Review

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Marine Major Ecological Disturbances of the Caribbean

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Abstract

Large-scale marine disturbances, called marine major ecological disturbances (MMEDs), have drastically increased in the last 20-25 years. Coral-reef bleaching has repeatedly killed or weakened coral-reef organisms throughout the Caribbean since 1979. Longspine sea urchins were almost extirpated from the Caribbean in 1983-84, and recurrences have followed, along with smaller die-offs of other sea urchins. A large array of new, epizootic diseases has emerged or become more common or widespread in the last few years to devastate Caribbean coral reefs, and some of the older diseases have also become epizootic. Sea fan mass mortalities removed most of these animals from the Southwestern Caribbean in the early 1980s and possibly related sea fan disturbances now threaten those remaining Caribbean sea fans. A Caribbean-wide fish mass mortality was possibly caused by slime-blotch disease (SBD) in 1980. Since then similar SBD mass mortalities have occurred in South Florida, Bermuda, and the Eastern Caribbean. Recent outbreaks of external lesions on fishes throughout the Caribbean seem to be due to SBD. Green Turtles began suffering a Caribbean-wide epizootic of fibropapillomas in the mid-1980s. These gross, external tumors continue to endanger this sea turtle. Although few non-coral reef mass mortalities (marine mammals, molluscs, seagrasses, sea stars, sponges etc; losses from harmful algal blooms) occur in the Caribbean Region, more coral-reef related disturbances occur here than in any other region. Research efforts require more coordination and cohesiveness. We believe MMEDs are driven by the most important phenomena of our times: global changes due to direct and indirect human impacts.

WE began work on marine major ecological disturbances (MMED) by confirming that coral-reef bleaching was both a worldwide and serious disturbance by documenting the 1986-1988 event complex and listing other coral-reef disturbances (1). We also demonstrated that the drastic Caribbean-wide increases in sea turtle fibropapilloma tumors were part of a worldwide panzootic (2). Over the last 20 years, we have worked with or tried to follow a variety of MMEDs [1-39]. We first presented a summary of Caribbean MMEDs (as "Mass mortality of marine organisms in the Caribbean") in the United Nations (UN)/IOCARIBE Mass Mortality and Red Tide Workshop in Cumaná, Venezuela, 16-19 September 1992, where we were co-founders and became country representatives for Puerto Rico and the USA in the UN/IOCARIBE Mass Mortality and Red Tide Network. This Workshop was a continuation of the work of the UN/IOCARIBE Caribbean Fishkill Committee (1980-1981), chaired by EHW, which met in Puerto Rico (36). The growing complexity and number of Caribbean MMEDs suggests that a review of these disturbances might be useful at this point in their study. A brief companion review of Indo-Pacific marine major ecological disturbances has also been published (30).

Each MMED below is defined or explained and a short summary of events is given. Some disturbances are discussed which do not now qualify as MMEDs, but are either related to MMEDs, or may eventually become MMEDs. Many of the descriptions are brief simply because very little is known about them. We have attempted to arrange the MMEDs in an order of their importance; however, no precision is promised in this arrangement.

1. CORAL REEF BLEACHING

Coral-reef bleaching and its associated mass mortalities are the largest and most long-term disturbances known. Bleaching is, simply, the loss of much of the symbiotic algae (zooxanthellae) and their associated pigments from the tissues of corals and other coral-reef organisms. This loss leaves the coral tissues intact, but the loss of pigmentation exposes the stark white of the coral skeleton. Major coral-reef bleaching events are caused by unusually elevated seawater temperatures (1). Simple bleaching can be caused by a great variety of other insults (1). Bleaching has a spectacular effect on corals, turning many species stark white (Figure 1), while other animals turn a paler shade of pink, green or beige. Zooxanthellae are not only important for providing much of the colors in corals, but also provide much of their nutrition. However, corals can survive after bleaching if temperatures return to normal, and if water quality is oligotrophic.

By documenting the 1986-1988 complex through the reports of hundreds of observers around the world, we demonstrated that major coral-reef bleaching was a worldwide or circumtropical/subtropical event, its primary cause was seawater temperatures above the normal annual maximum (1). We developed a model to show the relationship of bleaching to large-scale warming trends and seasonal elevations, showed parallels with the recurrences of bleaching and other MMEDs in the last 20-25 years, and suggested that these recurrences were becoming ever more destructive (1). World-wide coral-reef bleaching has now occurred in series of ever more tightly packed complexes of events.

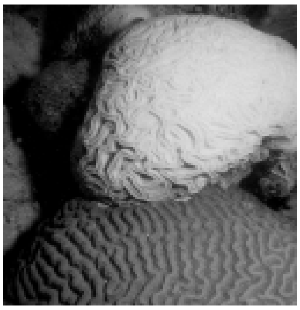

Figure 1. Bleached, grooved brain coral, *Diploria labyrinthiformis* (above), and unbleached, symmetrical brain coral, *Diploria stigosa* (below).

1979-80 Bleaching Complex

This series of bleaching events were poorly documented, only being recorded in Bonaire in 1979 and the Florida Keys and Easter Island in 1980, and were rather limited in severity and extent (1). Damage was probably limited to partial mortalities within colonies, or no mortality.

1982-83 Bleaching Complex

Although the 1982 preceding event began in the Florida Keys, and the 1983 effect in the Western Caribbean was well documented by Lasker (40), the brunt of this complex was concentrated in the Eastern Pacific (41). Whole coral reefs in the Eastern Pacific were severely damaged (41,42). Some coral species were thought to have become extinct (43-46) and others became extirpated (locally extinct). Vast 500 to 700 year old coral colonies died. The coral-reef systems of this region may take hundreds of years to recover, or may disappear entirely. Some partial mortalities occurred within colonies, but few whole colonies died. Most of the bleaching in the Caribbean in this event occurred in the Western Caribbean and Florida in 1983 (1,40).

1986-88 Bleaching Complex

Minor bleaching occurred in widely scattered areas in the Atlantic and Pacific in 1986. In 1987, major bleaching was concentrated in the Caribbean (1,5-7,24-27,35,36), although some occurred in other areas. In 1988, most bleaching was minor, except for severe bleaching in Bermuda (1,8,47). Extensive partial mortalities of colonies, and some total mortalities of coral-reef organisms occurred (48), including the death of some giant 400 - 500 year old colonies (1). This was the first complex of bleaching events documented in detail with the help of observers around the world (1).

1989-91 Bleaching Complex

Minor bleaching occurred in parts of the Caribbean in 1989. We used our “Preceding-major-following”, three year, event-complex pattern (1), to predict major bleaching would occur in 1990 (22), and later that year, there was the most severe bleaching ever experienced in the Western North Atlantic. The event extended from Bermuda, Texas, and Florida throughout the Caribbean, and seems to have had some effect down to Brazil. Mass mortalities immediately occurred in fire corals and stony corals in a number of areas. Over the longer term, corals, gorgonians, sponges and other coral-reef organisms died. Partial colony mortalities occurred in a wide variety of other organisms. Severe bleaching occurred in isolated parts of the Pacific in 1991.

1994-1996 Bleaching Complex

This complex began in French Polynesia (49,50). Severe and widespread coral-reef bleaching occurred throughout much of the Caribbean in 1995, and a few places were bleached which had not previously experienced bleaching events (51), but few mortalities of corals were reported. The event was not quite as destructive in the Caribbean as the major event of 1990 (39).

1997-99 Bleaching Complex

Coral-reef bleaching in the 1997-1999 complex was the most severe with the highest mortalities ever reported in major portions of the Indo-Pacific. It was so devastating that it spawned an alarm message from the International Society for Reef Studies “ISRS Statement on Global Bleaching 1997-1998” [http://www.coral.noaa.gov/bulls/isrs-bleaching.html]. In some areas, whole coral reefs were destroyed. Although severe bleaching occurred in the Caribbean, this paled in significance to that in the Indo-Pacific. From the reports we received and from our field observations at several islands, damage in the North West Caribbean seemed moderate; however, others (52) suggested that the Caribbean as a whole suffered damage comparable with other major bleaching events. At least two internet summaries of this complex exist: “Review of coral bleaching worldwide 1996-1998 by Dr. Peter W Glynn” [http://coral.aoml.noaa.gov/glynn/], and “The 1997-1998 mass bleaching event around the world compiled by Clive Wilkinson” [http://coral.aoml.noaa.gov/gcrmn/mass-bleach.html].

Research efforts

Ten years ago, the notion that elevated seawater temperatures were primarily the cause of coral-reef bleaching (1) was poorly accepted by the scientific community (53) despite eloquent field and aquarium experimental proof (54). Any potential loss of the coral reefs (1) was ridiculed (53) with scientific articles going so far as to suggest that some bleaching reports were simply the confusion caused by light-colored morphs (55). However, currently, the elevated seawater temperature cause is no longer disputed (56-58), and most scientists now accept the possibility of the loss of the coral reefs (59-60).

The US Senate (28) and US House of Representatives Hearings (29), a NOAA Workshop (25,36,61), a joint NOAA/EPA/NSF meeting (62), and numerous other meetings have recommended large scale investigation of coral-reef bleaching events. The most recent major bleaching shocked the scientific community into the rather drastic, although thoroughly justified, ISRS Statement (see above), and a spate of new meetings and initiatives (for example, A National Action Plan to Conserve Coral Reefs, Task Force Meeting, St. Croix, VI, 2 November 1999) (63).

Some progress has been made in recording, explaining, predicting, and posting alerts over internet. NOAA [Coral Health and Monitoring Program (CHAMP) http://coral.aoml.noaa.gov/] and The Global Coral Reef Alliance (GCRA) [http://www.fas.harvard.edu/~goreau/] now maintain internet sites for bleaching reports and databases. The Coral Disease Page [http://ourworld.compuserve.com/homepages/mccarty_and_peters/coraldis.htm] also presents a summation of coral-reef bleaching information. NOAAs Hot Spot Tracking System at the Oceanic Research and Applications Division (ORAD) [http://orbit35i.nesdis.noaa.gov/orad/index.html], [http://psbsgi1.nesdis.noaa.gov:8080/PSB/EPS/SST/climohot.html] posts alerts of elevated seawater temperatures which can potentially cause bleaching (64-65), to allow field scientists to locate ongoing outbreaks. The Coral List [http://coral-list@coral.aoml.noaa.gov] allows posting of bleaching alerts and online discussion of details. The Caribbean Coastal Marine Productivity Network (CARICOMP) Caribbean marine laboratories also posts alerts through its e-mail system to the labs.

Since bleaching events now occur more frequently, our prediction scheme (22) has become overpowered. A system based on temperature anomalies (57,64-65) is more applicable and precise. Most observers worry about coral-reef bleaching events becoming ever more intense and devastating, which they seem to be (60); however, this is not necessary to cause major damage to the reef. Corals require, at least 4-5 years and probably more, to fully recover zooxanthellae and energy reserves from major bleaching, and major events are occurring at least every 2-3 years, and approaching annually in some areas. Therefore, cumulative damage from bleaching must increase in devastation simply because corals never have the opportunity to recover between events.

This lack of adequate recovery time could eventually make corals and other photosymbionts more susceptible to diseases and injury (17). Even obscure or new diseases could suddenly cause problems throughout the ecosystem due to the exhausted energy reserves of coral-reef organisms (see Coral Diseases below) (Table 1).

2. SEA URCHINS

The most widespread mass mortality of sea urchins occurred in the Western North Atlantic in 1983-1984 (66), and mass mortalities of species of urchins in the same genus and/or family occurred in the Hawaiian Islands and Japan. Lesser Caribbean mass mortalities have also been recorded.

The largest mass mortality of a marine invertebrate that has ever been recorded occurred throughout the Western North Atlantic throughout 1983 and affected the longspine sea urchin, *Diadema antillarium*. This has recurred several times since, but no causative agent has ever been identified. It seemed to behave as a water-borne pathogen (66); possibly a virus (6,26), a bacterium (67), or possibly a variety of agents and environmental change. This urchin was formerly the most abundant large invertebrate in the Caribbean. It was ecologically important, and its loss may have resulted in other ecological disturbances, for example, algal overgrowth of reefs. The populations of this urchin have been slow to recover, and have suffered recurring mortalities (34). It appears to have been the first generalized and widely distributed marine invertebrate to be threatened with extinction during recorded history.

1983-84 Major event

The major event in the *D. antillarium* mass mortality (DAMM) began off the Caribbean coast of Panama in January 1983 and spread with the prevailing water currents throughout the western North Atlantic until most areas were affected by January 1984. From 95 - 99% of all the longspine sea urchins died in areas where they were monitored. The mortality passed through each area so rapidly (3-4 days) that study of the disturbance was difficult (66).

DAMM possible recurrences

In the fall of 1985, recurrences of longspine sea urchins mortalities were reported by people studying the after effects of the 1983-1984 DAMM in Panama and St. Croix (68). Mortalities may have occurred in many other Caribbean locations as well, but were not reported. The populations of this urchin were so low that researchers had to be closely examining populations of urchins to know that another mortality had occurred. In 1990, mortalities of this urchin were observed in Jamaica, the Cayman Islands and Belize. These events happened over a period of approximately a week in each area and killed most of the remaining longspine sea urchins (34). In 1991 mortalities occurred for several weeks in the Florida Keys and seemed to move along the Keys somewhat reminiscent of the 1983-1984 mass mortality (34). In 1992, these urchins died in two isolated areas in the US Virgin Islands. If mortalities had continued in these already depleted populations of urchins, this urchin could have eventually become extinct. However, we are aware of no new outbreaks since that time, thus the populations may have time to recover.

Research efforts

The rapid passage of the disease through a location made study difficult. Most of the specimens which were preserved in 1983-1984 consisted of internal organs of the urchin, while the agent seemed to affect the tegument and musculature of the spines. Analysis of preserved or frozen materials has not isolated the infectious agent responsible for the mortalities. Subsequent efforts have concentrated on the ecological effect of the urchin loss, not on the actual cause of the disturbance. Dr KE Nusbaum (Auburn University, personal communication) made a temporary cell culture (similar to the technique established to isolate shrimp viruses) from the infected urchin hosts we collected from one of the recurrences. Unfortunately, the cells died in the culture medium before a cytopathic effect (CPE) became obvious.

Recurring mass mortalities of other urchins in the temperate Atlantic region may have been encouraged by overpopulation and elevated seawater temperatures predisposing urchins to mass mortality (69-70). The DAMM event may have also involved overpopulation and elevated temperatures, but it may have also been caused by an exotic virus of these urchins imported from the Pacific into the Caribbean (see below) (6,26).

These urchins appear to be slowly recovering in parts of the Caribbean; however, still in very low population numbers. No recent recurrences of mortalities have been reported, but these would be difficult to recognize due to the low density of this urchin.

Similar disturbances

A mass mortality of *Echinothrix calamaris* was first reported on the west coast of Hawaii in the Hawaiian Islands in August 1981. By December 1981, the mortality was found throughout the Hawaiian Islands. Dying echinoids had drooping spines, spines falling out, and degeneration and sloughing of the epidermal tissues. Another diadematid, *Diadema paucispinum*, was also affected at the island of Hawaii, but not noted in reports from the other islands. Other echinoids, *Tripneustes gratilla*, *Heterocentrotus mammillatus* and *Echinometra mathaei*, were not affected. The exact extent and severity of the mass mortality was never determined. A number of bacteria, mostly *Vibrio* spp., occurred in the degenerated urchin tissues, but these were thought to be secondary invaders. No cause was determined for the mass mortality, which ended in early 1982 and has apparently not recurred since (Brock JA, Aquacult Develop Progr, Honolulu, Hawaii, personal communication) (71). The signs and general information concerning the spread, extent and severity of this disturbance seem reminiscent of the better documented Caribbean mass mortality of the longspine sea urchin. Drs EC Peters (Tetra Tech, Fairfax, Virginia, personal communication), and Brock (personal communication) compared histological preparations from the Hawaiian and Caribbean mass mortalities, but the similarities were not conclusive.

In 1987, a mass mortality of sea urchins occurred in Sagami Bay near Tokyo, Japan. The signs and progress of the disease was very similar to what occurred in the DAMM. Millions of urchins, mostly *Anthocidaris crassispina*, were killed. Early investigations searched for a virus, but no cause was determined (Shimada H, Hiroshima Univ, Japan, personal communication). Local experts examined this mortality and a number of urchin specialists in Japan were contacted, but no additional information has been obtained about this disturbance.

Numerous other Caribbean urchin species have suffered mass mortalities during or shortly after the DAMM, but they cannot be directly linked (10). The most interesting was a mass mortality of *Astropyga magnifica* on the West coast of Puerto Rico. The exact extent of these mortalities could not be determined due to the disjunct distribution of populations of this host. This urchin is closely related to the longspine sea urchin and showed the same signs as those of dying longspine sea urchins. A recurring mass mortality of white-spine sea urchins, *Tripneustes ventricosus*, began in Puerto Rico in 1991 and intensified in 1995 (32).

3. FISH

Both mass mortalities and enzootics of fishes have occurred in the Caribbean Region. We compare and contrast the largest of these events and suggest possible relationships. A number of other fish kills are routinely recorded in the Caribbean, but most of these involve too few fish, are too localized, and/or are of too short a duration to be considered MMEDs. Methods for investigating these events have been suggested (18,37,72).

Caribbean-wide fish mass mortality

In the last 20 years a number of large-scale fish mass mortalities have occurred in the Caribbean Region (Figure 2).

Figure 2. Dead and dying fish in a fish kill.

All of these affected a variety of fish, occurred over extensive geographic areas, and over a long time period. Unfortunately they were also poorly documented and practically unstudied (18,37,73). The otherwise rarity of such events and their close occurrence pattern is suggestive of events in a complex. These major fish events also seem to be relatively similar in terms of fish species killed, disease signs, and fish behaviour, but this may simply be as a result of poor documentation. If not a complex, then these episodes may at least represent recurring events.

Table 1. New diseases, syndromes, or conditions, and those becoming suddenly more common or widespread, affecting Caribbean coral reef organisms.

Disease / Syndrome	Organisms affected	Cause(s)	References
Algal overgrowth syndrome (AOS)	stony corals fire corals	various species macroalgae	14,106
Barrel sponge crumbling syndrome (BSCS)	Barrel sponge *Xestospongia muta*	Unknown	-
Black band disease II? (BBD-II?)	Sponges	Cyanobacteria?[a]	-
Blue-green algae overgrowth (BAO)	Branching corals	*Oscillatoria*, *Schizothrix*, *Microcoleus* spp.	106
Caitapa-mojarra mass mortality (CMM)	Caitipa mojarra *Diapterus rhombeus*	Virus?	11
Coralline lethal orange disease (CLOD)	Coralline algae	Bacterium	134
Coralline algae disease (CAD)[b]	Coralline algae	?bacterium	14
Coral snail outbreaks (CO)	Staghorn coral *Acropora palmata*	Coralsnail *Coralliophila abbreviata*	4
Damselfish-ridge denuding syndrome (DDS)	Boulder brain coral *Colpophyllia natans*	Threespot damselfish *Stegastes planifrons*	94
Dark-blotch or –spots disease I (DBD-I)	*Siderastrea siderea*	Unknown	14
Dark-blotch or –spots disease II (DBD-II)	Massive stony corals	Unknown	14
Epizootic black band disease (BBD-I)	Stony corals	*Phormidium corallyticum*[a]	3
Finger-coral denuding syndrome (FDS)	Finger coral *Porites porites*	Unknown	94
Flamingo tongue outbreaks (FTO)	Gorgonians	Flamingo tongue *Cyphoma gibbosum*	-
Patchy necrosis / white pox (PN/WP)	Elkhorn coral *Acropora palmata*	?bacterium	14,135
Rapid wasting syndrome (RWS)	Star coral complex and other stony corals[d]	Fungus[c] Parrotfish[c]	136 137
Reef-dwelling foram disease (RFD)	*Amphistegina gibbosa* (Foraminiphera)	Unknown	138
Red-band disease I (RBD-I)	Many stony corals	*Oscillatoria* spp.[a,e] (cyanobacteria)	89
Red-band disease II (RBD-II)	Many gorgonians	*Schizothrix mexicana*[a,e] *S. calciola* (cyanobacteria)	88 14 91
Sea-egg plague (SEP)	Sea egg (urchin) *Tripneustes ventricosus*	Unknown	32
Sea-fan fungus disease (SFD)	Venus / common sea fan *Gorgonia flabellum / ventalina*	*Aspergillus* sp. (fungus)	112-115
Sea-pussy disease (SPD)	Sea pussy *Meoma ventricosa*	*Pseudoalteromonas* sp. Tetrodotoxic bacteria	14,139
Sea-turtle tumour panzootic (STP)	Green turtle *Chelonia mydas*	virus[f] Toxic algae[f]	2,98 99

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Table 1. –continued -

Disease / Syndrome	Organisms affected	Cause(s)	References
Slime-blotch disease (SBD)	Coral reef fish	*Brooklynella hostilis*[a,g] (protozoan)	76
Sponge disease (SD)	Barrel, tube and encrusting sponges	Unknown	14
Sponge overgrowth syndrome I (SOS-I)	Stony corals Fire corals	*Cliona* spp.[h]	106
Sponge overgrowth syndrome II (SOS-II)	Stony corals[i]	*Mycale laevis*	-
Star-coral polyp necrosis (SPN)	Great star coral *Montastraea cavernosa*	Unknown	140
Stress-related necrosis (SRN)	Stony corals	?environmental conditions	81
White-band disease II (WBD-II)	Staghorn coral *Acropora cervicornis*	?*Vibrio* sp. (bacteria)	141,142
White or coral plague I (WP-I)	Star coral complex and other stony corals	Unknown	3,14
White or coral plague II (WP-II)	Many massive corals	*Sphingomonas* sp. (bacteria)	3,14, 143,144
Yellow-blotch or –band disease (YBD)	Star coral complex *Montastraea annularis*	Unknown	91
Conditions not to be confused with new diseases			
Threespot damselfish chimneys (TDC)	Elkhorn and staghorn coral	Threespot damselfish *Stegastes planifrons*	95
Yellowtail damselfish predation (TDP)	Elkhorn coral	Yellowtail damselfish *Microspathodon chrysurus*	95

[a]a consortium of microorganisms is involved. [b]also called coralline lethal disease (CLD); [c]the agent may be a fungus (136), bites by parrotfish (137), or both. [d]particularly boulder star coral, *Montastraea annularis*, and boulder brain coral, *Colpophyllia natans*. [e]different agents appear to be involved in different regions; 3 or more similar diseases may exist. [f]see discussion in text; both a viral agent (2,98) and toxic algae (99) have been proposed. [g]the 1980 Caribbean-wide fish kill (26,37) probably shared the same agent. [h]Some question which species are involved, we (20) reported *Cliona langae* from Puerto Rico, which Dr Jeff Holmquist (Department of Marine Science, University of Puerto Rico, personal communication) confirmed our identification and stands by his diagnosis, this sponge was identified as *C. caribbea* from Belize (106), while Dr Ernesto Weil (Department of Marine Science, University of Puerto Rico, personal communication) suggests this may be a *C. aprica - C. caribbea - C. langae* species complex, or an exotic species of Pacific *Cliona* may be involved. *Cliona caribbea*, *C. lampa*, and *C. varians* have been noted to kill Caribbean stony corals in the past (145), but not epizootically; *Chondrilla nucula* (146) and *Chondrilla* spp. (106) have also been noted to overgrow Caribbean corals, but not as extensively as *Cliona* spp. [i]The sponge *Mycale laevis* grows on the underside of the stony corals *Montastraea cavernosa*, *M. annularis*, *Mycetophyllia lamarckiana*, *Porites asteroides*, and *Agaricia agaricites*. Prior to coral reef bleaching (CRB), this relationship was stable. Now this sponge occasionally partially or completely overgrows corals weakened by CRB.

Possible preceding event
In mid-June to early July 1980, a mass fish kill occurred along the Florida reef tract from the Dry Tortugas to West Palm Beach. More than 30 species of reef fish were affected. Most reports came from deeper, offshore reefs adjacent to the Gulf Stream. No cause was determined but some of the fish had high levels of the protozoan parasite, *Cryptocaryon irritans* (74-75). This “marine ich” is usually seen only on captive fish, although it was later found in mortalities of wild Caribbean fish (9).

1980 Major event
The Caribbean-wide mass mortality of fish is one of the largest, longest lasting, and least understood fish kills. Most of the mass fish kills occurred in August and September, although reports of abnormal fish behavior continued into December. A great variety of fish died, including those from coral reefs to open ocean pelagics. All sizes of fish were affected up to very large groupers and big game offshore fish. Most areas in the West Indies and South Florida were affected, but the pattern and occurrence of the events were erratic, and no pattern could be discerned. The passage of Hurricane Allen occurred just before these disturbances began. Most observers thought temperature or other physical changes caused by the hurricane would be too small to produce mass mortalities of fish (37). Reports of red tides and increased parasites were too limited in extent to have caused such widespread mass mortalities (37).

1981-83 Bermuda possible recurrences
Mass mortalities of fish occurred in the summers of 1981, 1982 and 1983. They were similar to the major kills of 1980, but apparently did not occur elsewhere in the Western North Atlantic.

1993 Angelfish mortality in South Florida
A mass mortality of angelfish (blue angelfish, *Holacanthus bermudensis*; French angelfish, *Pomacanthus paru*; gray angelfish, *Pomacanthus arcuatus*; queen angelfish, *Holacanthus ciliaris*; rock beauty, *Holoacanthus tricolor*) occurred along the south Florida reef track in the fall through winter of 1993. A ciliate parasite, *Brooklynella hostilis*, was implicated as the primary pathogen involved in the kill (76).

1994 Coral-Reef fish mass mortality in Barbados
A widespread mass mortality of coral-reef fish occurred in Barbados from late July through September 1994. It began in fish in traps and bottom fish, but eventually spread to most coral-reef species. These last two disturbances are related in primary disease agent, and timing, if not in the species of fish involved. We suspect that these may also be related to the previous widespread Caribbean fish kills (discussed above).

1999 Eastern Caribbean mass mortality
From Barbados to Venezuela millions of Caribbean marine fish perished for more than a month in mid-1999. The Barbados Government requested assistance from the US State Department, which in turn contacted the Caribbean Fishery Management Council, and they in turn contacted the authors. Unfortunately the kill had ended before we could be sent to Barbados. The mortality was reported to have slowly spread South to North. This first made biologists fear that a toxic river discharge was the culprit, but this is unlikely considering the dilution inherent over such an area. One researcher examined a few fish samples and isolated a bacterium. Caribbean agencies announced this was the causative agent. However, information presented at a workshop held in Barbados after the event suggests this conclusion was unsubstantiated. As with many other major disturbances, little or no definitive sample analysis was properly conducted, and no progress was made in understanding the event.

Caribbean enzootic
Over the last five years we have been receiving reports of Caribbean marine fish with persistent lesions (particularly surgeonfishes), minor fish kills, and unusual fish behaviour. For those few in which we have received samples, *Brooklynella hostilis* and its associates were found to infect the fish. These signs, diagnoses, and patterns of occurrences lead us to predict that another Caribbean-wide mass fish mortality will eventually occur. The exact conditions favoring these long-term debilitations and ultimate mortalities are not clear. This could be related to the general decline of the coral-reef ecosystem in the Caribbean.

Research efforts
These events remain unexplained and only circumstantially related. Unusual meteorological conditions that favored upwelling or rapid cooling of waters occurred in June and July during the preceding event in Florida and during Hurricane Allen in the beginning of the major event in the Caribbean in August (73). Very little is known about the effect of such changes on coral-reef fish. The pattern of mortalities in the 1980 Caribbean event did not follow the path and timing of the hurricane. Mass mortalities and unusual fish behavior lasted for many months, which seems to suggest something more complicated than a single physical disturbance.

Coral-reef bleaching complexes also occurred in 1979-1980 and 1982-1983, but not in 1981. The coincidence of these major fish kills and coral-reef bleaching is intriguing, but we have no evidence to directly link these large scale disturbances. It is interesting to note that major coral-reef bleaching in Bermuda in 1988 occurred one year after major bleaching in the Caribbean in 1987. This is very similar to the pattern of the 1980 and 1981 occurrences of fish mass mortalities.

A meeting session (73) and an IOCARIBE (Intergovernmental Oceanographic Commission’s Regional Association for the Caribbean and Adjacent Regions, United Nations) Committee (37) examined the 1980 major fish kill and made recommendations to follow and solve this problem. However, as far as we know, none of these recommendations was implemented. During a subsequent IOCARIBE meeting in Cuba, the emphasis was shifted from the "mass fish kill" to "Caribbean mass mortalities" in general, but the same recommendations of the IOCARIBE 1980 committee were stressed. The latest IOCARIBE meeting on this topic was held in Venezuela in the fall of 1992 (see Introduction). The Caribbean Fishery Management Council has offered us travel and support to investigate Caribbean mass fish kills.

Few large-scale mortalities of open ocean and coral-reef fishes have ever been reported in the literature. The timing and similarities in disease signs and fish behavior among these events and disturbances make these events attractive candidates for being part of an interrelated disturbance or complex. Unfortunately, we lack definite evidence of this association.

Dr Jan Landsberg (Florida Marine Research Institute, personal communication) has suggested that *Brooklynella hostilis* and its associates are the causative agent of all of these fish kills and syndromes. This seems the best diagnosis available, although we do not have adequate samples for all of the cases. In the cases where she and her lab, or we, have examined fresh, or freshly preserved, material, this agent has been implicated. She has examined some preserved materials from the 1980 event and found the same agent. Of course, identifying the agent is only one part of the puzzle. The most important question is what is debilitating Caribbean coral-reef fish so thoroughly that a pathogen previously only known from aquarium fish is now killing them.

Caribbean herrings
Mass mortalities of the three species of herrings in the genus *Harengula* (false pilchard, *H. clupeola*; redear sardine, *H. humeralis*; and scaled sardine, *H. jaguana*), occurred in the Eastern Caribbean from Venezuela to Puerto Rico (23) and the Dominican Republic throughout the 1980s and 1990s. Mortalities varied in size from one bay to a series of islands, and in numbers of fish from thousands to many millions. Difficulties in obtaining fresh samples of dying fish hampered our efforts to explain this mortality. Because the species affected are in the same genus, we suspect that the agent is a virus and we arranged a cooperative investigation with a fish-virology laboratory.

At least two recent mass mortalities of herrings in Venezuelan coastal lagoons were caused by "red-brown tides" and/or low oxygen conditions (E Weil, Department of Marine Science, University of Puerto Rico, personal communication). These may explain some of the mortalities in confined locations, but as we previously discussed, open water areas in the Caribbean seldom suffer harmful algal blooms.

In the last five years, we have inexplicably received no new reports of this event. Unsubstantiated suggestions have been made by other diagnostic labs that the herring disturbances might be related to the Brown pelican disturbances either by becoming unavailable as a food source or by transmission of toxins (see below).

In June 1985 and May - June 1986, mass mortalities of herrings, *Clupea harengus*, occurred off Alaska (77). Similar mass mortalities occurred at almost the same times in Caribbean herrings, but this only seems coincidental (23). A viral disease, viral erythrocytic necrosis, was associated with the Alaska mass mortalities (77).

Caitipa mojarras
Mass mortalities of Caitipa mojarras, *Diapterus rhombeus*, occurred in Puerto Rico and the Dominican Republic in 1998 (11). Single-species fish kills are often caused by host-specific pathogens, however, unfortunately, fresh samples could not be obtained from any of the mortalities (11).

Atlantic anchoveta
Six to eight million Atlantic anchoveta, *Cetengraulis edentulus*, perished in a major mortality 9 March 1992 in the mangroves of Venezuela (78). Small fish kills of anchovies or herrings routinely occur in Caribbean mangroves perhaps related to epizootic anoxic events, but this major fish kill is more serious and could represent some form of MMED. We have received unsubstantiated rumours of frequent mass fish mortalities in Venezuelan waters. More information is needed to properly evaluate this event.

Parassi mullet
Hundreds of thousands of parassi mullet, *Mugil incilis*, died in a mass mortality between Cienaga Grande de Santa Marta and the Easternmost bays Northeast of Santa Marta, Colombia, during a two-week period in mid-December 1990. About a week into the mortality, a number of coral-reef fishes also began to die. We had agreed to examine frozen samples taken from the dying mullet and to forward a portion of the samples to other laboratories. Unfortunately, guerrilla bombings destroyed the samples. Kills of Caribbean mullets are unusual and more information is needed to properly evaluate this event.

4. CORAL DISEASES

We define "corals" in this section as either stony coral (*Scleractinia*) or fire coral (*Milleporina*). Until a few years ago, Caribbean coral diseases were limited to coral-reef bleaching, white-band disease, and black-band disease (1,8,26,38,79,80). Now suddenly, we are faced with 20-40 (depending on who counts) new, alarming, epizootic diseases, syndromes, or conditions of Caribbean corals and other coral-reef organisms (12-16,81-83) (Table 1). Most of these new disturbances are poorly known and the causative agents are unknown. A few occurred previously but in such low levels that they were not recognized. Discovering and defining these agents is important, but more vital is learning what precipitated this sudden "explosion" of epizootics.

A great deal of confusion exists over incompletely designated diseases or syndromes, duplicate names, and unsubstantiated causes or agents (Table 1). Many organizations exist to regulate standard names and definitions of diseases for different groups of host organisms or pathogens. We suggest that a coral-reef disease committee [Committee Ordering Reef-diseases And Lethalities (CORAL)] be established to form rules for naming, defining and recognizing coral-reef diseases and syndromes; and to publish an annual list of recognized diseases and syndromes.

White-band disease

White-band disease (WBD) is a mysterious ailment of corals which causes the tissue to slowly strip off exposing the white skeleton. It usually begins at the base of a colony and slowly moves upward until the entire colony is killed. Green and brown algae colonize the bare skeleton and move up the colony just behind the wide white band of WBD. Some attacks by WBD begin in the middle of a colony (possibly other diseases), and sometimes the entire colony is not killed. However, colonies that recover from one attack often suffer relapses.

In the late 1970s or early 1980s, an epizootic of white-band disease (WBD) began which drastically reduced the abundance of elkhorn coral, *Acropora palmata*, and staghorn coral, *A. cervicornis*, in the Caribbean (1,84). These corals are the fastest growing reef-building corals in the Caribbean and their destruction may reduce the ability of coral reefs to recover from other disturbances. This mass mortality was almost totally ignored for a number of years (1) and thus the pattern and rate of spread was not recorded. Bacteria have been found in some cases (85), but not all. WBD may be the reaction of corals to widespread adverse environmental conditions rather than a disease due to a microbial agent. WBD is also a serious problem on acroporid corals in the Indo-Pacific, but does not appear to have reached major disturbance status. Some WBD occurred concomitant with major bleaching in 1987 (1), but no relationship between these disturbances has been established. WBD has forever altered the physical and ecological structure of Caribbean coral reefs (21,70), and the drastic reduction in population levels and possible loss of the two fastest growing reef-building coral species may hasten their demise.

Black-band disease

Black-band disease (BBD) is characterized by a band, arranged in an arc or circle, of darkly colored cyanobacteria (also called bluegreen algae) that slowly spreads across a stony coral leaving white bare skeleton behind. The white area is soon covered with filamentous green and brown algae producing a greenish-brown dead area ringed in white and black bands with normal appearing tissue in front of the leading edge of the band. The prevalence of BBD fluctuates, but it had always occurred at low levels, or was enzootic, on coral reefs. Recently, BBD has caused epizootics similar to those found in WBD, but so far in a more limited geographic range. This condition seems to be most prevalent during the summer, and limited evidence suggests that incidence may increase during coral-reef bleaching events.

We received reports from many Caribbean locations of an increase in the incidence of BBD in the late 1980s and early 1990s (1,unpublished). Often the suggestion has been made that these increases follow or are concurrent with bleaching or other disturbances on the coral reefs. These opinions are of interest, but they must be backed-up with monitoring studies before this trend can be confirmed. Very few long-term monitoring studies exist in the Caribbean. BBD epizootics have recently occurred in, the Bahamas, Belize, Bonaire, the Cayman Islands, South Florida, Jamaica, Mexico, Panama, St. Vincent and Puerto Rico (3,79,80,86). BBD appears to have recently changed from a minor enzootic disease to a major epizootic problem.

Fire-coral fungal disease (FFD)

Coral-reef bleaching apparently reduces the resistance of Caribbean fire corals (*Millepora* spp.) to a fungal associate living in the skeleton of fire corals. This agent attacks the living tissues of fire coral and kills them. This agent was discovered in the Florida Keys (87), but probably occurs throughout the Caribbean Region. This may explain why fire corals suffer mass mortalities following bleaching events. The new epizootic diseases (Table 1) may be benefiting from a similar situation.

Red-band disease

Red Band Disease (RBD) is one of the new, epizootic diseases (Table 1). It has been known to occur in sea fans since 1983 (88) and in stony corals (89), but has only recently become widespread and epizootic (14). RBD is similar in many respects to BBD, but is caused by different cyanobacteria (90). The species of cyanobacteria seem to differ in different geographic localities (91), and include *Oscillatoria* spp. (89), *Schizothrix mexicana* (90), *S. calciola* (90), and others (14). RBD may represent a complex of three or more similar diseases, or different “phenotypes”.

Coralivorous (coral-eating) molluscs

Since the early 1980s outbreaks of the coral-predatory snail, *Drupella* sp., have occurred in the Red Sea, Japan, the Philippines, the Marshall Islands and Western Australia. Previous to these outbreaks, this snail was apparently rare. The outbreaks caused considerable damage in *Acropora* spp. colonies (92). The underlying reasons for these outbreaks is (are) unknown and the timing, extent, severity and distributions of outbreaks have often been incompletely documented. In the Caribbean, a coral-eating mollusc, *Coralliophila abbreviata*, has also begun to destroy *Acropora* spp. (4). We have also observed six outbreaks of Flamingo Tongues, *Cyphoma gibbosum*, killing Caribbean gorgonians (unpublished).

Sudden reef demise

Venezuela possesses a number of offshore islands with well developed coral reefs, but has few coastal coral-reef systems. One of the most important was the Parque Nacional Morrocoy, Estado Falcón (10°52’N, 69°16’W).

In January 1996, an unusual upwelling event, combined with large river outflows and poor water circulation, nutrified waters around the park, causing a massive plankton bloom. The reefs became covered with a mucus layer produced by the dinoflagellates and diatoms. Very calm seas allowed the bloom to remain in the park for a week. Almost all of the anemones, annelids, corals, crustaceans, echinoderms, fishes, gorgonians, sipunculids, sponges, and other coral-reef organisms were smothered by the mucus layer and died from anoxia (93). This sudden destruction of an entire coral reef and all its inhabitants was unprecedented in the Caribbean. A similar event killed coral reefs near Hong Kong when the Pearl River flooded. This mass mortality has also been blamed on a chemical spill of unknown origin and composition, however, there does not appear to be any evidence to support this suggestion. We do not list this catastrophic elimination of an entire reef system as a new disease or syndrome (Table 1) because we hope it was a unique event.

Research efforts

WBD has only become less widespread because the populations of its coral hosts have collapsed in many parts of the Caribbean. We suggest that this disease may cause the extinction of elkhorn and staghorn corals in the Caribbean. BBD seems to be changing from a minor background disease into an epizootic terror. So many new, epizootic Caribbean coral diseases have recently been observed that we do not have adequate names for most of them, much less causative agents (Table 1).

A number of researchers and research groups are studying individual diseases. After these new diseases emerged, several coral-reef organizations proposed the creation of plastic disease identification cards as an aid in identifying all the new diseases (94,95). An effort to coordinate this effort into one standard series of cards failed, and now at least eight different sets of varying quality exist. As part of the National Action Plan to Conserve Coral Reefs, a “Coral Disease Research Consortium ... would draw on the expertise of scientists from around the US who are actively involved in bleaching and disease research; the objectives are to 1. Document the condition of our coral-reef ecosystem, 2. Determine the causes(s) of diseases, bleaching, and mortalities, 3. Define exposure-response threshold values and associated criteria, as appropriate, and 4. Provide technical information and assistance to managers and scientists regarding the health of coral reefs and possible causes and remedies” (63). An examination of the possible interrelationship among events was not considered.

Learning the primary cause(s) of each disease or syndrome is important, but understanding the juxtaposition of so many new epizootic events, and what this new phenomenon means is vitally important. This unprecedented increase of epizootic diseases seems to indicate a collapse of the Caribbean coral-reef ecosystem. In the worst case, this could signal a demise of the system.

5. TURTLE TUMOUR (FIBROPAPILLOMA)

Fibropapillomas in sea turtles (Figure 3) are large (up to 30cm) lobate tumours on the skin, scales, scutes, eyes, mouth or viscera. They may cause disfigurement and interfere with vision, breathing, feeding and swimming. Fibropapillomas in sea turtles, and especially green turtles, *Chelonia mydas*, were first described more than 50 years ago in the Florida Keys. Until recently these tumours were very rare, but they have greatly increased in abundance in the last 20 years in Florida and Hawaii, and in the last 15 years in the Caribbean (2). This condition may be a significant threat to the survival of the already threatened sea turtles (96). This seems to be another new large-scale disturbance. Mass mortalities have not been recorded, but most of the “stranded” turtles that local stranding networks are seeing have these tumours. Sea turtles were threatened to endangered throughout much of their range before this new problem arose (2).

Figure 3. Fibropapillomata form large growths on the neck, flipper and head of this green turtle, *Chelonia mydas*.

The occurrence of tumours varies with the species of turtle. For example, they are very common in the green turtle, *Chelonia mydas* (2), rare in the loggerhead turtle, *Caretta caretta* (31,96), the green turtle / loggerhead hybrid, and the olive ridley, *Lepidochelys olivacea* (96), and very rare in the hawksbill turtle, *Eretmochelys imbricata* (31).

An informal working group (12 labs) in the Caribbean documented a dramatic increase in the last 15 years (2,97). An international group of researchers is cooperating with Sea Grant and other organizations in following this problem. A number of other research groups are working with this problem, particularly in Florida and Hawaii. We have concentrated on documenting recent cases in the West Indies (2). The consensus of opinion among Indo-Pacific experts is that very few sea turtles outside of Hawaii, and now Australia, have these tumours; and no epizootics are occurring outside of the Hawaiian Islands.

Early supposition about the cause of these tumours centered around the possibility of the eggs of blood-dwelling flukes clogging the capillaries. No conclusive evidence was ever presented and recent samples we collected from tumors, near tumours, and in areas without tumours were found histologically to have similar amounts of eggs (JC Harshbarger, Regist Tumors Lower Animals, personal communication). Although these tumours resemble ones caused by viruses in other animals, they cannot be transmitted like similar viral diseases, and viruses have been extremely difficult to isolate. Viruses have finally been isolated by several researchers (98), but the rarity detracts from accepting viruses as the causative agent. More recently, toxic algae have been suggested as the cause of these tumours (99). Like other diseases, this may be a combination of abiotic and biotic factors contributing to the drastic increase and cannot be easily explained.

6. SPONGES

Caribbean sponges (*Porifera*) suffered an early mass mortality, and some species have experienced general declines even to extirpation. More recently, recurring sponge blights and a new, undefined disease (Table 1) have begun to threaten these animals.

Lesser Antilles 1900-1950 extirpations
A number of sponge species of commercial importance disappeared from large areas of the Caribbean sometime from 1900 to 1950. This is thought to be related to decreases in seawater temperatures (101), but may possibly be related to the sponge mass mortalities described below. The exact extent and severity of the 1938-40 and 1947-48 events was never determined.

West Indian mass mortalities 1938-40 & 1947-48
A mass mortality occurred among commercial sponges in the Bahama Islands during the winter of 1938-1939. Later this occurred in Cuba, in March of 1939 in Florida, and in June 1939 in British Honduras. In 1939-1940 this mortality spread through the Gulf of Mexico. In 1947-1948 the mortality returned to the West coast of Florida (100,101).

Mangrove sponge disease (MSD)
Mangrove demosponge, *Geodia papyracea*, in Belize were apparently damaged and killed by their own photosymbionts, *Aphanocapsa* spp. These cyanobacteria overproliferated and attacked the sponge tissues (102). This disease was first noted in the mid-1980s. The geographic range and extent of this disease is not known, or if it may represent an MMED.

Florida Keys sponge blights 1983, 1987 & 1992
Mass mortalities of sponges occurred in the Florida Keys in the summers of 1983, 1987 (1) and 1992. The first two events coincided with major coral-reef bleaching and seawater temperatures elevated above the normal maximae in the same areas, and the last with a mass mortality of many organisms in Florida Bay (103).

Barrel sponge crumbling syndrome
Barrel sponges, *Xestospongia muta*, first lose pigmentation, then their rockhard tissues lose structural integrity and gradually become brittle or fragile, and finally crumble apart. Lesions often develop at the base or on the edges and gradually spread or increase in size. Loss of pigmentation spreads ahead of the crumbling. Lesions may sometimes disappear only to reappear at the same or different locations on a colony. Whole and sometimes giant colonies are killed. The death of large colonies sometimes takes weeks or months. Colonies become horribly disfigured before crumbling away. This syndrome has been observed in Belize; the Florida Keys, USA; and the Southern Caribbean. No causative agent has been isolated ("Coral List" Internet; Peters, personal communication).

Research efforts
The mangrove sponge disease was studied at the Smithsonian Institution. Sponge blights were examined by the Florida Department of Natural Resources. Many sponge species bleach much like other photosymbiotic reef organisms, except that most have symbiotic bacteria instead of algae. They also suffer partial to complete mortalities following bleaching. Their recent disease problems could be related to bleaching damage.

7. ALGAE

Toxic algal outbreaks or "Red or Brown Tides" are increasing in number, size, geographic extent, and types of toxic agents involved worldwide (104,105). Red tides have increased in the last 30 years while mass mortalities have increased in the last 20-25 years (1). There may be some relationship between red tides and other mass mortalities. We hear rumours of alleged occurrences of large-scale toxic algal outbreaks in different parts of the insular Caribbean. Various Caribbean mass mortalities have been blamed on "red" or "brown tides," but no evidence of toxic algae has ever been presented. The open waters of the insular Caribbean are poor sites for the development of toxic tides. The circulation is too good (no means to confine or concentrate algae) and the nutrient levels are too low to generate sufficient algal numbers. In short, we are aware of no toxic tides ever occurring in any relatively large, open, insular Caribbean area. Small restricted bays or confined continental waters in the extreme Southern Caribbean or South Florida may be vulnerable to these problems. However, in general, this is only rarely a Caribbean problem.

However, algal overgrowth of both coral reefs and seagrass beds has become a serious problem in the Caribbean (Table 1). Problems with ciguatera toxins, in contrast to harmful algal blooms, do not seem to be increasing.

Algal overgrowth of coral reefs
Increased growth of algae seems to be threatening Caribbean coral reefs (106,107). We have received a few reports of algal overgrowth of corals. Very few of these areas have been monitored for abundance of algae in the past and therefore, increases are difficult to confirm. In some extreme cases the death of corals or sections of the reef are caused by algal overgrowth. On 2-7 August 1998, we noted severe algal overgrowth problems (Figures 4 & 5) at most of 25 coral-reef sites we examined around all three of the Cayman Islands (unpublished).

Algal problems on Caribbean reefs are circumstantially and logically correlated with the loss of longspine sea urchins following the DAMM, loss of other herbivorous organisms, such as fish due to over fishing, and increases in nutrification. To a certain extent, many of the organisms that once controlled the algae have been lost and increased nutrient levels, which encourage additional algal growth, have occurred on all Caribbean reefs. Combined with the impact of other disturbances, algal over growth has drastically reduced the amount of coral cover, for example, 3-5% in Jamaica (60,108).

Algal mats
In the summer of 1990, mats of algae damaged coral reefs in Southwest Florida, the Florida Keys, and the Northern Bahamas (unpublished). There have been minor recurrences since that time. Early reports suggested that the green algae, *Codium* sp., was a major component of the mats. These mats smother coral reefs killing not only corals but other invertebrates as well. The problem is now found almost everywhere on coral reefs, even where grazers remain abundant. It seems to be linked to the presence of excess nutrients.

Ciguatera
The number of ciguatera fish poisoning cases in humans does not seem to be increasing. Ciguatera toxins have been shown to affect fishes as well as humans, but ciguatera apparently does not cause mortalities of fish (109). Ciguatera does not seem to be a MMED, but it and other accumulative toxins may possibly contribute to large scale disturbances in fish.

Research efforts
Most of the work with algal damage to coral reefs and sea grass beds, that we are aware of, is being conducted in the Florida Keys and the US Virgin Islands. DAMM removed a very important control of algae on the reefs, and their algal control does not appear to have been taken over by other urchins, fish, etc. Increased nutrients may also be contributing to algal problems.

Figure 4. Algae covers the upper half of a large colony of symmetrical brain coral, *Diploria strigosa*.

Figure 5. Tufts of algae invaded this bleached, grooved brain coral, *Diploria labyrinthiformis*, thus killing the colony.

8. GORGONIANS

Gorgonians and sea fans (*Gorgonacea*) seemed to be all but free of epizootic disease until 20 years or so ago, although this may have been largely due to the lack of any detailed disease analysis. Mysterious mass mortalities began in the Southwest Caribbean, and now two new diseases threaten the survival of sea fans, if not all gorgonians.

Caribbean sea fans
These large sea fans (whether one species: common sea fan, *Gorgonia flabellum*, or two: common and venus sea fan, *G. ventalina*) only occur in the Caribbean and are as much a Caribbean symbol as the queen conch (discussed below). Their loss or at least severe decline in abundance seems to be suggested by the extent and

severity of recent disturbances. This would have a devastating impact on the coral reefs since sea fans once dominated some high-energy habitats, have no structurally similar organisms that might replace them, and other dominant inhabitants of this shallow zone of the reef (staghorn coral, fire corals) have been equally devastated by new diseases. A mass mortality of the common sea fan occurred along the Caribbean coast of Costa Rica in 1982 (110), and later on the Caribbean coast of Colombia (111). The same condition has since been found at 20 sites along the Caribbean coast of Panama affecting all *Gorgonia* spp. (HM Guzmán, Smithsonian Tropical Research Institute, Panama, personal communication). This disturbance did not occur in Trinidad and Tobago at that time, and no reports were received concerning the Venezuelan coasts. No causative agent has been identified.

Aspergillosis (fungal disease) of sea fans (SFD)
This alarming condition suddenly appeared in sea fans across the Caribbean (112) (Table 1). It causes holes or lesions to open in the blade of the fan and the gradual loss of all tissue down to the axial skeleton (113). This is one of the few, new epizootic diseases for which an agent has been isolated, and is caused by *Aspergillus sidowii*, of terrestrial origin (114,115).

Red-band diseases. See Coral-reef diseases.

Other Mass Mortalities of Caribbean gorgonians
In the 1980s, unexplained mass mortalities of gorgonians occurred along the north coast of Trinidad; one outbreak of BBD occurred in South Florida (116). Outbreaks of tumors have been reported throughout the Caribbean, and new diseases (Table 1) are responsible for mortality (88,113). Little information is available concerning these disturbances. Gorgonians, their diseases and epizootics should be more closely followed as they are excellent environmental indicators.

Research efforts
We do not believe that the Southern Caribbean sea fan mass mortality or the Trinidad gorgonian mass mortality were caused by the sea-fan fungal disease (114,115) or RBD (89) (Table 1). While these new diseases are admittedly devastating to sea fans, they are rather insidious and slow in their action. Both previous mass mortalities stripped these gorgonians to their skeletons so rapidly that no direct observations were made. Also no evidence connects the Southwestern Caribbean and Trinidad events except adjacent geographic localities, host organisms, and timing. The uniformity of Caribbean events has been contrasted with the diversity of local events in the Pacific (117). This is one case where the Southern Caribbean experienced events distinct from the remainder of the Caribbean.

9. SEAGRASSES

Mortalities of seagrasses have recently occurred in Florida Bay, Chesapeake Bay, and other confined areas of the Atlantic coast of the USA. Algal overgrowth of seagrass beds has been reported in many Caribbean areas (1).

Since the summer of 1987, recurring mass mortalities of turtle grass, *Thalassia testudium*, have occurred in Florida Bay in South Florida (118,119). Similar events have occurred in eutrophic bays in Mexico. The cause of these disturbances has not been determined despite examination by a number of agencies in Florida.

In 1989, an overgrowth of sea turtlegrass, *Thalassia testudinum*, beds by bluegreen algae occurred in the US and British Virgin Islands (120). Similar events have been reported to us from Florida, Jamaica, and Mexico. It is not clear how serious this disturbance may be or what may be causing the problem.

10. MOLLUSCS

Severe mollusc disturbances have occurred in waters adjacent to the Caribbean (121), but so far, we are unaware of any regional problems. There is one potential disturbance worthy of note, and the potential exists for introducing exotic MMEDs.

Queen conch
Queen conch, *Strombus gigas*, have been extirpated from parts of the US Virgin Islands and on other small Caribbean Islands, and they have been made “commercially extinct” in Puerto Rico and in other parts of the Caribbean, through poor management practices. Yet this mollusc remains so commercially important that it is almost a symbol of the Caribbean. The human consumption of conch has not declined in many of the areas where this animal has been depleted, it is merely imported from other areas. Any mass mortality of queen conch has the potential of being extremely economically important. Until recently the only large scale mortalities concerned larval conch being reared in hatcheries, or heat shock of conch in shallow waters as occurred in South Florida in July 1988. From mid-September to mid-November 1991, a mass mortality of wild, adult queen conch occurred in one area of Belize. We contacted scientists in the field in an attempt to determine the geographic extent and severity of this disturbance. We also notified a number of conch and/or disease experts who we thought might have been interested in examining this problem. A tentative Alert was placed on the Coral List (Internet) and other computer information services.

The mass mortality seemed to have been confined to the Hol Chan Marine Reserve, Ambergris Cay, and immediate vicinity. This is an area of a few km^2. Approximately 45% of the conch died beginning in mid-September and continuing for approximately one to two months in the park and vicinity. Fishermen reported similar deaths in areas near the park and suggested that this event occurs annually. A “brown tide” bloom of a spherical diatom accompanied the mortalities, but has not been confirmed as a cause. Scientists in four other areas in Belize could find no queen conch mortality at this time, nor could our contacts in any other Western Caribbean country find any deaths of conch. Samples of the diatom bloom and dead queen conch were preserved for further study. We have not received samples and are not certain where the samples were sent for analysis. We have not heard any results of the examinations.

Giant clam

Giant clam mortalities involving the dangerous apicomplexan protozoan, *Perkinsus* sp., have occurred on the Great Barrier Reef (1,34,122). These animals also carry a snail predator, *Turbonilla* sp., that has caused mass mortalities in culture facilities, and which killed captive giant clams in Jamaica (unpublished), and has been introduced in Bonaire and Florida (123). We are particularly interested in these non-specific pathogens, because Pacific Giant Clams were being reared in the Caribbean on Bonaire in the late 1980s/early 1990s and possibly now in Belize (122). Plans to rear Giant Clams in the French Islands have been cancelled. In April 1995, we reviewed a proposal submitted to the Commonwealth Department of Natural and Environmental Resources to raise giant clams in Puerto Rico. Giant clams were brought into Jamaica in the 1960s, they are now being held in South Florida and possibly the Bahamas (unpublished). The shift from rearing giant clams for food and shells to smaller, pet-store aquarium animals, means that contamination of the Caribbean marine environment with giant clams and their diseases is inevitable. We might have some hope of controlling or regulating large aquaculture facilities and large, public aquaria, but private aquarists are beyond management.

Abalone withered foot disease

Sometime between 1983 and 1985, a decline of the black abalone, *Haliotis cracherodii*, and other species of abalone began on the West coast of the USA. Once mass mortalities occurred, this disturbance was recognized as “withered foot disease”. The disturbance has destroyed 95-100% of this abalone in some areas. California abalone are very important commercially and this condition has received considerable attention. A *Rickettsia* species has been shown to be the causative agent (124-126). This mortality is only of potential interest in the Caribbean because the culture of black abalone has been proposed for Puerto Rico and the Dominican Republic, and this disease might spread to local molluscs.

11. SEA BIRDS

Bird mass mortalities appear to be rare in the Caribbean. Only one lesser, but recurring, disturbance has been reported in the Brown Pelican, *Pelecanus occidentalis*. In late January 1989, brown pelicans began dying in Southeastern Puerto Rico (19,20,33). Through our information network, we learned that this mortality extended throughout Puerto Rico and the US Virgin Islands. A similar mortality of brown pelicans occurred along the Caribbean coast of Colombia from at least Cartagena to Santa Marta in August 1989 (33). Since that time, these mortalities have periodically recurred in Puerto Rico, the US Virgin Islands, and once in the Cayman Islands (127).

12. MARINE MAMMALS

Only routine, small-scale mortalities of marine mammals are known in the Caribbean (128). Recent mass mortalities of West Indian manatees, *Trichechus manatus*, have been caused by toxic algal outbreaks in Florida (129), but none are known from the Caribbean.

From June 1987 to March 1988 approximately 1/3 of the bottlenose dolphins, *Tursiops truncatus*, along the Atlantic coast of the USA died in a mass mortality (130-132). The cause of this mass mortality has never been satisfactorily explained (130). A possible recurrence of this event occurred from January to April 1990 along the Northern Gulf of Mexico and again in 1992 (131,132).

We suspected a smilar event among Caribbean spotted dolphins, *Stenella frontalis*, in 1989. In 122 years of stranding records for Puerto Rico and the US Virgin Islands, only one case of a spotted dolphin had been recorded. In September and October 1989, two spotted dolphins stranded in eastern Puerto Rico. In July and August 1989, two stranded at near Cartagena, Colombia; and in October 1989 one stranded at Isla del Rosario, Colombia. We issued an alert about the possibility of the beginning of a mass mortality of this animal (133), but we received no more reports. These cases were possibly a coincidence of natural mortalities.

CONCLUSIONS

The Caribbean Region has fewer and lesser non-corral-reef MMEDs (bird, marine mammal, mollusc, seagrass, harmful algae blooms) than almost any other comparable region on Earth. However, it has by far, the greatest number and severity of coral-reef-associated MMEDs on the planet. This dichotomy can be explained in part by the emphasis in research concentrating on coral reefs and ignoring other habitats in the region, and the scarcity of development of some of these other habitats, for example, estuaries, in the region. However, this cannot explain most of the disparity. Caribbean coral reefs are under such particular attack that a remarkable suggestion has recently been made that 20 years of unusual dust storm contamination from the African Sahara and its incipient fungal, viral and other disease organisms are responsible (EA Shinn, US Geology Survey, personal communication). This is an interesting idea worthy of investigation, and may be contributing to the devastation (114). However, the problem is much more complex. Scientists and the public invariably crave one simple, all encompassing cause for a problem. One disease agent, one simple cause. We no longer have that luxury, and we probably only fooled ourselves in the past that we ever did. A vast complex of human-related sins are killing the Caribbean coral reefs. These causes are direct (over fishing, pollution, sedimentation, anchor impact, coral harvest, etc.) and indirect (global warming due to green house gasses, increased UVB due to global destruction of the ozone layer, and global pollution) (1,12-15,59). We have attacked the reef internally, removing many of its key components, and externally changing the physical parameters to exceed the narrow band of conditions under which it evolved and in which it can survive.

The Caribbean is a "small fish bowl" compared to other coral-reef systems in the world. It is more easily destroyed. However, parts of these other coral-reef systems are already in as bad or worse condition. Their collapse may take a bit longer, but they will follow. Saving the coral reefs is no longer an option. We should now consider if we can save other ecosystems, and ultimately ourselves.

Despite the great body of work accomplished in the last ten years on MMEDs, almost all of it is concentrated on one host, one group of hosts, or one disease/condition. Far more important is the study of what has changed overall to precipitate this calamity. MMEDs present us with a great puzzle, the solution of which is of incalculable value, and all we can do is study individual pieces. Science has not begun to adequately study disturbances, categorize them, compare them, search for inter-relationships, find common causes, mitigation techniques, and solutions. The study of MMEDs is still a neglected field.

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REFERENCES

1. Williams EH Jr, Bunkley-Williams L. The world-wide coral reef bleaching cycle and related sources of coral mortality. Atoll Res Bull 1990;335:1-71.
2. Williams EH Jr, Bunkley-Williams L, Peters EC, et al. An epizootic of cutaneous fibro-papillomas in green turtle, *Chelonia mydas* of the Caribbean: Part of a panzootic? J Aquatic Animal Health 1994;6:70-78.
3. Bruckner AW, Bruckner RJ, Williams EH Jr. Spread of a black-band disease epizootic through the coral reef system in St. Ann's Bay, Jamaica. Bull Mar Sci 1997;61:919-928.
4. Bruckner RJ, Bruckner AW, Williams EH Jr. Life history strategies of *Coralliophila abbreviata* Lamarck (*Gastropoda*: *Coralliophilidae*) on the southwest coast of Puerto Rico. Proc 8th Coral Reef Sympos 1997;1:627-632.
5. Bunkley-Williams L, Morelock J, Williams EH Jr. Lingering effects of the 1987 mass bleaching of Puerto Rican coral reefs in mid to late 1988. J Aquatic Animal Health 1991;3:242-247.
6. [Bunkley-]Williams LB, Williams EH Jr. Coral reef 'bleaching' peril reported. Oceanus 1987;30(4):71.
7. [Bunkley-]Williams LB, Williams EH Jr. Coral reef bleaching: current crisis, future warning. Sea Frontiers 1988;34:80-87.
8. Bunkley-Williams L, Williams EH Jr. Global assault on coral reefs. Nat Hist 1990;4/90:cover,1,46-54.
9. Bunkley-Williams L, Williams EH Jr. Diseases caused by *Trichodina spheroidesi* and *Cryptocaryon irritans* (*Ciliophora*) in wild coral reef fishes. J Aquatic Animal Health 1994;6:360-361.
10. [Bunkley-]Williams LB, Williams EH Jr, Bunkley AG. Isolated mortalities of the urchins *Astropyga magnifica* and *Eucidaris tribuloides* in Puerto Rico. Bull Mar Sci 1986;38:391-393.
11. Bunkley-Williams L, Williams EH Jr, Jiménez-Marrero NM. A mass mortality of Caitipa mojarras, *Diapterus rhombeus* (Pisces), in southwestern Puerto Rico. Carib Mar Stud 2000;7:(in press).
12. Epstein PR et al. Marine ecosystems: Emerging diseases as indicators of change: Health of the oceans from Labrador to Venezuela. Year of the Oceans Special Report. Cent Health Global Environ, Harv Med Sch 1998:85 p.
13. Goreau, T. J., Bruckner AW, Cervino J, et al. Assessing coral reef health. Science 1997;277:165-166.
14. Goreau TJ, Cervino J, Goreau M, et al. Rapid spread of disease in Caribbean coral reefs. Rev Biol Trop, Spec Iss 1998;46(suppl 5):157-171.
15. Goreau TJ, Hayes RL, Strong A, et al. Coral reefs and global change: Impacts of temperature, bleaching, & emerging diseases. Sea Wind 1998;12(3):2-6.
16. Goreau TJ, Hayes RL, Strong A, et al. Global coral reef bleaching and sea surface temperature trends from satellite-derived hotspot analysis. Science 2000 (in press).
17. Mascarelli PE, Bunkley-Williams L. An experimental field evaluation of healing and colonization by algae in damaged, unbleached and artificially bleached star coral, *Montastrea annularis*. Bull Mar Sci 1999;65:577-586.
18. Williams EH Jr. Disease factors which should be considered in fish kill investigations. In: Atwood DK, ed. Unusual mass fish mortalities in the Caribbean and Gulf of Mexico. Atl Oceanogr Meteorolog Lab, Miami, Florida, 1982:42-43.
19. Williams EH Jr. Brown pelican die-off. Estuar Cal Bull 1989;April 1989:3.
20. Williams EH Jr. Endangered aquatic animals. Amer Sci 1989;77:318.
21. Williams EH Jr, Bartels PJ, Bunkley-Williams L. Predicted disappearance of coral-reef ramparts: a direct result of major ecological disturbances. Global Change Biol 1999;5:839-845.
22. Williams EH Jr, Bunkley-Williams L. Coral reef bleaching alert. Nature 1990;346:225.
23. Williams EH Jr, Bunkley-Williams L. Recurring mass mortalities of Caribbean herrings: Implications for the study of major marine ecological disturbances. J Aquatic Animal Health 1990;2:230-236.
24. Williams EH Jr, Bunkley-Williams L. Bleaching of Caribbean coral reef symbionts in 1987-1988. Proc 6th Intern Coral Reef Sympos 1989;3:313-318.
25. Williams EH Jr, [Bunkley-]Williams L. Bleaching of coral reef animals in 1987-1988: An updated summary. In: Ogden JC

Wicklund RI, eds. Mass bleaching of coral reefs in the Caribbean: A research strategy. Nat Undersea Res Prog, NOAA, Res Rept 1988;88-2(App III):19-21.
26. Williams EH Jr, [Bunkley-]Williams LB. Caribbean Mass Mortalities: A problem with a solution. Oceanus 1987;30(4):69-75.
27. Williams EH Jr, Bunkley-Williams L. Coral reef bleaching. Nat Geograph 1990;178(5):v.
28. Williams EH Jr, Bunkley-Williams L. Coral reef bleaching: Incidence, extent, cause, significance and the urgency in understanding this major disturbance. Testimony to the Hearing before the National Ocean Policy Study of the Committee on Commerce, Science, and Transportation, U S Senate, 101st Congress, 2nd Sess Coral Reef Bleaching, Congr Rec, Coral Bleaching Vol 1991:16-29.
29. Williams EH Jr, Bunkley-Williams L. Major marine ecological disturbances and potential impacts of global climate change on marine ecosystems. Testimony to Hearing before the Subcommittee on Health and the Environment of the Committee on Energy and Commerce House of Representatives 102nd Congr, 1st Sess, Ser No. 102-54, Congr Rec 1991:183-187.
30. Williams EH Jr, Bunkley-Williams L. A brief summary of marine major ecological disturbances in the Indo-Pacific and a plea for additional information. Galaxea 1996;13:109-121.
31. Williams EH Jr, Bunkley-Williams L. The earliest Pacific record and unconfirmed hawksbill records of fibropapillomas in Hawaiian sea turtles. Records of the Hawaii Biological Survey for 1995, Bishop Mus Occas Pap 1996;46:46-49.
32. Williams EH Jr, Bunkley-Williams L, Bruckner RJ, et al. Recurring mass mortalities of the white-spined sea urchin, *Tripneustes ventricosus*, (*Echinodermata*: *Echinoidea*) in Puerto Rico. Carib J Sci 1996;32:111-112.
33. Williams EH Jr, Bunkley-Williams L, López-Irizarry I. A die-off of brown pelicans (*Pelecanus occidentalis*) in Puerto Rico and the United States Virgin Islands. Amer Birds 1993;46:1106-1108.
34. Williams EH Jr, Bunkley-Williams L, Peters EC, et al. Threat to black sea urchins. Nature 1991;352:385.
35. Williams EH Jr, Goenaga C, Vicente V. Mass bleaching on Atlantic coral reefs. Science 1987;238:877-878.
36. Williams EH Jr, Lang JC. Timing, geographic extent, and preliminary assignment of cause of bleaching. In: Ogden JC Wicklund RI, eds. Mass bleaching of coral reefs in the Caribbean: A research strategy. Nat Undersea Res Prog, NOAA, Res Rept 1988;88-2(App III):2-4.
37. Williams EH Jr, Lankford RR, van Buurt G, et al. Summary report of the IOCARIBE steering committee for developing regional contingencies for fish kills. UNESCO, Paris, 1982;Rept. No. CARI/FK/-1/3:1-20.
38. Williams EH Jr, Sindermann CJ. Diseases and exotic marine organisms. Proc Introd Trans Mar Spp Workshop, SC Sea Grant 1992;1:71-77.
39. Winter A, Appledorn RS, Bruckner AW, Williams EH Jr, Goenaga C. Sea surface temperatures and coral reef bleaching off La Parguera, Puerto Rico (northwestern Caribbean Sea). Coral Reefs 1998;17:377-382.
40. Lasker HA, Peters EC, Coffroth MA. Bleaching of reef coelenterates in the San Blas Islands, Panama. Coral Reefs 1984;3:183-190.
41. Glynn PW. Widespread coral mortality and the 1982-1983 El Niño warming event. Environ Conser 1984;11:133-146.
42. Glynn PW. Coral bleaching and mortality in the tropical eastern Pacific during the 1982-83 El Niño event. In: Ogden JC Wicklund RI, eds. Mass bleaching of coral reefs in the Caribbean: A research strategy. Nat Undersea Res Prog, NOAA, Res Rept 1988;88-2(App III):42-45.
43. Glynn PW, de Weerdt WH. Elimination of two reef-building hydrocorals following the 1982-83 El Niño warming event. Science 1991;253:69-70.
44. de Weerdt WH, Glynn PW. A new and presumably now extinct species of *Millepora* (*Hydrozoa*) in the eastern Pacific. Zool Med Leiden 1991;65:267-276.
45. de Weerdt WH, Glynn PW. A new and presumably now extinct species of *Millepora* (*Hydrozoa*) in the eastern Pacific. Zool Med Leiden 1991;65:267-276.
46. Glynn PW, Feingold JS. Hydrocoral species not extinct. Science 1992;257:1845.
47. Lang JC, Lasker EH, Gladfelter EH, Hallock P, et al. Spatial and temporal variability during periods of “recovery” after mass bleaching on Western Atlantic coral reefs. Amer Zool 1992;32:696-706.
48. Goenaga C, Vicente VP, Armstrong RA. Bleaching induced mortalities in reef corals from La Parguera, Puerto Rico: a precursor of change in the community structure of coral reefs. Car J Sci 1989;25:59-65.
49. Goreau TJ, RL Hayes. Coral reef bleaching in the South central Pacific during 1994. Intern Coral Reef Init, US Dept State, Wash DC 1995:201 p.
50. Hoegh-Guldberg O. Mass-bleaching of coral reefs in French Polynesia. Rept Greenpeace Intern, Pac Campaign, Wash, DC, USA, 1994:36 p.
51. McGrath TA, Smith GW. The effects of the 1995/1996 Western Atlantic coral bleaching event on the patch reefs around San Salvador Island, Bahamas. Rev Biol Trop 1998;46(suppl5):91-99.
52. Goreau TJ, McClanahan T, Hayes RL, Strong A. Conservation of coral reefs after the 1998 global bleaching event. Conserv Biol 2000;14:5-15.
53. Atwood DK, Hendee JC, Mendez A. An assessment of global warming stress on Caribbean coral reef ecosystem. Bull Mar Sci 1992;51:118-130.
54. Glynn PW, L D’Croz. Experimental evidence for high temperature stress as the cause of El Niño-coincident coral mortality. Coral Reefs 1990;8:181-191.
55. Knowlton N, Weil E, Weigt, Guzman HM. Sibling species in *Montastraea annularis*, coral bleaching, and the coral climate record. Science 1992;255:330-333.
56. Glynn PW. Coral reef bleaching in the 1980s and possible connections with global warming. Trends Ecol Evol 1993;6:175-179.
57. Goreau TJ, Hayes RL. Coral bleaching and ocean “hot spots.” AMBIO 1994;23:176-180.
58. Goreau TJ, Hayes RL, Clarke JW, Basta DJ, Richardson CN. Elevated sea surface temperatures correlate with Caribbean coral reef bleaching. In: Geyer RA (ed.) A Global Warming Forum: Scientific, Economic and Legal Overview. CRC Press, Boca Raton, FL, 1993:225-255.
59. Hoegh-Guldberg, O. Climate change, coral bleaching and the future of the world’s coral reefs. Mar Freshwater Res 1999;50:839-866.
60. Goreau TJ. Bleaching and reef community change in Jamaica: 1951-1991. Amer Zool 1992;32:683-695.
61. Ogden JC, Wicklund RI (eds.). Mass bleaching of coral reefs in the Caribbean: A research strategy. Nat Undersea Res Progr, NOAA, Res Rept 1988:88-2.
62. D’Elia CF, Buddemeier RW, Smith SV (eds.). Workshop on coral [reef] bleaching, reef ecosystems and global change: Rept proc. NSF/EPA/NOAA Workshop, MD Sea Grant Coll 1991;Publ No UM-SG-TS-91-03:52 p.
63. Anonymous. Draft national action plan to conserve coral reefs. Working Groups of the U.S. Coral Reef Task Force, St. Croix, U.S. Virgin Islands 1999:52 p.
64. Strong AE, Barrientos CB, Duda C, Sapper J. Improved satellite techniques for monitoring coral reef bleaching. Proc 8th Intern Coral Reef Sympos 1997;2:1495-1498.
65. Strong AE, Goreau TJ, Hayes RL. Predicting coral reef bleaching from SST anomalies. Reef Encounters 1998;24:20-22.
66. Lessios HA, Robertson DR, Cubit JD. Spread of Diadema mass mortality through the Caribbean. Science 1984;226:335-337.

67. Bauer JC, Ager CJ. Isolation of bacteria pathogenic for the sea urchin *Diadema antillarum* (*Echinodermata*: *Echinoidea*). Bull Mar Sci 1987;40:161-165.
68. Lessios HA. Mass mortality of *Diadema antillarum* in the Caribbean: What have we learned? Ann Rev Ecol Sys 1988;19:371-393.
69. Miller RJ, Colodey AG. Widespread mass mortality of the green sea urchin in Nova Scotia, Canada. Mar Biol 1983;73:263-267.
70. Scheibling RE, Stephenson RL. Mass mortality of *Strongylocentrotus droebachiensis* (*Echinodermata*: *Echinoidea*) off Nova Scotia, Canada. Mar Biol 1984;78:153-164.
71. Birkeland C. The influence of echinoderms on coral-reef communities. In: Jangoux M, Lawrence JM (eds.) Echinoderm Studies. AA Balkema, Rotterdam 1989:1-79.
72. Meyer FB, Barclay LA (eds.). Field manual for the investigation of fish kills. US Fish Wildl Serv, Res Publ. 1990;177:1-120.
73. Atwood DK (ed). Unusual mass fish mortalities in the Caribbean and Gulf of Mexico. Atl Oceanogr Meteorolog Labs, NOAA, Miami, Florida 1982:59 p.
74. Burns CD. A report on the 1980 fish kill along the Florida reef tract. In: Atwood DK, ed. Unusual mass fish mortalities in the Caribbean and Gulf of Mexico. Atl Oceanogr Meteorolog Lab, Miami, Florida, 1982:36-41.
75. Juhl RT, Weidner D. Summary of information on mass fish mortalities in the Caribbean/Gulf of Mexico area collected by the U. S. NOAA/National Fishery Service and U. S. Department of State. In: Atwood DK, ed. Unusual mass fish mortalities in the Caribbean and Gulf of Mexico. Atl Oceanogr Meteorolog Lab, Miami, Florida, 1982:1-8.
76. Landsberg JH, Blakesley BA. Scanning electron microscope study of *Brooklynella hostilis* (*Protista*, *Ciliophora*) isolated from the gills of gray and French angelfish in Florida. J Aquat Animal Health 1995;7:58-62.
77. Meyers T, Hauck AK, Blankenbecker WD, Minicucci T. First report of viral erythrocytic necrosis in Alaska, USA, associated with epizootic mortality in Pacific herring, *Clupea harengus pallasi* (Valenciennes). J Fish Dis 1986;9:479-491.
78. Pannier F. Effects of the mortality and decomposition of a large fish population on mangroves in Venezuela. Ogden JC, Gladfelter EH (eds) Coral reefs, seagrass beds and mangroves: Their interaction in the coastal zones of the Caribbean. UNESCO/UN Repts Mar Sci 1983:128-130.
79. Peters EC. Symbiosis to pathology: are the roles of microorganisms as pathogens of coral reef organisms predictable from existing knowledge? Proc 6th Intern Coral Reef Sympos 1988;1:205-209.
80. Peters EC. Diseases of other invertebrate phyla: *Porifera, Cnideria, Ctenopora, Annelida, Echinodermata.* In: Couch JA, Fournie JW (eds) Adv Fish Sci: Pathobiology of marine and esturine organisms. CRC, Boca Raton, FL 1993:393-437.
81. Peters EC. Diseases of coral reef organisms. In: Birkeland C (ed) Life and death of coral reefs. Chapman & Hall, New York 1997:895-912.
82. Hayes RL, Goreau NI. The significance of emerging diseases in the tropical coral reef ecosystem. Rev Biol Trop 1998;46(suppl 5):173-185.
83. Harvell CD, Kim K, Burkholder JM, et al. Emerging marine diseases - climate links and anthropogenic factors. Science 1999;285:1505-1510.
84. Gladfelter W. White band disease in *Acropora palmata*: implications for the structure and growth of shallow reefs. Bull Mar Sci 1982;32:639-643.
85. Peters EC, Oprandy JJ, Yevich T. Possible causal agent of white band disease in Caribbean scleractinian corals. J Invert Pathol 1983;41:394-396.
86. Kuta KG, Richardson LL. Black band disease and the fate of diseased coral colonies in the Florida Keys. Proc 8th Intern Coral Reef Sympos 1996;1:575-578.
87. Te Strake D, Jaap C, Truby E, Reese R. Fungal elements in *Millepora complanata* Lamarck, 1816 (*Cnidaria: Hydrozoa*) after mass expulsion of zooxanthellae. Fla Sci 1988;51:184-188.
88. Rützler K, Santavy DL. The black band disease of Atlantic reef corals. I. Description of the cyanophyte pathogen. PSZNI (Mar Ecol) 1983;4:301-319.
89. Richardson LL. Red band disease: A new Cyanobacteria infestation of corals. Proc AAUS 1992;10:153-160.
90. Rützler K, Santavy DL, Antonius A. The black band disease of Atlantic reef corals. III. Distribution, ecology and development. PSZNI(Mar Ecol) 1983;4:329-358.
91. Santavy DL, Peters EC. Microbial pests: coral disease in the Western Atlantic. Proc 8th Intern Coral Reef Sympos 1996:607-612.
92. Gur O, Loya Y. Life history and population dynamics of the coral predatory snail Drupella cornus at Eilat, Red Sea. International Symposium of the University of the Ryukyus on Biodiversity and Adaptive Strategies of Coral Reef Organisms, Okinawa, Japan 1992;Abst Vol:11.
93. Bone D, Perez D, Villamizar A, Penchaszadeh PE, Klein E. Parque Nacional Morrocoy, Venezuela. In: Kjerfve B (ed) CARICOMP - Caribbean coral reef, seagrass and mangrove sites. UNESCO, Coast Reg Small Isl Pap 1998;3:151-159.
94. Bruckner AW, Bruckner RJ. Diseases and predators of Western Atlantic coral. Univ P R Sea Grant card 1998:2 p.
95. Bruckner AW, Bruckner RJ. Diseases, predation and bioerosion on *Acropora* spp. Univ P R Sea Grant card 1998:p2.
96. Balazs GH, Pooley SG (eds) Research plan for marine turtle fibropapilloma. NOAA Tech Memo 1991;NMFS, NOAA-TM-NMFS-SWFSC-156:1-113.
97. Dyer WG, Williams EH Jr., Bunkley-Williams L. Some digeneans (Trematoda) of the green turtle, *Chelonia mydas* (*Testudines: Cheloniidae*) from Puerto Rico. J Helminth Soc Wash 1991;58:176-180.
98. Quakenbush SL, et al. Three closely related herpsviruses are associated with fibropapillomatosis in marine turtles. Virol 1998;246:392-399.
99. Landsberg JH, Balazs GH, Steidinger KA, Baden DG, Work TM, Russell DJ. The potential role of natural tumor promoters in marine turtle fibropapillomatosis. J Aquat Animal Health 1999;11:199-210.
100. Smith, E. G. W. Sponge disease in British Honduras and its transmission by water currents. Ecol 1941;22:415-421.
101. Vicente VP. Regional commercial sponge extinctions in the West Indies: Are recent climatic changes responsible? Mar Ecol 1989;10:179-191.
102. Rützler K. Mangrove sponge disease induced by cyanobacterial symbionts: failure of a primative immune system? Dis Aquat Org 1988;5:143-149.
103. Butler MJ, Hunt JH, Herrnkind WF, et al. Cascading disturbances in Florida Bay, USA: cyanobacteria blooms, sponge mortality, and implications for juvenile spiny lobsters, *Panulirus argue*. Mar Ecol Prog Ser 1995;129:119-125.
104. Anonymous. Worldwide epidemic of toxic blooms. Nor'easter 1992;4(1):4.
105. Shumway SE. A review of the effects of algal blooms on shellfish and aquaculture. J World Aquacult Soc 1990;21:65-104.
106. Antonius A, Ballesteros E. Epizoism: a new threat to coral health in Caribbean reefs. Rev Biol Trop 1998;46(suppl 5):145-156.
107. LaPointe BE. Caribbean coral reefs: Are they becoming algal reefs? Sea Front 1989;35:82-91.
108. Hughes TP. Catastrophes, phase shifts, and large scale degredation of a Caribbean coral reef. Science 1994;265:1547-1549.
109. Tosteson TR (ed). Ciguatera: Proceedings of the Third

International Conference. Polysci Publ, Quebec, Canada 1992:204 p.

110. Guzmán HM. Mortandad de *Gorgonia flabellum* Linnaeus (*Octocorallia: Gorgoniidae*) en la Costa Caribe de Costa Rica. Rev Biol Trop 1984;32:305-308.
111. Garzon-Ferreira G, Zea S. A mass mortality of *Gorgonia ventalina* (*Cnidaria: Gorgoniidae*) in the Santa Marta area, Caribbean coast of Colombia. Bull Mar Sci 1992;50:522-526.
112. Nagelkerken IA, Buchan K, Smith GW, et al. Widespread disease in Caribbean sea fans: I. Spreading and general characteristics. Proc 8th Intern Coral Reef Sympos 1997;1:679-682.
113. Nagelkerken IA, Buchan K, Smith GW, et al. Widespread disease in Caribbean sea fans: II. Patterns of infection and tissue loss. Mar Ecol Progr Ser 1997;160:255-263.
114. Smith GW, Harvel CD, Kim K. Response of sea fans to infection with *Aspergillus* sp. (fungi). Rev Biol Trop 1998;46(suppl 5):205-208.
115. Smith GW, Ives LD, Nagelkerken IA, Ritchie KB. Caribbean sea fan mortalities. Nature 1996;383:487.
116. Feingold JS. Ecological studies of a cyanobacterial infection on the Caribbean sea plume *Pseudopterigorgia acerosa* (*Coelenterata: Octocorallia*). Proc 6th Intern Coral Reef Sympos 1988;3:157-162.
117. Birkeland C. Life and death of coral reefs. Chapman & Hall, New York, 1997.
118. Smith GW. Microbial contributions to the growth and degradation of tropical seagrasses. In: Smith RR (ed) Proc 2nd Sympos Bot Bahamas 1987:45-53.
119. Durako MJ. Seagrass die-off in Florida Bay (USA): Changes in shoot demographic characteristics and population dynamics in *Thalassia testudinum*. Mar Ecol Prog Ser 1994;110:59-66.
120. Muehlstein LK, Beets J. Seagrass declines and their impact on fisheries. Proc 42nd Gulf Carib Fish Inst 1998;42:55-65.
121. Sindermann CJ. Principal Diseases of Marine Fish and Shellfish. 2nd Ed, Acad Press, Inc., San Diego 1990:516 p.
122. Williams EH Jr, Bunkley-Williams L. Helpline for giant clams. Nature 1990;345:119.
123. Eldredge LG. Perspectives in aquatic exotic species management in the Pacific islands. Volume I. Introductions of commercially significant aquatic organisms to the Pacific islands. Inshore Fisheries Research Project Technical Document No. 7. SPREP Reports and Studies Series No. 78. 1994:127 p.
124. Davis GE. Mysterious demise of southern California black abalone, *Haliotis cracherodii* Leach, 1814. J Shellfish Res 1993;12:183-184.
125. Lafferty KD, Kuris AM. Mass mortality of abalone, *Haliotis cracherodii* on the California Channel Islands: tests of epidemiological hypotheses. Mar Ecol Progr Ser 1993;96:239-248.
126. Gardner GR, Harshbarger JC, Lake JL, et al. Association of prokaryotes with symptomatic appearance of withering syndrome in black abalone *Haliotis cracherodii*. J Invert Path 1995;66:111-120.
127. Dyer WG, Williams EH Jr, Mignucci-Giannoni AA, et al.. New host and locality records of brown pelican parasites in Puerto Rico. Carib J Sci 2000 (in press).
128. Mignucci-Giannoni AA. Zoogeography of cetaceans off Puerto Rico and the Virgin Islands. Carib J Sci 1998;34:173-190.
129. Landsberg JH, Steidinger KA. A historic review of *Gymnodium breve* red tides implicated in mass mortalities of the manatee (*Trichechus manatus latirostris*) in Florida, USA. In: Reguera B et al (eds.) Harmful algae. Xunta de Galicia and Intergov Oceanogr Comm UNESCO 1998:97-100.
130. Anonymous. The conclusions of the clinical investigation of the 1987-88 mass mortality of the bottlenose dolphins along the United States central and south Atlantic coasts. Hearing before Subcomm Oversight and Investigat, Comm Merchant Mar Fish, U. S. House Repres 1989:302 p.
131. Peters EC, Fisher WS. Scientific research on diseases and mortalities of dolphins in U.S. waters. EPA/600/R-93/153 1993:90 p.
132. Bossart G, Busbee D, Lahvis G, Worthy GAJ. Research perspectives for dolphin mortalities in North America. USEPA/600/R-93/217 1993:22 p.
133. Williams EH Jr, Mignucci-Giannoni AA, Bunkley-Williams L, Pinto-Rodriguez B. Prediction of a possible major marine ecological disturbance of the Atlantic spotted dolphin in 1989. In: Peters EC, Fisher WS. Res perspect dolphin mortalit NA 1993;EPA/600/R-93/153:90.
134. Littler MM, Littler DS. Impact of CLOD pathogen on Pacific coral reefs. Science 1995;267:1356-1360.
135. Porter JW, Meier OW. Quantification of loss and change in Floridian reef coral populations. Amer Zool 1992;23:625-640.
136. Bruckner AW, Bruckner RJ. Rapid wasting disease: pathogen or predator. Science 1998;279:2023-2025.
137. Cervino J, Goreau TJ, Hayes RL, et al. Coral disease. Science 1998;280:499-500.
138. Hallock P, Talge HK, Cockey EM, Müller RG. A new disease in reef-dwelling foraminifer: implications for coastal sedimentation. J Foram Res 1995;25:280-286.
139. Nagerkerken I, Smith GW, Shelder E, Karel M, James S. Sea urchin *Meoma ventricosa* die-off in Curaçao (Netherlands Antilles) associated with a pathogenic bacterium. Dis Aquat Org 1999;38:71-74.
140. Quirolo C. Select images from the Reef Relief photomonitoring Survey, Key West reefs, coral stress and diseases. Reef Relief, Key West, FL 1998:31 p.
141. Ritchie KB, Smith GW. Perential carbon utilization by surface bacterial communities from water mass, normal, and white-band diseased *Acropora cervicornis*. Molecular Mar Biol Tech 1995;4:345-352.
142. Ritchie KB, Smith GW. Type II white-band disease. Rev Biol Trop 1998;46(suppl 5):199-203.
143. Richardson LL, Goldberg WM, Carlton RG, Halas JC. Coral disease outbreak in the Florida Keys: Plague type II. Rev Biol Trop 1998;46(suppl 5):187-198.
144. Richardson L, Aronson W, Goldberg GW, et al. Florida's mystery coral killer identified. Nature 1998;392:557-558.
145. Vicente VP. An ecological evaluation of the West Indian demosponge *Anthostigmella varians* (*Hadromerida: Spirastrellidae*). Bull Mar Sci 1978;28:771-777.
146. Vicente VP. Overgrowth activity by the encrusting sponge *Chondrilla nucula* on a coral reef in Puerto Rico. In: Rützler K (ed) New perspectives in sponge biology. Smithsonian Institution, Washington, DC 1990:436-442.