II. GLOBAL PERSPECTIVE OF CORAL DISEASE

THE GLOBAL PERSPECTIVE OF INCIDENCE AND PREVALENCE OF CORAL DISEASES

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ABSTRACT

Diseases occur globally in most coral reef habitats whether near human population centers or remotely offshore. They generally affect a low proportion of the susceptible species, although localized outbreaks have produced significant mortalities to scleractinian corals, gorgonians, sea urchins, reef fish, sponges, algae and other coral reef organisms (Peters, 1993; Harvell et al., 1999; Williams and Bunkley-Williams, 2000). There are now over 30 named diseases in the Caribbean basin affecting 45 zooxanthellate scleractinian corals, three hydrozoan corals, ten octocorals, two zoanthids, nine sponges and two crustose coralline algae (Green and Bruckner, 2000; Weil et al., 2006), and at least seven major diseases from the IndoPacific, along with about 30 additional conditions that are associated with compromised health in scleractinian corals. While an apparently unprecedented increase in disease occurred in the Caribbean since the 1980s, much less is known about the status of disease in the IndoPacific and Red Sea. Surveys over the last decade in Australia, Palau, East Africa, the Philippines and other locations have revealed new diseases, suggesting a rapid emergence of disease, or at least a realization of their presence, throughout the Indo-Pacific. Between 1972 and 2005 coral diseases were reported on 39 genera and 148 species worldwide, with observations in 63 countries. Although Pacific reefs have a higher diversity of reef-building corals than the Atlantic and harbor 92% of the world's coral reefs (Spalding and Greenfell, 1997), only 14% of the global observations of coral disease were from the Indo-Pacific during this period (Green and Bruckner, 2000, Sutherland et al., 2004, GCDD, 2007), and 58% of all coral disease records are for BBD, WBD and WP. The Caribbean has historically been referred to as a "hotspot" for disease, largely because of the rapid emergence, high prevalence, wide distribution, large numbers of host species, and virulence of diseases in this region.

There are eight major diseases (BBD, WP, WBD, YBD, DSD, WPX, ASP and tumours) that have been reported from throughout the western Atlantic along with another 32 conditions (including different "types" of the major diseases) that have been reported since 1972. WBD, BBD and WP were first reported from the Caribbean in the 1970s from a small number of countries, with observations expanding to new locations during the 1980s including reports of WBD from about half of the Caribbean nations. During this period, BBD and WP caused localized mortality, while WBD contributed to a

regional decline of *Acropora*. Reports of WBD decreased dramatically during the 1990s, and then increased again since 2000, with most reports on *A. cervicornis*. Reports of WP and BBD have also escalated since 1998, with recent observations from 24 countries. While low level chronic infections of BBD have been observed on the same reef for years to decades, WP prevalence has dramatically increased since 1998, with outbreaks occurring over an expanding range. Many other new diseases have been reported on western Atlantic reefs since the mid 1990s, including four (DSD, YBD, WPX and ASP) that are widely distributed and four (YBD, WPX, WP-II and ASP) that are causing substantial coral mortality. Close to 80% of all western Atlantic corals are affected by diseases (41 species of scleractinian corals, 8 gorgonians, 2 hydrozoans), with some corals (especially *M. annularis* complex) being susceptible to as many as 8 diseases and corals showing signs of 2-3 diseases at one time. During the 1970s-early 1990s acroporids were most severely impacted by disease, while massive and plating corals, and in particular the *M. annularis* complex, are being affected more severly today. WP is the most virulent disease and has the widest host range.

Coral diseases were first reported from the IndoPacific and Red Sea in the late 1970s. Most observations during the 1970s and 1980s were for BBD and WBD by a single researcher working in three countries (Philippines, Egypt and Saudi Arabia), along with additional reports of abnormal skeletal development (tumors). By 1994, diseases had only been reported from six countries, including several new conditions first observed on reefs in Australia. In the mid to late 1990s, several new diseases emerged (YBD, SEB, PUWS), but these and other diseases were restricted to a few countries. IndoPacific diseases appear to be exhibiting a rapid expansion in range and in the types of disease since 2000. This includes reports from new regions that were previously unaffected (South Africa, Solitary Islands), a higher percentage of reefs in certain locations (e.g., Great Barrier Reef Australia) with diseases, an increasing incidence of diseases, and an emergence of several new conditions (fungal disease, WS, BrBD, Pink Line). Fast growing corals in the family acroporidae and pocilloporidae in the IndoPacific are affected by the largest number of diseases and are observed with disease more frequently than all other species.

Introduction

Coral reefs have experienced unprecedented losses of live coral cover from anthropogenic and natural stressors during the last three decades (Byrant et al., 1998; Jackson, 2001; Pandolfi et al., 2003). Coral diseases are one of the major factors responsible for this decline, especially in the wider Caribbean (Harvell et al., 1999; Aronson et al., 2003; Gardner et al., 2003). The Caribbean has been referred to as a "hot spot" for coral diseases, due to the rapid spread, wide distribution, expanding host ranges, and increased virulence of these diseases (Rosenberg and Loya, 2004; Weil, 2006). In addition to black band disease (BBD), white plague (WP) and white band disease (WBD), which have persisted on Caribbean reefs since the 1970s, there has been a recent emergence of diseases with new types of pathologies and elevated rates of tissue mortality (Richardson and Aronson, 2002; Weil, 2004).

By the late 1990s, diseases had been observed on 102 coral species in 54 different nations, with 27 diseases reported from the Caribbean and 13 from the Indo-Pacific and Red Sea (Green and Bruckner, 1999). Over 66% of these reports were for BBD, WBD

and WP in the western Atlantic (Green and Bruckner, 2000; Sutherland et al., 2004). Although western Atlantic reefs exhibit a low diversity of reef-building corals relative to the IndoPacific, and they constitute only 8% of the world's coral reefs (Spalding and Grenfell, 1997), this region hosted a disproportionate number of diseases and affected corals (>80%) (Sutherland et al., 2004).

Although coral diseases were reported from the Indo-Pacific in the 1980s (Antonius, 1985), the vast majority of these observations were made by one researcher in the Red Sea and Gulf of Arabia (Antonius, 1985; 1987; 1988). Recent surveys conducted in Australia (Willis et al., 2004), western Indian Ocean (McClanahan, 2004), Philippines (Raymundo et al., 2004), and Red Sea (Loya et al., 2004) illustrate the widespread, global distribution of coral diseases. Through annual and semi-annual monitoring programs on the Great Barrier Reef Australia, the Philippines, and other locations, researchers are identifying coral diseases on a greater number of reefs and species, and disease incidence appears to have increased since the late 1990s, suggesting that diseases have become more prevalent in the IndoPacific over the last five years (Raymundo et al., 2003; Willis et al., 2004; Kaczmarsky, 2006). However, it is difficult to determine "baseline" levels of coral diseases, and conclusively state that diseases are increasing, as the proliferation of reports at least partially reflects an increased monitoring effort.

Increases in the types of diseases and their abundance and severity may be at least partially related to an overall deterioration of the marine environment due to human stressors (e.g., land-based pollutants), climate warming, and other changing environmental conditions (Harvell et al., 2002; Kuta and Richardson, 2002; Garrison et al., 2003; Kaczmarsky et al., 2005). Sediment, sewage, toxic chemicals and other pollutants may facilitate disease outbreaks by introducing opportunistic pathogens, increasing pathogen virulence, and reducing host resistance (Antonius, 1977, Ducklow and Mitchell, 1979; Peters, 1984; Peters, 1993). However, reefs removed from direct anthropogenic inputs are also being impacted by disease (Santavy and Peters, 1997; Weil, 2004; Bruckner and Bruckner, 2006) highlighting potential associations between disease and elevated temperatures, light levels and other manifestations of global climate change including coral bleaching. Corals live close to their thermal tolerance limits, and a 1-2°C increase in SST is sufficient to induce coral bleaching. Recent outbreaks of WP in the eastern Caribbean following the 2005 bleaching event (Miller et al., 2006; Weil et al., 2006), provide additional evidence that bleached corals have a higher susceptibility to other diseases.

The Global Coral Disease Database

To begin gathering more comprehensive data on the global distribution and abundance of coral diseases, and quantify relationships between coral disease and various environmental stressors, NOAA Fisheries worked with the United Nations Environmental Program's World Conservation Monitoring Centre (WCMC) to develop a **Global Coral Disease Database** (GCDD)[4] . The GCDD is a web-accessible GIS database that compiles records of disease observations and tracks their spread over time, by geo-referencing disease locations and plotting their occurrences onto WCMC coral reef

[4] http://development.unep-wcmc.org/GIS/Coraldis/index.cfm

distributional maps. The GCDD includes a new online mapping tool (prototype IMAPS tool) that enables users to search and plot data by disease name and year, with zoom capabilities and full information sheet for each line of data. For each disease, information can be obtained on its global and regional occurrence and abundance, affected locations (e.g., country, reef, latitude and longitude) and species, and any available site-specific data on prevalence, incidence, and extent of mortality. A summary of all *in situ* observations on the prevalence, range of species affected, global geographic distribution, and mortality for reported coral diseases up to 1999 (2076 records of coral disease from 155 references) are included in the first iteration of the GCDD. The second version of the GCDD includes over 7100 data points compiled from information available through December, 2005, including peer-reviewed literature, grey literature, regional monitoring data from AGRRA (Atlantic and Gulf Rapid Reef Assessment surveys conducted between 1998-2000 in 22 countries; Lang, 2003), CARICOMP (survey of 19 reef sites from 6 countries in the Caribbean; Weil, 2004), Reef Check, and other programs, and reports submitted by researchers. These datasets reflect wider spatial coverage of disease surveys, repeat surveys, and increases in the types of diseases and species affected.

Global diversity and distribution of coral diseases

The GCDD contains records for over 40 coral diseases from the western Atlantic, 28 from the IndoPacific and 5 from the Red Sea that were reported between 1972 and 2005 (Table 1-4). Five coral diseases [BBD, WBD, WP, red band disease (RBD) and shut down reaction (SDR)] were first observed in the western Atlantic 20-30 years ago and three of these (BBD, WBD, SDR) were also reported from the Red Sea and IndoPacific during the 1980s (Antonius, 1977, 1981, 1985). Five other diseases [WP type II, white pox (WPX), yellow band disease (YBD), dark spots disease (DSD) and Aspergillosis (ASP)] first emerged on Caribbean reefs in the 1990s; all of these diseases (with the possible exception of DSD), have caused significant localized mortality and they represent continuing major threats to western Atlantic coral reefs. More recently, five IndoPacific diseases [white syndrome (WS), YBD, fungal syndrome, Porites ulcerative white spot disease (PUWS)] are causing substantial localized mortality and the prevalence of two of these (WS and PUWS) appears to be increasing. In addition to diseases that are presumed to be caused by bacteria, fungi and cyanobacteria, several conditions with rapidly expanding ranges [skeletal eroding band (SEB) and brown band disease(BrBD)] are being caused by ciliates and one disease observed so far only in Hawaii results from infection by a trematode (*Plagioporus*). Skeletal anomalies (tumors, hyperplasia, neoplasia, calicoblastic epitheliomas) have been reported from the Atlantic, Pacific and Indian Oceans and the Red Sea since at least 1965 (Squires, 1965), but few data are available on prevalence or impact. Some conditions are visible only with microscopy (e.g., coccidian infections, nematopsis spores). Most of the other conditions have been observed infrequently or are confined to localized areas.

A lot of confusion has been created by many reports of new diseases over the last ten years. There are also at least 19 other diseases that have been assigned on the basis of a few or single observations. These include 1) conditions presumed to be caused by a pathogen but later shown to result from predation; 2) conditions that lack details on gross signs or photographic documentation, or evidence of coral tissue destruction; 3) terminology that has been used interchangeably to describe similar signs, such as the

various white syndromes; and 4) similar conditions identified in the Caribbean that have been split into two or more syndromes (e.g., "Type 1" and "Type II"), based on rates or patterns of disease spread or species affected. Because of the difficulty in verifying which "type" of disease is present based on single observations (e.g., initial signs of infection may look different than later stages and rates of spread may vary over the duration of the infection), many researchers do not differentiate between types, or they use a different name overall (e.g., "plague-like"). Examples from the Caribbean include 1) white plague type I, II, II (Richardson and Aronson, 2002); 2) WBD type I and II; 3) DSD type I, II, dark band syndrome, purple band syndrome and tissue necrosis (Weil, 2004); and 4) white pox, patchy necrosis and necrotic patch syndrome.

1. White syndromes

There is a proliferation of names for coral diseases that are characterized by white lesions with a sharp, distinct line between apparently healthy tissue and exposed skeleton and an absence of an obvious microbial community at the disease line. These have been separated based on the identification of variable features such as 1) a zone of bleached tissue that may or may not be present used to differentiate WBD type I from WBD-II, differences in the rates of tissue loss and patterns of spread in WP type I, WP-II and WP-III, or differences in affected species (WP versus WBD). Antonius (1977, 1981) and other colleagues reported WBD on acroporids and other massive and plating corals in the western Atlantic, as well as corals in the IndoPacific. Other researchers from the Caribbean report WBD on *Acropora* and refer to similar signs in other host species as WP (Dustan, 1977; Richardson et al., 1998).

Table 1. Diseases, syndromes, abnormal tissue conditions, and parasitic infestations of scleractinian corals and gorgonians on coral reefs in the tropical western Atlantic.

condition	geographic range	host species	source
Black band disease (BBD)	W. Atlantic, 25 countries	26 scleractinians, 1hydrozoan, 6 gorgonians: faviids, *Agaricia*, *Siderastrea, Meandrina*; *A. palmata*[2], *P. astreoides*, *P. porites*[3], *Madracis mirabilis*, *M. decactis*[4]	Antonius, 1972 [2]Garzon-Ferreira *et al.*. 2001; [3]G. Smith[4]Sutherland et al., 2004
White band disease (WBD)	Caribbean, 27 countries	*A. palmata, A. cervicornis*	[1]Gladfelter et al., 1977
WBD type II	Bahamas, Puerto Rico	*A. cervicornis*	Richie and Smith, 1995; Weil, 2006
White pox (WPX)	Bahamas, Florida, Cuba Puerto Rico, Jamaica	*A. palmata* Synonyms: Patchy necrosis[2] Necrotic patch syndrome[3]	Porter, 1996 Patterson et al., 2002; Bruckner and Bruckner, 1997[2] Jordan-Dahlgren and Rodríguez-Martinez, 2004[3]
Plague (WP)	20 countries	31 species	GCDD records
WP type I	Florida and Bahamas	*Mycetophyllia*, *Montastraea, Colpophyllia, Agaricia*, *Mussa, Stephanocoenia, Porites*; 12 species	Dustan, 1977; 1984
WP type II	Bermuda, Bonaire, Colombia, Florida, Jamaica, Mexico, USVI, Puerto Rico, Venezuela	*D. stokesi* and 17 other species[1] 41 species[2]	Richardson et al., 1998 [2]Weil et al., 2006
WP type III	Florida	large corals (*M. faveolata, C. natans*)	Richardson, 2000
Yellow band disease (YBD)	12 countries	*M. annularis* complex; *M. cavernosa; C. natans* and other faviids *; P. astreoides; A. agaricites*	Reeves, 1994; Cervino et al., 2001; Bruckner and Bruckner, 2006
Dark-spots disease (DSD)	Caribbean	*M. annularis, S. siderea, S. radians*, *S. intersepta;* [1] also *M. franksi, M. faveolata and M. cavernosa*[2]	Garzón-Ferreira and Gil-Agudelo, 1998; [2]Garzon-Ferreira *et al.*. 2001
DSD- II	Bermuda, Bonaire, Colombia, Puerto Rico, Venezuela	*S. intersepta, M. annularis, M. faveolata, M. cavernosa, C. natans, C. amaranthus, S. siderea*	Weil et al., 2002; Weil, 2004; Weil, 2006
Dark band syndrome (DBS)	Puerto Rico, Mexico	*M. annularis, M. faveolata*	Weil, 2002;2004
Purple band syndrome (PBS)	Grenada, Venezuela	*S. siderea, S. intersepta*	Weil, 2004
Tissue necrosis	Puerto Rico	*M. faveolata*	Weil, 2004

Table.1a. Syndromes reported for scleractinian corals and gorgonians in the tropical western Atlantic (continued).			
Red band disease (RBD) type I	Bahamas, Belize, Bonaire, Colombia, Costa Rica, Curaçao, Dominica, Puerto Rico, Jamaica, Mexico, Turks and Caicos, Florida	11 species: *Gorgonia*, *Agaricia*, *Colpophyllia, Mycetophyllia, Diploria, Stephanocoenia Millepora, Meandrina, Montastraea, Porites, Siderastrea.*	Rützler et al., 1983; Santavy and Peters, 1997
RBD type II	Bahamas, Mexico	*D. strigosa, M. annularis, M. cavernosa, P. astreoides, S. radians*	Richardson, 1992
Mottling syndrome	Flower Gardens GOM	*C. natans*	Borneman, 2005
Pale ring syndrome	Flower Gardens GOM	*Montastraea, Colpophyllia, Diploria*	Borneman, 2005
Light patch syndrome	Flower Gardens GOM	*D. strigosa*	Borneman, 2005
Hyperplasia (accelerated growth)	Bermuda, Puerto Rico, USVI, Jamaica, Netherlands Antilles, Trinidad, Belize, Brazil	12 species: *Porites, Favia, Diploria, Montastraea, Stephanocoenia, Acropora, Siderastrea, Colpophyllia*.	Loya et al., 1984
Calicoblastic Neoplasm	Florida, Bonaire, Puerto Rico, Trinidad, Mexico	*A. palmata*	Peters et al., 1986
Folliculinid ciliates (SEB)	Venezuela	10 species	Croquer et al., 2006
Shut-down reaction	Belize, Florida	massive corals, acroporids	Antonius, 1977
Coccidiosis	Jamaica, Puerto Rico, USVI	*A. agaricites, D. cylindicus, D. strigosa, M. meandrites, M. cavernosa, P. astreoides, P. porites*	Upton and Peters, 1986
Nematopsis spores	USVI	*Porites* spp	Peters, 1984
Stress-related necrosis	Puerto Rico	Multiple species	Peters, 1984
Blistering necrosis	Puerto Rico, USVI	*S.siderea D. strigosa, D. labyrinthiformis M.annularis, P.astreoides, S. intersepta, A. agaricites*	Peters, 1984
Ring disease	Bermuda, Florida, Honduras	*D. labyrinthiformis*	Weil, 2001
Algal tumors	Bonaire, Trinidad, Florida	*Gorgonia Pseudoplexaura Plexaura*	Morse et al., 1977
Aspergillosis	18 countries	*Gorgonia* spp.	Nagelkerken et al., 1997
Fire coral fungal disease	Florida	*Millepora* spp.	TeStrake et al., 1988
Epizoism	Florida and Belize	*Acropora, P. porites*	Antonius, 1998
Epizootic Cyanobacteria	Florida	*Briareum asbestinum*	Harvell et al, 2001

In a review article, Sutherland et al. (2004) suggests these all represent a single disease which she refers to as "white plague like", however the term white plague has not been reported in the IndoPacific. In contrast recent IndoPacific studies are reporting a disease with signs that are similar to WBD as white syndrome (WS) (Willis et al., 2004). To avoid confusion, the white diseases are grouped here as 1) **WBD** for Caribbean acroporids; 2) **white pox** (WPX) for acroporids reported with WPX, patchy necrosis or necrotic patch syndrome; 3) **white plague** (WP type I or WP-II) for all non acroporids corals in the western Atlantic with signs similar to WBD; and 3) **white syndrome** for cases identified as WBD, white syndrome, white plague, or plague-like from the Red Sea and IndoPacific

White band disease (WBD) was first observed in the mid 1970s in St. Croix, USVI among *A. palmata* populations (Gladfelter et al., 1977). It subsequently spread throughout the Caribbean where it affected *A. palmata* and *A. cervicornis*, with reports of WBD from 27 countries during the 1980s. WBD has been reported much less frequently during the last decade; isolated cases of WBD were identified among *A. palmata* populations in 5 countries (Jamaica, Mexico, Cuba, Caymans and Bahamas) with an outbreak observed in a single location that spread throughout a population off Mona Island, Puerto Rico between 2003-2005 (Bruckner, 2005). Conversely, recent outbreaks of WBD on *A. cervicornis* populations appear to be more prevalent over the last decade. This condition may represent a new syndrome (it has also been referred to as WBD-II by Weil, 2004 and rapid tissue loss by Williams and Miller, 2005), as rates of tissue loss are much more rapid than that reported for WBD and patterns of tissue loss were more irregular (Williams and Miller, 2005).

White pox (WPX) was first observed in Puerto Rico in 1994 (called patchy necrosis (PN); Bruckner and Bruckner, 1996) and in Florida in 1996 (Patterson et al., 2002). WPX has also been reported from the USVI and Puerto Rico, with reports for PN from the Bahamas, Cuba, Puerto Rico, Jamaica and necrotic patch syndrome from Mexico. WPX is believed to have caused losses of 88% of the remaining acroporids in the Florida Keys between 1996-2002 (Porter et al., 2001; Sutherland et al., 2004).

White plague has been reported from 20 countries in the Caribbean, with few reports specifically identifying this as Type I or Type II . **WP (type I)** was first observed in 1975 on reefs off Key Largo Florida among six species, with the highest prevalence in *Mycetophyllia* spp. and *C. natans* (Dustan, 1977). It was still prevalent throughout the Key Largo region ten years later, although *M. annularis* (complex) colonies were affected most severely, along with 11 other species (Dustan, 1987). Since this time, WP-I has only been reported from the Bahamas and Puerto Rico. A condition with similar signs, but more rapid rates of tissue loss and a wider host range emerged on these reefs in 1995 (**WP type II**). The most susceptible species (*D. stokesi*) was unaffected during WP outbreaks in the 1970s and 1980s; it was also observed on 17 other species in Florida, including 8 (*M. annularis, M. cavernosa, M. faveolata, S. siderea, A. agaricites, C. natans, D. labyrinthiformis, S. intersepta*) reported during earlier WP outbreaks (Richardson et al., 1998). WP type II has been reported from 9 countries, with infections documented on 41 species (Weil et al., 2006). A separate condition termed WP Type III (based on rates of spread of up to 10 cm/day) was reported to affect the largest massive corals including *Montastraea* spp. and *C. natans* (Richardson and Aronson, 2001); it is unclear whether this is distinct from WP-II and epizootiological data are currently

unavailable. Outbreaks of WP have been reported more frequently since 2000, including offshore locations and deeper reefs (e.g., Sherwood Forest, Dry Tortugas; St Croix; La Parguera PR Shelf Edge). A similar condition has also been observed in a remote location (Flower Gardens, Texas) that was not previously affected (Hickerson, 2005).

White syndrome was first reported from the Red Sea in 1996 and Australia in 2001. This may be the same as WBD, which was first documented in the IndoPacific in the 1980s as many of the same species are affected and patterns of tissue loss are similar. Antonius (1981; 1985) reported WBD in the Red Sea on 17 genera and 31 species of corals, including 11 acroporids (Egypt, Saudi Arabia, United Arab Emirates) and 22 species in the Philippines, including two new genera (*Montipora* and *Podabacia*). Additional cases reported over the last ten years in Australia, Guam, Oman, India, Malaysia and the Philippines (Coles, 1994; Riegl, 2002; Jeyabaskaran and Raghukumar, 2004). Willis et al. (2004) observed a 20 fold increase in the number of corals affected by white syndrome between 1998 and 2003, with the greatest increases on outer reefs. In addition, infections spread from 75% of the regions and 45% of the reefs in 1998 to all regions and 89% of the reefs by 2003 (Willis et al., 2004). A disease that is similar to white syndrome and white plague was reported in a subtropical location (Solitary Islands) off Australia. Six coral genera were affected, with new observations for *Turbinaria* (2 species). Disease incidence in the Solitary Islands varied throughout the year but was lowest in March (6.2%) and highest in June (13.6%) (Dalton and Smith, 2006).

***Porites* ulcerative white spot syndrome** (PUWS) was first observed in 1996 in the Philippines, where it caused discrete bleached round lesions that may result in ulcerations that coalesce and cause tissue loss and colony mortality (Raymundo et al., 2003). This disease affected >20% of the *Porites* colonies on 8 out of 10 reefs examined in the 1990s (Raymundo et al., 2003). More recently up to 40% of the colonies were affected at sites near a populated city (Dumaguete), with prevalence declining with increasing distance from the city. The incidence of PUWS also increased between March and August, 2003, as water temperatures became elevated. In this study, PUWS was identified to affect 6 branching species of *Porites* and one massive species (Kaczmarsky, 2006).

Shutdown reaction (SDR) has been reported in the Caribbean and Red Sea, with a single report from Tonga (Chesher, 1985; Antonius, 1988). No information is available on the prevalence of this condition. There also was a single report of **white blotch disease** in Australia.

2. Cyanobacterial mat diseases

Interactions between cyanobacteria and corals have been documented throughout the Caribbean, and on reefs of Guam, Micronesia, NWHI and other locations, and cyanobacterial blooms are believed to be becoming more frequent (Thacker and Paul, 2001; Kuffner and Paul, 2004). A number of cyanobacteria have been identified as the primary causative agent of coral diseases (e.g., BBD and RBD) while others that form mats on the substrate and may smother corals and other organisms (e.g., *Schizothrix*).

Table 2. Various white syndromes reported to affect stony corals in the tropical Pacific Ocean, Indian Ocean and Red Sea.

Condition	Location and Species affected	Description	Source
White band disease	Australia, Egypt, Guam, India, Mauritius, Oman, Papua New Guinea, Philippines, Saudi Arabia, United Arab Emirates 18 genera; 37 species	A distinct band of white, recently exposed skeleton between healthy tissue and algal colonized skeleton. The white band forms a moving front that advances a few mm per day. It may be triggered by contact to cyanobacteria[1]	Antonius, 1981; 1985; 1987; 1995[1] Coles, 1994; Korrubel and Riegl, 1998; Baird, 2000; Riegl, 2002
White syndrome	Egypt[2], Australia, Solitary Islands, [4] 38 species[1, 2, 3] *Turbinaria, Acropora, Goniastrea, Pocillopora, Stylophora* and *Porites*[4]	A distinct band of white, recently exposed skeleton between apparently healthy tissue and algal colonized skeleton that advances several mm/day	[1]Willis et al., 205; [2]Riegl, 1998 [3]AIMS archives [4]Dalton and Smith, 2006
Shutdown reaction (SDR)	Saudi Arabia, Egypt, Tonga *Acropora*	Complete and sudden disintegration of coral tissue, starting at the margin of an injury. Coenosarc sloughs off skeleton in thick strands or blobs at rates of 10 cm/hr	Antonius, 1988 Chesher, 1984
Porites ulcerative white spot disease	Philippines *Porites: 7 species*	Ovoid bleached lesions, 3-5 mm diameter, affecting 3-4 polyps and surrounding coenosteum; discrete margin between bleached and apparently healthy tissue. Bleaching is followed by tissue mortality. Recovery observed in small lesions; larger lesions may coalesce and kill the coral	Raymundo et al., 2003; Kaczmarsky, 2006
White blotch disease	Australia *Acropora*	White blotches associated with infestations of polychaetes	Dinsdale, 1994

Black band disease (BBD) was first described in 1972 from reefs off Belize, Puerto Rico, Florida and Bermuda (Antonius, 1973). BBD is now known to occur in at least 25 countries in the western Atlantic, and 11 countries in the Red Sea and Indo-Pacific, although cyanobacteria differ depending on location (Cooney et al. 2002, Frias-Lopez et al. 2002, 2003). In the western Atlantic, BBD has been reported on 26 scleractinian corals, one hydrozoan coral (*M. complenata*) and six gorgonians (Rützler et al. 1983; Feingold 1988; Green and Bruckner 2000). Faviid corals are most susceptible, although infections are frequently observed on *S. siderea*, and occasionally on *Agaricia* spp, *Mycetophyllia* spp., and *M. meandrites*. Caribbean colonies of *Porites* spp. and *Acropora* spp. were thought to be resistant to BBD, although BBD was reported on *A. palmata* in Colombia (Garzon-Ferriera et al., 2001), *P. astreoides* in Cuba (AGRRA database), Bermuda (Garret and Ducklow, 1975) and Mexico (Ryan Walker, Coral Cay Conservation, pers. Comm.), and *P. porites* in the Bahamas and Jamaica (AGRRA database). Several cases of BBD have also been observed on *Solenastrea bournoni* in Mexico (Ryan Walker). Sutherland et al. (2004) also reports BBD on *Madracis mirabilis* and *M. decactis*, although the source of these records is not provided.

In the IndoPacific and Red Sea, BBD has been observed on 19 genera and 49 species, most commonly on faviids and acroporids (Antonius 1988; Miller 1996; Green and Bruckner 2000; Dinsdale 2002; Sutherland et al., 2004). BBD was observed on 19% of 91 reefs examined in 1993/94 (Miller, 1996). More recent surveys show that BBD is widely distributed throughout the GBR Australia, but prevalence remained very low (04-0.47 colonies per reef on any given year) between 1998 and 2003 (Willis et al., 2004). Kaczmarsky (2006) recently identified an outbreak of BBD affecting close to 8% of the corals at one site in the Philippines; these observations include 5 new hosts for BBD in the Philippines and one new genera overall (*Coscinaraea columna*).

Red band disease (RBD type I and RBD-II) are only known from the Caribbean, although another disease termed "red band" has also been reported from Palau on *Pachyseris* spp. (Harvell et al., 2004). RBD- I was first identified on gorgonians in Belize in the 1980s, and has since been reported from 12 countries in the Caribbean, with records from 10 scleractinian corals, *Millepora* spp., and the sea fan *G. ventalina* (Rutzler et al., 1983). RBD-II has only been observed in a single location in the Bahamas (Richardson, 1993).

Several other cyanobacterial diseases have also been reported from the IndoPacific. Black overgrowing cyanobacteria is associated with at least five cyanobacteria that overgrow *Acropora, Favia, Pocillopora* and *Porites* on reefs in the Indian Ocean (Antonius, 1995). Black aggressive band has been observed in a single location on branching acroporids (Antonius, 1995), while brown band disease has only been recorded on *A. formosa* on the GBR Australia (Dinesdale, 1994; Antonius, 1999). Pink line syndrome, reported on *Porites compressa* and *P. lutea* in the Indian Ocean, has also been associated with a cyanobacteria (*Phormidium valderianum*) that is thought to induce pink coloration in affected coral tissue (Ravindran & Raghukumar, 2002).

3. Color change

In many reported syndromes, color change is an important diagnostic feature used to identify and differentiate diseases. Color change may include darker than normal tissue, lighter tissues, or a change in color such as the appearance of purple or pink spots or bands. Three syndromes associated with lightening of tissue have been reported from the Flower Gardens (Texas). This includes: 1) **light patch syndrome** which is observed in *D. strigosa* and is associated with variably sized, solid patches of uniformly contrasting paler tissue on normally pigmented colonies; 2) **pale ring syndrome**, which causes a variably wide ring that occurs singly or in multiples on the corallum surface in *M. faveolata*, *M. cavernosa*, *C. natans* and *D. strigosa*; and 3) **mottling syndrome** in *C. natans*, in which the tissue appears mottled as a result of total to near-total bleaching associated with a focal lesion, with spotty bleaching occurring in a wide band that grades towards apparently healthy tissue (Borneman, 2005).

Table 3. Diseases associated with cyanobacteria reported to affect stony corals in the tropical Pacific Ocean, Indian Ocean and Red Sea.

Condition	Location and Species affected	Description	Source
Black band disease	Australia, Egypt, Fiji, India, Jordan, Papua New Guinea, Philippines, Saudi Arabia, Tonga, South Africa, CNMI, Palau 19 genera, 49 species; Pocillopora and Acropora most frequently affected	A darkly pigmented mat/band 1-30 cm wide on the surface of the coral that separates healthy tissue from recently denuded white skeleton.	Antonius, 1987; Chesher, 1985; Glazebrook and Steiner, 1994; Littler and Littler, 1996; Miller, 1996; Korrubel and Riegl, 1998; Fenner, 1998; Cervino, 1998; Jordan and Samways, 2001; Dinesdale, 2002, Willis et al., 2004
Brown band disease	Australia *Acropora Formosa*	Different condition from above associated with cyanobacteria	Dinsdale, 1994
Black aggressive band	Mauritius *Acropora* (staghorn coral)	Resembles BBD but the band material is thinner and appears grey rather than black; possibly caused by a cyanobacteria (*Spirulina*) or a spirochete	Antonius, 1995a
Black overgrowing cyanobacteria	Indian Ocean, Mauritius *Acropora, Favia Pocillopora, Porites,*	Cyanobacteria (*Calothrix, Hormothamnium, Lyngbia, Phormidium, Spirula*) cover coral tissue and progressively overgrow it; may penetrates and erodes skeleton	Antonius, 1995a
Red band disease	Palau *Pachyseris speciosa* and *Porites* spp.	A reddish band on the surface of the coral that separates healthy tissue from recently denuded white skeleton.	Harvell et al., 2004; Sussman et al., 2006
Pink line disease /syndrome	Papua New Guinea, Sri Lanka, Kavaratti Island, Indian Ocean *Porites compressa, P. lutea*	Band of pink pigmented tissue separating recently killed skeleton and normal tissue; it may begin as a small ring and progress outward. Associated with a cyanobacteria.	Ravindran et al., 2001; Goreau/Cervino, coral list server

Two distinct conditions have been reported as **yellow band disease**. In the Caribbean, YBD (also referred to as yellow blotch disease) was first reported from Florida in 1994 (Reef Relief), and subsequently observed in 24 countries throughout the Caribbean. It primarily affects *M. annularis* complex and 4 other massive faviids corals, *A. agaricites,* and *P. astreoides*. This disease has been reported at an unusually high prevalence in a number of countries (18-91%) including Puerto Rico, Mexico, Curacao, Bonaire, Grenada, Panama, and USVI (Cervino et al., 2001; Jordan-Dahlgren and Rodriguez-Martinez, 2004; Bruckner and Bruckner, 2006). **Yellow band disease** was first reported in 1995 from the Arabian Gulf off Dubai (United Arab Emirates) and in 1999 and 2003 off Fahr Island and Kish Island (Iran). It affects *Turbinaria, Porites, Cyphastrea* and *Acropora* (Korrubel and Riegl, 1998).

Dark spots disease was first observed in Colombia in the mid 1990s, but has since been reported from 15 other countries in the Caribbean (Garzon-Ferriera et al., 2001; Weil 2004). It is most commonly observed on the genera *Stephanocoenia, Siderastrea* and *Montastraea*, although similar signs are observed on 6 other species. Colonies are characterized by darkly pigmented spots or bands within the tissue, and occasionally extending into the skeleton, with depressed skeletal features observed in *Stephanocoenia*. Over time these dark spots may increase in size, or the center of the spot may die and dark tissue may expand into a band or ring that slowly migrates outward. Weil (2002; 2004) reported three additional syndromes that are similar in appearance to DSD (DSD-II, dark band disease, purple band disease and tissue necrosis). These syndromes could be related, or are a different stage in the progression of dark spots disease (Weil, 2004).

4. Other conditions

Two conditions have been reported in the GCDD that are associated with ciliates**, brown band disease (BrBD)** and **skeletal eroding band (SEB).** BrBD has only been reported from the GBR, Australia, where it affected a low proportion of corals (0.3%), including acroporids, pocilloporids and faviids (Willis et al., 2004). SEB has been observed in the Red Sea, Indian Ocean and Pacific (5 countries) on 21 genera of corals (Reigl and Antonius, 2003; Willis et al., 2004). In Australia, SEB was the dominant disease affecting acroporids and pocilloporids, with a 20 fold increase during summer (Willis et al., 2004). A similar condition (folliculinid ciliates) was recently reported from the Caribbean (Venezuela) on 10 species of coral (Croquer et al., 2006).

Tumors (including calicoblastic neoplasms, hyperplasias, abnormal growth) are among the most widely reported condition affecting corals with the first observations over 40 years ago (Squires, 1965), and subsequent reports from 15 countries in the IndoPacific and 13 countries in the Caribbean. Neoplasia has been reported most frequently on *Acropora*, with reports from the Caribbean, Philippines, Guam, Hawaii, and Oman.

Conclusions

1. Diseases occur globally, in most reef habitats and in most locations including reefs near human population centers and remote offshore locations. Although most of the reports available prior to 1998 were from areas that had a medium to high level of human impact, reports of disease from remote locations has escalated, and in some cases offshore locations are exhibiting the most dramatic increases in diseases incidence and mortality.
2. Diseases have been observed in 63 countries, a 17% increase since 1999. This includes increasing numbers of observations of disease in the IndoPacific, along with a number of new diseases and increasing prevalence of these diseases, but Caribbean reefs are still disproportionately affected by disease.
3. There are six major diseases of concern in the Caribbean (BBD, WBD, WP, YBD, ASP, WPX) that have caused substantial coral mortality since their discovery; two of these remain a major threat to acroporids (WBD, WPX), one is impacting a growing number of gorgonian species (ASP), and three (WP, YBD, BBD) are of major concern to *M. annularis* (complex) and other species. Two other conditions appear to be widespread (DSD and SEB), but are causing slow rates of mortality at this time.
4. The disease of most concern on IndoPacific reefs is white syndrome, which is having the largest impacts on acroporids throughout the region; PUWS is a growing threat to *Porites*, but at this time it appears to be restricted to the Philippines. Most other newly emerging IndoPacific diseases have caused localized mortality and appear to have a limited distribution.
5. Although a greater number of corals have been identified with disease in the IndoPacific (34 genera and 97 species), a higher percentage of coral species (close to 80% of all taxa; 41 species of scleractinian corals, 8 gorgonians, 2 hydrozoans) are affected by diseases in the Caribbean. This represents a 25% increase in number of genera and 45% increase in number of species and includes 7 new genera identified with disease in the IndoPacific since 1999.
6. Rapidly growing corals in the family acroporidae and pocilloporidae in the IndoPacific are affected by the largest number of diseases and are observed with disease more frequently than all other species, while the *M. annularis* complex is being affected most severely in the Western Atlantic.
7. Tumors (hyperplasia, neoplasia etc.) are the oldest known afflictions of corals, and are found on most corals in most locations, but their impacts appear to be minimal at this time.

Table 4. Other Diseases, syndromes, and anomalies reported to affect stony corals in the tropical Pacific Ocean, Indian Ocean and Red Sea.

Condition	Location and Species affected	Description	Source
Yellow band disease	United Arab Emirates; Arabian Gulf; Iran[2] 4 genera, 12 species	A broad band of denuded skeleton, yellow in color, adjacent to decaying and sloughing tissue; the band advances 9-20 mm/week.	Korrubel and Riegl, 1998 [2]Maghsoudlou, and Eghtesadi, 2004
Brown band disease	Australia *Acropora Formosa*	A brown band of variable width flanked by healthy tissue at6 the advancing front and exposed white skeleton at the trailing edge. The band moves in both directions along the branch, destroying coral tissue. Dense populations of ciliates, packed with zooxanthellae from coral cause brown coloration.	Willis et al., 2004
Skeleton eroding band (SEB)	Egypt, Jordan[1] PNG, Mauritius[2], Australia [2] 21 genera ; *Cyphastrea chalcidicum*, acroporids[2] 13 genera scleractinian, 1 hydrozoan in Australia [3]	Masses of black loricae of *Halofolliculina corallasia*, a colonial heterotrich ciliate, that forms a front separating live tissue from a white zone; the front advances like BBD, causing tissue loss and skeletal damage.	[1]Antonius, 1999; Winkler et al., 2004 [2]Riegl and Antonius, 2003 [3]Willis et al., 2004
Plagioporus	Hawaii *Porites compresssa, P. lobata*	Metacercaria of the digenetic trematode encyst in elevated nodules, causing enlarged pink polyps. Cyst wall is secreted by parasite, produces distortions of gastrovascular cavity and cellular alterations within tentacles	Aeby, 1991
Patchy necrosis	Adaman Islands, Indian Ocean *Porites,Goniastrea Goniopora, Montipora, Favia, Goniastrea* and *Pocillopora*	Hyphomycetous fungus associated with necrotic patches. Top layer of necrotic patches consists of epilithic algae, followed by a thin black zone of fungal growth, a green band containing shell-boring algae and a dense black fungal layer at the base	Raghukumar and Raghukumar, 1991; Ravindran et al., 2001
Fungal syndrome	East African Coast *Astreopora, Montipora, Echinopora, Acropora, Goniopora, Platygyra, massive Porites, Pocillopra, Goniastrea Hydnophora, Cyphastrea*	Corals develop ashy dull color and brittle or weak skeleton. Corals become covered in mucus, which traps debris. Once this clears, a white calcareous dust is left on the surface and a black layer forms underneath; death occurs in about two weeks	McClanahan et al., 2004

Table 4 (continued). Other Diseases, syndromes, and anomalies reported to affect stony corals in the tropical Pacific Ocean, Indian Ocean and Red Sea.

Condition	Location and Species affected	Description	Source
Hyperplasia (and other reports of tumors)	Australia, Hawaii, Guam, Palau, Enewatak, French Polynesia, New Caledonia, Maldives, Micronesia, Marshall Islands, Japan, Oman, China, Philippines *Pocillopora, Pavona, Fungia, Madrepora, Montipora, Platygyra*	Irregular growths on colonies reported as tumors and hyperplasms associated with a proliferation of cell types (normal in appearance, but larger in size)	Loya et al. 1984; Peters et al., 1986 ; Glazebrook and Steiner, 1994;Yamashiro et al., 2000
Neoplasia	CNMI, Oman Acropora	calicoblastic epitheliomas, neoplasms associated with a proliferation of cell types and white globular masses of skeleton with few discernable polyp structures.	Cheney, 1975; Coles and Seapy, 1998
Stress related necrosis	Hawaii *Porites lobata*	Gram negative bacterial aggregates in gastrodermal cells of tentacles. Tissues exhibit lysed nuclei and cell death	Hunter,
Pink-blue disease	Israel, India, Lackshadweep Islands *Acropora, Porites*	Pink to blue coloration adjacent to lesions	Red Sea Marine Park, 2001; Ravindran et al., 2001
Black necrosing syndrome	Australia Gorgonians, *Isis hippuris*	Black necrotic patches appearing on 10% of the population on one reef	Morrison Gardiner, 2001; Willis et al., 2004
Vibrionic Bleaching	Mediterranean, Israel, Tanzania *Oculina pategonica; Pocillopora*		Rosenberg, 2002
Atramentous necrosis	Florence Bay and Bright Point, Australia *Montipora aequituberculata*		Jones et al., 2004
Yellowing disease	Sodwana, South Africa *Favia pentagona* and *Lobophytum*		Jordan and Samways, 2001
Red plague syndrome	Kavaratti Island, India *Montipora* spp. and *Porites* spp.		Jeyabaskaran and Raghukumar, 2004

Fig. 1. Five major scleractinian coral diseases reported for the wider Caribbean compiled in the GCDD. Reports of syndromes with different "types" (e.g., WP type I and WP type II) have been pooled.

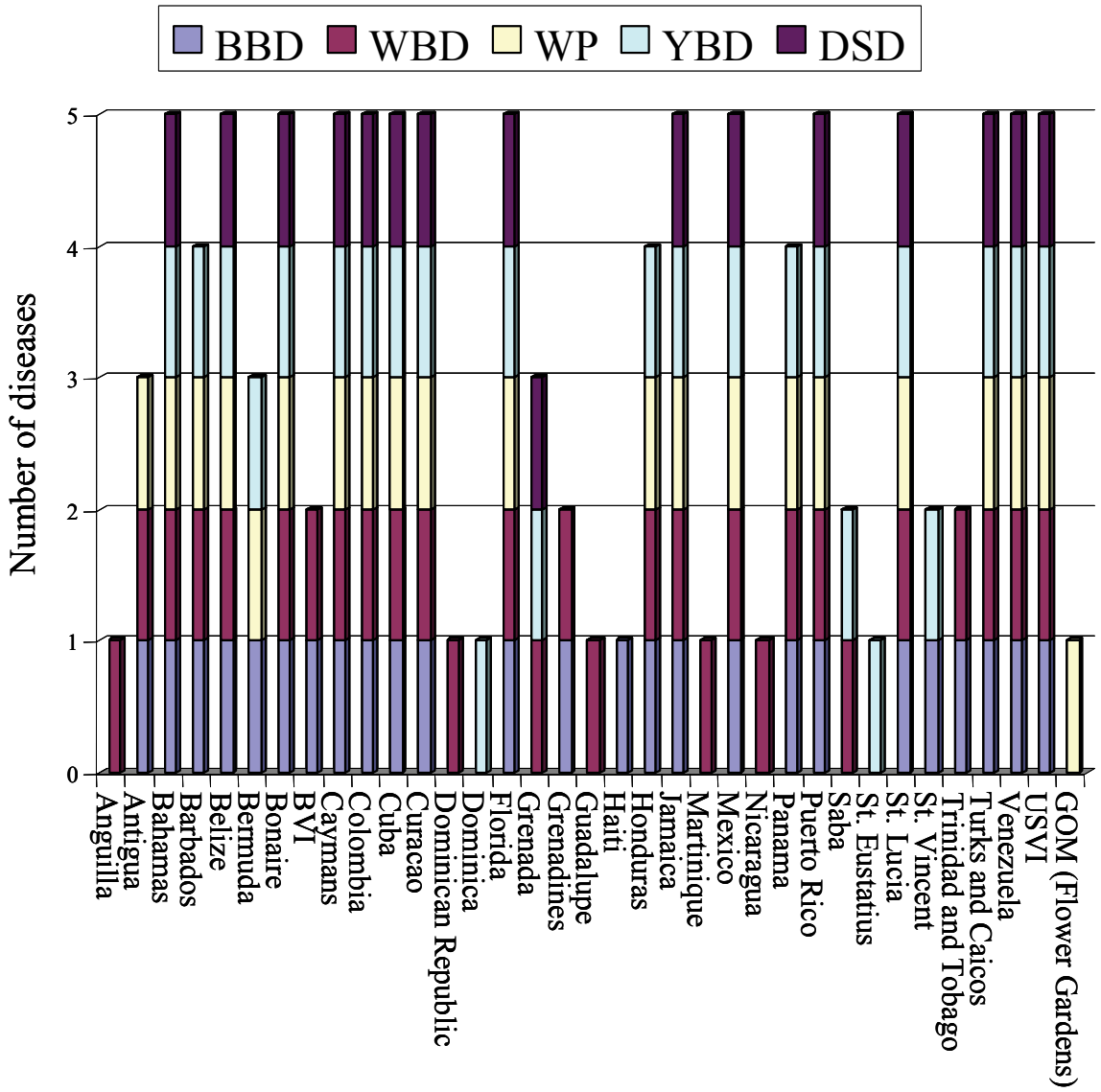


Fig. 2 Susceptibility of scleractinian corals to seven major syndromes observed in the Indo Pacific.

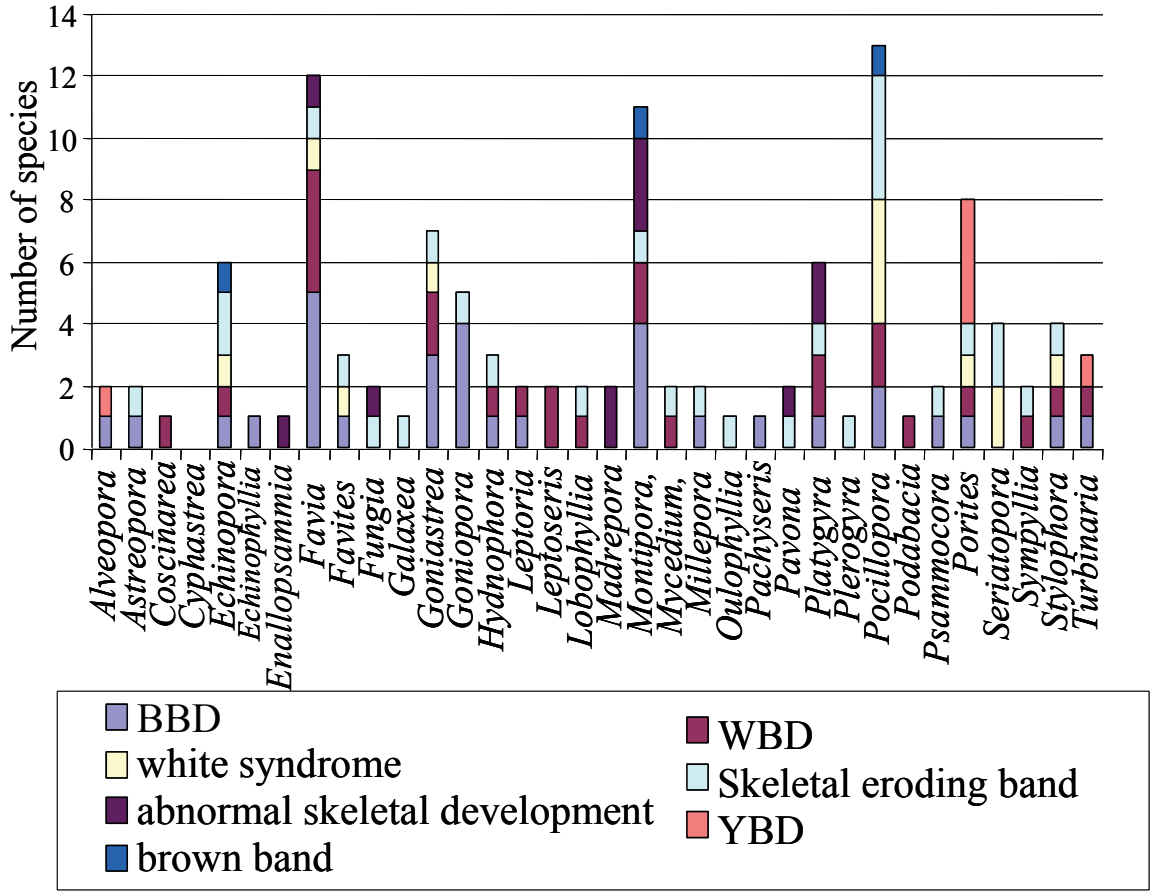


Fig. 3. Number of diseases observed on IndoPacific Reefs. Only those conditions reported in peer-reviewed publications are included

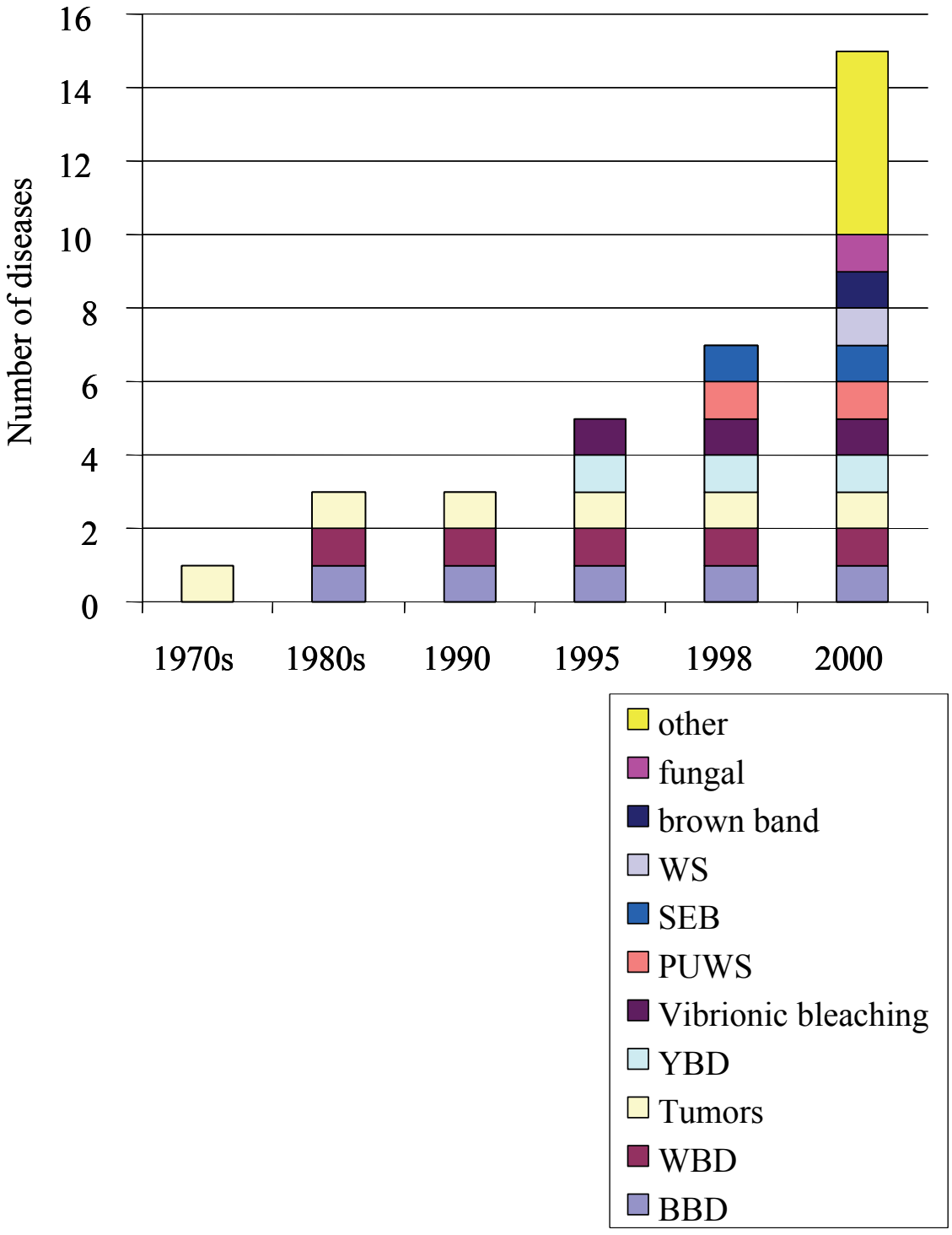
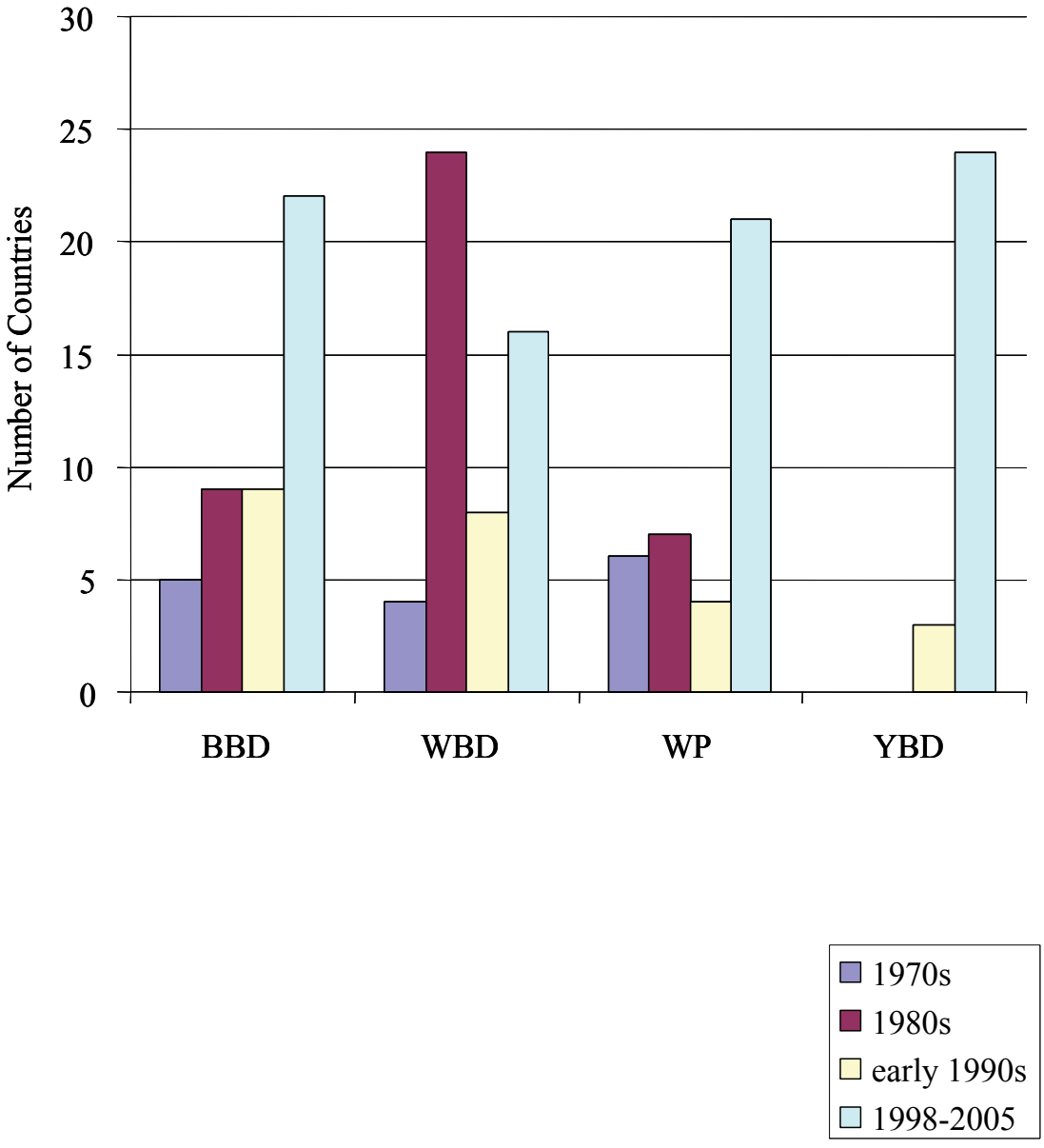


Fig. 4. Number of countries reported with BBD, WBD, WP and YBD during the 1970s, 1980s, 1990s and today



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WORLD BANK PROJECT: CORAL DISEASE WORKING GROUP

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CRTR Coral Disease Working Group

(excerpted from the CRTR webpage - http://www.gefcoral.org/**)**

Coral reefs are under increasing stress from a number of causes, including climate warming, poor water quality and over fishing. Disease outbreaks cause not only coral loss, but they can result in significant changes in community structure, species diversity and reef-associated organisms. Coral diseases potentially impact both well-managed and unmanaged reefs indiscriminately. However, strategies for dealing with disease outbreaks are currently non-existent. The increasing frequency with which diseases influence and alter reef communities means they must be considered and incorporated into management plans.

Background:

The CRTR Program is a partnership between the Global Environment Facility, the World Bank, The University of Queensland (Australia), the United States National Oceanic and Atmospheric Administration (NOAA), and approximately 50 research institutes and other third parties around the world. The CRTR Coral Disease Working Group's research will provide us with a greater understanding of the ways in which coral diseases can alter reef function and the conditions under which outbreaks may occur.

Global impact of coral disease

Coral disease stands out as a primary factor in the deterioration of many coral reefs worldwide, with preliminary surveys indicating that significant and damaging new diseases are now beginning to appear in all reef regions. The CRTR Program Disease Working Group is conducting a global coral disease census across 24 high priority sites. This major assessment is designed to catalogue syndromes for the first time, and to reveal whether disease outbreaks are correlated with climate warming anomalies. In each location the impact and prevalence of coral disease is being measured.

Global warming and anthropogenic inputs

Increases in disease following warming events may be because corals have lower ability to fight disease while under temperature stress, or because bacteria are more virulent. While connections between poor water quality (nutrient loading and sedimentation) and disease are of increasing concern, evidence of direct links and synergistic effects is limited. The CRTR Program Disease Working Group is measuring nitrogen and sediment loading at key research sites. The team will use molecular and enzymatic techniques to assess differences in microbial communities - in coral mucus, water and sediment

between sites with different loadings, and between healthy and bleached corals. There will also be an evaluation of climate and anthropogenic influences on changes within microbial communities.

The causes, reservoirs and vectors of corals disease

Current research on disease reservoirs and vectors is hampered by a lack of knowledge of the pathogens causing the majority of coral diseases. To date there are only five coral diseases for which the microbial cause is known. The Disease Working Group is developing a suite of techniques to facilitate the identification of pathogens in coral. Because only a small percentage of bacteria in nature are culturable, the identity and source of pathogens will be confirmed using various molecular fingerprinting techniques. Eventually a micro-array chip of global coral disease will be developed.

Coral resistance to disease

The microbial communities associated with coral are very complex, existing both inside the coral animal and in the surface mucous layers (SML). These normal communities protect the coral from disease. When the community structure changes, corals may become more susceptible to disease. Both bleaching and disease appear to change the microbial community profiles in the SML. The goal of the Disease Working Group's immunological work is to develop assays to determine general antimicrobial activity. Once resistant compounds are identified, they will be incorporated into a chip of biomarkers for stress. Field sampling will eventually allow the team to quantify and estimate the response of corals to different experimental treatments of enhanced nutrients and temperature, and map the spatial extent and variation of disease resistance in the field.

Our Research

Research Activities:

Over the last 20 years, unprecedented increases in disease on coral reefs have contributed significantly to coral reef degradation. Disease-related damage of coral reefs has been well documented in the Caribbean, but recent observations of coral disease in other regions of the world are just beginning. Disease occurrence in these other regions may be a potential harbinger for further outbreaks and impacts associated with increasing climate warming. The Disease Working Group is targeting investigations to address the causes of this rapid emergence of coral disease, to understand the impacts of the problem and to develop tools and responses that can be used for management.

Research Update:

The Disease Working Group has answered many pressing questions including which disease syndromes are infectious; which reef regions surveyed as part of the the CRTR Program have the greatest prevalence of coral disease; which Centres of Excellence would be the most suitable for identifying local factors that might impact on disease; and whether ocean warming affects coral disease levels.

Impact of fish farms
As part of its study of the impact of local environmental factors on coral health, the Group has found that the fish pens in Bolinao Bay (Philippines) have a strong influence on bacterial communities, nutrient input, primary production and the patterns of energy and carbon flux in the surrounding waters. Researchers are working to identity specific bacteria from fish farms that reside on the surface of reef corals, and whether aquaculture plays a role as an incubator, conveyor and facilitator of disease into natural populations.

Disease in a warming ocean
The Group has made significant discoveries in the Caribbean and Great Barrier Reef region in Australia regarding the potential impacts of heat stress, associated with climate warming events, on the outbreak of coral disease. In collaboration with the Remote Sensing Working Group, it is developing new models to predict disease outbreaks using satellite monitoring data. The models use predicted sea temperature data and can identify the potential efficacy of various management strategies for future scenarios.

Other causes of coral disease
The Group continues to survey the prevalence of coral disease in Caribbean, Yucatan and Australian coral reefs, and is making progress in determining agents that cause coral disease such as skeletal eroding band, brown band and white syndrome.

Tools for Management:
The Disease Working Group has developed important new tools for coral reef managers and researchers across the Western Atlantic and the Indo-Pacific to identify and address coral disease – the *Coral Disease Handbook: Guidelines for Assessment, Monitoring and Management* and two sets of underwater identification cards. These were launched at the 11th International Coral Reef Symposium in July 2008.

Handbook
Designed for reef managers by international experts in coral disease, the Handbook outlines procedures for describing indicators, measuring impacts, monitoring outbreaks, assessing causes, and managing reefs to minimize losses due to disease. This handbook helps managers not only to document and manage disease on their reefs, but also enables them to contribute to our scientific understanding of this grave and increasing threat.

Underwater Cards Caribbean
These Underwater Cards for assessing the health of coral reefs have been designed so that scientific, professional and recreational divers can all assist with gathering information on the occurrence of coral reef diseases in the Caribbean. These cards will assist in the identification and monitoring of diseases in Caribbean coral and other reef organisms.

Underwater Cards Indo-Pacific
These Underwater Cards for assessing the health of coral reefs have been designed so that scientific, professional and recreational divers can all assist with gathering information on the occurrence of coral reef diseases in the Indo-Pacific. These cards will assist in the identification and monitoring of diseases in Indo-Pacific corals and other reef organisms.

Who we are

Working Group Members:

Working Group members bring international expertise and experience to this targeted research: C. Drew Harvell (Chair), Garriet W. Smith (Co-Chair, Microbiology), Bette Willis (Co-Chair, Ecology), Farooq Azam, Eric Jordan Dahlgren, Eugene Rosenberg, Ernesto Weil, Laurie Raymundo.

Project Partners:

Working Group partners bring capacity to this research endeavour:
Section of Ecology and Evolutionary Biology, Cornell University, USA;
Department of Biology and Geology, University of South Carolina-Aiken, USA;
Scripps Institution of Oceanography, University of Southern California, USA;
Unidad Académica de Sistemas Arrecifiales, Instituto de Ciencias del Mar y Limnologia, Universidad Nacional Autónoma de México, Mexico;
Department of Molecular Microbiology and Biotechnology, Faculty of Life Sciences, Tel Aviv University, Israel;
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University of Guam Marine Laboratory, University of Guam, USA.

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