BEFORE THE SECRETARY OF COMMERCE

PETITION TO LIST 83 CORAL SPECIES UNDER THE ENDANGERED SPECIES ACT

Blue rice coral photo © Keoki Stender

CENTER for BIOLOGICAL DIVERSITY

Because life is good.

Submitted October 20, 2009

NOTICE OF PETITION

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PETITIONER

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Date: October 20, 2009

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Pursuant to Section 4(b) of the Endangered Species Act ("ESA"), 16 U.S.C. §1533(b), Section 553(3) of the Administrative Procedures Act, 5 U.S.C. § 553(e), and 50 C.F.R. §424.14(a), the Center for Biological Diversity ("Petitioner") hereby petitions the Secretary of Commerce and the National Oceanographic and Atmospheric Administration ("NOAA"), through the National Marine Fisheries Service ("NMFS" or "NOAA Fisheries"), to list 83 coral species and to designate critical habitat to ensure their survival and recovery.

The Center for Biological Diversity ("Center") is a non-profit, public interest environmental organization dedicated to the protection of native species and their habitats through science, policy, and environmental law. The Center has over 43,000 members throughout the United States and internationally. The Center and its members are concerned with the conservation of endangered species, including coral species, and the effective implementation of the ESA.

NMFS has jurisdiction over this petition. This petition sets in motion a specific process, placing definite response requirements on NMFS. Specifically, NMFS must issue an initial finding as to whether the petition "presents substantial scientific or commercial information indicating that the petitioned action may be warranted." 16 U.S.C. §1533(b)(3)(A). NMFS must make this initial finding "[t]o the maximum extent practicable, within 90 days after receiving the petition." *Id.* Petitioner needs not demonstrate that the petitioned action *is* warranted, rather, Petitioner must only present information demonstrating that such action *may* be warranted. While Petitioner believes that the best available science demonstrates that listing the 83 coral species as endangered *is* in fact warranted, there can be no reasonable dispute that the available information indicates that listing these species as either threatened or endangered *may* be warranted. As such, NMFS must promptly make a positive initial finding on the petition and commence a status review as required by 16 U.S.C. § 1533(b)(3)(B).

The 83 coral species covered by this Petition are as follows:

Acanthastrea brevis
Acanthastrea hemprichii
Acanthastrea ishigakiensis
Acanthastrea regularis
Acropora aculeus
Acropora acuminata
Acropora aspera
Acropora dendrum
Acropora donei
Acropora globiceps
Acropora horrida
Acropora jacquelineae
Acropora listeri
Acropora lokani
Acropora microclados
Acropora palmerae
Acropora paniculata
Acropora pharaonis
Acropora polystoma
Acropora retusa
Acropora rudis
Acropora speciosa
Acropora striata
Acropora tenella
Acropora vaughani
Acropora verweyi
Agaricia lamarcki
Alveopora allingi
Alveopora fenestrata
Alveopora verrilliana
Anacropora puertogalerae
Anacropora spinosa
Astreopora cucullata
Barabattoia laddi
Caulastrea echinulata
Cyphastrea agassizi
Cyphastrea ocellina
Dendrogyra cylindrus
Dichocoenia stokesii
Euphyllia cristata
Euphyllia paraancora
Euphyllia paradivisa
Galaxea astreata
Heliopora coerulea
Isopora crateriformis
Isopora cuneata
Leptoseris incrustans
Leptoseris yabei
Millepora foveolata
Millepora tuberosa
Montastraea annularis
Montastraea faveolata
Montastraea franksi
Montipora angulata
Montipora australiensis
Montipora calcarea
Montipora caliculata
Montipora dilatata
Montipora flabellata
Montipora lobulata
Montipora patula
Mycetophyllia ferox
Oculina varicosa
Pachyseris rugosa
Pavona bipartita
Pavona cactus
Pavona decussata
Pavona diffluens
Pavona venosa
Pectinia alcicornis
Physogyra lichtensteini
Pocillopora danae
Pocillopora elegans
Porites horizontalata
Porites napopora
Porites nigrescens
Porites pukoensis
Psammocora stellata
Seriatopora aculeata
Turbinaria mesenterina
Turbinaria peltata
Turbinaria reniformis
Turbinaria stellula

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EXECUTIVE SUMMARY

The world's corals and coral reef ecosystems are in crisis. Nearly 20% of the world's coral reefs have already been lost, and approximately one-third of all zooxanthellate reef-building coral species as at risk of extinction according to the IUCN (Carpenter et al. 2008; Veron et al. 2009). Corals face widespread threats ranging from habitat destruction, pollution, overharvest, and disease. Warming ocean temperatures and ocean acidification due to anthropogenic greenhouse gas pollution threaten the continued survival of corals and coral reef ecosystems. According to coral scientists, "reefs are likely to be the first major planetary-scale ecosystem to collapse in the face of climate changes now in progress" (Veron et al. 2009: 1433).

This petition seeks to list 83 species of corals which are designated as threatened with extinction by the IUCN and which occur in United States waters and thus stand to benefit most from listing under the US Endangered Species Act ("ESA"). All of the petitioned species have suffered population reductions of at least 30% over a 30-year period (Carpenter et al. 2008). The declines of the petitioned coral species to date have been linked to numerous major threats, including mass bleaching events; major disease and predation outbreaks; destructive fishing practices and chronic overharvest of corals, reef fish, and other associated species; and pollution, sedimentation, and physical damage due to human land and sea uses, which are intensifying with the recent and ongoing explosions in human population growth and marine vessel traffic. Anthropogenic climate change and ocean acidification pose the most serious short- and long-term threats to the survival of the petitioned corals.

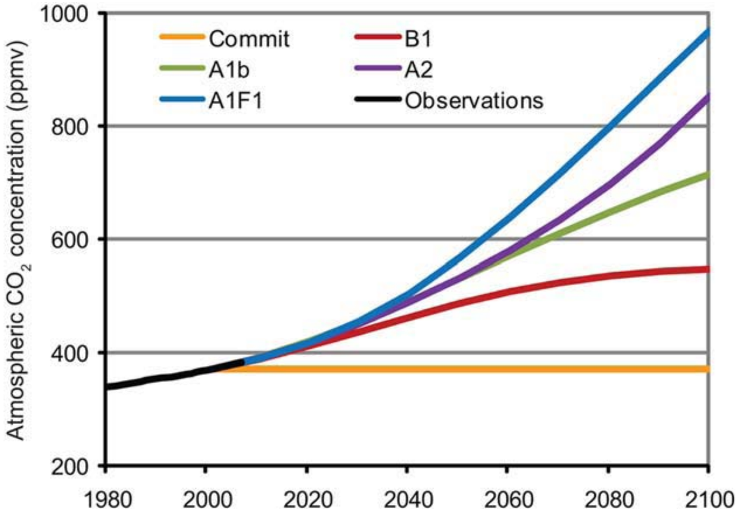
The best available science clearly indicates that the petitioned coral species are threatened with extinction before mid-century due to the increasing frequency of mass bleaching events at harmfully intervals and the projected dissolution of corals due to ocean acidification. At today's atmospheric carbon dioxide level of ~387 ppm, corals are experiencing detrimental bleaching events, and many of the world's reefs are committed to irreversible declines (Veron et al. 2009). Already, corals have been impacted by climate change, and mass bleaching events have become more frequent and severe with serious coral mortality resulting. The committed warming from greenhouse gases already in the atmosphere is projected to cause over half of the world's coral reefs, including reefs in the Indian Ocean and most of the Pacific, to experience harmfully frequent bleaching at five-year intervals by or before 2080 (Donner 2009). Studies projecting the impacts of ocean warming on corals indicate that the majority of the world's corals will be subjected to recurring mass bleaching events at frequencies from which they will be unable to recover (five-year-intervals or less) by the 2020s or 2030s under mid-to-low level IPCC emissions scenarios, in the absence of thermal adaptations by corals and their symbionts (Hoegh-Guldberg 1999; Sheppard 2003; Donner et al. 2005; Donner et al. 2007; Donner 2009). The most recent research by Donner (2009) projected that 80% of the world's reefs, including corals in the regions inhabited by the petitioned species, would experience bleaching at five-year intervals by 2030 under the lowest IPCC emission scenario (B1). Under the higher A1B and A1FI scenarios, the majority of the world's corals, including corals in the regions inhabited by the petitioned species, would be subjected to mass bleaching at unsustainable (< 5 year) intervals by 2020 (Donner 2009).

Ocean acidification will act synergistically with warming to further threaten the petitioned coral species with extinction. Since 1990, calcification of some corals has declined by 14-21% in Australia's Great Barrier Reef (De'ath et al. 2009). Studies projecting the impacts of ocean acidification on corals predict that coral erosion will exceed calcification rates at atmospheric carbon dioxide concentrations between 450 to 500 ppm (Hoegh-Guldberg et al. 2007), and all coral reefs will dissolve at carbon dioxide concentrations of 560 ppm (Silverman et al. 2009). Due to the synergistic impacts of ocean acidification, mass bleaching, and other impacts, reefs are projected to experience "rapid and terminal" declines worldwide at atmospheric carbon dioxide concentrations 450 ppm:

> If CO_2 levels are allowed to reach 450 ppm (due to occur by 2030-2040 at the current rates), reefs will be in rapid and terminal decline world-wide from multiple synergies arising from mass bleaching, ocean acidification, and other environmental impacts. Damage to shallow reef communities will become extensive with consequent reduction of biodiversity followed by extinction (Veron et al. 2009: 1428).

On the current global emissions trajectory, which is exceeding the most fossil-fuel intensive IPCC A1FI scenario (Raupach et al. 2007; Richardson et al. 2009; McMullen and Jabbour 2009), carbon dioxide levels would exceed 450 ppm by ~2030 and exceed 560 ppm by mid-century (Figure 1).

Figure 1. Annual globally averaged atmospheric carbon dioxide concentration (in ppm) from 2000 to 2100 in five IPCC scenarios. The observed global mean concentration from 1980 to 2007 is displayed for comparison. The concentration stabilizes at 370 ppm in the year 2000 in the Commit scenario.
Source: Donner (2009): Figure 2.



Given the documented detrimental impacts to corals at the current atmospheric CO_2 concentration of ~387 ppm CO_2, the best-available science indicates that atmospheric CO_2 concentrations must be reduced to at most 350 ppm, and perhaps much lower (300-325 ppm

CO_2), to adequately reduce the synergistic threats of ocean warming, ocean acidification, and other impacts (Veron et al. 2009; Donner 2009; Hansen et al. 2008; Hoegh-Guldberg et al. 2007; McMullen and Jabbour 2009). Clearly, immediate action is needed to reduce greenhouse gas concentrations to levels that do not jeopardize the petitioned coral species.

Regulatory mechanisms at the national and international level do not adequately address the impacts from climate change and ocean acidification to the petitioned coral species, nor require the greenhouse gas emissions reductions necessary to protect the petitioned coral species from extinction. While existing laws including the Clean Air Act, Energy Policy and Conservation Act, Clean Water Act, Endangered Species Act, and others provide authority to executive branch agencies to require greenhouse gas emissions reductions from virtually all major sources in the U.S., the federal government is currently not implementing these legal mechanisms. In addition, there are no international agreements governing greenhouse gas emissions in the years beyond 2012. Existing regulatory mechanisms have been ineffective at preventing the declines of the petitioned coral species and mitigating other threats to these species, which are now on a trajectory towards extinction. Based on their precipitous population declines, and multiple, ongoing threats to their continued existence, the petitioned corals merit prompt listing under the ESA.

Pursuant to the ESA, NOAA Fisheries is required to designate critical habitat for these coral species concurrent with their listing. Critical habitat is a foundation of the ESA's recovery system. A recent study found that species that have critical habitat protection are approximately twice as likely to have improving population trends than species without critical habitat (Taylor et al. 2005). For the petitioned coral species, critical habitat is particularly important because, although current statutes prohibiting take already exist in US waters, no appreciable recovery is occurring. Moreover, critical habitat designations would have immediate benefits extending far beyond the reefs themselves, including improved water quality throughout the coastal zone, limits on over-fishing, protections for spawning grounds, reduced impacts from development and dredging, and reduced human pressures on hundreds of thousands of reef-associated species. The habitats that critically impact the health of these corals must be immediately protected while additional research is conducted and resilience- and recovery-based management strategies are developed.

Congress and the Supreme Court have obliged NOAA Fisheries to prioritize species survival and recovery, "whatever the cost." *See TVA v. Hill*, 437 U.S. 153, 154 (1978). Given their incalculable intrinsic value, their pivotal role in marine ecosystems, and their critical importance to the survival of the human communities who rely upon them, the particularly imperiled corals identified in this petition warrant immediate protection under the ESA.

This Petition is divided in two parts. Part One contains species accounts organized by region, briefly summarizing the description, taxonomy, natural history, distribution, status, and threats for each of the petitioned species, followed by a discussion of the status of each region and subregion's coral reefs. Part Two describes current and future threats to these species in the context of the five statutory listing factors contained in the ESA. Taken together, the information in these two sections demonstrates that each of the petitioned species warrants the protections of the ESA.

PART ONE: NATURAL HISTORY AND STATUS OF PETIONTED CORAL SPECIES

I. BRIEF INTRODUCTION TO CORALS

Coral reefs are the most biodiverse ecosystems on earth, supporting an estimated one-third of described marine species, although they comprise only 0.2% of ocean area (Veron et al. 2009). Reefs form a protective barrier against wave erosion for fragile coastal habitats including mangroves, sea grass beds, and lagoons (Veron et al. 2009). The primary architects of reefs are coral animals, particularly those in the orders Scleractinia (true "stony corals," in the Anthozoa class), Helioporacea ("blue coral", the only true reef-building species within the Octocorallia subclass of Anthozoa), and Milleporina (i.e., "fire corals," within the Hydrozoa class of hydrocorals). Reefs are built over centuries or millennia as thousands of individual coral animals settle on new substrate or the reef structure that develops from it, grow, reproduce, and die. Myriad sessile coral species commingle in reef communities, and each individual ultimately contributes its own calcareous skeletal material to the reef structure.

Coral reefs grow and persist only when the growth (calcification) rates of reef-building species exceed various natural destructive forces of disturbance, sedimentation, and erosion. Coral communities rely on narrow ranges of water temperature, turbidity, light availability, and predator-prey balances to fend off competition from macroalgae and survive predation by corallivorous invertebrates and fishes. Disruptions in this dynamically balanced system can result in rapid coral mortality across the reef, with a resultant shift from healthy reef ecosystem to a macroalgae-dominated system and, eventually, to a completely barren state (Bellwood et al. 2004). Such transformations are known as "phase shifts." *See* Figure 2. Reef phase shifts threaten the survival not only of corals but of all reef-associated species, including those species that provide a primary source of protein for millions of people living in tropical coastal and island communities.

Figure 2. Alternate states in coral reef ecosystems. A, A conceptual model showing human induced transitions between alternate ecosystem states based on empirical evidence of the effects from fishing and excess nutrients. The 'stressed' state illustrates loss of resilience and increased vulnerability to phase-shifts. B, A graphic model depicting transitions between ecosystem states. 'Healthy' resilient coral-dominated reefs become progressively more vulnerable owing to fishing pressure, pollution, disease and coral bleaching. The dotted lines illustrate the loss of resilience that becomes evident when reefs fail to recover from disturbance and slide into less desirable states. C, Six characteristic reef states (as in A) from sites on the Great Barrier Reef (a, c, d, e) and in the Caribbean (b, f).
Source: Bellwood et al. (2004): Figure 2.

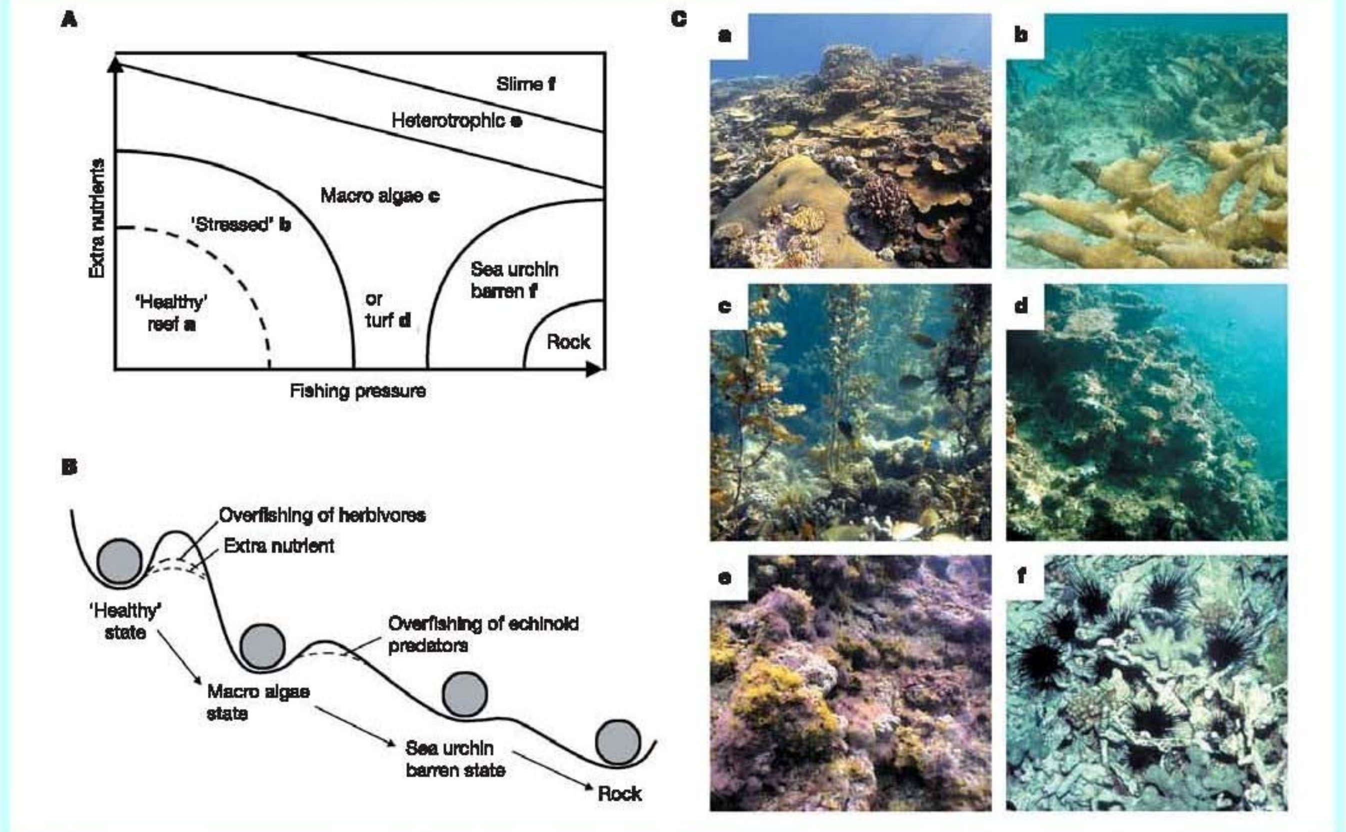


Figure 2 Alternate states in coral reef ecosystems. **A**, A conceptual model showing human-induced transitions between alternate ecosystem states based on empirical evidence of the effects from fishing and excess nutrients[15–17]. The 'stressed' state illustrates loss of resilience and increased vulnerability to phase-shifts. **B**, A graphic model depicting transitions between ecosystem states. 'Healthy' resilient coral-dominated reefs become progressively more vulnerable owing to fishing pressure, pollution, disease and coral bleaching. The dotted lines illustrate the loss of resilience that becomes evident when reefs fail to recover from disturbance and slide into less desirable states. **C**, Six characteristic reef states (as in **A**) from sites on the Great Barrier Reef (**a**, **c**, **d**, **e**) and in the Caribbean (**b**, **f**).

As detailed in the species accounts below, corals are rapidly succumbing to the synergistic effects of unsustainable direct human pressures and climate-associated stressors. Coral declines to date have been linked to numerous major threats, including (among others) the ecosystem-level effects of destructive fishing practices and chronic overharvest of corals, reef fish, and other associated species; major bleaching events; disease and predation outbreaks; and pollution, sedimentation, and physical damage due to human land and sea uses, which are intensifying with the recent and ongoing explosions in human population growth and marine vessel traffic.

II. NATURAL HISTORY AND STATUS OF PETITONED CORAL SPECIES IN THE CARIBBEAN

A. SPECIES ACCOUNTS

1. FAMILY: AGARICIDAE

All six extant genera in the Agaricidae family are zooxanthellate and form massive or laminar colonies (Veron 2000, Volume 2 at 169). Immersed corallites have poorly defined walls formed by thickened septo-costae, and seldom-fused septa are loosely packed and continuous between adjacent corallite centers. *Id.*

Agaricia lamarcki (Lamarck's Sheet Coral)

Species Description: *Agaricia lamarcki* is commonly recognized as an independent species (Veron 2000, Volume 2 at 176; IUCN Species Account). Its colonies "form flat, unifacial, explanate or encrusting plates, commonly arranged in whorls" (Veron 2000, Volume 2 at 176). The corallites of this species form in concentric valleys with widely spaced centers (3-5 per centimeter) and clearly alternating long and short septo-costae. *Id. A. lamarcki* is rust brown in color, with pale margins and white, star-shaped mouths. *Id.* It is common in intermediate to deep water (15-25 meters) and in highly turbid shallower water (10-15 meters) (IUCN Species Account).

Distribution: The Agaricia genus is restricted in range to the Western Atlantic (Veron 2000, Volume 2 at 169). *Agaricia lamarcki* is "the dominant species at the base of the reef in the southern and western Caribbean" (IUCN Species Account). It can be found throughout the Caribbean, the Gulf of Mexico, Florida, and the Bahamas. *Id. A. lamarcki* is present in U.S. protected areas including the Florida Keys National Marine Sanctuary, Biscayne N.P., Dry Tortugas National Park, Buck Island Reef National Monument, Flower Garden Banks National Marine Sanctuary. *Id.* Abroad, *A. lamarcki* also occurs in Belize's Hol Chan Marine Reserve and Bahamas' Exuma Cays Land and Sea Park. *Id. See* Figure 3.

Figure 3. Range map for *Agaricia lamarcki*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.

Status and Threats: *A. lamarcki* is listed as vulnerable by the IUCN due to significant localized past and ongoing declines, including an overall estimated 38% decline over 30 years[1] (IUCN Species Account). The major long-term threat to this species has been bleaching, to which its very thin tissues and limited ability to cope with variations in temperature make it particularly susceptible. *Id*. Mortality was reported during 1987/1988, 1990, 1995, 1998, and 2005 events throughout the Caribbean, including Puerto Rico, Netherlands Antilles, Florida, and Jamaica (IUCN Species Account; Sebens 1994). Little recovery was recorded after early mortality events (IUCN Species Account). This species' ability to resist and recover from especially virulent diseases like the white plague may be generally inhibited by the overlapping structure of its colonies. *Id.* Mortality rates due to white plague have increased dramatically since 2001. *Id.* Additional localized threats include black band disease and high sedimentation. *Id.*

2. FAMILY: FAVIIDAE

The Faviidae family has 24 genera, the most of any extant family of corals (Veron 2000, Volume 3 at 85). This is also one of the oldest extant coral groups, maintaining a consistent status as a major family for 150 million years (Veron 2000, Volume 1 at 40). Faviidae is the only coral family that was a major component of Mesozoic reefs and survived to be dominant in the Cenozoic. *Id.* at 41. All species in this family are zooxanthellate and colonial, with similar (when present) septa, paliform lobes, columellae, and wall structures (Veron 2000, Volume 3 at 85). Characteristic features include simple septal structures and columellae; the latter are comprised of a tangle of elongate septal teeth. *Id.*

Genus *Montastraea*: *M. annularis, M. faveolata,* and *M. franksi*

Until 1994 (Weil and Knowlton 1994) and in several key subsequent publications (including Veron 2000), all three of these species were included in *Montastraea annularis*. The IUCN follows Weil and Knowlton in recognizing three distinct species (IUCN Species Accounts).

Shared Characteristics: All of these species are commonly found across a variety of reef environments and are often the dominant species in lagoons and on upper reef slopes (IUCN Species Accounts). The sibling species overlap at intermediate depths, with *M. faveolata* showing the shallowest distribution of the three and *M. franksi* the deepest (Weil and Knowlton 1994). Colonies of these species can be massive, columnar, or flat (Veron 2000, Volume 3 at 214). Coloration is highly variable, with shades of gray, green, brown, and yellow predominating (Weil and Knowlton 1994).

Distribution: *M. annularis, M. faveolata,* and *M. franksi* are found throughout the Caribbean, the Gulf of Mexico, Florida, and the Bahamas; *M. annularis* has also been confirmed in Bermuda. *See* Figures 4-6 below (IUCN Species Accounts). US MPAs in which they are present include Florida Keys National Marine Sanctuary, Biscayne N.P., Dry Tortugas National Park, Buck Island Reef National Monument and Flower Garden Banks National Marine Sanctuary. *Id.*

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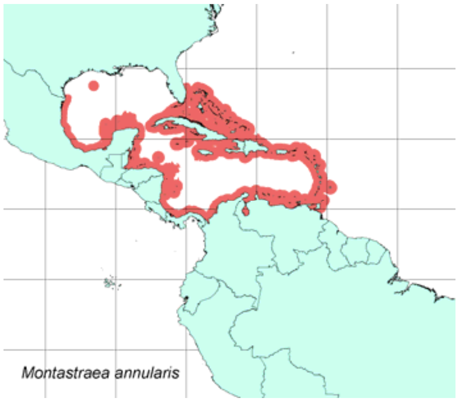
[1] Unless otherwise noted, all 30-year IUCN coral species loss estimates are based on an assessment period extending 20 years (2 generations) into the past and 10 years (1 generation) into the future.

Montastraea annularis (Boulder Star Coral)

Species Description: *M. annularis* forms large, branching, lobate plocoid colonies of long, thick, disjunct and irregular columns up to two meters in length via extratentacular budding (Weil and Knowlton 1994). Living tissue, which is generally restricted to the tops of columns, is comprised of closely packed, uniformly distributed and evenly exsert corallites that form a smooth surface lacking in ridges or bumps. *Id.* Corallites farther from living tissue tend to be larger, flatter, and more widely spaced. *Id.* Septo-costal teeth near the living tissue are sharp and arranged in a fan system that is inconspicuous in dorsal view, whereas septo-costae farther from live tissue are thicker with lacerate and dorsally conspicuous margins. *Id.* Column sides nearest the live tissue margin have few small polyps that are generally not actively growing; farther from the live tissue, the column sides tend to be fouled and bioeroded. *Id.*

Distribution: *See above* and Figure 4.

Figure 4. Range map for *Montastraea annularis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *M. annularis* is listed by the IUCN as endangered because the species is believed to have declined by 50% or more in 30 years due to anthropogenic factors (IUCN Species Account). Specifically, this species has suffered a severe decline in the overall cover and abundance in several parts of the Caribbean, including cover losses of 90% off the northern coast of Belize (Burke et al. 2004; IUCN Species Account) as well as in Jamaican coastal waters between 1980 and 1994 (Hughes 1994; IUCN Species Account); 40-60% off the south and southeast coasts of Puerto Rico (E. Weil, personal communication, in IUCN Species Account); 50% off Mona Island (Bruckner and Bruckner 2006; IUCN Species Account); 72% off of St. John (Edmunds and Elahi 2007; IUCN Species Account), and 31% on Carysfort Reef in Key Largo between 1975 and 1982 (Dustan and Halas 1987; IUCN Species Account). Threats to this species include climate-related ocean acidification and bleaching, infectious diseases, predation by *Sparisoma viride* (stoplight parrotfish), hurricane damage, loss of habitat at recruitment from algal overgrowth and sedimentation, localized bioerosion by sponges and other organisms, and other diseases (IUCN Species Account). The IUCN reports that current rates of mortality are exceeding growth and recruitment; that current threats are increasing; and that the scope for recovery of populations is limited due to the species' extreme longevity, low rates of recruitment, and long generation times. *Id.*

Montastraea faveolata (Mountainous Star Coral)

Species Description: This species has been called the "dominant reef-building coral of the Atlantic" (Smith et al. 2006, abstract). *Montastraea faveolata* buds extratentacularly to form head or sheet colonies with corallites that are uniformly distributed and closely packed, but sometimes unevenly exsert (Weil and Knowlton 1994). Septa are highly exsert, with septocostae arranged in a variably conspicuous fan system, and the skeleton is generally far less dense than those of its sibling species. *Id.* Active growth is typically found at the edges of colonies, forming a smooth outline with many small polyps. *Id. M. faveolata*'s depth range is similar but broader than *M. annularis*, with significant overlap. It is more aggressive than *M. annularis*, but less aggressive than *M. franksi. Id.*

Distribution: *See above* and Figure 5.

Figure 5. Range map for *Montastraea faveolata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.

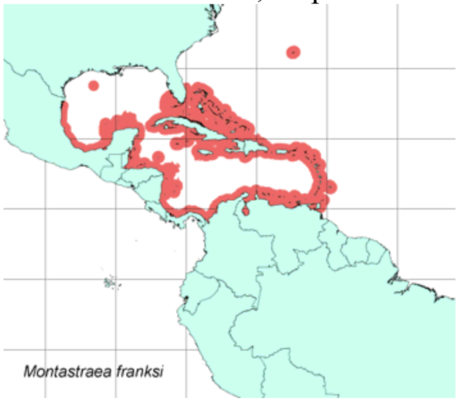
Status and Threats: Like *M. annularis, M. faveolata* is listed by the IUCN as endangered because it is believed to have declined by 50% or more over 30 years (IUCN Species Account). *M. faveolata* has experienced comparable cover losses in Jamaica, Puerto Rico, St. John, and Carysfort Reef. *Id.* A 40-80% loss was also recorded off Desecheo Island and Mona Island (Bruckner and Bruckner 2006; Bruckner pers. comm. in IUCN Species Account). *M. faveolata* faces the same threats as *M. annularis* (listed above). *Id.* These threats are increasing and spreading into new areas (IUCN Species Account). Current rates of mortality are exceeding growth and recruitment, and the chances of recovery are limited due to the species' extreme longevity, low recruitment rates, and long generation times. *Id.* A study of *Montastraea faveolata* colonies in the Florida Keys during and after the 2005 mass bleaching event found that corals with greater bleaching intensities later developed white plague infections (Brandt and McManus 2009), suggesting that this species is susceptible to loss of disease resistance during intense bleaching events.

Montastraea franksi

Species Description: *Montastraea franksi* builds massive, encrusting plate or subcolumnar colonies via extratentacular budding (Weil and Knowlton 1994). The characteristically bumpy appearance of this species is caused by relatively large, unevenly exsert, and irregularly distributed corallites. *Id.* *M. franksi* is distinguished from its sibling *Montastraea* species by this irregular or bumpy appearance; a relatively dense, heavy, and hard skeleton (corallum); thicker septo-costae with a conspicuous septocostal midline row of lacerate teeth; and a greater degree of interspecies aggression. *Id.*

Distribution: *See above* and Figure 6.

Figure 6. Range map for *Montastraea franksi*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: The threats faced by *M. franksi* are the same as those faced by *M. annularis*, detailed above (IUCN Species Account). This species has historically shown greater resistance to disease than its siblings, but the past 10 years have seen significant declines, with accelerating losses of cover in US waters since 2002. *Id.* *M. franksi* is listed as vulnerable by the IUCN due to these recent trends and the associated increased threat susceptibility (IUCN Species Account). Vulnerability to disease and habitat degradation increases the likelihood of the species being lost within one generation, and the species is projected to lose 38% of its population over 30 years. *Id.*

3. FAMILY: MEANDRINIDAE

Meandrinidae is a poorly defined family that can be distinguished from the similar Faviidae family by fine, non-porous skeletal structures of its species (Veron 2000, Volume 2 at 119). Among the few common features within this family are solid walls and septas that are solid, exsert, and evenly spaced. *Id.*

Dendrogyra cylindrus (Pillar Coral)

Species Description: The Dendrogyra genus has only one species, *Dendrogyra cylindrus* (Veron 2000, Volume 2 at 126). Because it propagates by fragmentation, this species thrives in shallower, well-circulated areas (IUCN Species Account). *D. cylindrus* colonies are typically found on flat or gently sloping back reef and fore reef environments in depths of 1-25 meters; they are absent from extremely exposed locations. *Id.* Colonies are comprised of cylindrical columns up to 2 meters high on top of encrusting bases (Veron 2000, Volume 2 at 126). Valleys are meandroid, with two thick, alternating orders of septo-costae. *Id.* Because the septo-costae do not join at the tops of valleys, they leave a neat grove along the tops of the walls. *Id.* During the day, this gray-brown coral's tentacles typically remain extended, giving *D. cylindrus* a furry and conspicuous appearance. *Id.* The species is resistant to heavy wave surge but occasionally topples when the base of the colony bioerodes (IUCN Species Account). In these instances, the upper portions of the colonies survive and new pillars are produced which continue to grow upward (A Bruckner, personal communication, in IUCN Species Account).

Distribution: *D. cylindrus* is widespread but uncommon throughout its range, which includes the Caribbean, the southern Gulf of Mexico, Florida, and the Bahamas (IUCN Species Account). *See* Figure 7. Local populations receive varying degrees of protection in Florida Keys National Marine Sanctuary, Biscayne N.P., Buck Island Reef National Monument, Hol Chan Marine Reserve (Belize), and Exuma Cays Land and Sea Park (Bahamas). *Id.*

Figure 7. Range map for *Dendrogyra cylindrus***.**
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.

Status and Threats: *D. cylindrus* has suffered partial colony mortality due to the white plague and is particularly sensitive to this disease (IUCN Species Account). Bleaching and extensive habitat reduction due to a combination of threats both pose significant challenges to the species (IUCN Species Account). Localized threats include hurricane damage, other diseases, damselfish predation, and bioerosion from sponges. *Id.* Its juvenile survivorship rate is low, and its population is at risk of being lost within one generation. *Id.* The IUCN classifies this species as vulnerable due to estimated habitat reduction and associated population loss of 38% over 30 years.

*Dichocoenia stokesii (*Elliptical Star Coral or Pineapple Coral)

Species Description: Though many scholars still lump both species into *Dichocoenia stokesii,* the IUCN differentiates *D. stokesii* from its sibling species, *Dichocoenia stellaris*. *See* IUCN Species Accounts for *D. stokesii* and *D. stellaris. Dichocoenia* colonies tend to be either massive and spherical or form thick, submassive plates (Veron 2000, Volume 2 at 124). The corallites of this species are evenly spaced and either plocoid or ploco-meandroid, and the septo-costae are usually in two neatly alternating orders. *Id.* Though sometimes green, they are usually orange-brown with white septo-costae. *Id. Dichocoenia* is uncommon but has been found in most reef environments within its range (*id.*), including both back and fore reef environments, rocky reefs, lagoons, spur and groove formations, channels, and occasionally at the base of reefs (IUCN Species Account). *D. stokesii* occurs in depths from 2-72 meters; when found in exposed reefs at depths less than 20 meters, its hemispherical heads are more abundant than usual. *Id.*

Distribution: *D. stokesii* occurs in the Caribbean, the Gulf of Mexico, Florida (including the Florida Middle Grounds), the Bahamas, and Bermuda (IUCN Species Account). *See* Figure 8. Numerous US MPAs, including Florida Keys National Marine Sanctuary, Biscayne N.P., Dry Tortugas National Park, Buck Island Reef National Monument, and Flower Garden Banks National Marine Sanctuary, host populations of *D. stokesii. Id.* This species is also found in Hol Chan Marine Reserve (Belize), Exuma Cays Land and Sea Park (Bahamas). *Id.*

Figure 8. Range map for *Dichocoenia stokesii.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.

Status and Threats: Because *D. stokesii* is suffering estimated population declines of 38% over 30 years and faces a significant likelihood of being lost within one generation from reefs at a critical stage, it is listed as vulnerable by the IUCN (IUCN Species Account). White plague, to which *D. stokesii* is highly susceptible, poses a major threat to this species. *Id.* Richardson et al. (1998) have documented localized mass mortalities due to white plague in Florida since 1995, with continued decline and no evidence of recruitment in subsequent years (Richardson et al. 1998; Richardson and Voss 2005; IUCN Species Account). Evidence suggests that the remaining population in this area, while growing, is no longer reproducing (IUCN Species Account). *D. stokesii* is also susceptible to black band disease, bleaching, high sedimentation, and damage by storms. *Id.*

4. FAMILY: MUSSIDAE

All coral species in the Mussidae family are zooxanthellate, with solid skeletal structures, large corallites and valleys, and thick columellae and walls (Veron 2000, Volume 3 at 3).

Mycetophyllia ferox (Rough Cactus Coral)

Species Description: Colonies of the genus *Mycetophyllia* consist of flat plates with radiating valleys (Veron 2000, Volume 3 at 72). *Mycetophyllia ferox* is a widely recognized valid species with colonies comprised of thin, weakly attached plates with interconnecting, slightly sinuous, narrow valleys. *Id.* at 74. Tentacles are generally absent in species of this genus except at the margins of colonies. *Id.* Corallite centers tend to form single rows, and columellae, when present, are rudimentary. *Id.* Valleys and walls are contrasting shades of grays and browns. *Id.* While *M. ferox* is most abundant in fore reef environments at depths of 10-20 meters, it is also found in a broader range of habitats including deeper back reefs and lagoons (IUCN Species Account).

Distribution: *M. ferox* is the most dominant species of the *Mycetophyllia* genus in shallow and intermediate depths throughout its range, which includes the Caribbean, southern Gulf of Mexico, Florida, and the Bahamas (IUCN Species Account). *See* Figure 9. It is present in Florida Keys National Marine Sanctuary, Biscayne National Park, Dry Tortugas National Park, and Buck Island Reef National Monument; it also occurs in Hol Chan Marine Reserve (Belize), and Exuma Cays Land and Sea Park (Bahamas). *Id.*

Figure 9. Range map for *Mycetophyllia ferox.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.

Status and Threats: *M. ferox* has suffered significant localized declines throughout its range due to disease and bleaching (IUCN Species Account). The first outbreaks of white plague were in Florida in 1975 and the 1980s, from which the species made a partial unexpected recovery with documented new recruits (Dustan and Halas 1987; IUCN Species Account). Subsequent outbreaks throughout the Caribbean since the 1990s have been increasingly virulent and have caused significant mortality (IUCN Species Account). A 2005 bleaching event caused high rates of mortality off Puerto Rico and its associated islands as well as off Grenada. *Id. M. ferox* is also susceptible to black band disease and sedimentation, especially when it is already compromised by white plague or bleaching. *Id.* The IUCN lists *M. ferox* as vulnerable due to its recent increased threat susceptibility and the estimated loss of 38% of the population within 30 years. *Id.*

5. FAMILY: OCULINIDAE

This family is comprised of colonial species that can be either zooxanthellate or azooxanthellate (Veron 2000, Volume 2 at 95). Characteristic features of Oculinidae species include solid, walled, tube-shaped corallites linked together by smooth and solid coenosteum; very exsert septa; and weakly developed columellae. *Id.*

Oculina varicosa (Large Ivory Coral, Ivory Bush Coral, Ivory Tree Coral)

Species Description: While most species in the *Oculina* family are azooxanthellate, *Oculina varicosa* can be zooxanthellate or azooxanthellate depending on light availability (Veron 2000, Volume 2 at 98). Zooxanthellate *O. varicosa* colonies are typically found in protected shallow environments. *Id.* While azooxanthellate colonies of *O. varicosa* form extensive banks, zooxanthellate colonies are comprised of clumps of tapered, fused branches that are less than 0.5 meters across (Veron 2000, Volume 2 at 98). The species reproduces sexually via broadcast spawning (NMFS 2007a). Corallites are exsert and 2-3 mm diameter in both types of colonies, and septa form in three cycles (Veron 2000, Volume 2 at 98). Preferred habitats at depths of up to 152 meters include limestone rubble, low-relief limestone crops, steep high-relief prominences, and soft-bottom slopes (IUCN Species Account). These deep water *O. varicosa* colonies are lavender to white and tend to grow quickly into massive coalescing thickets (NMFS 2007). At depths less than 30 meters, the species is zooxanthellate and tends to inhabit limestone ledges. *Id.* These slow-growing shallow colonies tend to be patchy, stout, and semi-isolated (NMFS 2007a.

Distribution: *Oculina* is the only genus of the Oculinidae family in the Atlantic. The range of *Oculina varicosa* includes the Caribbean, most of the Gulf of Mexico (but not the Flower Gardens), the US east coast from Florida to North Carolina, the Bahamas, and possibly Bermuda (IUCN Species Account). *See* Figure 10.

Figure 10. Range map for *Oculina varicosa.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.

Status and Threats: While *O. varicosa* appears unusually resistant to bleaching and disease, the IUCN lists this species as vulnerable due to the serious threat posed by destructive fishing practices (dredging, bottom long lines, trawl nets, and anchors), which have already decimated 30% of the population across its range (IUCN Species Account). The Oculina Banks, an area off the US east coast stretching from Florida to North Carolina, have lost more than 50% of the deep water population to bottom trawling since the 1970s, with little sign of recovery (IUCN Species Account). Because of these losses in the Oculina Banks, the US National Marine Fisheries Service has listed *O. varicosa* as a species of concern since 1991 (NMFS 2007a). NMFS has also identified *O. varicosa* as a keystone species due to the scientific correlation established between the local health of this species' colonies and the presence of both economically valuable fish and invertebrate biodiversity. *Id. Oculina* coral reefs off the US coast provide essential fish habitat for federally managed species. *Id.*

B. STATUS OF CORAL REEF ECOSYSTEMS OF THE WIDER CARIBBEAN

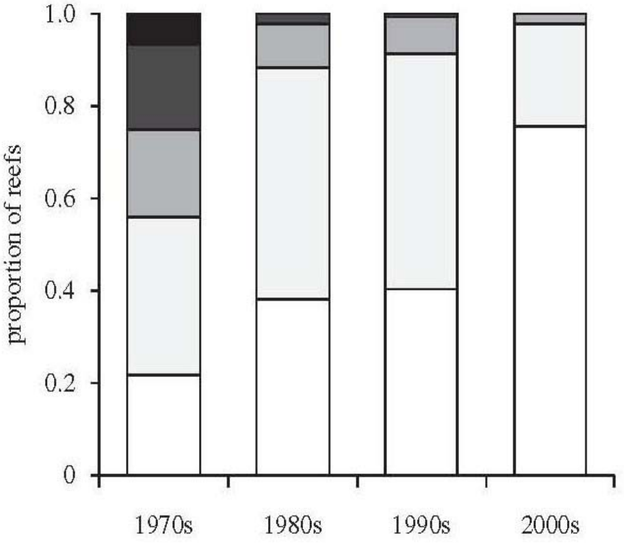
The Caribbean has the largest proportion of corals in IUCN high extinction risk categories (Carpenter et al. 2008). The region suffered massive losses in response to climate-related events of 2005, including a recordbreaking 26 tropical storms (13 hurricanes) and elevated ocean water temperatures (Wilkinson and Souter 2008). Extreme impacts included the loss of 51.5% of live coral cover in the US Virgin Islands; the bleaching of over 50% of coral colonies in Florida, Puerto Rico, the Cayman Islands, St. Maarten, Saba, St. Eustatius, Guadeloupe, Martinique, St. Barthelemy, Barbados, Jamaica and Cuba; and 10-30% coral mortality in Barbados, the French West Indies, and Trinidad and Tobago. *Id.* Climate models suggest that the combined 2005 bleaching events would have been extremely rare in pre-industrial times, occurring once every 1,000 years (Donner et al. 2007). Under a business-as-usual emissions scenario, thermal stress events like 2005 are predicted to occur biannually within 20-30 years due to anthropogenic climate warming. *Id.*

Over the three decades prior to the 2005 events, Caribbean reefs had already suffered an 80% decline in hard coral cover, from an average of 50% to an average of 10% throughout the region (Gardner et al. 2003). This massive shift was driven by the loss of over 90% of acroporids in the region, including two federally listed framework-building species, *Acropora palmata* and *A. cervicornis* (*Acropora* Biological Review Team 2005), as well as a subsequent dramatic decline in the Caribbean's largest reef species, *Montastraea annularis,* over the past 10 years (Carpenter et al. 2008). *M. annularis,* which is slow-growing and highly susceptible to disease, is now listed by the IUCN as endangered (see species account above). *Id.* There is little sign of recovery of these framework builders in recent years, with surveys and studies showing that the few instances of modest increases in coral cover have been primarily driven by non-framework builders of the *Agaricia* and *Porites* families, along with sponges (Gardner et al. 2003; Wilkinson 2008; Waddell and Clarke 2008). Overall, rugosity (three-dimensional complexity) of Caribbean reefs has declined dramatically over the past forty years, with accelerating "flattening" since the record-breaking bleaching events of 1998 (Alvarez-Filip et al. 2009). *See* Figure 11.

The consequence of this large-scale loss of framework species and hard coral cover has been a phase shift from a coral-dominated ecosystem to fleshy macroalgae overgrowth in reef systems across the Caribbean. NMFS has identified chronic overfishing of herbivorous species and the die-off of 95% of the region's long-spined sea urchins (*Diadema antillarum*) in the early

1980s as primary factors in this ecological shift (73 Fed. Reg. 72210). In the absence of grazing pressure from herbivorous fish and urchins, fast-growing algae, macroalgae and other epibenthic organisms easily outcompete coral larvae by preempting available space, producing toxic metabolites that inhibit larval settlement, and trapping excess sediment in algal turfs. *Id.*

Figure 11. Proportion of reefs in five rugosity index categories across the Caribbean between 1969 and 2008. Number of studies for each decade: 1970s: n = 32; 1980s: n = 52; 1990s: n = 136 and 2000s: n = 167. Rugosity categories: Black, >3; dark grey, 2.5–3; mid grey, 2–2.5; pale grey, 1.5–2; white, 1–1.5.
Source: Alvarez-Filip et al. (2009): Figure 5.



Other significant regional factors encouraging the algae-coral imbalance are (1) nutrient enrichment from sewage, storm water and agricultural runoff, river discharge, and groundwater, as well as natural sources; and (2) sediment deposition and accumulation due to anthropogenic erosion of coastlines, re-suspension of bottom sediments, terrestrial run-off from land and forest clearing, beach management, and nearshore dredging and disposal for coastal development and navigation. *Id.*

Coral reef habitat degradation is negatively impacting reef fish populations, which have been declining at a rate of 2.7 to 6% in all Caribbean subregions throughout the past decade (Paddack et al. 2009). Harvested fish populations in Florida and throughout the US Caribbean are now largely depleted (Waddell and Clarke 2008). While the wider Caribbean has suffered significant historic declines in fish abundance due to centuries of overexploitation, coral reef degradation will likely drive a “degradation debt” resulting in the ongoing and accelerating reductions in fish abundance in response to the observed changes to the benthic ecosystem throughout the region (Waddell and Clarke 2008; Alvarez-Filip et al. 2009).

Between 1996 and 2006, the mean sea surface aragonite saturation state in the Greater Caribbean Region decreased from 4.05 to 3.9, at a rate of -0.012 per year, as a consequence of ocean acidification (Gledhill et al. 2008). *See also* Figure 12. Hoegh-Guldberg et al. (2007) modeled the impacts of a 20% decline in coral growth rate in response to ocean acidification on a Caribbean forereef and found marked reductions in resilience accompanied by increased grazing requirements to facilitate reef recovery, as indicated in Figure 13. These impacts of ocean acidification may be particularly problematic for the Caribbean region, where grazing pressures are consistently low in recent years due to the decimation of the *Diadema* population and chronic overfishing referenced above.

Figure 12. NOAA Coral Reef Watch Aragonite Saturation State Composite for May 2009. Source: NOAA Coral Reef Conservation Program 2009.

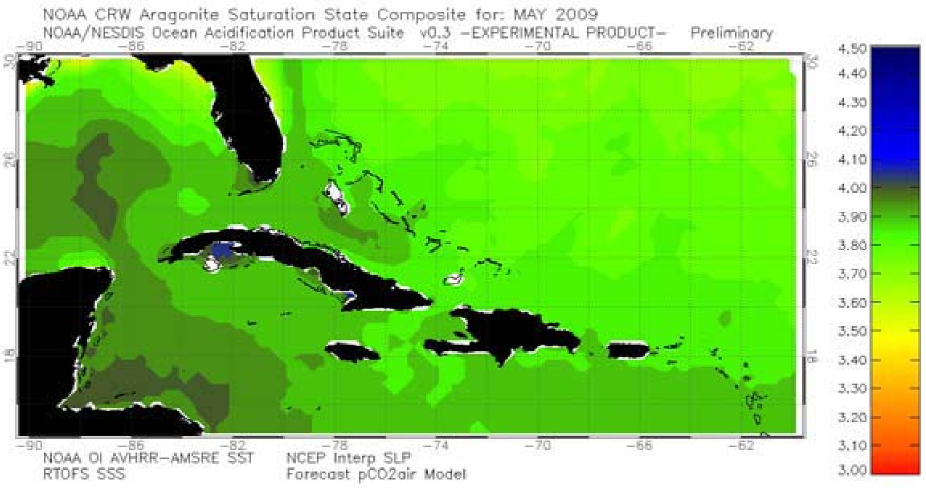
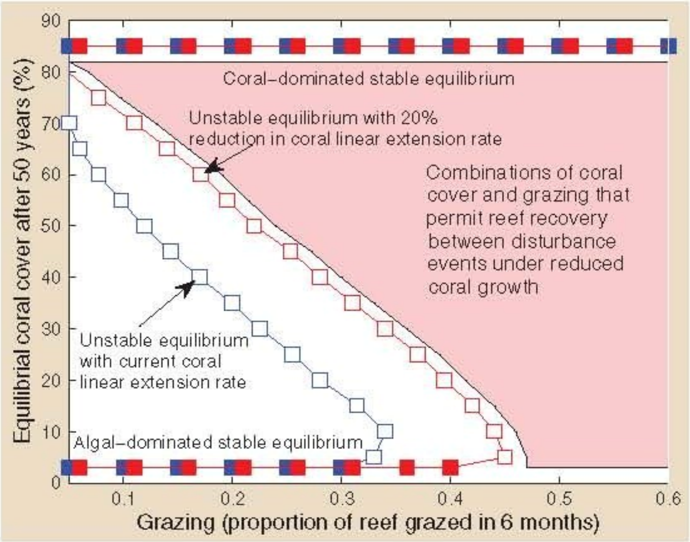


Figure 13. Reduction in the resilience of Caribbean forereefs as coral growth rate declines by 20%. Reef recovery is only feasible above or to the right of the unstable equilibria (open squares). The "zone of reef recovery" (pink) is therefore more restricted under reduced coral growth rate and reefs require higher levels of grazing to exhibit recovery trajectories.
Source: Hoegh-Guldberg et al. (2007): Figure 2.



1. US Caribbean Territories: Florida, Flower Garden Banks, Puerto Rico, Navassa, USVI

Serious threats facing US Caribbean reefs include (1) bleaching due to high water temperatures, (2) disease, (3) intensifying tropical storms and hurricanes, (4) nutrient pollution and sedimentation from unsustainable coastal development, and (5) chronic destructive overfishing practices (Monaco et al 2008). Each of the sub-regions in this area manifests a different balance of these threats. *Id*. In addition, ocean acidification poses an ever-increasing threat to US Caribbean reefs.

In Southeast Florida and the Florida Keys, coastal development, chronic overfishing, and tropical storms have continued to degrade reef health in recent years, whereas disease and bleaching rates have been low relative to other subregions. *Id.* Local NMFS scientists report 50-80% declines in Florida Keys live coral cover over the past decade (Palacio 2009).

Though still overfished and suffering pollution impacts, the biggest recent problems for the reefs of Puerto Rico and the US Virgin Islands were bleaching and disease associated with the high water temperatures of 2005, which devastated the principal reef-building species, *Montastraea annularis*, along with the entire reef ecosystem (Monaco et al. 2008). Reefs of this region suffered 90-100% bleaching, subsequent disease outbreaks (e.g., white plague-II, yellow band, white band, black band, aspergillosis and coralline white band diseases in Puerto Rico), and 50-90% mortality rates at monitored sites. *Id.*

The Flower Garden Banks, perhaps the healthiest reefs in the US Caribbean in recent years, suffered significant physical damage and bleaching from Hurricane Rita and subsequent elevated water temperatures in 2005. *Id.*

Off uninhabited Navassa Island, coral cover has declined as much as 28.8% between 2002 and 2006 in response to intensifying multinational fishing, the area's first disease outbreak in 2004 ("white disease" affecting 15 coral species and disproportionately attacked especially larger colonies and *Montastraea* colonies), and severe localized bleaching in 2006 (of primarily *Montastraea and Agaricia* species, especially *M. faveolata*). *Id.* Macroalgal cover is 36-70% in many Navassa reef areas. *Id.*

2. Northern Caribbean and Western Atlantic:
Bahamas, Bermuda, Cayman Islands, Cuba, Dominican Republic, Haiti, Jamaica, Turks and Caicos

The Northern Caribbean includes some of the most anthropogenically influenced reefs in the Caribbean, such as those in Haiti, as well as some of the most protected or isolated, as in Bermuda and Cuba (Creary et al. 2008). While the resilience of individual reef ecosystems varies with latitude as well as socioeconomic conditions, the entire region now faces severe annual threats from climate change-related intensifications of tropical storms and bleaching events. *Id.* Disease, bleaching, storms, and bioerosion have caused significant losses of nearshore coral cover in the Bahamas, the Cayman Islands, and the Turks and Caicos Islands. *Id.* Overfishing and/or damaging land use practices present continued challenges to coral reefs in Cuba, the Dominican Republic, Haiti, and Jamaica. *Id.* Bermuda, where high latitudes and protective policies have prevented appreciable decline in reef health over the past 25 years, presents an optimistic exception in an otherwise bleak regional picture. *Id.* Yet Bermuda has not escaped invasion by the Indo-Pacific lionfish (*Pterois volitans*), which now poses a serious threat to native species there as well as in Cuba, Jamaica, and Turks and Caicos. *Id.*

3. Mesoamerican Barrier Reef System:
Belize, Mexican Yucatan, Honduras, Guatemala

The Mesoamerican Reef includes the longest barrier reef in the Western Hemisphere and extends 1,000 kilometers from the Northern Mexican Yucatan to the Bay Islands of Honduras (Garcia-Salgado et al. 2008). The latest surveys indicate an average coral cover across the region of 11% since 2004 (Garcia-Salgado et al. 2008; Wilkinson 2008 (Executive Summary)). Live coral cover has declined up to 50% in many areas in response to escalating human pressures, ongoing natural threats, and environmental changes. *Id.* Coral losses have been severe in every country in the region, with live coral cover at surveyed reef sites averaging 14.8% in Honduras (25.3% macroalgal cover), 8.5% in Guatamala (12.5% macroalgal cover), 7.5% in Mexico (14.9% macroalgal cover), and 11% (16% macroalgal cover) in Belize, which was once regarded as home to the Caribbean's healthiest reefs. *Id.* Consistent low coral cover indicates that the region's reefs have not yet shown significant signs of recovery following mass bleaching and physical destruction from Hurricane Mitch in 1998. *Id.*

4. Lesser Antilles:
The French West Indies, The Netherlands Antilles, Anguilla, Antigua, Grenada, Trinidad and Tobago

The Lesser Antilles, a semi-circular chain of islands from 18 to 11 degrees North and 59 to 70 degrees West, form the western boundary of the Caribbean Sea (Bouchon et al. 2008). All islands in this region face high anthropogenic pressures from over-fishing and unsustainable coastal development as tourism and populations increase. *Id.* While the Lesser Antilles was spared the worst impacts of elevated sea temperatures in 1984, 1987, and 1998, the 2005 event hit this region particularly hard. *Id.* Waters in reef habitat remained as high as 29-31 degrees Celsius from May to November of 2005, causing over half of the region's corals to bleach. The 2005 bleaching event, combined with subsequent disease outbreaks, led to the apparent loss of approximately 50% of live coral cover on many reefs by 2006. *Id.* High human pressures throughout the region are thought to be limiting reef recovery and contributing to the prevalence of algal overgrowth and coral diseases since 2005. *Id.* Five hurricanes have caused significant coral damage in the region since 1989, including Hugo (1989), Luis and Marilyn (1995), Lenny (1999), and Dean (2007).

Curacao corals drew recent scientific attention following declines in the 1990s, and though overall coral cover has returned to approximately 40%, community structures have shifted to favor brooding *Agaricia* and *Porites* species over the major framework builders, *Montastraea annularis* and *M. faveolata* (Bruckner and Bruckner 2006). Bonaire reefs, which are currently among the healthiest in the Caribbean, show coral cover averages of 50% and recent increases in juvenile coral densities (from 20 individuals per square meter in 2005 to 39 per square meter in 2007). Hopeful signs for the region include the recovery of large *A. cervicornis* stands after each recent hurricane and increasing populations of the algae-grazing *Diadema antillarum* in both Bonaire and Curacao (Bouchon et al. 2008).

5. Southern Tropical America: Brazil, Columbia, Costa Rica, Panama, and Venezuela

Coral reef development in Southern Tropical America is impeded by sedimentation and turbidity due to numerous large rivers and heavy rainfall as well as major upwellings in Perú, the Gulf of Panamá, the Gulf of Papagayo, Eastern Colombian Caribbean, and Eastern Venezuela (Rodriguez-Ramirez et al. 2008). Consequently, the region's most extensive coral reefs are off the Caribbean coast of Panama, on oceanic reef complexes of the San Andrés Archipelago off of Colombia, and near the oceanic islands off Venezuela. *Id.* Though the overall status of reefs in the region has not changed significantly in the past five years, there have been some alarming local trends, such as the dramatic increase in disease affecting Venezuela's framework building species (incidences of Caribbean yellow band and other diseases rose from 1.5% of colonies at two sites in 2003 to 26% of colonies at all reef sites in 2008). *Id.* Impacts of the 2005 season varied across the region, with massive bleaching occurring in some areas. *Id.*

III. NATURAL HISTORY AND STATUS OF PETITIONED CORAL SPECIES OF THE INDO-PACIFIC

A. SPECIES ACCOUNTS FOR CORALS OCCURING IN HAWAI'I

1. FAMILY: ACROPORIDAE

All species of the Acroporidae family are colonial and zooxanthellate (Veron 2000, Volume 1 at 61). Except in the genus *Astreopora*, corallites are small with two or fewer cycles of septa and seldom developed columellae. *Id.* Three of the four genera are exclusive to the Indo-Pacific. *Id.*

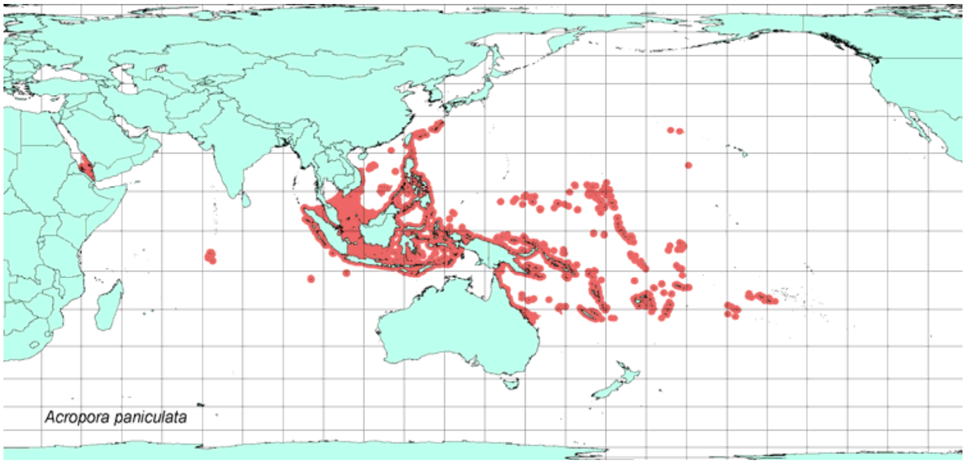
Acropora paniculata (Fuzzy Table Coral)

Species Description: Members of the *Acropora* genus are the most abundant corals on most reefs in the Indo-Pacific (Veron 2000, Volume 1 at 176-177). While this genus displays more varied growth forms than any other (*id.* at 180), shared features of *Acropora* species include distinct axial and radial corallites, as well as porous coenosteum and corallite walls. *Id.* at 176-77. Traits common to most species include lack of columellae, septa in two cycles, and extension of tentacles only at only at night. *Id.*

Acropora paniculata colonies form long plates or tables (25 mm thick and often over one meter in diameter) with elongate tubular and incipient axial corallites that crowd the upper surface (Veron 2000, Volume 1 at 378). Branchlets of *A. paniculata,* which cover the upper surface of the colony, are short and compact, with immersed radial corallites on the lower branchlets (Veron 2000, Volume 1 at 378; Fenner 2005). This cream, gray or blue species occurs in shallow, tropical reefs on upper reef slopes, where it is uncommon (Veron 2000, Volume 1 at 378; IUCN Species Account). It can be found just subtidal to reef edges and upper slopes and also in sheltered lagoons at depths of 10-35 meters (IUCN Species Account).

Distribution: *A. paniculata* is widespread, occurring in the Central Indo-Pacific, Southeast Asia, Japan and the East China Sea, Eastern Australia, the Oceanic West Pacific, Rodrigues, and the Society Island (IUCN Species Account). US waters in which it is found include the Northwestern Hawaiian Islands and Johnston Atoll. *Id. See* Figure 14.

Figure 14. Range Map for *Acropora paniculata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



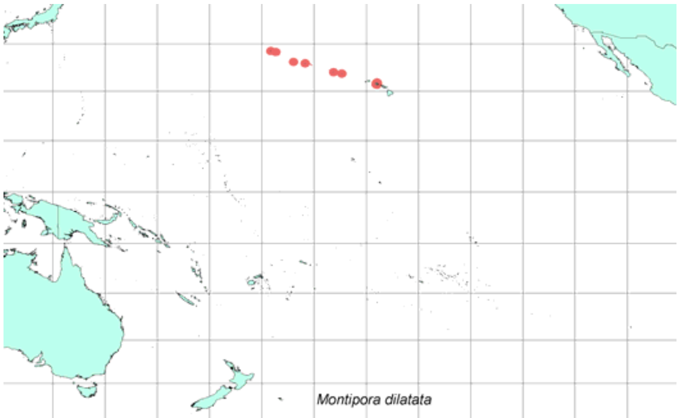
Status and Threats: Members of the *Acropora* genus have low resistance and tolerance to bleaching and disease and are a preferred prey of the crown-of-thorns starfish (*Acanthaster planci*), which is a significant and increasing threat to corals throughout the Indo-Pacific (IUCN Species Account). When subjected to these threats, *Acropora* species are slow to recover. Additionally, *Acropora* is one of the top three genera collected for the aquarium trade. *Id.* While the severity of these combined threats to the global population of *A. paniculata* is unknown, an overall decline in population can be inferred from estimates of habitat degradation based on the estimated destruction and critical degradation of reefs within its range. *Id. A. paniculata* lost an estimated 35% of its population and habitat over 30 years, which meets IUCN criteria for listing the species as vulnerable.

Montipora dilatata (Irregular Rice Coral or Hawaiian Reef Coral)

Species Description: *Montipora dilatata* forms encrusting to submassive colonies up to 0.3 meters in diameter (Veron 2000, Volume 1 at 98). The papillae of *M. dilatata* are smaller than and grouped around the corallite, but they are less conspicuous than those of other species in this group (Veron 2000, Volume 1 at 64, 94, 98). Pale to dark brown colonies have irregular, branch-like protrusions that flatten at the ends and can be up to 100 millimeters in diameter (Veron 2000, Volume 1 at 98). This species is rare and occurs in subtidal environments with calm waters at depths of 1-10 meters (Veron 2000, Volume 1 at 98; NMFS 2007b). *M. dilatata* colonies break easily due to storms or bioerosion, and the resulting fragments readily form new colonies (NMFS 2007b).

Distribution: *M. dilatata* has been found in only a few locations within the Hawaiian Island chain, where it is thought to be endemic (IUCN Species Account). Its primary site appears to be Kaneohe Bay on Oahu, though it was also documented in 2004 on four Northwestern Hawaiian Islands, including two sites on Midway, two sites on Kure, two on Pearl and Hermes, and one location on Lisianski. *Id.* Reports of possible sightings in one location in the Line Islands (Palmyra) have yet to be confirmed. *Id. See* Figure 15.

Figure 15. Range map for *Montipora dilatata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *M. dilatata* is listed as endangered by the IUCN because it exists in fewer than five locations and its total area of occupancy is less than 500 square kilometers (IUCN Species Account). It is also considered a species of concern by NMFS (NMFS 2007b). It has experienced significant climate-related population fluctuations over the last 20 years (IUCN Species Account). The Northwestern Hawaiian Islands populations appear more resistant to bleaching than their sibling species, *M. capitata,* but a devastating bleaching event reduced the Oahu population to two known colonies in 1996. *Id. M. dilatata* was the first species to bleach during that event and the slowest to recover, with high mortality (NMFS 2007b). While the Oahu population now numbers 10 colonies, the extremely limited distribution of the population renders the entire species highly susceptible to future bleaching events, storm floods, exposure during extreme low tide, and habitat degradation or modification (IUCN Species Account; NMFS 2007b). Additionally, *M. dilatata* is at risk of future predation by crown-of-thorns starfish, which have become a serious threat to corals in the Indo-Pacific and have been observed preferentially preying on species of the *Montipora* genus (Colgan 1987; IUCN Species Account). Impacts of crown-of-thorns starfish predation on corals include reductions in living coral abundance, surface cover, species diversity and composition, and overall habitat (IUCN Species Account).

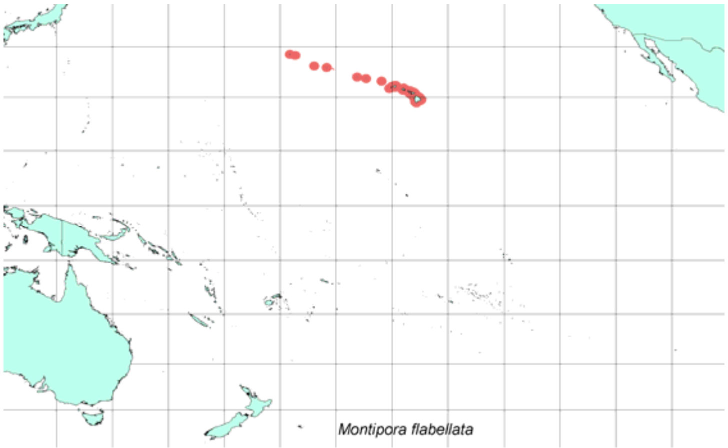
***Montipora flabellata* (Blue Rice Coral)**

Species Description: A Hawaiian endemic, *M. flabellata* is characterized by irregular lobes, small corallites, poorly developed septa, and papillae that cover the colony surface and are sometimes fused into ridges (Veron 2000, Volume 1 at 99). While the species' common name derives from its typical blue coloration, it can also be brown or purple and sometimes appears pink in photographs. *Id.* Colonies typically form encrusting sheets in shallow water up to 10 meters deep, with colony edges occasionally forming raised plates on steep slopes (Fenner 2005 at 49; IUCN Species Account). The surface of the colony is generally irregular and appears rough. *Id.*

M. flabellata is uncommon and tends to thrive in shallow reef environments, especially those with high wave-energy that prohibits the growth of more aggressive vertical corals (Veron 2000, Volume 1 at 99; Jokiel et al. 2004). Normally, *M. flabellata* does not have a branching growth form and cannot compete with branched species, but unique branched colonies do occur on the South Molokai outer reef flat (Jokiel et al. 2008). This branching is due to a symbiotic relationship with a small unidentified shrimp, around which the branch of coral skeleton grows. *Id.* The branch is hollow with an opening at the tip, providing a home for the shrimp. *Id.*

Distribution: *M. flabellata* is endemic to Hawaii and occurs on all of the Hawaiian Islands with the exception of Johnston Atoll (IUCN Species Account). *See* Figure 16.

Figure 16. Range map for *Montipora flabellata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: The IUCN considers *M. flabellata* vulnerable due to its restricted range and the associated susceptibility to predicted future climate-associated habitat degradation and bleaching events (IUCN Species Account). While the impacts to this species have been minor so far, the *Montipora* genus is susceptible to bleaching, *id.*, and "[c]oral reefs of the Hawaiian region will be increasingly vulnerable to large-scale bleaching events if the observed trend of increasing ocean temperatures continues" (Jokiel and Brown 2004). Recent disease outbreaks in the Northwestern Hawaiian Islands, discussed below, are considered harbingers of future warming-related increases in disease for all Hawaiian corals.

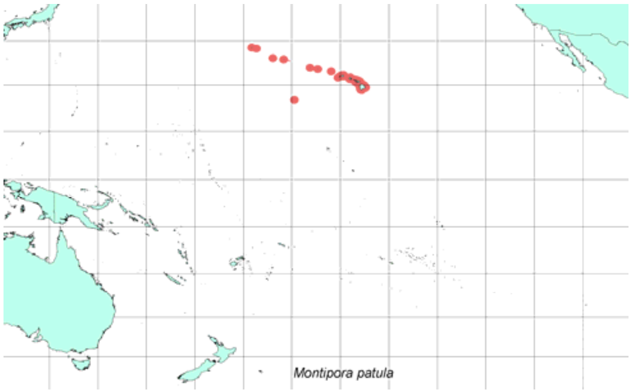
Additionally, crown-of-thorns starfish (*Acanthaster planci*), which are found throughout the Pacific Ocean in dramatically increasing numbers since the 1970s, have been observed preferentially preying on *Montipora* species (Colgan 1987 in IUCN Species Account; IUCN Species Account). Crown-of-thorns starfish predation has decimated large areas of coral reef habitat and contributed to the overall decline of reefs in the Indo-Pacific region (IUCN Species Account). As discussed above, crown-of-thorns starfish can dramatically decrease living coral abundance, surface cover, species diversity and composition, and overall habitat. *Id.*

Montipora patula (Sandpaper Rice Coral/Spreading Coral/Ringed Rice Coral)

Species Description: *M. patula* colonies are comprised of encrusting or tiered plates with free edges that can be over two meters in diameter (Veron 2000, Volume 1 at 106). The "sandpaper"-like consistency of the colony surface results from tiny corallites of irregular height and their surrounding papillae (Fenner 2005 at 50). *M. patula* colonies appear tan in color and generally have purple polyps (Veron 2000, Volume 1 at 106). This is a shallow reef species that has been found in depths of up to 10 meters (*Id.;* IUCN Species Account).

Distribution: *M. patula* is abundant throughout and endemic to the Hawaiian Islands. Unlike *M. flabellata*, its range also includes Johnston Atoll. *See* Figure 17.

Figure 17. Range map for *Montipora patula.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: While *M. patula* is the most abundant of the three *Montipora* species that are endemic to Hawaii, its very limited range (fewer than five locations) puts it at high risk from the threats to sibling species described above, including climate-related bleaching and disease as well as crown-of-thorns starfish predation (IUCN Species Account). It is listed as vulnerable by the IUCN. *Id.* "Escalating anthropogenic stressors combined with the threats associated with global climate change of increases in coral disease, frequency and duration of coral bleaching and ocean acidification place coral reefs in the Indo-Pacific at high risk of collapse." *Id.* at 3.

2. FAMILY: AGARICIDAE

All species in the Agaricidae family are colonial, and all extant species are zooxanthellate (Veron 2000, Volume 2 at 169). Immersed corallites have poorly defined walls of thickened septo-costae. *Id.* Loosely packed septa have smooth or finely serrated margins, are continuous between adjacent corallite centers, and seldom fuse. *Id.* There are six extant genera: *Leptoseris* occurs in both the Western Atlantic and the Indo-Pacific, *Agaricia* is restricted to the Western Atlantic, and the other four genera (*Pavona*, *Gardineroseris*, *Pachyseris*, and *Coeloseris*) are restricted to the Indo-Pacific. *Id.*

Leptoseris incrustans

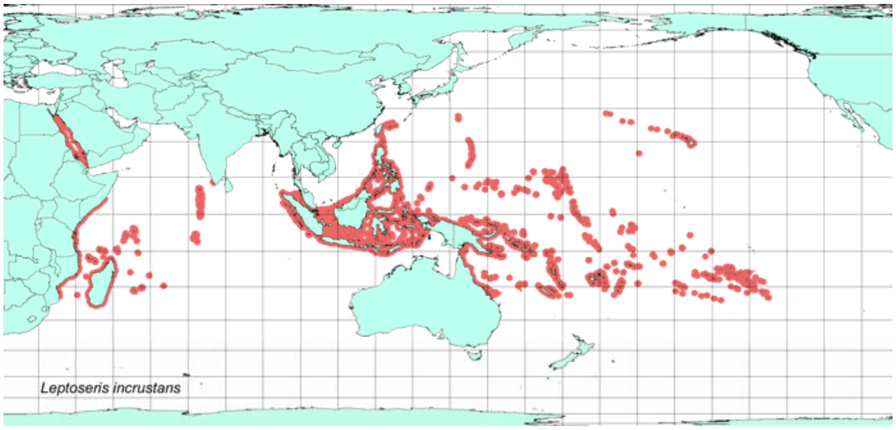
Species Description: Species in the *Leptoseris* genus have generally small (under 20 cm) colonies that are laminar or encrusting (frequently unifacial), and they often have a distinctive central corallite (Veron 2000, Volume 2 at 202; IUCN Species Account). Corallites have the poorly defined walls that are characteristic of the Agaricidae family and form small, shallow depressions (Veron 2000, Volume 2 at 202). Corallites are further distinguished by central columellae, and they are usually separated by ridges and interconnected by fine septo-costae. *Id.* Tentacles generally extend only at night. *Id.*

Pale to dark brown or greenish-brown *Leptoseris incrustans* colonies are usually encrusting, though sometimes they develop broad explanate laminae that often have radiating ridges (Veron 2000, Volume 2 at 218). The colonies have a smooth surface due to thin, uniform septo-costae. *Id.* Other distinctive features include columellae that are small styles and small, compacted, and superficial corallites with sections of shared walls that have a secondary radial symmetry (*Id; see also id.,* Volume 3 at 465 (Glossary)).

L. incrustans is found on reef slopes and on vertical walls at depths of 10-20 meters. (IUCN Species Account).

Distribution: *L. incrustans* is restricted to the Indo-West Pacific (IUCN Species Account). Its range encompasses the Red Sea, the Southwest and Central Indian Ocean, the Central Indo-Pacific, Southern Japan and the South China Sea, Eastern Australia, the Oceanic West Pacific, and the Central Pacific. *Id.* US-affiliated waters within this range include the Hawaiian Islands, Johnston Atoll, American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 18.

Figure 18. Range map for *Leptoseris incrustans.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *L. incrustans* is an uncommon species with unknown population trends (IUCN Species Account). It is susceptible to bleaching, disease, crown-of-thorns starfish predation, and already extensive reef habitat reduction due to a combination of threats. *Id.* Vulnerabilities to these threats increase the likelihood that it will be entirely lost within one generation from critically degraded reefs. *Id.* The IUCN has listed *L. incrustans* as vulnerable and estimates that it faces the loss or degradation of 35% of its habitat over 30 years. *Id.*

3. FAMILY: PORITIDAE

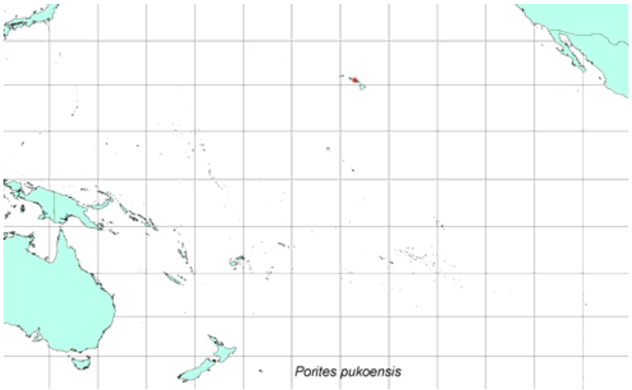
Veron describes the Family Poritidae as "a heterogeneous assembly of distantly related genera" (Veron 2000, Volume 3 at 275). All species in this family are colonial and zooxanthellate, with generally porous walls and septa. *Id.*

Porites pukoensis

Species Description: There is significant interspecies variation within the genus *Porites*, which is one of the most difficult genera to identify (Veron 2000, Volume 3 at 276). The corallites of species within this genus are small, immersed, and filled with septa. *Id.* While most *Porites* species extend their tentacles only at night (*Id.*), *P. pukoensis* tentacles are usually extended during the day. *Id.* at 299. Colonies of this brown or tan species are massive and tend to form columns in shallow water (specific depth limits unknown). *Id.* The distinctive corallite has a relatively large central columella surrounded by eight large pali. *Id.*

Distribution: This Hawaiian endemic is found in lagoons and other protected reef environments in one small location off of Molokai (IUCN Species Account). It is extremely rare and is thought to be limited to fewer than 50 total colonies. *Id. See* Figure 19.

Figure 19. Range map for *Porites pukoensis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: This species is known from only one small site, is thought to be limited to fewer than 50 colonies, and is listed as critically endangered by the IUCN (IUCN Species Account). *P. pukoensis* is not particularly vulnerable to bleaching, but it is more susceptible to disease than many corals. *Id.* Its extremely limited range places it at high risk from anticipated climate-related disease outbreaks and habitat degradation in the future. *Id.*

4. FAMILY: FAVIIDAE

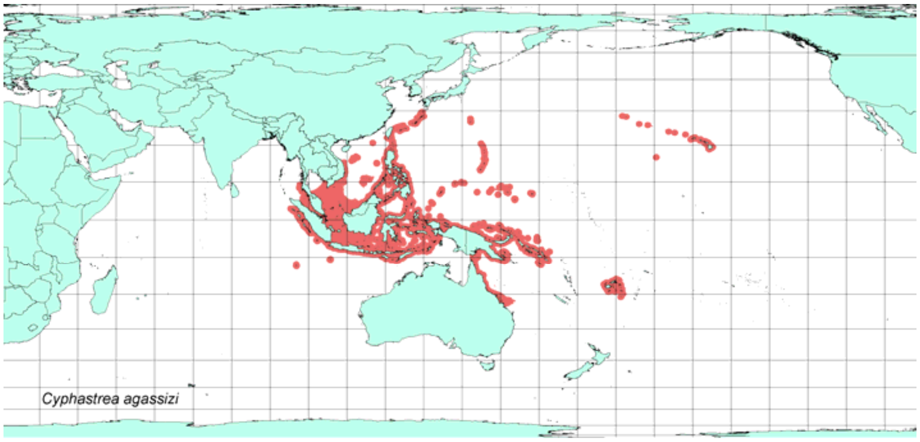
The Faviidae family has 24 genera, the most of any extant family of corals (Veron 2000, Volume 3 at 85). This is also one of the oldest extant coral groups, maintaining a consistent status as a major family for 150 million years (Veron 2000, Volume 1 at 40). Faviidae is the only coral family that was a major component of Mesozoic reefs and survived to be dominant in the Cenozoic. *Id.* at 41. All species in this family are zooxanthellate and colonial, with similar (when present) septa, paliform lobes, columellae, and wall structures (Veron 2000, Volume 3 at 85). Characteristic features include simple septal structures and columellae; the latter are comprised of a tangle of elongate septal teeth. *Id.*

Cyphastrea agassizi (Agassiz's Coral)

Species Description: *Cyphastrea agassizi* colonies are massive and usually only a few inches in diameter (Fenner 2005), often with deeply grooved surfaces (Veron 2000, Volume 3 at 248; IUCN Species Account). Corallites are widely spaced and, as in other *Cyphastrea* species, plocoid with small calices (Veron 2000, Volume 3 at 240, 248). The coenosteum is usually whitish and smooth, while corallites are pale brown or green. *Id.* at 248. The septa, which are sometimes orange, are arranged in three unequal orders, with the first order exsert. *Id.* The species sometimes has irregular “groove and tubercle” formations. *Id.* It is uncommon and occurs in shallow reef environments (up to 20 meters depth) including back slopes, foreslopes, and lagoons; it can also be found in the outer reef channel. *Id.*

Distribution: US waters in which *C. agassizi* is found include the Hawaiian Islands, US Minor Outlying Islands (Johnston Atoll), and the Northern Mariana Islands, along with the freely associated states of Palau and the Federated States of Micronesia ("Micronesia") **(**IUCN Species Account). More broadly, *C. agassizi* occurs in the Andaman Sea, the Central Indo-Pacific, Southeast Asia, Japan and the East China Sea, Eastern Australia, the Oceanic West Pacific, and Fiji. *Id. See* Figure 20.

Figure 20. Range map for *Cyphastrea agassizi.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



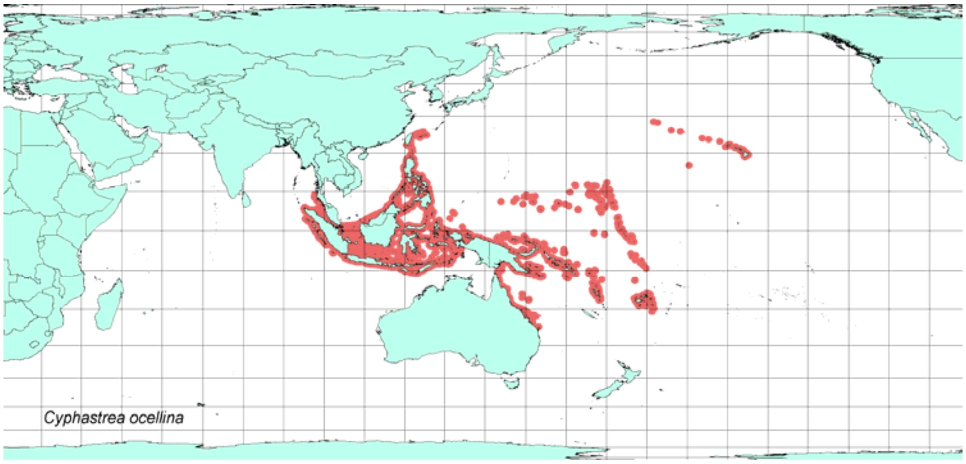
Status and Threats: *C. agassizi* has a restricted depth range and is therefore susceptible to bleaching, disease, and the habitat reduction that has already occurred throughout its range (IUCN Species Account). Losses over 30 years are estimated to be 36%, which qualifies this declining species as vulnerable under IUCN criteria. *Id.*

Cyphastrea ocellina (Ocellated Coral)

Species Description: *C. ocellina* colonies are massive or encrusting and have an undulating surface and small (less than 3 mm in diameter), tightly compacted corallites (Veron 2000, Volume 3 at 244). Other characteristic features of this pale greenish-yellow or dark green species include coenstenum covered with short spinules, small or absent paliform lobes, and two or three unequal orders of 12 septa. *Id. C. ocellina* occurs on upper reef slopes in shallow, tropical reef environments, including lagoons and the outer reef channel (*Id.,* IUCN Species Account).

Distribution: *C. ocellina* occurs in the Hawaiian Islands and the US Minor Outlying Islands (Johnston Atoll), and in freely associated states including the Marshall Islands, Micronesia, and Palau. Its broader range includes the Central Indo-Pacific, Japan and the East China Sea, Eastern Australia, and Oceanic West Pacific (IUCN Species Account). *See* Figure 21.

Figure 21. Range map for *Cyphastrea ocellina*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: Like its sibling, *C. agassizi*, *C. ocellina* is listed as vulnerable by the IUCN due to its restricted depth range and associated heightened susceptibility to climate-related and other threats, including bleaching and disease (IUCN Species Account). The declining population faces escalating habitat degradation and has already lost 36% of its habitat over 30 years. *Id.*

5. FAMILY: SIDERASTREIDAE

All six extent genera in the Siderastreidae family are zooxanthellate and colonial (massive or laminar) (Veron 2000, Volume 2 at 133). Siderastreidae species have immersed corallites with poorly defined walls formed by thickened septo-costae. *Id.* Their septa have granulated upper margins, are closely compacted and equally spaced, and are usually fused along their inner margins to form fan-like groups when viewed from above. *Id.*

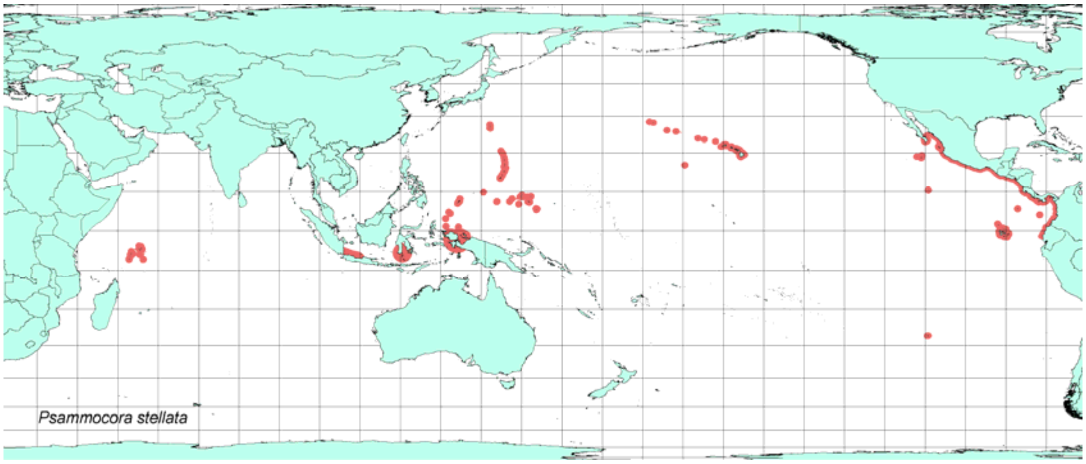
Psammocora stellata (Stellar Coral)

Species Description: *Psammocora* species tend to be very slow growing, but they are also known to be among the most opportunistic of corals due to their ability to rapidly recolonize areas left vacant by disturbances (Guzman and Cortes 2001; IUCN Species Account). *Psammocora stellata* colonies are submassive or branching and have encrusting bases (Veron 2000, Volume 2 at 148). When present, branches are smooth and approximately 0.25 inches in diameter, and colonies are rarely larger than three inches in diameter (Fenner 2005). Columellae are poorly developed or absent, and approximately half of the septo-costae are tear-shaped (Veron 2000, Volume 2 at 148). This tan, gray, or purple species occurs in shallow, wave-washed rock habitat or on coarse, sandy bottoms at depths of 15-20 meters. *Id.*, IUCN Species Account. It is rare to uncommon in the Indo-West Pacific, but it can be locally abundant in some locations in the Eastern Tropical Pacific (see below) (IUCN Species Account).

Distribution: *P. stellata* is found in both the Indo-West Pacific and the Eastern Tropical Pacific (IUCN Species Account). US locations include the Hawaiian Islands and the US Minor

Outlying Islands (Johnston Atoll), and it is also found in the Northern Mariana Islands, Palau, and Micronesia. *Id.* It has been recorded in the Seychelles, Indonesia, the Oceanic West Pacific, Mexico, Costa Rica, Panama, Columbia, Ecuador, and the far Eastern Pacific (including Easter Island). *Id. See* Figure 22.

Figure 22. Range map for *Psammocora stellata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: Though *P. stellata* shows high resilience and capacity to recover from disturbance, it has already lost an estimated 32% of the habitat within its range, and it therefore qualifies as vulnerable under IUCN criteria (IUCN Species Account). This loss of habitat is the most significant threat to this species, which is also moderately susceptible to bleaching and crown-of-thorns starfish (*Acanthaster planci*) predation. *Id. Psammacora* species also face predation by the puffer fish, *Arothron meleagris,* as well as mortality due to algae overgrowth. *Id.*

B. SPECIES ACCOUNTS FOR CORALS NOT OCCURING IN HAWAII

1. FAMILY: ACROPORIDAE

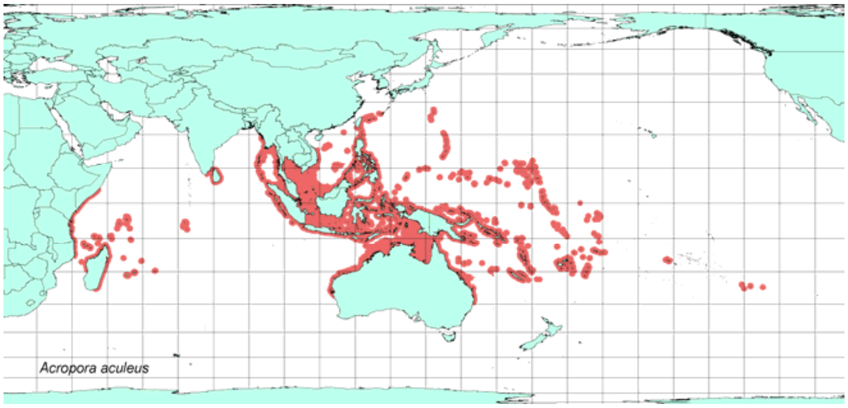
All species of the Acroporidae family are colonial and zooxanthellate (Veron 2000, Volume 1 at 61). Except in the genus *Astreopora*, corallites of species within this family are small with two or fewer cycles of septa and seldom developed columellae. *Id.* Three of the four genera are exclusive to the Indo-Pacific. *Id.* The *Acropora* genus is among the top three coral genera collected for the aquarium trade (IUCN Species Accounts). All genera except *Isopora* reproduce via external fertilization and larval development (Wallace et al. 2007).

Acropora aculeus

Species Description: *Acropora aculeus* colonies form corymbose clumps characterized by thin, spreading, interlocking horizontal branches and fine, upward projecting branchlets (Veron 2000, Volume 1 at 356). Radial corallites along the sides of the branches are nariform, with slightly flaring lips. *Id.* On the branchlet tips, axial and radial corallites are not clearly differentiated. *Id. A. aculeus* colonies are usually gray, bright blue-green, or yellow, with branch tips that are yellow, lime green, pale blue or brown. *Id.* They are found on upper reef slopes and lagoons at depths of 5-35 meters (IUCN Species Account).

Distribution: This species is common in the Central Indo-Pacific and less abundant in other parts of its range, which includes the Southwest, Northern, and Eastern Indian Ocean, Australia, Southeast Asia, Japan and the East China Sea, and the Oceanic West Pacific (IUCN Species Account). *A. aculeus* is also reported from Society and Pitcairn Islands. *Id.* US-affiliated waters in which it occurs include American Samoa, the Northern Mariana Islands, the Marshall Islands (found at 17 of 87 surveyed sites), Micronesia, Palau, and unspecified US minor outlying islands. *Id. See* Figure 23.

Figure 23. Range map for *Acropora aculeus.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



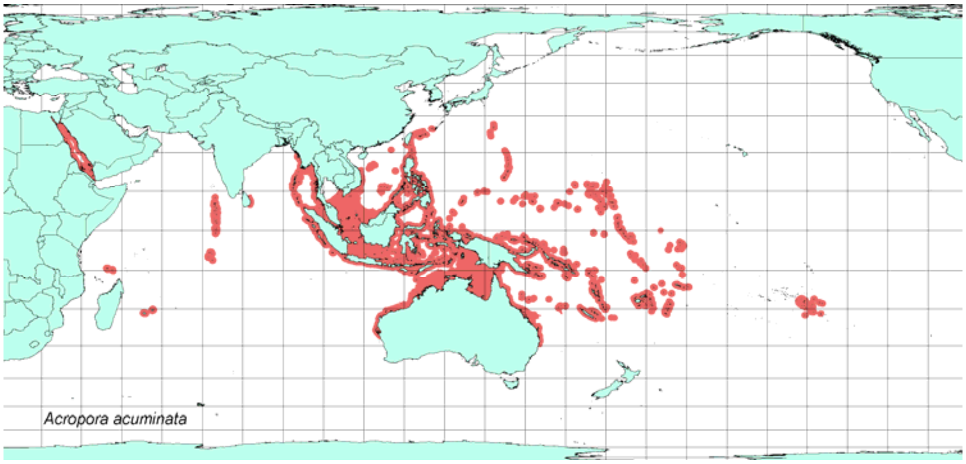
Status and Threats: Like other *Acropora* species, *A. aculeus* is especially susceptible to bleaching and disease and is slow to recover (IUCN Species Account). This species' corymbose colonies are also particularly vulnerable to crown-of-thorns starfish predation (De'ath and Moran 1998; IUCN Species Account). Other threats include aquarium harvest and extensive habitat reduction (IUCN Species Account). Habitat and associated population loss over 30 years is estimated at 37%. *Id.* The IUCN classifies this species, which has a decreasing population trend, as vulnerable. *Id.*

Acropora acuminata

Species Description: *Acropora acuminata* colonies have horizontal branches that are fused to form small tables and usually have upturned and tapered ends (Veron 2000, Volume 1 at 230). Corallites on the horizontal branch sections are mostly immersed, whereas those on the upturned ends are of two sizes, including a larger tubular size with sharp edges. *Id. A. acuminata* colonies are usually bright or pale blue or brown, with permanently dark-colored skeletons. *Id.* They are generally uncommon and found in turbid or clear water on reef slopes at depths of 5-20 meters. *Id.*, IUCN Species Account.

Distribution: *A. acuminata* is found in the Red Sea, the Northern Indian Ocean, the Central Indo-Pacific (including the Chagos Archipelago), Australia, Southeast Asia, Japan and the East China Sea, and the Oceanic West Pacific (IUCN Species Account). US territories and affiliated areas include American Samoa, Marshall Islands, Micronesia, Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 24.

Figure 24. Range map for *Acropora acuminata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



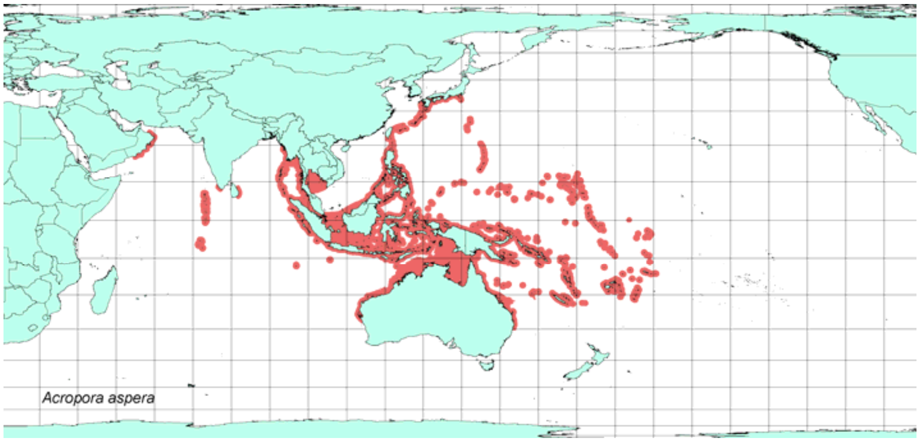
Status and Threats: This declining species suffered the estimated loss or degradation of 35% of its habitat over 30 years and is therefore classified as vulnerable by the IUCN (IUCN Species Account). *Acropora acuminata* is particularly susceptible to bleaching and disease, from which it is slow to recover. *Id.* Its branching form also makes it especially vulnerable to crown-of-thorns starfish predation. *Id.* Other serious threats include harvest for the aquarium trade, wave damage, and the widespread loss and degradation of habitat referenced above. *Id.*

Acropora aspera

Species Description: The thick branches that comprise the corymbose colonies of *Acropora aspera* vary in length based on exposure to wave action (Veron 2000, Volume 1 at 342). Other characteristic features include small but distinct axial corallites and crowded, dual-sized radial corallites with a scale-like appearance due to prominent lower lips. *Id.* This pale blue-gray, green, cream, or bright blue species is found on reef flats, shallow lagoons and exposed upper reef slopes at depths up to 5 meters; it is also found in deep water. *Id.,* IUCN Species Account.

Distribution: *A. aspera* is widespread but uncommon throughout its range (IUCN Species Account). US-affiliated waters in which it is found include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and unspecified minor US outlying islands. *Id*. More broadly, the species occurs in the Northern Indian Ocean, the Central Indo-Pacific, Australia, Japan and the East China Sea, and the Oceanic West Pacific. *Id.* It has also been reported in Oman. *Id. See* Figure 25.

Figure 25. Range map for *Acropora aspera.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



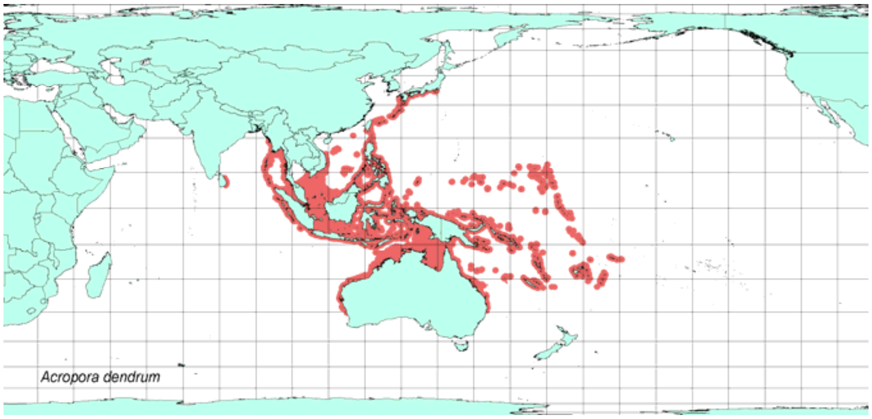
Status and Threats: *A. aspera* is listed by the IUCN as vulnerable because it shows decreasing population trends and has suffered estimated habitat losses of 37% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora dendrum

Species Description: Pale brown or cream *Acropora dendrum* colonies form corymbose plates that are 0.5-1 meter across and have widely spaced, tapering branchlets (Veron 2000, Volume 1 at 327). The axial corallites of this species are small. *Id.* Because the radial corallites are nearly or fully immersed, the branchlets appear smooth. *Id. A. dendrum* is rare, occurring only in areas of high *Acropora* diversity on upper reef slopes at depths of 5-20 meters. (*Id.*; IUCN Species Account).

Distribution: *Acropora dendrum* is uncommon throughout its range, which includes the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, the Oceanic West Pacific, Vanuatu, Tonga, and Samoa (IUCN Species Account). US affiliated waters include American Samoa, the Marshall Islands, Micronesia, and Palau. *See* Figure 26.

Figure 26. Range map for *Acropora dendrum.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



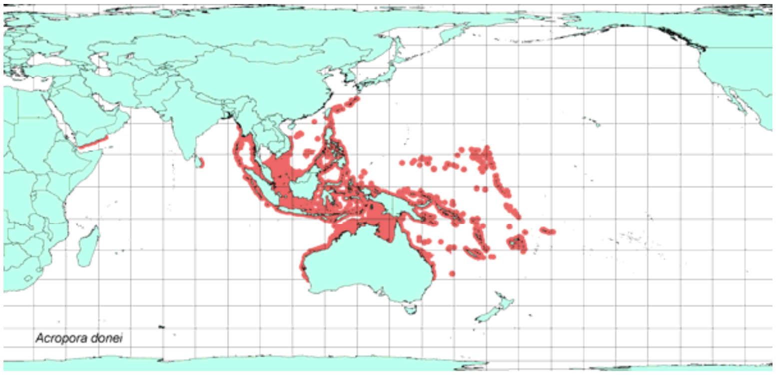
Status and Threats: *Acropora dendrum* is listed by the IUCN as vulnerable because it shows decreasing population trends and has lost 35% of its habitat over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora donei

Species Description: Masses of fused *A. donei* branches form large table-like colonies up to two meters in diameter (Veron 2000, Volume 1 at 228-229). All branches in the colony are neatly arranged and have blunt ends, with those at the periphery being horizontal and those at the center of the colony upturned. *Id.* The branches appear rough due to characteristically coarse coenosteum. *Id.* The larger of dual-sized radial corallites has flared lips. *Id. Acropora donei* is found only on shallow fringing reefs and upper reef slopes where *Acropora* diversity is high (depths of 5-20 meters) (*Id.*; IUCN Species Account).

Distribution: The range of *A. donei* includes the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, the Oceanic West Pacific, Yemen, and Japan (IUCN Species Account). It occurs in the following US affiliated waters: American Samoa, Marshall Islands, Micronesia, and Palau. *Id. See* Figure 27.

Figure 27. Range map for *Acropora donei*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *A. donei* is listed by the IUCN as vulnerable because it shows decreasing population trends and has lost 37% of its habitat over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

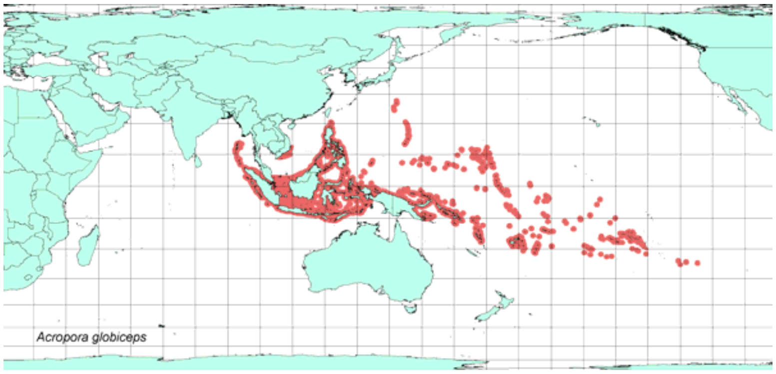
Acropora globiceps

Species Description: Generally small *Acropora globiceps* colonies are digitate, with short, closely compacted branches shaped like upturned fingers (Veron 2000, Volume 1 at 317).

Exposure to strong wave action creates pyramid-shaped branchlets. *Id.* Uniform blue or cream colonies are common on upper reef slopes, where their corallites are tubular, and on reef flats, where the corallites are usually immersed. *Id.* Axial corallites are small and sometimes indistinguishable, while radial corallites are irregularly sized and usually arranged in rows along the sides of branches. *Id. A. globiceps* occurs intertidally on upper slopes and flats in tropical reef environments at depths of up to 8 meters (IUCN Species Account).

Distribution: *Acropora globiceps* is found in the Central Indo-Pacific, the Oceanic West Pacific, the Central Pacific, the Great Barrier Reef, the Philippines, the Andaman Islands, Polynesia, and the Pitcairn Islands (IUCN Species Account). US-affiliated waters in which it is found include American Samoa, Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 28.

Figure 28. Range map for *Acropora globiceps.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *Acropora globiceps* is listed by the IUCN as vulnerable because it shows a decreasing population trend and faces estimated habitat losses of 35% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

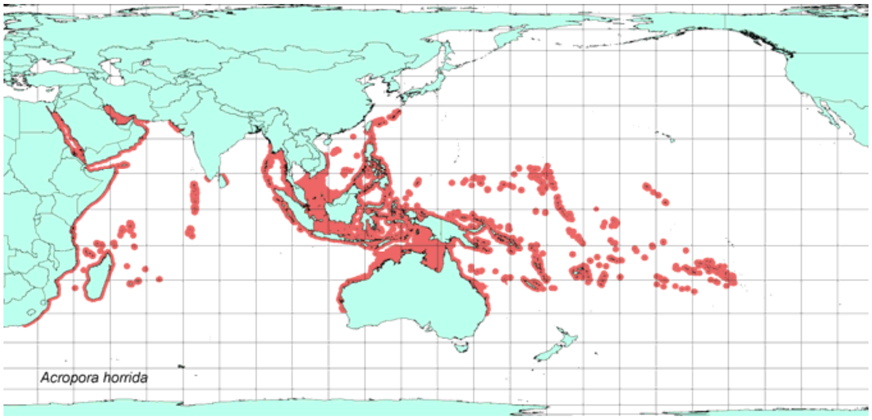
Acropora horrida

Species Description: When found in turbid water, *Acropora horrida* colonies usually have an open branched form with irregular branchlets (Veron 2000, Volume 1 at 266). Branchlets tend to become more compact in shallow, clear water and on upper reef slopes, creating a bushy appearance. *Id.* Irregular corallites create a rough branch surface, and tentacles are usually extended during the day. *Id. A. horrida* is most commonly pale blue (photographing pink or purple), but it can also be dark blue, pale yellow, or brown with white or pale blue polyps. *Id.* The species is usually uncommon and found on or near fringing reefs at depths of 5-20 meters (*Id.*; IUCN Species Account).

Distribution: *A. horrida* is found in the Red Sea and the Gulf of Aden, the Southwest and Northwest Indian Ocean, the Arabian/Iranian Gulf, the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, the Oceanic West Pacific, and the Central Pacific (IUCN Species Account). US-affiliated waters within its range include

American Samoa, Marshall Islands, Micronesia, Palau, and the Line Islands. (*Id.*; Randall 1995). *See* Figure 29.

Figure 29. Range map for *Acropora horrida.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



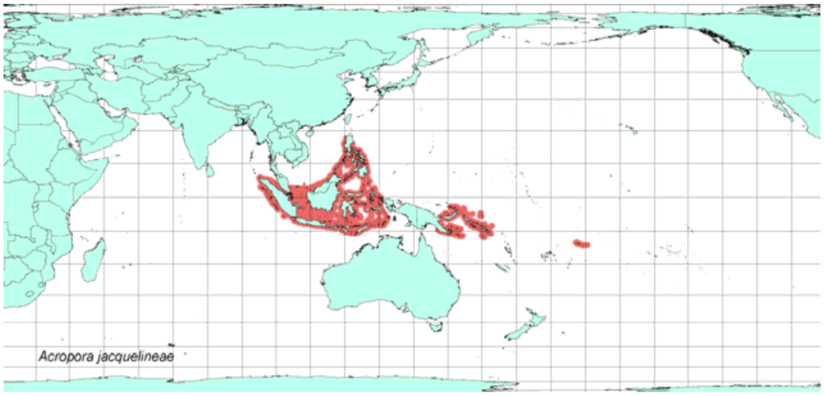
Status and Threats: *Acropora horrida* is believed to be in general decline with sustained local extirpations (IUCN Species Account). It has undergone dramatic population declines at Orpheus Island, Great Barrier Reef, and Kimbe Bay, Papua New Guinea, where large sterile zones have replaced healthy colonies. *Id. A. horrida* is listed by the IUCN as vulnerable because it shows a decreasing population trend and faces estimated habitat losses of 36% over 30 years. *Id*. Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events, after which it loses reproductive capacity. *Id.*

Acropora jacquelineae

Species Description: Uniform gray-brown or pinkish *Acropora jacquelineae* colonies form flat plates up to one meter in diameter (Veron 2000, Volume 1 at 384). A mass of delicate, curved, and very fine axial corallites (the smallest of any *Acropora* species) cover the plates and give them a moss-like appearance. *Id.* at 378. Radial corallites are virtually absent. *Id.* at 384. *A. jacquelineae* is uncommon and found on shallow reef slopes with minimal wave action. *Id.* It is subtidal on walls and ledges and also occurs on submerged reefs at depths of 10 to 35 meters (*Id.*; IUCN Species Account).

Distribution: This species is found in the Central Indo-Pacific (IUCN Species Account). More specifically, it occurs in Indonesia, Papua New Guinea, the Philippines, and Suluwesi, as well as in American Samoa. *Id. See* Figure 30.

Figure 30. Range map for *Acropora jacquelineae.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



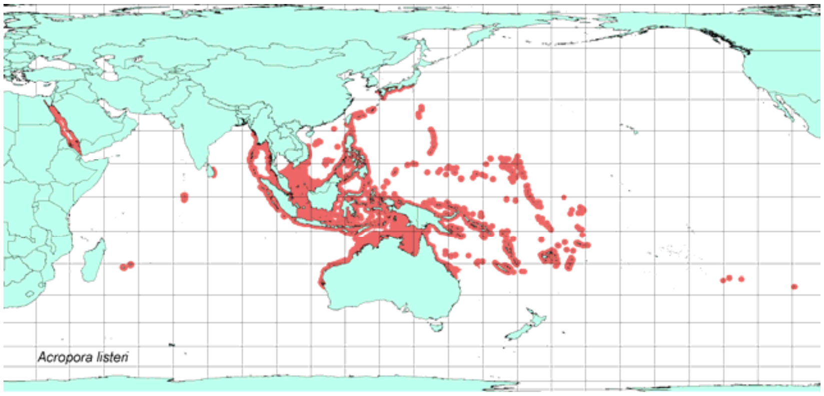
Status and Threats: *Acropora jacquelineae* is listed by the IUCN as vulnerable because it shows a decreasing population trend and has suffered estimated habitat losses of 37% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade (1,842 *A. jacquelineae* specimens were exported for the aquarium trade in 2005), and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora listeri

Species Description: Like its sibling species, *A. polystoma* and *A. massawensis*, *Acropora listeri's* growth form varies significantly depending on wave action (Veron 2000, Volume 1 at 334). Cream or brown colonies form irregular clumps or corymbose plates. *Id.* Thick branches are tapered in wave-washed habitats or, depending on the degree of axial corallite formation in less exposed habitats, can be conical, dome-shaped or globular. *Id.* Radial corallites range from irregularly immersed to tubular and often have slit-like openings and pointed rims, which give colonies a spiny appearance. *Id. A listeri* is uncommon and found on upper reef slopes, particularly those exposed to strong wave action. *Id.* It also occurs just subtidal to upper reef edges (IUCN Species Account). This species is found at depths from 3 to 15 meters. *Id.*

Distribution: *A. listeri's* exact range is uncertain. It occurs in the Northern Indian Ocean, the central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, the Oceanic West Pacific, the Central Pacific, and Mauritius. It has also been reported in the Red Sea and the Gulf of Aden, but these sections of the range are questionable (IUCN Species Account). US-affiliated waters included in the range of *A. listeri* include American Samoa, Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 31.

Figure 31. Range map for *Acropora listeri.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



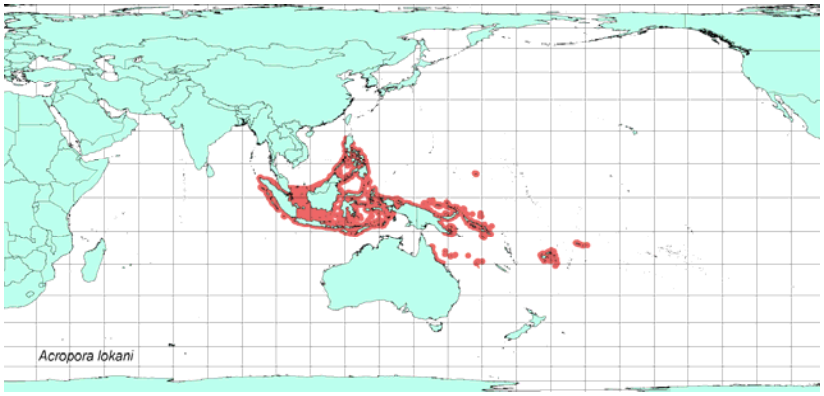
Status and Threats: *A. listeri* is listed by the IUCN as vulnerable because it shows a decreasing population trend and has lost an estimated 35% of its habitat over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora lokani

Species Description: Cream, brown, or blue *Acropora lokani* colonies form corymbose bushes of robust, horizontal, and generally divergent main branches and short, upright branchlets (Veron 2000, Volume 1 at 378). Large, tubular axial and incipient axial corallites radiate from the branchlets, while radial corallites are small and pocket shaped. *Id. A. lokani* is sometimes common in reef environments at 8-25 meters depth, including sheltered lagoonal patch reefs and shallow reef flats (*Id.*, IUCN Species Account).

Distribution: *Acropora lokani* is present in US-affiliated waters including American Samoa and the Federated States of Micronesia (IUCN Species Account). More broadly, it occurs in the Central Indo-Pacific, Southeast Asia, Fiji, Pohnpei, Raja Ampat, Coral Sea, the Solomon Islands, and the Great Barrier Reef. *Id. See* Figure 32.

Figure 32. Range map for *Acropora lokani.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



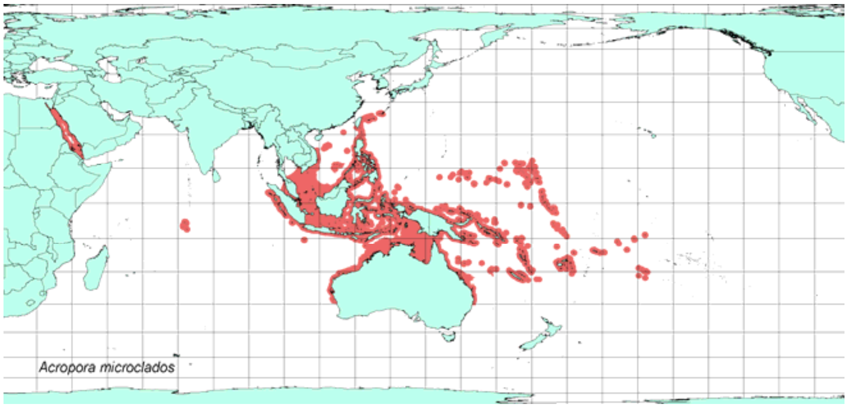
Status and Threats: *A. lokani* is listed by the IUCN as vulnerable because it shows a decreasing population trend and suffered estimated habitat losses of 36% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora microclados

Species Description: *Acropora microclados* colonies are corymbose plates up to one meter in diameter, usually distinctive pale pinkish-brown, with short, uniform, tapered branchlets that are up to 10 mm thick at their bases (Veron 2000, Volume 1 at 374). Tentacles are pale gray and often extended during the day. *Id.* Axial corallites of this species are tubular and conspicuous; incipient axial corallites are common; and irregular radial corallites are usually tubular, appressed, and nariform with sharp-edged openings. *Id. A. microclados* is found on upper reef slopes at depths of 5-20 meters, where it is usually uncommon (*Id.*; IUCN Species Account).

Distribution: *Acropora microclados* is found in the Red Sea and the Gulf of Aden, the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, the Oceanic West Pacific, Samoa, the Cook Islands, and the Chagos Archipelago. US-affiliated waters within its range include American Samoa, the Marshall Islands, the Federated States of Micronesia, and Palau. *Id. See* Figure 33.

Figure 33. Range map for *Acropora microclados.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



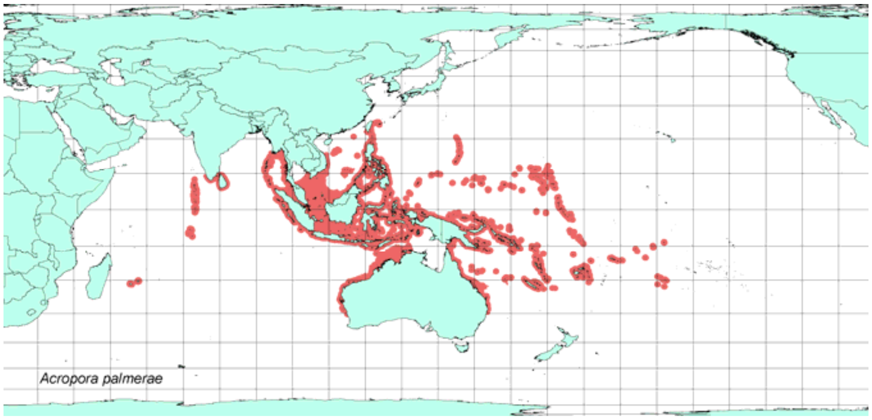
Status and Threats: *A. microclados* is listed by the IUCN as vulnerable because it shows a decreasing population trend and has suffered estimated habitat losses of 33% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora palmerae

Species Description: Greenish- or pinkish-brown *Acropoa palmerae* colonies are encrusting and usually do not exceed one meter in diameter (Veron 2000, Volume 1 at 211). Branches, when present, are short and irregularly shaped. *Id.* Axial corallites are conspicuous if present, and variably sized, mostly rasp-like radial corallites face in different directions. *Id. A. palmerae* is uncommon, occurring at depths of 0-12 meters on wave-exposed reef flats, in lagoons, and intertidally or subtidally on reef tops or edges exposed to strong currents. (*Id.,* IUCN Species Account).

Distribution: US-affiliated waters within the range of *A. palmerae* include American Samoa, the Federated States of Micronesia, the Northern Mariana Islands, and Palau (IUCN Species Account). It is also found in the Andaman Islands, the Great Barrier Reef, Okinawa, Mauritius, the Cook Islands, and the Philippines. *Id.* The broader range includes the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, the Oceanic West Pacific. *Id. See* Figure 34.

Figure 34. Range map for *Acropora palmerae.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



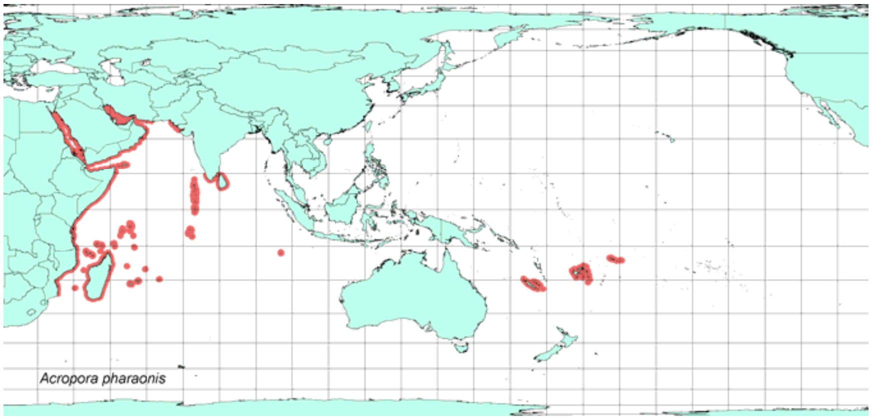
Status and Threats: *A. palmerae* is listed by the IUCN as vulnerable because it shows a decreasing population trend and has lost 39% of its habitat over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora pharaonis

Species Description: Gray-brown *Acropora pharaonis* colonies form large, horizontal tables or irregular clusters of short, pointed, horizontal or upright and contorted branches with pale tips that are linked by short branchlets (Veron 2000, Volume 1 at 296). Other distinctive features include small axial corallites and appressed, nariform radial corallites. *Id.* Abundant incipient axial corallites create a spiky surface on branches. *Id. A. pharaonis* is common on sheltered reef slopes at depths of 5-25 meters (*Id.*, IUCN Species Account).

Distribution: *A. pharaonis* is found in American Samoa; it also occurs in the Red Sea and the Gulf of Aden, the Southwest and Northwest Indian Ocean, the Arabian/Iranian Gulf, the Northern Indian Ocean, New Caledonia, and Fiji (IUCN Species Account). *See* Figure 35.

Figure 35. Range map for *Acropora pharaonis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



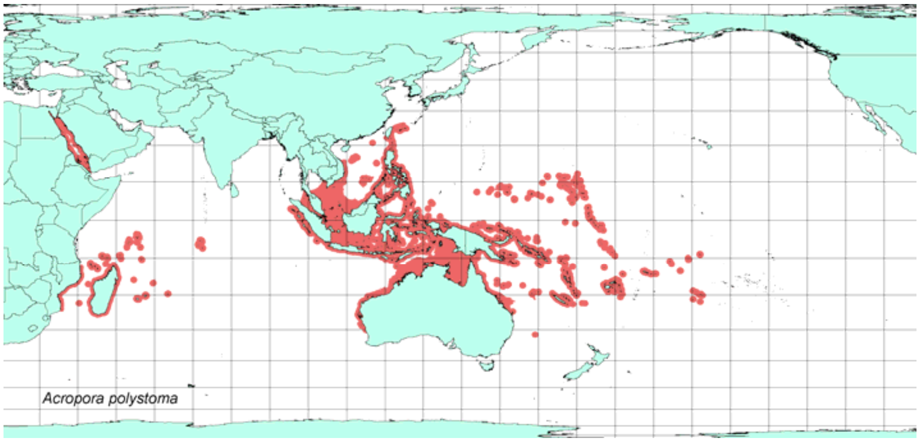
Status and Threats: *A. pharaonis* is listed by the IUCN as vulnerable because it shows a decreasing population trend and has suffered estimated habitat losses of 30% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora polystoma

Species Description: Cream, blue (sometimes photographing pink), or yellow *Acropora polystoma* colonies form irregular clumps or corymbose plates with tapered, uniform branches (Veron 2000, Volume 1 at 335). Radial corallites are arranged in rows along branchlet sides and range from irregularly immersed to tubular in shape, giving this species its characteristically spiny appearance. *Id.* Small axial corallites are exsert. *Id. A. polystoma* is uncommon, occurring in tropical reef-edge habitats at depths of 3-10 meters with good water circulation, including upper reef slopes exposed to strong wave action (*Id.,* IUCN Species Account).

Distribution: *A. polystoma* is found in the Red Sea and the Gulf of Aden, the Southwest and Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, the Oceanic West Pacific, Japan, Samoa and the Cook Islands (IUCN Species Account). US-affiliated waters within its range include American Samoa, Marshall Islands, Micronesia, and Palau. *Id. See* Figure 36.

Figure 36. Range map for *Acropora polystoma.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



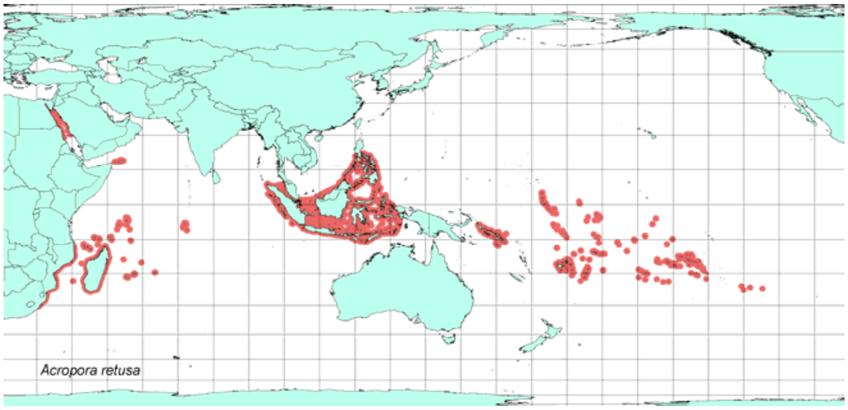
Status and Threats: *Acropora polystoma* is listed by the IUCN as vulnerable because it shows a decreasing population trend and has lost 35% of its habitat over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora retusa

Species Description: Brown *Acropora retusa* colonies have short, thick, digitate branches that form flat plates (Veron 2000, Volume 1 at 322). Corallites have wide openings and thick rounded walls; radial corallites are appressed and nariform near branch ends, whereas axial corallites are indistinct. *Id. A. retusa* is found on upper reef slopes and in tidal pools at depths of 1-5 meters (*Id.,* IUCN Species Account).

Distribution: *A. retusa* occurs in the Southwest and Northern Indian Ocean, the Central Indo-Pacific, the Solomon Islands, the Oceanic West Pacific, the Central Pacific, and the Pitcairn Islands (IUCN Species Account). It is found in American Samoa and in unspecified US minor outlying islands. *Id. See* Figure 37.

Figure 37. Range map for *Acropora retusa*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



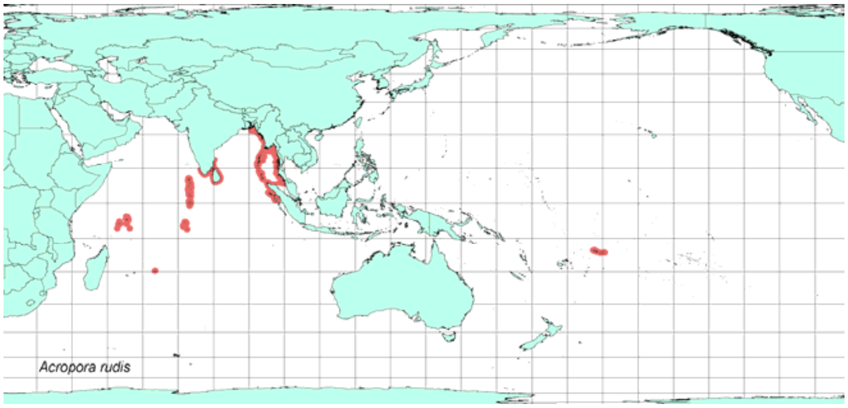
Status and Threats: *A. retusa* is listed by the IUCN as vulnerable because it shows a decreasing population trend and faces estimated habitat losses of 49% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora rudis

Species Description: Uniformly dark tan *Acropora rudis* colonies have large, tapered, prostrate branches with pale tips (Veron 2000, Volume 1 at 201). Distinctive features include dome-shaped axial corallites with small openings, mixed size radial corallites on upper branch surfaces that range from small and immersed to large (4 mm in diameter) and bead-like, and a smooth and dense coenosteum comprised of fine spinules without elaborated tips. *Id.* Veron reports the presence of this uncommon, conspicuous species on shallow to deep rocky foreshores, while the IUCN describes its habitat as shallow and fringing reef environments at depths of 3-15 meters (*Id.,* IUCN Species Account).

Distribution: *Acropora rudis* has a disjunct distribution in the Northern Indian Ocean and the Central Indo-Pacific that includes Thailand, West Indonesia, Rodrigues, the Andaman Islands, and American Samoa (IUCN Species Account). *See* Figure 38.

Figure 38. Range map for *Acropora rudis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



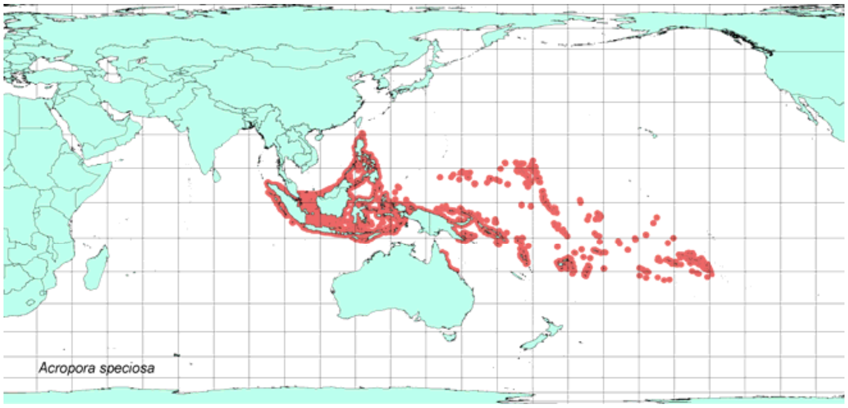
Status and Threats: *A. rudis* is listed by the IUCN as endangered because it shows a decreasing population trend and has suffered estimated habitat losses of 59% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora speciosa

Species Description: *Acropora speciosa* colonies form thick cushions and bottlebrush branches that are cream-colored with contrasting corallite tips (Veron 2000, Volume 1 at 424). Small, appressed, and tubular or pocket-like radial corallites intergrade with large, elongate, and slightly tapered axial and incipient axial corallites. *Id. A. speciosa* is found in protected reef environments with clear water and a high *Acropora* diversity; it also occurs subtidally on walls and steep slopes in deep or shaded shallow conditions (IUCN Species Account). Its typical depth range is 12-30 meters. *Id.*

Distribution: *A. speciosa* appears in US-affiliated waters including American Samoa, Marshall Islands, Micronesia, Palau, and unspecified minor US outlying islands (IUCN Species Account). The broader range of the species includes the Central Indo-Pacific, the Oceanic West Pacific, Southeast Asia, the Central Pacific, New Caledonia, Philippines, Fiji, Sarawak, Ban Ngai (Viet Nam), Papua New Guinea, and Western Samoa. *Id. See* Figure 39.

Figure 39. Range map for *Acropora speciosa.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



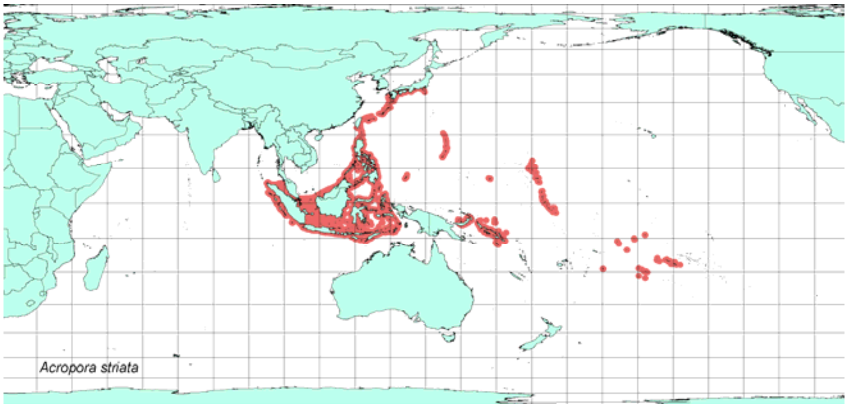
Status and Threats: *A. speciosa* is listed by the IUCN as vulnerable because it shows a decreasing population trend and has lost 35% of its habitat over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora striata

Species Description: Grayish-brown *Acropora striata* colonies form sometimes extensive stands of dense thickets of short, cylindrical branches with white tips and white branch coenosteum (Veron 2000, Volume 1 at 272). This species has irregular radial corallites, some of which are exsert with prominent lower lips. *Id.* Rare throughout its range except in Japan, *A. striata* occurs on rocky foreshores or reef flats at depths of 10-25 meters (*Id.,* IUCN Species Account).

Distribution: *Acropora striata* occurs in the Central Indo-Pacific, Japan and the East China Sea, and possibly in the Southwest Indian Ocean (IUCN Species Account). US-affiliated waters within its range include the Marshall Islands (found at 44 sites of 87 sites surveyed), Micronesia, the Northern Mariana Islands, and Palau. *Id.* It is also found in the Society Islands, Cook Islands, Kiribati, Solomon Islands, Western and Eastern Australia including the Great Barrier Reef, the South Marianas, and Pohnpei. *Id. See* Figure 40.

Figure 40. Range map for *Acropora striata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



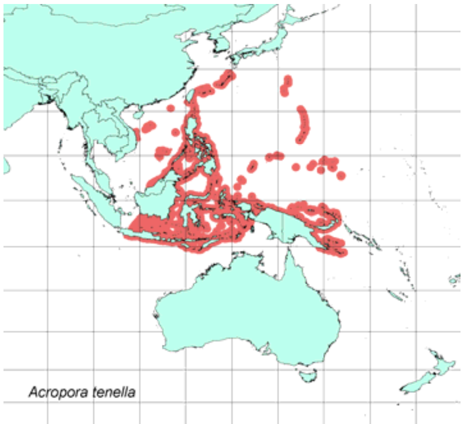
Status and Threats: *A. striata* is listed by the IUCN as vulnerable because it shows a decreasing population trend and suffered estimated habitat losses of 36% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora tenella

Species Description: Cream *Acropora tenella* colonies consist of horizontal plates of flattened, generally unfused branches with white or blue tips that either fan out or form irregular tangles (Veron 2000, Volume 1 at 285). Radial corallites, which are distinct from axial corallites, are scattered over the branch surface and occur laterally on old branches. *Id. A. tenella,* which is common in some areas, occurs on lower reef slopes below 40 meters and on subtidal, protected slopes and shelves at depths of 25-70 meters (*Id.*; IUCN Species Account).

Distribution: *Acropora tenella* is found in the Central Indo-Pacific, Southeast Asia, Japan and the East China Sea, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters within its range include Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 41.

Figure 41. Range map for *Acropora tenella.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



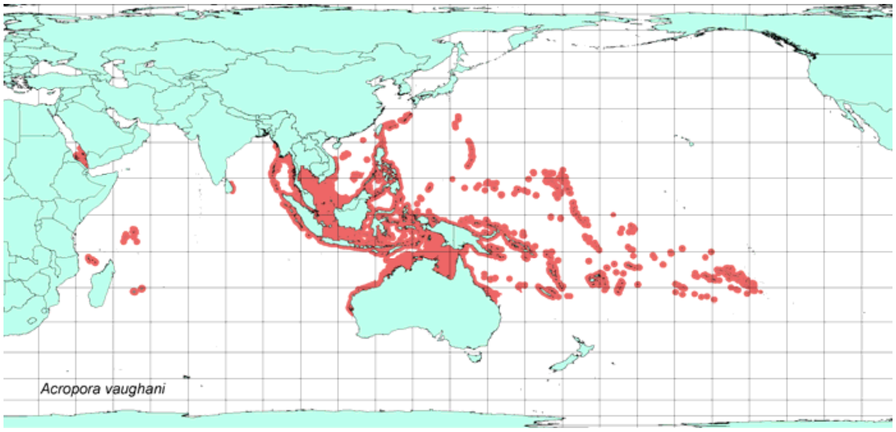
Status and Threats: *A. tenella* is listed by the IUCN as vulnerable because it shows a decreasing population trend and faces estimated habitat losses of 39% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora vaughani

Species Description: Blue, cream, or pale brown *Acropora vaughani* colonies are usually open branched, though on upper reef slopes and in open lagoons the species develops a bushy appearance due to compact branchlets protruding from the main branches (Veron 2000, Volume 1 at 268). Other distinctive features include abundant incipient axial corallites, widely spaced radial corallites that are variable in length, and a fine coenosteum that gives branches a smooth appearance. *Id. A. vaughani* is an uncommon species found in turbid water around fringing reefs at depths of 3-20 meters (*Id.,* IUCN Species Account). It is thought to be restricted to protected subtidal habitats such as contained lagoons and sandy slopes (IUCN Species Account).

Distribution: *Acropora vaughani*'s range includes the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, the Oceanic West Pacific, the Central Pacific, and Madagascar (IUCN Species Account). US-affiliated waters within this range include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 42.

Figure 42. Range map for *Acropora vaughani.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



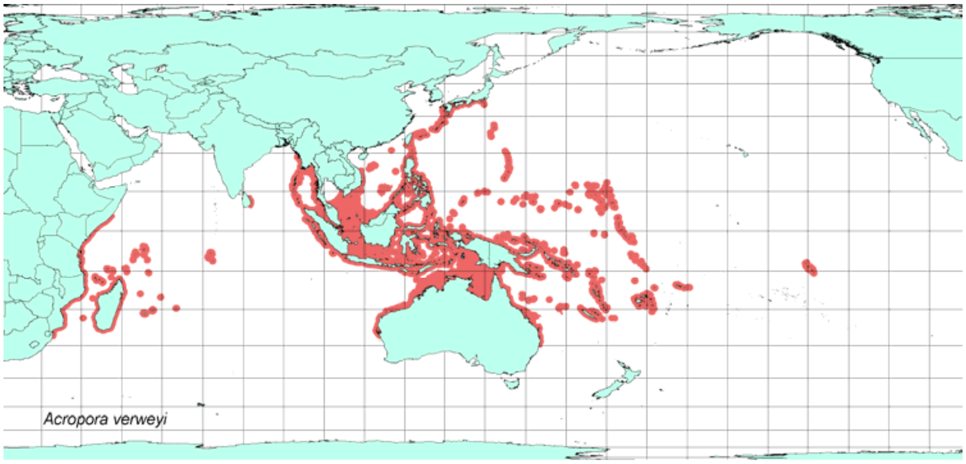
Status and Threats: *A. vaughani* is listed by the IUCN as vulnerable because it shows a decreasing population trend and has lost an estimated 35% of its habitat over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Acropora verweyi

Species Description: Creamy brown *Acropora verweyi* colonies form cushions, extensive corymbose bushes, or encrusting plates with short, untapered branches that are 7-9 millimeters thick and have short branchlets near their bases (Veron 2000, Volume 1 at 386-7). Rounded, tubular, and appressed radial corallites are arranged in rows, and yellow axial corallites are prominent. *Id.* This common species is found on upper reef slopes, especially those exposed to wave action or currents, at depths of 2-15 meters (*Id.,* IUCN Species Account). It frequently occurs amidst other Acropora species in shallow reef top and reef edge habitats (IUCN Species Account).

Distribution: *Acropora verweyi* is found in the Southwest and Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters in which it occurs include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, Palau. *A. verweyi* is also found in the Philippines, Fiji, and Rodrigues. *Id. See* Figure 43.

Figure 43. Range map for *Acropora verweyi.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



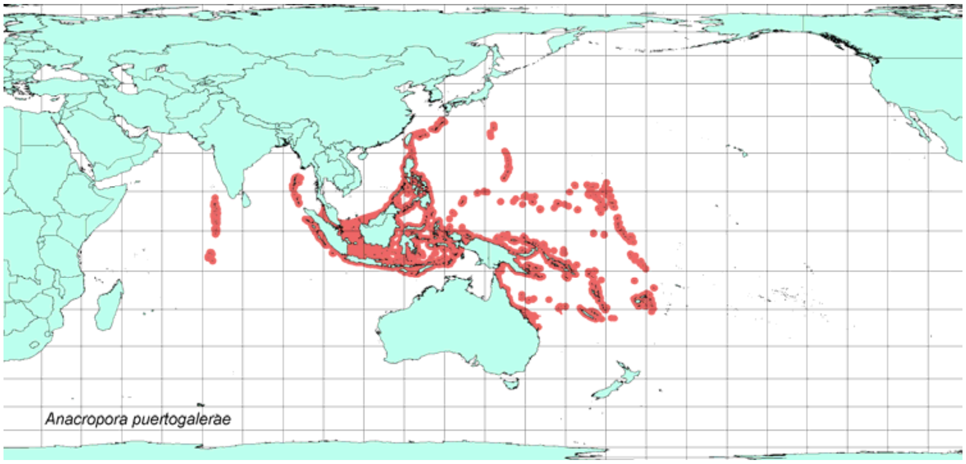
Status and Threats: *Acropora verweyi* is listed by the IUCN as vulnerable because it shows a decreasing population trend and faces estimated habitat losses of 37% over 30 years (IUCN Species Account). Like other members of its genus, this species is particularly susceptible to bleaching, disease, crown-of-thorns starfish predation, trade, and habitat degradation. *Id.* It is slow to recover from disturbance events. *Id.*

Anacropora puertogalerae

Species Description: Like other members of the *Anacropora* genus, *A. puertogalerae*'s arborescent colonies have thin, tapered branches, small and immersed radial corallites, porous corallite walls and coenosteum, widely spaced and small polyps with fine tentacles, and no axial corallites or columellae (Veron 2000, Volume 1 at 168). Septa of *Anacropora* species are in two cycles and have inward projecting teeth. *Id.* Pale brown *A. puertogalerae* branches are compact (less than 13 mm thick) and its corallites are widely spaced with thin, projecting spines underneath (Veron 2000, Volume 1 at 170). This species is uncommon and found in shallow reef environments at depths of 5-20 meters (*Id.*, IUCN Species Account).

Distribution: *Anacropora puertogalerae* is found in the Central Indo-Pacific, Japan and the East China Sea, Eastern Australia, the Oceanic West Pacific, the Philippines, Maldives, the Andaman Islands, Rodrigues, Fiji, and Vanuatu (IUCN Species Account). US-affiliated waters within its range include Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 44.

Figure 44. Range map for *Anacropora puertogalerae.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



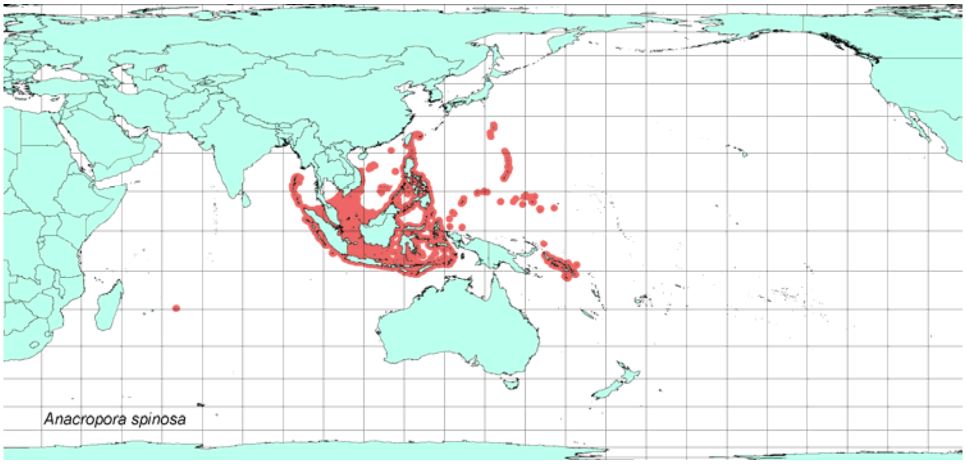
Status and Threats: Like other members of its genus, *A. puertogalerae* is susceptible to, and slow to recover from, bleaching, disease, and habitat degradation (IUCN Species Account). This very fragile and declining species suffered the loss or degradation of 38% of its habitat over 30 years due to a combination of threats. *Id.* The IUCN has classified *A. puertogalerae* as vulnerable. *Id.*

Anacropora spinosa

Species Description: *Anacropora spinosa* is similar to *A. puertogalerae,* but has thinner (less than 10 mm in diameter), twisted branches, with crowded and less tapered corallites (Veron 2000, Volume 1 at 173). Its pale brown branches are similarly compact and tapered, though sometimes white at the tips. *Id.* Features common to the genus include thin, tapered branches, small and immersed radial corallites, porous corallite walls and coenosteum, widely spaced and small polyps with fine tentacles, and no axial corallites or columellae. *Id.* at 168. *A. spinosa* is usually uncommon and occurs in shallow reef environments at depths of 5-15 meters (*Id.* at 173; IUCN Species Account). The few records of this species indicate that it is generally found in clear or slightly turbid water and on soft substrates of lower reef slopes (IUCN Species Account).

Distribution: US-affiliated waters in which this species is found include Micronesia, the Northern Mariana Islands, and Palau (IUCN Species Account). More broadly, *Anacropora spinosa* occurs in the Central Indo-Pacific, Southeast Asia, the Solomon Islands, Japan and the East China Sea, the Oceanic West Pacific, Rodrigues, and the Andaman Islands. *Id. See* Figure 45.

Figure 45. Range map for *Anacropora spinosa.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



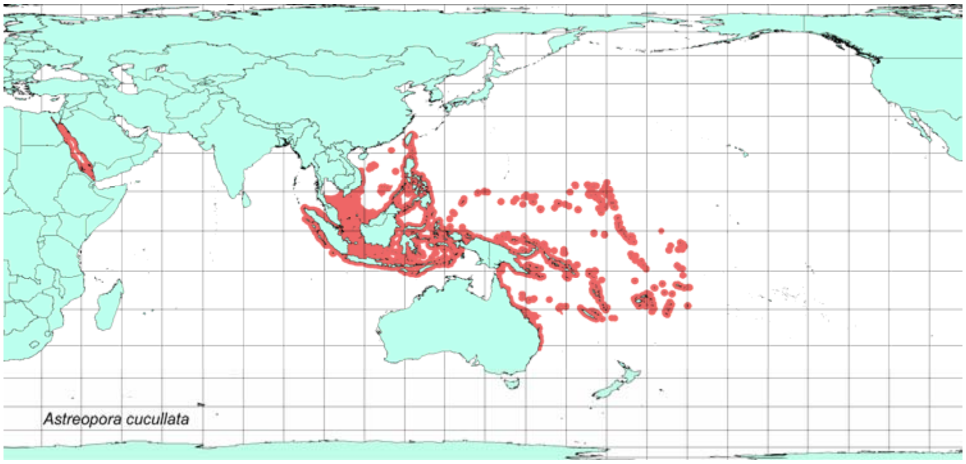
Status and Threats: Because *Anacropora spinosa* has suffered the loss or degradation of 58% of its habitat over 30 years and shows a declining population trend, it is listed as endangered by the IUCN (IUCN Species Account). Like other members of its genus, *A. spinosa* is susceptible to, and slow to recover from, bleaching, disease, and habitat degradation. *Id.*

Astreopora cucullata

Species Description: *Astreopora cucullata* colonies form cream or pale brown plates that are thick or encrusting and sometimes have short rootlets (Veron 2000, Volume 1 at 445). Corallites, which are generally inclined with elliptical openings, are immersed on concave surfaces and exsert on convex surfaces. *Id.* Feathery papillae surround *A. cucullata* corallites and may form a hood over the openings. *Id.* Species of the *Astreopora* genus have conspicuous and compact columellae, slightly porous corallite walls, and many neatly spaced septa. *Id.* at 434. Tentacles of *Astreopora* species extend only at night. *Id. A. cucullata* is a rare species found in shallow reef environments at depths of 5-15 meters. *Id.* at 445.

Distribution: *A. cucullata* is found in the Central Indo-Pacific, Southeast Asia, Eastern Australia, the Oceanic West Pacific, Fiji, and possibly the Red Sea and the Gulf of Aden (IUCN Species Account). US-affiliated waters include American Samoa, the Marshall Islands, Micronesia, Palau, and unspecified minor US outlying islands. *Id. See* Figure 46.

Figure 46. Range map for *Astreopora cucullata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: The IUCN classifies *A. cucullata* as vulnerable because it is declining in population and has lost 34% of its habitat over 30 years (IUCN Species Account). When subjected to bleaching and disease, *Astreopora* species have low tolerance, low resistance, and are slow to recover. *Id.* Fortunately, *A. cucullata* appears to be less threatened by crown-of-thorns starfish predation and harvest for the aquarium trade than other species. *Id.* The IUCN notes that only 95 specimens of this genus were exported for aquariums in 2005. *Id.*

Genus *Isopora: I. crateriformis and cuneata (formerly Acropora crateriformis and cuneata)*

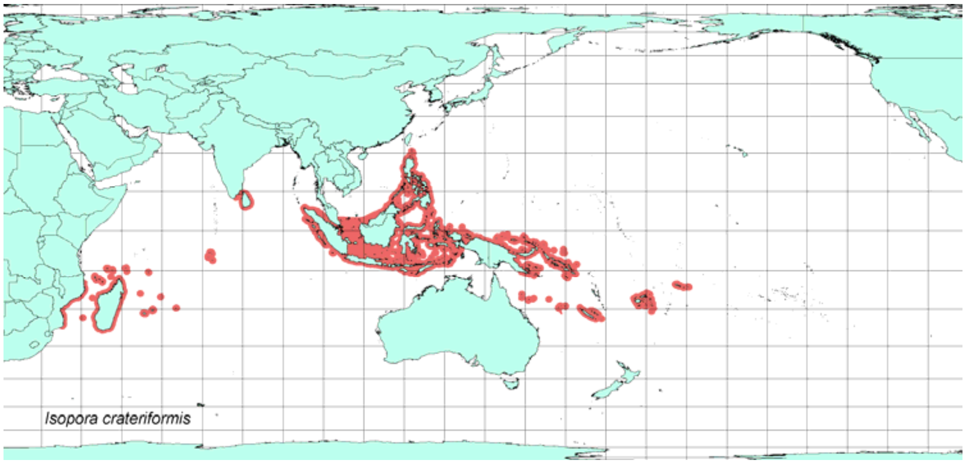
Isopora was classified as a subgenus of *Acropora* until *Isopora* was elevated from subgenus to genus by Wallace et al. (2007). While Veron (2000) refers to these species as *Acropora*, we follow the IUCN and Wallace et al. and use the new *Isopora* taxonomy. *See* IUCN Species Accounts; Wallace et al. 2007. Distinguishing features of *Isopora* species include a unique configuration of ocytes attached by a stalk to the mesenteries; and a reproductive process involving release of sperm followed by internal fertilization and larval development (all other *Acroporidae* genera have unstalked gonads and external fertilization) (Wallace et al. 2007). The *Isopora* genus is additionally structurally distinctive because the coenosteum in these species is comprised of fine spinules with elaborated tips that are not visible underwater (Veron 2000, Volume 1 at 184).

Isopora crateriformis

Species Description: *I. crateriformis* forms pale brown, solid, encrusting plates that sometimes exceed one meter in diameter and commonly have pink or blue margins (Veron 2000, Volume 1 at 190). Irregular and intergraded axial, incipient axial, and radial corallites are smooth and rounded and sometimes form short branchlets. *Id.* Like other *Isopora* species, *I. crateriformis* has a coenosteum comprised of fine spinules with elaborated tips that are not visible underwater (Veron 2000, Volume 1 at 184). This species occurs on reef flats exposed to strong wave action, subtidally on submerged reef tops, and in other shallow reef environments at depths of 1-15 meters; it is common in Indonesia. (*Id.* at 190, IUCN Species Account).

Distribution: *I. crateriformis* is found in American Samoa; its full range includes the Central Indo-Pacific, the Solomon Islands, New Caledonia, the Oceanic West Pacific, Madagascar, Ellice Islands (Tuvalu since 1978), the Coral Sea, Fiji, Australia, Western Samoa, and Indonesia (IUCN Species Account). *See* Figure 47.

Figure 47. Range map for *Isopora crateriformis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: Because *I. crateriformis* is a brooder, it has limited reproductive and dispersal capacity (IUCN Species Account). *Isopora* species are known for their low resistance to and tolerance of bleaching and disease, as well as their slow recovery from these disturbances. *Id.* Additionally, the growth form of *I. crateriformis* renders it potentially susceptible to crown-of-thorns starfish predation, which has had a devastating impact on reefs throughout the Indo-Pacific. *Id.* The IUCN classifies *I. crateriformis* as vulnerable because it shows decreasing abundance and the estimated loss or degradation of 38% of its habitat over 30 years. *Id.*

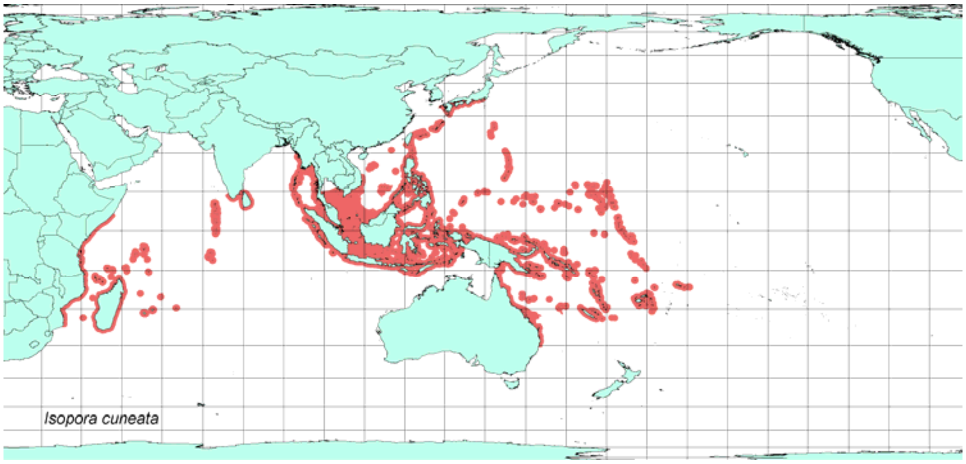
Isopora cuneata

Species Description: Pale cream or brown *I. cuneata* colonies form solid plates or short flattened branches with smooth, rounded, and not very exsert corallites (Veron 2000, Volume 1 at 184). While axial corallites are generally not present, they sometimes occur in multiples on branch margins. *Id.* This is a relatively common species that occurs in all reef environments at depths up to 15 meters, particularly on upper reef slopes and reef flats (*Id.;* IUCN Species Account). It occurs intertidally or just subtidally on reef tops, flats, and submerged reefs (IUCN Species Account).

Distribution: *Isopora cuneata* is found in several US-affiliated waters, including American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau (IUCN Species Account). The full range of the species includes the Southwest and Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, the Oceanic West Pacific, Samoa, Indonesia, the Philippines, Fiji, Madagascar, Raja Ampats

(West Paupa, Indonesia), Lord Howe, New Caledonia, and Papau New Guinea. *Id. See* Figure 48.

Figure 48. Range map for *Isopora cuneata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



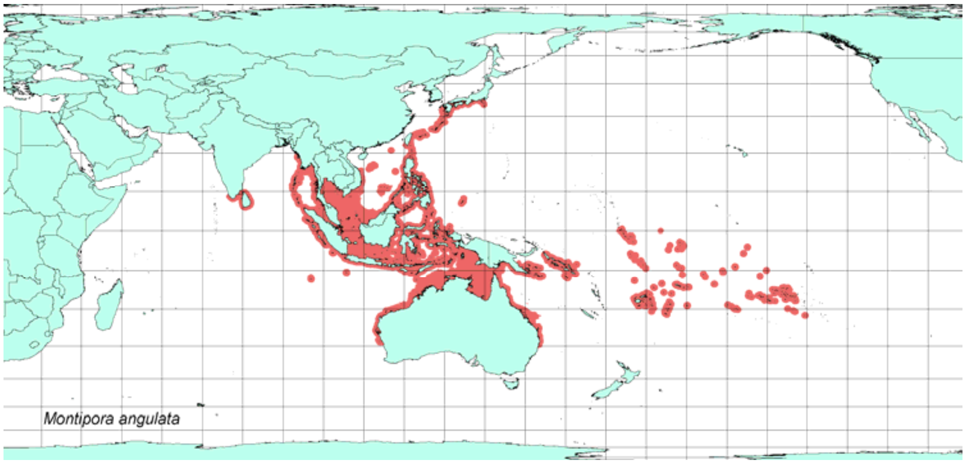
Status and Threats: *Isopora cuneata* is exceptionally susceptible to crown-of-thorns starfish predation, which is a major and increasing threat to global reef health (IUCN Species Account). It is also known to be vulnerable to, and slow to recover from, bleaching and diseases including black band disease. *Id.* As with other species in its genus, *Isopora cuneata* is limited in its capacity to recolonize an area after disturbance events or spread to new areas because it reproduces via internal fertilization and larval development. Wallace et al. 2007; *see also I. crateriformis* IUCN Species Account. The IUCN classifies *I. cuneata* as vulnerable because it has demonstrated population declines and has lost 37% of its habitat over 30 years. *Id.*

Montipora angulata

Species Description: Pale brown *Montipora angulata* colonies are comprised of extensive encrusting bases with short branches that form a compact clump (Veron 2000, Volume 1 at 127). Corallites of this species are slightly funnel-shaped and immersed in the coenosteum, which is either smooth or forms thin ridges between corallites. *Id.* The *Montipora* genus is characterized by small corallites, two cycles of septa with inward projecting teeth, porous coenosteum and corallite walls, and tentacles that extend only at night. *Id.* at 62. *M. angulata* is rare and found on fringing reef flats at depths of 1-20 meters (and possibly in deeper water as well) (*Id.* at 127; IUCN Species Account).

Distribution: US-affiliated waters within the range of *M. angulata* include American Samoa, Palau, and unspecified US minor outlying islands (IUCN Species Account). More broadly, the species is found in the Northern Indian Ocean, the Central Indo-Pacific, the Solomon Islands, East Papua New Guinea, Australia, Southeast Asia, Japan and the East China Sea, and the Oceanic West Pacific. *Id. See* Figure 49.

Figure 49. Range map for *Montipora angulata*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



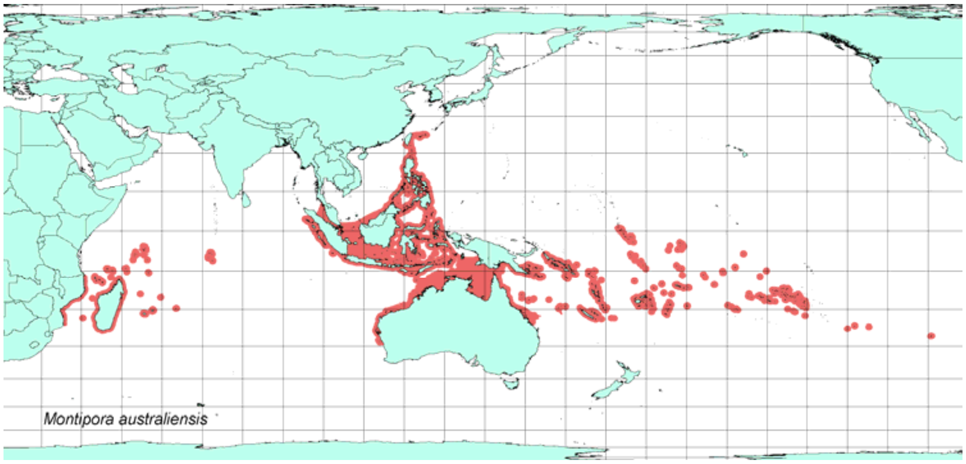
Status and Threats: *Montipora angulata* shows decreasing population trends and an estimated habitat loss of 39% over 30 years, which has led the IUCN to list this species as vulnerable. While it is known to be susceptible to the serious and increasing threats of bleaching, disease, crown-of-thorns starfish predation, and extensive habitat degradation, the widespread distribution and depth range of *M. angulata* could offer it some level of increased resilience on the population level. *Id.*

Montipora australiensis

Species Description: Pale brown *Montipora australiensis* colonies are thick plates with irregular column-like branches (Veron 2000, Volume 1 at 152). Exsert corallites have a prominent ring of fused thecal papillae, whereas other corallites are immersed. *Id.* Coenosteum are finely ridged, mostly vertical on branches, and form a network with corallites. *Id.* Like other members of the *Montipora* genus, *M. australiensis* has small corallites, two cycles of septa with inward projecting teeth, porous coenosteum and corallite walls, and tentacles that extend only at night. *Id.* at 62. This is a rare species that is found in shallow reef environments with strong wave action. *Id.* at 152. It occurs at depths of 2-30 meters, and possibly in deeper water as well (IUCN Species Account).

Distribution: *Montipora australiensis* is widespread in the Indo-West Pacific, including the Southwest and Northern Indian Ocean, the Central Indo-Pacific, Australia, Japan and the East China Sea, the Oceanic West Pacific, and the Solomon Islands (IUCN Species Account). It occurs in American Samoa. *Id. See* Figure 50.

Figure 50. Range map for *Montipora australiensis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



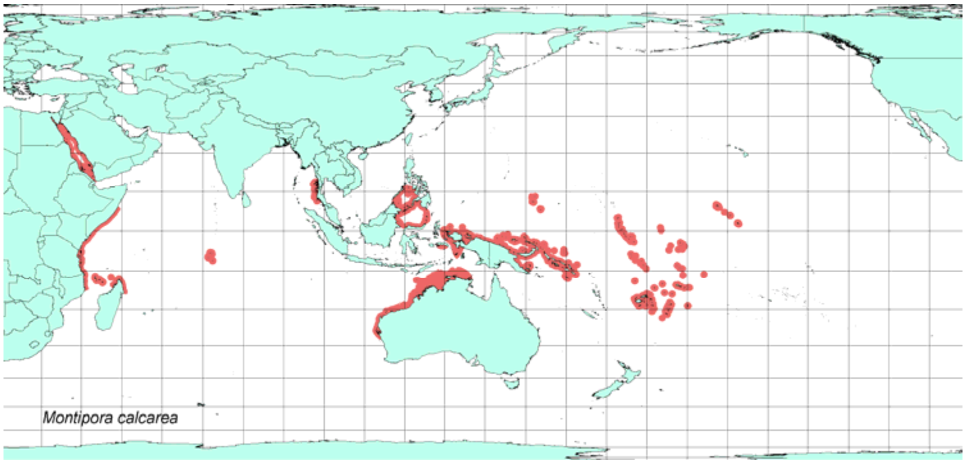
Status and Threats: *M. australiensis* is naturally rare throughout its range, shows decreasing population trends, and has suffered the loss or degradation of 37% of its habitat over 30 years (IUCN Species Account). It is susceptible to bleaching, disease, and crown-of-thorns starfish predation in addition to habitat degradation. *Id.* Species of this genus are also vulnerable to heavy harvest levels, with a 2006 Indonesian export quota of 19,200 *Montipora* specimens. The IUCN classifies this species as vulnerable. *Id.*

Montipora calcarea

Species Description: Pale brown or blue *Montipora calcarea* colonies form irregular, thick plates with columnar upgrowths (Veron 2000, Volume 1 at 116). Other distinctive features include crowded, immersed, and small corallites, with those on upgrowths having slight lower lips; and a coarse, lightly textured, and porous coenosteum. *Id.* This species has no exsert papillae. *Id.* at 114. *M. calcarea* is rare and found in shallow reef environments, including reef crests, outer reef flats, and upper slopes, at depths of up to 20 meters (possibly deeper). *Id.* at 116, IUCN Species Account.

Distribution: US-affiliated waters include American Samoa, Micronesia, and unspecified US minor outlying islands (IUCN Species Account). More broadly, *M. calcarea* occurs in Eastern Africa, Northern Madagascar, the Red Sea, Chagos Archipelago, Thailand, Philippines, Australia, Papua New Guinea, and the Central Pacific. *Id. See* Figure 51.

Figure 51. Range map for *Montipora calcarea.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



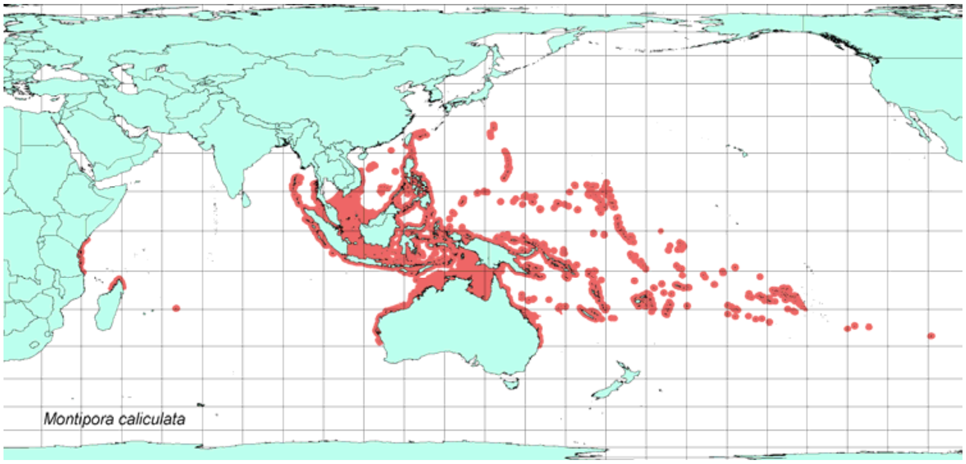
Status and Threats: *M. calcarea* shows decreasing population trends and has lost 34% of its habitat over 30 years (IUCN Species Account). While generally uncommon, it is locally abundant in some areas. It is susceptible to bleaching, disease, and crown-of-thorns starfish predation in addition to habitat degradation. *Id.* Species of this genus are also vulnerable to heavy harvest levels, with a 2006 Indonesian export quota of 19,200 *Montipora* specimens. The IUCN classifies this species as vulnerable. *Id.*

Montipora caliculata

Species Description: Massive brown or blue *Montipora caliculata* colonies have a mixture of immersed and funnel-shaped corallites; the latter generally have wavy rims (Veron 2000, Volume 1 at 128). Adjacent corallites form short valleys, and existing corallite walls are sometimes tuberculae-like. *Id. M. australiensis* shares the characteristic features of the *Montipora* genus, including small corallites, two cycles of septa with inward projecting teeth, porous coenosteum and corallite walls, and tentacles that extend only at night. *Id.* at 62. Though uncommon, *M. australiensis* is found in most reef environments within its range and at depths of up to 20 meters or more. *Id.* at 128.

Distribution: In addition to the US-affiliated waters of Palau, the Northern Mariana Islands, Micronesia, and the Marshall Islands, *Montipora caliculata* is found in Kenya, Tanzania, Northern Madagascar, the Andaman Islands, Thailand, Southeast Asia, South China Sea, Southern Japan, Papua New Guinea, Australia, the Solomon Islands, Vanuatu, New Caledonia, Ogasawara Island (Japan), Samoa, Fiji, the Cook Islands, Kiribati, French Polynesia, and the Pitcairn Islands (IUCN Species Account). *See* Figure 52.

Figure 52. Range map for *Montipora caliculata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



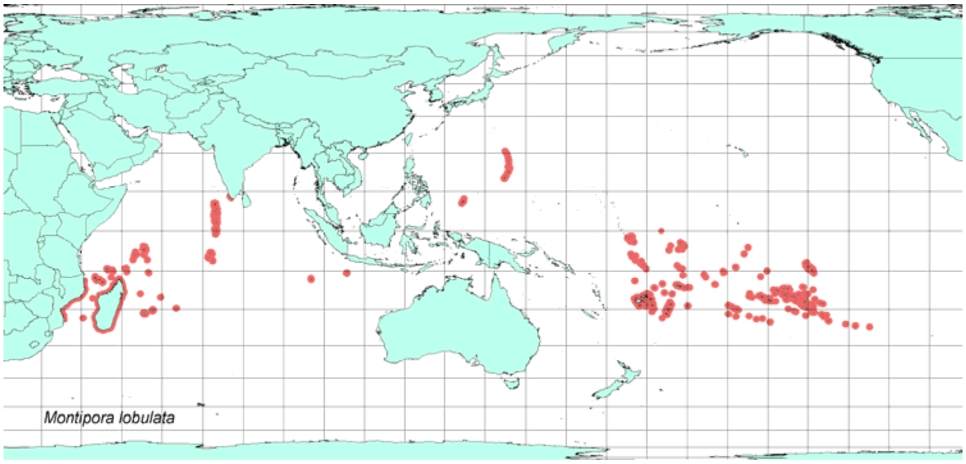
Status and Threats: *M. caliculata* is uncommon throughout its broad range (IUCN Species Account). It shows decreasing population trends and has suffered the loss or degradation of 36% of its habitat over 30 years (IUCN Species Account). *M. caliculata* is susceptible to bleaching, disease, and crown-of-thorns starfish predation in addition to habitat degradation. *Id.* Species of this genus are also vulnerable to heavy harvest levels, with a 2006 Indonesian export quota of 19,200 *Montipora* specimens. The IUCN classifies *M. caliculata* as vulnerable. *Id.*

Montipora lobulata

Species Description: Mottled brown and white submassive *Montipora lobulata* colonies are comprised of irregular mounds covered by irregular tuberculae with complete continuity in size between mounds and tuberculae (Veron 2000, Volume 1 at 95). Irregularly distributed corallites are less common in tuberculae, and the coenstenum is irregularly coarse. *Id.* Like other species in *Montipora* Group 4, *M. lobulata* has prominent thecal papillae. *Id.* at 94. It likewise demonstrates the characteristic features of the genus, including small corallites, two cycles of septa with inward projecting teeth, porous coenosteum and corallite walls, and tentacles that extend only at night. *Id.* at 62. *Montipora lobulata* is a rare species found in shallow reef environments at depths of up to 20 meters (possibly deeper) (*Id.* at 95; IUCN Species Account).

Distribution: *M. lobulata* occurs in US-affiliated waters, including American Samoa, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands (IUCN Species Account). More broadly, the species has a disjunct distribution in the Indo-West Pacific and is found in the Southwest and Northwest Indian Ocean, the Oceanic West Pacific, and the Central Pacific. *See* Figure 53.

Figure 53. Range map for *Montipora lobulata*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: The IUCN has listed *Montipora lobulata* as vulnerable because its population is decreasing and it has lost an estimated 35% of its habitat over 30 years (IUCN Species Account). This species is rare throughout its range and is particularly susceptible to bleaching, disease, and crown-of-thorns starfish predation in addition to habitat degradation. *Id.*

2. FAMILY: AGARICIDAE

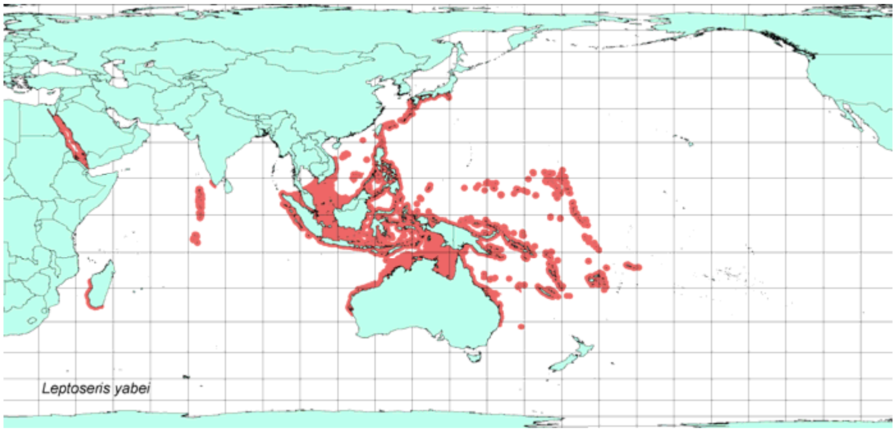
All species in the Agaricidae family are colonial, and all extant species are zooxanthellate (Veron 2000, Volume 2 at 169). Immersed corallites have poorly defined walls of thickened septo-costae. *Id.* Loosely packed septa have smooth or finely serrated margins, are continuous between adjacent corallite centers, and seldom fuse. *Id.* There are six extant genera: *Leptoseris* occurs in both the Western Atlantic and the Indo-Pacific, *Agaricia* is restricted to the Western Atlantic, and the other four genera (*Pavona*, *Gardineroseris*, *Pachyseris*, and *Coeloseris*) are restricted to the Indo-Pacific. *Id.*

Leptoseris yabei

Species Description: *Leptoseris yabei* colonies are laminar, either vase-shaped or forming whorls or tiers, and frequently larger than one meter in diameter (Veron 2000, Volume 2 at 220). They are generally pale brown or yellowish in color, sometimes with white margins. *Id. L. yabei* has unique rectangular pockets that form between radiating ridges and low walls (parallel to frond margins) and enclose the corallites. *Id.* Septo-costae alternate and are moderately exsert. *Id. L. yabei* is an uncommon and conspicuous species that is usually found on flat substrates (*id.)* or lower slopes at depths of 6-20 meters (IUCN Species Account).

Distribution: *L. yabei* is found in the Red Sea, the Southwest and Central Indian Ocean, the Central Indo-Pacific, tropical Australia, Southern Japan and the South China Sea, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters include American Samoa, the Marshall Islands, Micronesia, and Palau. *Id. See* Figure 54.

Figure 54. Range Map for *Leptoseris yabei*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



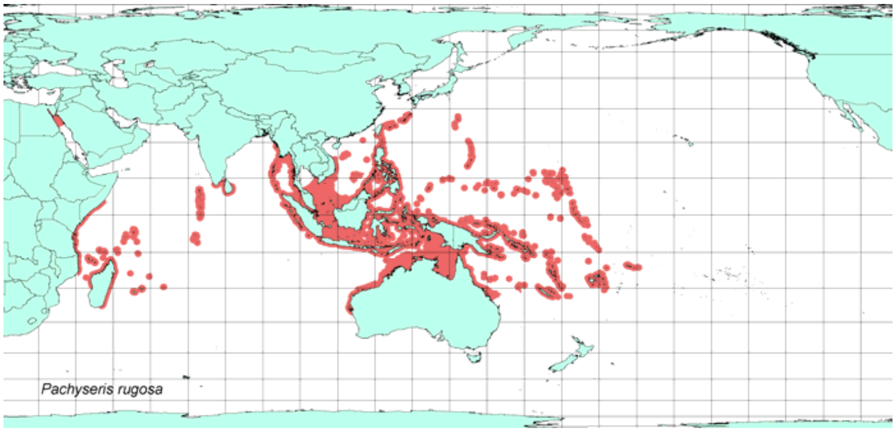
Status and Threats: Though its population trends are unknown, *L. yabei* is susceptible to bleaching and disease and is facing the estimated loss or degradation of 36% of its habitat over 30 years (IUCN Species Account). These risks make it more likely to be lost entirely from critically degraded reefs within one future generation. *Id. L. yabei* is listed by the IUCN as vulnerable. *Id.*

Pachyseris rugosa

Species Description: Consistent with its genus, *Pachyseris rugosa* is usually contorted in appearance and has columellae that form wall-like lobes (Veron 2000, Volume 2 at 226). Its colonies are deep bluish gray or brown and comprised of upright, irregular, bifacial plates that are frequently over one meter in diameter. *Id.* Shallow water habitats sometimes support large, mound-shape colonies of *P. rugosa*, but smaller colonies are found in a wide range of depths and habitats, including those exposed to strong wave action. *Id. P. rugosa* forms large fields and can be found at depths of 5-20 meters (IUCN Species Account). It is commonly found from 9-20 meters in the South China Sea and Gulf of Siam. *Id.*

Distribution: US-affiliated waters in which *P. rugosa* is found include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau (IUCN Species Account). The broader Indo-West Pacific range of this species includes the Red Sea, the Southwest and Central Indian Ocean, the Central Indo-Pacific, Australia, Southern Japan and the South China Sea, and the Oceanic West Pacific. *Id. See* Figure 55**.**

Figure 55. Range map for *Pachyseris rugosa*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



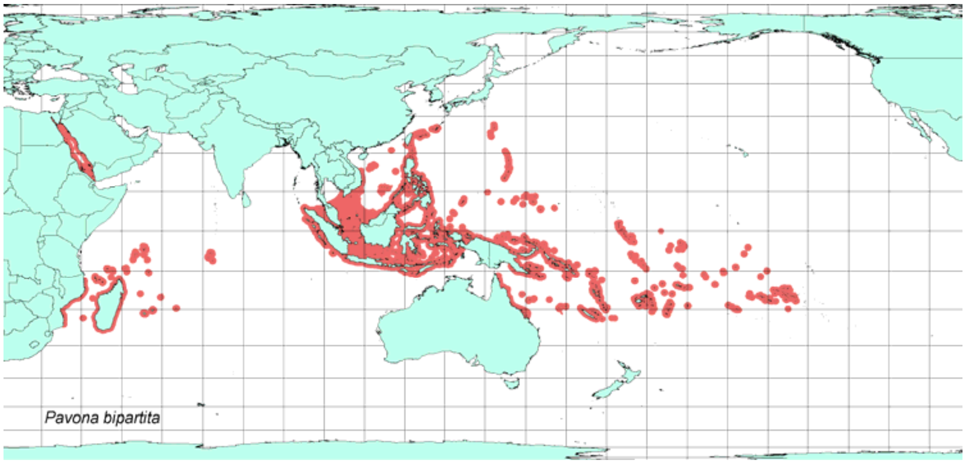
Status and Threats: *P. rugosa* has demonstrated high susceptibility to and mortality from bleaching events (IUCN Species Account). It is heavily harvested for the aquarium trade, with 2,351 specimens exported in 2005, and it has already suffered extensive habitat reduction. *Id.* These vulnerabilities increase the risk that the species could be lost entirely from critically degraded reefs within one generation. *Id.* The IUCN estimates that *P. rugosa* faces the loss or degradation of 36% of its habitat over 30 years and lists the species as vulnerable. *Id.*

Pavona bipartita

Species Description: Uniformly pale to dark brown *Pavona bipartita* colonies are submassive or encrusting and can exceed one meter in diameter (Veron 2000, Volume 2 at 197). Species in the family *Pavona* have corallites in small, shallow depressions with poorly defined walls that are separated by exsert septo-costae. *Id.* at 178. In *P. bartita,* uniformly distributed corallites are separated by characteristically uneven ridges that are sometimes several centimeters long. *Id.* at 197. There are two slightly alternating orders of septo-costae. *Id. P. bipartita* is an uncommon species that is found in shallow reef environments at depths of 3-20 meters, including reef slopes and vertical walls (*Id.*, IUCN Species Account).

Distribution: *P. bipartita* is found in the Red Sea, the Southwest and Central Indian Ocean, the Central Indo-Pacific, Southern Japan and the South China Sea, the Oceanic West Pacific, the Central Pacific, and the Great Barrier Reef (IUCN Species Account). US-affiliated waters within its range include American Samoa, Micronesia, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 56**.**

Figure 56. Range map for *Pavona bipartita.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



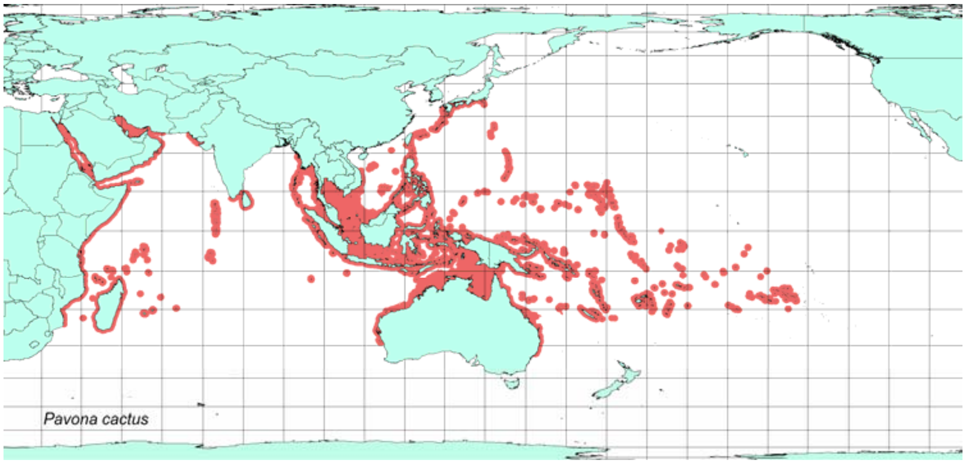
Status and Threats: Population trends for this uncommon species are unknown, but it is susceptible to bleaching and is projected to lose 34% of its habitat over 30 years (IUCN Species Account). The IUCN has determined that *P. bipartita* faces an increased likelihood of being entirely lost from critically degraded reefs within one generation and has listed this species as vulnerable. *Id.*

Pavona cactus

Species Description: Pale brown or greenish-brown *Pavona cactus* colonies form thin, contorted, bifacial, upright fronds with white margins and sometimes thickened branching bases (Veron 2000, Volume 2 at 180). Colonies can exceed 10 meters in diameter (IUCN Species Account). Species in the family *Pavona* have corallites in small, shallow depressions with poorly defined walls that are separated by exsert septo-costae (Veron 2000, Volume 2 at 178). Fine, shallow *P. Cactus* corallites are aligned in irregular rows parallel to the frond margins (Veron 2000, Volume 2 at 180). *P. cactus* is usually found in lagoons and on upper reef slopes, especially those of fringing reefs, and in turbid water protected from wave action (IUCN Species Account). This species may be found at depths of 3-20 meters, though more commonly at depths of 3-11 meters. *Id.*

Distribution: US-affiliated waters within the range of *P. cactus* include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands (IUCN Species Account). More broadly, the species can be found in the Red Sea and the Gulf of Aden, the Persian and Arabian Gulfs, the Southwest and Central Indian Ocean, the Central Indo-Pacific, Australia, Southern Japan and the South China Sea, the Oceanic West Pacific, and the Central Pacific. *Id. See* Figure 57.

Figure 57. Range map for *Pavona cactus.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



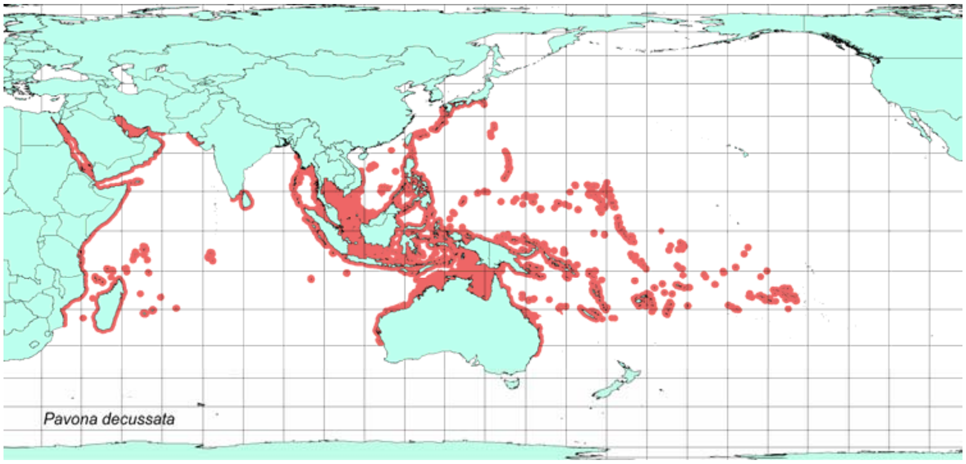
Status and Threats: *Pavona cactus* is listed by the IUCN as vulnerable (IUCN Species Account). It is susceptible to bleaching and extensive reduction of reef habitat (estimated 36% habitat loss or degradation over 30 years). *Id.* It is also targeted for the aquarium trade, with 1,362 specimens exported in 2005. *Id.* These threats increase the risk that *P. cactus* will be eliminated entirely from critically degraded reefs within a single generation. *Id.*

Pavona decussata

Species Description: Brown, creamy yellow, or greenish *Pavona decussata* colonies are variable in growth form, manifesting either as thick, interconnecting, bifacial upright plates or as submassive, in which case they may or may not have lobed horizontal margins and upright plates (Veron 2000, Volume 2 at 198). Colonies sometimes form fields that are several meters across (IUCN Species Account). Species in the family *Pavona* have corallites in small, shallow depressions with poorly defined walls that are separated by exsert septo-costae (Veron 2000, Volume 2 at 178). *P. decussata* corallites are irregular, deep-seated, and are sometimes aligned parallel to margins or radiating ridges. *Id.* at 194. *P. descussata* is found in most reef environments, commonly at depths of 3-11 meters and more rarely at depths of 12-15 meters (IUCN Species Account).

Distribution: *P. decussata's* Indo-West Pacific range includes the Red Sea and the Gulf of Aden, the Southwest and Central Indian Ocean, the Arabian/Iranian Gulf, the Central Indo-Pacific, Tropical Australia, Southern Japan and the South China Sea, the Oceanic West Pacific, and the Central Pacific (IUCN Species Account). US-affiliated waters within this range include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 58.

Figure 58. Range map for *Pavona decussata*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



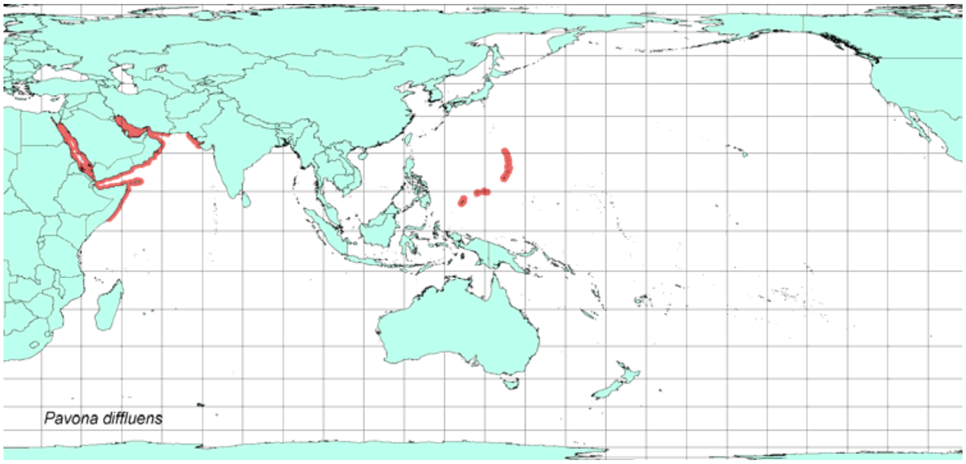
Status and Threats: While its current population trends are unknown, population reduction is inferred for *Pavona decussata* because it is projected to lose 36% of its habitat over 30 years (IUCN Species Account). This species is also susceptible to bleaching. *Id.* The IUCN is concerned that *P. decussata* could be entirely lost from critically degraded reefs within one generation and has listed this species as vulnerable. *Id.*

Pavona diffluens

Species Description: Tan *Pavona diffluens* colonies are submassive and irregular, often with a rough surface appearance (Veron 2000, Volume 2 at 188). Species in the family *Pavona* have corallites in small, shallow depressions with poorly defined walls that are separated by exsert septo-costae. *Id.* at 178. *P. diffluens* corallites are relatively deep, with characteristically exsert septo-costae that strongly alternate with primary septa. *Id.* at 188. Columellae, when present, are peg-like. *Id.* Though uncommon, *P. diffluens* is found in a wide variety of reef environments at depths of 5-20 meters (IUCN Species Account).

Distribution: *P. diffluens* is found in the Red Sea and the Gulf of Aden, the Northwest Indian Ocean and the Arabian/Iranian Gulf (IUCN Species Account). US-affiliated waters in which *P. diffluens* has been documented include Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 59.

Figure 59. Range map for *Pavona diffluens*.
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



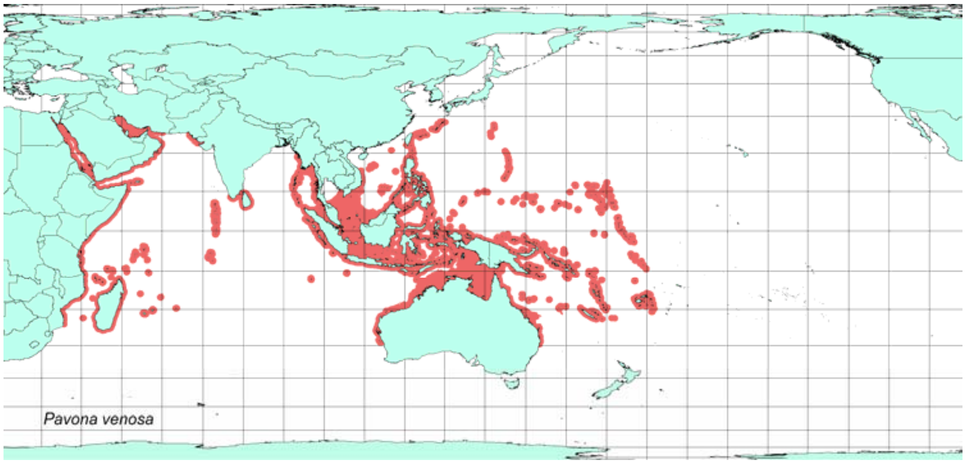
Status and Threats: The IUCN lists *P. diffluens* as vulnerable because it is projected to lose 36% of its habitat over 30 years and is also susceptible to bleaching (IUCN Species Account). This threat susceptibility increases the likelihood that *P. diffluens* could be entirely lost from critically degraded reefs within one generation. *Id. P. diffluens* is uncommon throughout its range, and the current population trend is unknown. *Id.*

Pavona venosa

Species Description: Massive to encrusting *Pavona venosa* colonies are yellow- or pinkish-brown, sometimes mottled, and generally less than 50 cm in diameter (Veron 2000, Volume 2 at 190; IUCN Species Account). Species in the family *Pavona* tend to have sunken corallites with poorly defined walls that are separated by exsert septo-costae (Veron 2000, Volume 2 at 178). In *P. venosa*, corallites are arranged in short valleys with acute walls, three orders of septo-costae are widely spaced, and columellae are poorly developed or absent. *Id.* at 190. This uncommon and distinctive species occurs in shallow reef environments at depths of 2-20 meters (IUCN Species Account).

Distribution: *Pavona venosa* is an Indo-West Pacific species that is found in the Red Sea and the Gulf of Aden, the Southwest and Northwest Indian Ocean, the Arabian/Iranian Gulf, the Central Indian Ocean, the Central Indo-Pacific, Tropical Australia, Southern Japan and the South China Sea, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters in which *P. venosa* occurs include the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 60.

Figure 60. Range map for *Pavona venosa.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: While *Pavona venosa* is thought to be common throughout its widespread range, its current population trend is unknown and it is susceptible to bleaching and disease as well as extensive habitat reduction (IUCN Species Account). The IUCN estimates that it is projected to lose 37% of its habitat over 30 years and notes that the threat susceptibility of *P. venosa* increases its likelihood of being completely lost from critically degraded reefs within one generation. *Id.* Because of these concerns, *P. venosa* is listed as vulnerable. *Id.*

3. FAMILY: DENDROPHYLLIIDAE

Dendrophylliidae corals are mostly azooxanthellate and are the most common azooxanthellate species found on reefs and in other shallow water habitats (Veron 2000, Volume 2 at 385). Species in the Dendrophylliidae family can be solitary or colonial. *Id.* Corallites have porous walls that are usually composed of coenosteum and septa that are fused in a distinctive "Pourtales plan" pattern (at least in immature corallites).

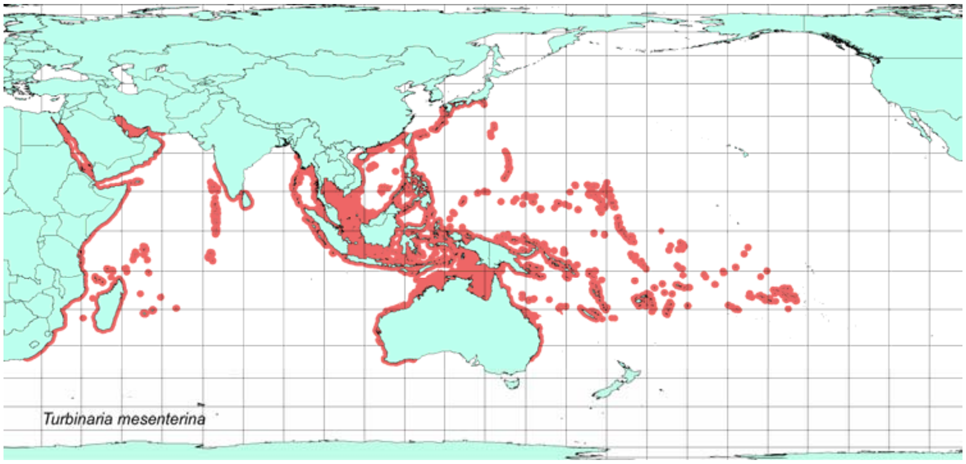
Turbinaria is one of only four zooxanthellate genera within the Dendrophylliidae family (Veron 2000, Volume 2 at 385). Species in this genus form large colonies that are usually laminar, but sometimes submassive or columnar. *Id.; id.* at 388. Immersed to tubular corallites are round, with porous walls that have the same structure as the surrounding coenosteum. *Id.* at 388. Septa of *Turbinaria* species are short and neat, while columellae are broad and compact. *Id.*

Turbinaria mesenterina

Species Description: Usually gray-green or gray-brown *Turbinaria mesenterina* colonies form highly contorted, unifacial laminae with a variable growth form based on light availability: fused in subtidal habitats, tiered when on upper reef slopes, and horizontal in deeper water (Veron 2000, Volume 2 at 394). While the colonies are generally less than one meter in diameter, they can be much larger on fringing reefs. *Id. T. mesenterina* corallites are crowded, slightly exsert, and average 2.5 mm in diameter. *Id. T. meserina* is common in shallow turbid environments at depths of up to 20 meters (IUCN Species Account).

Distribution: *Turbinaria mesenterina* is found in the Red Sea and the Gulf of Aden, the Southwest and Northwest Indian Ocean, the Arabian/Iranian Gulf, the Central Indian Ocean, the Central Indo-Pacific, Australia, Southern Japan and the South China Sea, the Oceanic West Pacific, and the Central Pacific (IUCN Species Account). US-affiliated waters within its Indo-West Pacific range include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 61.

Figure 61. Range map for *Turbinaria mesenterina.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



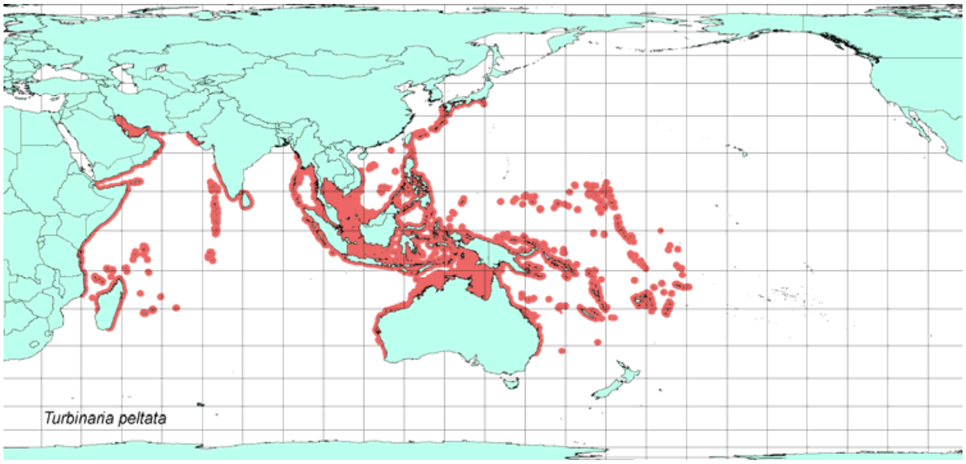
Status and Threats: *Turbinaria mesenterina* is a major target of the aquarium trade, with 17,739 specimens exported in 2005 (IUCN Species Account). It has also already suffered extensive habitat reduction. *Id.* These threats combine to increase the likelihood that *T. mesenterina* could be entirely lost from critically degraded reefs within one generation. *Id.* The IUCN estimates that *T. mesenterina* is projected to lose 36% of its habitat over 30 years and has listed this species as vulnerable. *Id.*

Turbinaria peltata

Species Description: Generally gray or brown *Turbinaria peltata* colonies form flat laminae, often in overlapping tiers, which can be several meters in diameter (Veron 2000, Volume 2 at 390). Colony surfaces appear furry when large polyp tentacles extend during the day. *Id.* Corallites, which average 6 mm, are immersed to tubular. *Id. T. peltata* is found on shallow, sandy reef flats and on deep, sandy reef bases in a depth range of 0.5-25 meters (IUCN Species Account).

Distribution: US-affiliated waters in which *Turbinaria peltata* is found include American Samoa, the Marshall Islands, Micronesia, Palau, and unspecified US minor outlying islands (IUCN Species Account). More broadly, its Indo-West Pacific range includes the Red Sea and the Gulf of Aden, the Southwest and Northwest Indian Ocean, the Arabian/Iranian Gulf, the Central Indian Ocean, the Central Indo-Pacific, Australia, Southern Japan and the South China Sea, and the Oceanic West Pacific. *Id. See* Figure 62.

Figure 62. Range map for *Turbinaria peltata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



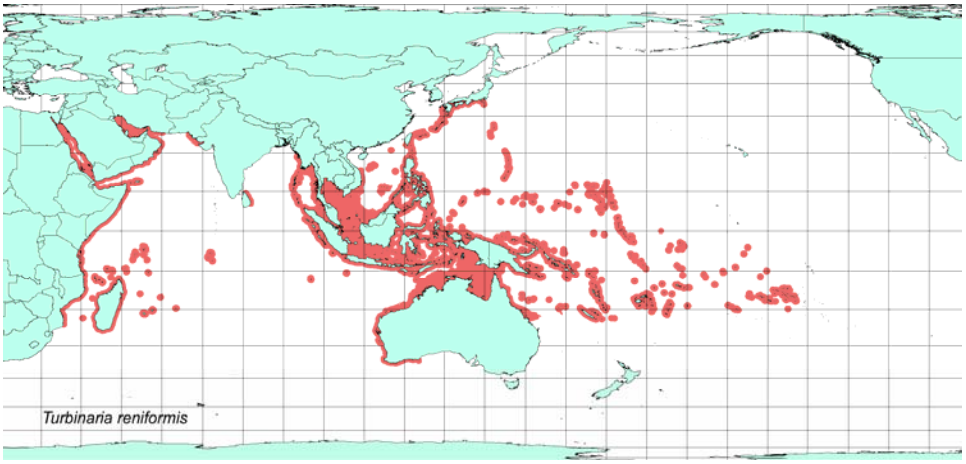
Status and Threats: *T. peltata* faces the same threats as its sibling species, *T. mesenterina. T. peltata* is a major target of the aquarium trade, with 17,191 specimens exported in 2005 (IUCN Species Account). It has also already suffered extensive habitat reduction. *Id.* These threats combine to increase the likelihood that *T. peltata* could be entirely lost from critically degraded reefs within one generation. *Id.* The IUCN estimates that *T. peltata* is projected to lose 36% of its habitat over 30 years and has listed this species as vulnerable. *Id.*

Turbinaria reniformis

Species Description: *Turbinaria reniformis* colonies are usually yellow-green in color with contrasting colored margins (Veron 2000, Volume 2 at 396). Unifacial laminae sometimes form tiers, which are mostly horizontal. *Id. T. reniformis* can form large stands on fringing reefs if water is turbid. *Id.* Corallites, which average 2.5 mm in diameter, are widely spaced, thick-walled, and immersed to conical in shape. *Id. T. reniformis* is an uncommon species found at a depth range of 2-15 meters.

Distribution: *T. reniformis* occurs in the Red Sea and the Gulf of Aden, the Southwest and Northwest Indian Ocean, the Arabian/Iranian Gulf, the Central Indian Ocean, the Central Indo-Pacific, Tropical and Sub-tropical Australia, Southern Japan and the South China Sea, the Oceanic West Pacific, and the Central Pacific (IUCN Species Account). US-affiliated waters within this Indo-West Pacific range include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 63.

Figure 63. Range map for *Turbinaria reniformis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



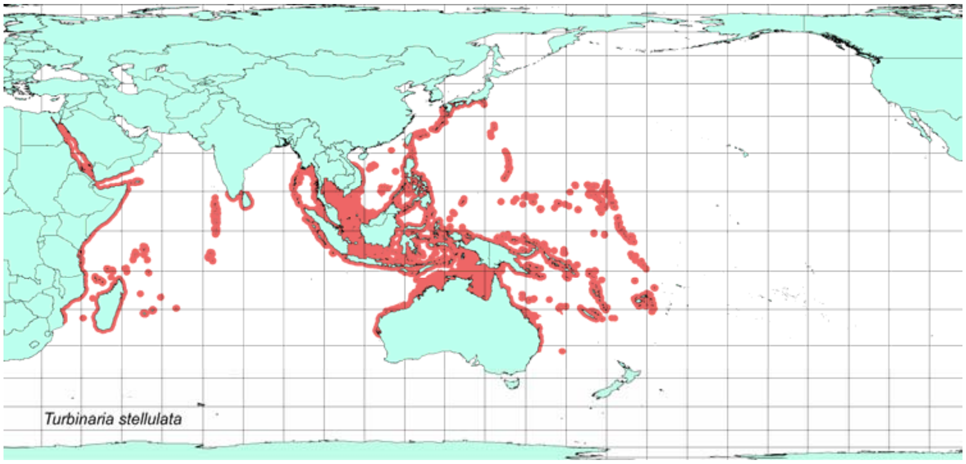
Status and Threats: *T. reniformis* is much less heavily harvested for the aquarium trade than its sibling species, *T. mesenterina* and *T. peltata,* but its restricted depth range makes it more susceptible to bleaching and disease (IUCN Species Account). It is also at risk due to extensive habitat reduction, with an estimated 36% habitat degradation over 30 years. *Id.* Current population trends are unknown, but its threat susceptibility renders *T. reniformis* more likely to be entirely lost from critically degraded reefs within one generation. *Id.* The IUCN has listed *T. reniformis* as vulnerable. *Id.*

Turbinaria stellulata

Species Description: While *Turbinaria stellulata* colonies are primarily encrusting, they are sometimes dome-shaped on upper reef slopes (Veron 2000, Volume 2 at 400). Colonies are typically less than 50 cm in diameter and occur in a wide range of colors but are most frequently brown or green, with thick corallite walls that are usually lighter in color than the coenosteum (*Id.,* IUCN Species Account). Corallites average 2.5 mm in diameter and are conical in shape. *Id.* Unlike other *Turbinaria* species, *T. stellulata* is seldom found in turbid waters. *Id.* Its depth range is 2-15 meters. *Id.*

Distribution: *Turbinaria stellulata* occurs in American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau (IUCN Species Account). Its full Indo-West Pacific range includes the Red Sea and the Gulf of Aden, the Southwest and Central Indian Ocean, the Central Indo-Pacific, Tropical Australia, Southern Japan and the South China Sea, and the Oceanic West Pacific. *Id. See* Figure 64.

Figure 64. Range map for *Turbinaria stellulata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: While current population trends are unknown, *T. stellulata* is uncommon and restricted in its depth range, which makes it more susceptible to bleaching and disease (IUCN Species Account). It is also at risk of significant habitat reduction, having lost 36% of its habitat over 30 years. *Id.* This combination of threats increases the likelihood that *T. stellulata* will be entirely lost from critically degraded reefs within one generation and meets IUCN criteria for vulnerable status. *Id.*

4. FAMILY: EUPHYLLIDAE

Veron describes species of the Euphyllidae family as "among the most beautiful of all corals" (Veron 2000, Volume 2 at 67). Euphyllidae contains five colonial, zooxanthellate, Indo-Pacific genera. Phaceloid, meandroid, or flabello-meandroid colonies have large, solid, and widely spaced septo-costae with little or no ornamentation. *Id.*

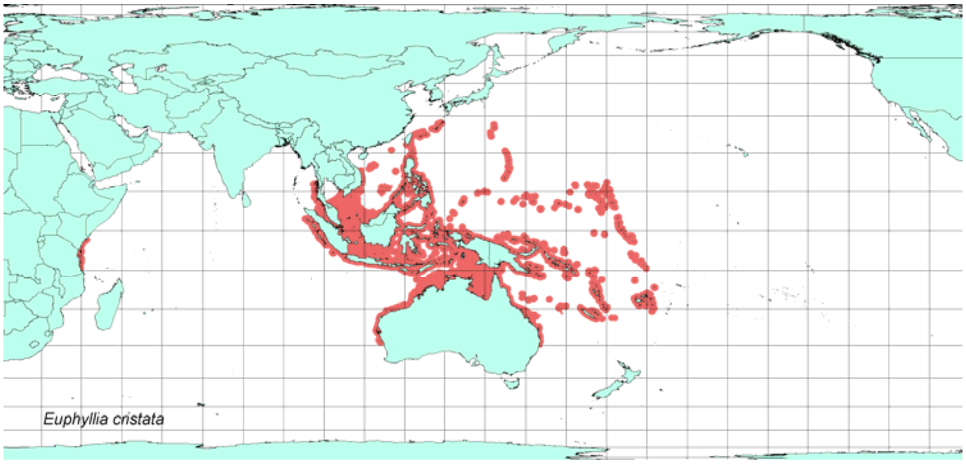
The *Euphyllia* genus is characterized by thin and solid walls; exsert, smooth-edged, and solid septa; and large, fleshy tentacles that are variable in shape and extended day and night (Veron 2000, Volume 2 at 68). *Euphyllia* species generally lack columellae. *Id.* All members of the genus are associated with commensal shrimp (IUCN Species Account (*Euphyllia cristata*)).

Euphyllia cristata

Species Description: Phaceloid *Euphyllia cristata* colonies are usually pale gray or green, with contrasting knob-like tips on large tubular tentacles (Veron 2000, Volume 2 at 69). Closely compacted corallites are 20-40 mm in diameter. *Id.* Primary septa are conspicuous underwater and very exsert, with first and second orders plunging steeply near the center of the corallite. *Id.* Columellae are absent. *Id. Euphyllia cristata* occurs on all reef sections at depths of 1-35 meters (IUCN Species Account). It is rare throughout its range. *Id.*

Distribution: This Indo-West Pacific species is found in East Africa, the Andaman Sea, the Central Indo-Pacific, Australia, Southeast Asia, Southern Japan and the East China Sea, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters within this range include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 65.

Figure 65. Range map for *Euphyllia cristata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



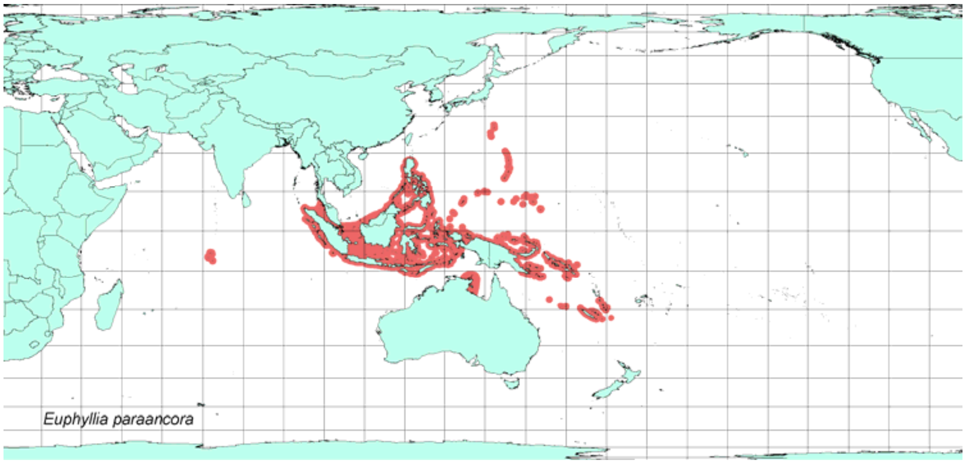
Status and Threats: *Euphyllia cristata* is heavily harvested for the aquarium trade; Indonesia alone had an annual quota for this species of 30,100 live pieces in 2005 (IUCN Species Account). While its population appears to have stabilized recently, this rare species has suffered an estimated 36% loss or degradation of habitat over 30 years, and its threat susceptibility increases the likelihood that *E. cristata* will be entirely lost from critically degraded reefs within one generation. *Id.* The IUCN has listed *Euphyllia cristata* as vulnerable. *Id.*

Euphyllia paraancora

Species Description: Phaceloid, pale tan or greenish-brown *Euphyllia paraancora* colonies are distinguishable from sibling species *E. glabrascens, E. paraglabrascens,* and *E. paradivisa* only by their anchor-shaped tentacle tips, which form concentric circles (Veron 2000, Volume 2 at 74). All of these species have similar skeletal structures, including thin walls with sharp edges, septa that plunge steeply near the corallite center and are not exsert, lack of columellae, and large tubular tentacles. *Id.; see also id. at 70. E. paraancora* corallites are 20-40 mm in diameter. *Id.* at 74. The depth range for this species is 3-30 meters, and it can occur in most reef areas (IUCN Species Account).

Distribution: *Euphyllia paraancora* is found in the Central Indo-Pacific, the Central Indian Ocean, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters where it occurs include Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 66.

Figure 66. Range map for *Euphyllia paraancora.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



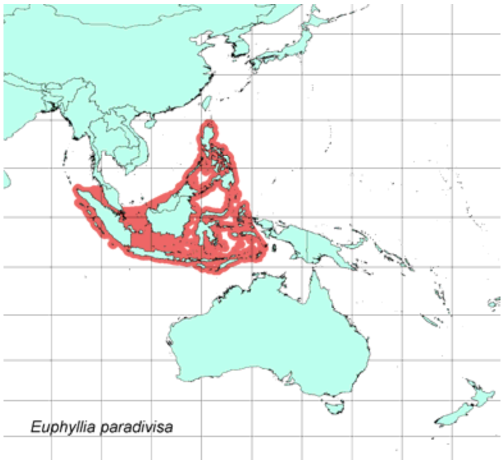
Status and Threats: Indonesia's annual export quota for *E. paraancora* was 28,000 live pieces in 2005, which illustrates the heavy threat posed by the aquarium trade to this species (IUCN Species Account). *E. paraancora* is an uncommon species with unknown current population trends, but population reduction is inferred from habitat reduction, including an estimated 36% loss or degradation of habitat over 30 years. *Id.* The IUCN has determined that *E. paraancora* faces a heightened risk of being entirely lost from critically degraded reefs within one generation and has listed this species as vulnerable. *Id.*

Euphyllia paradivisa

Species Description: *Euphyllia paradivisa* has a similar skeletal structure to *E. paraancora* (see above), but its polyps have large, branching, tubular tentacles with knob-like tips on the branches that are paler than the rest of the greenish-gray colony (Veron 2000, Volume 2 at 73; *id.* at 78). *E. paradivisa* occurs at depths of 5-20 meters, in midslope reef environments protected from wave action (IUCN Species Account).

Distribution: *Euphyllia paradivisa* is found in the Central Indo-Pacific (Australia, Indonesia, Malaysia, the Phillippines, Samoa, Singapore, and Thailand) and in American Samoa (IUCN Species Account). *See* Figure 67.

Figure 67. Range map for *Euphyllia paradivisa.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



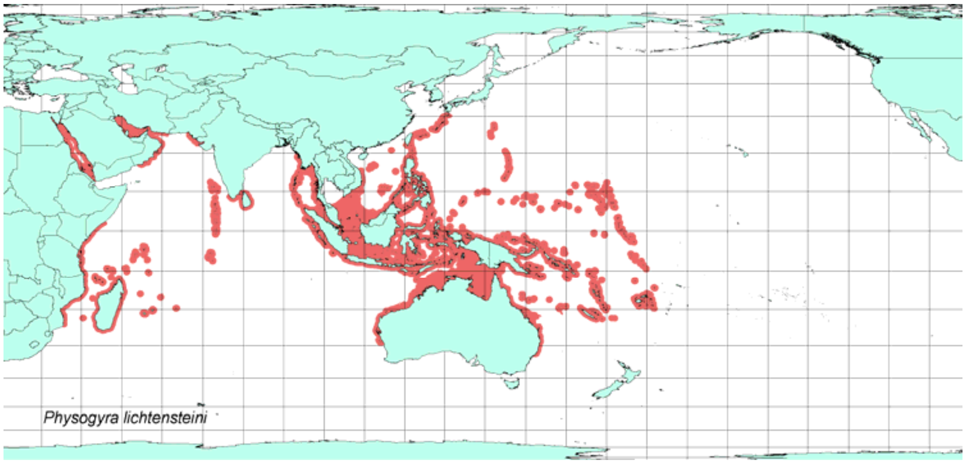
Status and Threats: *Euphyllia paradivisa* is uncommon and potentially rare, with unknown current population trends (IUCN Species Account). It is heavily targeted for the aquarium trade, with an Indonesian export quota of 5,416 live pieces in 2005. *Id.* It faces the estimated loss or degradation of 38% of its habitat over 30 years and an increased likelihood of being lost entirely from critically degraded reefs within a single generation. *Id.* The IUCN has listed *Euphyllia paradivisa* as vulnerable. *Id.*

Physogyra lichtensteini

Species Description: *Physogyra lichtensteini* is the only species in its genus (Veron 2000, Volume 2 at 92). Its pale gray or occasionally dull green meandroid colonies are either massive or form thick plates. *Id.* Short, widely separated valleys are interconnected with light, blistery coenosteum. *Id.* Other distinctive features include large, solid, smooth-edged, exsert, and widely spaced septa; solid walls; and no columellae. *Id.* While tentacles extend only at night, grape-like vesicles cover the colony surface during the day and retract when disturbed. *Id.* Veron reports that *P. lichtensteini* is "common in protected crevices and overhangs, especially in turbid water with tidal currents." *Id.* According to the IUCN, *P. lichtensteini* occurs in most shallow, tropical reef environments, though more commonly in turbid water, at depths of 1-20 meters (IUCN Species Account).

Distribution: *Physogyra lichtensteini* is found in the Red Sea and the Gulf of Aden, the Southwest and Northwest Indian Ocean, the Arabian/Iranian Gulf, the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters within its range include the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 68.

Figure 68. Range map for *Physogyra lichtensteini.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: Though *P. lichtensteini* is a common and widespread species, it is heavily harvested for the aquarium trade, with an Indonesian annual export quota of 10,500 live pieces in 2005 (IUCN Species Account). It has also suffered extensive habitat reduction and is estimated to have lost 37% of its habitat over 30 years. *Id.* While current population trends are unknown, the heightened threat susceptibility of this species increases the likelihood that *P. lichtensteini* will be completely lost from critically degraded reefs within one generation. *Id.* The IUCN has listed *P. lichtensteini* as vulnerable. *Id.*

5. FAMILY: OCULINIDAE

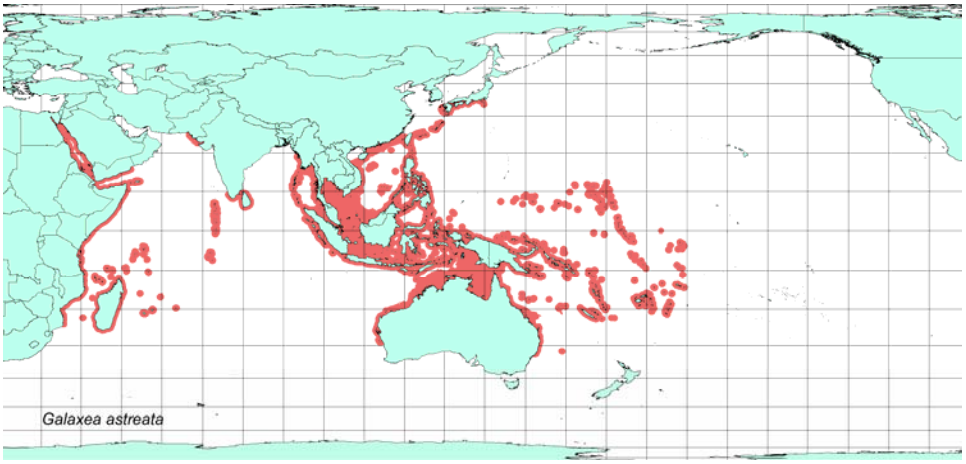
This family is colonial and zooxanthellate or azooxanthellate (Veron 2000, Volume 2 at 95). Features common to Oculinidae include very exsert septa; weakly developed columellae; paliform lobes that sometimes form a distinct crown; and solid-walled, tubular corallites that are linked together by a smooth, solid coenosteum. *Id.* While most Oculinidae species are azooxanthellate, *Galaxea* is a common zooxanthellate genus in the Indo-Pacific. *Id.* The three other genera in the family include *Simplastrea* (Indo-Pacific, zooxanthellate), *Oculina* (Atlantic, mostly azooxanthellate), and *Schizoculina* (azooxanthellate and endemic to the West African coast). *Id.*

Galaxea astreata

Species Description: Gray, pink, green, or brown *Galaxea astreata* colonies are submassive, columnar or encrusting and commonly exceed 2 meters in diameter in turbid water (Veron 2000, Volume 2 at 110). While variable in size based on location in the colony, most corallites are 3-4.5 mm in diameter, with 8-12 septa reaching the corallite center. *Id.* Tentacles partially extend during the day. *Id. G. astreata* is commonly found in reef environments protected from strong wave action (*Id.,* IUCN Species Account). Colonies are found at depths of 3-15 meters in the South China Sea and Gulf of Siam, and at 20-30 meters on the Chagos lagoon (IUCN Species Account).

Distribution: *Galaxea astreata's* Indo-West Pacific range includes the Red Sea and Gulf of Aden, the Southwestern Indian Ocean, the Central Indian Ocean, the Central Indo-Pacific, Australia (Northern, Western and Eastern), Japan and the South China Sea, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters in which it occurs include American Samoa, the Marshall Islands, Micronesia, Palau, and unspecified US minor outlying islands. *Id. See* Figure 69.

Figure 69. Range map for *Galaxea astreata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *G. astreata* is particularly susceptible to bleaching and aquarium trade harvest, with a total of 5,529 specimens exported in 2005 (IUCN Species Account). While *G. astreata* is common and widespread with unknown current population trends, population reduction can be inferred based on the estimated loss or degradation of 35% of its habitat over 30 years. *Id.* Its heightened susceptibility to these threats renders it more likely to be lost entirely from critically degraded reefs within a single generation. *Id.* The IUCN has listed *G. astreata* as vulnerable. *Id.*

6. FAMILY: PECTINIIDAE

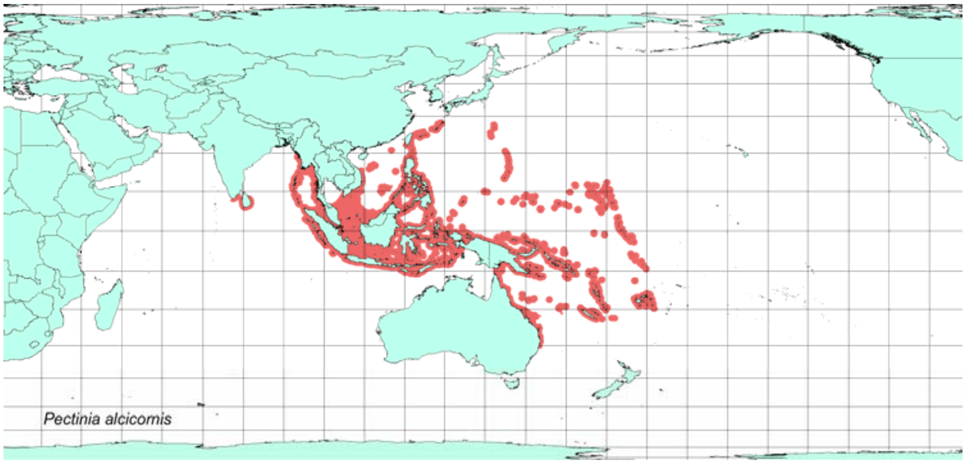
Pectiniidae is a small, distinct, entirely zooxanthellate family with only four genera (Veron 2000, Volume 2 at 321). Common features include laminar colonies composed of thin plates and corallite walls that are either absent or formed by the non-porous coenosteum of the laminae. *Id.*

Pectinia alcicornis

Species Description: *Pectinia alcicornis* colonies form clusters of fluted laminae in mixed greens, yellows, and browns that are commonly 20cm or less in diameter (Veron 2000, Volume 2 at 356; IUCN Species Account). Exsert costae form short walls as well as upward-projecting spires that are frequently tall, dominant, and paler in color than the colony center (Veron 2000, Volume 2 at 356). *P. alcicornis* columellae are well-developed and the costae are distinctively toothed. *Id.* This uncommon and conspicuous species is found in turbid water, especially on horizontal substrates; it is also sometimes found in clear water and in a variety of reef habitats. *Id.*, IUCN Species Account. 25 meters is the maximum depth at which it occurs. *Id.*

Distribution: *Pectinia alcicornis* is an Indo-West Pacific species found in the Northern Indian Ocean (Sri Lanka and southern tip of India), Southeast Asia, Southern Japan and the South China Sea, Eastern Australia, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters within this range include the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 70.

Figure 70. Range map for *Pectinia alcicornis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: While current population trends for *P. alcicornis* are unknown, population reduction can be inferred from the estimated loss or degradation of 38% of this species' habitat over 30 years (IUCN Species Account). *P. alcicornis* is also particularly susceptible to bleaching and harvest for the aquarium trade. *Id.* Its susceptibility to this combination of threats increases the likelihood that *P. alcicornis* could be entirely lost from critically degraded reefs within one generation. *Id.* The IUCN has listed this species as vulnerable. *Id.*

7. FAMILY: FAVIIDAE

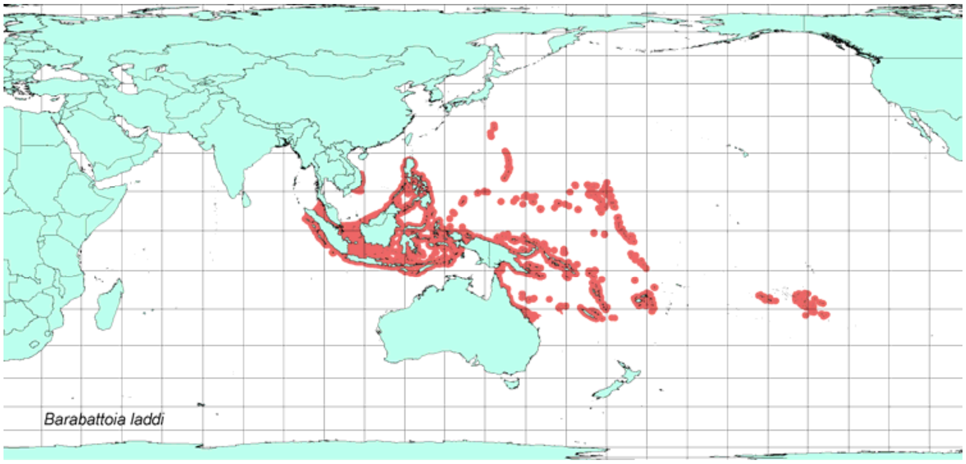
All species in the Faviidae family are zooxanthellate and colonial, with structurally similar septa and paliform lobes (when present), walls of thickened septa and cross linkages, and columellae that are simple tangles of elongate septal teeth (Veron 2000, Volume 3 at 85). There are 24 genera in the Faviidae family, more than any other coral family. *Id.*

Barabattoia laddi

Species Description: The two species in the *Barabattoia* family have elongate, tubular, irregularly fused corallites and reproduce via extratentacular budding (Veron 2000, Volume 3 at 85). *Barabattoia laddi* colonies are pale brown clusters of tubular corallites that bifurcate at 10 mm intervals and frequently fuse. *Id.* at 132. It has been found in shallow lagoons, foreslopes, back slopes, and reef flats at depths to at least 10 meters.

Distribution: *B. laddi* occurs in the Central Indo-Pacific, Eastern Australia, and the Oceanic West and South Pacific (IUCN Species Account). US-affiliated waters within its range include the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 71.

Figure 71. Range map for *Barabattoia laddi.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



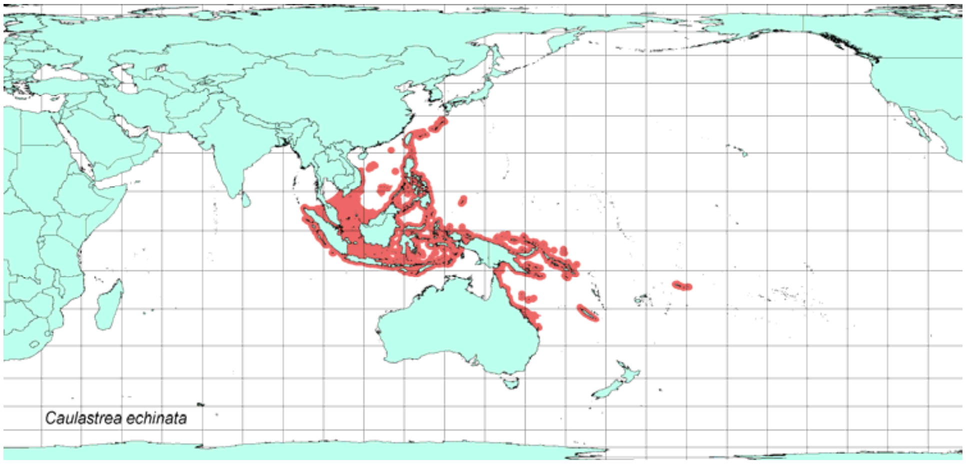
Status and Threats: While this species is widespread and common throughout its range, its restricted depth range makes it more susceptible to bleaching, disease, habitat loss, and other disturbance events (IUCN Species Account). Climate change is expected to significantly increase the frequency and severity of all of these threats in the future. *Id.* The high threat susceptibility of *B. laddi* increases the probability that the species could be entirely lost within one future generation from critically degraded reefs. *Id.* Because it shows decreasing population trends and is projected to lose an estimated 35% of its habitat over 30 years, *Barabattoia laddi* is listed as vulnerable by the IUCN. *Id.*

Caulastrea echinulata

Species Description: Species in the *Caulastrea* genus are usually phaceloid, with numerous fine septa and well developed columellae (Veron 2000, Volume 3 at 91). They generally lack paliform lobes and only rarely extend their tentacles during the day. *Id.* Tan to dark brown *C. echinulata* colonies are phaceloid and generally less than 30 cm in diameter, with pale oral discs. *Id.* at 97, IUCN Species Account. Corallites are usually close together and smaller than 10 mm in diameter, with exsert and irregular septa of uniform width that are partially concealed by fleshy polyps (Veron 2000, Volume 3 at 97). *Caulastrea echinulata* is found in lagoons, on protected slopes and horizontal substrates in turbid water, and at depths of up to 18 meters (possibly deeper) (IUCN Species Account).

Distribution: US-affiliated waters within the range of *Caulastrea echinulata* include American Samoa and Palau (IUCN Species Account). More broadly, *C. echinulata* occurs in the Central Indo-Pacific, Japan, the East and South China Sea, the Solomon Islands, Eastern Australia, Fiji, and New Caledonia. *Id. See* Figure 72.

Figure 72. Range map for *Caulastrea echinata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *C. echinata* is uncommon throughout its range and shows declining populations (IUCN Species Account). This species is heavily harvested for the aquarium trade, with 10,114 specimens exported in 2005. *Id. C. echinata* has also suffered extensive reduction of reef habitat and is projected to lose 36% of its total habitat over 30 years. Because it is a declining species with high threat susceptibility, the IUCN has listed *C. echinata* as vulnerable. *Id.*

8. FAMILY: MUSSIDAE

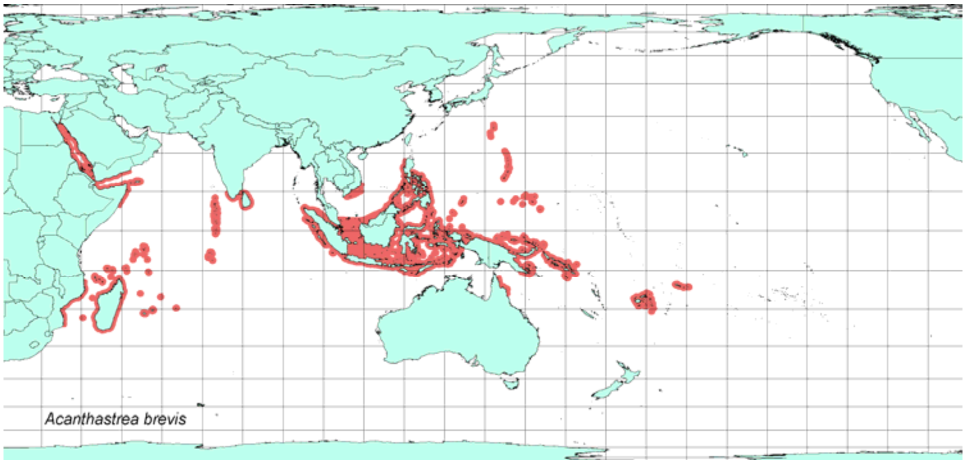
Species in the *Mussidae* family are zooxanthellate, with solid skeletal structures, large corallites and valleys, thick and well-developed columellae and walls, and septa with large teeth or lobes (Veron 2000, Volume 3 at 3). They can be solitary or colonial. *Id.* Eight of the 13 genera in this family are restricted to the Indo-Pacific. *Id.*

Acanthastrea brevis

Species Description: Uniform or mottled brown, yellow, or green *Acanthastrea brevis* colonies are mostly submassive and, unlike the other species in this genus, generally not fleshy (Veron 2000, Volume 3 at 17). Corallites have moderately thin walls that are frequently shared (cerioid). The spiny appearance of *A. brevis* is due to thin and widely spaced septa, the largest of which have very long upward teeth. *Id.* This species is reported from all types of reef habitats at depths of 1-20 meters (IUCN Species Account).

Distribution: *Acanthastrea brevis* is found in the Red Sea and Gulf of Aden, the Southwest Indian Ocean, Northern Indian Ocean, the Central Indo-Pacific, the Oceanic West Pacific, the Great Barrier Reef, and Fiji (IUCN Species Account). US-affiliated waters include American Samoa, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 73.

Figure 73. Range map for *Acanthastrea brevis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



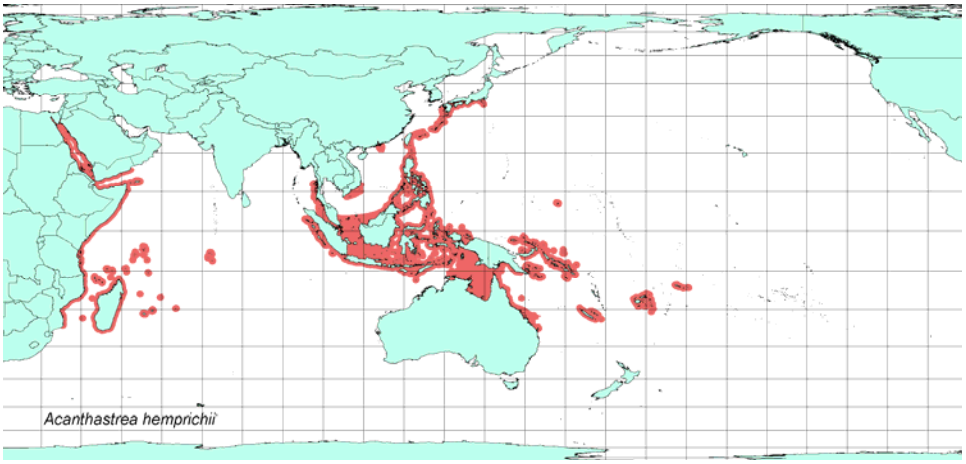
Status and Threats: *A. brevis* is particularly susceptible to crown-of-thorns starfish predation, which is a significant and increasing threat to coral reef survival throughout the Indo-Pacific (IUCN Species Account). This species also shows decreasing population trends and is projected to lose 36% of its habitat over 30 years. *Id.* For these reasons, the IUCN has listed *A. brevis* as vulnerable. *Id.*

Acanthastrea hemprichii

Species Description: *A. hemprichii* colonies are encrusting to massive and can be quite large, with diameters exceeding one meter (Veron 2000, Volume 3 at 22). Fleshy tissue covers the skeleton but is not thick enough to obscure the underlying skeletal structure. *Id. A. hemprichii* has cerioid corallites and septa with exsert teeth. *Id.* Its coloration is generally mottled brown and/or green, frequently manifesting as brown walls with green oral discs. *Id.* This species is found in mid-reef slopes at depths of up to 20 meters (IUCN Species Account).

Distribution: US-affiliated waters within the range of *A. hemprichii* include American Samoa and Micronesia (IUCN Species Account). More broadly, the range of this species includes the Red Sea and Gulf of Aden, the Southwestern and Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan, the East China Sea, the Solomon Islands, New Caledonia, and Fiji. *Id. See* Figure 74.

Figure 74. Range map for *Acanthastrea hemprichii.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



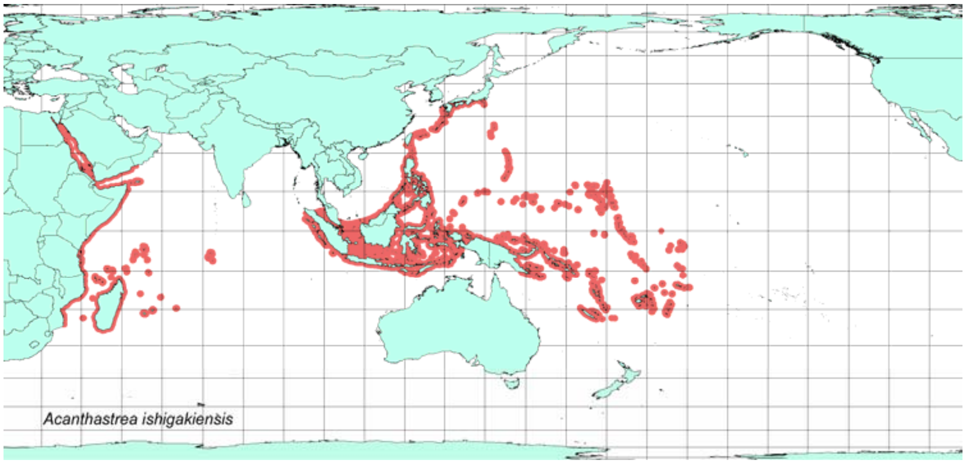
Status and Threats: The IUCN has listed *Acanthastrea hemprichii* as vulnerable because it shows decreasing population trends and is projected to lose 35% of its habitat over 30 years (IUCN Species Account). *A. hemprichii* is particularly susceptible to bleaching, disease, and habitat reduction, and this heightened vulnerability increases the chances that the entire population could be lost from critically degraded reefs within one generation. *Id.*

Acanthastrea ishigakiensis

Species Description: Massive *Acanthastrea ishigakiensis* colonies are usually hemispherical and can exceed 0.5 meter in diameter (Veron 2000, Volume 3 at 30). They are either uniform blue-gray or sometimes contrasting mixtures of gray, brown, cream, and green. *Id.* Like most species in this genus, thick fleshy tissue covers the skeleton, and the mostly uniform septa have large teeth. *Id. A. ishigakiensis* corallites are up to 25 mm in diameter and most are cerioid, though those on the sides of the colony are plocoid. *Id.* This uncommon but conspicuous species is found in depths of 1-20 meters in all sheltered reef areas away from high wave action (*Id.,* IUCN Species Account).

Distribution: *Acanthastrea ishigakiensis* is found in the Red Sea and Gulf of Aden, the Southwestern and Northern Indian Ocean, the Central Indo-Pacific, Japan and East China Sea, and the Oceanic West Pacific as far as Samoa (IUCN Species Account). The numerous US-affiliated waters within this range include American Samoa, Marshall Islands, Micronesia, Palau, and unspecified US minor outlying islands. *Id. See* Figure 75.

Figure 75. Range map for *Acanthastrea ishigakiensis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



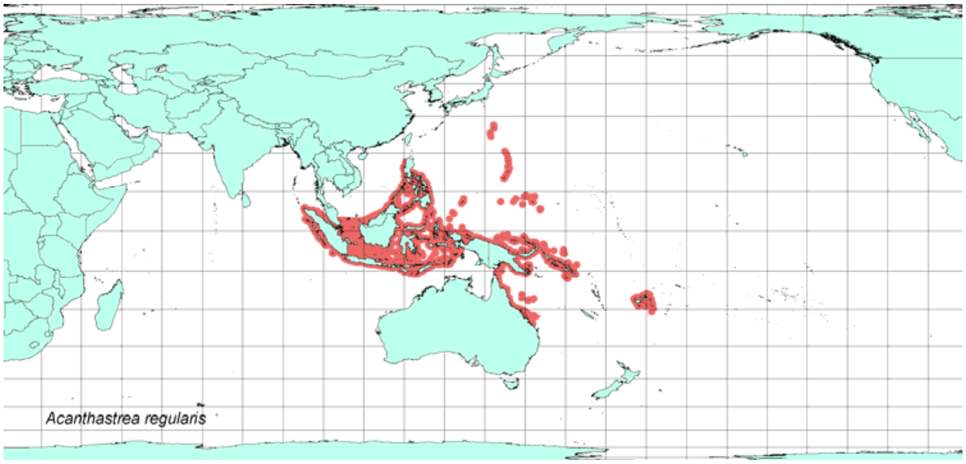
Status and Threats: *A. ishigakiensis* is thought to be uncommon and declining throughout its range (IUCN Species Account). It is especially susceptible to bleaching and disease due to its restricted depth range, and it has already suffered extensive habitat reduction. The IUCN estimates that this species is projected to lose 34% of its habitat over 30 years and has listed it as vulnerable. *Id.*

Acanthastrea regularis

Species Description: Variably brown or yellow-brown *A. regularis* colonies are massive and subplocoid, with corallites that are less than 15 mm in diameter and usually contrasting in color (Veron 2000, Volume 3 at 13, 16). Though some septa are more prominent than others, they are uniformly spaced with 8-10 evenly spaced, rounded teeth. *Id.* at 16. The teeth on adjacent septa often align to form concentric circles. *Id.* Columellae are weakly developed, and this species lacks the fleshy skeletal covering that is typical of the genus. *Id. A. regularis* is uncommon and is found at depths of up to 20 meters (*Id.*, IUCN Species Account).

Distribution: The Indo-West Pacific range of *Acanthastrea regularis* includes the Central Indo-Pacific, Eastern Australia, the Oceanic West Pacific, the Solomon Islands, and Fiji (IUCN Species Account). US-affiliated waters within this range include the Northern Mariana Islands as well as Micronesia and Palau. *Id. See* Figure 76.

Figure 76. Range map for *Acanthastrea regularis.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *Acanthastrea regularis* is uncommon and has a narrow depth range, which renders it especially susceptible to bleaching, disease, and the habitat reduction it has already suffered due to a combination of threats (IUCN Species Account). The IUCN notes declining population trends and the estimated loss or degradation of 36% of its habitat over 30 years as the rationale for listing *A. regularis* as a vulnerable species. *Id.*

FAMILY: POCILLOPORIDAE

The Pocilloporidae family of corals is colonial and zooxanthellate (Veron 2000, Volume 2 at 23). Colonies are submassive or branching. *Id.* Corallites are small, immersed to conical, have well developed columelllae and neatly arranged septa in one or two cycles. *Id.* There are three genera in this family, all Indo-Pacific. *Id.*

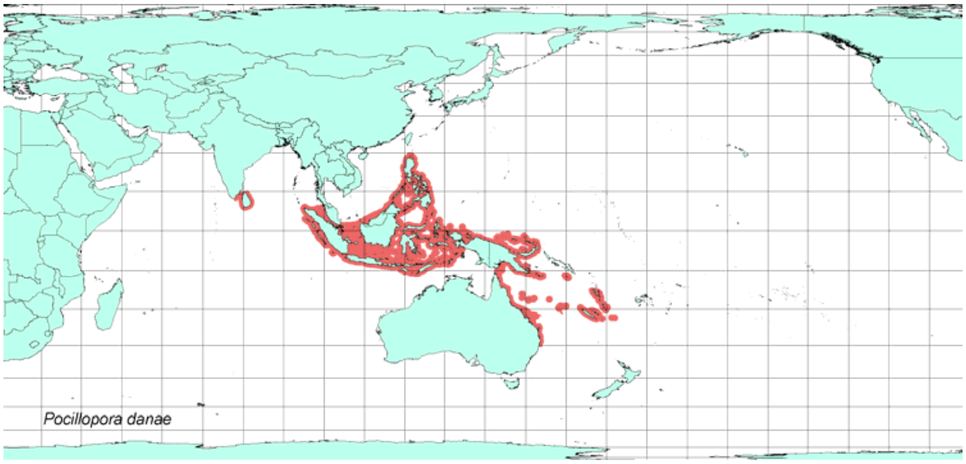
Pocillopora danae

Species Description: The Pocillopora genus is characterized by verrucae covering colonies, immersed corallites, a coenosteum typically covered by granules, and tentacles usually extended only at night (Veron 2000, Volume 2 at 24.)

Pocillopora danae colonies may be more than one meter across and comprised of irregular, mostly prostrate brances that typically form a three dimensional tangle (Veron 2000, Volume 2 at 25). Verrucae are widely spaced and irregular in size although they remain distinct from branches. *Id.* Their color is cream, brown, or pink. *Id. P. danae* is found in partly protected reef slopes in up to 15 meters water depth (IUCN Species Account). This species is usually uncommon. *Id.*

Distribution: *Pocillopora danae* occurs in the US-affiliated waters of the Northern Mariana Islands and Palau (IUCN Species Account). Its broader range encompasses the Northern Indian Ocean, the Central Indo-Pacific, Eastern Australia, and the Oceanic west Pacific. *Id. See* Figure 77.

Figure 77. Range map for *Pocillopora danae.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *P. danae* is widespread but usually uncommon across its range. It is particularly susceptible to bleaching, disease, crown-of-thorns predation, and has already suffered extensive habitat reduction due to a combination of threats (IUCN Species Account). The IUCN estimates that the species is projected to lose 38% of its habitat over 30 years and has listed *P. danae* as vulnerable. *Id.*

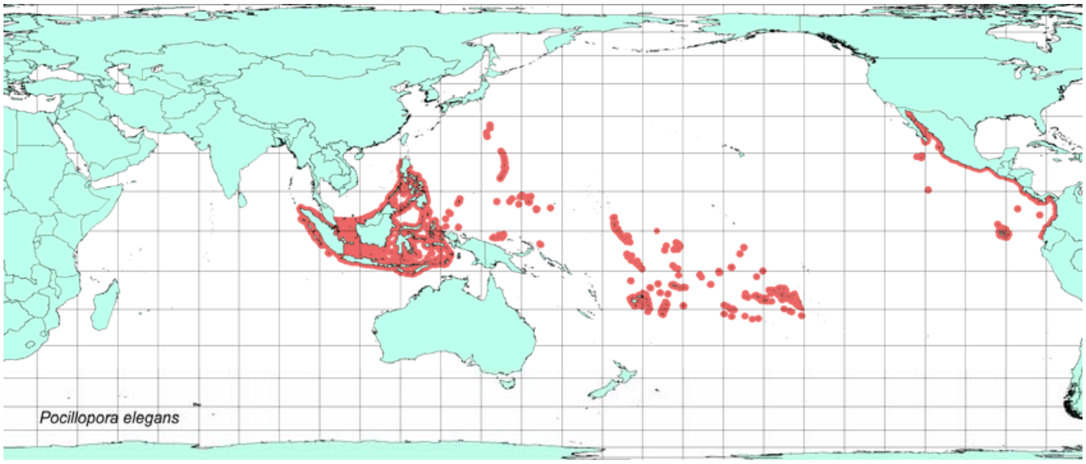
Pocillopora elegans

Species Description: *Pocillopora elegans* is characterized by compact clumps of uniform, thick, primarily upright branches with flattened ends; verrucae are uniform, rounded and smooth (Veron 2000, Volume 2 at 34). They are cream, brown-green, or pink in color. *Id.*

P. elegans is found in shallow water habitats on rocky substrata to at least 20 meters depth but is more common between 1 – 10 meters in depth (IUCN Species Account). The maximum size is 25 cm. *Id.* In the Eastern Tropical Pacific, *P. elegans* is one of the major reef building species that forms intermeshing compact frameworks that can grow to 2 to 3 meters in relief. *Id.*

Distribution: *P. elegans* occurs in the US-affiliated waters of American Samoa, Micronesia, the northern Mariana Islands, Palau, and unspecified US Minor Outlying Islands (IUCN Species Account). Its range in the Indo-West Pacific encompasses the Central Indo-Pacific, the Oceanic West Pacific, the Central Pacific, Solomon Islands and Papua New Guinea, and the Eastern Tropical Pacific. *Id. See* Figure 78.

Figure 78. Range map for *Pocillopora elegans.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *P. elegans* is widespread and locally common across its range. It is particularly susceptible to bleaching, disease, crown-of-thorns predation, and has already suffered extensive habitat reduction due to a combination of threats (IUCN Species Account). The IUCN estimates that the species is projected to lose 35% of its habitat over 30 years and has listed *P. elegans* as vulnerable. *Id.*

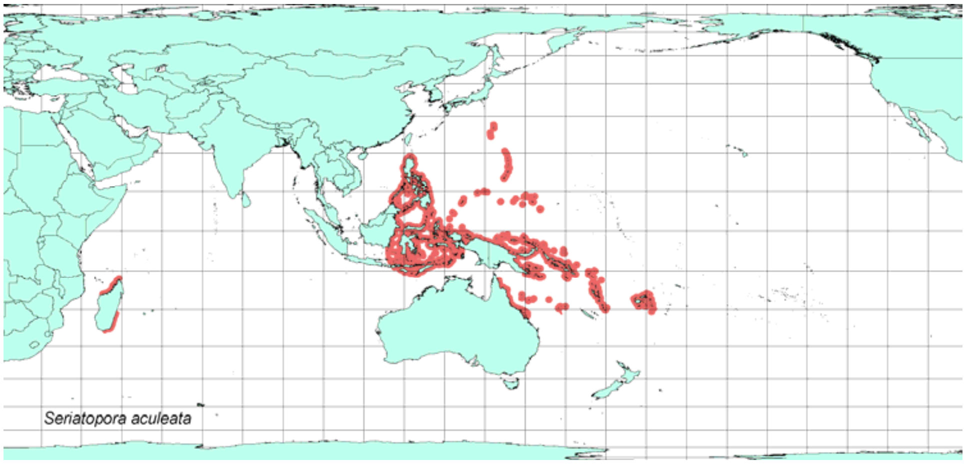
Seriatopora aculeata

The Seriatopora genus is characterized by compact colonies with thin anastomosing branches; corallites are arranged in neat rows along the branches; corallites are typically immersed with poorly developed internal structures with the exception of solid style-like columellae; one to two cylces of septa are developed and fused to the columella; and the coenosteum is covered by fine spinules (Veron 2000, Volume 2 at 46).

Species Description: *S. aculeata* is characterized by thick, short, and strongly tapered branches, usually in fused clumps; corallites are irregularly distributed on branches, and tentacles are commonly extended during the day (Veron 2000, Volume 2 at 52). They are usually pink or cream in color. *Id.* This species occurs in shallow reef environments. *Id.*

Distribution: *S. aculeata* occurs in the US-affiliated waters of Micronesia, the northern Mariana Islands, and Palau (IUCN Species Account). Its range encompasses the Central Indo-Pacific and the Oceanic West Pacific. *Id. See* Figure 79.

Figure 79. Range map for *Seriatopora aculeata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *S. aculeata* has a widespread and disjunct distribution, and is uncommon throughout its range (IUCN Species Account). It is particularly susceptible to bleaching, disease, and has already suffered extensive habitat reduction due to a combination of threats. *Id.* The IUCN estimates that the species is projected to lose 37% of its habitat over 30 years and has listed *S. aculeata* as vulnerable. *Id.*

9. FAMILY: PORITIDAE

The Poritidae family of corals is colonial and zooxanthellate, with most species extant (Veron 2000, Volume 3 at 275). Corallites, widely variable in size, are usually compacted, with porous walls and septa and little or no coenosteum. *Id.* There are five heterogeneous and distantly related genera in this family. *Id.*

Alveopora allingi

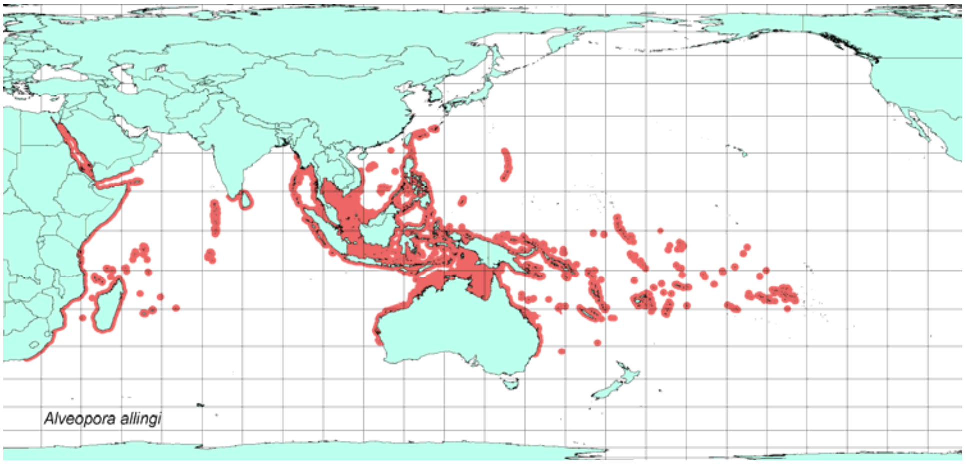
Species Description: The *Alveopora* genus is characterized by light skeletal structures consisting of interconnecting rods and spines, corallites with lattice-like walls, septa composed of fine spines sometimes connecting in the middle to form a columella tangle, and large and fleshy polyps with 12 tentacles that are extended day and night (Veron 2000, Volume 3 at 380).

Alveopora allingi demonstrates the features distinctive to its genus. Its columellae are usually present and sometimes well-developed, and its polyps are long and tightly compacted, usually with white oral cones (Veron 2000, Volume 3 at 384). While some *Alveopora allingi* colonies are encrusting, others have short, irregular lobes with rounded surfaces or are columnar. *Id.* Their color is usually yellow, green or brown. *Id.*

A. allingi is found in protected reef environments. While it is most commonly reported at depths of 5-10 meters, its tolerance of dim light conditions suggests that it can occur at depths greater than 10 meters, and its exact depth range is unknown (IUCN Species Account).

Distribution: *Alveopora allingi* occurs in several US-affiliated waters, including American Samoa, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands (IUCN Species Account). Its broader range encompasses the Red Sea and Gulf of Aden; the Southwest and Northern Indian Ocean, the Central Indo-Pacific, Australia (North, West and South), Southeast Asia, Japan and East China Sea, Eastern Australia; the Oceanic West Pacific, and the Central Pacific. *See* Figure 80.

Figure 80. Range map for *Alveopora allingi.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: While species of this genus are thought to be relatively unsusceptible to disease, *Alveopora* has the highest bleaching response of any coral genus, suffers high harvest rates for the aquarium trade, and is among the top 10 genera genera for extinction risk in the Western Indian Ocean (IUCN Species Account). *A. allingi* is an uncommon species that is particularly susceptible to bleaching due to its shallow depth range and has already suffered extensive habitat reduction due to a combination of threats. *Id.* The IUCN estimates that the species is projected to lose 35% of its habitat over 30 years and has listed *A. allingi* as vulnerable. *Id.*

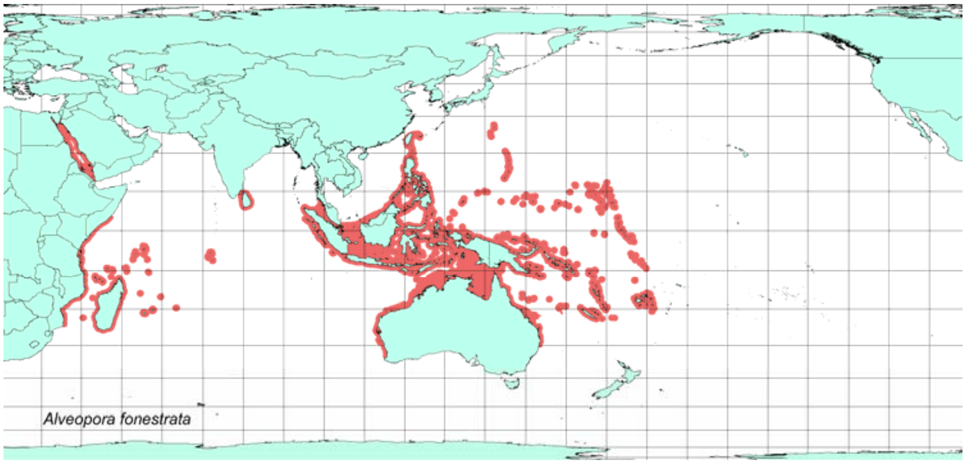
Alveopora fenestrata

Species Description: Gray or greenish-brown *Alveopora fenestrata* colonies are generally hemispherical, with surfaces divided into lobes (Veron 2000, Volume 3 at 386). They appear ragged due to long polyps with long tentacles. *Id. A. fenestrata's* corallite wall structure of compacted rods and spines and its spiny septa are consistent with its genus. *Id.* This uncommon species is found in shallow reef environments at depths of up to 30 meters (*Id.*, IUCN Species Account).

Distribution: *Alveopora fenestrata* is found in the Red Sea and Gulf of Aden, the Southwestern Indian Ocean, the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters within its range include the Marshall Islands, Micronesia, the Northern Mariana Islands, and Palau. *Id. See* Figure 81.

Figure 81. Range map for *Alveopora fenestrata.*

Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



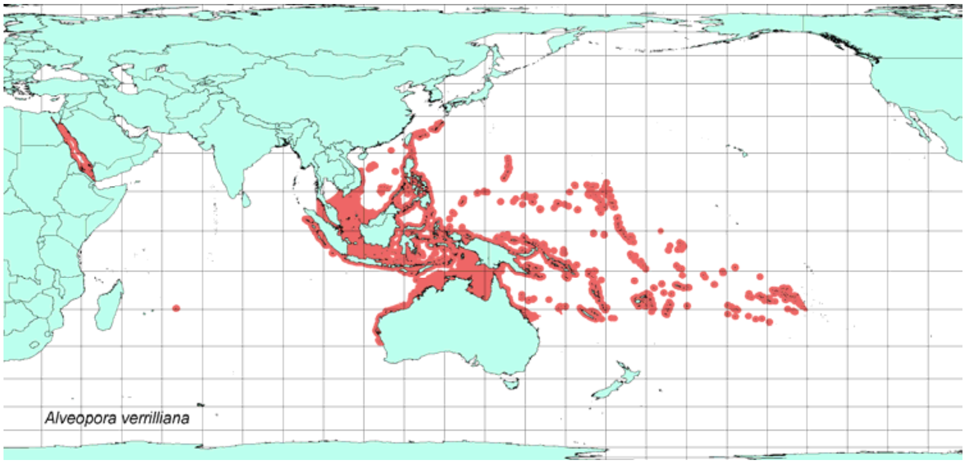
Status and Threats: *A. fenestrata* is listed as vulnerable by the IUCN because it faces the estimated loss or degradation of 36% of its habitat over 30 years and is vulnerable to a number of threats (IUCN Species Account). While species of this genus are thought to be relatively unsusceptible to disease, *Alveopora* has the highest bleaching response of any coral genus, suffers high harvest rates for the aquarium trade, and is among the top 10 genera for extinction risk in the Western Indian Ocean. *Id.* Combined, these heightened susceptibilities increase the likelihood of this uncommon species being entirely lost from critically degraded reefs within one generation. *Id.*

Alveopora verrilliana

Species Description: *Alveopora verrilliana* is distinguished from its similar sibling *A. fenestrata* by its smaller corallites with short, blunt, septal spines and vertical spines above the corallite walls (Veron 2000, Volume 3 at 387). Short and irregularly dividing knob-like branches can be dark greenish-brown, gray, or chocolate brown in color, though tentacle tips and/or oral cones are sometimes white. *Id. A. verrilliana's* polyps, when extended, are long. *Id.* It is found in reef environments at depths of up to 30 meters (IUCN Species Account).

Distribution: *A. verrilliana* occurs in numerous US-affiliated waters, including American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, Palau, and Johnston Atoll (IUCN Species Account). More broadly, its range encompasses the Red Sea and Gulf of Aden, the Northern Indian Ocean, the Central Indo-Pacific, Australia, Southeast Asia, Japan and East China Sea, the Oceanic West Pacific, the Central Pacific, and the Southern Mariana Islands. *Id. See* Figure 82.

Figure 82. Range map for *Alveopora verrilliana.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



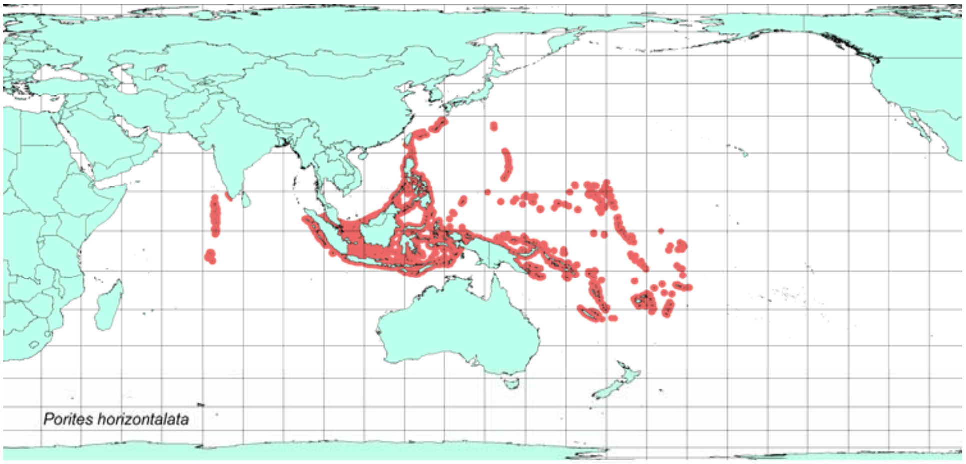
Status and Threats: Recent population trends for this uncommon species are unknown (IUCN Species Account). *Alveopora verrilliana* faces the estimated loss or degradation of 34% of its habitat over 30 years. *Id.* Like others in its genus, it is susceptible to bleaching and harvest for the aquarium trade. *Id. Alveopora* ranks in the top 10 genera for extinction risk in the West Indian Ocean. *Id.* The IUCN is concerned about the possibility that this species could be entirely lost from critically degraded reefs within one generation, and it has listed *A. verrilliana* as vulnerable. *Id.*

Porites horizontalata

Species Description: *Porites horizontalata* colonies are composites of encrusting laminae and contorted branches that divide and then re-fuse (Veron 2000, Volume 3 at 316). *P. horizontalata* is generally pale brown with cream branch and plate extremities except in shallow water, where it is sometime brightly colored. *Id.* Its corallites are separated into groups by ridges. *Id. P. horizontalata* occurs in shallow reef environments at depths of less than 10 meters and greater than 20 meters (IUCN Species Account).

Distribution: *P. horizontalata* is found in the Northern Indian Ocean, the Central Indo-Pacific, Papua New Guinea, Southern Japan and the South China Sea, and the Oceanic West Pacific (IUCN Species Account). US-affiliated waters include American Samoa, the Marshall Islands, Micronesia, the Northern Mariana Islands, and unspecified US minor outlying islands. *Id. See* Figure 83.

Figure 83. Range map for *Porites horizontalata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



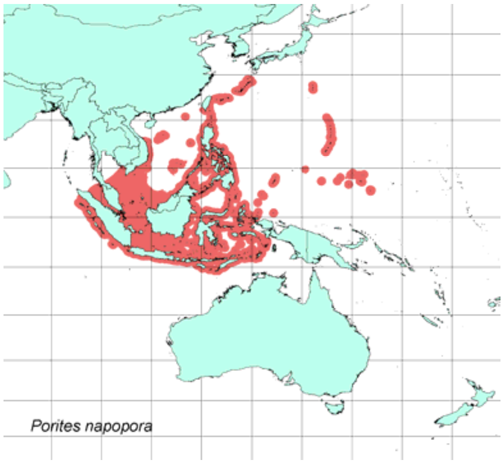
Status and Threats: *Porites* species are heavily harvested for the aquarium trade; in Indonesia, for example, the catch quota for the genus is 55,500 specimens per year (IUCN Species Account). Branching members of the genus, including *P. horizontalata,* are especially vulnerable to bleaching and rank in the top 10 coral genera for bleaching response. *Id. Porites* species are also more susceptible to disease than most corals. *Id. P. horizontalata* is projected to lose 37% of its habitat over 30 years and is at increased risk of being entirely lost from critically degraded reefs within one generation. *Id.* The IUCN lists *P. horizontalata* as vulnerable. *Id.*

Porites napapora

Species Description: *Porites napapora* colonies are typically brown in color, with broad basal laminae, clumps of tapered, irregularly fused branches, and corallites in excavated pits that are irregularly spaced with white centers and thin walls (Veron 2000, Volume 3 at 318). The corallites on branches are in particularly deep pits, which gives the branches a rough appearance. *Id. P. napapora* is found in shallow reef environments at depths up to 15 meters (IUCN Species Account).

Distribution: *P. napapora* occurs in the US-affiliated waters of Micronesia, the Northern Mariana Islands, and Palau (IUCN Species Account). Its broader range includes the Central Indo-Pacific, Southeast Asia, and Southern Japan and the South China Sea. *Id. See* Figure 84.

Figure 84. Range map for *Porites napopora.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



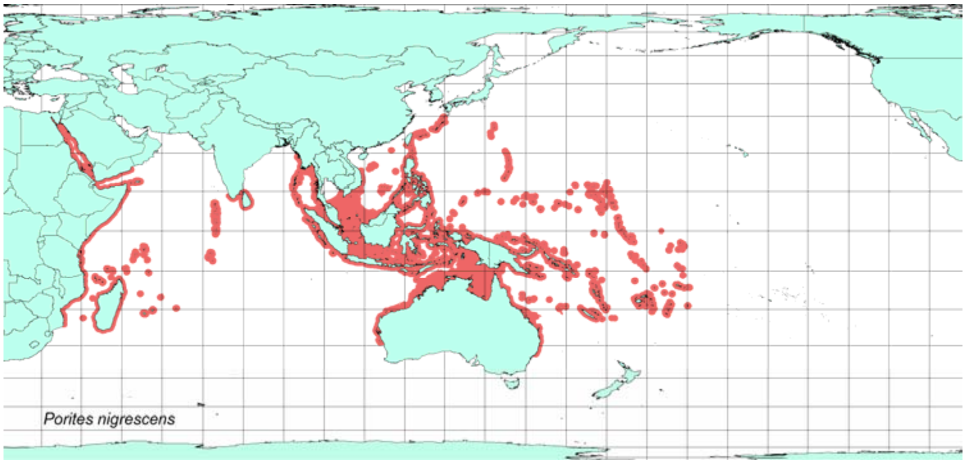
Status and Threats: Recent population trends for *P. napapora* are unknown (IUCN Species Account) *Porites* species are heavily harvested for the aquarium trade; in Indonesia, for example, the catch quota for the genus is 55,500 specimens per year. *Id. P. napapora* is more susceptible to disease than many corals. *Id.* The widespread and common species has demonstrated resistance to bleaching, which might make it more resilient in the face of anticipated significant coral reef habitat degradation. *Id.* The IUCN estimates that the species faces the loss or degradation of 33% of its habitat over 30 years and has listed it as vulnerable. *Id.*

Porites nigrescens

Species Description: Brown or cream *P. nigrescens* colonies are branching and occasionally have encrusting bases (Veron 2000, Volume 3 at 334). The surface of the colony appears pitted due to concave calices. *Id. Porites nigrescens* tentacles are generally extended during the day. *Id.* It is common on lower reef slopes and in lagoons protected from wave action, with a depth range of up to 20 meters (*Id.,* IUCN Species Account).

Distribution: *Porites nigrescens* is found in the Red Sea and the Gulf of Aden, the Southwest and Northern Indian Ocean, the Central Indo-Pacific, Australia (West, North and East), Southeast Asia, Southern Japan and the South China Sea, the Oceanic West Pacific, and the Central Pacific (IUCN Species Account). US-affiliated waters within its range include American Samoa, Marshall Islands, the Northern Mariana Islands, Palau, and unspecified US minor outlying islands. *Id. See* Figure 85.

Figure 85. Range map for *Porites nigrescens.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *Porites* species are heavily harvested for the aquarium trade; in Indonesia, for example, the catch quota for the genus is 55,500 specimens per year (IUCN Species Account). Branching members of the genus, including *P. nigrescens,* are especially vulnerable to bleaching and rank in the top 10 coral genera for bleaching response. *Id. Porites* species are also more susceptible to disease than most corals. *Id.* While its recent population trends are unknown, *P. nigrescens* is projected to lose 35% of its habitat over 30 years and is at increased risk of being entirely lost from critically degraded reefs within one generation. *Id.* The IUCN lists *P. nigrescens* as vulnerable. *Id.*

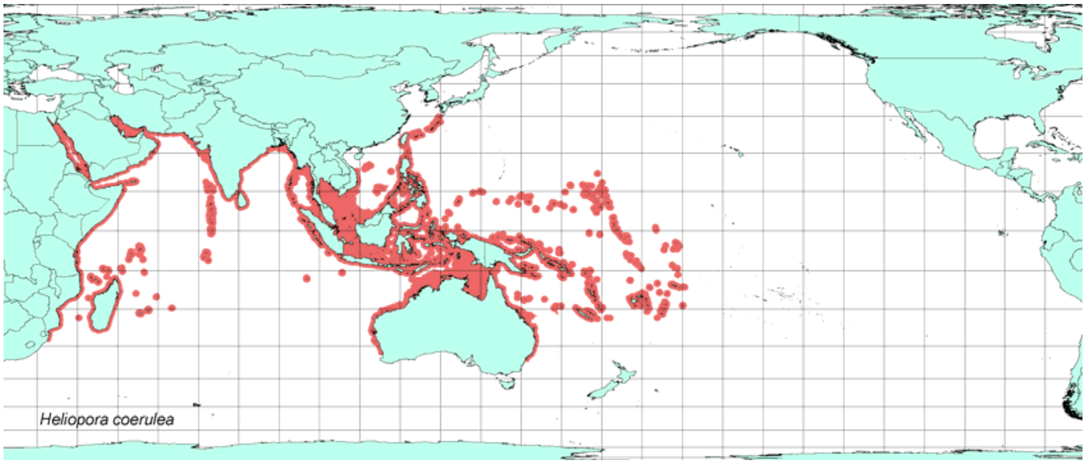
10. ORDER: HELIOPORACEA

Heliopora coerulea (Blue Coral)

Species Description: *Heliopora coerulea* is the only member of the Helioporacea Order, which is within the Anthozoa class and the Octocorallia subclass of stony, non-scleractinian corals (Veron 2000, Volume 3 at 404). The species has polyps with eight tentacles and appears blue or greenish underwater. *Id. H. coerulea's* permanently blue skeleton, which is comprised of fibrocrystalline aragonite, is easily recognized in fossil outcrops. *Id. H. coerulea* can be traced back through the Cretaceous Period, which gives it the greatest geological longevity of any coral species. *Id.* It is found in very shallow (less than 2 meters) reef flats and intertidal zones (IUCN Species Account), and potentially in deeper waters as well (Veron 2000, Volume 3 at 404). It demonstrates significant variability in growth form based on habitat (Veron 2000, Volume 3 at 404).

Distribution: *Heliopora coerulea's* widespread Indo-Pacific range spans from the Red Sea and East Africa to Southeast Asia and Polynesia, including Southern Japan, Australia, and throughout the Coral Sea to America Samoa (IUCN Species Account). Blue coral has been found in Fiji, and Ishigaki Island in Southwest Japan is believed to be home to the largest stand of blue coral in the world. *Id.* US-affiliated waters in which it occurs include American Samoa, the Marshall Islands, Micronesia, Palau, and unspecified Mariana and US minor outlying islands. *See* Figure 86.

Figure 86. Range map for *Heliopora coerulea.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *Heliopora coerulea* is widespread and locally common, but the population is thought to be decreasing throughout its range (IUCN Species Account). It is heavily harvested for curios, jewelry, and the aquarium trade, with 8,655 specimens exported in 2005. *Id. H. coerulea* forms huge stands (10 km or more) in Indonesia and Japan, which have proven very susceptible to earthquake damage. *Id.* The species is generally vulnerable to bleaching, local stochastic events, and habitat reduction due to a combination of threats. *Id.* The IUCN has estimated that *Heliopora coerulea* is projected to lose of 37% of its habitat over 30 years and has listed the species as vulnerable. *Id.*

11. FAMILY: MILLEPORIDAE (GENUS: MILLEPORA)

There are approximately 50 zooxanthellate species in the *Millepora* genus, which are common on reefs (Veron 2000, Volume 3 at 400). Their growth forms range from arobrescent to submassive and encrusting. *Id.* The *Millepora* genus belongs to the Milleporidae family, which is in turn part of the Milleporina order and the Hydrozoa class of non-scleractinian stony corals. *Id.* at 399-400. Each *Millepora* coral is a colonial hydrozoan that builds a massive calcareous skeleton (coenosteum) from excreted calcium (Razak and Hoeksema 2003). They differ from Scleractinia in their absence of corallites and the presence of two distinct types of minute but visible pores, containing near-microscopic polyps, which are scattered over the surface of the corallum (*Id.;* Veron 2000, Volume 3 at 400). Dactylopores, which house dactylozooid polyps that have visible, fine, stinging hairs that catch prey, surround the gastropores, in which the retractable gastrozooids that engulf prey are embedded (Veron 2000, Volume 3 at 400). The embedded polyps are linked by a network of minute canals called the “cyclosystem.” *Id.* Generations of asexual polyps alternate with free-living, sexually reproductive medusae; the swollen canals (“ampullae”) that produce the medusae are also visible on the colony surface. *Id.*

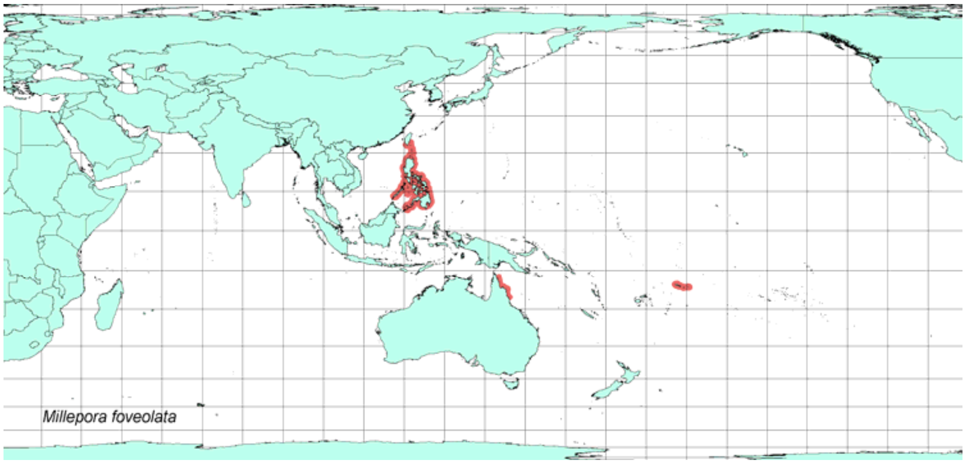
Millepora species are generally found in turbid inshore areas and are tolerant of siltation (IUCN Species Accounts). They are also sometimes found in clear offshore areas. *Id.* While not generally favorites of the aquarium trade, they are harvested for jewelry and curios. *Id.* They show a high bleaching response, but are also quicker to recover from bleaching events than some corals. In Fiji, *Millepora* species appear to be resistant to both crown-of-thorns predation and disease.

Millepora foveolata

Species Description: *Millepora foveolata* forms encrusting colonies with nodules (Razak and Hoeksema 2003 at 333). It is easily distinguished from other *Millepora* species by its finely wrinkled appearance, which is due to low ridges surrounding single pores or groups of pores on the corallum surface. *Id. M. foveolata* is found at depths of up to 20 meters. *Id.*

Distribution: *Millepora foveolata* has a patchy distribution and has been recorded in the Philippines, Taiwan, the Great Barrier Reef, and American Samoa (IUCN Species Account). *See* Figure 87.

Figure 87. Range map for *Millepora foveolata.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *M. foveolata* is uncommon and is thought to be decreasing in population (IUCN Species Account). Its restricted range heightens its threat susceptibility to habitat reduction, bleaching, and harvest for the jewelry/curio trade and increases the likelihood of the species being lost within one generation from critically degraded reefs. *Id.* The IUCN estimates that *M. foveolata* has suffered the loss or degradation of 39% of its habitat over 30 years and has listed this species as vulnerable. *Id.*

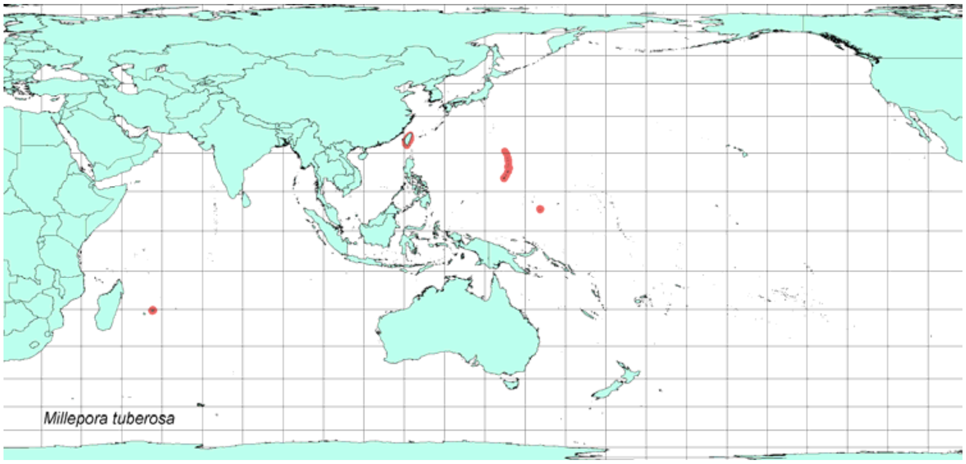
Millepora tuberosa

Species Description: When *Millepora tuberosa* colonies are attached, they form short knobbed, vertically projecting branches that often fuse with adjacent branch nobs to form bigger protruberances with rounded and blunt tips (Razak and Hoeksema 2003 at 228-300). When the species is free-living, its growth form varies depending on the coral fragments that act as the substrate. *Id*. Branches are covered with abundant nodules, and obvious pores dot the colony surface. In *M. tuberosa,* there are usually more than 10 dactylopores encircling each gastropore, though in the surface valleys there are only 6-7 dactylopores per gastropore. *Id. M. tuberosa* and *M. exaesa* are very similar and were separated by Boschma (1966, *see* Razak and Hoeksema

2003) based on geographic distribution, with *M. exaesa* restricted to the Red Sea and all other occurrences in the Indo-Pacific ascribed to *M. tuberosa* (see below).

Distribution: *Millepora tuberosa* is found only near Rodriguez Island, Taiwan, the Mariana Islands (including the Northern Mariana Islands), and Micronesia (Yap and Truk, exclusively) (IUCN Species Account). *See* Figure 88.

Figure 88. Range map for *Millepora tuberosa.*
Source: IUCN Data; map available at http://www.sci.odu.edu/gmsa/about/corals.shtml.



Status and Threats: *M. tuberosa* is listed as endangered by the IUCN because it is thought to be decreasing in population and has already suffered a 59% loss or degradation of its already restricted and disjunct habitat over 30 years (IUCN Species Account). Like other species in its genus, it is susceptible to harvest for jewelry and curios and is also among the first hard corals to bleach. *Id.*

C. STATUS OF CORAL REEF ECOSYSTEMS OF THE GREATER INDO-PACIFIC

The Indo-Pacific, roughly stretching from the Indonesian island of Sumatra in the west (95 degrees East) to French Polynesia in the east (145.5 degrees West), contains 75% of the world's coral reefs (Bruno and Selig 2007); *see* Figure 89. In the historical past of 1,000 to 100 years ago, this region probably averaged approximately 50% coral cover, but 20-50% of that total has been lost. *Id.* Regional total coral cover averaged 42.5% during the early 1980s, 36.1% in 1995, and 22.1% in 2003. *Id.*

Bruno and Selig (2007) were surprised to find that this reduced coral cover was relatively consistent across 10 subregions of the Indo-Pacific in 2002-2003, despite dramatic differences in levels of human exploitation within the various subregions (e.g., the Philippines and the Great Barrier Reef). *See* Figure 90. Recent declines in coral cover have affected nearly all reefs in the Indo-Pacific, with only 3% of 390 reefs surveyed in 2003 having coral cover of 50% or higher. *Id.* In contrast, cover equaled or exceeded 50% on nearly a third of reefs surveyed between 1980 and 1983. *Id.* Between the early 1980s and 2003, coral cover declined at an average rate of 1%

(1,500 square kilometers) per year across the Indo-Pacific, with accelerating average annual losses of 2% between 1995 and 2003.

Despite common assumptions that reefs of the Indo-Pacific remained relatively pristine until recent years, several frequently overlooked studies document Indo-Pacific coral declines beginning in the 1960s, including *Acanthaster plancii* outbreaks and other disturbances resulting in the collapse of coral cover to an average of 16.8% at 19 sites on the Great Barrier Reef by 1970. *Id.; see also* Colgan 1987. These losses pre-date the first mass mortalities noted in the Caribbean by 15 years. *Id.* Unlike more recent mortality events, however, these earlier disturbances were generally followed by rapid and often complete recovery (Colgan 1987). Indo-Pacific reef ecosystems have demonstrated resilience to catastrophic events in the past, but anthropogenic stressors are increasing the frequency and intensity of these events and interfering with the natural ability of coral communities to recover (McClanahan et al. 2004; Pandolfi et al. 2003).

The future of Indian Ocean reefs is a particular concern because over 90% of corals on many shallow water reefs died in 1998 in response to elevated sea surface temperatures, and average temperatures in the Indian Ocean are expected to rise above 1998 levels within a few decades (Sheppard 2003). Initial recovery from the 1998 mass mortality was marginal and slow, with shallow water coral cover increasing from 1-2% immediately after the 1998 event to 3-5% in 2003, compared to pre-1998 coral covers of 40-75%. *Id.* Within 10-15 years, most reefs between 0 and 15 degrees South will have a one in five annual probability of suffering a month of 1998-level sea surface temperatures. *Id.* As elevated sea surface temperatures and associated climate-induced mass mortality events occur more frequently, it becomes less likely that there will be enough time between events for Indian Ocean reefs to recover. *Id.*

Figure 89. Greater Indo-Pacific Region, including 2,667 reefs surveyed between 1968 and 2004. Source: Bruno and Selig (2007): Figure 1.

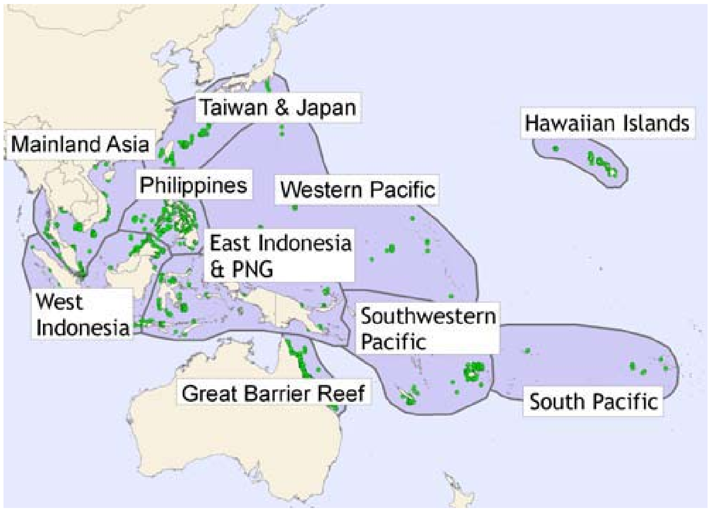
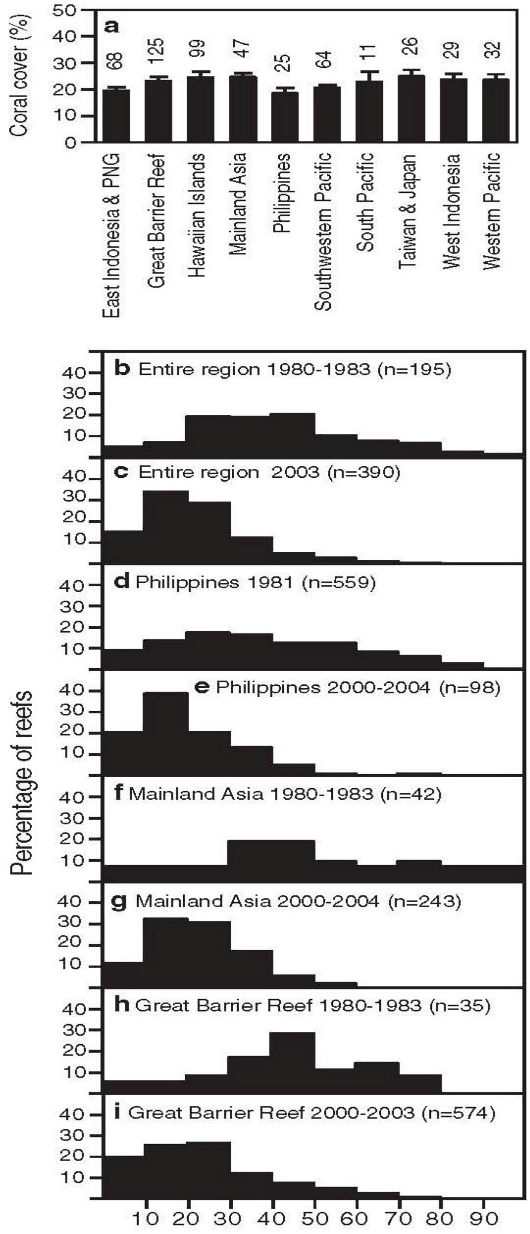


Figure 90. Coral cover in 10 subregions of the Indo-Pacific. Data are from 2003 for seven subregions and from 2002 for three subregions (Hawaiian Islands, Taiwan & Japan, and Western Pacific). Values above the bars are the number of reefs surveyed in each subregion. (b-i) Histograms illustrating percent coral cover in the Indo-Pacific and selected subregions during different periods.

Source: Bruno and Selig (2007): Figure 2.



1. Hawaii

The Hawaiian Archipelago is comprised of 18 islands and atolls in the Central Pacific (Friedlander et al. 2008). It stretches over 2,500 kilometers, from the active volcanic island of Hawaii in the southeast to Kure Atoll, formed 28 million years ago, in the northwest. *Id.* The reefs off this most isolated collection of islands on earth are influenced by large ocean swells and strong trade winds and demonstrate the highest endemism of any tropical marine ecosystem in the world. *Id.* The Hawaiian Archipelago has experienced three major bleaching events (Main Islands in 1996, Northwest Islands in 2002 and 2004) and eight coral diseases in the major coral genera of the region (*Porites, Montipora,* and *Pocillopora*), but associated impacts have been relatively mild compared to other regions. *Id.* Average sea surface temperatures throughout the Archipelago have increased 0.8 degrees Celsius since 1956. *Id.*

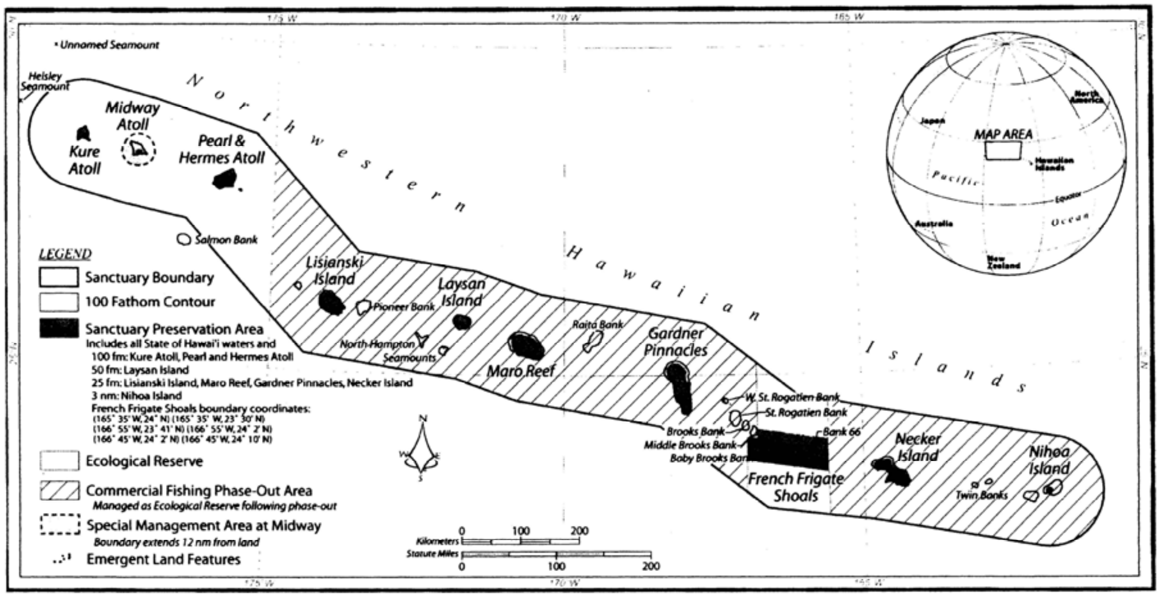
Main Hawaiian Islands

Human pressures within the Archipelago are concentrated in the Main Hawaiian Islands, which face challenges relating to coastal development, tourism, fisheries, and the aquarium trade (Friedlander et al. 2008). Sediment runoff from agricultural and urban development is a significant problem for the coral ecosystems of the Main Islands, as are invasive populations of alien algae and other species (Friedlander et al. 2008; Jokiel et al. 2008, Jokiel et al. 2004). The commercial aquarium trade is now the region's biggest fishery (Friedlander et al. 2008). It extracts 990,000 specimens annually, 75.6% of which from the island of Hawaii. *Id.* Seine net fisheries in the Main Islands report catch rate declines of 35% between 1966 and 2006. *Id.* Health of fish stocks varies between islands and is negatively correlated with human population density: remote Nauru measured highest in fish biomass, while intense fishing pressures near the population center of Oahu have decimated apex predators and dramatically decreased overall fish biomass. *Id.* At 1,682 Main Island reef sites, coral cover averaged 19.9% (varying between islands from 4-49% and generally decreasing with geological age and latitude of the islands). *Id.* Seven species comprise 96% of the total coral cover. *Id.* Long-term monitoring shows declines in regionwide coral cover of 8-12% over the past 10-30 years. *Id.*

Northwest Hawaiian Islands (NWHI)

The Northwest Hawaiian Island reefs "are remote, nearly pristine and represent one of the last remaining intact large-scale predator-dominated coral reef ecosystems" (Friedlander et al. 2008 at 215). The NWHI were designated a Marine National Monument in 2006. 71 Fed. Reg. 36443 (amended February 28, 2007 and named the part of the Papahānaumokuākea Marine National Monument); *see also* Figure 91 and Part Two of this petition. Fish stocks in this more isolated section of the Archipelago are significantly healthier than in the Main Hawaiian Islands. *Id.* Coral cover in the NWHI averages 19.9%, with recent monitoring showing no significant declines between 2000 and 2006. *Id.* The cool water temperatures, high latitudes, and exposure to large waves in this region are thought to be natural limiting factors for coral development. *Id.*

Figure 91. Map of the Papahānaumokuākea Marine National Monument.
Source: 71 Fed. Reg. 36443.



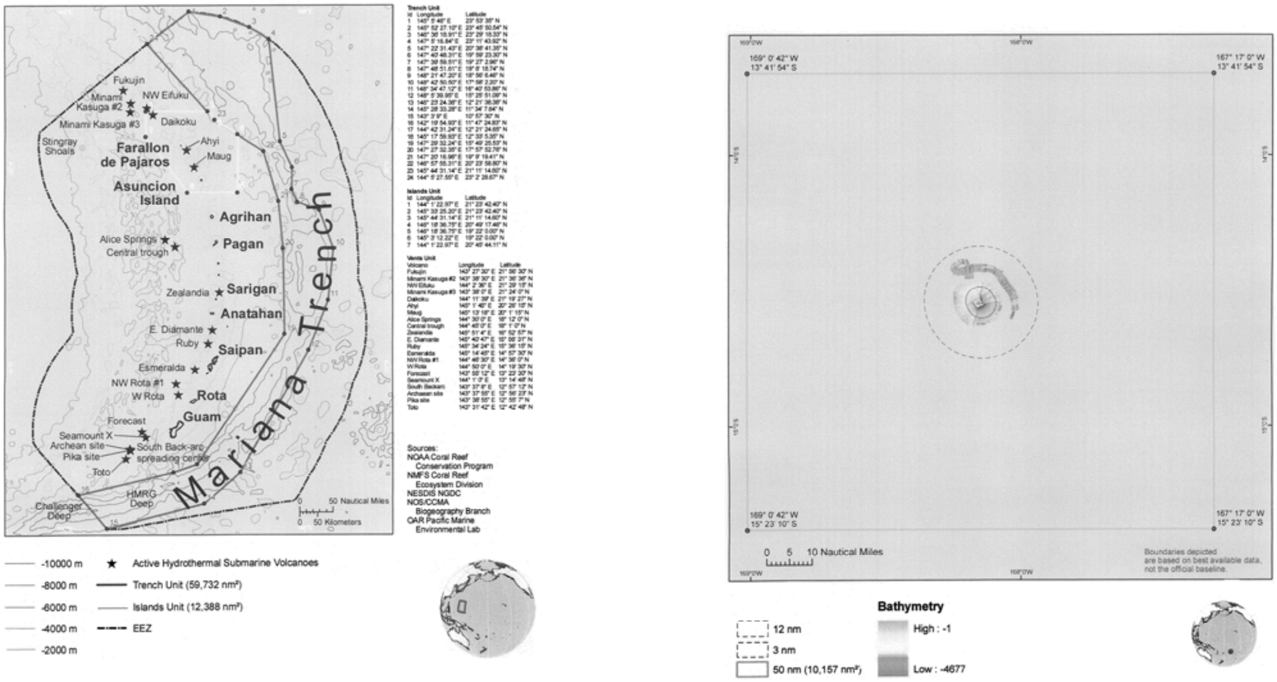
2. Micronesia, CNMI, Guam, Palau, Marshall Islands, and American Samoa

The reefs in this region have demonstrated remarkable resilience despite serious on-going threats from non-live, live food, and aquarium fisheries; non-point source pollution; coastal development; sedimentation and nutrient discharge; coral dredging; and major increases in diseases and crown-of-thorns starfish outbreaks in many areas (Goldberg et al. 2008). Reefs in the Federated States of Micronesia and the Marshall Islands have been spared most impacts from human and natural stressors and remain in excellent health. *Id.* Mass bleaching events and extreme low tides have caused dramatic immediate coral mortality in areas like Palau (known for extremely high densities of tropical marine biota) and American Samoa, but recovery has been rapid. *Id.* Reefs in the US territories of Guam and American Samoa face serious threats from expanded military activities and population growth, respectively, in the near future. *Id.*

The Northern Mariana Islands are a Commonwealth of 14 islands in the North Pacific Ocean in political union with the United States. North of Papua New Guinea and east of the Philippines, these islands are scattered along the Mariana Trench, which is the deepest known location in the Pacific. Waters within 50 nautical miles of the three northernmost Mariana Islands, Farallon de Pajaros (Uracas), Maug, and Asuncion, were designated the “islands unit” of the Marianas Trench National Monument on January 6, 2009 (74 Fed. Reg. 1557). *See* Figure 92. These waters host an apex predator-dominated, nearly pristine reef ecosystem including one of the most diverse scleractinian coral assemblages in the Western Pacific and one of the highest reef fish biomasses in the Marianas Archipelago. *Id.* A total of 95,216 square miles of land and water are now protected from commercial fishing and otherwise regulated for preservation purposes within the Marianas Trench National Monument. *Id.*

An additional 13,451 square miles of land and water in American Samoa including and surrounding Rose Atoll, the tiny easternmost Samoan Island and southernmost point in the United States, was proclaimed the Rose Atoll Marine National Monument and protected from commercial fishing on January 6, 2009 (74 Fed. Reg. 1577). *See* Figure 92. Rose Atoll supports 272 species of reef fish, 18 federally protected bird species, and over 100 species of scleractinian coral on fringing reefs dominated by crustose coralline algae, which give the Atoll its distinctive pink hue. *Id*

Figure 92. (a) Map of Marianas Trench National Monument. Source: 74 Fed. Reg. 1557; (b) Map of Rose Atoll National Monument. Source: 74 Fed. Reg. 1577.


(a)

(b)

3. Pacific Remote Island Areas: Johnston and Palmyra Atolls; Kingman Reef; and Baker, Howland, Jarvis, Johnston, and Wake Islands

These US sovereign islands and atolls are dispersed over a vast and remote area in the central Pacific Ocean that was proclaimed the Pacific Remote Islands Marine National Monument on January 6, 2009 (74 Fed. Reg. 1565). Due to limited human impacts on most of these islands, the reefs are nearly pristine communities of coral and predator-dominated fish assemblages (Friedlander et al. 2008). Those "at Howland, Baker, Palmyra, Kingman, and especially Jarvis rank among the highest biomass (3000–8000 kg/ha) and most predator-dominated (54–74%) reefs ever surveyed." *Id.* at 222. Palmyra and Kingman are thought be benefit from the influence of the North Equatorial Countercurrent, which transports coral larvae from the Western Pacific and contributes to overall coral species diversity at these two larger atolls (190 cnidarian species in 50 genera) that is twice the levels found in Hawaii or Florida (*Id.*; 74 Fed. Reg. 1565). Live coral cover in the Pacific Remote Island Areas commonly exceeds 40% in protected, leeward, and lagoon habitats and is less than 20% in areas of heavy wave exposure (Friedlander et al. 2008).

Especially now that they have received monument status and protections, the reefs of the Pacific Remote Islands provide a unique laboratory of ecosystem function and resilience in the near absence of anthropogenic stressors. *Id.* *Acropora* species, generally thought to be sensitive indicators of environmental stress, continue to flourish at many sites throughout the Monument. *Id.* The only remaining human threats to islands within the Monument are climate-related anomalies and residual impacts from military use on Johnston, Palmyra and Wake Atolls and Baker Island. *Id.* Bleaching has been uncommon in the region to date, though Palmyra is more susceptible to bleaching due to lagoon degradation from military activities. *Id.* Crown-of-thorns starfish infestations have occurred on Kingman, but their impacts to healthy reefs have been mild. *Id.* While overall disease rates are low, the former military base of Johnston Atoll demonstrated evidence of disease at 78% of monitored sites. *Id.* One of the best global case studies for the influence of fishing pressures and other anthropogenic stressors comes from a comparative study of Kingman and Palmyra with the closest islands to the south, Tabuaeran and Kiritimati, which are not included in the Monument (Sandin et al. 2008).

4. Red Sea and Gulf of Aden:
Egypt, Djibouti, Saudi Arabia, Sudan, Yemen, Somalia, Jordan

Reef ecosystems of the Red Sea and Gulf of Aden are generally healthy, with average live coral cover exceeding 50%, despite significant threats from the region's many urban and industrial centers and the use of these waters as a major global transit route for petroleum, dry bulk, and other cargoes (Kotb et al. 2008). While the region's reefs were severely damaged by bleaching in 1998, most are now recovering. *Id.* Outbreaks of crown-of-thorns starfish have been reported from the Iles des Sept Freres and Ras Siyyan in Djibouti, on the Red Sea Reefs of Yemen, and in Ras Mohammed National Park in Egypt. *Id.* Climate-influenced reef damage occurred in 2007, when corals suffered significant bleaching and mortality in parts of Egypt, Sudan, and Jordan. *Id.* Intensive and escalating human pressures, including industrial and sewage discharges, oil spills and contamination, and destructive overfishing of sharks and other reef-associated species are chronic threats to corals and their habitat throughout the region. *Id.*

5. Persian Gulf, Gulf of Oman and Arabian Sea:
Bahrain, Oman, United Arab Emirates, Qatar, Kuwait and Iran

The corals of this region are some of the most damaged in the world, with the lowest predictions for recovery (Wilkinson 2008 (Executive Summary)). They live under extreme temperature and salinity conditions and generally exist at their physiological tolerance limits, making them promising models for studies of global climate change impacts (Maghsoudlou et al. 2008). Coral diversity is relatively low in the Persian Gulf and parts of the Gulf of Oman due to these extreme conditions. *Id.* In the Persian Gulf, extreme maximum and minimum temperatures are key determinants of reef growth and structure, causing frequent mass bleaching and mortality. *Id.* The most significant climate-related mass bleachings occurred in 1996, 1998, and 2002. These bleaching events disproportionately impact *Acropora* species, providing competitive advantages to more resilient coral genera including *Porites, Favia, Platygyra, Pavona, Siderastrea,* and *Psammacora.* In June 2007, Cyclone Gonu, the strongest cyclone on record in the Arabian Sea, destroyed 25-90% of Oman's corals, inflicting severe damage on some of the region's most pristine reefs. *Id.* Bahrain's reefs, which include 31 coral species, are at extreme and imminent risk due to inappropriately engineered construction projects and excessive sedimentation. *Id.*

6. East Africa:
Kenya, Tanzania, Mozambique, South Africa

East Africa's coral reefs stretch from 10 degrees North to 28 degrees South and generally occur within two kilometers of the coast (Muthiga et al. 2008). Land and river influences are intense throughout the region, as are fishing pressures. *Id.* The 1998 bleaching event devastated many of East Africa's reefs, driving coral cover in Kenya down to 10%. Subsequent recovery in Kenya, Tanzania, and Mozambique has occurred but is impeded by overfishing and crown of thorns starfish outbreaks in some areas. *Id.* The average colony size of 26 coral species in Kenya declined over 14 years, which is thought to be due to bleaching as well as intense fishing pressures. *Id.* The combined impacts of starfish outbreaks and bleaching have negatively impacted coral species richness and diversity in Tanzania, with overall coral cover declining from 55% to 40% (27%) since 1992 and *Porites* replacing *Acropora* species in many reef areas. Coral cover in South Africa's marginal but diverse reef areas decreased 5.5% between 1993 and 2006. *Id.* A regionwide study indicated that diversity and resilience of corals increased with temperature fluctuations, perhaps because corals acclimated to these conditions can better survive bleachings and other climate influences. *Id.*

7. Southwest Indian Ocean Islands:
Comoros, Madagascar, Mauritius, Rodrigues, Reunion, Seychelles

Human impacts and coral bleaching are the two main threats to corals in the Southwest Indian Ocean (Ahamada et al. 2008). Whereas reefs on the northern islands (Comoros and Seychelles) were seriously damaged by the 1998 bleaching event and are now slowly recovering, southern island reefs (La Reunion, Mauritius and Rodriguez) escaped destruction in 1998 but have subsequently declined. *Id*. Milder bleaching events have been recorded annually in the Southwest Indian Ocean since 2000, causing some coral mortality and retarding recovery rates. *Id.* Recovery in Comoros, Madagascar, and Seychelles has varied in dramatic inverse relationship to human pressures, with reefs in protected areas thriving while unprotected sites remain sparse. *Id.* Protected sites also recovered quickly from minor bleaching events in 2004 and 2005. *Id.* Though stable since 2004, the reefs of La Reunion are considered seriously threatened, with 50% of the reef area degraded due to elevated water temperatures, freshwater input, and cyclones. *Id.* Mauritius has suffered a 70% decline in coral cover since 1998. *Id.*

8. South Asia:
Bangladesh, Chagos, India, Maldives and Sri Lanka

Climate change is the primary threat to South Asian reefs, with direct human impacts responsible for the majority of reef degradation near population centers (Tamelander and Rajasuriya 2008). Management of coastal areas is poor in all countries, including in existing Marine Protected Areas. The reefs of South Asia suffered catastrophic coral cover reductions and up to 90% mortality in many areas following the 1998 bleaching event. *Id.* Recovery from 1998 bleaching has been strong in Chagos, the western Maldives, the west-facing reefs of India's Lakshadweep Islands, the Gulf of Mannar, and the remote reefs of Northern Sri Lanka. *Id.* Many of these areas show unusually high rates of *Acropora* species recovery. *Id.* Localized bleaching has been observed almost annually in subsequent years, but in most instances reefs fully recover within a few months. *Id.* While the Indian Ocean Tsunami of 2004 caused significant damage (mostly from debris and sediment washed off the land) and interfered with ongoing recovery from 1998 losses, human impacts and climate change have been more significant factors in recent years. *Id.* One of the biggest challenges to the region's reefs is extreme overfishing and destructive fishing practices for both food and ornamental fish, including dynamite and cyanide fishing in many areas. *Id.* Coral mining has been a serious problem historically across the region and continues at high rates in Sri Lanka. *Id.* Reef development in Bangladesh is limited by high turbidity and unstable substrate, and little is known about Pakistan's coral communities. *Id.*

9. South-East Asia:
Thailand, Philippines, Vietnam, Singapore, Indonesia, Malaysia, Cambodia, Myanmar, Timor-Leste and Brunei

The Southeast Asian countries of Indonesia, Philippines, Malaysia, Papua New Guinea, the Solomon Islands, and Timor Leste constitute the "Coral Triangle," which is considered the epicenter of tropical marine life and the earth's most biodiverse ecosystem. Though occupying less than 1% of the earth's surface, the Coral Triangle contains more than 30% of the world's coral reefs, including 76% of all reef-building corals and 36% of all reef fish (Hoegh-Guldberg et al. 2009). The Coral Triangle is also home to more than 150 million people, including 100 million who live along the coasts. *Id.* Under current trajectories of greenhouse gas emissions, many parts of the Coral Triangle will be rendered unliveable by the end of this century due to sea level rise and increasingly severe weather patterns, including floods and landslides as well as devastating droughts. *Id.*

The reefs of Southeast Asia are among the most threatened in the world due to overfishing and destructive fishing practices (including cyanide and bomb fishing), sedimentation, and pollution associated with exploding population growth over 30 years (Tun et al. 2008). Within the Coral Triangle, for example, 40% of reefs and mangroves have been lost in the past 40 years (Hoegh-Guldberg et al. 2009). Recovery of reefs from these pressures to date has been very limited (Tun et al. 2008). Between 2004 and 2008, the coral reefs of Indonesia and Malaysia continued to decline, while slight improvements occurred in Thailand, Philippines, Singapore, and especially Vietnam. *Id.*

Though the 2004 tsunami caused significant damage, most reefs in the region are expected to fully recover within 5-10 years (Tun et al. 2008). Very little is known about the reefs of Myanmar, Cambodia, Timor-Leste, and East Timor; Myanmar's abundant reefs are thought to be largely pristine and to provide important refuges for corals and associated-species. *Id.*

Overall, reef degradation in the region continues to accelerate faster than conservation efforts (Wilkinson 2008). Global warming presents serious future challenges in the Coral Triangle, with sea surface temperatures expected to rise 1-4 degrees Celsius by the end of this century, while acidification will likely create "marginal" ocean habitat for corals between 2020 and 2050 (Hoegh-Guldberg et al. 2009). Since water temperature increase of more than 2 degrees Celsius are projected to eliminate most coral-dominated reef systems, the likely outcome of these climate shifts is that the region's reefs will begin to crumble by mid-century as the calcium carbonate structures underpinning them weaken, with most of those coral-dominated ecosystems that survive near-term acidification subsequently destroyed due to rising sea surface temperatures by 2100. *Id.*

10. East and North Asia:
China, Hong Kong, Taiwan, South Korea and Japan

East and North Asian reefs have declined overall due to significant and increasing human pressures, bleaching, and crown-of-thorns starfish predation in recent years (Kimura et al. 2008). Climate-induced sea temperature increases appear to be catalyzing phase shifts, with historically seaweed-dominated systems to the north in Korea and Japan showing some expansion of coral communities, while macro-algal cover is increasing at the expense of corals at half the survey sites in Taiwan. *Id.* Reef systems in China, Taiwan and Hong Kong, which had been healthy in the 1980s, have been steadily declining due to population growth and subsequent increases in sedimentation and sewage discharge. *Id.* Healthy as well as unhealthy reefs bleached in 1998 due to high water temperatures throughout the region. *Id.* Fishing pressures are intense and fish abundances have declined in China, Japan, and Taiwan, whereas Korea is witnessing increases in some tropical fish species due to warming sea temperatures. *Id.* Commercially important fish are absent from most reefs, and illegal use of explosives, poisons, and electricity continue. *Id.* Spear fishing, bottom-trawling, and gill nets are common and cause significant damage to the reef ecosystem. *Id.* Pollution from aquaculture is expected to be an increasing problem for reefs in the future. *Id.* Unsustainable tourism pressures are stressing reefs in Korea, Taiwan, and offshore islands. *Id.* Coral disease outbreaks were first reported in the region in 2004-2005 and are associated with pollution from increased marine tourism. *Id.* Reefs in Japan and Taiwan are battered by several typhoons each year. *Id.*

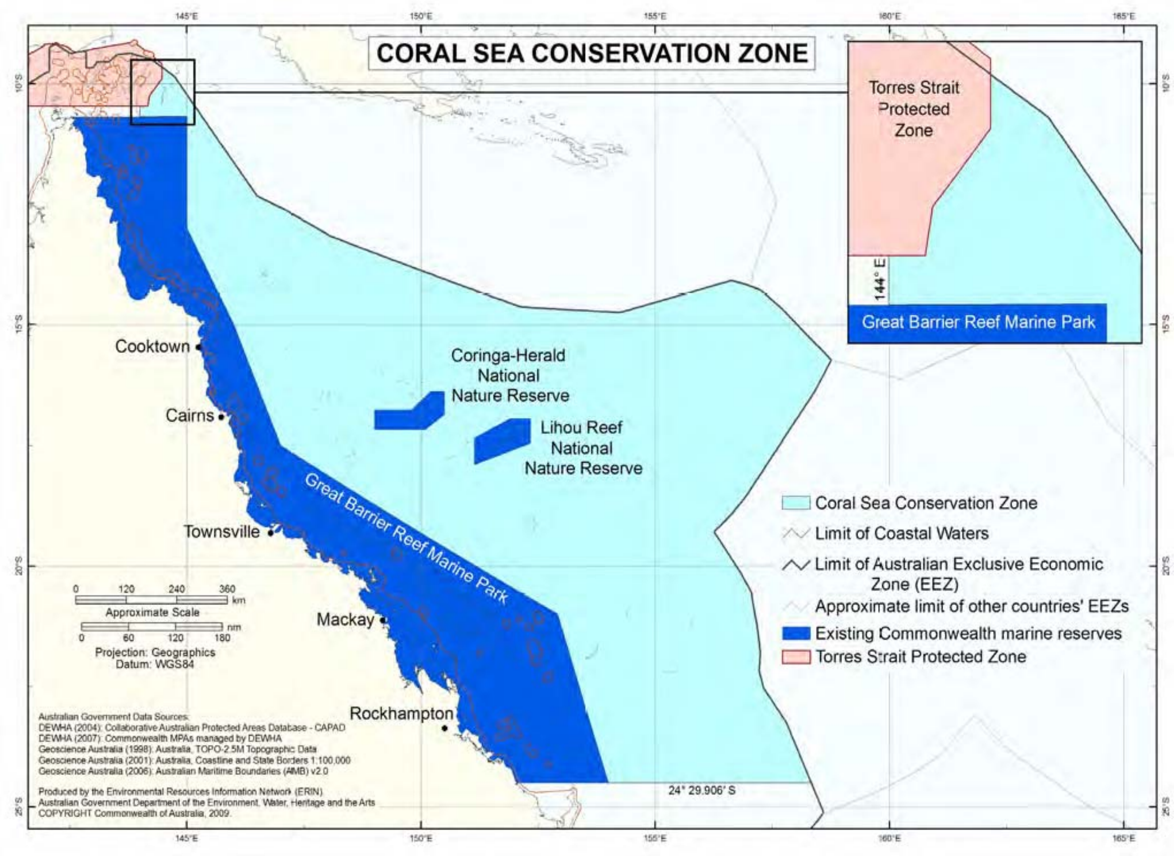
11. Australia and Papua New Guinea

This region contains 19% of the world's coral reefs and rivals the Philippines and Indonesia in its marine biodiversity, with much less overall exposure to human pressures (Chin et al. 2008). The reefs of Australia and Papua New Guinea are in relatively good condition but require ongoing resilience-oriented management in the face of significant, climate-related threats as well as anthropogenic stresses in unprotected areas. *Id.* Thermal stress and ocean acidification are emerging as particularly alarming challenges to the region's corals, with recent studies revealing unprecedented declines of 14-21% in calcification rates for *Porites* species across the Great Barrier Reef in the past two decades (De'ath et al. 2009; Cooper et al. 2008). Sea surface temperatures are expected to exceed the current thermal tolerances of Great Barrier reef corals by 2020, with annual bleaching and significant subsequent shifts in coral species diversity and abundance expected within 30-50 years (McClanahan et al. 2004). Moreover, the average interval between cyclone impact and inundation by a flood plume is likely to decrease across the Great Barrier Reef under all scenarios for global climate change (Pittock 1999).

Eastern Australia leads the world in protective reef management (Chin et al. 2008). The Great Barrier Reef, which encompasses 2,000 individual reefs and 350,000 square kilometers along the east coast of Queensland, was rezoned in 2004 such that 33% of the area is now protected as “no take” zones. *Id.* While the Great Barrier Reef is in relatively good condition, it is at risk of degradation due to coastal development, declining water quality, changes in the community structure of frequently visited inshore reefs, cyclones, and the first significant outbreaks of black band disease (10% of *Montipora* corals were infected during the summer of 2009), in addition to the climate-related threats highlighted above (Chin et al. 2008; Carter 2009). In 2003, average coral cover at 125 sites on the Great Barrier Reef was less than 25%, which is assumed to be less than half what it was in the historical past (Bruno and Selig 2007). Crown-of-thorns starfish are a significant threat, particularly in those areas outside of the no-take zones, where they occur almost four times as frequently as they do inside the reserves (Chin et al. 2008).

Eastern Australia also includes the Coral Sea, which contains the most southerly coral reefs in the world. *Id.* Coral Sea reefs are strongly influenced by the East Australian Current and are primarily threatened by climate change. *Id.* On May 19, 2009, the Australian Government proposed a Coral Sea Conservation Zone encompassing all Coral Sea waters from the Great Barrier Reef Marine Park to the eastern boundary of Australia’s Exclusive Economic Zone (972,000 square kilometers, exclusive of existing Coral Sea reserves) (Garrett 2009). *See* Figure 93**.** The Coral Sea Conservation Zone is undergoing assessment through 2010, with protections to be decided and established following the conclusion of that assessment.

Figure 93. Map of Coral Sea Conservation Zone and GBR Marine Park.
Source: Australian Dept. of the Environment, Water, Heritage and the Arts, Marine Division (http://www.environment.gov.au/coasts/mbp/publications/east/pubs/fact-sheet-coral-sea.pdf).



Australian Government Data Sources:
DEWHA (2004): Collaborative Australian Protected Areas Database - CAPAD
DEWHA (2007): Commonwealth MPAs managed by DEWHA
Geoscience Australia (1998): Australia, TOPO-2.5M Topographic Data
Geoscience Australia (2001): Australia, Coastline and State Borders 1:100,000
Geoscience Australia (2006): Australian Maritime Boundaries (AMB) v2.0

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Western Australia, which includes 44% of Australia's coastline, is second only to the Hawaiian Islands in marine endemism. *Id.* Most Western Australian reefs are isolated from population centers and spared from terrestrial run-off due to the dry and arid nature of the adjacent coast. *Id.* Ningaloo reef, the longest fringing reef in the world, sustained heavy losses due to infestation by a coral eating snail, *Drupella cornus,* in the 1980s and 1990s, but has subsequently recovered. *Id.* Similarly, the reef has almost fully recovered from its first major bleaching event, which occurred in the winter of 2006. Ongoing threats include storms and cyclones, pollution, damage from fishing and boat use, coastal development, and non-native species. *Id.*

The reefs of Papua New Guinea, which lie within the Coral Triangle, are generally close to shore and susceptible to terrestrial influences, including sedimentation from mining, land clearing, oil-palm plantations, and logging. *Id.* Other serious threats include overfishing of apex predators and invertebrates, the live fish trade, crown-of-thorns starfish outbreaks, and coral bleaching. *Id.* Recent stress is indicated by severe localized bleaching in early 2008 in the New Britain Province and increases in macro-algal cover from 52% in 2006 to 72% at three of six sites in the New Ireland Province (with corresponding decreases in coral cover from 40% to 20%). *Id.*

12. South West Pacific: Fiji, New Caledonia, Samoa, Solomon Islands, Tuvalu and Vanuatu

The Southwest Pacific hosts 28,364 square kilometers of diverse coral communities, including fringing, barrier, double barrier, submerged barrier, platform, patch, oceanic ribbon, mid ocean, atolls, oceanic atoll and near-atoll reefs (Morris and Mackay 2008). Coral cover is relatively high overall, with individual island averages ranging from 26 to 65%, and there are no indications of catastrophic changes at monitored reef sites within the past 9-10 years. *Id.* Marine protected areas are increasing throughout the region and appear to be facilitating reef resilience in the face of growing climate-related and human stressors. Yet there are significant and increasing problems in the region relating to over-fishing, pollution, sedimentation, eutrophication, coastal development, and a lack of resources available for effective reef monitoring and protection. *Id.* Natural threats to reefs include coral predation, temperature variation, coral bleaching, cyclones, tsunamis and earthquakes. In April 2007, a catastrophic earthquake and tsunami caused widespread destruction in the Solomon Islands, including lifting some islands and major fringing reefs three meters. *Id.*

Reef scientists believe climate-related bleaching to be the biggest threat to the future of this region's reefs (Wilkinson 2008). Extensive coral bleaching occurred throughout the region in 2000-02, with variable rates of recovery, and monitoring efforts in Fiji show a clear correlation between sustained elevations in sea temperature over 29 degrees Celsius (2000, 2002, 2005) and local bleaching events (2000, 2001, 2002 and 2006) (Morris and Mackay 2008). Additional localized bleaching and increasing crown-of-thorns starfish outbreaks are predicted for 2008-2010, with associated negative impacts to reef health expected. *Id.*

13. Polynesia Mana:
Cook Islands, French Polynesia, Niue, Kiribati, Tonga, Tokelau, and Wallis and Futuna

The low human population pressures throughout most of Polynesia Mana have helped preserve the reefs of the region (Vieux et al. 2008). Wallis and Futuna, Tuamotu-Gambier and Marquesas Archipelagos of French Polynesia all have healthy coral communities, with some recent increases in coral cover and signs of resilience to natural threats. *Id.* Yet on populated islands, such as Rarotonga, the Society Archipelago (Tahiti and Moorea) of French Polynesia, and Tarawa, Kiribati, reefs show reduced coral cover and water quality, overgrowth by algae, reduced and changed fish populations and degradation due to accumulated marine debris, especially plastics. *Id.* Poor water quality resulting from unsustainable land and sanitation management poses the most serious threat to reefs in these areas. *Id.*

Though climate-associated damage has been limited across the region to date, global warming remains the primary overall threat to the reefs of Polynesia Mana. *Id.* Bleaching and crown-of-thorns starfish outbreaks have afflicted many of the islands, with subsequently slow recovery, loss of coral diversity (especially formerly dominant *Acropora* species), and phase shifts noted in some areas of Kiribati, the Cook Islands, and Niue. *Id.*

PART TWO: ANALYSIS OF ENDANGERED SPECIES ACT LISTING FACTORS

I. Criteria for Listing Species as Endangered or Threatened under the Endangered Species Act

Under the ESA, 16 U.S.C. § 1533(a)(1), NMFS is required to list a species for protection if it is in danger of extinction or threatened by possible extinction in all or a significant portion of its range. In making such a determination, NMFS must analyze the species' status in light of five statutory listing factors, relying "solely on the best scientific and commercial data available," 16 U.S.C. § 1533(b)(1)(A):

> (A) the present or threatened destruction, modification, or curtailment of its habitat or range;
> (B) overutilization for commercial, recreational, scientific, or educational purposes;
> (C) disease or predation;
> (D) the inadequacy of existing regulatory mechanisms;
> (E) other natural or manmade factors affecting its continued existence.

16 U.S.C. § 1533(a)(1)(A)-(E); 50 C.F.R. § 424.11(c)(1) - (5).

A species is "endangered" if it is "in danger of extinction throughout all or a significant portion of its range" due to one or more of the five listing factors. 16 U.S.C. § 1531(6). A species is "threatened" if it is "likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." 16 U.S.C. § 1531(20).

Under the ESA, a "species" includes any species, subspecies, or a "distinct population segment" of a vertebrate species. 16 U.S.C. § 1532(16). As explained in the individual species accounts above, each of the petitioned taxa is recognized as a distinct species or subspecies, and therefore each qualifies as a "species" under the ESA.

While the ESA does not define the "foreseeable future," NMFS must use a definition that is reasonable, that ensures protection of the petitioned species, and that gives the benefit of the doubt regarding any scientific uncertainty to the species. The minimum time period that meets these criteria is 100 years.

Because climate change and ocean acidification are foremost threats to the petitioned coral species, NMFS should consider the timeframes used in climate modeling. Predictions of climate impacts in the next 100 years or more are routine in the literature, demonstrating that climate impacts within this timeframe are inherently "foreseeable."

As a primary example of the feasibility of a 100-year time frame, the Intergovernmental Panel on Climate Change ("IPCC"), a foremost world scientific authority on climate change, has provided climate change projections through 2100 under a range of plausible emissions scenarios, the most recent of which are provided in the 2007 Fourth Assessment. For the Fourth Assessment, the IPCC performed an unprecedented internationally coordinated climate change experiment using 23 models by 14 modeling groups from 10 countries to project future climate conditions. This large number of models ranging from simple to complex, running the same experiments, provided both quantification of future climate conditions through the end of this century and the uncertainty of the results. As stated by the IPCC itself, climate projections run through the end of the 21st century under different emissions scenarios, and accompanied by the range of uncertainty, were provided in their 2007 Fourth Assessment Report specifically because of their policy-relevance:

> Advances in climate change modelling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emission scenarios. Results for different emission scenarios are provided explicitly in this report to avoid loss of this policy-relevant information. Projected global average surface warmings for the end of the 21st century (2090–2099) relative to 1980–1999 are shown in Table SPM.3. These illustrate the differences between lower and higher SRES emission scenarios, and the projected warming uncertainty associated with these scenarios.
> (IPCC 2007b: 13).

Moreover, in planning for species recovery, NMFS and its sister agency, the US Fish and Wildlife Service, routinely consider a foreseeable future threshold of roughly 100 years, particularly when addressing climate change considerations. For example, the agencies jointly stated in the second revision of their recovery plan for the Northwest Atlantic population of loggerhead sea turtles:

> Research has identified sea level rise as one of the most important potential impacts of global climate change. The best available science indicates that *by 2100* South Florida seas will be approximately 20 inches higher than they were in 1990 (IPCC 2001). An increase of this magnitude would drastically alter the coastline, changing the extent, quality, and location of sandy beaches available for loggerhead nesting. In the short term, even small changes in sea level could be expected to exacerbate beach erosion and increase artificial beach/dune alterations meant to protect coastal properties. (NMFS and USFWS 2008 at II-53 (emphasis added)).

Furthermore, following a recent workshop on reclassification criteria for endangered large whale species, NMFS has adopted a policy guideline that "[a] large cetacean species shall no longer be considered endangered when, given current and projected conditions, the probability of quasi-extinction is less than 1% in 100 years" (NMFS 2005 at III-1, Recovery Plan for the North Atlantic Right Whale).

Perhaps most importantly, the time period NMFS uses in its listing decision must be long enough so that actions can be taken to ameliorate the threats to the petitioned species and prevent extinction. *See Defenders of Wildlife v. Norton*, 258 F.3d 1136, 1142 (9th Cir. 2001) (quoting legislative history noting that the purpose of the ESA is "not only to protect the last remaining members of [a listed] species but to take steps to insure that species which are likely to be threatened with extinction never reach the state of being presently endangered"). Slowing and reversing impacts from anthropogenic greenhouse gas emissions, a primary threat to all of the petitioned coral species, will be a long-term process for a number of reasons, including the long lived nature of carbon dioxide and other greenhouse gases and the lag time between emissions and climate changes. NMFS must include these considerations in its listing decision.

For all these reasons, the use of less than 100 years as the "foreseeable future" in this rulemaking would be clearly be unreasonable, frustrate the intent of Congress to have imperiled species protected promptly and proactively, and fail to give the benefit of the doubt to the species as required by law.

As detailed throughout, neither anthropogenic greenhouse gas emissions nor any of the other threats to the petitioned coral species are speculative or too far in the future to understand or address. These new and modern threats are already here, and the impacts are already manifesting in coral populations. Urgent action, including listing under the ESA and dramatic cuts in greenhouse gas emissions levels, is needed now to ensure that these species do not become extinct in the foreseeable future. As described below, each of the petitioned coral species qualifies for listing under the ESA.

II. IUCN Status of Petitioned Coral Species

The International Union for the Conservation of Nature ("IUCN") is the world's foremost authority on the status of threatened species. The IUCN Redlist classification system is widely regarded as the most authoritative list of globally threatened species (Akçakaya et al. 2006; IUCN 2001). It is intended to be an easily and widely understood system for classifying species at high risk of global extinction (IUCN 2001). The general aim of the system is to provide an explicit, objective framework for the classification of the broadest range of species according to their extinction risk (IUCN 2001). The system used to evaluate coral species ("Version 3.1") is the result of a comprehensive and continuing process of drafting, consultation and validation (IUCN 2001).

In its most recent assessment of coral species, the IUCN partnered with Conservation International (CI) in a joint effort known as the Global Marine Species Assessment (Carpenter et al 2008). Leading coral experts evaluated 704 zooxanthellate reef-building coral species and found that 32.8% faced an elevated risk of extinction. *Id.* More corals were assigned the three most threatened categories of vulnerable, endangered, or critically endangered than any terrestrial animal group with the exception of amphibians, primarily due to their extreme susceptibility to climate change. *Id.*

Figure 94 depicts the IUCN classification system graphically, and Table 1 provides the definitions for each category. A reviewer categorizing a species considers each category in turn and places the species in the highest category of threat for which it meets any one of the IUCN's criteria (some criteria may never be applicable to some species, no matter how likely they are to become extinct) (IUCN 2001). Table 2 provides the criteria for the various categories. A species is classified as vulnerable, endangered, or critically endangered if it meets any one of criteria A through E shown in Table 3. All of the petitioned coral species are currently classified in one of these three categories by the IUCN.

Figure 94: IUCN Species Classification System
Source: IUCN Redlist Guidelines

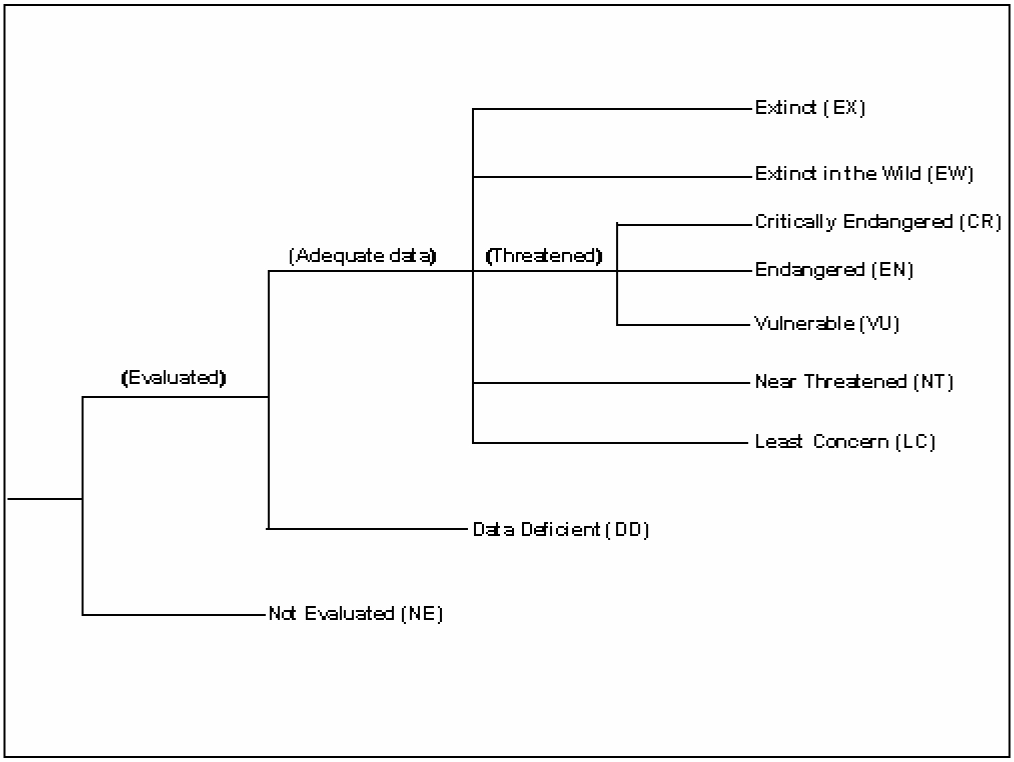

Table 1: IUCN Categories and Definitions
Source: IUCN Redlist Guidelines

CATEGORY	DEFINITION
EXTINCT (EX)	A taxon is Extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed Extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.
EXTINCT IN THE WILD (EW)	A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalized population (or populations) well outside the past range. A taxon is presumed Extinct in the Wild when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.
CRITICALLY ENDANGERED (CR)	A taxon is Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered (see Section V), and it is therefore considered to be facing an extremely high risk of extinction in the wild.
ENDANGERED	A taxon is Endangered when the best available evidence indicates that it

CATEGORY	DEFINITION
(EN)	meets any of the criteria A to E for Endangered (see Section V), and it is therefore considered to be facing a very high risk of extinction in the wild.
VULNERABLE (VU)	A taxon is Vulnerable when the best available evidence indicates that it meets any of the criteria A to E for Vulnerable (see Section V), and it is therefore considered to be facing a high risk of extinction in the wild.
NEAR THREATENED (NT)	A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.
LEAST CONCERN (LC)	A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa are included in this category.
DATA DEFICIENT (DD)	A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution are lacking. Data Deficient is therefore not a category of threat. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases great care should be exercised in choosing between DD and a threatened status. If the range of a taxon is suspected to be relatively circumscribed, and a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.
NOT EVALUATED (NE)	A taxon is Not Evaluated when it is has not yet been evaluated against the criteria.

Table 2: Quantitative Criteria for Endangered and Vulnerable Listings
Source: IUCN Redlist Guidelines, Version 3.1

CRITICALLY ENDANGERED	ENDANGERED	THREATENED
A. DECLINING TOTAL POPULATION – Reduction in population size based on any of the following 4 options and specifying a-e as appropriate		
(1) population size reduction that is observed, estimated, inferred, or suspected in the past 10 years or 3 generations, whichever is longer, where the causes of the reduction are clearly reversible AND understood AND ceased, based on (and specifying) any combination of a-e below:		
≥90%	≥ 70 %	≥ 50 %
(2) population size reduction that is observed, estimated, inferred, or suspected in the past 10 years or 3 generations, whichever is longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible, based on (and specifying) any combination of a-e below:		
≥80%	≥ 50 %	≥ 30 %
(3) population size reduction that is projected or suspected to be met within in the next 10 years or 3 generations, whichever is longer (up to a maximum of 100 years), based on (and specifying) and combination of b-e below:		
≥80%	≥ 50 %	≥ 30 %
(4) population size reduction that is observed, estimated, inferred, projected or suspected over any 10 year or 3 generation period, whichever is longer (up to a maximum of 100 years), where the time period includes both the past and the future, AND where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible, based on (and specifying) any combination of a-e below.		
a) direct observation **b)** an index of abundance appropriate for the taxon **c)** a decline in area of occupancy, extent of occurrence and/or quality of habitat **d)** actual or potential levels of exploitation **e)** the effects of introduced taxa, hybridization, pathogens, pollutants, competitors, or parasites		
B. SMALL DISTRIBUTION, AND DECLINE OR FLUCTUATION		
1. Extent of occurrence		
<100 km^2	< 5,000 km^2	< 20,000 km^2
OR		
2. Area of occupancy		
<10 km^2	< 500 km^2	< 2,000 km^2
For either of the above, specify at least two of a-c:		
(a) either severely fragmented or known to exist at # locations		
1	≤ 5	≤ 10
(b) continuing decline observed, inferred or projected in any of the following:		
i) extent of occurrence ii) area of occupancy iii) area, extent and/or quality of habitat iv) number of locations or populations		

CRITICALLY ENDANGERED	ENDANGERED	THREATENED
v) number of mature animals		
(c) extreme fluctuations in any of the following:		
	> 1 order of magnitude	> 1 order of magnitude
i) extent of occurrence ii) area of occupancy iii) number of locations or populations iv) number of mature animals		
C. SMALL TOTAL POPULATION SIZE AND DECLINE		
Number of mature individuals		
<250	< 2,500	< 10,000
And 1 of the following 2:		
(1) an estimate of continuing decline at a rate of at least:		
25% within 3 years or one generation (up to a maximum of 100 years in the future)	20% in 5 years or 2 generations (up to a maximum of 100 years in the future)	10% in 10 years or 3 generations (up to a maximum of 100 years in the future)
(2) continuing decline, observed, projected or inferred, in numbers of mature individuals and at least one of the following (a-b):		
(a) fragmentation – population structure in the form of one of the following:		
(i) no population estimated to contain >50 individuals	(i) no population estimated to contain >250 mature individuals	(i) no population estimated to contain >1,000 mature individuals
(ii) at least 90% of mature individuals in one subpopulation	(ii) at least 95% of mature individuals in one population	(ii) all mature individuals are in one population
(b) extreme fluctuations in the number of mature individuals		
D. VERY SMALL POPULATION OR RESTRICTED DISTRIBUTION		
(1) Number of mature individuals		
<50	< 250	< 1,000
(2) Applies only to threatened: Population with a very restricted area of occupancy or number of locations such that is prone to the effects of human activities or stochastic events within a very short time period in an uncertain future, and thus is capable of becoming highly endangered or even extinct in a very short time period.		
(not applicable)	(not applicable)	Area of occupancy typically < 20 km² or number of locations ≤ 5
E. QUANTITATIVE ANALYSIS		
Indicating the probability of extinction in the wild to be at least:		
50% in 10 years or 3 generations, whichever is the longer (up to a maximum of 100 years)	20 % in 20 years or 5 generations, whichever is longer (up to a maximum of 100 years)	10 % in 100 years

As discussed in the species accounts above, the current IUCN classification of each of the petitioned coral species is as follows:

Table 3: IUCN Listing Status of Petitioned Coral Species
Sources: IUCN Species Accounts

FAMILY	SPECIES	IUCN STATUS
Acroporidae	*Acropora aculeus*	Vulnerable
Acroporidae	*Acropora acuminata*	Vulnerable
Acroporidae	*Acropora aspera*	Vulnerable
Acroporidae	*Acropora dendrum*	Vulnerable
Acroporidae	*Acropora donei*	Vulnerable
Acroporidae	*Acropora globiceps*	Vulnerable
Acroporidae	*Acropora horrida*	Vulnerable
Acroporidae	*Acropora jacquelineae*	Vulnerable
Acroporidae	*Acropora listeri*	Vulnerable
Acroporidae	*Acropora lokani*	Vulnerable
Acroporidae	*Acropora microclados*	Vulnerable
Acroporidae	*Acropora palmerae*	Vulnerable
Acroporidae	*Acropora paniculata* (Fuzzy Table Coral)	Vulnerable
Acroporidae	*Acropora pharaonis*	Vulnerable
Acroporidae	*Acropora polystoma*	Vulnerable
Acroporidae	*Acropora retusa*	Vulnerable
Acroporidae	*Acropora rudis*	Endangered
Acroporidae	*Acropora speciosa*	Vulnerable
Acroporidae	*Acropora striata*	Vulnerable
Acroporidae	*Acropora tenella*	Vulnerable
Acroporidae	*Acropora vaughani*	Vulnerable
Acroporidae	*Acropora verweyi*	Vulnerable
Acroporidae	*Anacropora puertogalerae*	Vulnerable
Acroporidae	*Anacropora spinosa*	Endangered

FAMILY	SPECIES	IUCN STATUS
Acroporidae	*Astreopora cucullata*	Vulnerable
Acroporidae	*Isopora crateriformis*	Vulnerable
Acroporidae	*Isopora cuneata*	Vulnerable
Acroporidae	*Montipora angulata*	Vulnerable
Acroporidae	*Montipora australiensis*	Vulnerable
Acroporidae	*Montipora calcarea*	Vulnerable
Acroporidae	*Montipora caliculata*	Vulnerable
Acroporidae	*Montipora dilatata* (Irregular Rice Coral)	Endangered (also NMFS Species of Concern)
Acroporidae	*Montipora flabellata* (Blue Rice Coral)	Vulnerable
Acroporidae	*Montipora lobulata*	Vulnerable
Acroporidae	*Montipora patula* (Sandpaper Rice Coral/Spreading Coral/Ringed Rice Coral)	Vulnerable
Agaricidae	*Agaricia lamarcki* (Lamarck's Sheet Coral)	Vulnerable
Agaricidae	*Leptoseris incrustans*	Vulnerable
Agaricidae	*Leptoseris yabei*	Vulnerable
Agaricidae	*Pachyseris rugosa*	Vulnerable
Agaricidae	*Pavona bipartita*	Vulnerable
Agaricidae	*Pavona cactus*	Vulnerable
Agaricidae	*Pavona decussata*	Vulnerable
Agaricidae	*Pavona diffluens*	Vulnerable
Agaricidae	*Pavona venosa*	Vulnerable
Dendrophylliidae	*Turbinaria mesenterina*	Vulnerable
Dendrophylliidae	*Turbinaria peltata*	Vulnerable
Dendrophylliidae	*Turbinaria reniformis*	Vulnerable
Dendrophylliidae	*Turbinaria stellulata*	Vulnerable
Euphyllidae	*Euphyllia cristata*	Vulnerable

FAMILY	SPECIES	IUCN STATUS
Euphyllidae	*Euphyllia paraancora*	Vulnerable
Euphyllidae	*Euphyllia paradivisa*	Vulnerable
Euphyllidae	*Physogyra lichtensteini*	Vulnerable
Faviidae	*Barabattoia laddi*	Vulnerable
Faviidae	*Caulastrea echinulata*	Vulnerable
Faviidae	*Cyphastrea agassizi* (Agassiz's Coral)	Vulnerable
Faviidae	*Cyphastrea ocellina* (Ocellated Coral)	Vulnerable
Faviidae	*Montastraea annularis* (Boulder Star Coral)	Endangered
Faviidae	*Montastraea faveolata* (Mountainous Star Coral)	Endangered
Faviidae	*Montastraea franksi*	Vulnerable
Helioporidae	*Heliopora coerulea*	Vulnerable
Meandrinidae	*Dendrogyra cylindrus*	Vulnerable
Meandrinidae	*Dichocoenia stokesii* (Elliptical Star Coral)	Vulnerable
Milleporidae	*Millepora foveolata*	Vulnerable
Milleporidae	*Millepora tuberosa*	Endangered
Mussidae	*Acanthastrea brevis*	Vulnerable
Mussidae	*Acanthastrea hemprichii*	Vulnerable
Mussidae	*Acanthastrea ishigakiensis*	Vulnerable
Mussidae	*Acanthastrea regularis*	Vulnerable
Mussidae	*Mycetophyllia ferox*	Vulnerable
Oculinidae	*Galaxea astreata*	Vulnerable
Oculinidae	*Oculina varicosa* (Large Ivory Coral)	Vulnerable (also NMFS Species of Concern)
Pectinidae	*Pectinia alcicornis*	Vulnerable
Pocilloporidae	*Pocillopora danae*	Vulnerable
Pocilloporidae	*Pocillopora elegans*	Vulnerable
Pocilloporidae	*Seriatopora aculeata*	Vulnerable

FAMILY	SPECIES	IUCN STATUS
Poritidae	*Alveopora allingi*	Vulnerable
Poritidae	*Alveopora fenestrata*	Vulnerable
Poritidae	*Alveopora verrilliana*	Vulnerable
Poritidae	*Porites horizontalata*	Vulnerable
Poritidae	*Porites napopora*	Vulnerable
Poritidae	*Porites nigrescens*	Vulnerable
Poritidae	*Porites pukoensis*	Critically endangered
Siderastreidae	*Psammocora stellata* (Stellar Coral)	Vulnerable

While the IUCN Listing affords no actual regulatory protection to any species, such a listing is an unequivocal statement from scientists that the species is imperiled and warrants protection. These classifications are prima facie evidence that the petitioned species warrant protection under the ESA. Certainly, an IUCN listing is sufficient to meet the "may be warranted" threshold for initiating a status review as required by 16 U.S.C. § 1533(b)(3)(B).

As detailed below, scientific understanding of global warming and scientists' ability to predict future impacts from anthropogenic greenhouse gas emissions have advanced very rapidly in recent years, and in particular, over the past decade. We now know that greenhouse gas emissions, global warming, and ocean acidification pose a much greater and more urgent threat to organisms like the petitioned coral species than previously understood.

The current IUCN Redlist classification system was not designed to explicitly evaluate the widespread and pervasive threat posed by global warming and ocean acidification, and therefore may result in an underestimate of the threat faced by species impacted by climate change (Akçakaya et al. 2006).[2] For example, the restriction of consideration to a time frame of three generations or 10 years, whichever is longer, under Factor A3 prevents the listing of a coral species expected to suffer large scale declines in more than 30 years from global warming (IUCN Species Accounts; Akçakaya et al. 2006). Because of the lag time in the climate system, a species may already be committed to declines that will not manifest themselves for many decades. Factor E may be used to classify species based on the probability of extinction over longer time periods, but the problem here is that for most species available data are not sufficient for building models to estimate this probability (Akçakaya et al. 2006). This is a further reason why the IUCN classifications for each petitioned coral species must be considered a minimum estimate of its current degree of imperilment.

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[2] The IUCN Species Accounts for corals specifically acknowledge this shortcoming, noting for each of the petitioned species that "[i]t will be important to reassess this species in 10 years time because of predicted threats from climate change and ocean acidification." *See* IUCN Species Accounts, "Rationale for the Red List Assessment" sections.

III. The Survival of Each of the Petitioned Coral Species Is Threatened by One or More of the Endangered Species Act Listing Factors

A. The Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

Worldwide, habitat loss and degradation is the primary cause of species extinction (Primack 2001). This is particularly true for the petitioned corals. All the petitioned species are under severe and pervasive threat from anthropogenic greenhouse gas emissions, which are resulting in increasing ocean temperatures, rising ocean acidification, increasing storm intensities, changes in precipitation, and sea level rise, which are degrading and modifying their habitat. In addition, habitat destruction and degradation from factors including ship traffic, dredging, coastal development, pollution, and agricultural and land use practices that increase sedimentation and nutrient-loading threaten many of the petitioned coral species. These threats to the continued existence of the petitioned coral species are discussed below as well as in the species accounts and regional status reviews above.

1. Anthropogenic Greenhouse Gas Emissions Resulting in Climate Change and Ocean Acidification that Threaten the Petitioned Coral Species

Coral reef ecosystems are widely recognized as among the most vulnerable ecosystems to the impacts of climate change (Fischlin et al. 2007): “reefs are likely to be the first major planetary-scale ecosystem to collapse in the face of climate changes now in progress” (Veron et al. 2009: 1433). Corals have already experienced significant impacts from mass bleaching events and ocean acidification. In addition, scientific studies indicate that the petitioned coral species are threatened with extinction before mid-century due to the projected increase in frequency of mass bleaching events and the dissolution and weakening of corals due to rising ocean acidification. Immediate protection of the petitioned coral species is needed since the degradation of coral reefs due to climate change is expected to progress faster than many other prominently researched impacts of climate change, including ice sheet melting, Amazonian forest dieback, migration of tropical diseases, and declines in agricultural productivity (Donner 2009).

This section reviews the best available scientific information regarding (a) the greenhouse effect and current levels of greenhouse gases; (b) observed and projected climate change and ocean acidification in the range of the petitioned coral species; and (c) observed and projected impacts to the petitioned coral species from climate change and ocean acidification within this century.

a. The Greenhouse Effect, Greenhouse Gas Concentrations, And Global Warming

In its most recent 2007 report, the Intergovernmental Panel on Climate Change (IPCC)[3] expressed in the strongest language possible its finding that global warming is occurring: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (IPCC 2007a: 30). The international scientific consensus of the IPCC is that most of the recent warming observed has been caused by human activities (IPCC 2007a). The U.S. Global Change Research Program also stated that "global warming is unequivocal and primarily human-induced" (USGCRP 2009: 12). One of the most troubling recent findings is that the concentration of atmospheric carbon dioxide, the biggest contributor to global warming, has been rapidly increasing throughout the 2000s and is generating stronger-than-expected and sooner-than-predicted climate forcing (Canadell et al. 2007, Raupach et al. 2007).

The basic physics underlying global warming are as well established as any phenomena in the planetary sciences. The earth absorbs heat in the form of radiation from the sun, which is then redistributed by atmospheric and oceanic circulations and also radiated back to space (Le Treut et al. 2007). The earth's climate is the result of a state in which the amount of incoming and outgoing radiation is approximately in balance. Changes in the earth's climate can be caused by any factor that alters the amount of radiation that reaches the earth or the amount that is lost back into space, or that alters the redistribution of energy within the atmosphere and between the atmosphere, land, and ocean (Le Treut et al. 2007). A change in the net radiative energy available to the global earth-atmosphere system is called "radiative forcing" (Le Treut et al. 2007). Positive radiative forcings tend to warm the earth's surface while negative radiative forcings tend to cool it (Albritton et al. 2001).

Radiative forcings are caused by both natural and anthropogenic factors (Albritton et al. 2001, Le Treut et al. 2007). The level of scientific understanding of these different forcings varies, and the forcings themselves and interactions between them are complex (Le Treut et al. 2007). The primary cause of global warming, however, is society's production of massive amounts of "greenhouse gases" such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons that cause positive radiative forcings (Forster et al. 2007, Le Treut et al. 2007).

The Enhanced Greenhouse Effect is caused by increasing concentrations of these greenhouse gases in the earth's atmosphere. As greenhouse gas concentrations increase, more heat reflected from the earth's surface is absorbed by these greenhouse gases and radiated back into the atmosphere and to the earth's surface. Increases in the concentrations of greenhouse gases slow the rate of heat loss back into space and warm the climate, much like the effect of a common garden greenhouse (Forster et al. 2007, Le Treut et al. 2007). The higher the level of greenhouse gas concentrations, the larger the degree of warming experienced.

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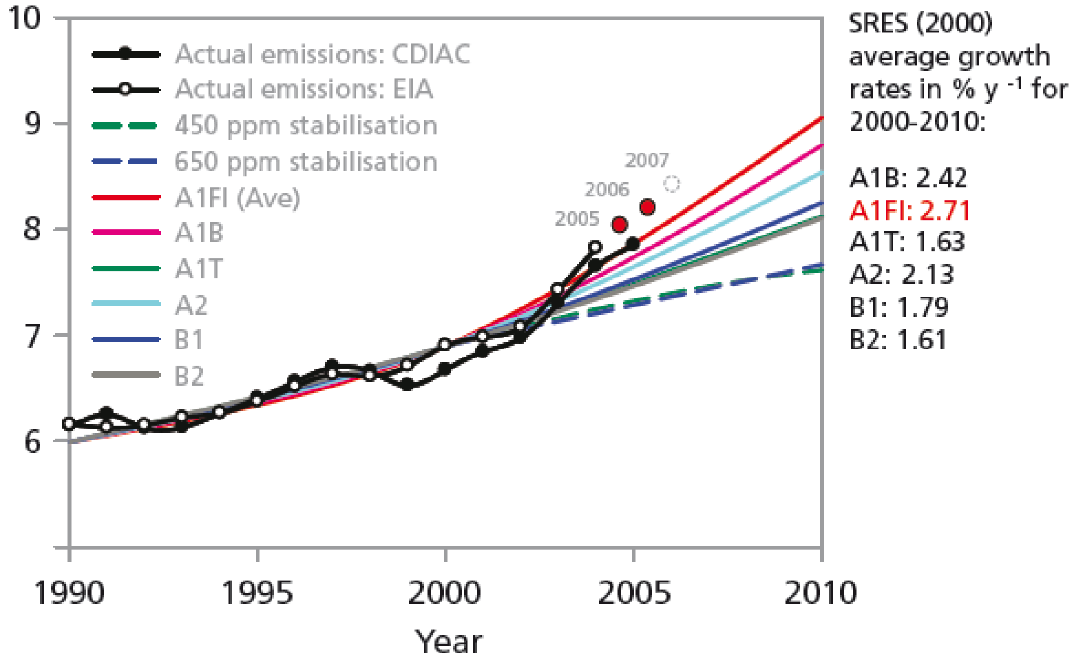
[3] The IPCC was established by the World Meteorological Organization and the United Nations Environment Programme in 1988 (IPCC 2001). The IPCC's mission is to assess available scientific and socioeconomic information on climate change and its impacts and the options for mitigating climate change and to provide, on request, scientific and technical advice to the Conference of the Parties to the United Nations Framework Convention on Climate Change (IPCC 2001). Since 1990, the IPCC has produced a series of reports, papers, methodologies, and other products that have become the standard works of reference on climate change (IPCC 2001). The 2007 *Fourth Assessment Report* is the most current comprehensive IPCC reference and has built and expanded upon the IPCC's past products.

By the time of the Fourth Assessment Report of the IPCC in 2007, the atmospheric concentration of carbon dioxide had increased by 36% since 1750 to a level that has not been exceeded during the past 650,000 years and likely not during the past 20 million years (Denman et al. 2007). About three fourths of anthropogenic carbon dioxide emissions come from fossil fuel burning, and most of the remaining emissions are due to land-use changes, primarily deforestation (Denman et al. 2007). Carbon dioxide is considered the most important greenhouse gas overall because the volume emitted is greater that of all the other greenhouse gases combined. The atmospheric concentration of methane, another important greenhouse gas, has increased by about 150% since 1750, continues to increase, and has not been exceeded during the past 650,000 years (Forster et al. 2007). Similarly, the atmospheric concentration of nitrous oxide has increased by about 18% since 1750, continues to increase, and has not been exceeded during at least the last 2000 years. *Id.*.

The rate of increase of total atmospheric carbon dioxide concentrations is accelerating, with especially rapid increases observed in the 2000s (Canadell et al. 2007). The emissions growth rate rose from 1.1% per year from 1990-1999 to 3.5 % per year from 2000-2007 (McMullen and Jabbour 2009). The emissions growth rate since 2000 has even exceeded that of the most fossil-fuel intensive IPCC SRES emissions scenario, A1FI (Figure 95) (Raupach et al. 2007, Richardon et al. 2009, McMullen and Jabbour 2009). These increased emissions have been attributed to rises in fossil fuel burning and cement production (average proportional growth increased from 1.3% yr^{-1} to 3.3% yr^{-1}) rather than emissions from land-use change which remained approximately constant (Canadell et al. 2007). During the past 50 years, carbon dioxide sinks on land and in the oceans have become less efficient in absorbing atmospheric carbon dioxide, which is also contributing to the observed rapid rise (Canadell et al. 2007). With atmospheric carbon dioxide at ~387 ppm and worldwide emissions continuing to increase by more than 2 ppm each year, rapid and substantial reductions are clearly needed immediately.

Figure 95. Observed CO_2 emissions from 1990-2007 from U.S. Department of Energy Information Administration (EIA) data and U.S. Department of Energy Carbon Dioxide Information and Analysis (CDIAC) data, compared with six IPCC emissions scenarios and with stabilization trajectories describing emissions pathways for stabilization of atmospheric CO_2 at 450 and 650 ppm.
Source: Richardson et al. (2009): 11.



b. Observed and Projected Climate Change and Ocean Acidification

i. Ocean Surface Temperature

Observed surface temperature increases

The global average surface temperature rose by approximately 0.74° C ± 0.18° C (1.33° F ± 0.32° F) during the past ~100 years (1906-2005) over both ocean and land surfaces (Trenberth et al. 2007). Global ocean temperatures have increased by 0.31 °C on average in the upper 300 m during the past 60 years (1948-1998) (Levitus et al. 2000), and locally, some ocean regions are experiencing even greater warming (Bindoff et al. 2007). Global ocean temperatures increased by 0.10 °C in the upper 700 m between 1961-2003 (Bindoff et al. 2007) and by 0.037 °C in the upper 3000 m (Levitus et al. 2005). The largest increases in global ocean temperature have occurred in the upper ocean inhabited by the petitioned coral species.

In some tropical ocean regions, surface temperature rose by 1.25-1.7°C during the 20th century (Hoegh-Guldberg 1999: Table 2). Ocean surface warming has accelerated in recent decades (Figure 96) (Trenberth et al. 2007). At a number of reef sites across the globe, regional sea surface temperature trends averaged 0.24°C per decade during 1985-2006 (Table 4) (Eakin et al. 2009). Regional trends are discussed further below.

Figure 96. Latitude-time sections of zonal mean temperature anomalies (°C) from 1900 to 2005, relative to the 1961 to 1990 mean. SST annual anomalies across each ocean from HadSST2. Source: Trenberth et al. (2007): Figure 3.5.

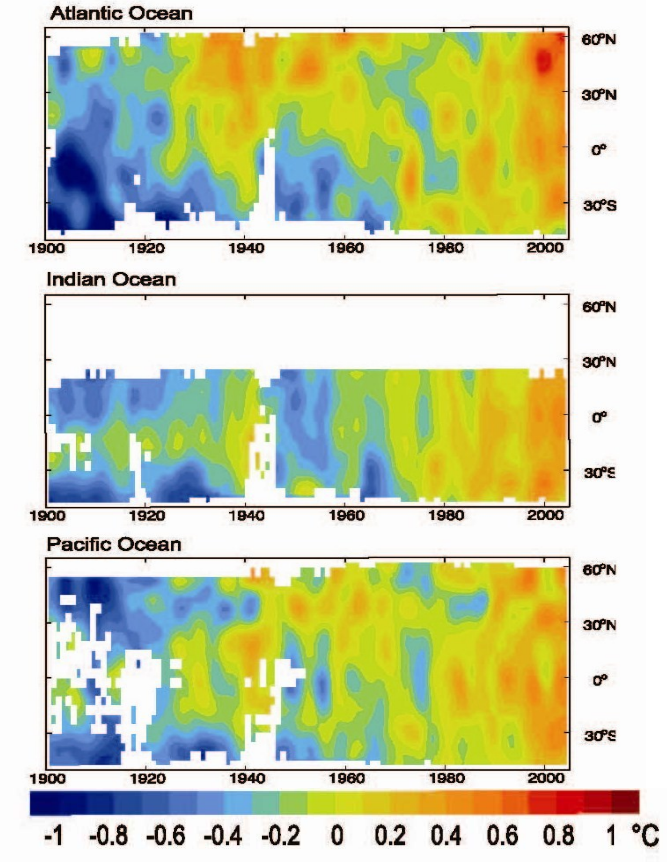


Table 4. Trends in SST anomalies across five geographic regions from the Pathfinder reanalysis of the 22-year satellite record, 1985–2006. The SST anomaly values are averaged across specific reef pixels within each region and for each year.
Source: Eakin et al. (2009): Table 4.1.

Region	Number of reef pixels	Trend in SST anomaly (°C/decade)	S.E. in trend (°C/decade)
Global	50	0.237	0.061
Indian Ocean and Middle East	18	0.261	0.074
Southeast Asia	9	0.232	0.078
Pacific Ocean	11	0.181	0.056
Caribbean and Atlantic Ocean	12	0.257	0.061

Regional trends in ocean warming

Warming in the Tropical Pacific

Over the past 128 years (1880-2007), the Eastern Pacific warmed at a rate of 0.24°C per century, the Central Pacific at 0.35°C per century, and the Western Pacific at 0.40°C per century (Heron et al. 2008). Further west, the reefs of Southeast Asia warmed at a rate of 0.44°C per century, with warming rates at the Great Barrier Reef and in the warm water pool region of 0.52°C. *Id.*

The warming of the tropical Pacific has worldwide repercussions because it is a primary driver of the global atmosphere and ocean (Hansen et al. 2006). The tropical Pacific atmosphere–ocean system is the main source of heat transported by both the Pacific and Atlantic Oceans (Hansen et al. 2006). Heat and water vapor fluxes to the atmosphere in the Pacific have a profound effect on the global atmosphere, as demonstrated by El Niño Southern Oscillation climate variations (Hansen et al. 2006).

The El Niño Southern Oscillation (ENSO)

Although the effects of climate change on the ENSO cycle are difficult to predict, leading climate scientists believe that global warming leads to an increased likelihood of stronger ENSO events in the near term, given the differential warming to date in the Western Equatorial Pacific compared to the Eastern Equatorial Pacific (Hansen et al. 2006). Deep water upwelling in the east appears to be buffering the impacts of global warming in the Eastern Equatorial Pacific to date, whereas the Western Equatorial Pacific is warming at a faster rate. *Id.* The increasing temperature differential between the near-equatorial Western and Eastern Pacific allows the possibility of increased temperature swing from a La Niña phase to an El Niño event. *Id.* In the longer term, anthropogenic climate change is expected to slow the mean tropical circulation, including the Walker circulation that sustains normal climate conditions. *Id.*

Some climate scientists have hypothesized that during the early Pliocene, when the Earth was 3° C (5.4° F) warmer than today, a permanent ENSO-like condition existed. *Id.* From the observational record, intense ENSO events were more abundant in the later part of the 20th century. The 1982-83 and 1997-98 ENSO events were successively labeled the "El Niño of the Century" because the warming in the Eastern Equatorial Pacific was unprecedented in the past 100 years. *Id.*

Warming in the Indian Ocean

The top 100 meters of the Indian Ocean has been warming everywhere with the exception of a band centered at 12°S that is highly influenced by the South Equatorial Current (Bindoff et al. 2007). Over the 20th century, sea surface temperatures in the Middle East and the Western Indian Ocean increased at a rate of 0.50°C per century, with increases of 0.59°C per century in the Central and Eastern Indian Ocean over the same period (Heron et al. 2008). Between 1970 and 1999, warming rates significantly increased, exceeding 0.2°C per decade in some regions (Bindoff et al. 2007). The Central and Eastern Indian Ocean has warmed faster than any other tropical region since 1950 (Heron et al. 2008).

Global ocean circulation patterns transport warm, relatively fresh waters from the tropical Pacific Ocean through the Indonesian Seas, the Indian Ocean, and finally into the South Atlantic (Bindoff et al. 2007). The tropics south of the equator (between 3°S and 15°S) represent the key flowthrough zone for this circulatory pattern, and this region is strongly influenced by ENSO and the Indian Ocean Dipole ("IOD"). *Id.* The IOD is an aperiodic, often interannual oscillation of sea surface temperatures and associated precipitation trends in the Western and Eastern Indian Ocean, which produces pronounced thermocline variability in the flowthrough zone. *Id.* A positive IOD phase is defined by warmer sea surface temperatures and increased precipitation in the Western Indian Ocean, with cooler water and drier conditions in the East. In 1997-1998, a positive IOD coincided with an El Niño event, with consequent extreme sea surface temperatures causing over 90% mortality on most Indian Ocean reefs (Sheppard 2003).

Warming in the Atlantic and the Caribbean

The North Atlantic Ocean and Caribbean Sea has experienced warming trends of 0.36 and 0.37°C per century, respectively (Heron et al. 2008). Superimposed on top of this warming, the Atlantic Multi-decadal Oscillation ("AMO") influences Atlantic and Caribbean reef temperatures on a cycle of 65-70 years. *Id.* The synergistic effects of the AMO and anthropogenic warming could have devastating consequences for the region's coral reefs in the future, perhaps similar to the catastrophic warming and bleaching events of 2005. *Id.*

Projected surface temperature increases

The IPCC has projected 1.1 to 6.4°C (2° to 11.5° F) of additional surface warming (relative to 1980-1999) by the end of this century, with higher warming produced by more intensive greenhouse gas emissions scenarios (Solomon et al. 2007). Under the current emissions trajectory, which is now exceeding the most fossil-fuel intensive IPCC projection (A1FI), global average surface temperatures would rise by more than 4.0°C on average (2.4°C to 6.4°C) (Solomon et al. 2007).

On a regional basis, under a mid-level A1B emissions scenario, surface temperature by 2100 would increase by an average of 2.0°C (range: 1.4-3.2°C) in the Caribbean; by 2.1°C (range: 1.4-3.7°C) in the Indian Ocean; by 2.3°C (range: 1.5-3.7°C) in the North Pacific Ocean (0 to 40°N, 150°E to 80°W); and by 1.8°C (range: 1.4-3.1°C) in the South Pacific Ocean (0 to 55°S, 150°E to 80°W) (Christensen et al. 2007: Table 11.1).

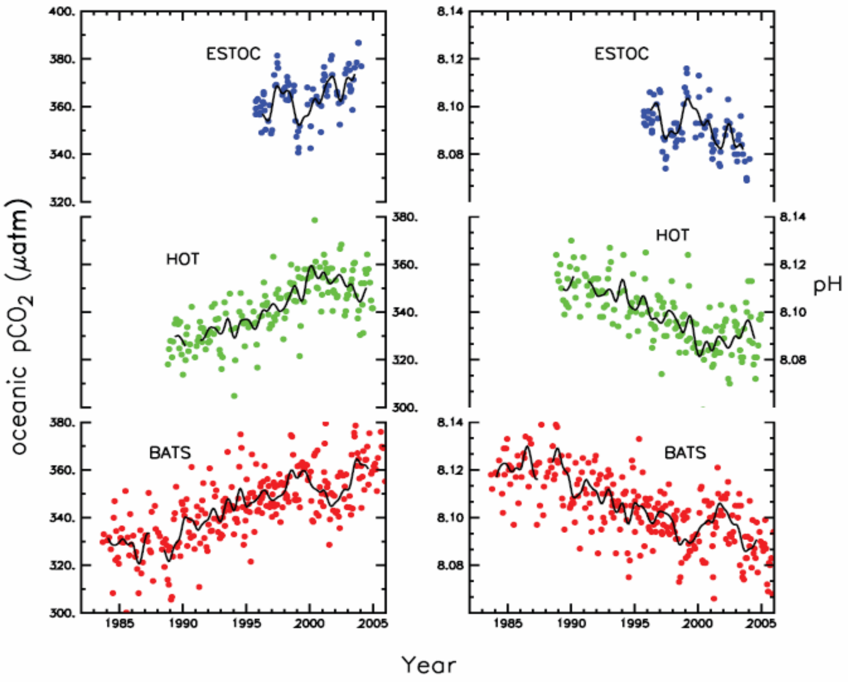
ii. Ocean Acidification

The world's oceans are an important part of the planet's carbon cycle, absorbing large volumes of carbon dioxide and cycling it through various chemical, biological, and hydrological processes. The oceans have thus far absorbed approximately 30% of the excess carbon dioxide emitted since the beginning of the industrial revolution (Feely et al. 2004; Schubert et al. 2006). The world's oceans, in fact, store about 50 times more carbon dioxide than the atmosphere (Schubert et al. 2006), and about half of the carbon dioxide released into the atmosphere from human activities will ultimately be absorbed by the oceans (74 Fed. Reg. 17484). Currently, global oceans are absorbing about 22 million tons of carbon dioxide each day (Feely et al. 2006).

The ocean's absorption of anthropogenic carbon dioxide from the atmosphere is fundamentally changing the chemistry of the ocean (Caldeira and Wickett 2003; Orr et al. 2005; Caldeira et al. 2007; Feely et al. 2008). Slightly alkaline waters are becoming more acidic and carbonate ions are becoming less available. Specifically, carbon dioxide is readily absorbed into surface waters where it reacts with seawater to form carbonic acid. Carbonic acid dissociates to form bicarbonate ions and hydrogen ions which in turn react with carbonate ions to form more bicarbonate. This reaction reduces the availability of carbonate ions and decreases pH. Surface ocean pH has already dropped by 0.11 units on the pH scale, from 8.16 in 1800 to 8.05 today, equivalent to a 30% increase in acidity (Figure 97), and the surface concentration of carbonate ions has decreased by more than 10% since the pre-industrial era (Caldeira and Wickett 2003; Orr et al. 2005; Caldeira et al. 2007; Feely et al. 2008).

At present, the effects of ocean acidification are greatest in surface waters (less than 1000 meters depth) where carbon dioxide exchange occurs with the air (Orr et al. 2005). Because the spread of carbon dioxide from the surface waters into intermediate and deep ocean levels is a slower mixing process on the timescale of hundreds of years, most of the carbon dioxide absorbed by at the ocean surface remains in the shallowest 100 meters of water for a long time (Royal Society 2005). However, the decline in aragonite and calcite saturation will extend throughout the water column in the foreseeable future (Orr et al. 2005).

Figure 97. Changes in surface oceanic pCO_2 (left; in μatm) and pH (right) from three time series stations: Blue: European Station for Time-series in the Ocean (ESTOC, 29°N, 15°W; Gonzalez-Dávila et al., 2003); green: Hawaii Ocean Time-Series (HOT, 23°N, 158°W; Dore et al., 2003); red: Bermuda Atlantic Time-series Study (BATS, 31/32°N, 64°W; Bates et al., 2002; Gruber et al., 2002). Values of pCO_2 and pH were calculated from DIC and alkalinity at HOT and BATS; pH was directly measured at ESTOC and pCO_2 was calculated from pH and alkalinity. The mean seasonal cycle was removed from all data. The thick black line is smoothed and does not contain variability less than 0.5 years period.
Source: Bindoff et al. (2007): Figure 5.9.



Ecological impacts of ocean acidification

One of the major impacts of ocean acidification is that it impairs the ability of marine organisms like corals to build protective calcium carbonate shells, liths, and skeletons because carbonate minerals, calcite and aragonite, become less available (Feely et al. 2004; Orr et al. 2005; Fabry et al. 2008). Nearly all calcifying organisms studied, including species from the major marine calcifying groups and plankton at the base of the marine food web, have shown an adverse response of reduced calcification in response to elevated carbon dioxide in laboratory experiments (Kleypas et al. 2006; Fabry et al. 2008). In addition, reduced calcification is already being detected in marine organisms in the wild, including reduced coral calcification rates on the Great Barrier Reef (De'ath et al. 2009) and reduced shell weights of modern foraminifera in the Southern Ocean (Moy et al. 2009). According to the EPA:

> As more CO_2 dissolves in the ocean, it reduces ocean pH, which changes the chemistry of water. These changes present potential risks across a broad spectrum of marine ecosystems…For instance, ocean acidification related reductions in pH is forecast to reduce calcification rates in corals and may affect economically important shellfish species including oysters, scallops, mussels, clams, sea urchins, and lobsters…Impacts to shellfish and other calcifying organisms that represent the base of the food web may have implications for larger organisms that depend on shellfish and other calcifying organisms for prey. (74 Fed. Reg. 17485)

Ocean acidification also disrupts metabolism and other biological functions in marine life. Changes in the ocean's carbon dioxide concentration result in accumulation of carbon dioxide in the tissues and fluids of fish and other marine animals, called hypercapnia, and increased acidity in the body fluids, called acidosis. These impacts can cause a variety of problems for marine animals including difficulty with acid-base regulation, metabolic activity, respiration, and ion exchange, leading to impairment of growth and higher mortality rates (Fabry et al. 2008; Pörtner et al. 2004; Royal Society 2005; Ishimatsu et al. 2004).

Projected increases in ocean acidification and decreases in carbonate

Ocean acidification will worsen due to the continuing rise in atmospheric carbon dioxide concentrations. At an atmospheric CO_2 level of 560 ppm, pH would drop 0.24 units to ~7.9 and most ocean surface waters would be adversely undersaturated with respect to aragonite (Veron et al. 2009). If CO_2 levels reach 788 ppm, ocean pH would drop 0.3 or 0.4 units amounting to a 100–150% change in acidity, and tropical surface concentrations of carbonate would decline by 45% (Orr et al. 2005; Meehl et al. 2007). A pH change of this magnitude has not occurred for more than 20 million years (Feely et al. 2004).

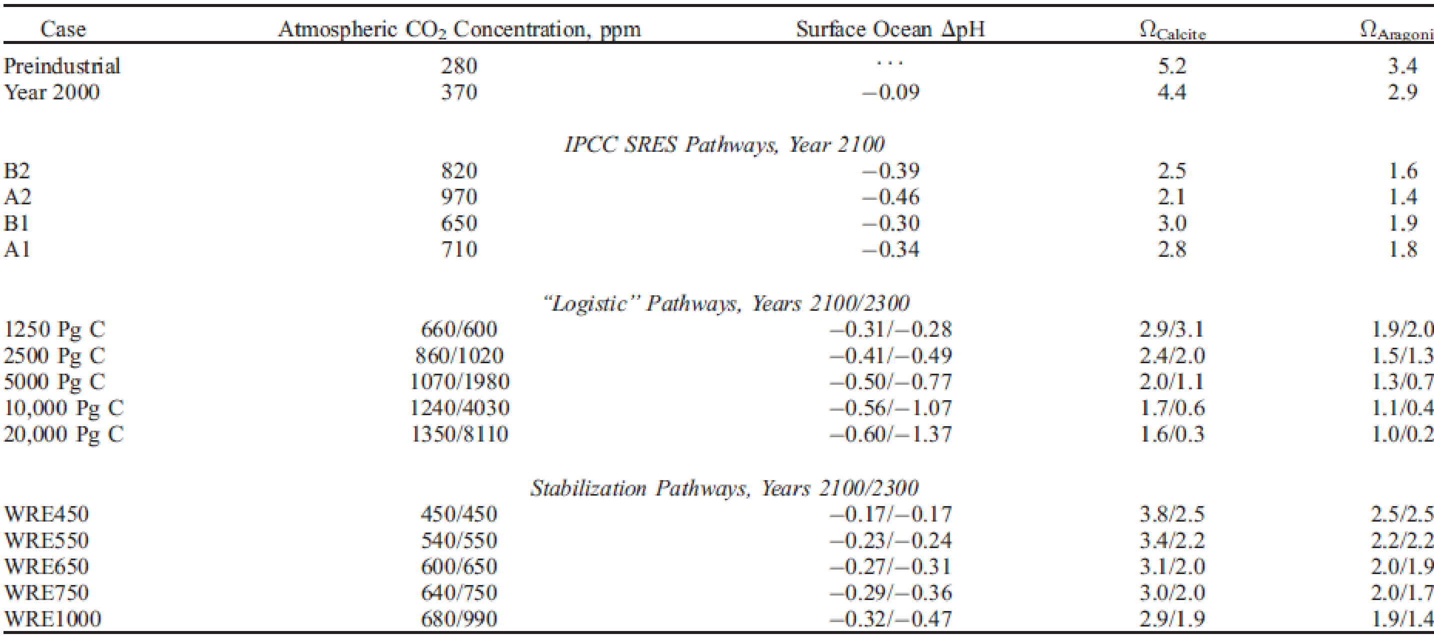
Caldeira and Wickett (2005) projected changes in surface ocean pH and the saturation state of aragonite (ΩAragonite) and calcite (ΩCalcite) under four IPCC emissions scenarios (A1, A2, B1, and B2) and the WRE pathways that stabilize CO_2 at 450 to 1000 ppm. The lowest emission SRES pathway considered (B1) produces global surface pH reductions of about 0.3 pH units by year 2100, a drop in ΩAragonite from 3.4 pre-industrial to 1.9 in 2100, and a drop in

ΩCalcite from 5.2 pre-industrial to 3.0 in 2100 (Table 5). The highest emission pathway considered (A2) produces global surface pH reductions approaching 0.5 pH units, a drop in ΩAragonite to 1.4 in 2100, and a drop in ΩCalcite to 2.1 (Table 5). The lowest stabilization pathway WRE 450 results in global surface pH reductions of 0.17 pH units, a drop in ΩAragonite to 2.5 in 2100 and 2300, and a drop in ΩCalcite to 3.8 in 2100 and to 2.5 in 2300 (Table 5). Importantly, coral reef accretion stops and erosion begins at aragonite saturation values < 3.3 (Hoegh-Goldberg et al. 2007). There are five classes of saturation levels for aragonite in sea water (Steinacher et al. 2009):

(i) More than 400% saturated ($\Omega>4$)—optimal for coral growth
(ii) 300-400% saturated ($3<\Omega<4$)—adequate for coral growth
(iii) 200-300% saturated ($2<\Omega<3$)—marginal to inadequate for coral growth
(iv) 100-200% saturated ($1<\Omega<2$)—marginal to inadequate for coral growth
(v) Undersaturated ($\Omega<1$)—unsuitable for pteropods

Moreover, even if carbon dioxide emissions ceased immediately, the ocean would continue to absorb the excess carbon dioxide in the atmosphere, resulting in further acidification until the planet's carbon budget returned to equilibrium.

Table 5. Mean surface ocean results for simulated years 2100 and 2300, including changes in surface ocean pH and the calcite (ΩCalcite) and aragonite (ΩAragonite) saturation state. Source: Caldeira and Wickett (2005): Table 1.



Case	Atmospheric CO_2 Concentration, ppm	Surface Ocean ΔpH	$\Omega_{\mathrm{Calcite}}$	$\Omega_{\mathrm{Aragoni}}$
Preindustrial	280	···	5.2	3.4
Year 2000	370	−0.09	4.4	2.9
		IPCC SRES Pathways, Year 2100		
B2	820	−0.39	2.5	1.6
A2	970	−0.46	2.1	1.4
B1	650	−0.30	3.0	1.9
A1	710	−0.34	2.8	1.8
		"Logistic" Pathways, Years 2100/2300		
1250 Pg C	660/600	−0.31/−0.28	2.9/3.1	1.9/2.0
2500 Pg C	860/1020	−0.41/−0.49	2.4/2.0	1.5/1.3
5000 Pg C	1070/1980	−0.50/−0.77	2.0/1.1	1.3/0.7
10,000 Pg C	1240/4030	−0.56/−1.07	1.7/0.6	1.1/0.4
20,000 Pg C	1350/8110	−0.60/−1.37	1.6/0.3	1.0/0.2
		Stabilization Pathways, Years 2100/2300		
WRE450	450/450	−0.17/−0.17	3.8/2.5	2.5/2.5
WRE550	540/550	−0.23/−0.24	3.4/2.2	2.2/2.2
WRE650	600/650	−0.27/−0.31	3.1/2.0	2.0/1.9
WRE750	640/750	−0.29/−0.36	3.0/2.0	2.0/1.7
WRE1000	680/990	−0.32/−0.47	2.9/1.9	1.9/1.4

iii. Intensification of Storms and Changes in Precipitation

The number of tropical storms reaching categories four and five has increased by 75% since 1970 (Mimura et al. 2007; Trenberth et al. 2007). The most dramatic increases in storm intensity were in the North Pacific, Indian, and Southwest Pacific Oceans. Between 1995 and

2006, numbers of hurricanes in the North Atlantic have also been above normal in nine of those 11 years, culminating in the devastating and record-breaking 2005 season (Trenberth et al. 2007).

While tropical storms and their associated precipitation have become more intense in recent decades, overall precipitation trends in the tropics (25°S to 25°N) over the past 25 years show a 2% decrease in precipitation over land coupled with a 4% increase in ocean precipitation within that latitude belt (Trenberth et al. 2007). As a result, droughts have increased in tropical land areas, which negatively impacts human communities and land use practices and increases sediment and nutrient run-off into nearshore reef ecosystems, especially during extreme storm events. *Id.* In its technical report, *Climate Change and Water,* the IPCC noted that "[p]recipitation increases over the tropical oceans and in some of the monsoon regimes, e.g., the south Asian monsoon in summer (June to August) and the Australian monsoon in summer (December to February), are notable and, while not as consistent locally, considerable agreement is found at the broader scale in the tropics" (Bates et al. 2008: 25).

Climate models indicate that the severity of tropical storms will increase in the future in most tropical regions as a result of global warming. The IPCC concluded that "[i]t is *likely* that future tropical cyclones will become more intense, with larger peak wind speeds and heavier precipitation, associated with ongoing increases of tropical [sea surface temperatures]" (Bates et al. 2008: 31). Maximum tropical cyclone wind intensities will likely increase 5-10% by 2050, and peak tropical precipitation rates are likely to increase by 25%, which in turn causes higher storm surges. *Id.* Since hurricanes and typhoons can form only where sea surface temperatures exceed 26°C, the warming of the oceans may increase the areas over which tropical storms can form (Trenberth et al. 2007). Thus, there is a strong possibility of more persistent and devastating tropical storm events in the future due to anthropogenic warming (Mimura et al. 2007).

Higher sea surface temperatures also increase evaporation at the surface of the ocean, heightening concentrations of water vapor in the atmosphere. This increased water vapor provides added moist-static energy to fuel intense storm events, and functions as a heat trapping greenhouse gas (Trenberth et al. 2007). According to the IPCC, "[w]ater vapour changes represent the largest feedback affecting equilibrium climate sensitivity" (IPCC 2007a: 38).

iv. Sea Level Rise

Sea level rise is occurring due to thermal expansion of sea water and ice discharge from the large ice sheets and marine-terminating glaciers (Milne 2009). Global average sea level rose at an average rate of 1.8 mm per year during 1961 to 2003 and at a higher average rate of about 3.1 mm per year during the more recent period from 1993 to 2003 (IPCC 2007a). The rate of sea-level rise increased in the period since 1993 largely due to the growing contribution of ice loss from Greenland and Antarctica (Richardson et al. 2009).

Estimates of future sea-level rise vary according to the projection method utilized, which include (1) extrapolation of recent observed relationships between global average temperature rise and sea-level rise; (2) reconstruction of sea-level rise from the geological record; and (3) "process" models that attempt to simulate processes that control ice discharge from ice sheets

(Milne 2009; Richardson et al. 2009). Importantly, many studies using different methodologies project that sea-level rise could reach one meter or more within this century.

Sea-level rise projections based on the observed relationship between global average temperature rise and sea-level rise over the recent observational record (~120 years) suggest that sea level will rise by a meter or more by 2100 (Richardson et al. 2009). This approach assumes that the observed relationships between temperature and sea-level rise will continue into the future, although rapid, dynamic changes in ice flow from the ice sheets could increase ice sheet contribution.

Studies that have reconstructed past sea-level rise based on the geological record have constrained the upper limit of global mean sea-level rise possible over the 21st century to less than one meter to 2.5 to 4 meters (Milne 2009). The high rates of sea-level change of 2.5 to 4 meters per century interpreted from oxygen isotope and coral records are certainly troubling (Milne 2009), and provide evidence that the rate of future melting and related sea-level rise could be faster than previously widely believed (Overpeck et al. 2006).

"Process" models attempt to simulate the processes that control ice discharge from the large ice sheets and marine-terminating glaciers to estimate the contribution of land-ice to sea-level rise. Since process models are as yet unable to accurately simulate ice sheet behavior, projections based on these models are uncertain (Richardson et al. 2009). For example, the sea-level rise estimate provided in the IPCC's Fourth Assessment Report explicitly did not include "rapid dynamical changes in ice flow" (IPCC 2007a: 45) due to the difficulties in modeling ice discharge and important feedback processes. Sea-level rise included in the IPCC estimate was primarily due to the thermal expansion of the ocean from ocean temperature rise and glacier melt, with only a negligible contribution from loss of the Greenland and Antarctic ice sheets. Accordingly, the IPCC explicitly stated that the sea level rise projection of 0.19 to 0.59 meters (7 to 23 inches) by 2100 does not represent "best estimates" or "upper bounds" for sea level rise because it failed to adequately incorporate ice sheet contributions. Pfeffer et al. (2008) attempted to include estimates of increased ice flow dynamics in projections of sea-level rise by 2100 and estimated a range of 0.8 to 2.0 meters.

Recent studies documenting the accelerating ice discharge from the Greenland and Antarctic ice sheets indicate that the IPCC projections are a substantial underestimate. For example, new satellite data show that thinning of the Greenland and western Antarctica ice sheets at their ocean margins is occurring at a rapid pace due to "dynamic melting," and some glaciers have entered a dynamic runaway melting mode (Pritchard et al. 2009):

> We find that dynamic thinning of glaciers now reaches all latitudes in Greenland, has intensified on key Antarctic grounding lines, has endured for decades after ice-shelf collapse, penetrates far into the interior of each ice sheet and is spreading as ice shelves thin by ocean-driven melt. (Pritchard et al. 2009: 1).

In Greenland, 81 of the 111 glaciers surveyed were thinning at an accelerating pace, with some glaciers thinning at an average rate of 0.84 meters per year (Pritchard et al. 2009). In Antarctica, thinning exceeded 9 meters per year for some glaciers (Pritchard et al. 2009). Overall, the pervasive occurrence of accelerating dynamic ice sheet melting indicates that sea-level rise is more likely to approach the upper range of sea-level rise projections.

v. The Climate Commitment, Irreversible Climate Change, Tipping Points, and Feedbacks

As scientific understanding of climate change and ocean acidification has advanced, so too has the urgency of the warnings from scientists about the consequences of our greenhouse gas emissions. Of particular importance for corals, scientists have highlighted several processes that delay the full impacts of greenhouse gases and make climate change impacts extremely long-lasting. In considering the extinction risk of the petitioned coral species, NOAA should take these processes into account: (1) the climate commitment (i.e. future warming and sea-level rise resulting from present greenhouse gas levels); (2) the irreversibility of climate change and ocean acidification from CO_2 emissions; (3) the triggering of tipping points; and (4) the enhancement of positive feedback cycles that amplify climate change.

The climate commitment

Due to thermal inertia in the climate system, there is a time lag between the emission of greenhouse gases and the full physical climate response to those emissions (IPCC 2007a,b). Thus, the climatic changes experienced so far are only part of the full response expected from the greenhouse gases already in the atmosphere (IPCC 2007a,b, Hansen et al. 2008). The delayed effects from existing emissions are known as the “climate commitment.” Based on the greenhouse gases already emitted, the Earth is committed to additional warming estimated at 0.6°C to 1.6°C within this century (Meehl et al. 2007, Ramanathan and Feng 2008), and up to 2°C in the long-term (Hansen et al. 2008). In addition, sea-level rise will continue for centuries due to continuing thermal expansion of the oceans and melting of the Greenland ice sheet (Meehl et al. 2007). This committed warming and sea level rise poses a significant threat to the petitioned coral species. For example, Donner (2009) found that the physical warming commitment from greenhouse gases in the atmosphere in 2000 will cause over half of the world’s coral reefs to experience harmfully frequent bleaching at 5-year intervals by 2080.

Irreversible impacts of CO_2 emissions

Although largely underappreciated, climate changes, including temperature and sea level rise, that result from increases in CO_2 concentrations are largely irreversible for 1,000 years after emissions cease (Archer and Brovkin 2009, Solomon et al. 2009), while increases in ocean acidification will persist for hundreds of thousands to millions of years (Richardson et al. 2009). An important contributing factor is the long atmospheric lifetime of CO_2 compared to other greenhouse gases. A significant fraction of anthropogenic CO_2, ranging from 20–60%, remains airborne for a thousand years or longer after emissions cease (Archer and Brovkin 2008, Solomon et al. 2009). In the case of temperature, although some of the anthropogenic CO_2 is removed from the atmosphere by deep ocean mixing, global average temperatures do not drop significantly for at least 1,000 years after the cessation of emissions because the removal of CO_2 by deep-ocean mixing is largely compensated by the loss of heat from the ocean (Solomon et al.

2009). Anthropogenic CO_2 also causes irrevocable sea-level rise. Long-lasting warming from persistent CO_2 causes the oceans to continue to expand and the continued melting of the glaciers and ice sheets contributing to milennia of sea-level rise (Solomon et al. 2009). In addition, the long tail of fossil fuel CO_2 in the atmosphere may trigger slow processes and feedbacks including methane hydrate release from the ocean and methane release from melting permafrost (Archer and Brovkin 2008).

As stated by Solomon et al. (2009):

> It is sometimes imagined that slow processes such as climate changes pose small risks, on the basis of the assumption that a choice can always be made to quickly reduce emissions and thereby reverse any harm within a few years or decades. We have shown that this assumption is incorrect for carbon dioxide emissions, because of the longevity of the atmospheric CO_2 perturbation and ocean warming. Irreversible climate changes due to carbon dioxide emissions have already taken place, and future carbon dioxide emissions would imply further irreversible effects on the planet, with attendant long legacies for choices made by contemporary society. (Soloman et al. 2009: 1708-1709).

According to Archer and Brovkin (2008):

> The notion is pervasive in the climate science community and in the public at large that the climate impacts of fossil fuel CO_2 release will only persist for a few centuries. This conclusion has no basis in theory or models of the atmosphere/ocean carbon cycle, which we review here. The largest fraction of the CO_2 recovery will take place on time scales of centuries, as CO_2 invades the ocean, but a significant fraction of the fossil fuel CO_2, ranging in published models in the literature from 20–60%, remains airborne for a thousand years or longer. Ultimate recovery takes place on time scales of hundreds of thousands of years, a geologic longevity typically associated in public perceptions with nuclear waste. The glacial/interglacial climate cycles demonstrate that ice sheets and sea level respond dramatically to millennial-timescale changes in climate forcing. There are also potential positive feedbacks in the carbon cycle, including methane hydrates in the ocean, and peat frozen in permafrost, that are most sensitive to the long tail of the fossil fuel CO_2 in the atmosphere.
> (Archer and Brovkin 2008: 283).

Certainly, NOAA must consider the long legacy of impacts from anthropogenic CO_2 on the petitioned coral species. NOAA must act in time to protect the petitioned coral speies while actions can still be taken to ameliorate the threats to these species and prevent their extinction, before irreversible climate impacts commit them to extinction.

Tipping points

Current climate forcings have the potential to trigger “tipping points,” critical points where rapid climate changes proceed without any additional forcing (Hansen et al. 2008) and the system shifts to qualitatively different state (Lenton et al. 2008). In reviewing the "tipping elements" in the Earth's climate system that could be altered by anthropogenic climate forcing, Lenton et al. (2008) found that a mean global temperature increase of 1-2°C above ~1990 levels has the potential to trigger irreversible melting of the Greenland ice sheet, a process that could result in an eventual seven-meter sea-level rise (Hansen et al. 2006), which would have profound effects on corals.

Feedbacks

Climate forcings can trigger reinforcing positive feedbacks that can further amplify warming. For example, the Arctic ice-albedo feedback loop is already occurring, where the loss of sea ice due to warming reduces the surface albedo and makes the Arctic more vulnerable to future warming. Scientific studies indicate that increased warming will trigger other feedbacks, including the mobilization of carbon in tropical peatlands which are vulnerable to land clearing and drainage, and the release of methane from Arctic permafrost due to warming (Richardson et al. 2009).

c. The Impacts of Climate Change and Ocean Acidification on Corals

Climate change and ocean acidification are already impacting corals through a variety of processes, including the increased frequency of mass bleaching events from rising ocean temperatures; decreased coral calcification rates due to rising ocean acidification; increasing tropical storm intensity that damages reefs; and rising sea levels that threaten to drown some coral reefs (Dodge and Aronson 2008). Additionally, climate change acts synergistically to exacerbate other stressors to coral reef ecosystems such as disease and predation. The impacts to the petitioned coral species will worsen as climate change and ocean acidification continue unabated.

The significant threats to corals from climate change and ocean acidification are highlighted by Veron et al. (2009):

> Temperature-induced mass coral bleaching causing mortality on a wide geographic scale started when atmospheric CO_2 levels exceeded ~320 ppm. When CO_2 levels reached ~340 ppm, sporadic but highly destructive mass bleaching occurred in most reefs world-wide, often associated with El Niño events. Recovery was dependent on the vulnerability of individual reef areas and on the reef's previous history and resilience. At today's level of ~387 ppm, allowing a lag-time of 10 years for sea temperatures to respond, most reefs world-wide are committed to an irreversible decline. Mass bleaching will in future become annual, departing from the 4 to 7 years return-time of El Niño events. Bleaching will be exacerbated by the effects of degraded water-quality and increased severe weather events. In addition, the progressive onset of ocean acidification will cause reduction of coral growth and retardation of the growth of high magnesium calcite-secreting coralline algae. If CO_2 levels are allowed to reach 450 ppm (due to occur by 2030–2040 at the current rates), reefs will be in rapid and terminal decline world-wide from multiple synergies arising from mass bleaching, ocean

> acidification, and other environmental impacts. Damage to shallow reef communities will become extensive with consequent reduction of biodiversity followed by extinctions. Reefs will cease to be large-scale nursery grounds for fish and will cease to have most of their current value to humanity. There will be knock-on effects to ecosystems associated with reefs, and to other pelagic and benthic ecosystems. Should CO_2 levels reach 600 ppm reefs will be eroding geological structures with populations of surviving biota restricted to refuges. Domino effects will follow, affecting many other marine ecosystems. This is likely to have been the path of great mass extinctions of the past, adding to the case that anthropogenic CO_2 emissions could trigger the Earth's sixth mass extinction. (emphasis added) (Veron et al. 2009: 1428).

In addition:

> Warming temperatures and ocean acidification are already affecting coral reefs, causing frequent bleaching events and slowing the formation of coral skeletons. We can avoid catastrophic damage to coral reefs but to do so means we must reduce both climate change and local threats. All available evidence suggests that time is running out and that soon conditions on the planet will be so severe that coral reefs will no longer thrive. (Eakin et al. 2008: 30)
>
> National Oceanic and Atmospheric Administration (USA) satellites reveal that tropical oceans have warmed significantly faster during the last 10 years than previously. At this rate of change, only 8–10 years remain before CO_2 concentrations are predicted to exceed 450 ppm in the atmosphere. The extra CO_2 dissolving in seawater will threaten the existence of coral reefs as we know due to rising acidification. One third of the world's coral species are at high risk of extinction following widespread losses since the 1970s, with climate change as the major driver. Healthy and resilient coral reefs can respond robustly to damage but climate change stresses are eroding that resilience. (Dodge and Aronson 2008: 43).

i. Ocean Surface Temperature

Coral reefs live within a fairly narrow range of environmental conditions constrained by water temperature, light, salinity, nutrients, bathymetry and the aragonite saturation state of seawater (Eakin et al. 2009). Zooxanthellate corals are predominantly found in tropical coastal waters at latitudes from 25 degrees south to 25 degrees north of the equator, in water temperatures of 18-30°C, and at depths of less than 100 meters (Hoegh-Guldberg 1999). These shallow, low-latitude waters provide a naturally stable thermal environment, in which water temperatures barely fluctuate between seasons and within the diurnal cycle, with averages varying less than 2°C over the past 18,000 years (Hoegh-Guldberg 1999). Corals appear to have become highly adapted to the narrow temperature regimes of their particular locality (Spalding et al. 2001), and live close to their upper thermal limits (Hoegh-Guldberg 1999).

Warming of the tropical oceans has raised the baseline sea surface temperature to levels where coral reefs live much closer to their upper thermal limits and are more vulnerable to thermal stress and bleaching (Eakin et al. 2009). A primary threat to corals from warming ocean temperatures is that natural temperature variability is now pushing corals into temperatures that cause bleaching more readily than in the past (Eakin et al. 2008).

Coral bleaching occurs when ocean temperatures exceed summer maxima by 1° to 2°C for 3 to 4 weeks, causing zooxanthellate corals expel their endosymbiotic dinoflagellates (*Symbiodinium* spp.) which they rely on for energy and growth (Hoegh-Guldberg et al. 2007). High ocean temperatures and high light conditions destabilize the relationship between host coral and dinoflagellate and cause the photosymbiotic system to break down and accumulate reactive oxygen derivatives, resulting in the loss of the dinoflagellates (Veron et al. 2009). Coral bleaching and mortality become progressively worse as thermal anomalies intensify and lengthen (Hoegh-Guldberg et al. 2007). The reduction of photosynthetic pigment in the algae during the bleaching process causes the coral tissue to lose at least some of its characteristic coloration and sometimes renders the coral tissue completely transparent, revealing the underlying white coral skeleton (Rosenberg and Ben-Haim 2002).

Coral bleaching affects corals and coral reefs by causing direct mortality; lowering reproductive capacity; reducing growth, calcification rates, and repair capabilities following bleaching; making corals more susceptible to disease and other stressors; and altering community structure (Hoegh-Guldberg 1999; Rosenberg and Ben-Haim 2002; Fischlin et al. 2007; Baker et al. 2008). One of the most direct effects of bleaching is that affected corals tend to die at greater rates, where the mortality of corals following a bleaching event is generally proportional to the length and extent to which temperatures rise above summer maxima for any locality (Hoegh-Guldberg 1999). Increased temperatures and bleaching can also reduce coral reproductive capacity by inhibiting spawning and lowering the number of reproductive propagules after bleaching events. *Id.* This impairment of reproductive capacity can slow the rate at which coral populations can re-establish themselves by lowering the number of available recruits. *Id.* Numerous studies have found that reef-building corals that undergo bleaching have reduced growth, calcification and repair capabilities following bleaching (Hoegh-Guldberg 1999; Fischlin et al. 2007). Bleaching can also make corals more vulnerable to other stressors, leading to increases in coral diseases and the breakdown of the reef framework by bioeroders (Baker et al. 2008). Overall, corals that survive and recover their dinoflagellate symbionts after mild thermal stress typically show reduced growth, calcification, and fecundity and may experience greater incidences of coral disease (Hoegh-Guldberg et al. 2007). Mass bleaching events can also catalyze fundamental phase shifts in coral communities, wherein algae or other non-coral taxa become dominant and corals are unable to reestablish themselves (Baker et al. 2008). In many cases where reef communities have "recovered" from bleaching events, significant declines in diversity and shifts in the relative abundances of zooxanthellate corals have occurred, as those more susceptible to disturbance (e.g., highly imperiled, framework-building *Acropora* and *Montastraea* species) are replaced with more resilient species. *Id.*

Observed impacts to corals from rising temperatures: mass bleaching events

Mass bleaching of corals (bleaching of multiple species on an ecologically significant scale) was first recorded in 1978/79 when atmospheric CO_2 was 336 ppm (Veron et al. 2009). Until the late 1970s, the bleaching of corals had been reported for small-scale events (meters to hundreds of meters) in response to a range of localized stresses: low salinity conditions (such as from the inundation of rain onto exposed reefs), pollution, or unusually high or low water temperatures (such as warm water flowing from the water cooling exhaust of a power plant) (Hoegh-Guldberg 2004). The role of elevated sea temperatures in triggering mass coral bleaching has been extensively supported by field and laboratory studies (Hoegh-Guldberg 2004). For example, McWilliams et al. (2005) examined the relationships between yearly temperature anomalies and the geographic extent and intensity of coral bleaching in the Caribbean between 1983 and 2000, and found exponential increases in the geographical extent and intensity of coral bleaching in the Caribbean with increasing SST anomalies. A rise in regional SST of 0.18°C resulted in a 35% increase in geographic extent of coral bleaching and a 42% increase in intensity of bleaching. *Id.*

Severn major world-wide bleaching events have occurred since 1978/79 (Veron et al. 2009) "with a pattern of increasing frequency and intensity" (Hoegh-Guldberg 1999). The mass coral bleaching event of 1997/1998 affected every geographic coral-reef realm in the world (Hoegh-Guldberg 1999) and killed 16% of coral communities globally (Veron et al. 2009). In the Western Indian Ocean, an estimated 46% of corals disappeared by the end of the event (Hoegh-Guldberg 2004). The 1997/1998 event marked "the start of a decline from which there has been no significant long-term recovery" (Veron et al. 2009: 1430). The 2002 event had particularly severe impacts on Asia and the Great Barrier Reef (Veron et al. 2009), while the 2005 event severely impacted the Caribbean and tropical Atlantic (Donner et al. 2007), leading to "a new phase of decline characterized by diminishing habitat complexity in reefs of the Caribbean and a deterioration of species diversity" (Veron et al. 2009). With the 2005 event, coral cover surveys detected bleaching of 90% of coral cover in the British Virgin Islands, 80% in the U.S. Virgin Islands, 66% in Trinidad and Tobago, 52% in the French West Indies, and 85% in the Netherlands Antilles (Donner et al. 2007). Donner et al. (2007) found that anthropogenic warming likely contributed to the high sea surface temperature warming in the Eastern Caribbean in 2005 that led to this widespread coral bleaching event. Anthropogenic warming may have increased the probability of thermal stress events for corals in this region by an order of magnitude (Donner et al. 2007).

Mass bleaching is commonly associated with El Nino Southern Oscillation ("ENSO") events, which are characterized by unusually high sea surface temperatures and are thought to be accurate harbingers of future oceanic conditions under global warming (Spalding et al. 2001). For example, the ENSO event of 1998-1999 sparked global mass coral bleaching on an unprecedented scale (Spalding et al. 2001). Baseline warming of ocean temperatures due to climate change increases the probability that warmer waters from ENSO events will reach or exceed critical temperature thresholds for bleaching (Eakin et al. 2009).

Detailed information on the regional occurrences of mass bleaching events and the impacts of these events on the petitioned coral species are provided in the species accounts and regional status reviews in Part One of this petition.

Projected impacts to corals from rising temperatures

Studies projecting how rising temperatures from climate change will alter the frequency and severity of coral bleaching events indicate that the petitioned coral species are threatened with extinction. These studies similarly conclude that the majority of the world's corals will be subjected to recurring mass bleaching events at frequencies from which they will be unable to recover (five-year-intervals or less) by the 2020s or 2030s under mid-level emissions scenarios in the absence of thermal adaptations by corals and their symbionts. In addition, committed warming from greenhouse gases already in the atmosphere is projected to cause over half of the world's coral reefs to experience harmfully frequent bleaching at 5-year intervals by 2080 (Donner 2009).

Hoegh-Guldberg (1999) was the first major study to project the impacts of climate warming on coral bleaching frequency. Hoegh-Guldberg (1999) predicted the occurrence of coral bleaching at sites in French Polynesia, Jamaica, Rarotonga, Thailand, and at three sites on the Great Barrier Reef under the IPCC mid-level IS92a scenario, using coral temperature thresholds based on historical observations of bleaching and mortality at each site. This study found that most regions would experience mass bleaching at the level experienced in the 1997-1998 bleaching event biannually within 20 to 40 years and annually within 30 to 50 years.

Sheppard (2003) predicted the occurrence of coral bleaching for 33 Indian Ocean coral reefs using temperature thresholds based on observations during the 1998 coral bleaching event and a minimum recovery period of five years. The study found that most coral reefs south of the Equator would experience mass bleaching at least every five years by 2010 to 2030, although not until the latter half of the century for some coral reefs north of the equator.

In a comprehensive global assessment of coral bleaching, Donner et al. (2005) found that under IPCC A2 and B2 scenarios, severe bleaching would occur every 3–5 years at the majority of the world's reefs in the 2030s and would become a biannual event by the 2050s. Severe bleaching would be an annual or biannual event at 80–100% of the reefs worldwide by the 2080s in each model under each scenario. In addition, Donner et al. (2005) estimated the rate of temperature adaptation or acclimatization required to avoid surpassing the coral bleaching thresholds in future decades. The majority of the world's coral reefs would require adaptation of at least 0.2–0.3°C per decade to ensure that low-intensity bleaching events (degree heating month > 1°C month) would not occur more than once or twice a decade by the 2030s to 2050s.

Donner et al. (2007) projected impacts to the Eastern Caribbean region, and found that ocean warming under the IPCC B1 and A1B scenarios would lead to mass bleaching conditions (i.e. degree heating month >2°C per month) at least biannually to annually by the 2020s or 2030s. If corals were able to adapt by increasing their thermal tolerance level by 1–1.5°C, mass coral bleaching events might be postponed by 30–50 years.

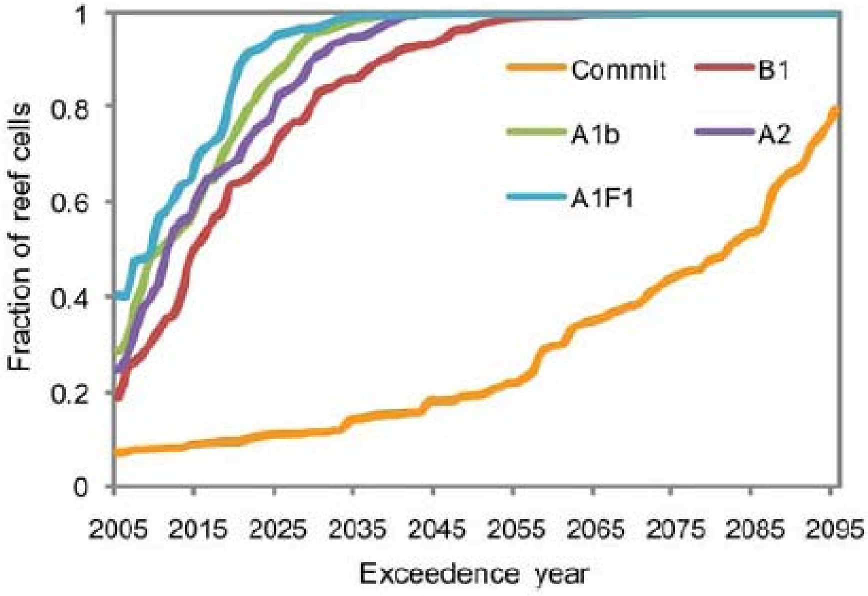
Even more imminently, new research from Donner (2009) predicted bleaching events based on the "committed warming" from the greenhouse gases already in the atmosphere, as well as the continuing warming under five IPCC scenarios ranging from the B1 scenario in which atmospheric CO_2 concentrations reach 550 ppm in the year 2100, the A1B in which CO_2 concentrations reach 700 ppm by 2100, and the A1FI in which CO_2 concentrations reach >950 ppm in 2100. (In comparison, the current global emissions trajectory exceeds the A1FI (Richardson et al. 2009)). This study found that sea surface temperature will increase by 0.4–0.6°C by 2090–2099 just based on the physical commitment from greenhouse gas accumulation until the year 2000. Sea surface temperature will warm by an additional 0.7–0.9°C (adding to 0.4–0.6°C warming commitment) under the B1 scenario, and by an additional 2.4–3.1°C under the A1FI scenario by the end of the century.

Donner (2009) found that the physical warming commitment from current accumulation of greenhouse gases in the atmosphere in 2000 is projected to cause over half of the world's coral reefs to experience harmfully frequent bleaching at 5-year intervals by 2080. The most susceptible reefs occur in the East Pacific, Polynesia, Central Pacific, Micronesia, SE Asia, Western Australia, and the Indian Ocean (Table 6). Further, under the lowest emission scenario considered, the B1, 80% of the world's reefs, including corals in the regions inhabited by the petitioned species, would experience bleaching at 5-year intervals by 2030 (Figure 98) with the exception being reefs in the Middle East. Under the A1B and A1FI scenarios, the majority of the world's corals (75-80%), including those in regions inhabited by the petitioned species, would be subjected to mass bleaching at unsustainable (< 5 year) intervals by 2020 (Figure 98). Donner (2009) found that a 1.5°C increase in the thermal tolerance of corals and their symbionts would postpone the A1B severe bleaching forecast by 50–80 years for most of the world's coral reefs.

Table 6. The year that reefs experience degree-heating-months ≥2°C per month at a probablility that exceeds once every five years (i.e. exceeds 205).
Source: Donner (2009): Table 2

	Commitment		SRES B1		SRES A1b	
	Base	+1.5 K	Base	+1.5 K	Base	+1.5 K
Caribbean	n/a	n/a	2016	n/a	2018	2074
Middle East	n/a	n/a	2033	n/a	2023	2070
W Indian Ocean	2063	n/a	2024	n/a	2013	2088
C Indian Ocean	2063	n/a	2019	n/a	2012	2082
Western Australia	2071	n/a	2024	n/a	2016	2086
SE Asia	2061	n/a	2021	n/a	2012	2074
GBR+Melanesia	2095	n/a	2028	n/a	2017	2092
Micronesia	2009	n/a	2010	n/a	2005	2065
Central Pacific	2005	n/a	2005	2062	2005	2051
Polynesia	2072	n/a	2016	n/a	2015	2094
East Pacific	2048	n/a	2014	n/a	2012	2073

Figure 98. Frequency distribution of the year in which the probability of severe mass bleaching events (degree heating month ≥2°C per month) exceeds 20% for each the 1687 coral reef cells. The probability of mass bleaching in each scenario is estimated from running 10-year intervals of both the CM2.0 and CM2.1 simulations.
Source: Donner (2009): Figure 4.



In summary, if the world were to follow the lowest IPCC emissions scenario considered by these impact studies, B1, 80% of the world's coral reefs would experience harmfully frequent bleaching by 2030. Even if all greenhouse gases were to cease immediately, the warming commitment from greenhouse gases accumulated until 2000 would cause over half of the world's coral reefs to experience harmfully frequent bleaching by 2080. Clearly, the best-available science shows that the petitioned coral species are threatened with extinction. These studies also provide strong support that a greenhouse gas stabilization target at a level lower than current atmospheric greenhouse gas concentration of ~387 ppm is needed to protect these coral species, and that immediate, coordinated efforts are needed to maximize coral reef resilience.

ii. Ocean Acidification

Ocean acidification poses a profound threat to the petitioned coral species by reducing the availability of carbonate ions (specifically aragonite) essential for building calcium carbonate skeletons, thereby impairing coral calcification rates and skeletal formation (Kleypas et al. 1999; Dodge and Aronson 2008). The full impacts of ocean acidification on corals include the slowing of carbonate accumulation, reduction of growth rates, weakening of coral skeletons, reduction of cementation, and destabilization of reef structures (Kleypas et al. 2001; Guinotte and Fabry 2008). Reduced calcification that slows coral growth can make corals less able to compete for space and can weaken coral skeletons increasing their vulnerability to erosion, storm damage and predation (Eakin et al. 2008; Guinotte et al. 2003). As a result, coral abundance and reef-building capabilities are expected to largely diminish over this century (Hoegh-Guldberg 2004).

Reef-building corals may exhibit several responses to reduced calcification, all of which have deleterious consequences for reef ecosystems. First, coral may exhibit a decreased linear extension rate and decreased skeletal density (Hoegh-Guldberg et al. 2007). Notably, the significant decline in calcification rate of *Porites* corals throughout the Great Barrier Reef since 1990 was principally due to a decline in linear extinction rate of 13.3% (De'ath et al. 2009). Secondly, corals may reduce skeletal density in order to maintain their physical extension or growth rates, which in turn can increase coral erosion (Hoegh-Guldberg et al. 2007). Brittle coral skeletons are more vulnerable to storm damage, and coral grazers such as parrotfish prefer to remove carbonates from lower-density substrates (Hoegh-Guldberg et al. 2007). As noted by Hoegh-Guldberg et al. (2007), erosion rates that outpace calcification rates would reduce the structural complexity, habitat quality, and habitat diversity of corals, and would impact the ability of reefs to absorb wave energy. Third, corals might invest greater energy in calcification in order to maintain skeletal growth and density, which would divert resources from essential activities such as reproduction and potentially reduce the recolonization ability of corals (Hoegh-Guldberg et al. 2007).

Ocean acidification and warming temperatures also interact in ways that can increase impacts to corals. Recent experimental work has demonstrated that ocean warming interacts with ocean acidification to lower the temperature threshold for bleaching. High CO_2 levels acted as a bleaching agent for *Acropora* and *Porites* corals and crustose coralline algae under high irradiance (Anthony et al. 2009). This study suggests that rising atmospheric CO_2 will cause coral bleaching through both rising ocean temperatures and ocean acidification (Anthony et al. 2009).

Finally, research indicates that increased ocean acidification may have another significant impact on corals by reducing the photosynthetic capacity and photoprotection of their symbiotic algae (Crawley et al. 2009). When *Acropora formosa* was exposed to increased CO_2 levels, the production of a key enzyme that protects its symbiotic algae from sunlight was significantly reduced, which exposes the algae to oxidative stress and reduces their ability to convert sunlight into nourishment for the coral (Crawley et al. 2009).

Observed impacts of ocean acidification

Corals are already experiencing significantly lower calcification rates that have been linked to ocean acidification. In the Australian Great Barrier Reef, scientists investigated hundreds of colonies of massive *Porites* corals and found that calcification has declined by 14-21% since 1990 (De'ath et al. 2009). This sudden, large-scale decline in calcification rate is unprecedented in the past 400 years and was linked to the declining saturation state of aragonite and increasing temperature stress (De'ath et al. 2009). Similarly, the linear growth rates of *Acropora palmata* in Curaçao were 7.2% lower in summer and 10.7% lower in winter 2002-2004 compared with 1971–1973, which was linked to ocean acidification (Bak et al. 2009).

On a global scale, modeling by Silverman et al. (2009) suggests that most reefs are already calcifying 20-40% slower today compared with their pre-industrial rates, and that 30% of the world's coral reefs have decreased their gross calcification by 60-80% compared with pre-industrial rates (Silverman et al. 2009).

Numerous experiments on tropical reef-building corals tested to date also indicate that calcification rates will be reduced as CO_2 concentrations rise (Gattuso et al. 1998; Kleypas et al. 2006; Fischlin et al. 2007; Guinotte and Fabry 2008). In addition, crustose coralline algae (CCA), which form the structural crust on reef flats, attract settlement of new coral recruits, and cement carbonate frameworks, are particularly vulnerable to reduced growth and recruitment rates from ocean acidification (Kuffner et al. 2007). The impacts of ocean acidification on CCA will likely negatively affect corals by reducing coral settlement rates (Eakin et al. 2008 in Wilkinson 2008).

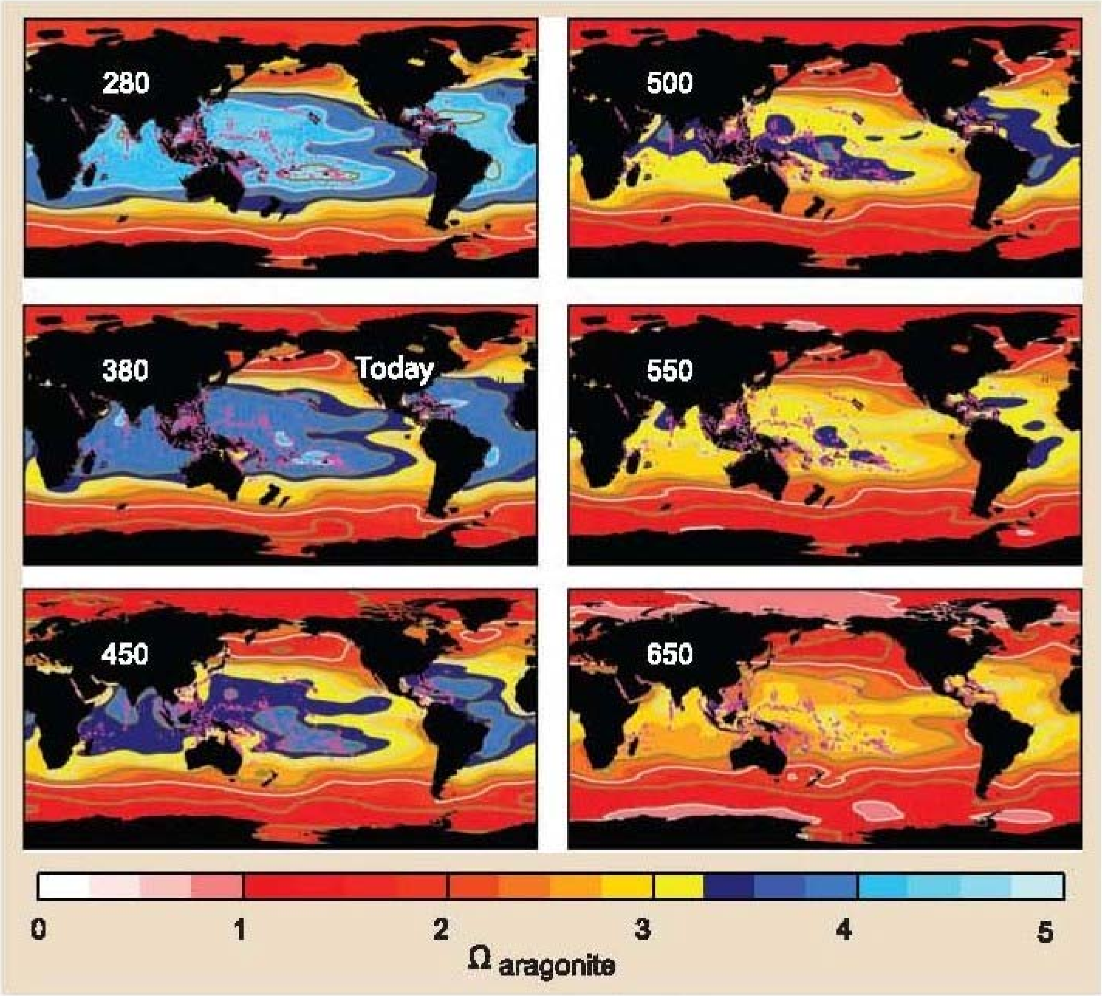
Projected impacts of ocean acidification and ocean warming

Several studies have examined the combined effects of ocean acidification and ocean warming on corals (Hoegh-Guldberg et al. 2007, Silverman et al. 2009). Hoegh-Gulberg et al. (2007) projected three scenarios for coral reefs based on different atmospheric CO_2 concentrations: (1) At an atmospheric CO_2 concentration stabilized at 380 ppm, coral reefs would remain coral-dominated and carbonate-accreting in most areas of their current distribution. (2) At atmospheric CO_2 concentrations of 450 to 500 ppm, reef erosion will exceed calcification (Hoegh-Guldberg et al. 2007), threatening the existence of many coral species. This results because coral reef accretion stops and erosion begins at aragonite saturation values < 3.3 which is projected to occur when CO_2 concentrations approaches 480 ppm and carbonate ion concentrations drop below 200 mmol kg^{-1} in most of the global ocean (Hoegh-Guldberg et al. 2007). In this scenario, the density and diversity of corals will decline, habitat complexity and reef biodiversity will diminish, disease incidence will likely increase, coralline algae will decline leading to reduced availability of settlement substrate for corals, macroalgae will likely form stable communities that are resistant to coral settlement, and corals will become even more sensitive to local stressors (Hoegh-Guldberg et al. 2007). (3) At atmospheric CO_2 concentrations greater than 500 ppm, carbonate-ion concentrations would fall well below 200 mmol kg^{-1} (aragonite saturation < 3.3) and ocean temperatures would rise above 2°C relative to current values (Hoegh-Guldberg et al. 2007). According to Hoegh-Guldberg et al. (2007), "[t]hese changes will reduce coral reef ecosystems to crumbling frameworks with few calcareous corals." Further, the long-lasting impacts from rising temperatures and sea levels will continue to adversely affect corals for centuries (and hundreds of thousands of years in the case of ocean acidification):

> The continuously changing climate, which may not stabilize for hundreds of years, is also likely to impede migration and successful proliferation of alleles from tolerant populations owing to continuously shifting adaptive pressure. Under these conditions, reefs will become rapidly eroding rubble banks such as those seen in some inshore regions of the Great Barrier Reef, where dense populations of corals have vanished over the past 50 to 100 years. Rapid changes in sea level, coupled with slow or nonexistent reef growth, may also lead to "drowned" reefs in which corals and the reefs they build fail to keep up with rising sea levels. (Hoegh-Guldberg et al. 2007: 1741).

Hoegh-Guldberg et al. (2007) also mapped the regional vulnerability of corals to decreasing aragonite saturation levels, illustrated in Figure 99. Before the industrial revolution when atmospheric CO_2 level was about 280 ppm, nearly all shallow-water coral reefs had aragonite saturation state above 3.25 (blue regions in the figure), which is the minimum aragonite saturation that coral reefs are associated with today. *Id.* The number of existing coral reefs with this minimum aragonite saturation decreases rapidly as atmospheric carbon dioxide concentration increases. *Id.* Changes in ocean acidity will vary somewhat across regions with the Great Barrier Reef, Coral Sea, and the Caribbean Sea attaining risky levels of aragonite saturation more rapidly than others. *Id.*

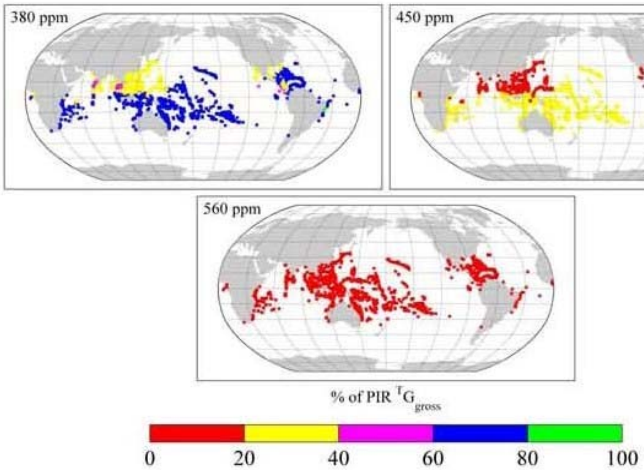
Figure 99. Changes in aragonite saturation predicted to occur as atmospheric CO_2 concentrations (ppm) increase (number at top left of each panel) plotted over shallow-water coral reef locations shown as pink dots.
Source: Hoegh-Guldberg et al. (2007): Figure 3.



Similarly, Cao and Caldeira (2008) found that before the industrial revolution, 98.4% of coral reefs were found near open ocean waters with an aragonite saturation state above 3.5. If atmospheric CO_2 were to be stabilized at 380 ppm, 62% coral reefs would be surrounded by waters that are less saturated than 3.5. *Id.* At a CO_2 stabilization of 450 ppm, only 8% of coral reefs would be surrounded by open ocean waters with aragonite saturation state above 3.5, and at a stabilization level of 550 ppm no existing coral reefs would be near such waters. *Id.*

Finally, Silverman et al. (2009) provided global estimates of the decline in calcification of corals taking into account the synergistic effects of elevated sea surface temperatures and ocean acidification at different levels of atmospheric CO_2. At 450 ppm CO_2, all corals are expected to decrease calcification by 60-80% relative to pre-industrial rates (Figure 100). Once atmospheric carbon concentrations reach 560 ppm, all corals are expected to decrease calcification by 80%, at which point they will cease to grow and start to dissolve (Silverman et al. 2009). Because studies indicate that the community calcium carbonate dissolution rate offsets approximately 20-30% of gross calcification even in the absence of acidifying influences, gross calcification rates of 20% at 560 ppm atmospheric carbon concentrations are conservatively expected to result in net dissolution within the reef ecosystem. *Id.* While these researchers accounted for the synergistic effects of elevated sea surface temperature, bleaching, and ocean acidification, they note that their projections are likely conservative given the unexamined additional negative impacts due to pollution, predation, and disease. *Id.*

Figure 100. Global coral reef distribution and projected gross calcification, as percentages of pre-industrial rates, at carbon dioxide concentrations of 380 ppm, 450 ppm, and 560 ppm. Assumes live coral cover in all reefs was reduced by 50% cumulatively from an initial value of 50% when the SST at the reef location exceeded 1 degree Celsius over its maximum monthly average summer SST at the pre-industrial (280 ppm) stabilization level.
Source: Silverman et al. (2009): Figure 3.



Resilience of Corals to Climate Change and Ocean Acidification

The potential for corals to change their tolerance to rising temperatures and ocean acidification through natural selection or physiological acclimation appears to be limited (Hoegh-Guldberg 2004, Hoegh-Guldberg et al. 2007, Hoegh-Guldberg 2009):

> Evidence that corals and their symbionts can adapt rapidly to coral bleaching is equivocal or nonexistent. Reef-building corals have relatively long generation times and low genetic diversity, making for slow rates of adaptation. Changes in species composition are also possible but will have limited impact, as even the most thermally tolerant corals will only sustain temperature increases of 2° to 3°C above their long-term solar maxima for short periods (24, 31). However, such changes come at a loss of biodiversity and the removal of important redundancies from these complex ecosystems. Some studies have shown that corals may promote one variety of dinoflagellate symbiont over another in the relatively small number of symbioses that have significant proportions of multiple dinoflagellate types (38). These phenotypic changes extend the plasticity of a symbiosis (e.g., by 1° to 2°C) (21) but are unlikely to lead to novel, long-lived associations that would result in higher thermal tolerances (39). The potential for acclimation even to current levels of ocean acidification is also low given that, in

> the many studies done to date, coral calcification has consistently been shown to decrease with decreasing pH and does not recover as long as conditions of higher acidity persist. (Hoegh-Guldberg et al. 2007: 1741).

The potential for poleward range expansion of corals in response to increasing sea surface temperatures is very low due to declining carbonate ion concentrations worldwide as well as limited light availability at higher latitudes (Guinotte et al. 2003; Hoegh-Guldberg 2004). In addition, high current and future rates of climate change will make it difficult for corals to adapt:

> Sea temperatures are warmer (+0.7°C), and pH (−0.1 pH units) and carbonate-ion concentrations (~210 mmol kg−1) lower than at any other time during the past 420,000 years…. In addition to the absolute amount of change, the rate at which change occurs is critical to whether organisms and ecosystems will be able to adapt or accommodate to the new conditions. Notably, rates of change in global temperature and [CO2] atm over the past century are 2 to 3 orders of magnitude higher than most of the changes seen in the past 420,000 years (Table 1). Rates of change under both low (B1) and high (A2) Intergovernmental Panel on Climate Change (IPCC) emission scenarios are even higher, as are recent measurements of the rate of change of [CO2] atm. The only possible exceptions are rare, short-lived spikes in temperature seen during periods such as the Younger Dryas Event (12,900 to 11,500 yr B.P.). Given that recent and future rates of change dwarf even those of the ice age transitions, when biology at specific locations changed dramatically, it is likely that these changes will exceed the capacity of most organisms to adapt. (Hoegh-Guldberg et al. 2007: 1737).

Finally, local stressors are likely to reduce the resilience of coral reefs to climate change. Carilli et al. (2009) found that recent reductions in growth rate of the dominant reef-builder corals *Montastraea faveolata* in the Mesoamerican Reef were best explained by both thermal stress and the effects of chronic local stressors. Woolridge and Done (2009) investigated geographic patterns of coral bleaching in 1998 and 2002 on the Great Barrier Reef and found evidence that thermal stress and nutrient flux acted synergistically to increase coral bleaching.

iii. Intensification of Storms and Changes in Precipitation

Most coral reefs are found in climates that periodically experience intense, short storm events (Waddell 2005). Corals are thought to be somewhat resilient to these regular "pulse disturbances," which are thought to facilitate species diversity and abundance by, for example, making new substratum space available for the settlement of coral recruits and assisting asexual reproduction via fragmentation. *Id.* The intermediate disturbance hypothesis, as applied to coral communities, indicates that the highest species diversity is associated with intermediate frequency and intensity of natural disturbances. *Id.*

Although tropical storms can be a positive, regenerative force in reef ecosystems (*see,* e.g., Hillis and Bythell 1998), unusually intense storms have decimated coral communities over the past few decades, and are thought to be contributing to overall declines in both diversity and abundance (Lirman and Fong 1997; Emanuel 2005; Gardner et al. 2005; Wilkinson 2008). The dramatic global declines in coral reef ecosystems since 1970 coincide with a 75% increase in the number of tropical storms reaching categories four and five (Mimura et al. 2007; Trenberth et al. 2007). Strong storms physically damage coral reefs by breaking off colonies and polluting the waters with sediment and runoff from flooded coastlines and rivers. Significantly decreased light availability associated with increased sedimentation from climate-influenced severe weather events could impede distribution and survival of zooxanthellate corals (Brooks et al. 2006). Immediate mortality to colonies and fragments from severe storms is sometimes high, and damaged populations are more susceptible to subsequent disturbances. *Id*. Storms also serve as an erosional force which, if increased in intensity, could upset the balance of reef formation and erosion and reduce reefs to rubble over time (Hoegh-Gulberg 2004). Of particular concern, the damage from storms will be exacerbated by the weakening of corals from ocean acidification (Veron et al. 2009).

Increased precipitation can damage reefs as observed in the Great Barrier reef in 2009 (Veron et al. 2009). Low salinity conditions from increased rainfall may also threaten the survival of coral larvae that are sensitive to salinity. *Id.*

iv. Sea Level Rise

Sea level rise threatens corals by affecting light penetration and the availability of suitable areas for corals to live (Lough and van Oppen 2009). In addition, the inundation of entire island nations will likely have significant impacts, such as dramatic increases in sediment, nutrient loads, and pollution, on nearshore reefs (Brooks et al. 2006). Gradual rises in sea level will impact coastal marine ecosystems via changes in tidal height and tidal range, which will alter available light, current velocities, and temperature and salinity distributions, all of which have critical influence in coral ecosystems. *Id.* Though corals have adapted to sea level changes throughout their geological history by colonizing newly flooded habitats, current rapid sea level rise is expected to interact with other anthropogenic and climate-related threats, including physical disturbance from human activity and tropical storms, predation, disease, an increased frequency of bleaching episodes resulting from high sea-surface temperatures, and pollution to adversely affect coral reefs in the future (Brooks et al 2006; Hoegh-Guldberg 2004; Gardner et al. 2003; Hughes et al. 2003; Aronson et al. 2003; Veron et al. 2009). In such circumstances, it is likely that corals will not be growing and reproducing at healthy rates, which will in turn impede their ability to settle new recruits in newly available areas as their former habitat becomes inhospitable (Hoegh-Guldberg 2004).

d. Greenhouse Gases Emissions Must Be Reduced to Less than 350 ppm CO_2 To Protect the Petitioned Coral Species

Because the temperature-related effects of global warming on coral reefs have been extensively documented, relationships between rising CO_2 levels, rising ocean temperature, and reef responses provide a well-grounded basis for predicting how reefs will be affected by future levels of warming and CO_2 (Veron et al. 2009). As detailed above, numerous studies have documented detrimental effects to the petitioned coral species at our current atmospheric concentration of 387 ppm CO_2, and many studies indicate that an atmospheric CO_2 concentration of less than 350 ppm is needed to protect corals.

In a paper entitled "The coral reef crisis: the critical importance of <350 ppm CO_2," Veron et al. (2009) found that temperature-induced mass bleaching events causing widespread coral mortality began to when atmospheric CO_2 levels exceeded ~320 ppm, and outlined evidence for the need to reach an atmospheric CO_2 concentration of less than 350 ppm CO_2 to protect corals:

> Temperature-induced mass coral bleaching causing mortality on a wide geographic scale started when atmospheric CO_2 levels exceeded ~320 ppm. When CO_2 levels reached ~340 ppm, sporadic but highly destructive mass bleaching occurred in most reefs world-wide, often associated with El Niño events. Recovery was dependent on the vulnerability of individual reef areas and on the reef's previous history and resilience. At today's level of ~387 ppm, allowing a lag-time of 10 years for sea temperatures to respond, most reefs world-wide are committed to an irreversible decline. Mass bleaching will in future become annual, departing from the 4 to 7 years return-time of El Niño events. Bleaching will be exacerbated by the effects of degraded water-quality and increased severe weather events. In addition, the progressive onset of ocean acidification will cause reduction of coral growth and retardation of the growth of high magnesium calcite-secreting coralline algae. If CO_2 levels are allowed to reach 450 ppm (due to occur by 2030–2040 at the current rates), reefs will be in rapid and terminal decline world-wide from multiple synergies arising from mass bleaching, ocean acidification, and other environmental impacts. Damage to shallow reef communities will become extensive with consequent reduction of biodiversity followed by extinctions. Reefs will cease to be large-scale nursery grounds for fish and will cease to have most of their current value to humanity. There will be knock-on effects to ecosystems associated with reefs, and to other pelagic and benthic ecosystems. Should CO_2 levels reach 600 ppm reefs will be eroding geological structures with populations of surviving biota restricted to refuges. Domino effects will follow, affecting many other marine ecosystems. This is likely to have been the path of great mass extinctions of the past, adding to the case that anthropogenic CO_2 emissions could trigger the Earth's sixth mass extinction. (Veron et al. 2009: 1428).

Similarly, Hansen et al. (2008) found that a ~385 CO_2 concentration is already deleterious for corals and that a concentration of 300-350 ppm CO_2 would significantly alleviate stresses from ocean warming and ocean acidification:

> Coral reefs are suffering from multiple stresses, with ocean acidification and ocean warming principal among them. Given additional warming 'in-the-pipeline', 385 ppm CO_2 is already deleterious. A 300-350 ppm CO_2 target would significantly relieve both of these stresses. (Hansen et al. 2008: 226).

The United Nations Environment Programme's 2009 Climate Science Compendium found that we are already committed to ocean acidification that will damage or destroy coral reefs:

> Already we are committed to ocean acidification that will damage or destroy coral reefs and the many species of marine life that inhabit or depend upon the ecosystem services of the reefs. (McMullen and Jabbour 2009: 7)

Donner (2009) found that that atmospheric greenhouse gas concentrations in 2000 have committed half of the world's coral reefs to harmfully frequent bleaching at 5-year intervals by 2080, meaning that today's level of ~387 ppm CO_2 is unsustainable for corals. Donner (2009) concluded that "Without any thermal adaptation, atmospheric CO_2 concentrations may need to be stabilized below current levels to avoid the degradation of coral reef ecosystems from frequent thermal stress events" (p. 1).

2. Dredging

The dredging of harbors and lagoons for shipping and anchorage directly impacts coral reefs with sediment and pollution. The subsequent loss of reef structure removes protection from ocean waves and storms, exposes shorelines to increased tidal action, and facilitates coastline erosion and degradation. In some areas, such as Guam's Apra Harbor, healthy coral reefs are targeted for dredging because their growth impedes ship traffic and naval activities (Goldberg et al. 2008; Burdick et al. 2008). Dredging sand to replenish beaches degrades water quality during the operation, buries corals in silt, removes protection from storms, and requires frequent reapplication every 5-10 years (Turgeon et al. 2002).

3. Coastal Development

Studies consistently conclude that proximity to coastal development is a primary factor in the decline of coral reef ecosystems. Around the world, reefs close to population centers, ports, and tourism are either of lower quality than reefs removed from such activities or they have simply disappeared (Wilkinson 2008; Waddell and Clarke 2008; Jokiel et al. 2004; Pandolfi et al. 2005; Jackson 2008). Coastal development has long been a major problem throughout the Caribbean and is increasingly threatening the Coral Triangle, an area comprising 2% of the global oceans that hosts 75% of coral species and 35% of the world's coral reefs (Wilkinson 2008; Turgeon et al. 2002; Waddell and Clarke 2008).

Coastal development causes both short and long term damage to corals. During initial development, construction can physically damage reefs through dredging to create and maintain shipping channels, building marinas and docks, and disturbances to the coastline resulting in erosion, sedimentation, and increasing water turbidity. After construction, long-term chronic impacts include pollution from sewage and chemicals associated with the increased human presence and storm run-off from roads (Turgeon et al. 2002; Waddell and Clarke 2008). Runoff from developed watersheds tends to carry more sediment and higher concentrations of waste products (including freshwater inputs from wastewater, oil, pesticides and fertilizer, animal excrement, and garbage) than that from undeveloped areas (Waddell 2005). Sediments tend to accumulate in nearshore areas with gentle slopes and low flushing rates, and wave action typical of reef habitat can continuously re-suspend introduced sediment with subsequent negative impacts on coral communities. *Id.*

4. Coastal Point Source Pollution

In many parts of the world, coral reefs are subjected to direct point source pollution such as sewage outfalls, factory wastewater, direct chemical dumping, chemically contaminated domestic wastewater, and waste and ballast water from ships (Waddell 2005). These point source pollutants can dramatically reduce coral recruitment, productivity, diversity, and shallow depth distribution limits, and can also shift species composition from phototrophic to heterotrophic fauna-dominated systems. *Id.*

5. Agricultural and Land Use Practices

Of increasing concern is degradation of the coral reefs caused by agricultural and other activities inland, sometimes far from the coast. The introduction of sediment from agricultural and land use practices smothers coral communities, decreases light availability for photosynthetic processes of zooxanthellae, and increases nutrient levels in near-shore waters (Waddell 2005). High nutrient levels promote the growth of algae over coral and eventually can transform coral reefs into algal fields devoid of hard coral cover. *Id.*; see also http://www.virginislandsdailynews.com/index.pl/article?id=17635642. Sediment runoff from land use practices such as logging, land clearing, and agriculture ranks among the highest threats to reefs throughout Central and South America, in the main Hawaiian Islands, and in other areas characterized by steep nearshore slopes (Garzon-Ferreira et al. 2002; Jokiel et al. 2008; Wilkinson 2008). These threats to reefs are predicted to continue. *Id.*

B. Disease and Predation

1. Disease

As detailed in Part One of this petition, numerous diseases have caused substantial impacts to global reef ecosystems over the past 40 years, including direct effects of coral pathogens on coral abundance and cover, as well as indirect but profound ecological shifts in the balance of predator-prey and competitive relationships when other reef-associated species such as sea urchins are infected (Knowlton 2001). The increase in disease outbreaks and the rapid emergence of new diseases in recent years represents an ever-growing threat to all species of corals, particularly as anthropogenic climate change weakens coral colonies and renders them more susceptible to disease (Harvell et al. 1999; Knowlton 2001; Harvell et al. 2005).

While little is known about the pathogens and environmental factors associated with coral disease, most coral diseases, including black-band disease, white plague, dark-spots disease, and aspergillosis, occur at higher-than-normal ocean temperatures (Harvell et al. 2005; Rosenberg and Ben-Haim 2002; Bruno et al. 2007; Waddell 2005). Increasing ocean temperatures have been positively correlated with the growth of multiple coral pathogens, marine bacteria, and fungi (Harvell et al. 2005). Optimum temperatures for marine fungi correspond with thermal stress and bleaching thresholds for corals, resulting in likely co-occurrence of bleaching and fungal infection as sea temperatures rise. *Id.* Pathogen ranges have also been shown to spread in response to increased water temperatures and El Niño events. *Id.*

Bruno et al. (2007) demonstrated a highly significant relationship between warm temperature anomalies and the emerging white syndrome disease afflicting corals of the Great Barrier Reef. Coral cover was also shown to be a decisive factor in white syndrome outbreaks, with 88% of areas of coral cover greater than 50% showing at least one infected colony and no infections recorded in areas with less than 50% cover. *Id.* While the mechanisms underlying this relationship of coral cover to disease have not yet been deciphered, these results indicate that reefs with high coral cover likely warrant additional protections from controllable stresses in order to minimize the risk of disease-induced mortality.

Brant and McManus (2009) found positive correlation between bleaching extent and disease incidence in corals in the Florida Keys during and after the 2005 bleaching event, although the nature of the relationships differed among coral and disease species. *Id*. Colonies of *Montastraea faveolata* (a petitioned species) that bleached more intensely were more prone to later developing white plague infections. *Id.* In this case, physiological changes associated with bleaching, including loss of antimicrobial activity in the surface mucus, reduced energy reserves, and reduced regenerative ability, may have weakened the corals' disease resistance. *Id*. Microbial communities may also increase in abundance during bleaching events and become opportunistic pathogens. *Id*. *Siderastrea siderea* colonies with dark spot disease bleached more extensively than apparently healthy colonies. *Id*. In this case, the adverse effects of dark spot disease on the corals may have increased susceptibility to bleaching. Finally, black band disease incidence was highest during periods of elevated temperatures, consistent with previous findings that black band disease is prevalent at higher-than-normal ocean temperatures. *Id*.

Some infectious agents appear to be temperature dependent (Rosenberg and Ben-Haim 2002). For example, the coral pathogens *Vibrio shiloi* in Israel and *V. coralyticus* in the Indian Ocean, are effective only at elevated temperatures. *Id*. When exposed to *V. coralyticus,* the coral *Pocillopora damicornis* appeared healthy at temperatures under 24°C, bleached at temperatures over 25°C, and showed disease-induced tissue mortality at temperatures above 27°C. *Id.*

Nutrient enrichment has also been found to exacerbate coral diseases, including yellow band disease in *Montastraea franksi and M. faveolata* (both petitioned species), aspergillosis in Gorgonian sea fans (Bruno et al. 2003), and black band disease in *Siderastrea siderea* (Voss and Richardson 2006).

Some of the most devastating coral diseases to date are discussed below:

- **Black band disease,** which manifests as a dark band that destroys coral tissue as it moves across colonies at rates of up to two centimeters per day, was first observed in the Caribbean (1973) and subsequently reported in the Western Atlantic and Indo-Pacific in 1985 and the Red Sea in 1988 (Rosenberg and Ben-Haim 2002). It is most active in warm summer months and most common in waters polluted by sewage and terrestrial run-off. *Id.* Scientists speculate that the microbes within the spreading black band produce concentrations of sulfide sufficient to kill the coral tissue. *Id.* The first occurrence of black band disease in the Red Sea near Eliat, Israel was associated with a temperature anomaly in 2001, when sea water at the site reached 27 °C. *Id.* Black band disease first occurred on the Great Barrier Reef in 2006, infecting at least 10% of all *Montipora* species on the Great Barrier Reef by the Australian summer of 2009 (Carter 2009).

- **White band disease** was first observed at Buck Island Reef in the US Virgin Islands in 1977 and has subsequently devastated acroporid populations throughout the Western Atlantic, Gulf of Mexico, and the Caribbean (Rosenberg and Ben-Haim 2002**).** A white band appears at the base of the coral and spreads toward branch tips at a rate of a few millimeters per day, causing coral tissue to die (type 1) or bleach and slough off (type 2). *Id.* The spread of white band disease dramatically exceeds coral growth, resulting in the decline and eventual death of entire colonies. *Id.*

- **Coral plague/white plague,** first reported in 1977, kills afflicted massive and plate-forming colonies within four months, and in some instances within days (Rosenberg and Ben-Haim 2002). White plague is similar in appearance to white band disease and is characterized by an abrupt line or band of white between living tissue and exposed coral skeleton. Coral plague is contagious and can be transmitted via floating strands of dissolved, infected tissue (Madl and Yip 2002). Coral plague generally affects species of the Caribbean, such as *Dichocoenia stokesii, Dendrogyra cylindrus,* and *Montastraea annularis* (all petitioned species). *Id.*

- **Aspergillosis,** caused by the infectious pathogen *Aspergillus sydowii,* caused tissue-degrading lesions leading to mass mortality of gorgonian corals in the Caribbean and the Florida Keys in the mid-1990s (Rosenberg and Ben-Haim 2002).

- **Yellow band disease (i.e., yellow blotch)** has been afflicting the important framework-building species *M. annularis* (a petioned species) throughout the Caribbean since the early 1990s (Cervino et al. 2001). It appears as rings or blotches and spreads through coral tissue, causing necrosis and impairing zooxanthellae cell division, at a rate of 0.6 centimeters per month. *Id.* Surveys at various locations in 1997-1998 indicated that up to 90% of *M. annularis* colonies were infected. *Id.*

- **Dark spot syndrome** has been causing tissue necrosis and depressions in the colony surface of at least two species, *Stephanocoenia michelinii* and *Siderastrea siderea,* throughout the Caribbean since the early 1990s (Cervino et al. 2001). An estimated 56% of *S. michelinii* and *S. siderea* were infected with dark spot syndrome in 1997-1998 surveys. *Id.* Dark spot syndrome kills affected coral tissue at a rate of 4.0 centimeters per month. *Id.*

- **White syndrome** is an emerging disease that has been reported in 17 species of Pacific reef-building corals, including Acroporidae, Pocilloporidae, and Faviidae (Bruno et al. 2007). These families comprise the majority of dominant species on the

> Great Barrier Reef. *Id.* White syndrome is presumed infectious and presents similarly to white band disease and coral plague in the Caribbean. *Id.* White syndrome increases in frequency with both coral cover and thermal stress from warm sea surface temperature anomalies. *Id.* Occurrence on the Great Barrier Reef increased 20-fold in 2002, immediately following the second warmest summer on record. *Id.*

Finally, coral communities have also been impacted by diseases that decimate important reef-associated species, resulting in shifts in the balance of predator-prey and competitive relationships. *Diadema antillarum,* the long-spined black sea urchin, was the most important herbivore on Caribbean reefs until 1983, when a region-wide outbreak of an unidentified pathogen resulted in the most extensive and severe mass mortality ever recorded for a marine species (Lessios 1995, Lessios et al. 2001). Genetic studies suggest that *D. antillarum* had been a significant Caribbean reef herbivore for 200,000 years, but within two years of the disease outbreak, its population densities declined by more than 97% throughout the tropical western Atlantic (Lessios et al. 2001). Recovery of the species has been very slow in most areas and is limited by its strongly density-dependent fertilization (Hughes 1994). This massive mortality of a keystone herbivore is closely associated with the subsequent region-wide decline of Caribbean reefs and is notable as the first of many significant reef-associated diseases that have devastated coral communities over the past four decades.

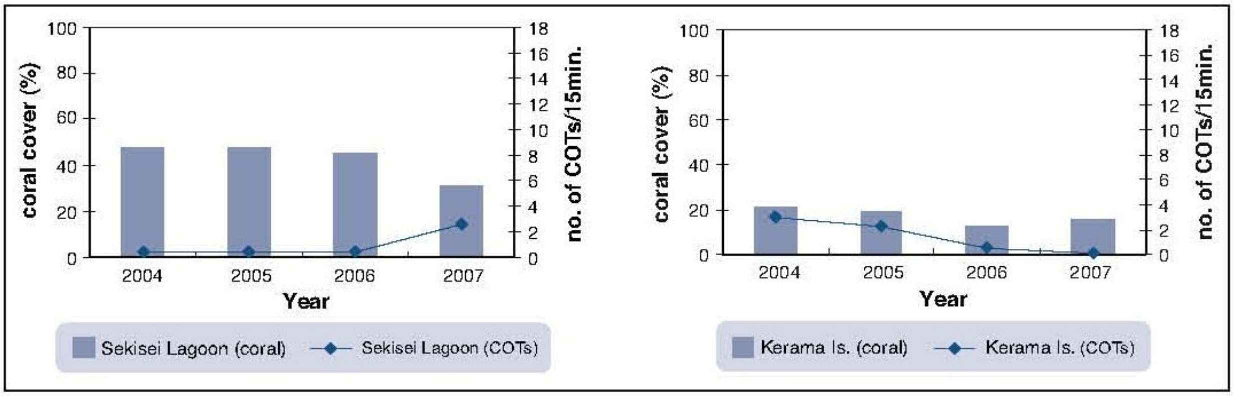
2. Predation

Major corallivorous species include starfish (*Acanthaster, Culcita*), sea urchins (*Eucidaris*), snails (*Coralliophila, Drupella, Jenneria*), polychaetes (*Hermodice*), butterflyfish (Chaetondontidae), some pufferfishes (Tetraodontidae), and some triggerfishes (Balistidae) (Knowlton and Jackson 2001). Other primarily herbivorous species, such as parrotfishes, damselfish, and the sea urchin *D. antillarum,* can also damage coral via excessive grazing and associated bioerosion. *Id.* Because many of these species preferentially prey on fast-growing, dominant coral species or also graze on coral competitors such as algae, they help maintain coral species diversity and abundance in healthy ecosystems. But coral predator populations have exploded over the past 50 years, wreaking havoc on reefs throughout the Indo-Pacific and, to a lesser extent, the Caribbean. Human influences, including overfishing of keystone predators and nutrient enrichment from coastal development and land use practices, have played a key role in increasing the frequency, intensity, and geographic extent of predator outbreaks in the recent past (McClanahan et al. 2002; Bellwood et al. 2004; Dulvy et al. 2004; Hughes et al. 2003; Birkeland 1982).

The **crown-of-thorns starfish (COTS)** is the cause of the largest known pest-related reef disturbances in the Indo-Pacific, periodically killing over 90% of the corals on many reefs region-wide since the 1960s and frequently returning to affected reefs at approximate 15 year intervals (McClanahan et al. 2002). The COTS preferentially consumes the tissue of abundant, fast-growing plate and branching corals, but it also preys upon rarer, slow-growing massive species such as *M. annularis* (a petitioned species) that take much longer to replace themselves. *Id.* Aggregations of hundreds of thousands of crown-of-thorns starfish have been reported across the Indo-Pacific, including Australia's Great Barrier Reef, Fiji, Micronesia, American Samoa, the Cook Islands, the Society Islands, the Ryukyu Islands (Japan), Hawaii, Malaysia, the Maldives, and the Red Sea (Waddell 2005). A global survey in 2008 revealed new outbreaks devastating coral reefs in the Red Sea around Egypt; in Kenya and Tanzania; in parts of Southeast and East Asia including the Philippines, Japan and China; and in Guam, Majuro Atoll (Marshall Islands), Fiji and French Polynesia in the Pacific (Wilkinson 2008). In many of these areas, COTS outbreaks have slowed recovery after the mass bleaching in 1998. *See, e.g.,* Kimura et al. 2008. COTS are expected to be an ongoing and likely worsening problem for the South West Pacific, Guam, the Cooks Islands, French Polynesia, Mauritius and the Southwest Indian Ocean islands, the US Pacific Remote Island Areas, the Red Sea, and Africa (Morris and McKay 2008; Vieux et al. 2008; Goldberg et al. 2008; Friedlander et al. 2008; Kotb et al. 2008; Muthiga et al. 2008; Ahamada et al. 2008).

Studies have shown a strong inverse relationship between COTS populations and percentage coral cover. *See,* e.g., Figure 101. Full recovery from a major outbreak is estimated to take many decades or hundreds of years. *Id.*

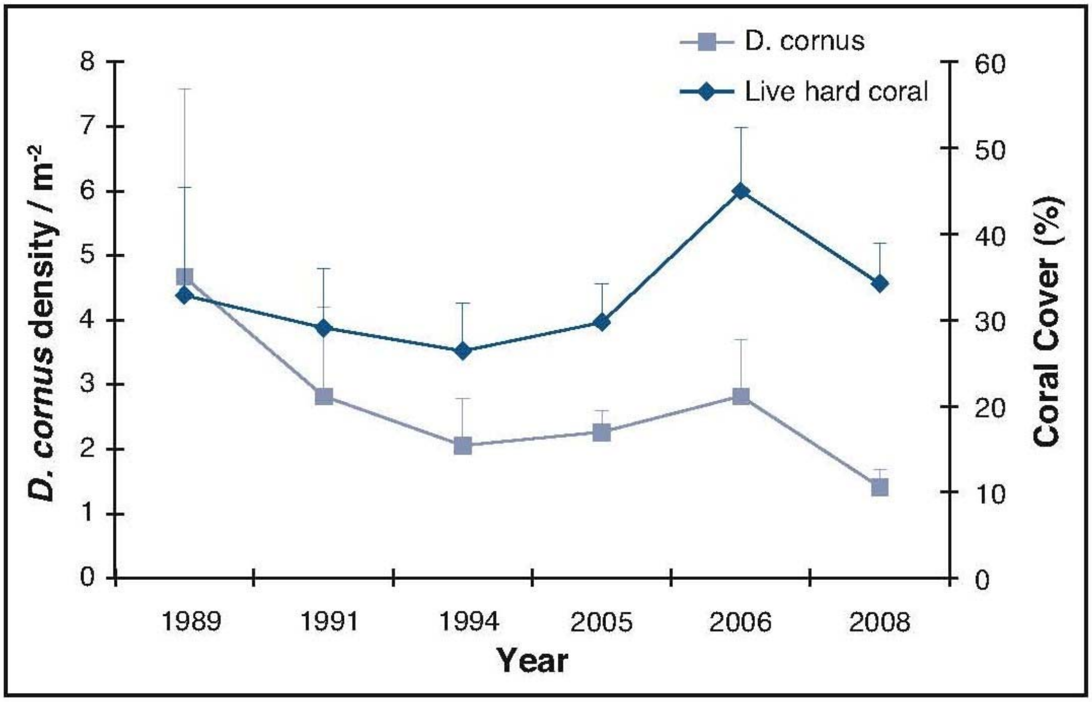
Figure 101. Average percentage coral cover and crown of thorns starfish sightings at Sekisei Lagoon and Kerama Island in Japan, 2004-2007.
Source: Kimura et al. (2008): 153.



Heavy fishing pressure on invertebrate-feeding fishes has played a major role in outbreaks of COTS and other corallivores (Waddell 2005). The main predators of COTS, including triggerfish (Balistidae) and pufferfish (Tetradontidae) as well as the giant triton (*Charonia tritonis*), have largely disappeared from many Indo-Pacific reef ecosystems due to overharvest (Wilkinson 2008; Waddell 2005; Hodgson 1999). Extensive surveys of the Great Barrier Reef Marine Park over a 10 year period of active COTS outbreaks showed that the relative frequency of COTS outbreaks was 3.75 times higher on reefs open to fishing compared to reefs in ‘no-take’ marine reserves, suggesting that removing fishing pressures might be an important way to control COTS populations and restore reef ecosystem balance (Chin et al. 2008).

Though less widespread than *Acanthaster plancii,* **corallivorous gastropods** consume coral tissue and, while natural and beneficial in healthy ecosystems, have caused significant localized coral mortality and loss of live cover in the Red Sea, Japan, the Phillippines, Western Australia, Southern China, and the Caribbean when ecological stresses enable population explosions (Schumacher 1992; Brawley and Adey 1982; Chin et al. 2008; Wilkinson 2008). One of the most destructive species is the mobile snail ***Drupella cornus***, which preferentially feeds on branching corals (Schuhmacher 1982). Between 1988 and 2008, coral cover at Ningaloo Reef tracked closely with *D. cornus* density. *See* Figure 102**.** Yet overall trends mask the significant local impacts of infestations of *D. cornus* in the 1980s and 1990s that caused nearly 100% mortality in some areas (Chin et al. 2008). Another common species in the Red Sea, ***Coralliophila costularis***, kills coral polyps by sucking on them continuously for several days and then moves on to healthy tissue (Schuhmacher 1982). Sessile ***Coralliophila violacea*** (found on *Porites* and *Synarea* species) and ***Quoyula madreporarum*** (common on *Stylophora, Seriatopora* and *Pocillopora* species) dissolve and re-precipitate coral skeletal material, creating an attachment scar around which tissue dies and falls off, which then becomes a substrate for bores and coral competitors. *Id.* On Gulf of Aqaba reefs, a clear link was found between intense outbreaks of white syndromes and *Drupella* infestations, illustrating the synergistic effects of multiple modern stressors on reef environments (Antonius and Riegl 1997).

Figure 102. Overall trends in *Drupella cornus* and live hard coral cover, 1989-2008, Ningaloo Marine Park, Western Australia.
Source: Chin et al. (2008).



Predation of corals by carnivorous and herbivorous fish can be intense on specific reefs, but the overall impacts of fish on the ecosystem are usually beneficial to reefs, largely because these species to also and in most cases preferentially prey on coral predators (e.g., triggerfish and the sea urchin *Echinometra viridis*; *see* Pinnegar et al. 2000) or competitors (e.g., herbivorous fish and algae, *see* Hughes et al. 2007). While stoplight parrotfish (*Sparisoma viride, see* Sanchez et al. 2004 and Francini-Filho et al. 2008) and large damselfish populations are known to cause damage and partial mortality to reefs in recent years, most corallivorous fish species are not considered a threat to coral reefs, and some, including butterflyfish and most parrotfishes, are considered weak but positive indicator species for healthy reef ecosystems (Mumby et al. 2007a; Mumby et al. 2007b; Bouchon et al. 2008; Roberts et al. 1988). The apparent epidemic of low and/or declining fish biomass on reefs around the world (*see,* e.g., Morris and McKay 2008, Muthiga et al. 2008; Chin et al. 2008; Goldberg et al. 2008) is a cause for serious concern among coral scientists due to the documented effects of trophic cascades on reef ecosystems. *See above plus* Pandolfi et al. 2003; Dulvy et al. 2004; Newton et al. 2007; Bellwood et al. 2004; Pandolfi et al. 2005.

C. Overutilization for Commercial, Recreational, Scientific or Educational Purposes

1. Reef Fishing

Coral reef ecosystems operate under a near balance of production and consumption, which leads to relatively low net production of fish available for extraction compared to other marine ecosystems (McClanahan 2006). Yet coral reefs have been a major source of food for hundreds of years, today yielding an average of 6.6 tonnes of food per kilometer per year. *Id*. In reef ecosystems, fishing pressure tends to disproportionately extract longer-lived, larger-bodied predators that are important in controlling smaller corallivorous fishes (e.g., damselfish and stoplight parrotfish), gastropods, and echinoderms (e.g., crown-of-thorns starfish and sea urchins) (Sandin et al. 2008, Pinnegar et al. 2000). Large herbivorous fish species, which graze on algae, are also targeted for extraction (Pinnegar et al. 2000). A NMFS-sponsored 2005 survey designated overfishing as the most widespread threat to coral reef ecosystems, noting that it was identified as a medium or high threat to over 35% of the world's coral reefs (Waddell 2005).

Pandolfi et al. (2003) analyzed historical records for reef ecosystems in 14 regions and found that all reefs were substantially degraded long before modern outbreaks of disease and bleaching were first documented. The most important factor influencing the trajectory of this long-term degradation are the sharp declines in large carnivorous and herbivorous reef species in response to overfishing pressures commencing with colonial occupation of the respective areas. *Id.* Scientists postulate that the historic and ongoing overharvest of herbivorous fish from the reef ecosystem hinders the ability of corals to successfully compete against fast-growing algae species and renders corals more susceptible to subsequent disturbances such as bleaching, disease, and predation (Pandolfi 2003; Knowlton 2001; Hughes 2004). Reduction in diversity of herbivorous species can also have disastrous effects on coral communities, as evidenced throughout the Caribbean in the 1980s when *Diadema antillarum*, which had monopolized reef ecosystems in the absence of competition from overfished herbivorous species, was devastated by a pathogen (Pinnegar et al. 2000). Whereas an unfished reef would naturally support a wide array of algae grazers, many of which would be resistant to any given pathogen, Caribbean reefs were suddenly bereft of their last effective herbivore and were quickly overgrown with macroalgae. *Id.* In light of the overwhelming evidence of the inverse relationship between fishing pressures and reef health, Pandolfi et al. (2003) concluded that "coral reef ecosystems will not survive for more than a few decades unless they are promptly and massively protected from human exploitation" (Pandolfi et al. 2003: 957).

Modern fishing technologies are exacerbating the chronic overharvesting of reef fish and bycatch species while causing significant collateral damage to the reef ecosystem (McClanahan

2006). Scientists have called for the discouragement of the most destructive fishing gear, including nets that are dragged or have heavy weights on the drag lines, heavy traps made of non-degradable materials, explosives, poisons, and any method that breaks corals as a means of exposing and extracting the target species. *Id.* Seine nets, which catch the widest variety of species and the smallest individuals, have been identified as a top priority for elimination due to their disproportionate impact on coral reef ecosystems. *Id.*

The burgeoning live fish trade poses a serious threat to coral reef ecosystems worldwide (Vincent 2006). Most of the species sought after for the live fish market come directly from reefs. *Id.* Targeted species are long-lived and late maturing, rendering them particularly vulnerable to high harvest levels. *Id.* Cyanide poisoning is a very common method of live fish harvest, despite its associated high mortality rates during capture, holding, and transport. *Id.*

Global trade in live food fish was estimated to be 30,000-50,000 tonnes per year in the late 1990s, with total estimated extraction of roughly double that amount due to high handling and transportation mortality (Vincent 2006). As demand has increased, wild fish populations have declined dramatically and fish extraction efforts are now occurring in most countries of the Indo-Pacific and at ever greater distances from the consumption hub of Hong Kong. *Id.* Live fish are also increasingly exported to Australia, the United States, and many Southeast and Eastern Asian countries with large ethnic Chinese populations. *Id.* Current levels of live fish production throughout Southeast Asia and the Maldives significantly exceed estimates of sustainable extraction. *Id.*

2. Aquarium Trade in Corals

The trade in ornamental species for marine aquaria is global, with 30-45 countries exporting specimens and roughly the same number creating the import market (Vincent 2006). It is estimated that there are 1.5 million marine aquarium hobbyists worldwide, including 1 million Americans (USCRTF 2000). The vast majority of the organisms sold for marine aquaria are wild specimens directly extracted from coral reefs, with less than 1% of the live coral reef fish and live coral markets cultured (Vincent 2006).

140 scleractinian species and 61 soft corals are harvested and traded for the international aquarium market (Vincent 2006). Approximately 5% the global wild coral population was harvested annually in the late 1980s for the live coral trade, and harvest levels increased by 30-50% each year until 1997. *Id.* Between 1998 and 2003, 11-12 million stony and soft corals were traded annually. *Id.* The United States is by far the largest consumer of live corals, importing more than 70% of the total market. *Id.* In the 1990s, Americans imported an estimated 8 to 8.8 million pieces of live coral each year. *Id.* Virtually all live coral exports between 1997 and 2001 came from Indonesia, Fiji, the Solomon Islands, and Tonga, with 71% of the total market exported from Indonesia. *Id.* Between 1990 and 2000, the international aquarium trade in coral and live rock (reef substrate) increased at a rate of 12-30% per year (USCRTF 2000: 4).

Historic harvest of corals is thought to have severely depleted local populations of numerous petitioned species, including many *Acropora* and *Porites* species, *Caulastrea echinulata, Heliopora coerulea.* Such harvest clearly constitutes "overutilization." Direct harvest of corals for the aquarium trade still occurs for many imperiled coral species, even in countries where it has been banned.

In addition to the coral fishery, other reef species are also targeted by the strong and growing global aquarium market, including reef fish and marine invertebrates (Vincent 2006; USCRTF 2000). The United States dominates these import markets as well. *Id.* Reefs and coral colonies can be physically damaged or destroyed when skeletons are broken or overturned to pursue target species hiding in reef structures (Vincent 2006: 217). Reef fish are frequently harvested using poisons, including cyanide, chlorine bleach, quinaldine, and plant toxins (USCRTF 2000: ii). Some of these poisons damage or kill non-target corals and the reef itself. *Id.* Laboratory studies of cyanide, for example, have shown that very brief exposures cause bleaching and inhibit calcification and photosynthesis in corals (USCRTF 2000: 3). Exposures of 30 minutes or more result in coral mortality even at concentrations several fold lower than those typically used in cyanide fishing. *Id.* at 7.

The harvest of coral, live rock, and reef-associated species for aquarium trade can also have longer term impacts on local species populations and coral reef ecosystems. These ecosystems have evolved to become efficient nutrient recyclers in very nutrient-poor environments, and the impacts of removing significant biomass from the system are not fully understood. Alterations in community coral structure in the Philippines from excessive harvest inspired the federal government to ban all domestic take as well as all exports in the late 1980s. Recent studies of Hawaiian reef fish have demonstrated population declines of 38-59% for the most popular aquarium fish species in recent decades (USCRTF 2000: 7). Some targeted reef fish are herbivorous species that play an important role in preventing the overgrowth of algae on reefs, and their declining numbers can upset the fragile balance of reef ecosystem health. *Id.* Finally, excessive harvest of substrate deprives the reef ecosystem of important fish and invertebrate habitat and interferes with the settlement and recruitment of corals and other benthic organisms (USCRTF 2000: 4). Numerous studies have documented how such impacts of unsustainable extraction can lead to phase shifts within the ecosystem and localized extirpations of corals and other reef-associated species (USCRTF 2000: 4).

3. Curios Trade

The curios trade for corals primarily targets branching species that are particularly susceptible to other threats, such as bleaching and crown-of-thorns starfish predation (USCRTF 2000: 4). Because large specimens fetch higher prices, reproductively mature colonies are disproportionately harvested, with detrimental results for recruitment and population growth (Bruckner et al. 2002). The curios trade employs many of the same destructive harvesting methods as the aquarium trade (Vincent 2006: 217). Some scientists have voiced concern over the potential overharvest of sea urchins and other herbivorous reef-associated species in the curios trade, which could lead to algal overgrowth and coral reef decline. *Id.*

4. Mining

The use of coral, reef rock, and sand extracted from reef ecoystems for the construction of buildings dates back many centuries, particularly in Red Sea communities and the Maldives

(Spalding et al. 2001). More recently, coral, reef rock, and reef sand has been extensively mined in many coralline island nations as a primary construction material for buildings and roads; as a soil additive in agricultural areas; and in the refinement of food staples such as sugar. *Id.* The impacts of reef mining have been dramatic in many areas; in the Maldives, for example, 500,000 cubic feet of coral were extracted from Male Atoll alone in 1986 (Naseer 1997). Reef mining has been banned in many countries (Bruckner 2002; Tamelander and Rajasuriya 2008; Seino et al. 2006), but illegal harvest continues. Coral mining is still a serious problem in East Africa (Muthiga et al. 2008); Sri Lanka (Tamelander and Rajasuriya 2008); Southeast Asia (Tun et al. 2008); Panama (Rodriguez-Ramirez et al. 2008); the Southwest Pacific (Morris and McKay 2008); and at individual sites such as Bali's Turtle Island and Majuro Atoll in the Marshall Islands, where it has been associated with recent, rapid reef ecosystem deterioration (Seino et al. 2006; Beger et al. 2008). In 2008, Taiwan's Council of Agriculture repealed a 1989 prohibition on coral harvest and opened 7,811 square kilometers of reef habitat to regulated collection, citing concerns over the environmental impacts of the rampant unregulated poaching that has ensued in spite of the 1989 ban (Taipai Times 6-15-08).

5. Diving and Snorkeling

While diving and snorkeling can generate huge revenues for local communities and create strong incentives for reef preservation, chronic coral damage is a concern in areas of recreational use (Waddell 2005). Physical contact from divers and snorkelers damages corals, as evidenced at heavily trafficked sites such as the US Virgin Islands National Park's Trunk Bay and Oahu's Hanauma Bay Nature Preserve as well as less used sites within Australia's Great Barrier Reef Park. *Id.* Divers also stir up sediment and can introduce disease, nutrients, and contaminants into fragile coral ecosystems that would otherwise be physically isolated from such threats. *Id.* Harms associated with boats and anchors, discussed below, likewise increase with recreational demand on coral reefs.

D. Other Natural and Anthropogenic Factors

1. Physical Damage from Boats and Anchors

Boat traffic is a major threat wherever humans come in contact with coral reefs. Propellers speeding through shallow waterways break corals, scar seagrass beds, and kill endangered marine mammals. Coral reef habitat frequently overlaps with heavy shipping and boating traffic, and island ports as well as large ports located near shallow water reefs increase the probability of vessel-associated damage to reefs. In Guam's Apra Harbor, for example, an average of 1,600 vessels are routed through the some of the highest coral cover areas of the island each year on their way to the largest U.S. deepwater port in the Western Pacific and the busiest port in Indonesia (Burdick et al. 2008). Ship groundings and reef damage from navigational buoys are common in Guam due to the frequency of typhoons in the region. *Id.* In Hawaii, the expected tripling of Hawaiian cruise ship port calls (currently 400 per year) in the next few years has raised serious concerns about reef damage due to the limited port facilities available. *Id.*

Boat groundings and anchors cause significant localized damage to shallow water coral reefs (Wadell and Clarke 2008). Physical coral reef damage associated with anchors and ship groundings includes the direct loss of corals and other marine invertebrates when they are dislodged, fractured, and crushed. On April 27, 2006, for example, a 228-meter tanker ran aground on the reefs off of Guayanilla, Puerto Rico, causing extensive damage to 8,500 square meters of a bank type coral reef with significant live coral cover (García-Sais et al. 2008). Severe damage to 15 acres (6 hectares) of coral habitat was similarly sustained when the 555-foot *Cape Flattery* ran aground off the coast of the Hawaiian Island of Oahu on February 2, 2005 (Friedlander et al. 2008), as well as with the grounding of the 567-foot warship USS Port Royal in what was one of Oahu's most pristine remaining reef areas on February 5, 2009 (Honolulu Advertiser 3-2-09). In the US Virgin Islands, newly established anchorages on a highly valued local reef were shown to reduce coral cover by over 87%, coral species richness by 54%, and rugosity (reef surface complexity) by 43.5% (Rothenberger et al. 2008). Following repeated incidents of significant reef damage from large vessel anchorings, the International Maritime Organization designated the Flower Garden Banks National Marine Sanctuary in the Northwestern Gulf of Mexico as the first international "no anchor zone" in 2002 (Hickerson et al. 2008).

Groundings also increase the risk of contamination from oil and toxic chemicals. One such grounding and fuel spill occurred in the popular, formerly intact snorkeling lagoon of Majuro (Marshall Islands) in 2007, resulting in the destruction of several dozen *Porites* colonies and the near destruction of an endemic colony of three-banded anemone fish (Beger et al. 2008). Oil spills are of particular concern in areas where offshore oil production overlaps with extensive coral communities, such as in the Northwestern Gulf of Mexico (Hickerson et al. 2008). In Palau, a 2005 grounding event damaged 875 square meters reef edge with high coral cover, crushing 350 square meters of reef and causing an additional 300 square meters of coral to bleach (Marino et al. 2008). Virtually 100% of bleached corals died following this event, and studies of the area 14 months later revealed a complete lack of any coral recruitment in the damaged area, leading scientists to conclude that toxins from the large amount of copper-based bottom paint deposited during this event subsequently prohibited the reestablishment of many organisms. *Id.*

2. Marine Debris

Marine debris is a serious and growing threat to ocean ecosystems. It originates from human actions on land, such as improper waste disposal, transport, and storage as well as stormwater discharge; human actions on the oceans, including discarded fishing gear, cargo lost from ships, waste disposal from public and private vessels, offshore oil and gas platforms and rigs, and aquaculture installations; and natural events such as tsunamis, storms, and floods that can wash debris from land or ocean-based sources into the oceans (NOAA 2008).

Some of this debris washes to nearby shores, where it accumulates on beaches and presents serious problems for coastal ecosystems (UNEP 2009). Plastics are the largest constituent of debris collected from beaches, and studies have consistently documented the presence of plastics in the digestive systems of the majority of seabirds. Pinnipeds, and sea turtles tested. *Id.* But marine debris from various sources can also be transported large distances via ocean currents and can accumulate in "convergence zones" such as those created by the North Pacific Subtropical Gyre (NOAA 2008). One such convergence zone is the Papahanaumokuakea Marine National Monument, from which 570 metric tons of derelict fishing nets were removed between 1996 and 2007. *Id.*

Fishing nets, lines and traps are perhaps the most dangerous types of marine debris for coral reef ecosystems (Waddell 2005). Most modern fishing equipment is made of synthetic materials that continue to entangle and destroy marine life for decades after they are lost or discarded, effectively "ghost fishing" across thousands of miles. *Id.* Abandoned fishing nets similarly trap, consolidate and transport other marine debris to convergence zones, many of which contain coral reef ecosystems (NOAA 2008). These nets full of garbage and bycatch become ensnared on reefs, crushing corals and continuing to trap reef-associated wildlife (Waddell 2005). Moreover, these conglomerations of marine debris provide habitat for marine organisms and can transport species and infectious diseases many thousands of miles from their native ranges. *Id.* Invasive species can subsequently create serious problems as they colonize and overwhelm local reef ecosystems, as discussed in more detail below. *Id.*

3. Aquatic Invasive Species

Invasive species are the second leading cause of biodiversity declines behind habitat destruction and are estimated to impact nearly half of all species listed as threatened or endangered (Waddell 2005). Aquatic invasives have been documented in all US regions and are believed to exist in every region of the world. *Id.* Ballast water from ships, which can carry bacteria, protists, dinoflagellates, diatoms, zooplankton, algae, benthic invertebrates (including corals and corallivores), and fish, is a common means by which non-native species are introduced to reef ecosystems. *Id.* Other pathways include aquaculture, marine debris, and aquarium releases. *Id.* Home aquarium releases are thought to be responsible for the introduction of an Indo-Pacific lionfish, *Pterois volitans,* into many Caribbean reef ecosystems (U.S., Bermuda, Cuba, Jamaica, Turks and Caicos), where it has created serious problems for native species (Waddell 2005; Creary et al. 2008).

4. Military Activities

The US has military installations near coral reefs in Hawaii (Hickam Air Force Base, Pearl Harbor, and Kaneohe Bay); the Pacific Remote Island Areas (Johnston and Wake Atolls); the Marshall Islands (Kwajelein Atoll); the Northern Mariana Islands and Guam; Florida (Key West and Panama City); Puerto Rico; US Virgin Islands; Cuba; and Diego Garcia (in the Indian Ocean) (Waddell 2005). Reefs in several of these areas were historically used for target practice or nuclear testing, and hazardous waste has been dumped on numerous islands (Spalding et al. 2001). Adverse impacts associated with military activities include physical reef damage and mortality of corals and reef-associated species due to detonation of explosives, munitions disposal, boat anchorings and groundings (*see* discussions above), and debris; contamination from oil and fuel spills and other toxic chemicals used in military equipment, including nuclear wastes; and non-native species introductions from ship bilge water and aircraft cargo. *Id.* Military activities are generally not restricted within Marine National Monuments, National Marine Sanctuaries, or Marine Protected Areas. *See* 74 Fed. Reg. 1557, 74 Fed. Reg. 1565, 74

Fed. Reg. 1577, 71 Fed. Reg. 36443; 16 U.S.C. § 1431 *et seq.* Moreover, Executive Order 13089 allows degradation to coral reef ecosystems in circumstances of war, national emergencies, and "in any case that constitutes a danger to human life or a real threat to vessels, aircraft, platforms, or other man-made structures at sea" (63 Fed. Reg. 32701 (Executive Order 13089)).

5. Oil and Gas Development

The negative impacts of oil and gas development for coral species, as documented in numerous studies, include physical breakage from drilling machinery and debris as well as ship traffic; sedimentation and smothering; toxic contamination from heavy metals; the inhibition of growth and recruitment; and problems associated with feeding, behavior, and mucus cell function (Waddell 2005). Sheltered coastal tropical environments where reef habitat is found are particularly susceptible to damage from oil spills, since these areas are typically difficult to navigate with cleanup equipment, reduced water circulation hinders natural dispersal by currents, and the use of dispersants in cleanup efforts causes oil to sink into sensitive reef habitats. *Id.* Extensive, chronic effects on vital reef processes were documented on surviving colonies five years after a major 1986 oil spill in Panama. *Id.* Oil pollution also affects benthic faunal species distributions, with reduced abundances of preferred prey species for fish in contaminated sediments. *Id.*

Oil and gas exploration involves disruptive activities with largely unknown impacts, including seismic testing, platform installation, dredging, drilling, the discharge of various wastes and drill cuttings, and light and air pollution. *Id.* Removal of drilling platforms generally requires the use of explosives, which can cause mass mortality of reef-associated species. *Id.* In the Gulf of Mexico, site of the Flower Garden Banks National Marine Sanctuary and its extensive reef habitat, 6,500 production platforms and nearly 161,000 kilometers of pipeline and other infrastructure had been installed as of 2005. *Id.*

E. The Inadequacy of Existing Regulatory Mechanisms

Existing regulatory mechanisms are inadequate to address the principal threats to the petitioned coral species. Regulatory mechanisms addressing greenhouse gas emissions and impacts to the petitioned corals from associated ocean warming and ocean acidification are woefully inadequate. Unless strong near-term emissions reductions are implemented in short order at the national and international levels, it is likely that the petitioned coral species will be committed to extinction. This section reviews regulatory mechanisms addressing greenhouse gas emissions as well as regulatory mechanisms directed at non-greenhouse-gas-related threats to corals and reef ecosystems.

1. Regulatory Mechanisms Addressing Greenhouse Gas Emissions, Climate Change, and Ocean Acidification Are Ineffective

Greenhouse gas emissions pose the primary threat to the continued existence of the petitioned coral species principally through impacts from ocean warming and ocean acidification, and yet are among the least regulated threats. The best-available science indicates that the current atmospheric CO_2 concentration of ~387 ppm is already detrimental to coral species, and that atmospheric CO_2 concentrations must be reduced to at most 350 ppm, and perhaps much lower (300-325 ppm CO_2), to adequately reduce the synergistic threats of ocean warming, ocean acidification, and other impacts (Veron et al. 2009; Donner 2009; Hansen et al. 2008; Hoegh-Guldberg et al. 2007; McMullen and Jabbour 2009), as discussed in detail above. Regulatory mechanisms at the national and international level do not adequately address the impacts from climate change and ocean acidification to the petitioned coral species, nor require the greenhouse gas emissions reductions necessary to protect the petitioned coral species from extinction.

a. National and International Emissions Reductions Needed to Protect the Petitioned Coral Species

In order to protect the petitioned coral species, the best-available science indicates that atmospheric CO_2 concentrations must be reduced to at most 350 ppm, and perhaps much lower (300-325 ppm CO_2), to adequately reduce the synergistic threats of ocean warming, ocean acidification, and other impacts (Veron et al. 2009; Donner 2009; Hansen et al. 2008; Hoegh-Guldberg et al. 2007; McMullen and Jabbour 2009). U.S. and international regulatory mechanisms must achieve the near-term emissions reductions by 2020 and 2050 required to reach a 350 ppm CO_2 target or below.

The Intergovernmental Panel on Climate Change (IPCC) has found that to reach a 450 ppm CO_2eq target, the emissions of the United States and other developed countries should be reduced by 25 to 40% below 1990 levels by 2020 and by 80-95% below 1990 levels by 2050 (Gupta et al. 2007: 776). A 450 ppm CO_2eq target is expressed in terms of "CO_2 equivalents" which includes the climate effect of all human-induced greenhouse gases, tropospheric ozone, and aerosols, and is equivalent to a ~400 ppm CO_2 target (Hare and Meinshausen 2006). Thus to reach a 350 ppm CO_2 target, the United States and developed countries must achieve or exceed the upper end of the reduction range of 25 to 40% below 1990 levels by 2020. Climate scientists, including the former chair of the IPCC Sir John Houghton, have called for developed countries to make a commitment at the U.N. climate summit in Copenhagen to cut carbon emissions by at least 40% below 1990 levels by 2020 "to avoid the worst impacts of climate change" (http://www.panda.org/about_our_earth/search_wwf_news/?174261/40-of-worlds-leading-scientists-call-for-40-emission-cut).

b. United States Climate Initiatives are Ineffective

As acknowledged by the Department of Interior in the final listing rule for the polar bear, regulatory mechanisms in the United States are inadequate to effectively address climate change (73 Fed. Reg. 28287-28288). While existing laws including the Clean Air Act, Energy Policy and Conservation Act, Clean Water Act, Endangered Species Act, and others provide authority to executive branch agencies to require greenhouse gas emissions reductions from virtually all major sources in the U.S., the federal government is currently not implementing these legal mechanisms. While full implementation of these flagship environmental laws, particularly the Clean Air Act, would provide an effective and comprehensive greenhouse gas reduction strategy, due to their non-implementation, existing regulatory mechanisms must be considered inadequate to protect the petitioned coral species from climate change and ocean acidification.

State Greenhouse Gas Mitigation Measures

In the absence of federal leadership, state and local governments have taken the lead in measures to reduce greenhouse gas emissions. While certainly a step in the right direction, unfortunately, these measures on their own are insufficient to prevent the extinction of the petitioned coral species. For example, the strongest law enacted to date is the California Global Warming Solutions Act of 2006. Signed into law in September, 2006, it is the nation's first mandatory cap on a state's overall greenhouse gas emissions. The California Legislature declared:

> Global warming poses a serious threat to the economic well-being, public health, natural resources, and the environment of California. The potential adverse impacts of global warming include the exacerbation of air quality problems, a reduction in the quality and supply of water to the state from the Sierra snowpack, a rise in sea levels resulting in the displacement of thousands of coastal businesses and residences, damage to marine ecosystems and the natural environment, and an increase in the incidences of infectious diseases, asthma, and other human health-related problems. (Cal. Health and Safety Code § 38501(a)).

The Global Warming Solutions Act requires the reduction of greenhouse gas emissions to 1990 levels by the year 2020. *Id.* at § 38550. While the California Global Warming Solutions Act is a promising first step, like the Kyoto Protocol, it is insufficient on its own to slow climate change and ocean acidification sufficiently to ensure the survival of the petitioned coral species.

c. International Climate Initiatives are Ineffective

The primary international regulatory mechanisms addressing greenhouse gas emissions are the United Nations Framework Convention on Climate Change and the Kyoto Protocol. As acknowledged by the Department of Interior in the final listing rule for the polar bear, these international initiatives are inadequate to effectively address climate change (73 Fed. Reg. 28287-28288). Additionally, the Kyoto Protocol's first commitment period only sets targets for action through 2012. Importantly, there is still no international agreement governing greenhouse gas emissions in the years beyond 2012. Thus international regulatory mechanisms must be considered inadequate to protect the petitioned coral species from climate change and ocean acidification.

2. Regulatory Mechanisms Addressing Non-Greenhouse-Gas-Related Threats to Corals and Tropical Ecosystems Provide Inadequate Protection to the Petitioned Species

Florida State Law

Florida is the only state in the continental United States to have extensive shallow coral reef formations near its coasts. Florida laws protecting coral reefs and species focus mainly on the prevention of human contact, such as direct destruction or take of coral. In 2009, Florida enacted the Coral Reef Protection Act which authorizes the state to collect penalties for damages to coral reefs resulting from vessel groundings. Additionally, Florida Administrative Code Section 68B-42.009 prohibits the take, attempted take, destruction, sale or attempted sale of any hard or stony coral (Order Scleractinia) or any fire coral (Genus *Millepora*), as well as prohibiting the possession of any fresh, uncleaned, or uncured specimen of these species. These prohibitions do not apply to specimens that are legally farmed or harvested outside state waters.

Only one coral species, *Dendrogyra cylindrus* (pillar coral, endangered), is listed as an imperiled species under the Florida Endangered Species Act. FL Fish and Wildlife Commission 2008. Because it was designated prior to June 23, 1999, *Dendrogyra cylindrus* is afforded the protections of Chapter 68A-27.003 of the Florida Endangered Species Act which prohibits take, including harm, of protected species without a permit.[4]

The continued decline of corals in Florida waters is indication of the inadequacy of these prohibitions and penalties. The laws do not tackle the overarching threats of global warming and ocean acidification. Additionally, they are inadequate to avoid other key threats such as nutrient and sediment deposition. Moreover, there is inadequate enforcement and penalties for violations of these laws.

Hawaii State Law

Hawaii is home to 84 percent of coral under U.S. jurisdiction. In Hawaii, state law prohibits breaking or damaging stony corals. H.A.R. 13-95-70. The sale of stony corals native to Hawaii is also prohibited. *Id.* Hawaii law also imposes fines on vessels that run aground on coral reefs. *Id.* Nonetheless, state laws are unable to fully address key threats to coral reefs in Hawaii.

In sum, the protections offered by state laws are important, but inadequate to protect these corals. Endangered Species Act listing would afford greater protection from a variety of threats and greater deterrents from harming corals.

Existing US Federal Laws and Programs

Acropora palmata and *Acropora cervicornis* were listed as threatened under the **Endangered Species Act** in 2006 (71 Fed. Reg. 26852). Citing recent drastic declines, historic lows in abundance, local extirpations leading to range constrictions, limited sexual recruitment and habitat, and declining fertilization success, NMFS concluded that both species were in danger of extinction throughout their entire ranges within the next 30 years. *Id.* at 26856-26857. Critical habitat was designated for these species in 2008, and included four specific areas: (1) 1,329 square miles of marine habitat in the Florida area; (2) 1,383 square miles in the Puerto Rico area; 121 square miles in the St. John/St. Thomas area, and 126 square miles in the St. Croix area (73 Fed. Reg. 72210). While these two species of corals are afforded the protections

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[4] Art. IV, Sec. 9, Fla. Const. Law Implemented Art. IV, Sec. 9, Fla. Const. History–New 8-1-79, Amended 6-22-80, 7-1-83, 7-1-84, 7-1-85, Formerly 39-27.03, Amended 6-1-86, 5-10-87, 4-27-89, 9-14-93, 6-23-99, Formerly 39-27.003. Amended 12-16-03.

of the Endangered Species Act, the other corals proposed here receive no such federal protections that would greatly benefit their conservation and recovery.

The Coral Reef Conservation Act, passed in 2000, requires NMFS to develop a national coral reef action strategy, initiate a matching grants program for reef conservation, and create a conservation fund to encourage public–private partnerships (US Commission on Ocean Policy 2004a). **H.R. 860, Coral Reef Conservation Act Reauthorization and Enhancement Amendments of 2009**, was introduced in the US House of Representatives in February 2009. *See* http://www.opencongress.org/bill/111-h860/text. The Coral Reef Conservation Act can be viewed as Congress' acknowledgement that the government needs and is willing to fund assistance from outside organizations. While this effort funds research, mapping, and monitoring efforts, it is inadequate to address the multifaceted threats facing corals. Congress has not mandated that any projects focus on bleaching, global warming or ocean acidification. And the law does not provide any enforceable regulatory measures that will protect coral habitat or protect corals from direct human threats or the overarching threats of global warming and ocean acidification.

The **US Coral Reef Task Force ("Task Force")** was established in 1998 by **Presidential Executive Order 13089**, which mandates that federal agencies (1) use their programs and authorities to protect and enhance US coral reef ecosystems; and (2) to the extent permitted by law, ensure that any authorized, funded, or executed actions will not degrade the conditions of these ecosystems (Maurin and Bobbe 2009 (US Coral Reef Task Force Federal Member Coral Profiles)). The Task Force currently consists of 12 Federal agencies; 7 U.S. states, territories, commonwealths (Commonwealths of the Northern Mariana Islands and Puerto Rico, States of Florida and Hawaii, and the Territories of Guam, American Samoa, and the US Virgin Islands); and the three US Freely Associated States (Federated States of Micronesia, Republic of the Marshall Islands, and the Republic of Palau – all non-voting members). *Id.* Task Force responsibilities include (1) overseeing implementation of Executive Order 13089 and developing and implementing efforts to map and monitor US coral reefs; (2) researching reef decline and its solutions; (3) minimizing and mitigating coral reef degradation from pollution, overfishing, and other causes; and promoting international conservation and sustainable reef use. *Id.* The Task Force is an important step toward the conservation of corals and it has acknowledged the severity of the threats faced by coral reefs including global warming. However, the Task Force has not responded to threats by taking measures to prevent long term threats to corals from global warming and ocean acidification. Primarily the Task Force has focused on research, monitoring, and reporting without needed action to protect corals. Moreover, the objectives set out by the Executive Order do not mandate any federal agency action because they are framed as creating a policy, which is simply a guiding principle or procedure and is not legally binding or enforceable. Exec. Ord. 13089 §§ 2 & 6. The Order explicitly denies the creation of any right, substantive or procedural, enforceable in law or equity by a party against the U.S., its agencies, and its officers. *Id.* § 6. Additionally, the ability of the Task Force to carry out its goals is limited by discretionary appropriations. *Id.* § 3.

In 1996, the United States launched the **United States Coral Reef Initiative (USCRI).** Created as a platform for U.S. support of national and international coral reef conservation efforts, the USCRI's goal "is to strengthen and fill the gaps in existing efforts to conserve and sustainably manage coral reefs and related ecosystems (sea grass beds and mangrove forests) in U.S. waters." The USCRI consists of federal, state, territorial and commonwealth governments, the nation's scientific community, the private sector, and other organizations. The National Oceanic and Atmospheric Administration (NOAA), one of the prime federal agency contributors to the USCRI, has worked to reduce pollution, create marine protected areas, educate import and export officials to identify corals, monitor and research coral reefs. The U.S. Coral Reef Initiative, whose achievements are primarily attributed to NOAA and its partners, has filled some of the gaps left open by inadequate state and congressional statutes in terms of coral reef monitoring and the ability to effect change within local communities across the nation. The USCRI and NOAA can locate bleaching events and measure their severity, but their role is merely one of reaction, not action. The USCRI and NOAA have only enacted tools to chart the *results* of increasing greenhouse gases emissions and global warming. There exist no efforts to tackle the issue of how to reduce, mitigate, and adapt to global warming.

The **US All-Islands Coral Reef Initiative** is "a collaboration of marine resource managers from state, commonwealth, territorial agencies and freely associated states working together with federal agencies to conserve and protect coral reefs in the United States." (http://www.allislandscorals.org/. It was established in 1994 and includes governor-appointed representatives from American Samoa, Commonwealth of the Northern Marianas, Guam, Hawai'i, Puerto Rico, the U.S. Virgin Islands, and Florida, as well as Affiliate Members from the freely associated states of the Federated States of Micronesia, the Republic of the Marshall Islands, and the Republic of Palau. *Id.* Most of these efforts are focused on direct human threats to corals, and they do not have a comprehensive approach to addressing greenhouse gas emissions and ocean acidification.

The Marine Protection, Research, and Sanctuaries Act, which includes the **Ocean Dumping Act** and the **National Marine Sanctuaries Act (NMSA)**, was passed in 1972. 33 U.S.C. §§ 1401 *et seq.* The Ocean Dumping Act seeks to regulate ocean discharge and limit or prevent the dumping of any material that would adversely affect (1) human health, welfare, or amenities; or (2) the ecological systems or economic potential of the marine environment (US Commission on Ocean Policy 2004a). The NMSA authorizes NMFS to designate marine sanctuaries and promulgate conservation and management regulations for those areas. *Id.; see* discussion of Marine Sanctuaries, *infra.* The NMSA includes a provision that allows NMFS to fund habitat restoration within sanctuaries, including coral reefs, with cost recovery from responsible parties. Recovered funds may be used to restore the damaged habitats or other habitats within national marine sanctuaries. *Id.* There are currently thirteen sanctuaries managed under the National Marine Sanctuaries Program, at least five of which contain coral communities (US Commission on Ocean Policy 2004a). Coral research, monitoring, and management activities are conducted in these sanctuaries. *Id.; see also* http://sanctuaries.noaa.gov/. For example, The Florida Keys National Marine Sanctuary encompasses 2,800 square nautical miles and is jointly managed by the State of Florida's Department of Environment and NMFS. *See* http://www.florida-keys.fl.us/ntmarine.htm. The NMSA has no provisions for projects designed to prevent physical or long-term chronic damages to reefs from global warming, ocean acidification, nutrient overloading, or disease. (US Commission on Ocean Policy 2004a). The continued loss of corals in marine sanctuaries indicates that the designations alone are not sufficient to arrest the decline and encourage the recovery of species. The designation of a sanctuary and its boundaries does not lessen the key threats such as bleaching and impaired calcification. Bleaching will occur whether or not a reef is within a sanctuary. Thus, while the designation of marine sanctuaries and other marine protected areas is crucial to prevent some forms of direct human damage, yet the designation cannot protect corals from larger long-term global threats.

US National Marine Monuments are also managed under the NMFS National Marine Sanctuaries Program. Some activities are prohibited in National Monuments thus affording limited protections to corals there. The Papahaaumokuakea Marine National Monument, which was created by Presidential proclamation on June 15, 2006, around the Northwest Hawaiian Islands (71 Fed. Reg. 36443; *see also* 71 Fed. Reg. 51134 (original designation of the Northwest Hawaiian Islands National Marine Monument)). Other Marine National Monuments that contain coral reefs include the Marianas Trench National Monument in the Northern Marianas Islands, 74 Fed. Reg. 1557 (Jan. 6, 2009), the Pacific Remote Islands Marine National Monument, 74 Fed. Reg. 1565(Jan. 6, 2009) *see also* discussion in Part One of this Petition, *supra*, and Rose Atoll Marine National Monument in American Samoa, 74 Fed. Reg. 1577 (Jan. 6, 2009); *see also* discussion in Part One of this Petition, *supra*. Additionally, in 2001, areas in the Virgin Islands with coral reefs were designated as National Monuments and managed by the National Park Service. Virgin Island Coral Reef National Monument and Buck Island Reef National Monument were designated by Presidential Proclamations 7199 & 7392. Similar to marine sanctuaries, the regulatory mechanisms within National Monuments are also inadequate to protect imperiled corals.

Executive Order 13,158 created an advisory committee for coordinating and strengthening a coordinated system of **Marine Protected Areas** ("MPAs"). Corals within MPAs benefit from the management of uses within the designated areas. There are 207 Marine Protected Areas ("MPAs") encompassing coral reef ecosystems within the United States (Waddel et al. 2008; *see also* Wusinich-Mendez and Trappe 2007). 76% of these MPAs are multiple use areas allowing some level of resource extraction throughout the entire site, and almost one quarter of them were established for the explicit purpose of continued extraction (Waddle et al. 2008). Take of marine resources is prohibited in part or all of 49 of these MPAs. 86% of these MPAs are permanent, whereas protections are only temporarily provided at 14% of the sites. *Id.* Management plans have been approved for only 42 MPAs, illustrating the challenge of long-term plan development. *Id.* Enforcement, funding, management capacity, monitoring, and public support have been identified as key problems at a majority of the MPAs. *Id.* 45% of the MPAs support some sort of ongoing monitoring activity, and some level of enforcement effort is reported at 74% of the sites. *Id.* Again, like the regulatory mechanisms for marine sanctuaries, and national monuments other marine protected areas are good at protecting reefs from some of the direct human threats, but are inadequate to address the global threats posed by climate change and ocean acidification. Additionally, these various forms of protecting marine areas are all managed differently and most do not completely remove direct human impacts, for example many designated areas still permit various forms of fishing that can adversely impact coral reefs.

There are other U.S. laws that could be brought to bear to further protect corals, however, thus far the implementation of these laws does not provide much protection for imperiled corals. In large part, these laws have not yet been employed to the benefit of corals. Even if fully utilized they would still provide only piecemeal protection for corals. Moreover, they cannot sufficiently address the key long-term threats to corals. Instead these laws provide a patchwork of environmental laws that are important, but inadequate to provide a safety net for corals. These laws include:

- **Magnuson–Stevens Fishery Conservation and Management Act**, established sovereign federal rights to all fishery resources within 200 miles of US shores. 16 U.S.C. §§ 1801 *et seq.*
- The **Coastal Zone Management Act** of 1972 (16 U.S.C. §§ 1451 *et seq.*) provides technical assistance and financial incentives for sustainable state management of coastal areas (US Commission on Ocean Policy 2004b).
- The **Lacey Act** of 1900 prohibits trade of wildlife (including all invertebrates) that is illegally harvested, possessed, transported, or sold. 16 USC §§ 3371-3378
- The **National Environmental Policy Act** (42 U.S.C. §§ 4321 *et seq.*), which requires the federal government to thoroughly analyze the environmental impacts of any federal action that could significantly affect the environment, including those in coral reef habitat.
- The **Clean Water Act (**33 U.S.C. §§ 1251 *et seq.*), which regulates the discharge of dredged or fill materials into U.S. waters.
- The **Sikes Act** (16 U.S.C. § 670), which requires the U.S. Department of Defense to provide for conservation and rehabilitation of natural resources on military installations, which in some locations include corals.

International Programs

Agenda 21 was an international agreement to cooperate and take action to protect the environment giving coral reefs high priority. The resulting **International Coral Reef Initiative ("ICRI"),** established in 1994, is a voluntary informal network consisting of several countries, including the US, as well as US and international non-governmental organizations. The ICRI has built important international partnerships, has raised international public awareness of the coral reef crisis, and has called on nations to reduce greenhouse gas emissions, but it lacks the ability to mandate change in this sector. The **Global Coral Reef Monitoring Network,** one of the operating units of the ICRI, aims to develop and support consistent regional ecological and socioeconomic monitoring networks for coral reefs and to disseminate the results of monitoring efforts at local, regional, and global scales. *See* http://www.gcrmn.org/about.aspx.

The **Convention on International Trade in Endangered Species (CITES)** is an international agreement of which there are 175 parties that aims is to ensure that international trade in specimens of wild animals and plants does not threaten their survival. Trade of species listed in Appendix I is prohibited, and trade of other species protected by CITES is regulated.

Several coral species are listed in Appendices II and III. Since trade is only a threat to some species of coral CITES listing can help reduce pressures on some species from harvest, but other species would not benefit from listing. Furthermore, CITES listing can only provide protection against global trade in imperiled species and does not regulate the other threats facing corals.

Other international agreements could potentially provide added protection to corals, however, since they are aimed generally at protecting the environment or ocean resources they have not been fully applied to the protection of coral reefs. For example, the **Convention on Biological Diversity** and **United Nations Convention on Law of the Sea** both have general provisions that aim for environmental conservation and therefore could affect the protection of coral reefs. However, international treaties are rarely binding and have not thus far afforded coral reefs needed protections.

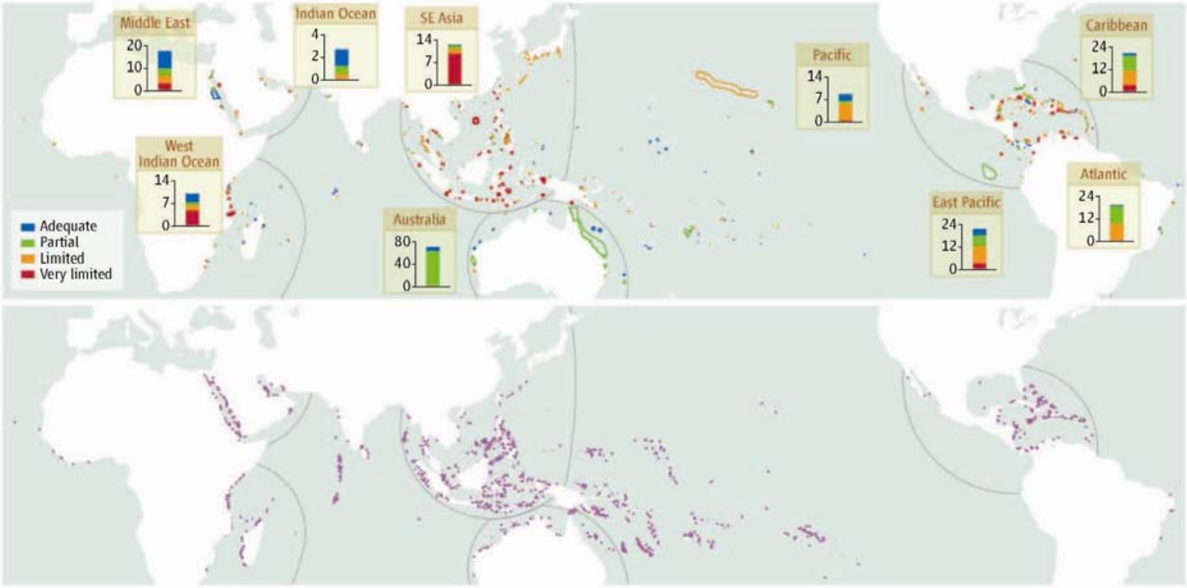
The **United Nations Convention Concerning the Protection of World Cultural and Natural Heritage** provides funding and technical assistance to protect areas designated as world heritage sites. Approximately ten of these sites contain coral reefs. Like other marine protected areas, designation can only provide limited protection against some of the direct human impacts.

The **Micronesia Challenge to Conserve Biodiversity,** launched in 2006, is a coordinated effort by Palau, the Federated States of Micronesia, the Marshall Islands, Guam and the Commonwealth of the Northern Mariana Islands to effectively conserve at least 30% of their nearshore marine resources and 20% of terrestrial resources by 2020 (Wilkinson 2008). More than $100 million will be needed to complete this Challenge, which will not succeed without independent international concrete actions to combat global climate change. *Id.*

Marine Protected Areas ("MPAs") are designated in a variety of regions worldwide. As of 2007, only 0.65% of the world's oceans and 1.6% of the total marine area within national Exclusive Economic Zones are protected within approximately 5,000 MPAs worldwide (IUCN-WCPA 2008). These MPAs collectively encompass 2.58 million square kilometers, with approximately 12% of this area designated no-take. *Id.* Mora et al. (2006) verified the existence of 980 MPAs containing coral reef ecosystems, which offered some level of regulation and management for 98,650 square kilometers (18.7%) of the world's coral reef habitats. *See* Figure 105. Dozens of new MPAs have been established each year since the mid 1990s. *Id.* Unfortunately, the conservation value of existing MPAs is severely limited by uneven global distribution and generally poor management and enforcement (*Id.;* IUCN-WCPA 2008). Additionally, because approximately 40% of existing MPAs as of 2006 were smaller than 1-2 square kilometers in size (Mora et al. 2006), and only half of existing reserves are part of a coherent network (IUCN-WCPA 2008), ecosystem-level benefits are often not conferred. After analyzing various attributes including extraction regulations, poaching, external risks, size, and isolation, Mora et al. (2006) concluded that only 2% of the world's reefs are located within adequately protective MPAs, and that no regional network provides adequate protections to more than 10% of its reefs. While designating MPAs is crucial to prevent some forms of direct human impact to corals, as discussed before they cannot protect them from long-term global threats.

Figure 105. Top: 980 existing MPAs as of 2006, with conservation status. Bottom: Optimum distribution of global MPAs, with dots representing MPAs of 10 square kilometers, 15

kilometers apart.
Source: Mora et al. (2006): 1751.



In sum, the various state, federal, and international regulatory mechanisms are inadequate to protect corals. These measures are important for the conservation of coral reefs and can effectively reduce some of the direct human threats to corals. Nonetheless, these regulatory mechanisms form a patchwork of approaches and offer only piecemeal protection to corals. Meanwhile, the overarching threats to the corals from bleaching associated with increased ocean temperatures and ocean acidification are largely unaddressed. The existing protections for corals either do not address bleaching, global warming, and ocean acidification, or they only provide research and monitoring of those impacts. Protection under the ESA for these imperiled coral species will provide comprehensive protections for which no other regulatory mechanisms can substitute. The threats facing these coral species are particularly troublesome because of their interrelated nature. The effects of these threats are synergistic, indicating that addressing each threat independently will not be sufficient to conserve these species.

CRITICAL HABITAT

The ESA mandates that, when NMFS lists a species as endangered or threatened, the agency generally must also concurrently designate critical habitat for that species. Section 4(a)(3)(A)(i) of the ESA states that, “to the maximum extent prudent and determinable,” NMFS:

> shall, concurrently with making a determination . . . that a species is an endangered species or threatened species, designate any habitat of such species which is then considered to be critical habitat . . . .

16 U.S.C. § 1533(a)(3)(A)(i); *see also id.* at § 1533(b)(6)(C). The ESA defines the term “critical habitat” to mean:

> i. the specific areas within the geographical area occupied by the species, at the time it is listed . . . , on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and
>
> ii. specific areas outside the geographical area occupied by the species at the time it is listed . . . , upon a determination by the Secretary that such areas are essential for the conservation of the species.

Id. at § 1532(5)(A).

The Center for Biological Diversity expects that NMFS will comply with this unambiguous mandate and designate critical habitat concurrently with the listing of the petitioned coral species. We believe that all current and historic areas utilized by these species meet the criteria for designation as critical habitat and must therefore be designated as such.

CONCLUSION

As demonstrated in this Petition, each of the 83 petitioned coral species faces threats to its continued existence. NMFS must promptly make a positive 90-day finding on this Petition, initiate a status review, and expeditiously proceed toward listing and protecting these species. We look forward to the official response as required by the ESA.

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Copies of many of the references cited are included on a compact disc. Please consider these references along with the Petition, and include them in the administrative record for the 90-Day Finding on the Petition.

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* *Certain voluminous books and online resources are not included in the compact disc, but they are readily available.*