8. Status of Coral Reefs of the Lesser Antilles after the 2005 Coral Bleaching Event

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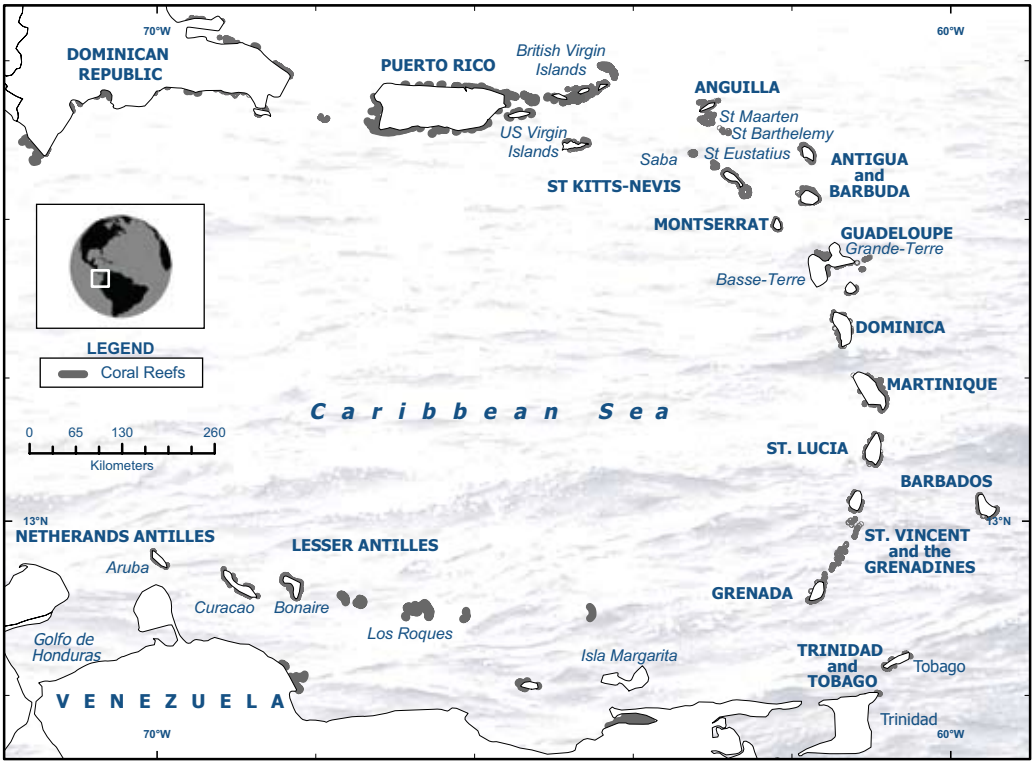
Summary

- During summer 2005, a persistent 'HotSpot' surrounded these islands;
- Coral bleaching and mortality was probably the most severe ever recorded in the Lesser Antilles and was the most extreme for the wider Caribbean during 2005;
- The most severe bleaching event ever recorded at Barbados occurred during September and October 2005, and affected all coral species at all depths, and all reef types and habitats;
- There was between 25% and 52% mortality of corals in the French West Indies, especially at Guadeloupe and Martinique. Bleaching affected most coral species and resulted in reduced larval recruitment in the following 2 seasons. However, there appears to be no effects on fish populations;
- There was extensive bleaching (80%) on the northern Netherlands Antilles islands of St. Maarten, Saba, and St. Eustatius in August 2005; but only minor bleaching and minimal mortality on the southern islands of Bonaire and Curaçao;
- On the island of Tobago, most species bleached, with 66% average cover of bleached coral. Bleaching in *Montastraea annularis* was highly variable; there was 73% bleaching in one stand, but only 6% in another, on Buccoo Reef;
- No hurricanes passed through this region in 2005; this partially explains the severity of bleaching as there were no strong winds to lower seawater temperatures;
- These islands are highly dependent on their coral reefs, thus there is an urgent need for appropriate management responses as sea temperatures are predicted to rise further in future.



Map of the Lesser Antilles region.

The French West Indies

Introduction

The French West Indies (FWI) in the Lesser Antilles lie between 14°20' and 18°00' N and consist of the islands of Martinique, the Guadeloupe Archipelago (with Guadeloupe, La Désirade, Marie-Galante and Les Saintes islands), St. Barthélémy, and the French part of St. Martin/St. Marteen. The population in these islands was 834,000 people in 2004, including about 2500 registered fishers.

Guadeloupe and Martinique are volcanic and mountainous islands, situated roughly in the centre of the West Indies and surrounded by a narrow island shelf that receives high levels of volcanic sediments. Corals grow on the rocky surfaces and form fringing reefs on the eastern sides. These reefs are especially important for tourism; 665,000 tourists visited Guadeloupe in 2005 and 381,000 visited Martinique in 2004. Thus tourism is a major economic contributor in the FWI with hotel capacity of Guadeloupe and Martinique exceeding 13,000 rooms and additional accommodation available in small-scale rural cottages. The most common marine tourist activities are glass-bottom boat tours, kayaking, water skiing, surfing, sailboat rentals, sport fishing and particularly scuba diving. There are 40 scuba diving clubs in Guadeloupe and a similar number in Martinique, with diving focused on the Caribbean (leeward) coasts. For example, about 100,000 divers visit the Îlets Pigeon in Guadeloupe each year.

A mix of fringing and barrier reefs grow on the narrow shelves surrounding Guadeloupe and Martinique. These are similar to reefs growing around high islands in the Eastern Caribbean States with better development on the windward coasts of the islands, but greater biodiversity on the protected leeward coasts. There are 4 marine reserves: 2 in Guadeloupe; 1 each in St. Barthélemy and St. Martin; and 9 no-take zones in Guadeloupe and Martinique.

Saint-Barthélemy and Saint-Martin are the northern-most islands in the FWI, situated on a shallow, sediment covered shoal. Saint-Barthélemy is surrounded by numerous small islands, and Saint-Martin/Sint-Maarten is under French and Dutch control. There are poorly developed fringing reefs and extensive seagrass beds around both islands, and large areas of mangroves have been destroyed by land reclamation.

Status of Coral Reefs Prior to 2005

There is very clear evidence of coastal ecosystem degradation throughout the FWI, which has affected coral reefs, seagrass beds and mangroves. Long-term monitoring since 1999 has shown that the coral communities of Guadeloupe and Martinique have been degraded, particularly during the last 7 years, confirming qualitative observations since the early 1980s. High rainfall, deforestation for agriculture, poorly managed coastal development and mangrove clearing have resulted in excessive sediments and nutrients flowing into coastal waters, especially into enclosed bays and lagoons. Elevated nutrient loads from overuse of fertilizers and poor wastewater treatment have fueled the proliferation of algae, particularly *Sargassum* and *Turbinaria* on the exposed outer slopes on the Atlantic coasts, and *Dictyota* on more sheltered areas in lagoons and reefs on the Caribbean coasts. *Turbinaria* and *Sargassum* are highly resistant to waves generated by hurricanes, whereas *Dictyota* is removed by each passing hurricane, although it recolonizes reefs rapidly after storms. Chronic over-fishing has reduced fish stocks, particularly herbivorous fish that control algal communities.

Previous coral bleaching from elevated sea surface temperatures (SST) during El Niño years in 1984 and 1987 was relatively minor. The first significant bleaching occurred in September and October 1998, when the SSTs exceeded 29°C for several weeks. There was extensive bleaching of hard corals, actinarians, zoantharians and gorgonians. Although these reefs suffered some mortality among certain corals, the effects of bleaching in the FWI were relatively small compared with other regions in the Caribbean. Bleaching occurred again in 1999 in Guadeloupe, but the effects of bleaching were obscured by damage caused by Hurricane Lenny. FWI reefs show chronic but minor bleaching almost every year in September when SSTs exceed 29°C for a short period.

The waves generated by hurricanes limit coral reef growth in the Lesser Antilles, and severe hurricanes cause serious damage to coasts every 10 years on average. Direct physical damage to coral reefs occurs to 15 m depth and recovery can take years to decades. Hurricanes are usually accompanied by torrential rains that wash massive quantities of sediments and nutrients onto nearshore reefs, resulting in short-lived algal blooms. Since 1989, there have been 4 hurricanes that have directly damaged the FWI: Hurricane Hugo (1989) hit Guadeloupe; and Saint-Barthélemy and Saint-Martin were damaged by Hurricanes Luis and Marilyn in 1995, and Lenny in 1999, which also caused damage to Guadeloupe.

Guadeloupe: The first signs of reef decline were evident in the 1980s, and by 2000, satellite remote sensing showed that only 15-20% of the marine habitats in Guadeloupe still had healthy coral communities. Coral cover varied from 15-22% on reef flats; and 24-26% on outer slopes before 2005. The proportion of coral colonies showing disease ranged from 23-33%, with the average surface area of dead tissue ranging from 27-32%. Algal turf was the dominant component of the benthic community, but the greatest changes were in the cover of brown macro-algae, which were influenced by nutrient concentrations, seasonal temperature changes and wave action. The increase in macro-algae was also favored by the decline in sea urchin populations during the early 1980s and over-fishing of herbivorous fish.

The reefs of Guadeloupe were not severely damaged by previous coral bleaching, although 56% of corals bleached in 1998, with up to 80% of the surface area of colonies being pale. There was, however, little mortality except among colonies of *Diploria labyrinthiformis*, which suffered 80% mortality. Another bleaching episode that was confined to the reefs of Guadeloupe occurred in September 1999, affecting almost 50% of corals. Subsequent mortality was negligible because the passage of Hurricane Lenny in November 1999 cooled the waters and allowed corals to recover.

In 1989, Hurricane Hugo destroyed branching corals (*Acropora palmata, A. cervicornis, Madracis mirabilis*) on the outer reef slopes down to depths of 15 m. The *A. palmata* stands, which were prominent on the outer reef slopes, have not recovered but *Madracis mirabilis* has quickly recolonized the area. Hurricanes Luis, Marilyn and Lenny damaged Guadeloupe's coral reefs more severely than Hugo, mainly because large waves up to 13 m high destroyed corals, sponges and gorgonians down to 25 m depth. This damage was compounded by torrential rains and extensive soil erosion. The high diving pressure on these reefs causes additional damage, particularly from inexperienced divers, especially on the Ilets Pigeon, which receives between 80-100,000 divers annually.

Surveys at Guadeloupe in 2000 recorded 228 fish species in 59 families, with the average fish density between 119 and 550 fish per 600 m^2. The highest numbers were in the protected area of Pigeon Island. The fish biomass in Guadeloupe and the other islands was 368 to1893 kg. ha^{-1}. In 2004, the average number of fish species in 600 m^2 areas was 45 and the average fish biomass in Guadeloupe was 807 kg.ha^{-1}, indicating that fish communities have not changed significantly in recent years. However, fish stocks around all the islands are over-exploited and large fish (groupers, snappers, parrotfish) are rarely seen. Most fishing is artisanal with 1200 registered fishers, working from 947 fishing boats that are generally small (6-8 m long) and operate in inshore waters. Only 10 boats are equipped to operate offshore. There are however, about 1000 unregistered fishers who fish regularly. About 40,000 Caribbean traps are used, with many of these traps being 'lost' after each hurricane. However, those traps with wire or plastic netting continue to catch fish long after they are lost.

Martinique: Coral cover in 2004 varied between 32% and 40% on various reefs. The dominant cover type was algal turf followed by brown macro-algae, indicating that nutrient pollution from the land is affecting the marine environment. The increase in brown macro-algal cover is a major factor contributing to the deterioration of the reefs. The proliferation of macro-algae was first noticed on the Atlantic coast in the early 1980s, coinciding with the mass mortality of the herbivorous sea urchin *Diadema antillarum*. Since 1984, macro-algae, particularly *Sargassum*, have become abundant along the Caribbean coast, probably because

of eutrophication resulting from urban and industrial wastes from Fort-de-France Bay and sediment from agriculture. In the early 1980s, Fort-de-France Bay had the highest coral diversity in a variety of different habitats (reefs, seagrass beds, shoals, rocky shores). However, increasing pollution is threatening these ecosystems and those in the nearby Baie du Marin.

Like Guadeloupe, the reefs of Martinique were not severely affected by previous bleaching events. In 1998, 59% of coral colonies bleached, with an average of 69% of the surface area of colonies being bleached. However, there was little subsequent mortality and recovery was reasonably rapid. There was minimal bleaching in 2003 and 2004, but no significant mortality.

Hurricanes have caused significant damage to the coral reefs of Martinique; Hurricanes David in 1978 and Allen in 1980 damaged *Acropora palmata* and *A. cervicornis* communities, especially in the Sainte-Luce region. Although there has been no major hurricane damage since then, these reefs have not recovered completely.

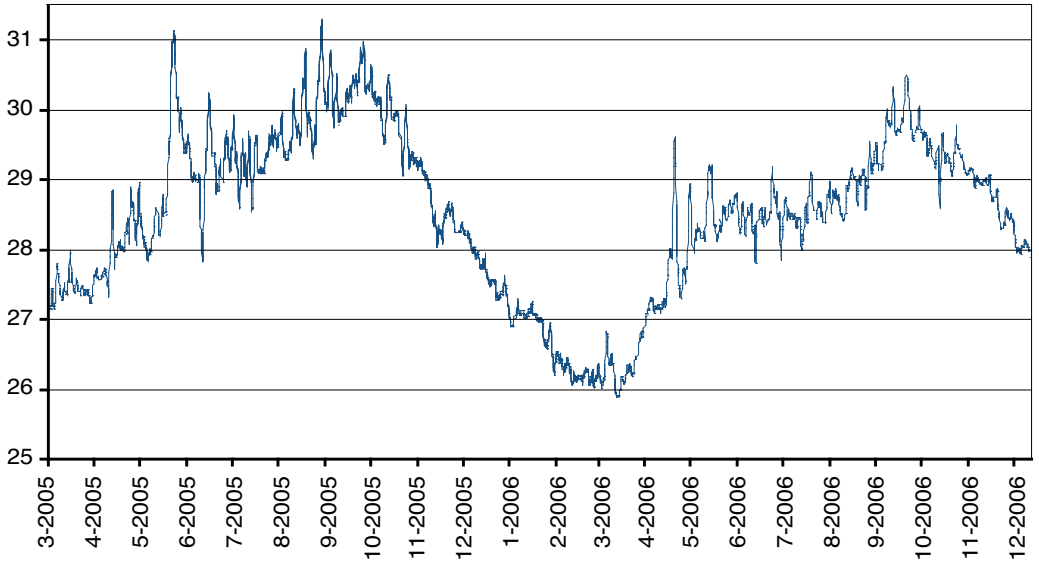
Fishing in Martinique is also primarily artisanal. At present, there are about 1300 registered fishers who use traps and concentrate their fishing effort on inshore reefs. There are many more unregistered fishers, making the total fishing population closer to 2500. The catch of pelagic species has risen with the introduction of anchored fish aggregating devices. There was a major fish kill in September 1998, which affected all trophic levels on the Atlantic coast of Martinique. However, there were no obvious changes in the structure of the reef fish community. Surveys in 2004, showed an average of 46 fish species in 600 m^2 areas and an average fish biomass of 788 $kg.ha^{-1}$, indicating that no significant changes in fish communities have occurred recently.

Saint-Martin and Saint-Barthélemy: Coral cover varied in 2004 between 20% and 26%. Algal turf was the most abundant cover type on the reefs of Saint-Barthélemy. Brown macro-algae were also abundant, indicating that nutrient pollution was affecting these reefs. The reefs of Saint-Martin and Saint-Barthélemy have been colonized by *Dictyota* and *Lobophora*, which out-compete corals and other benthic invertebrates for space. Hurricane Luis caused some damage to the coral reefs of Saint-Martin and Saint-Barthélemy, but the most significant impact was caused by the re-suspension of very fine sediments from the shallow continental shelf. These sediments remained in suspension for several months and smothered many organisms. Re-suspension of sediments is probably a reason for the limited development of coral reefs on these islands.

In 2004, the average number of fish species in 600 m^2 areas was 48 and the average fish biomass was 751 $kg.ha^{-1}$. There have been no apparent changes in fish communities in recent years, although seasonal variations of fish biomass were noted on the reefs of Saint-Barthélemy.

The 2005 Temperature Anomaly in the French West Indies

Generally, Caribbean reef corals tolerate a maximum sea water temperature of 29°C; any increase above this for a long period will stress corals and induce bleaching. The severity of bleaching is linked to the magnitude of the temperature increase and its duration. There is usually some minor bleaching every September when sea temperatures reach their annual maximum.

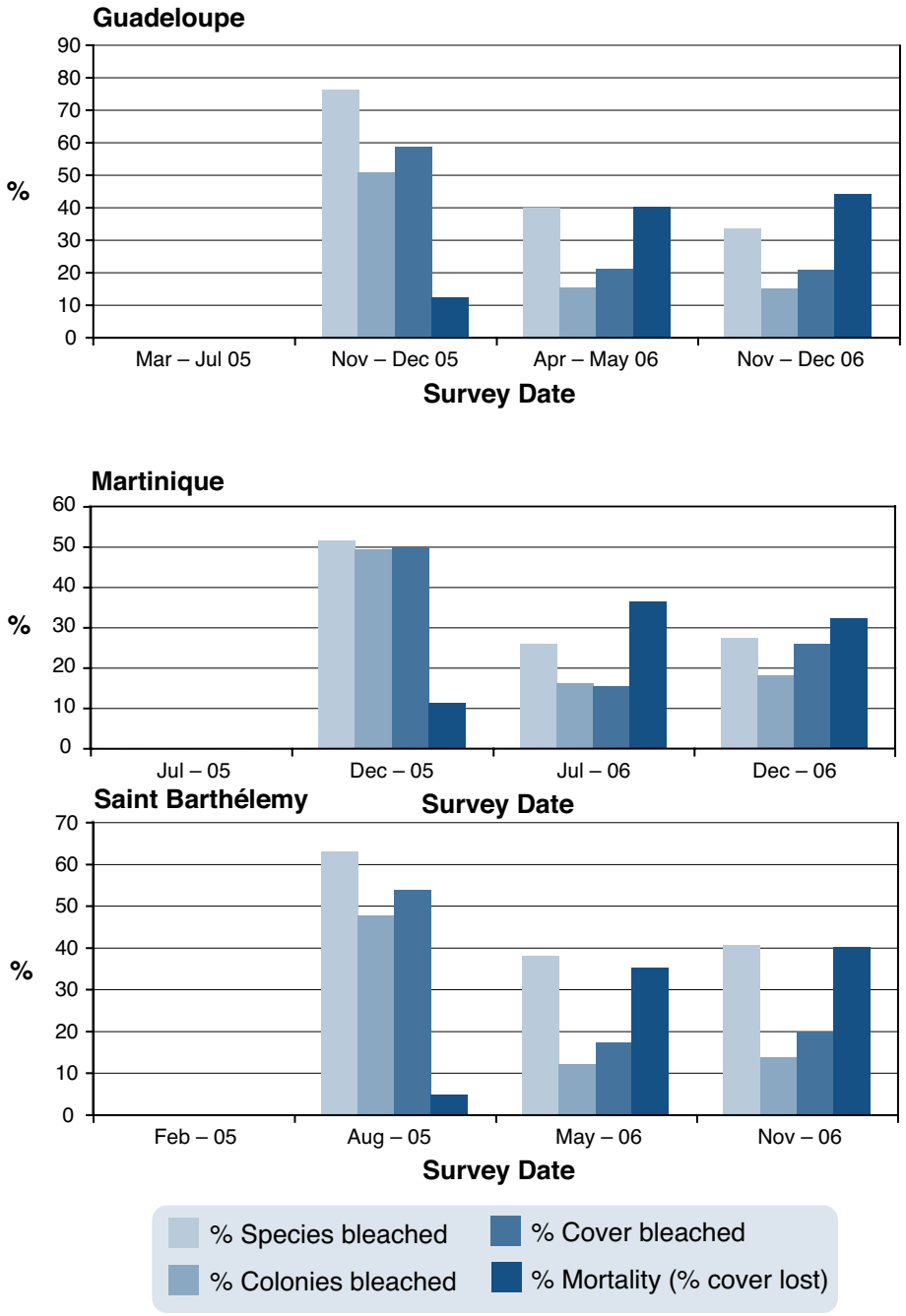


This figure daily sea temperatures in Guadeloupe from March 2005 to December 2006, with consistent temperatures over the 29°C 'bleaching threshold' for almost 6 months in 2005, reaching a maximum of 32°C in September, and then for a short period in 2006. (24 h moving average).

Effects of the 2005 Bleaching Event

Guadeloupe: Severe coral bleaching developed in August after sea temperatures exceeded 29°C between May and November. Surveys in December 2005, showed that bleaching had affected 76% of all coral species in the community; 51% of all colonies; an average of 58% of the surface area of affected colonies; and a 12% loss of coral cover. The density of coral recruits during this period was the lowest recorded, declining from a mean of 23 recruits per 10 m^2 prior to 2005 to 10 per 10 m^2 in December 2005. There was also a significant drop in the number of coral species and colonies recruiting in 2006.

Few corals recovered in 2006, particularly in shallow areas, and there was delayed mortality throughout the year despite normal sea temperatures at most reef sites. Some of this mortality was the result of coral diseases, but most was because of the slow death of bleached colonies that had not recovered their zooxanthellae symbionts. At the end of 2006, bleaching still affected 33% of coral species, 15% of all colonies, and an average of 21% of the cover of coral. The condition of surviving colonies also deteriorated in 2006, with the number of coral species showing coral disease increasing from 60% to 71%, while disease in colonies rose from 33% to 39%. The average colony surface area affected by tissue necrosis varied from 32%-49%. The delayed mortality resulted in a decline of live coral cover on the outer reef slopes, from between 44% and 25% cover before bleaching, to 14% after. Simultaneously, the mean cover of algae rose by 15% on the outer reef slopes.



The effects of increased sea temperatures on the coral reefs of the French West Indies are presented in these 3 figures. There was no apparent bleaching by July 2005; but between August and December, there was clear evidence of a major bleaching event with about half of all corals bleached, but few signs of mortality. However, by mid-2006, 30% to 40% of the coral cover had died, and more than 10% of the remaining corals were bleached.

Observations in June 2007 showed that many corals remained pale or partially bleached and had not fully recovered their stock of zooxanthellae, despite normal seawater temperatures. The three-dimensional structure of the reefs was apparently not affected by the bleaching; for example, in 2004, the average number of fish species per 600 m^2 was 45 and the average fish biomass was 807 $kg.ha^{-1}$ and by the end of 2006, comparable measures were 48 species and 994 $kg.ha^{-1}$.

Martinique: Bleaching started in August 2005 and the first surveys in December showed that bleaching affected 51% of coral species, 49% of all coral colonies, and an average of 50% of the surface area of each colony. Coral mortality was moderate in December with a loss of 11% in coral cover. The number of coral recruits decreased from an average of 49 recruits per 10 m^2 in July 2005 to 28 recruits per 10 m^2 in December 2005, even though coral recruitment is usually greater in December. Juvenile recruitment was still low in 2006 (32 recruits per 10 m^2).

Bleaching persisted during 2006 and by the end of the year, 27% of all coral species showed signs of bleaching and 18% of coral colonies were affected. The average bleached surface area of corals was 26%. As a consequence of the delayed coral mortality, the average coral cover had declined from 28% to 19%. Most of the recently dead corals were colonized by algae, which increased cover by 15%. The health of surviving coral colonies was threatened by coral disease, with 49% of colonies showing tissue necrosis and 48% of the colony surface area affected.

The fish communities did not appear to be affected: in the 2005 bleaching there was an average of 46 species per 600 m^2 and fish biomass of 788 $kg.ha^{-1}$; whereas in 2006 there were 44 species on average and the biomass was 1207 $kg.ha^{-1}$.

Saint-Barthélemy: Bleaching was recorded first in August 2005 and affected 63% of coral species, 48% of colonies, and an average of 54% of the coral cover. No immediate coral mortality was seen. Coral recruit density was the lowest noted during this season, declining from 50 recruits per 10 m^2 to 35 recruits per 10 m^2. Recruitment of juveniles remained low in 2006. Throughout 2006, there was delayed coral mortality and by the end of the year coral communities showed no signs of recovery, with 40% of coral species, 14% of colonies and an average of 20% of the surface of individual colonies still being bleached. By November, the live coral cover had declined by 40%, from 20% before bleaching to 12% afterwards and the dead corals were mainly colonized by algae, with cover increasing by 12%.

The surviving colonies deteriorated significantly throughout 2006; early in the year, tissue necrosis on colonies rose from 18% to 23%, and the colony surface area affected increased from 30% to 48%. The number of infected colonies was still high although many had died from coral disease. By mid-2007, many corals remained pale or partially bleached and had not totally recovered from bleaching, despite normal sea surface temperatures.

The average fish species richness on reefs was 48 species per 600 m2 and the fish biomass 751 $kg.ha^{-1}$ before 2005; and 57 species per 600 m^2 and a similar fish biomass of 742 $kg.ha^{-1}$ in 2006

Impacts of Hurricanes in 2005

The three island groups, Guadeloupe, Martinique, and Saint-Barthélemy and Saint-Martin were not affected by hurricanes in 2005. Previous hurricanes caused some damage: Iris, Luis and Marilyn in 1995; and Lenny in 1999.

Socioeconomic Impacts and Management Responses

In Guadeloupe, the Grand Cul-de-Sac Marin marine reserve was created in 1987 and an experiment to farm the branching corals *Acropora palmata* and *A. cervicornis* was initiated by the Université des Antilles et de la Guyane in 2005 in the lagoon. The project was achieving encouraging results, until the bleaching event killed all the farmed corals. This indicates that coral farming in an uncontrolled environment may not be a good palliative solution to coral repopulation. The alerts issued about potential bleaching in the MPAs resulted in increased surveillance and monitoring, but there was no other specific management intervention.

Conclusions - 2005 Bleaching in the French West Indies.

Coral mortality on the outer reef slopes of the FWI islands ranged between 25% and 52% at different reefs. The variation in mortality was primarily associated with the species composition of the reefs, rather than differing ecological conditions between the reef sites. Coral species showed a large range of bleaching responses to the increased sea temperatures, for example, corals of the families Agaricidae, Favidae and Mussidae were particularly susceptible to bleaching. There was a significant positive correlation between the delayed coral mortality seen and the degree of bleaching in most of the corals. However, some species that bleached rapidly in 2005 recovered well during 2006 e.g. the Poritidae. The hydrocoral, *Millepora squarrosa*, which was common on the reefs previously, appears to have almost disappeared from the FWI and no recruits were seen in 2006 and 2007.

As the three-dimensional structure of the reefs and their capacity to provide shelter for the associated animals have not changed significantly as a result of the bleaching event, the species richness, abundance and community structure of reef fish assemblages have remained similar.

The Netherlands Antilles

Introduction

There are 2 distinct island groups in the Netherlands Antilles: Bonaire and Curaçao are small oceanic islands 70 km north of Venezuela, with continuous fringing reefs around the islands that are particularly well developed on the leeward sides; and St. Maarten, Saba and St. Eustatius are on the northern arc of the Lesser Antilles and are volcanic with steep cliffs, narrow shelves and limited reef development along the windward coasts. There is limited coastal development on St. Eustatius and Saba, thus anthropogenic effects are minimal. St. Eustatius has true calcareous reefs and also corals growing on the volcanic rocks. The only true reefs on Saba are on the eastern side of the island and most sheer walls are populated by sponges. St. Maarten, which is shared between the Dutch (southern portion) and the French (northern portion), has seen rapid population growth and unmanaged expansion of tourism such that the reefs have been degraded by pollution, deforestation, sedimentation, eutrophication from sewage, recreational boating and anchors, particularly along the south and west coasts. A submerged atoll with actively growing reefs, known as the Saba Bank, is also within Netherlands Antillean waters.

Status of Coral Reefs Prior to 2005

Bonaire and Curaçao: The greatest diversity of corals are on the leeward (western) side on a 30 m to 150 m wide terrace that slopes gently to about 12 m depth. The prominent corals are *Acropora palmata, A. cervicornis* and *Montastraea annularis*, with many large hard coral heads and a variety of gorgonians. After the drop-off at 10–15 m depth, the fore-reef slopes downwards at 30-60 degrees to a sediment bottom between 30 m and 50 m depth. The dominant corals are *M. annularis, M. faveolata*, and *Agaricia agaricites*, with *M. cavernosa* and *Stephanocoenia* in deeper waters. On the northern side of Bonaire at Boca Bartol and Playa Benge, the reefs have unusual shallow water spur and groove formations, while the southern facing shore has buttresses that slope steeply down to the sediment platform at 100 m depth. The reefs on Klein Bonaire are varied with some descending steeply close to the shore to a sediment platform at 25-30 m depth. The reefs of Curaçao are similar although there are vertical drop-offs from 6-35 m depth on the eastern side.

The terrace on the eastern side of Bonaire and the north-eastern side of Curaçao extends 100-200 m offshore and to a depth of 12 m, with primarily crustose coralline algae, *Sargassum*, and some gorgonians. The leeward reef slope has less coral cover and abundant brown algae.

On Curaçao, there are about 250 fish species and 55 coral species, with an average of 19 coral species per 200 m^2 at 6 m depth and 23 species at 12 m. Live coral cover at most sites declined by 10% between 1997 and 2002, with a greater decline at 6 m depth than at 12 m. In 2002, coral cover at 6 m depth on the leeward side of Curaçao was 30-50%, and 30-70% at 12 m. Since 1983, *A. cervicornis* has almost disappeared because of white-band disease, except for a few small stands. *A. palmata* has also declined on both Curaçao and Bonaire. The shallow reefs (0-2 m depth) have completely disappeared since the early 1980s.

There are only 20-30 commercial fishers on Bonaire, but many people fish recreationally. The commercial targets are mostly pelagic species (tuna, dorado, wahoo) caught with hook and line, although trai (throwing nets) and reda (encircling nets) are used to catch bait and big-eye scad respectively. Spear-fishing is illegal, but still occurs, and the use of kanasters (fish traps) is discouraged because of the conflicts they cause with recreational divers. In 2000, reef fish were abundant and diverse and biomass was high. However, in 2002, grouper, conch and lobster were absent from some of Bonaire's reefs and snapper populations were declining. Parrotfish were still abundant because they are considered inedible. Illegal poaching of turtles also occurs, killing as many as 20 turtles per month. Collection for the aquarium trade is banned.

On Curaçao, there are a few hundred artisanal fishers who mostly target pelagic species. Fish traps and gill nets are also used and illegal spear-fishing is still practiced. Fish populations have been severely reduced by heavy fishing pressure; larger fish, particularly groupers and parrotfish, lobsters and conchs are rarely encountered. However, snappers and small parrotfish are still fairly common. Turtles are protected, but are occasionally caught as by-catch.

Saba: There are 35 coral species and some gorgonians, with the dominant corals being *Montastraea anularis, M. cavernosa*, and *Diploria strigosa*. Rough seas reduce coral cover in shallow waters (0-7 m) and storms in 1998 and 1999 caused major declines in the abundance of *Acropora palmata*. Coral cover does not exceed 20% because of high sediment loads and frequent benthic algal blooms, and massive corals are often overgrown by bioeroding sponges.

In 1996, there were 28 coral species on the Saba Bank, with 60-90% coral cover. However, AGRRA surveys in December 1999 recorded only 24% coral cover with the highest cover at 21 m depth, and 27.5% dead coral cover. This indicated that disease and bleaching had severely damaged these shallower reefs.

There is limited fishing around Saba and fish populations are considered healthy, but still recovering from historical over-fishing. Grouper and snapper biomass continues to rise after the establishment of the Saba National Marine Park. About 50 fishers (mostly from Saba) fish on the Saba Bank targeting mainly lobsters, red snapper and conch. There was an intensive grouper fishery until populations declined.

St. Eustatius: The offshore reefs begin at 25 m depth with complex spur and groove formations that extend to 60 m. There are steep buttresses on the northern part with 80% coral cover and 35 species. The northern complex has a labyrinth of encrusted ridges, sand channels and huge encrusted rocks, with a fringing reef on the exposed Atlantic side. The leeward side is mostly a sandy plateau with large populations of Queen Conch down to 17 m. Hurricanes Luis and Marilyn (1995) removed large amounts of sediment from the eroding cliffs and severely damaged soft corals and sponges; recovery was rapid.

There are only 15 full- or part-time fishers on St. Eustatius, who use traps to catch fish and lobsters for restaurants. Yellowtail snapper and grouper are highly prized, but locals eat almost any reef fish. Spear-fishing with scuba is illegal, but is still practiced. Many conch were collected until 2001, when regulations were enforced, but some are still taken illegally. Conch populations appear healthy, and turtles are protected, although some poaching of eggs still occurs despite an intensive public awareness campaign.

St. Maarten: Patch reefs with spur and groove structures at 8-18 m depth are concentrated near the east and south-eastern part. In 1999, average hard coral cover was about 30% with bleaching and some diseased corals evident. Hurricane Luis damaged reefs, seagrass beds and beaches, and re-suspended sand smothered *Acropora palmata* stands in shallow water, but these have largely recovered.

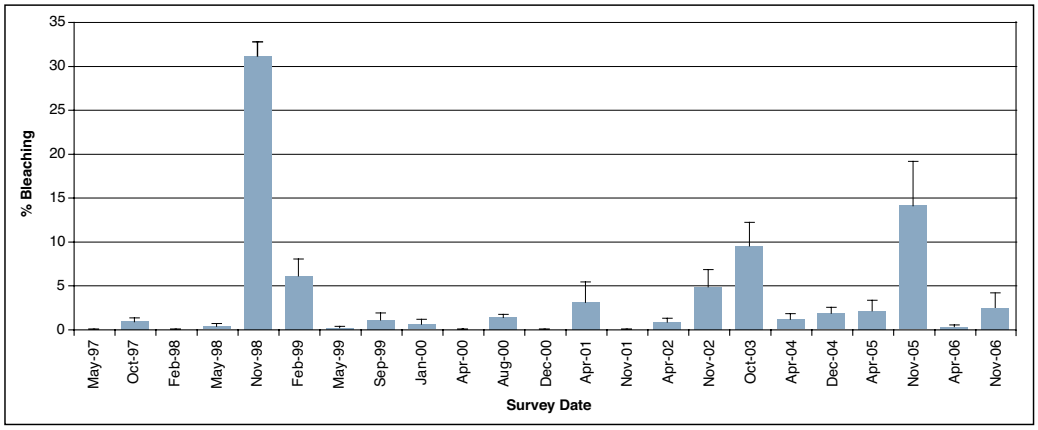
There are about 30 fishers who use fish traps and other artisanal practices. Fish populations are still reasonable, although big groupers are uncommon and conch populations have been depleted.

Effects of the 2005 Bleaching Event

Coral bleaching was first noticed in the north on St. Maarten, Saba, and St. Eustatius in late August 2005 and continued until mid-November 2005. Around 80% of coral colonies were bleached on these islands in mid-October. Coral loss on St. Eustatius from June 2005 to June 2006 was 18% at 15 m depth (coral cover dropped from 24% to 6%) and 11% at 25 m (from 26% to 15%). No mortality data are available for St. Maarten and Saba.

Bleaching was less common on Bonaire and Curaçao, with bleaching affecting an average of 14% of coral colonies during November 2005. No mortality was apparent and average coral cover remained at around 40% at 12 m depth and 30% at 6 m, between April 2005 and April 2006.

There was negligible bleaching in 2006 on St. Maarten, Saba, and St. Eustatius and in Bonaire and Curaçao. At Bonaire, 9% of coral colonies were partially bleached in October 2006 (normally the peak bleaching month) and only 2% were completely bleached. Bleaching (pale and fully bleached) affected only 3% of coral colonies on Curaçao, in early November 2006.



Records of the average percentage of hard coral colonies that bleached on Curaçao during the last 10 years show that bleaching was greatest in 1998 and 2005.

Impacts of Hurricanes in 2005

The northern islands of St. Maarten, St. Eustatius and Saba are regularly hit by hurricanes, whereas Bonaire and Curaçao are south of the path of most Caribbean hurricanes and are only rarely damaged. Thus, the reefs of Bonaire and Curaçao are extremely well developed with very old and large coral heads. The last hurricane damage occurred in 1999 when Hurricane Lenny generated 6 m high waves that struck the lee side of the islands, particularly Bonaire, completely destroying many shallow reef areas to depths of 6 m. In some areas, broken coral heads rolled down the reef slopes causing serious damage at greater depths. In 2004, Hurricane Ivan caused minor damage, but Bonaire and Curaçao were not affected by hurricanes in 2005.

There was no serious hurricane damage during 2005 on St. Maarten, St. Eustatius or Saba, where regular hurricanes have meant that optimum reef development occurs in deeper waters.

Socioeconomic Impacts and Management Responses

No special management responses resulted from the events of 2005, except that monitoring and surveillance were increased in the MPAs, e.g. in the Bonaire Marine Park, the Curaçao Marine Park, the Saba National Marine Park, and the St. Eustatius Marine Park. In 2006, nature conservation legislation was passed in St. Maarten to provide legal designation of the St. Maarten Marine Park. This will include the levying of a diver fee, and will enable the well-established local NGO (St. Maarten Nature Foundation) to manage the intended marine park. Ten years of funding has already been donated by WWF and other Dutch donors to help management until it becomes financially self sufficient. The NGO employs a park manager and assistant manager to establish moorings, conduct monitoring, and undertake outreach activities.

Barbados

Introduction

Barbados is the most easterly of the Lesser Antilles island chain. The uplifted fossil coral island is surrounded by a 2-3 km wide shelf that supports a variety of coral reefs. Fringing reefs distinguish the west (leeward) coast and make up 8.4% of the mapped reefs; beyond that there is an almost continuous bank reef parallel to the north, west and south coasts 0.5 to 1.2 km offshore. The crest of this bank reef is 5-35 m deep in the north, west and south and is shallower along the more exposed southeast coast, where it becomes a bank barrier reef. This bank contains 87.1% of the mapped reefs. There are also a few patch reefs at 5-16 m depth between the shore and the bank reef, along the west to southeast coasts.

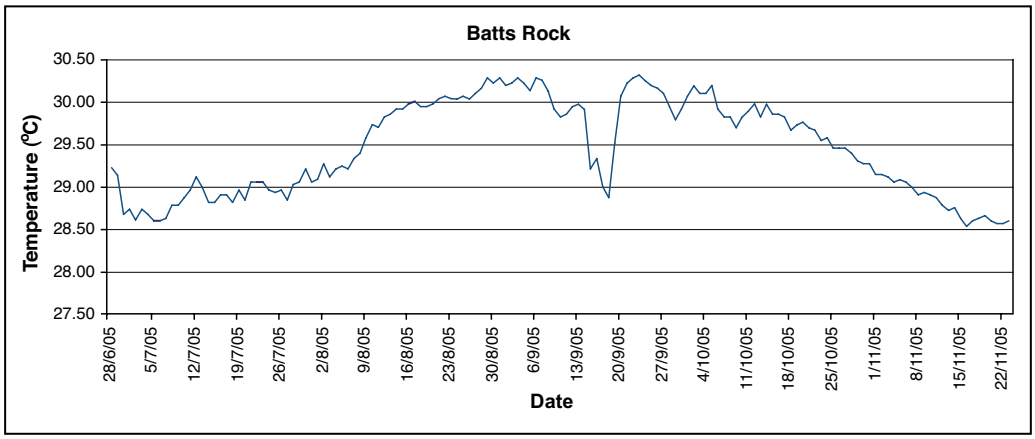
Status of Coral Reefs Prior to 2005

The inshore fringing reefs have been affected by poor water quality caused by coastal construction, tourism infrastructure and inland agriculture; by storms; and by over-exploitation of fish and corals. Average live coral cover is about 10% in the seaward spur and groove zone (range 1-30%). The offshore bank reefs are relatively undamaged with about 30% coral cover along the crest. These bank reefs are far enough offshore to escape damage from poor water quality, and are also less accessible to fishers. The patch reefs are more variable; they are dominated by hard corals and sponges on the west coast, and soft corals on the more exposed windward coasts, although hard coral cover averages 25%. There have been infrequent bleaching events in south-eastern Caribbean islands; most have occurred within the last decade but were usually of low to moderate intensity.

Effects of the 2005 Bleaching Event

NOAA satellite sea surface temperature (SST) data for the eastern Caribbean, including Barbados, showed a coral bleaching 'HotSpot' (SSTs in excess of 1°C above the maximum expected temperatures) that developed to the northeast of Barbados in early June, and strengthened in June-July to cover Barbados and the Lesser Antilles by early August. The HotSpot strengthened during August and September and covered much of the Caribbean Sea by early October. It finally disappeared in late October.

Sea temperatures at 8 m depth on a shallow patch reef confirmed the satellite data, with daily mean temperatures climbing steadily from 28.6°C in late June to more than 30°C in late August and early September. This was 1-2°C above the 'typical' summer maximum. During the second and third weeks of September, strong currents brought cooler water onto the reefs and reduced temperatures by almost 1.5°C, before they returned again to 30°C for the last week of September. Sea temperatures declined to 29.3°C by the end of October and to 28.6°C by the end of November. Benthic temperature loggers at 20 m depth on other sites showed similar temperature patterns to those reported by research divers and dive operators, with widespread warm waters extending to at least 30 m depth.

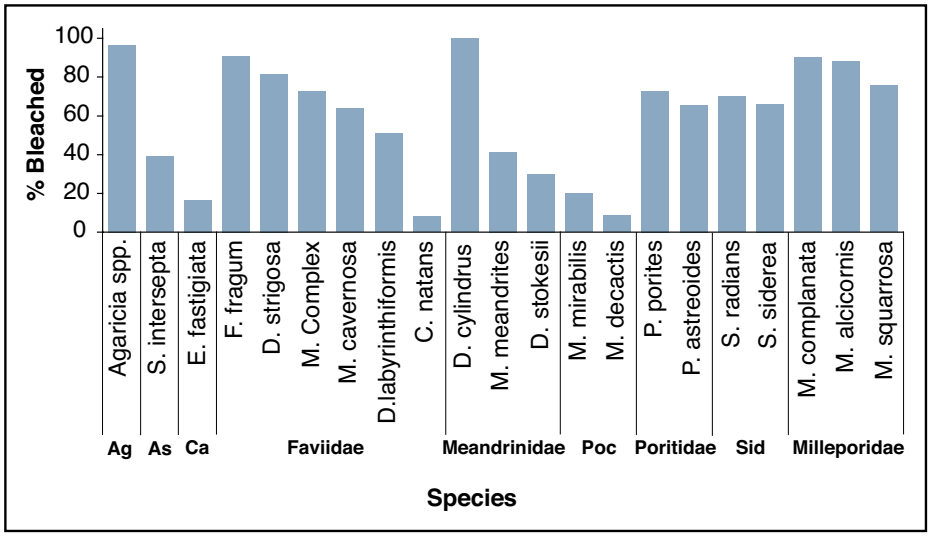


An automatic temperature recorder placed on Batts Rock in 2005 showed that water temperatures rose above the normal bleaching threshold of 29°C in mid-year and continued until late October. Additional temperature recorders paced at North Bellairs, Coconut Court and Atlantis showed that these sites had a similar temperature profile to that of Batts Rock, with a characteristic decline of almost 1.5°C during the second and third weeks of September caused by strong currents that brought cooler water onto the reefs before returning again to 30°C in the last week of September. Such prolonged hot water stress had never been recorded previously in Barbados.

The accumulated heating stress was severe for the eastern Caribbean including Barbados, with Degree Heating Weeks (DHWs) exceeding 5 for much of the summer and reaching a maximum of 13-14 weeks by the end of October and beginning of November 2005.

The first bleached corals were noticed on 24 August at Batts Rock (8 m depth), where several colonies of *Siderastrea siderea* were a pale mauve/blue color. Two days later, similar bleaching of *S. siderea* was seen at 16-20 m depth on the Atlantis bank reef, as well as colonies of *Meandrina meandrites* and the fire corals *(Millepora* spp.*)*. By 3 September, bleaching affected colonies of *Dendrogyra cylindrus* and *Porites astreoides*, and some colonies of *Montastraea annularis*. By mid-September there was widespread bleaching of whole coral colonies in all reef habitats on the west and southwest coasts of Barbados. Dive operators, charter boat captains, fishers and the public reported bleaching. Surveys of 6 reef habitats between mid-September and October 2005 showed severe coral bleaching in all reef habitats, with 59-86% of all hard coral colonies showing some bleaching. Inshore reefs were more severely affected (80.6% of colonies bleached) than offshore reefs (60.5%).

Bleaching also affected 90% of the 29 coral species, with some species being more vulnerable than others. Among the more common species, the most susceptible to bleaching were *D. cylindrus, Agaricia* spp.*, Favia fragum* and *Millepora complanata*, with 90% or more of colonies affected, whereas fewer than 10% of colonies of *Colpophyllia natans* and *Madracis decactis* bleached. More colonies of *Diploria strigosa* and *P. astreoides* bleached on shallow reefs than on deeper reefs, while the converse was true for *S. siderea*.



The proportion (%) of colonies of the more abundant hard coral species (10 or more colonies observed) that bleached in 2005. Data were collected at 6 reefs around Barbados during Sept/Oct 2005. Abbreviated family names: Ag – Agariciidae, As – Astrocoeniidae, Ca – Caryophylliidae, Poc – Pocilloporidae, Sid – Siderastreidae (Adapted from Oxenford et al. 2007).

This table summarizes the affects of bleaching from late September 2005 to February 2006, at 6 sites around Barbados that have been monitored regularly. Most species and a majority of colonies showed bleaching in shallow and deep water. Live cover estimates are from on-going monitoring at adjacent sites at the time of the survey (adapted from Oxenford et al.

		2005				2006		
Site, Reef type & Location (depth m)	**GPS coordinate**	**Survey date**	**Coral species bleached of total per 100m²**	**Total no. colonies (100m²)**	**Mean % colonies bleached (SE)**	**Survey date**	**Mean % colonies bleached (SE)**	**% Live coral cover**
Batts Rock, Patch West Coast (8)	N 13°08'08 W 59°38'18	15-Sep	15/20	791	73.8 (6.8)	7-Feb	46.0 (1.7)	29.9
Maycocks, Bank West Coast (22)	N 13°17'32 W 59°39'47	23 Sep	14/16	409	59.1	9-Feb	32.6 (2.7)	37.8
Atlantis, Bank West Coast (16-20)	N 13°07'18 W 59°38'55	30-Sep	15/17	445	63.0 (3.8)	7-Feb	43.7 (6.7)	34
North Bellairs, Fringing West Coast (3-5)	N 13°11'18 W 59°38'31	4-Oct	14/17	1629	82.0 (3.1)	9-Feb	39.7 (8.7)	23.3
Welcome Inn, Bank Southwest Coast (15)	N 13°03'35 W 59°33'25	5-Oct	20/21	621	59.4 (6.9)	6-Feb	43.1 (3.0)	22.9
Coconut Court, Patch Southwest Coast (5-6)	N 13°04'24 W 59°36'11	6-Oct	15/16	713	86.0 (1.3)	6-Feb	19.9 (1.5)	25.8
Overall			**26/29**	**4608**	**70.6 (4.8)**		**37.5 (2.5)**	**28.9**

The bleaching event developed rapidly and simultaneously on deep and shallow reefs on both the west and southwest coasts of the island. The first signs of bleaching in the most susceptible species appeared when SSTs rose above 30°C for more than 1 week. As the length of exposure increased, virtually all hard coral species eventually bleached, regardless of whether they were on degraded inshore or healthy offshore reefs. This demonstrated that elevated SSTs can cause coral bleaching on a massive scale and override other stress signals.

The onset of bleaching mortality was rapid in some corals, notably *Millepora* and *Porites porites,* whilst the vast majority remained bleached for many months without significant mortality. In February 2006, there was a mean of 37.5% of colonies still bleached, although mortality was only 3.8%. By June 2006, bleaching persisted in 17.2% of colonies and recent mortality was much higher at 18.7%. Inshore reefs were harder hit, with 20.1% colony mortality, compared with 17.4% mortality for the offshore reefs.

Socioeconomic Impacts and Management Responses

The events of 2005 are of great concern for tropical islands like Barbados; particularly as the global warming trend is predicted to continue. If SSTs rise by 2-3°C, annual bleaching will probably become common in the Caribbean. Therefore, a well-coordinated, regional monitoring program is required so that more effective management strategies can be implemented at both the regional and local levels.

Coral reefs are recognized as being particularly important to the Barbados economy; thus the Government, through its Coastal Zone Management Unit, has developed a coastal management plan with sections devoted specifically to coral reef protection. This includes a long-term program of monitoring for reefs at 5 yr intervals on 21 west coast, 16 southwest coast fringing and patch reefs and 6 west and southwest coast bank reefs. Previous monitoring indicates that much of the reef deterioration on the west coast was the result of increasing nutrients from the land. In response, the Government constructed the South and West Coast Sewage Treatment Project to reduce pollution. This was part of a coastal zone management plan that outlines permitted coastal development and is enforced through the Coastal Zone Management Act, which protects all corals from physical damage, and the Marine Pollution Control Act, which protects corals from land-based sources of pollution.

The Government has recognized that healthy reefs are more resilient to coral bleaching and other effects of climate change (e.g. potentially greater incidence of coral disease) than degraded reefs. As a result, increasing efforts to reduce anthropogenic stress has become a management priority. Efforts to manage and conserve coral reefs must include all reef types to cover the spectrum of resistance and resilience to bleaching demonstrated by the various coral species in different reef habitats. Small, vulnerable states like Barbados should strive to minimize anthropogenic effects on corals to conserve coral reef resources locally, and put pressure on the international community to reduce global greenhouse gas emissions.

CORAL MORTALITY IN BARBADOS, MARTINIQUE AND THE BRITISH VIRGIN ISLANDS AFTER THE BLEACHING

The eventual fate of stony corals that have bleached is known to be highly variable among sites, and bleaching may persist for many months after seawater temperatures return to 'normal'. The severity of bleaching is likely to be underestimated when surveys are of limited duration and spatial coverage, or focused only on coral color. AGRRA scientists conducted surveys in Barbados, Martinique and the British Virgin Islands using BLAGGRA; a new protocol for rapidly assessing coral condition (available online at www.agrra.org). Prolonged exposure to high sea surface temperatures in 2005 had affected Barbados < Martinique < British Virgin Islands (BVI), and many surviving corals were still partially pale in January 2006; bleaching-related mortality was pronounced in *Agaricia agaricites* (plus *Porites porites* in Barbados and Martinique). In addition, colonies of *Diploria labyrinthiformis* and the *Montastraea annularis* complex were being killed by white plague in the southern BVI. Recent partial-colony mortality estimates of all the ≥ 10 cm corals in belt transects were 5% in Barbados (n = 10 sites), and 11-13% in the southern BVI and Martinique, respectively (n = 7 sites each). Average 'recent loss' of live coral cover in line transects showed similar losses from about 7% in Barbados to about 15% in Martinique and the southern BVI. Despite regaining much of their pigmentation, stony corals continued to die during spring 2006, apparently from the delayed effects of bleaching in Barbados, and, in part, from diseases that were conspicuous for several months in southern Martinique. When most sites were resurveyed in May to early June, recent partial-colony estimates had tripled at repeat sites in Barbados and nearly doubled in Martinique. These dramatic increases are most probably disease-related to the 2005 bleaching 6 months earlier. They demonstrate how essential repeated post-mortem surveys are for at least 6 months after initial bleaching to evaluate the full impact of an event.

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Trinidad and Tobago

Introduction

The reefs of the island of Tobago are far more extensive than those on the larger island of Trinidad. Tobago's reefs are a mixture of biogenic reefs (built by corals and coralline algae) and geological reefs (base of rock, colonized by hard corals). Most of the reefs are 'shallow' in their structure, ending abruptly in a sand seabed at depths between 15 m and 25 m.

Status of Coral Reefs Prior to 2005

The most commonly occurring corals are the *Montastraea annularis* complex, which occupied 37% of the substrate, with fire corals (*Millepora* spp.) contributing 12%, and the 'brain' corals, *Colpophyllia natans* and *Diploria strigosa*, contributing 11% and 9% respectively. *Agaricia* spp. and the branching corals *(Porites porites, P. furcata and P. divaricata)* are far less abundant than on many other Caribbean reefs. This is similar for macro-algae, which covered less than 3% of the substratum, with uncolonized rock accounting for 41%. Coral disease, tissue necrosis or turf-algal/cyanobacterial overgrowth of bleached or unbleached corals has not been recorded during previous surveys, indicating that the reefs were predominantly healthy prior to 2005.

Effects of the 2005 Bleaching Event

Following warnings of potential bleaching in 2005, the Buccoo Reef Trust and Coral Cay Conservation assessed 22 discreet reef sites on the Caribbean coast in October/November. Surveys at two deep (~12 m) and two shallow (~7 m) sites showed that coral cover was highly variable around the island. The mean cover was 21.4% (SD ± 12.9%), with the maximum cover recorded being 60% at Pirate's Bay on the north-west coast. Coral cover was greater at deeper sites (~24%) than shallower ones (~19%).

The first bleaching was noticed in *Palythoa* and fire corals *(Millepora)* in September 2005. By October/November, bleaching affected 66% of hard corals (71% on deeper sites and 63% on shallow sites). The extent of bleaching was largely consistent throughout, with most sites showing extensive bleaching (> 85%). However, there was less than 20% bleaching along 9 transects, 5 of which were located near Speyside in the northeast of Tobago. This may indicate either localized tolerance to bleaching or better water quality with either less polluted water or cooler water entering the area.

The incidence of bleaching was highly variable within and between species. *Agaricia agaricites* and *Siderastrea radians* were most affected, with 93% of colonies being bleached. *Madracis mirabilis* and *Acropora palmata* were the least affected species (3% and 0% respectively). The once prominent *A. palmata* is becoming particularly rare throughout the Caribbean, however there was no bleaching seen on the few colonies on or adjacent to the transects. The average incidence of bleaching among species of the *Montastraea annularis* complex was 73%, although there was great variability between these species. For example, at one site at Buccoo Reef, one stand of *M. annularis* exhibited 97% bleaching while bleaching affected only 6% of the surface area of an adjacent stand. This probably demonstrates the presence of bleaching resistant clades (genetic varieties) of the coral and/or the algal symbionts.

By March 2006, only 7% of 180 colonies that had been tagged in November had died. The majority of these corals regained their pigmentation, although partial mortality was evident in 32.5% of the colonies, including some with clear symptoms of coral disease. Mortality was greatest in brain corals *(Colpophyllia natans, Diploria strigosa* and *Diploria labyrinthiformis)*, with 73% of colonies dying. Most of the reefs had still not recovered from the bleaching event of 2005, with many colonies showing signs of diseases and an apparent rise in colony mortality among the massive corals.

Socioeconomic Impacts and Management Responses

After the 2005 event, the Buccoo Reef Trust introduced a monitoring program under the regional GEF-IWCAM project and Coral Cay Conservation started coral reef mapping around Tobago. These studies, conducted in partnership with the Tobago House of Assembly, will provide detailed information about the long-term damage to the island's coral reefs from the 2005 bleaching event.

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