronger.

Coral reef managers and policy makers urgently need guidance from the research community on appropriate responses to these mounting levels of global stresses. Management has largely been based on controlling the direct pressures of pollution and over-exploitation. There are now urgent questions for researchers: are there linkages between human activities and the increasing reports of global stresses on reefs and if so, how are they manifested and how can they be controlled or at least minimised?

In the 3 previous reports (*Status of Coral Reefs of the World*: *1998, 2000* and *2002*), there was a chapter on the major coral bleaching and mortality event of 1998. In the following section we examine the fate of reefs that were severely damaged in that event and examine subsequent coral bleaching events.

Coral Bleaching and Global Climate Change

Summary of Recovery After the 1998 Bleaching Event

This episode was the largest coral bleaching and mortality event ever recorded on coral reefs globally, with major effects in the Arabian/Persian Gulf, Eastern Africa, throughout the Indian Ocean, in Southeast Asia, parts of the western Pacific and the Caribbean and Atlantic region (Box p 22). Overall, it was estimated that 16% of the world's area of coral reefs was severely damaged; some areas no longer resembled coral reefs. Approximately half of the reefs in the Indian Ocean and around South Asia were reported to have lost most of their living corals. The Status 2000 and particularly the 2002 reports indicated significant recovery of many affected reefs, especially areas that were remote or within well managed MPAs (Table p 9).

Summary of Coral Bleaching from 1999 - 2004

There has been no repeat of the massive global-scale bleaching of 1998 in the subsequent 6 years, although several minor bleaching events have been reported in many regions worldwide. Coral bleaching has also occurred outside the tropics. In mid to late 1999, there was extensive mortality of 28 species of non-symbiotic gorgonians, sponges, ascidians, bryozoans, and bivalves mainly in South-Eastern France. Two symbiotic corals *Oculina patagonensis* (invasive) and *Cladocora caespitosa* (native) bleached because there were prolonged elevated temperatures of 22.0°C to 23.9°C (1.2°C above summer maxima). Similar mortality had been seen in La Spezia, Italy, in September 1997 and August 1998, likely caused by high temperature bleaching and pathogens.

Middle East

Bleaching in 1998: The devastating bleaching damage to virtually all shallow coral reefs in the Arabian/Persian Gulf in 1996 and 1998 is still clearly evident and recovery is slow. There is more recovery on some of the reefs than was predicted at the time indicating that the coral reefs retain a degree of resistance to coral bleaching. Coral cover was reduced to less that 1% on all reefs and with no apparent parent stocks of corals, there were fears of localised extinctions of some species. Recovery is occurring apparently from larvae of corals growing on the deeper water patch reefs off the United Arab Emirates. It is certain that recovery will take many years, with the proviso that there is not a repeat of the conditions that resulted in the 1996 and 1998 bleaching. There has been slow recovery of corals on the Iranian coast after moderate to slight losses in 1998. Bleaching impacts in the Arabian Sea on the Oman coast and in the Red Sea were relatively minor in 1998.

Bleaching from 1999-2004: Coral bleaching was recorded in 1999 around Kish, Farur, and Larak Islands on 30% of shallow water (3-6 metres) coral populations in Nay Band Bay, in the northern Gulf. Bleached corals were mostly massive colonies such as *Favia sp*. and *Porites sp.* and typically 70% of each colony bleached. Bleaching was also observed from 1999 through 2003 yet no event was as intense as 1998, with between 1% to 10% of colonies typically being affected (from Mohammad Reza Shokri Bousjein, mohammad.shokri@studentmail.newcastle.edu.au).

There have been a 3 bleaching events in Oman since 1998, all of which appear to have been localised and not resulting in any significant mortality. In June 2000, a survey of coral rich areas in Musandam (Straits of Hormuz) showed that 19% of survey sites had paling or bleaching of at least 10% of all coral, particularly *Platygyra* and other faviids. Observations in the Gulf of Oman during 2002 indicated that bleaching was affecting some genera, particularly *Astreopora* and *Porites* inhabiting shallow (2-3 m) water although little or no coral mortality resulted. Similar assessments of sites in Musandam showed severe bleaching at the mouth of Ghubb Ali River while other sites remained unaffected. Temperatures at the bleached site exceeded 32.5ºC for almost a month, while the non-bleached site temperatures remained below 31.5ºC. There have been reports of minor, localised bleaching in sheltered areas around Muscat (from Bandar Jissah and Bandar Khayran) in 2004, affecting *Acropora*, *Montipora* and *Pocillopora* in shallow water (down to 3-4 m) but corals inhabiting deeper water remain healthy (from Simon Wilson, simon.wilson@adelphi-env.com).

Eastern Africa

Bleaching in 1998: Africa's coral reefs were severely affected by bleaching and mortality levels varied from <1% in South Africa to 80% or greater on reefs in Tanzania and Kenya. Recovery of affected reefs continues but improvements have been very patchy and hindered by chronic and local threats, including over-fishing, COTS infestations, and repeated minor bleaching events.

Bleaching from 1999-2004: Minor bleaching was reported in northern Tanzania and Kenya during 2003. Mortality was generally minimal and in some cases the species that suffered the most bleaching damage in 1998 showed less bleaching than other species, such as *Pocillopora damicornis* and some *Acropora* species. Reefs that had high coral diversity prior to 1998 have recovered to less than one quarter of their previous coral cover. Degraded reefs with low coral cover outside MPAs have generally recovered half to all of the pre-bleaching cover. The highest coral recruitment has been on protected reefs with reasonably healthy stocks of parent corals nearby. Recovery is higher on shallow reefs than in deeper water and reefs within MPAs have shown better recovery than those outside, especially on Chumbe Island, Zanzibar, and Mombasa Marine Park, Kenya. Most of the new recruits are *Pocillopora* species, with the highest densities of more than 20 per m^2 at Mafia, Tanzania, and Kiunga, Kenya, whereas on most other reefs the range is 1-3 new recruits per m^2.

South West Indian Ocean

Bleaching in 1998: In the southern Indian Ocean islands of Madagascar, Mauritius and Reunion, most corals recovered immediately after the bleaching and mortality was minor. Recovery and new coral growth on Madagascar is encouraging, but in many areas this recovery merely balances damage from anchors and pollution from the land. The major impacts of this bleaching event were in the Comoros and Seychelles. Reefs in the Comoros appear to be recovering well, for example the corals in the Moheli MPA have recovered about half of their former coral cover (to about 20%) by early 2002, with even better prospects as recruitment was strong in 2002. The situation is less encouraging in the Seychelles with very low rates of natural recovery, even in the protected areas, and most recovery is in deeper water. In Mauritius, the 1998 bleaching event was widespread yet relatively mild. The main cause of bleaching was an increased SST and solar radiation, exacerbated by increased rainfall leading to decreased salinity and increased terrestrial runoff. The synergy of factors is most likely responsible for the observed bleaching. *Acropora* species were found to be more affected on the reef flat yet non-*Acropora* were more susceptible on the reef slope.

Bleaching from 1999-2004: There was virtually no bleaching on Rodrigues, Western Indian Ocean, in 1998, probably due to Cyclone Annacelle bringing clouds and strong winds. However in early 2002, there were very warm temperatures, clear skies and calm seas, and a massive fish kill. By early March, extensive coral mortality was observed in shallow waters and all table and branching *Acropora* were dead. Other corals were bleached, however the bleaching was not widespread, occurring in only one third of sites, but in these up to 75% of corals were affected. By 2003 there was some recovery, but there was simultaneous bleaching at sheltered sites with high mortality of branching and tabular *Acropora*. The recovery at damaged sites is encouraging with many new *Acropora* recruits, however exposed sites still had a cover of loose rubble (from Emily Hardman (osp829@bangor.ac.uk), John Turner, Sabrina Meunier and Tracy Clark)

Temperatures along southwest Madagascar remained above 30°C from December 2002 through March 2003, resulting in such severe bleaching of some inner reefs that they were beyond recognition. The outer reefs of Madagascar are more resilient to, and less affected by, bleaching than other reefs, possibly due to hydrological conditions such as the Comoros gyre, which is impervious to unseasonal warm water incursion, and deeper waters upwelling cooler water to the surface, preventing bleaching events. Little evidence of bleaching was seen in northeastern Madagascar in 2000 and reefs are still recovering from the 1998 event. Extensively bleached and dead corals were seen in 2001 along the southeastern coral meadows of the Lokaro lagoon.

South Asia

Bleaching in 1998: Reefs in the Chagos Archipelago in the Indian Ocean suffered up to 95% coral mortality in many areas in 1998 and in the following 2-4 years there was some new recruitment in all reef areas, from reef flats to at least 30 m depth. This is encouraging, but most of the new corals settled on dead *Acropora* tables, which are eroding and collapsing thereby threatening their survival while others settled on reef slopes, which are being damaged by large quantities of mobile coral rubble. In addition, recruits of certain species are settling more successfully than others, with more faviids recruiting now than before the 1998 mortality. The consensus is that recovery will be slow and that there will be a shift in the species composition of the reefs.

Massive corals now dominate the reefs in the Gulf of Mannar, India as the branching forms (mostly *Acropora*) were lost in 1998. There was further bleaching in 2002 that killed many of the remaining non-massive corals. The massive corals also bleached, but most recovered rapidly. There was no serious bleaching in the Andaman and Nicobar Islands in 1998 and most reefs there remain healthy. This is not the case for the reefs of the Lakshadweep Islands, which suffered massive damage in 1998 (Box p 219). However, there are now clear signs of recovery with many small coral colonies settling on the bare reefs.

There have been reports of bleaching in Bangladesh in 2003 as well as 1998.

In the Maldives, the early reports were of almost total devastation across all the atolls, however more recent data show that some of the atolls in the far south escaped most of the major bleaching damage. Most of the other atolls were reduced to 0 to 5% coral cover, from previous cover in the range of 40 to 60%. Most sites show some encouraging signs of recovery, with the species most susceptible to bleaching showing strong levels of recruitment.

Recovery after 1998 on Komandoo Reef in the Maldives is weak and is not predicted to keep pace with sea level rise or rates of bioerosion. There are prospects of local extinction of species if there are repetitive bleaching events (from Karen Loch, Wolfgang Loch, Helmut Schuhmacher (h.schuhmacher@uni.essen.de), and Wolf See)

Recovery in Sri Lanka has been variable. Many small colonies of *Acropora* and *Pocillopora* are evident on the shallow parts of the Bar Reefs, where coral cover had been reduced to very low levels from about 80% prior to 1998. About 14% coral cover has remained in deeper areas (8m depth) on these reefs and probably represent the parent stock for the shallow water recruitment. Coral cover in the Hikkaduwa MPA has increased from 7% in 1999 to 12% in 2002, but there is a long way to go to the tourist attraction that it was previously.

Bleaching from 1999-2004: Minor bleaching episodes were observed in 2003 and 2004 during periods of warmer weather in the Maldives, Bangladesh, and the Gulf of Mannar. Some islands around India had 10-20% of corals totally bleached and a similar percentage suffered partial mortality although recovery occurred within months. Sri Lanka's reefs showed minor bleaching episodes with minimal mortality.

Southeast Asia

Bleaching in 1998: Moderate to severe damage was reported on Indonesia's coral reefs after the 1998 bleaching event and recovery has been variable. Reefs in the Philipines, Thailand, and Vietnam suffered widespread bleaching episodes leading to high, variable mortality. Recovery is occurring, yet will take time due to continued anthropogenic threats causing further stress.

Bleaching from 1999-2004: There is evidence of coral recovery in Cambodia, Indonesia, Philippines, Thailand and Vietnam after extensive coral bleaching mortality, mostly in the northern parts of Southeast Asia. In Indonesia, recovery has been slow in Sumatra and Lombok, but rapid in the Seribu Islands adjacent to Jakarta where coral cover is 40% on some reefs. Coral

WHAT EFFECT WOULD DOUBLING ATMOSPHERIC CO_2 HAVE ON CORALS?

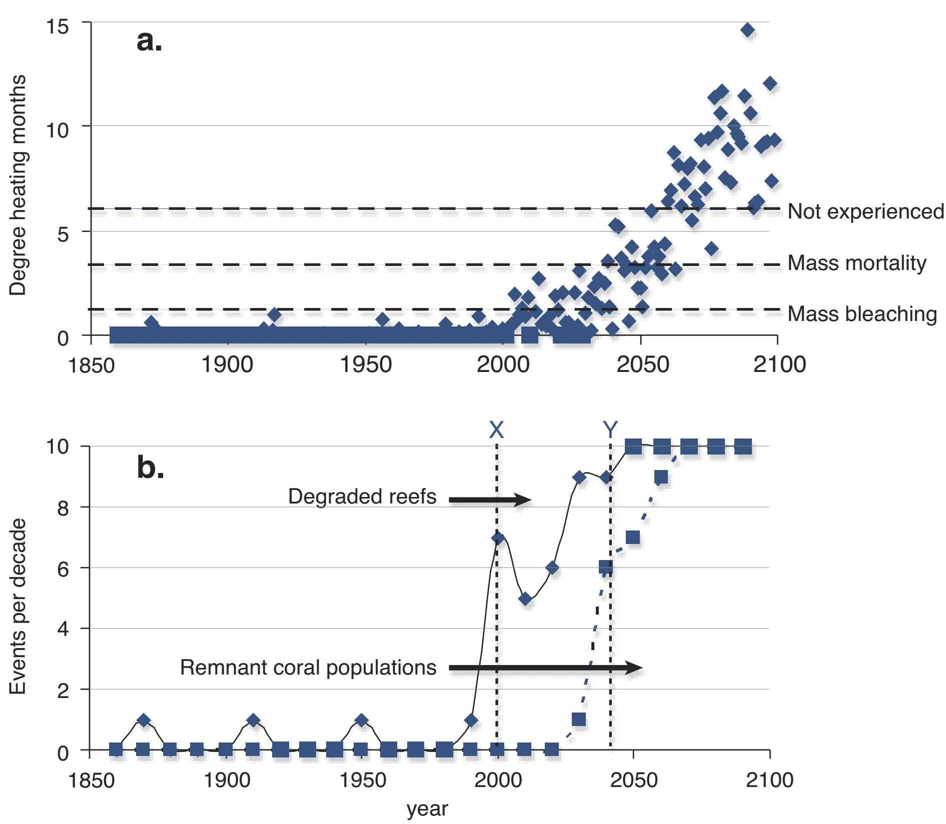
There have been at least 6 global mass coral bleaching events since 1979, with the most damaging being in 1998. These events were triggered by unusually warm conditions and water temperatures and have severely damaged many coral reefs around the world. The past damaging events have been analysed with satellite images by the National Oceanic and Atmospheric Administration (NOAA of USA) to produce 'degree heating weeks or months' anomalies in sea surface temperatures to predict potential future events. Degree heating months considers the size of the upward anomaly and the time that coral reefs were exposed, combined with direct observations of coral bleaching. When combined with projections of how sea temperature will change in tropical regions, the predictions are alarming with expected increases in frequency and severity of coral bleaching and mortality events.

Changes to the heat tolerance of corals may occur through acclimation or adaptation (Box p 25); however, there is no convincing evidence of large scale changes to the thermal tolerance of corals and their symbiotic algae. Changes to the composition of the symbiont populations inside corals (a form of acclimation) will provide some improved thermal tolerance to some corals. However, as with acclimation in all other organisms, there are limits to the role that this mechanism can play in coping with climate change. With changes in ocean temperature set to exceed the mild scenario (relative to other IPCC 2001 scenarios) presented here, reef scientists and resource managers must consider additional management options to account for some of the disturbing future scenarios in these analyses (from Ove Hoegh-Guldberg, oveh@uq.edu.au).

recruitment is low in the Gulf of Thailand indicating that recovery from the 1998 bleaching will be delayed. The coral reefs in the World Heritage Tubbataha reefs south of Palawan are showing rapid recovery after years of blast fishing and the 1998 bleaching event. Coral reefs in Bali show minimal bleaching and many corals are in excellent condition except for physical damage caused by dynamite explosions and localised anchor damage. In Tulamben and Seraya corals show little sign of bleaching.

East and North Asia

Bleaching in 1998: Recovery in southern Japan from 1998 continues to be rapid. Coral mortality in the Ryuku and Yaeyama Islands were 30 to 90% with losses of large areas of *Acropora*. Although these are returning, there were some losses from bleaching in 2001. Shiraho Reef (Ryukyu Islands, Japan) survived the 1998 bleaching and is recovering at an unexpectedly fast rate. However, similar rapid recovery has not been observed on other reefs of the Ryukyu Islands. Much of the recovery is from asexual growth and fragmentation of larger colonies. There has been reasonable recovery on Taiwan after extensive coral bleaching in 1998, when 20% of coral colonies died on Penghu Islands, Lutao, and Lanyu.



The figures show the effect of applying thermal thresholds derived from the last 10 years for bleaching of corals on the central Great Barrier Reef. The thermal threshold for most corals is around 28°C. The predicted changes to sea temperature with a doubling of CO_2 in the atmosphere were calculated using the best available global circulation models. The top part (a) shows how accumulated heat stress (as degree heating months) rises steadily over this century; bleaching events per decade over the next century (>1.0, dotted line) and severe events (>3.2, second dotted line) are drawn on the top part (a). More threateningly, the calculated values eventually rise above any value seen on reefs so far (> 6.0 upper dotted line). The lower diagram (b) projects outcomes for coral reefs as a result of the changes to thermal stress and reasonable mean responses by reef corals. Coral reefs that experience bleaching events every 2 years would degrade significantly; the dotted line X indicates when this point will be reached. When severe mortality events (when degree heating months >3.2) are experienced every 2 years, coral reefs are expected be severely depleted as mortality will grossly exceed recovery rates; dotted line Y.

Bleaching from 1999-2004: The corals on Ishigaki Island, Japan may be showing potential acclimation to thermal stress, and were observed to survive in a bleached state for 6 months. Species richness has decreased at all sites because of 1998 and subsequent bleaching, with marked decrease of the former dominant species of *Acropora* (from Hajime Kayanne, Saki Harii, Yoichi Ide, and Fujio Akimoto).

BLEACHING IN REEF-DWELLING FORAMINIFERA: A 20 YEAR RETROSPECTIVE

Reef-dwelling larger foraminifera share key characteristics with reef-building corals: both groups are prolific producers of calcium carbonate, both groups are physiologically dependent upon algal endosymbionts, and representatives of both groups have suffered bleaching episodes in recent decades. Bleaching symptoms were first observed in foraminifera in the early 1980s in laboratory experiments aimed at determining optimal culture conditions for the most common Caribbean and Indo-Pacific larger species, *Amphistegina gibbosa* and *A. lessonii*. Bleaching was first noted in field specimens collected in the Bahamas in 1988 during a coral post-bleaching survey. Since 1991, bleaching has been observed in populations of *Amphistegina* in all subtropical oceans, with peak bleaching in 1991, 1992 and 1998. *Amphistegina* populations exhibiting chronic, intermediate-intensity bleaching characteristically also show anomalously high incidences of shell breakage, shell deformities, and attack by predators and microorganisms, as well as damage to asexual reproduction and changes in population structure. A key difference between bleaching in corals and foraminifers is that coral bleaching correlates most consistently with elevated sea surface temperatures, while bleaching in *Amphistegina* is associated with photic stress. Throughout the 1990s, the incidences of bleaching in Florida Keys populations of *A. gibbosa* increased through the spring and peaked near the summer solstice, preceding late summer temperature maxima. Photic stress in laboratory cultures induced visible bleaching that was cytologically indistinguishable from bleaching in specimens freshly collected from the field. Increasing radiant energy by 20% above established optimal laboratory conditions by changing fluorescent light sources from “white” to “blue” induced chronic bleaching, without affecting rates of shell increase. Thus, while corals that are susceptible to bleaching apparently live near their upper thermal thresholds, *Amphistegina* thrive near their photic thresholds and are particularly sensitive to shorter wavelengths of solar radiation. Recognizing the similarities and differences between these taxonomically very different symbiotic systems may facilitate understanding the global decline of coral reefs (from Pamela Hallock Muller, pmuller@seas.marine.usf.edu).

Australia and PNG

Bleaching in 1998: The reefs of the Great Barrier Reef have shown substantial recovery after the 1998 bleaching, assisted by the large scale of these reefs and the ready availability of coral larvae on reefs upstream. Some reefs that were severely bleached in 1998 still show dead standing corals, but most have healthy populations of new coral recruits. There has also been considerable recovery of reefs in the northern and central sections of the GBR after major losses of corals from the coral predator, the crown-of-thorns starfish. Similarly there has been substantial recovery on reefs damaged in 1998 off the Western Australian coastline. There is insufficient data to assess either the extent of coral bleaching or recovery in PNG, however the few data presented in Chapter 9 do indicate that there are concerns about coral bleaching damage to these reefs.

Bleaching from 1999-2004: There was significant coral bleaching along the length of the Great Barrier Reef (GBR) in 1998, with fringing inshore reefs in the Central GBR the worst affected;

but it was variable. Between 11% and 83% of colonies were bleached with 1% to 16% mortality, but also variable in species affected. By March 2004, many of the catastrophic declines in some species have been fully reversed, but others remain rare. Coral that reproduce by spawning have many new recruits, whereas those that brood larvae, are still rare. Thus the damage of the 1998 event is still evident in the coral communities, but total coral cover is returning to pre-1998 levels, illustrating the resilience of the GBR to impacts (from Andrew Baird and Paul Marshall). No bleaching occurred in Cobourg Marine Park, Northern Territory, in 2003 and 2004 (from victor.gomelyuk@plmbay.pwcnt.nt.gov.au). Minimal bleaching occurred in 2002 and no major damage was reported due to relatively quick recovery.

Southwest Pacific

Bleaching in 1998: Coral bleaching and mortality was not a significant problem during the major global bleaching event in 1998 but there have been several bleaching episodes since then, particularly in Fiji, Tuvalu, and Vanuatu.

Bleaching from 1999-2004: In Taveuni (Somosomo Straits), there has been no recent bleaching and recovery from 2000 bleaching is variable but clearly evident, with many non symbiotic corals in high abundance. In Bligh Water, the pillar reefs are in excellent condition, and there is vigorous recovery of dead areas from earlier bleaching, including patches of table and branching *Acropora*. In Lomaiviti, there is regeneration of hard corals everywhere, including much vigorous growth. Kadavu (south Great Astrolabe Reef, Madava to Ono) has some high coral cover, but generally very low coverage and sparse regeneration. (from Les Kaufman, lesk@bu.edu).

There was an average of 70% bleaching of the *Acropora* corals in Funafuti Lagoon, Tuvalu in 2000, when water temperatures were 30.5°C to 32°C. But there was less than 10% for the Agariciidae, Faviidae and Mussidae (from Samasoni Sauni, sauni_s@usp.ac.fj and Ron Vave).

Hard and soft corals on some Fijian reefs began bleaching in early 2000 and by mid-July most colonies were either recovering or dead and being colonized by algae. Some Savusavu reefs experienced 60 to 80 % hard and soft coral mortality down to a depth of 10 m with Acroporids most affected. Reefs with lower coral diversity and abundance seemed to suffer less than those with increased cover and diversity yet the bleaching and resultant mortality was quite variable, with the highest mortality along the southern portion of Viti Levu and Vanua Levu. Inshore reefs showed greater survivorship and these large areas of healthy coral, as well as deeper reefs, which were less affected should bode well for a large recruitment to the areas of high mortality (from Richard Murphy, Rmurphy000@aol.com and Ed Lovell, lovell@suva.is.com.fj).

The Mamanucas Islands of Fiji are continuing to recover from the 2000 bleaching event and show an increase in total hard coral cover and a decrease in dead coral and macroalgae cover between 2001 and 2003, suggesting that the reef habitat is generally in a good condition. However, assessments of new sites in 2003 suggest that tourist development may have impacted shallow reef habitats around some of the smaller islands within the archipelago. The presence of dense beds of the macroalgae *Gracilaria* may be related to elevated nutrient levels in nearshore waters yet the potential causes of these extensive macroalgal beds are unknown (from Ryan Walker, rw@coralcay.org).

Polynesia Mana -Southeast Pacific

Bleaching in 1998: There were no large impacts throughout Polynesia from bleaching in 1998, however there was severe bleaching on some parts of reefs e.g. coral mortality was over 90% on some outer reef slopes in Rangiroa. These reefs have shown rapid recovery, although there has been some repeat bleaching.

Bleaching from 1999-2004: Bleaching events in Polynesia Mana have been more frequent and severe during recent times. Approximately 80% of *Acropora* bleached in 2000 in the Cook Islands and up to 90% of *Platygyra* and *Goniastrea* bleached in Tonga. The Society Islands in French Polynesia suffered bleaching in 2001 along many barrier reefs and lagoons, and general bleaching along the outer reef slopes persisted for several months, with about 10% mortality.

Micronesia

Bleaching in 1998: Some of the most extensive bleaching and subsequent coral reef damage was seen in Palau in 1998. Some reefs have coral cover in the range of 50 - 70% suggesting that they escaped the major impacts of the 1998 bleaching, or recovered soon after. There are, however, reefs with 10 - 25% coral cover and with large amounts of dead standing coral indicating that these reefs were badly affected. There were reports from Palau immediately after the 1998 bleaching of up to 50% mortality on some reefs. *Acropora* corals were virtually wiped out on some offshore reefs, whereas reefs in more sheltered lagoon waters showed lower rates of loss. New coral recruitment has been very encouraging, including many of the *Acropora* species which were severely affected in 1998, however the major concern is that there are large numbers of crown-of-thorns starfish feeding on the newly settled colonies. The other countries of the Micronesian Node were not seriously affected in 1998.

Bleaching from 1999-2004: Bleaching was restricted to most shallow water *Acropora* in the Republic of the Marshall Islands during 2000. More shallow bleaching was reported on Jaluit, Mili, Arno, and Likiep in 2002 with complete mortality of many *Acropora* dominated coral reefs particularly along inshore regions such as reef flats. Deeper episodes occurred in 2003, with partial bleaching of giant *Porites* colonies, *Millipora*, *Lobophyllia* and other species showing substantial recovery. Shallow lagoons dominated by *Acropora* colonies showed signs of mortality alongside scattered bleaching of *Pocillopora* colonies. A visit to Jaluit atoll in early 2004 revealed that bleaching still persisted in many large tabulate/branching *Acropora* colonies: bleaching was restricted to well lit surfaces and was absent in shaded areas. Lagoon mortality was detected in the shallows (< 3 meters) (from Dean Jacobson, atolldino@yahoo.com).

Hawaiian Archipelago

Bleaching in 1998: The 1998 bleaching event was not significant for Hawaii's coral reefs. In fact, there were colder than normal sea temperatures while the other side of the Pacific was abnormally warm.

Bleaching from 1999-2004: The first mass coral bleaching ever recorded in the remote Northwestern Hawaiian Islands (NWHI), a chain of small islands, atolls, and banks that span ~1800 kilometres in the northwest portion of the Hawaiian Archipelago, was documented in late summer 2002. Towed-diver surveys covering more than 195 km of benthic habitat and belt-transect surveys at 118 sites were conducted at 10 reef systems throughout the NWHI to assess coral bleaching across latitude, depth, zone, and taxon. The incidence of bleaching was greatest at the 3 highest-latitude atolls in the Hawaiian Archipelago (Pearl and Hermes, Midway, and

MARINE TURTLES NEED CORAL REEFS AND VICE VERSA

Marine turtles across the globe are endangered or critically endangered following continued and unrelenting anthropogenic stress: they are harvested for their meat and oils, shells are taken for curio-making, eggs are taken for food, and a number of body parts are considered potent aphrodisiacs. Millions of hawksbill turtles were killed during the 20th century to supply worldwide demand for tortoise shell. In the late 1970s at least 46 countries exported raw shell to numerous importing countries. Although now protected by laws in nearly every range country, loopholes and unscrupulous exploitation fuel a level of exploitation far in excess of that which can be supported by most populations, although some show clear signs of rebound and recovery, such as some Caribbean species. Hawksbills in this region inhabit inshore reef ecosystems and the majority of the population is within the national waters of many different countries at any time, making their conservation a shared concern. There have been reductions in excess of 80 % at many important breeding sites throughout the world. Nicaragua, Panama, Madagascar, Sri Lanka, Thailand, Malaysia, Indonesia, and the Philippines have shown turtle declines during the last 100 years. Currently, a handful of hawksbill populations are stable or increasing, but these are the exception rather than the rule, and involve populations that have been subject to long-term and effective protection for over a decade.

Coral reefs are well known for harbouring the critically endangered hawksbill turtle *Eretmochelys imbricata* which relies on sponges living among corals among its main diet components, making it one of the only organsisms that has glass as a main component of its daily intake. The glass spicules in sponges serve to deter a major portion of underwater predators, but once the soft tissues are opened up by turtles many sponges are prey for less robust feeders. Turtles play an integral role in the maintenance of underwater life cycles, and a decline in turtles will likely result in an overpopulation of sponges, taking up valuable reef space and not contributing to reef-building in the way calcareous corals do. Turtles additionally provide a tourist attraction and the link between turtles, conservation funding and habitat protection cannot be overemphasised. The successful conservation of hawksbill and other turtles, such as the green turtle *Chelonia mydas*, is inextricably linked to the protection and maintenance of their habitats. No habitat, no turtles, it's that simple (from Nicolas Pilcher, pilcher@tm.net.my, and Roderic Mast r.mast@conservation.org).

Kure), with lesser incidences of bleaching on reefs at Lisianski and farther south in the NWHI. At the 3 northern atolls, bleaching was most severe on the back-reef, moderate in the lagoon, and low on the deeper fore-reef. The average incidence of coral bleaching experienced closely corresponds to the composition of the dominant coral fauna coupled with its susceptibility to bleaching. Prolonged, elevated sea surface temperatures are a likely explanation for the bleaching response.

In 2004, thermal stress began to develop in the Northwestern Hawaiian Islands beginning in mid-August and increased through early-September. Recent surveys have confirmed substantial coral bleaching among *Montipora patula*, *Porites evermanni*, and *Porites lobata* at Maro Reef, Laysan, and Lisianski. The shallow backreef habitats of Pearl and Hermes Atoll and Midway Atoll were also significantly bleached while Kure, the northernmost atoll in the Hawaiian Archipelago, showed similar yet less pronounced bleaching. (from Jean Kenyon, Jean.Kenyon@noaa.gov).

US Caribbean and Gulf of Mexico

Bleaching in 1998: In 1998 there was extensive and intensive bleaching affecting the majority of coral reefs around Puerto Rico and the US Caribbean. In the southwest region and Mona Island, a large number of coral colonies, hydrocorals, octocorals, and zoanthids bleached completely (100% of living surface area) down to 40 m deep. Maximum temperatures measured during 1998 in several reef localities ranged from 30.15°C (20 m deep) to 31.78°C at the surface. Of the 386 totally bleached colonies tagged and monitored for over a year after the event, many colonies of corals and zoanthids remained bleached for over 120 days, even after water temperatures dropped to 25-26.5°C in winter. While most of these colonies regained their normal coloration by December 1998, some showed bleached tissue until 1999 before they recovered their coloration (zooxanthellae). Mortality rates were minimal (< 0.1%) with some colonies (< 5%) showing increased partial mortality.

Bleaching from 1999-2004: Bleaching occurred in 1999 yet was less intense than the 1998 episode; a significantly lower number of colonies were affected and no colonies fully bleached. Between 6 and 13% of all corals and between 12 and 31% of the hydrocorals showed bleaching symptoms (from pale to white areas over the colony) and a further 15% bleached in 1998 and 1999. No coral or hydrocoral mortality was observed this year and 99% of all bleached colonies regained their normal coloration by the end of the year. Minimal bleaching was observed in many reef localities including Bonaire, parts of the Caribbean and Bermuda in mid-1999.

No significant bleaching occurred from 1999 through 2002, but the 2003 bleaching event was an intense event producing complete mortality of many colonies (mostly hydrocorals (*Millepora complanata* and *M. alcicorrnis*, the colonial zoanthid *Palythoa caribaeorum* and the crustose octocoral *Erythropodium caribaeorum*). Some shallow areas (< 10 m) dominated by these organisms appeared white for over a month. The 2003 bleaching event was more intensive and extensive in shallow water reef habitats (< 10 m) compared to the 1998 event, which started in the deep areas of the reefs (> 15 m) before affecting the shallow habitats. Coral colonies on the other hand, showed a highly variable pattern of coloration loss, from white and pale blotches irregularly distributed over the colony surface to uniformly paling all over the colony. It was significantly less intensive (with very few colonies bleaching totally) in deeper waters this time around. This pattern was different from that of 1998, when a high proportion of colonies went completely white all over the depth gradient of the reefs, from shallow to deep reef habitats. The 2003 event also affected a wider range of taxa compared with the 1998 event. These included scleractinian corals, octocorals, hydrocorals, other hydrozoans, anemones, zoanthids, and even some sponges. Shallow, near-to-shore reefs were more affected (an average of 20.2% of all coral colonies bleached) than mid-shelf fringing reefs (13% of all coral colonies bleached), and deep, offshore (> 7 km from coast) bank reefs at the edge of the insular platform (7.3% of all colonies bleached). This same trend was observed for hydrocorals with an average 36.5% colonies bleached in near shore shallow reefs compared with 26.7% and 27.0% for mid-shelf fringing reefs and deep offshore bank reefs, octocorals (5.5% and 5% of bleached colonies in near-shore and mid-shelf reefs compared with 1.1% bleached colonies in deep bank reefs) and zoanthids (37.3% in near shore reefs 31.8% in mid-shelf reefs and 1.85%

of colonies bleached in deep bank reefs). Of the 386 colonies tagged in 1998, 17 have been affected by diseases in the last years. Only 2% of the deep-water colonies bleached all the way to a white patterns, 155 were pale and the rest showed no signs of bleaching. Only 5% of shallow water colonies showed intensive bleaching pattern (white blotches and extensive paling areas), however, the great majority (95%) of the tagged colonies (mostly *Montastraea faveolata and M. annularis, Colpophyllia natans, Acropora palmata, Siderastrea siderea, Stephanocoenia intersepta, Diploria strigosa and D. labyrinthyformis*) were slightly pale all over or showed few pale areas over the colony compared to other nearby colonies that did not bleached in 1998. Overall the event lasted a short period of time compared to the 1998. This is probably related to the late onset of the event and the drop in water temperature soon after it started (from Ernesto Weil**,** eweil@caribe.net).

In early November 2003, pale corals were observed along the south coast of Jamaica, including the Portland Bight area. Rackham's Cay and Drunkenman's Cay displayed widespread bleaching in shallow (3-5 m) water (*M. annularis* appeared worst affected along with *M. faveolata*, *Colpophyllia natans*, *Porites porites* and the zoanthid *Palythoa caribaeorum*). Additional species seen to be bleached at Portland Bight included the gorgonians *Erythropodium caribaeorum* and *Plexaurella* sp. In early 2004, bleaching at Rackhams Cay was still widespread, but corals appeared to be recovering. Some *M. annularis* colonies had small dead patches, probably resulting from the severe bleaching. By April, bleaching had almost completely gone, but there were many small dead patches on some coral heads. Hot-spot maps confirmed the presence of abnormally warm water at the south coast of Jamaica during October 2003. This period was also notable as having been unusually calm, clear water (from George Warner, george.warner@uwimona.edu.jm).

There was no large scale bleaching observed in Florida during 2004 but minor and moderate evidence of bleaching was seen in the lower Florida Keys and Tortugas areas, mostly of *Millepora complanata*. The hurricanes which struck Florida this year, possibly decreased the chances for coral bleaching by cooling the water via cloud cover and heavy rain fall. However, quantitative data from the resultant physical damage caused by the hurricanes high winds and storm surge are still being acquired and processed (from Walt Jaap, Walt.Jaap@MyFWC.com). In St. Croix, US Virgin Islands, variable bleaching was noted across a variety of depths (0-25 m) in 2002-2004 with some sites containing no bleached colonies while others had up to 30% of colonies showing bleaching symptoms. Similar surveys at St.Thomas, US Virgin Islands in 2003 and 2004 found more severe bleaching with some corals bleaching at over 40 m depth (from Steve Herzlieb, sherzli@uvi.edu).

Mesoamerica

Bleaching in 1998: The coral reefs from the Yucatan, Mexico to Honduras suffered severe damage from two major disturbances in 1998. First there was severe coral bleaching which was followed soon after by the major hurricane 'Mitch'. This double impact destroyed many corals with some losses up to 75% in Belize. Overall there has been a 50% reduction in live coral cover in Belize between 1997 and 1999, and cover has remained relatively stable at that level with slow recovery in progress.

Bleaching from 1999-2004: In June and August 2004 at several sites in Belize, there was bleaching of *Acropora* but not other species. This bleaching was to low numbers of *Acropora* in Glovers following Hurricane Mitch in 1998 and other bleaching events (from Brie Cokos, bcokos@rsmas.miami.edu).

Eastern Caribbean
Bleaching in 1998: Like other parts of the wider Caribbean region, there was moderate to severe coral bleaching in 1998, but generally there were low levels of mortality. At one site on Barbados, approximately 20% of bleached corals did not survive, but there were complicating pollution factors. Most reefs are showing signs of recovery from hurricanes, and sediment and bleaching damage from the previous 10 years.

Bleaching from 1999-2004: There has been regrowth of *Acropora palmata* and *A. cervicornis* in small patches on the reefs where they had been completely killed in the 1998 event on San Salvador, Bahamas. These are growing quickly, although some have white band disease Type II that infected the original colonies at the time of the bleaching. The regrowth is a mix of recovery of old colonies but mostly new recruits. The bleaching event in 1998 event killed all the *Acropora cervicornis* most of the *A. palmata* on their monitoring transects, along with about 20% of the *Montastraea* spp. The monitoring shows no regrowth of *A. cervicornis* on the transects, but it is growing elsewhere, illustrating the need for broader surveys at the same time (from Tom McGrath, mcgratta@corning-cc.edu).

Southern Tropical America
Bleaching in 1998: Bleaching appears to have increased in frequency, but not in severity throughout the 1990s. Mild bleaching occurred throughout the region in 1998 although coral mortality was insignificant.

Bleaching from 1999-2004: There was predominantly slight coral bleaching during the major 1997-98 El Niño throughout the region and minimal mortality. The exception was in the North Bahia and the Abrolhos region, Brazil where there was up to 80% of corals bleached, but nearly all the corals recovered after 6 months. The major damage to these reefs from bleaching occurred in the 1980s and early 90s. Recovery is slow as the reefs are under a wide range of anthropogenic pressures.

Coral and other Diseases

There has been a worldwide increase in reports of diseases of marine organisms including fish, sea urchins, shellfish, sponges, marine mammals, and especially corals. Since the 1990s, coral diseases have increased in number, affected species, and geographic range, with diseases affecting over 150 species from the Caribbean and Indo-Pacific alone. The rate of discovery of new diseases has also increased considerably, with more than 29 coral diseases now described. Coral diseases can potentially produce severe population declines, threaten biodiversity, and shift the structure of reef communities by challenging the resilience of these systems. This has been emphasised in the wider Caribbean when several outbreaks of coral diseases resulted in massive losses in corals, particularly the dominant reef builders the *Acropora* species in 1970s and 90s.

Although coral disease is emerging as a major threat to Caribbean coral reef health, we currently know very little about the ecology or pathology of coral disease on Indo-Pacific reefs, despite the region encompassing more than 80% of reefs worldwide. The relatively few reports of coral disease from Indo-Pacific reefs suggest that either disease is genuinely more prevalent in the Caribbean or a lack of research in other regions is underestimating influence and severity. The rising incidence of marine diseases worldwide in the past few decades emphasises the need for increased assessment of the status of disease in order to identify the origins and reservoirs of pathogens and the vectors involved in disease transmission (from Bette Willis, bette.willis@jcu.edu.au).

Stress appears to lower a coral's resistance to disease and thus affects its ability to survive. Because elevated temperature is a coral stress, increasing predictions of global climate change (Box p 72) may also result in increasing incidence of coral disease. It is possible that proximity to human population centres may increase the likelihood of infection. Disease outbreaks are nearly impossible to manage because the connectivity of the marine environment increases the speed of disease transmission and renders standard response such as quarantine and vaccines ineffective. Preventing nutrient runoff into coastal areas by managing water quality could be an important measure and the relationship between increased nutrients and disease severity should be viewed as a top priority for ecologists and resource managers.

Now that there are many reports of diseases found in coral reefs around the world, 2 questions need to be asked: Are there now more reports of disease because more people are looking for such incidences and are there actually more incidences of disease in many parts of the coral reef world? The answer to these questions is probably yes as the reports below indicate.

Coral Disease in the Indian Ocean

There has been a worldwide increase in the reports of diseases affecting marine organisms however our ability to fully understand recent disease outbreaks is hampered by the paucity of baseline and epidemiological information on the normal disease levels in the ocean. The Indo-Pacific region has a much greater species richness than the Caribbean yet the number of species affected by disease is proportionally much lower. The coral reefs of the wider Caribbean have experienced major levels of disease to corals and other organisms for many decades, whereas there have been few reports of coral disease in the Indo-Pacific region – until recently. New research, combined with recent surveys and observations, indicates that infectious pathogens may be a common component of Indo-Pacific reef communities and may have a greater role in structuring coral communities in the region than previously thought.

Surveys in the Central Visayas and Lingayen Gulf, Philippines showed that 8.3% of coral colonies were affected by 1 of 3 diseases on *Porites* species: *Porites* Ulcerative White Spot Disease; an undescribed neoplasia; and 'Pigmentation Response' (previously 'Pink Line Disease'). The long-term consequences are not known but *Porites* are major reef builders on Indo-Pacific reefs. No signs of the previously recorded Black Band Disease and White Band Disease were observed (from Laurie Raymundo, lraymundo@guam.uog.edu).

The first incidence of Yellow-Band Disease in the northern Persian Gulf was observed around Farur Island in 2000 at a moderate level (<5%) in depths from 6 to 12 m. This disease has been previously reported from the Southern Persian Gulf and Gulf of Oman (from Mohammad Reza Shokri Bousjein, mohammad.shokri@studentmail.newcastle.edu.au).

Although rapid surveys of a number diseases identify general trends, more detailed surveys are needed to accurately estimate the impact of disease on coral populations. A key objective will be to determine rates of mortality caused by disease and to put them into context with mortality caused by other disturbance agents on Indo-Pacific reefs, such as bleaching events, cyclones and *Acanthaster planci* outbreaks. It will be equally important to determine rates of disease spread and tissue loss within colonies and their associated impacts on colony fecundity and growth, to fully understand the impact of diseases on coral populations.

ISRS STATEMENT ON DISEASES ON CORAL REEFS

Diseases of corals and other organisms have caused significant damage to the structure and appearance of coral reefs, at similar scales to coral bleaching and plagues of the crown-of-thorns starfish. Marine diseases are natural processes, but have been poorly studied because they are often ephemeral and rarely observed until much too late. The International Society for Reef Studies and a group of experts compiled a consensus statement of current knowledge. They concluded that disease epidemics pose serious threats to the health of coral reefs worldwide and that human activity is at least partially responsible for recent disease outbreaks following the identification of many of the responsible pathogens. Two diseases have had major impacts on Caribbean reefs: in 1983-84 a disease (possibly arriving in ship ballast water near the Panama Canal) was carried by currents throughout the Caribbean killing more than 95% of the long-spined sea urchin, *Diadema antillarum* and White-band disease inflicted enormous losses on the major reef builders, the staghorn and elkhorn corals (*Acropora cervicornis* and *Acropora palmata*) throughout the Caribbean in the 1980s and 1990s. The effects still remain and the urchin populations have not recovered. There is no evidence of similar diseases in the fossil record for several thousand years on recently devastated reefs.

Ecological studies on coral reefs suggest that the incidence of disease has risen recently. However, there is very little historical information and this conclusion cannot be confirmed as real or a reflection of more research activity. There are 4 to 6 confirmed coral diseases in the Caribbean, possibly up to 15, with bacteria, fungi, and cyanobacteria ('blue-green algae') the known causal agents. A fungal disease of gorgonians (sea fans) probably came with sediment runoff from the land as a result of human activity. This is one example why marine scientists suspect that human stresses, such as pollution and changing patterns of land use, have promoted the spread of white-band disease in Florida and the Caribbean. Stress may compromise disease resistance, allowing infections to take hold and new diseases to emerge. Reliable information states that black-band disease and 'plague type II' are caused either by a single bacterium or a consortium of bacteria (including cyanobacteria) and these attack mostly the massive brain and star corals. Now diseases are killing corals on Pacific, Indian, and Atlantic Ocean reefs. It is probable that stressed and bleached corals because of high sea temperatures are more susceptible to disease. For example, black-band disease and white-band disease have now been identified throughout the tropical Indo-Pacific, including the Red Sea, Mauritius, the Philippines, Papua New Guinea, and the Great Barrier Reef of Australia. The newly discovered yellow-band disease is affecting up to 75 percent of the coral colonies in parts of the Arabian/Persian Gulf. The rate of reef construction will be less if corals are affected by disease and reduce their capacity to act as shoreline protectors and keep up with sea-level rise. Damaged reefs will also provide fewer resources, especially fish and other seafood. Improved studies of coral diseases and associated impacts are required to assist in the management reduce threats to coral reefs. The full text is available at: www.fit.edu/isrs/council/disease.htm.

Coral disease in the Pacific Ocean

Recently, significant attention has been paid to the study of coral disease in the Pacific Ocean, resulting in emerging information on the identification, characterization and distribution of diseases. As more studies are conducted on Pacific reefs, a clearer picture of what diseases exist and the mechanisms of dispersal across the Pacific should develop. Future work should seek to compare types, distribution and prevalence of coral disease in the Pacific Ocean with coral reefs from other ocean regions.

Coral populations in the Hawaiian Archipelago continue to be spared from epidemic disease outbreaks unlike many other corals reefs around the world. Surveys at 18 sites around Oahu show an average prevalence of disease (# diseased colonies/total # colonies) at less than 1% although differences in disease prevalence were found between coral genera. *Porites* sp. had the highest prevalence of disease and the most common was growth anomalies or 'tumours'. Similar anomalies have not been documented in the Northwestern Hawaiian Islands (NWHI) despite extensive coral disease surveys. The cause of *Porites* tumours is unknown but the occurrence of tumours is positively correlated with colony size (a broadly generalized proxy for colony age).

Another common disease found in the main and NWHI is *Porites* trematodiasis, caused by the larval stage of the digenetic trematode *Podocotyloides stenometra* and characterised by pink, swollen nodules. The greatest abundance of infected coral has been found on the reefs in Kaneohe Bay on the windward side of Oahu where infected corals have been found in all reef zones and have persisted on the reefs since the 1970s. Trematode infection can cause reductions in coral growth of up to 50%. General coral necroses also commonly occur on Hawaiian reefs and can follow only three outcomes:

- complete recovery;
- successional change from turf to crustose coralline algae on which new coral recruits become established; or
- persistence of the turf community with a net loss of coral cover.

The Northwestern Hawaiian Islands are considered to be one of the last relatively pristine large coral reef ecosystems remaining in the world. There has been historically little research done to capitalise on the unique opportunity to document normal disease levels in a coral reef system exposed to limited human influence.

During a multi-agency research survey conducted in 2002, disease investigation was incorporated into the protocol and a characterization of coral disease was initiated. In July 2003, surveys were conducted at 73 sites throughout the NWHI to quantify and characterise coral disease occurrence. Low levels of coral disease was found at 68.5% of the sites throughout all regions and the most common disease was *Porites* trematodiasis which was found at 57.5% of the sites exclusively affecting *Porites* sp. Numerous other conditions were observed at much lower frequency of occurrence (1.4% - 16.4% of the sites). The overall average prevalence of disease was approximately 0.5% (range 0-7.1%) yet a disease outbreak at one site at French Frigate Shoals resulted in massive tissue loss on large acroporid table corals. Differences in types of conditions and prevalence of disease were found among coral genera. Pocilloporids, which are one of the most common types of corals found on the reefs of the NWHI, appear comparatively resistant to disease as only a single diseased colony found out of over 6000 colonies that were searched (prevalence=0.016%). In contrast, acroporids make up less than 5% of the coral community yet showed the greatest damage due to disease and the highest prevalence of disease (prevalence=2.7%). Although no major die-off of corals has ever been documented due to disease in Hawai'i increasing human usage and the impacts of global climate change are raising concern about the health of Hawaiian reefs. Plans are currently underway to extend base-line disease surveys out to the other main Hawaiian Islands and the Hawaii State Division of Aquatic Resources will also be integrating coral disease assessment in their monitoring program.

In 2004, surveys were conducted at 12 sites at Johnston Atoll to quantify and characterise coral disease. Due to harsh weather conditions surveys were limited to sites within the lagoon. Signs of coral disease were evident at 92% of the sites surveyed. The average prevalence of disease (# diseased colonies/total # colonies) was estimated at 3.1%, which is higher than what has been reported for the Northwestern Hawaiian Islands (avg. estimated prevalence=0.5%). Types of diseases included growth anomalies on *Acropora* and *Montipora*, white syndrome on the table coral, *Acropora cytherea*, distinct patches of tissue loss on *Montipora patula* and *M. capitata* and Pacific Montiporid ring syndrome with affected corals having abnormal growths with many having tissue death in the centre producing a ring-like lesions. Similar disease signs during a qualitative assessment of coral disease in 2001 (from Greta Aeby, greta@hawaii.edu).

Until recently, it has been assumed that disease has had little impact on the population dynamics or community structure of coral assemblages on the Great Barrier Reef (GBR). However, the presence of a number of pathogens on the Great Barrier Reef that have had major impacts on other coral communities around the Caribbean such as black band disease and one or more of the diseases within the white syndrome category, emphasises the severity of the threat posed by predicted environmental changes. Surveys of disease prevalence on reefs representative of the major habitats and community types throughout the GBR are required in order to document the full range of pathogens and to establish a baseline to judge whether disease incidence is increasing.

Research is now also underway to document coral disease in Japan however there have been neither quantitative surveys for coral disease nor any studies examining disease outbreaks associated with water quality. The primary objective being to document the baseline levels of disease in the major genera of corals in Japanese waters.

Minimal signs of coral disease were found at 11 sites during surveys around Tutuila, American Samoa in 2004. The most common diseases were Acroporid White Syndrome (prevalence ranging from 0-1.1%), Acroporid growth anomalies (prevalence ranging from 0-5.3%), Montiporid White Syndrome (prevalence ranging from 0-1.9%) and Montiporid growth anomalies (prevalence ranging from 0-0.97%). Coralline Lethal Orange Disease was found at 45% of the sites and the number of infections ranged from 0-33 CLODs/site (From Greta Aeby, greta@hawaii.edu).

A fatal epizootic to tabulate *Acropora* (as well as some non-tabulate species such as *A. gemminifera*) is progressing along the south ocean shore of Majuro, Marshall Islands. The disease was quite common among the smallest *Acropora sp.* on the coral platform (4-6 m) on the far eastern end of Arno (south ocean shore). The disease is characterised by a white band ranging from mm to cm in width (depending on spread rate) sweeping across the colony, preferentially along the edge. Typical spreading at 2-6 cm/day the disease involves *Acropora* from 2 m to 15 m depth. Densities of actively diseased tables are typically 100-200/ km of coast and as of mid 2004 densities of diseased killed corals are 1000-2000 colonies/km. The disease progression lasts approximately 20-30 days for small colonies, up to 9 months for a 2 m colony, sometimes spreading between adjacent colonies, but most affected colonies are solitary and seemingly randomly distributed, although disease clusters of 5 or more adjacent colonies are encountered. Highest incidence rates are at the west and east ends of Majuro. A low incidence of disease is found in sparsely-populated Woja and Kalalen pass along the northern margin of the atoll. Other notable diseases include the fatal "green band" disease infecting *Platygyra sinensis* and CLOD, which is found at Delap Point (from Dean Jacobson, atolldino@yahoo.com)

Coral Disease in the Atlantic Ocean

For some reason, the Caribbean appears to have experienced a far higher incidence of disease to coral reef organisms than reefs of the Indo-Pacific (at least 82% of Caribbean coral species are susceptible to disease, compared to 25% of Indo-Pacific corals). Several hypotheses have emerged: the Caribbean is semi-enclosed such that the reefs are in relatively close contact due to the gyres of water; there are higher concentrations of nutrients and possibly pollutants because of these gyres that circulate large volumes of waters flowing in from major rivers e.g. Amazon and Mississippi; and the reefs have been isolated from the others for millions of years. The region also has a higher population of scientists regularly monitoring the reefs for problems. These remain fundamental questions for researchers to address in coming years.

In the 1930s, there was a major disease outbreak that devastated the sponge industry. This seems to have been repeated in the 1990s when commercial sponges to the west of Florida were virtually eliminated. But the most dramatic and devastating diseases have been to corals, gorgonians and to sea urchins.

Populations of the sea urchin, *Diadema antillarum* were virtually obliterated when a disease killed over 95% of them throughout the Caribbean during 1983-84. This emphasised a major difference between coral reefs in the Caribbean, where urchins are the major grazers on algae, and elsewhere where the major grazers are fishes. These urchins had been so prolific that the numbers reached as many as 6 per square metre – until the die off. The disease that killed these urchins probably originated near the Caribbean entrance to the Panama Canal and spread to the southeast and north from this point. The major impact on the reefs, however, was a massive explosion in fleshy algae causing many corals to be smothered. Thus this disease outbreak had far reaching consequences which are still evident in 2004; 20 years after the death of the urchins and the populations have only recovered to about 4% of their original status and the coral cover is still depleted.

Stress is often associated with increased susceptibility to disease and many studies have suggested a correlation between elevated sea temperatures, sedimentation, and pollution. Of the 18 coral diseases described to date, 4 are reported globally, 9 are found only in the Caribbean, and 6 appear to be found only in the Indo-Pacific. Increases in the number of new diseases and affected species may be linked directly to human-induced alterations in coral reef environments both in terms of land-based sources of pollution as well as global climate change issues such as global warming. Increasing ocean temperatures may play a significant role in coral disease as pathogen growth and virulence increases with temperature while at the same time coral immune response decreases. Nutrient and sediment loading may deliver disease organisms to the marine environment (from Jim Porter, jporter@uga.edu).

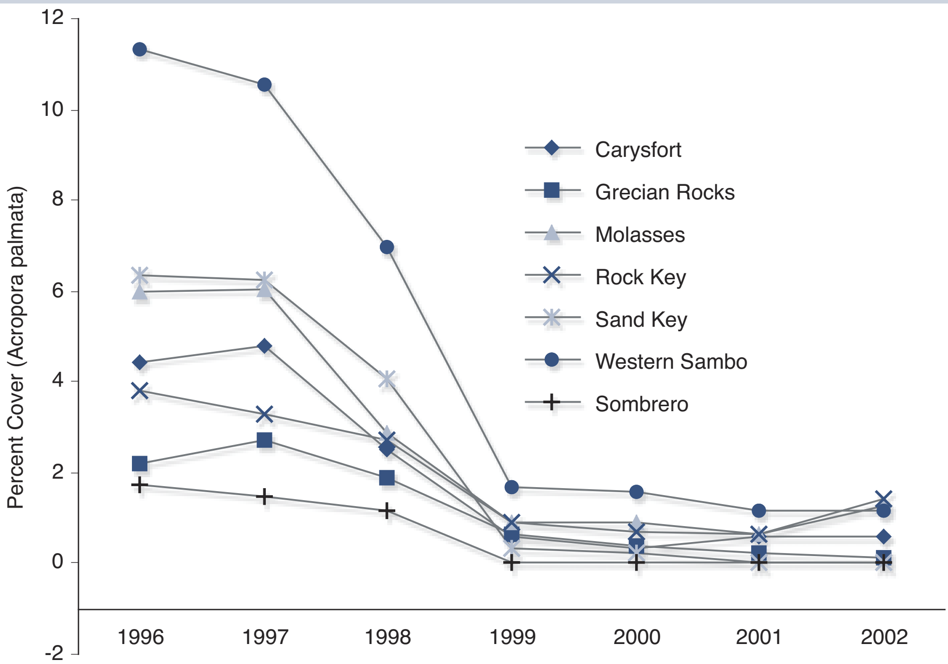
In the Caribbean, populations of elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) corals are being devastated by disease. Within the Florida Keys National Marine Sanctuary from 1996-2004, the number of stations exhibiting disease increased 404% and the number of species exhibiting disease increased 218%. These increases correspond to a 37% decline in coral cover at the same stations during the same time.

Field experiments have shown that increased nutrient levels can significantly increase the severity of 2 important Caribbean diseases: aspergillosis of the common gorgonian sea fan and yellow band disease of some reef-building corals. Researchers hypothesize that the additional nutrients increase pathogen fitness and virulence, leading to increasing intensity and frequency of disease outbreaks. Nutrient enrichment can occur at many scales (metres to kilometres) and is influenced by human activities including agricultural runoff and increased reliance on fertilizers as well as many natural processes including upwelling and internal tidal bores. Researchers hypothesize that pristine reefs may eventually experience nutrient enrichment and mortality as a result of increasing human activities and development. Scientists have already observed a high prevalence of Dark Spot Syndrome on *Siderastrea siderea* at 5 "pristine" reefs near Lee Stocking Island, Exuma Cays, Bahamas. Reefs in Belize and Puerto Rico are showing similar patterns with 39% disease prevalence among *S. siderea* at Ambergris Cay on the northern part of the Belize barrier reef and 29% on the central barrier reef at Southwater Cay. In Puerto Rico, there is also a high prevalence of Dark Spot Syndrome prevalence with 46% at La Parguera, 65% at Aquadilla, 70% at Cabo Rojo, and 40% at Culebra (from Deb Gochfield). White plague disease has also been observed in the region along the islands of San Andres and Old Providence (Western Caribbean, Colombia). The incidence of disease has increased in both islands, but the species affected vary with brain corals (genera *Diploria* and *Colpophyllia*) seeming to be the most affected at San Andres and *Montastraea annularis* and *M. faveolata* most distressed in Old Providence. Approximately 20% of the coral cover has been killed by the disease at San Andres yet the extent of mortality in San Andres is around 10% (from Valeria Pizarro).

Disease is changing the composition, structure, and function of the Florida Keys coral reef ecosystems. In extensive surveys from Key Largo to Key West in 160 stations at 40 sites, there has been an enormous increase in the number of locations affected, the number of species affected, and the rate of coral mortality. The disease outbreaks are having community-wide effects as common corals are becoming rarer and rare corals may be becoming locally extinct. The future of certain coral reef sites may be in jeopardy as predictions of coral disease becoming more common and more widespread over the next quarter century become increasingly more believable. It is uncertain whether these diseases are the expression of an episodic pathogen with short term ramifications or a widespread pandemic with long-term ramifications. Research and monitoring is absolutely critical to discern which of these alternative ecosystem-wide processes is at work (from Jim Porter, jporter@uga.edu).

WHITE POX DISEASE RAVAGES CARIBBEAN CORAL

Within the Caribbean, populations of the once most common reef-building coral, *Acropora palmata*, are being decimated, with losses of living cover in the Florida Keys averaging 87%. Severe population declines of *A. palmata* in Florida and elsewhere in the Caribbean have led to the identification of this species as a candidate for protection under the Endangered Species Act (Box p 15). The majority of recent losses of elkhorn coral in the Florida Keys are associated with white pox disease. The disease was first documented in 1996 on reefs near Key West and has since been reported Caribbean-wide. In Florida, signs of active white pox disease were observed at Eastern Dry Rocks Reef every year between 1996 and 2000 and at each of the other 7 monitored reefs with living cover of *A. palmata* every year between 1997 and 2002. Observations of white band disease were rare at monitored reefs in the Florida Keys between 1996 and 2002. The Gram-negative faecal enteric bacterium, *Serratia marcescens,* is the cause of white pox (also known as acroporid serratiosis). The bacterium is pathogenic yet commonly occurs in the intestines of humans and other animals and in freshwater and soil. While *S. marcescens* is considered to be ubiquitous in terrestrial and freshwater environments, the distribution and prevalence of this bacterium in the marine environment is unknown and the source of the strain that causes white pox is uncertain. The coral pathogen may originate from an environmental source or from human sewage. Investigations are currently underway to determine the environmental prevalence and ecology of *S. marcescens* in offshore tropical and coral reef environments and to elucidate a source of the coral pathogen in the Florida Keys (from Kathryn Patterson Sutherland, kathrynp@uga.edu, and James Porter).



Predator Plagues

Predator plagues such as COTS are increasingly reported around areas of human activities with 2 strong hypotheses advanced:

- the plagues may be initiated and certainly exacerbated by either over-fishing of key starfish predators, and/or
- increases in nutrient runoff from the land favours the planktonic stages of the starfish.

The increasing frequency of COTS outbreaks continues despite decades of scientific study in the Pacific and Australasia and the cause of these plagues remains unclear. The negative effects of COTS are exacerbated by many other impacts including pollution, fishing pressures, sedimentation, river runoff, global climate change and associated coral bleaching events. These synergistic pressures lead to widespread, large-scale losses of coral cover and biodiversity, which may ultimately affect the biological and ecological processes of the ecosystem.

The highest densities of COTS in recent years have been on coral reefs in Tanzania and Kenya. Initial reports suggest that the northern area of Bawe was destroyed by COTS within 8 months and that COTS is also rampant around Pange. COTS aggregations of 10-30 individuals per 10 m^2 were reported in the Songo Songo Archipelago in 2004 and further aggregations were seen around Unguja Island (Zanzibar), Pemba, Mafia Island, Dar es Salaam, Tanga, and an isolated reef near St. Lucia, South Africa. COTS have increased one hundred-fold from initial densities of approximately 10 per 1,000 m^2 in 2003 to densities of 10 per 10 m^2 in 2004 in the largest population observed in western Zanzibar in the last seven years. Dive operators have organised some removal efforts yet localised damage exceeds 50% coral mortality with unknown wider implications. Unfortunately, 2004 has also marked the first observation of COTS around the Marine Protected Area of Chumbe Island Coral Park (Box p 185) (from Carol Daniels).

Southeast Asia has experienced COTS outbreaks around North Sulawesi (Bunaken NP and adjacent waters) in 2003 and in central Vietnam in 2002. Loss of coral cover and community structure is occurring in Bunaken NP, and is presently subject to control by NSWA (see box below). Teams of MPA staff, village hookah divers, and local tourist dive operators were quick to respond and collected large numbers of sub-adults and adults in both parks. In Permuteran Bay, Bali, there is conspicuous damage on both natural and artificial reefs from COTS and *Drupella*, which are approaching plague densities but are not conspicuously aggregated. Daily removal of these organisms has been very effective and has prevented further damage (from Jim Porter, jporter@uga.edu).

In the Marshall Islands, COTS have been found in densities exceeding 20 per 100 m^2 with estimates of lagoon populations of 1000/km and some regions showing over 75% coral mortality. A major COTS outbreak is also in progress on Jaluit, opposite the population center of Jabwot with few COTS found on Arno.

Recent outbreaks in Micronesia have resulted in COTS densities up to 10,000/ km of shore, mostly in shallow lagoons dominated by *Acropora*. Local fishermen have also reported outbreaks around Laura, Kalelin, and Woja. A major outbreak of COTS on the GBR is discussed in Chapter 11.

There is an indication of *Diadema* sp. outbreaks in some areas around Nacula Island in the northern part of the Yasawa Islands, Fiji. High numbers of sea urchins (mainly long spine) may potentially be a result of high artisanal fishing pressure.

Invasive Species

Invasions of non-native species in marine ecosystems can be ecologically damaging as well as economically costly should they become established into their new habitats. Although invasive species introductions have been documented on coral reefs, there have been no incidences of deleterious effects or other significant negative impacts on ecosystem processes or biodiversity. The most likely causes of invasive species introductions are:

- the necessary ballast-water exchange for cargo ships traveling long distances between ports releasing gametes, larvae, or juvenile individuals into new systems; and
- aquaria related incidents whereby individuals import specimens from all over the world and release them into the wild after a time in captivity (Box p 37).

With increasing global trade and exportation of marine aquaria species around the world, caution must be taken in coming years to monitor these introductions and to act as soon as they are observed in order to prevent economic and environmental consequences similar to those documented in freshwater and terrestrial systems. Prevention is undoubtedly the best management strategy and anticipation of further releases and subsequent invasions resulting from marine aquarists and the aquarium industry requires education, community outreach, and enforcement efforts. One potentially useful solution involves identification of 'hot-spots' of non-native species and their sources of introduction which can maximize the effectiveness of invasion quarantine programs.

Since Indo-Pacific live rock is exported widely and there are live reef tank enthusiasts at low as well as high latitudes, the risk of introduction of Pacific organisms to the tropical Atlantic is high. If fishes can do it, and they have, certainly invertebrates can.

Coral reefs on the islands of Kaua'i, Moloka'i, Maui, Hawai'i and O'ahu were surveyed for the presence and impact of invasive algae, invertebrate, and fish species along 41 sites. Only 26 invasives comprised of 3 species of algae, 19 invertebrates, and 4 fishes were recorded from a total of 486 total taxa. However, the invasive Orange Keyhole Sponge (*Mycale armata*) and Snowflake Octocoral (*Carijoa riisei*) appear to be increasing in both abundance and distribution on some coral reefs. *C. riisei* is overgrowing and seriously impacting Black Corals in the Maui Lanai Channel, causing the mortality of large, sexually mature colonies that are believed to be critical for maintaining reproduction and replenishment of harvestable Black Coral at shallower depths. This expansion requires monitoring and research effort to obtain basic biological and ecological information that may be utilized by management and conservation groups to assist in controlling their proliferation.

Surveys around American Samoa found 28 non-indigenous species (NIS), considerably fewer than have been determined on harbour surveys in Hawai'i or Guam but more than found at each of 4 North Queensland ports. A maximum of 17 NIS occurred at the main dock, comprising about 10% of the total biota identified at the site, and 5 NIS, or 5% of the total biota, were found at the drydock station. Introduced species were found at other sites in the region including Utulei, Onesosopo, Aua, and Leloaloa. By comparison, relatively few introduced species have

PROACTIVE AND REACTIVE MANAGEMENT:VOLUNTARY MAINTENANCE OF CROWN-OF-THORNS STARFISH (COTS) OUTBREAK IN NORTH SULAWESI, 2003

A voluntary COTS removal effort began immediately after the discovery of a population outbreak in late 2003 on a fringing reef at Mokupa area (Pasir Panjang), south of Manado. The Bunaken MPA Authority and surrounding areas joined the control program on the fringing reef, ultimately collecting more than 500 COTS (mostly small adults although some large individuals (>40 cm) were present) from several ha of reef slope. With spawning expected to occur during the full moon periods in the following months, more COTS outbreaks were discovered at a further 26 dive sites, mostly on the islands of Bunaken National Park. Large female COTS can produce millions of eggs, and when aggregated in outbreak densities, high fertilization rates are common. Thus timing of the control program was particularly important: if the COTS were to reproduce there was great potential to overwhelm the Park and damage the coral reefs. To date, a concerted effort by multiple parties has removed more than 2,700 COTS. The prevention of future outbreaks has limited the damage to popular dive sites (e.g. Lekuan I - III where more than 500 COTS have been collected) and reduced the COTS reproductive output (as COTS were removed prior to annual spawning).

Managing coral reefs is a major challenge for present and future human generations. It is inconceivable that local control programs will cause any change in the COTS overall population abundance globally. However, local controls may help to protect crucially important reservoirs of reef biodiversity, such as those in Bunaken NP, and also local people reliant on reef production and tourism. In this regard local villagers should be actively encouraged to participate in such proactive management projects and to develop a sense of stewardship for their local reefs. In places such as Bunaken NP, one of the most strategic MPAs on earth, it is crucially important to protect the good coral areas for their rich biodiversity, ecological function, and economic value to locals and tourism. In so doing, a high marine tourism capacity can be maintained sustainably.

been propagated in the waters of Tutuila, and those that do occur are mostly restricted to inner portions of Pago Pago Harbor and are not invasive in coral reef areas either within or outside of the harbour. A program of periodic rapid assessment and monitoring should be implemented to ensure that potentially invasive introduced organism that may arrive in the future can be detected and intercepted in their early stages of propagation and spread. A further recommendation is to implement a program to inspect the hulls of large craft such as barges moving between harbours and islands that may transport introduced organisms already occurring in Pago Pago Harbor.

Although results indicate introduced marine invertebrates have not seriously impacted Hawaiian or American Samoan coral reefs under most circumstances, it is important to remember that negative impacts can occur unpredictably and rapidly. Introductions of exotic species should

INDO-PACIFIC MUSHROOM CORALS FOUND ON JAMAICAN REEFS

Researchers recently documented the reappearance of an exotic coral on a Caribbean reef, 37 years after it was originally introduced. While diving on the fore-reef of Discovery Bay, Jamaica (15 m depth) in 2003, 2 individuals of the mushroom coral *Fungia scutaria* were discovered. These free-living corals (11 and 14 cm in length and each contained an extratentacular bud), which comprise a single large polyp are naturally distributed across the western Indo-Pacific. The impact of non-native, or "exotic" species, is considered to be a leading cause of native species extinction and overall habitat degradation. This threat is well documented in many ecosystems, but the presence and effects of exotic species on tropical coral reefs are rarely considered.

F. scutaria was brought to Jamaica from Eilat, Israel in 1966 by Thomas F. Goreau, founder of the Discovery Bay Marine Laboratory. He used the fore-reef at Discovery Bay as a "holding tank" for specimens that were eventually used in laboratory experiments. However he died unexpectedly in 1970 and some experimental subjects must have remained on the reef because researchers found and removed a group of 12 individuals there in 1980. Recent surveys show this removal did not eradicate the species from Discovery Bay and amazingly, it has survived 2 of the most damaging hurricanes in Jamaican history, the collapse of the native coral populations, and the subsequent domination of the reef by macroalgae. It is interesting to note that these specimens have been overlooked for more than 20 years on one of the best-studied coral reefs in the world. Although the impact of *F. scutaria* on native species has probably been minimal, the fact that it has survived in this new environment should be viewed as an ominous warning of potential future invasions by other tropical marine species (from John F. Bruno, jbruno@unc.edu).

in all cases be discouraged. Of course, the impact of introduced algae on Hawaiian nearshore reefs has been far more extensive, serious and well documented (from Steve Coles).

A surprising number of non-native fishes have been surveyed on the reefs of Florida, USA; mostly the result of aquarium releases. The presence of 16 non-native marine fish species off the southeastern USA should spur researchers and managers to take several actions. The density and reproductive status of each exotic species must be determined. If the problem is restricted to a few isolated adults, it may be possible to remove all or most of the individuals and prevent the establishment of a viable population (from Brice Semmens, semmens@u.washington.edu). Elsewhere in the region, the Indo-Pacific lionfish (*Pterois volitans*) has been observed with increasing regularity on Bermuda coral reefs since 2000. Approximately 20 individuals, including both juveniles and adults, have been observed in shallow waters, with some of these individuals being removed from the reef, and in deeper waters (50 - 60 m) with the use of remotely operated vehicle sightings and incidental captures in lobster traps. As a result, the abundance of this species in local waters may be greater than first thought yet the significance of lionfish impact on local fish populations is unknown (from Joanna M. Pitt, jopitt@bbsr.edu).

Tubastraea coccinea is an Indo-Pacific coral species, that until recently had not been found in Florida, but is now often reported on artificial structures such as wrecks and piers. It has recently its range into the Gulf of Mexico and has been discovered on many wrecks and on natural substrate at one location. Monitoring data suggests that the coral has spread along current paths from Puerto Rico and Curacao and then into the Gulf, moving from platform to platform. It took about 60 years to spread throughout the Caribbean and Gulf to Florida, and most likely spreads by current dispersed larvae. *T. coccinea* was recently introduced to Brazil on mobile oil rigs, along with a second species, *Tubastraea taguensis*, and both species are now invading Brazilian reefs. Because it is an invasive, fouling species, it must compete with other organisms for space. There are no reports of any adverse effects to date although future monitoring and research efforts will provide insight.

Management efforts should focus on preventing the initial introduction of invasive marine species into local waters, their transport between regions, and preservation of the integrity of coral reef species richness, especially in semi-enclosed embayments and other areas most likely to be initially colonized by introduced species.

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