Proceedings of the Caribbean *Acropora* Workshop: Potential Application of the U.S. Endangered Species Act as a Conservation Strategy

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The Proceedings of the Caribbean *Acropora* Workshop summarizes the outcome of a meeting held in Miami, Florida in April, 2002, funded through the NOAA Coral Conservation Program with additional financial support by NOAA Fisheries Office of Protected Resources, Office of Habitat Conservation and the Southeast Fisheries Science Center. The workshop was developed and conducted in response to the listing of elkhorn coral and staghorn coral as Candidate Species for the Endangered Species Act (ESA) with the primary objective of obtaining recent information on the status and trends of these corals throughout the wider Caribbean and the severity of threats affecting them. This information is needed to complete a status review of these species, which will be used to determine whether these species qualify for listing on the ESA as threatened or endangered. The workshop objectives and the working group tasks were developed by Andrew Bruckner and Margaret Miller through consultations with key *Acropora* biologists, State, Territorial and Federal Wildlife Agencies, as well as ESA experts at the NOAA Fisheries Headquarters Office and the NOAA Fisheries Southeast Regional Office (SERO).

The workshop and this document would not have been possible without the dedicated efforts of all of the participants and in particular, the Working Group Chairs, including Dr. Brain Keller, Ms. Patricia Kramer, Dr. Diego Lirman, and Dr. John McManus. The success of the workshop is also due in part to the National Center for Caribbean Coral Reef Research (NCORE) including Cara Dickman, Robin Fortuna and several graduate students who provided facilities, coordinated all logistics, and ensured that the speakers and participants had all necessary equipment and supplies used during the workshop.

I am deeply indebted to the numerous experts from Florida, Puerto Rico and the U.S. Virgin Islands, including 1) Margaret Miller, Walt Jaap, Mark Chiappone, Bernardo Varga-Angel, Brian Keller, Rich Aronson and Eugene Shinn (Florida); 2) Ernesto Weil, Edwin Hernandez-Delgado, Antonio Ortiz, Michael Nemith and Hector Ruiz (Puerto Rico) ; and 3) Caroline Rogers, William Gladfelter, Dennis Hubbard, Elizabeth Gladfelter, John Bythell, Rikki Dunsmore, Christy Loomis, Barry Devine, Zandy Hillis-Starr, and Brendalee Phillips (U.S. Virgin Islands) for their efforts in developing white papers on the status, trends, threats, and patterns of recovery of *Acropora* populations in their respective areas.

I would also like to acknowledge each of the speakers, without whom much of the key background information on these corals would not have been included in the working group reports. I am also grateful for the contributions by Dr. Eric Jordan-Dahlgren and Dr. Steve Vollmer, who were unable to attend, but still provided important information that contributed to the workshop goals. Finally, I am grateful to each of the participants for all of their efforts and contributions to the working group reports, as well as the final edits and revisions which have greatly improved this document.

PREFACE

The Caribbean *Acropora* Workshop was conceived to obtain recent information on the status of *Acropora* populations throughout the wider Caribbean and determine appropriate strategies to conserve these critical resources. Because the emphasis was on the potential use of the U.S. Endangered Species Act (ESA) as a conservation tool, the majority of the participants were from the United States, including fisheries officials, resource managers and scientists from Federal, State and Territorial governments, universities and non-government organizations. Scientific and management expertise from a number of other countries were also represented to obtain a more regional perspective, as a determination of an endangered or threatened listing in the U.S. ESA for invertebrates requires an evaluation of the status, trends and threats affecting these species throughout their range.

The workshop was divided into background presentations given by the participants followed by two days of working group discussions. Presentations were given on the status and trends, threats, and biology and ecology of *Acropora cervicornis* and *A. palmata*[1]; the application of research data to improve our understanding of these species; and existing and new management tools necessary to develop effective conservation programs for these species. The morning session included a regional overview as well as more detailed presentations on *Acropora* populations in Florida, Puerto Rico, the U.S. Virgin Islands and several non-U.S. countries including the Dominican Republic, Jamaica, Belize, Netherlands Antilles, Colombia and the northeast Caribbean. The afternoon session discussed mapping of *Acropora* habitat and colonies, the relevance of geological information in evaluating risk factors, population dynamics and life history traits, genetic information, the use of aquaculture and mariculture to restore degraded populations, existing management measures, and potential application of the ESA as a conservation strategy. This was followed by four concurrent breakout working group sessions on 1) status and trends of *Acropora* populations throughout the Caribbean; 2) biology and ecology of *Acropora* spp. and how these influence the potential for recovery; 3) existing management measures in the U.S. and wider Caribbean and their relevance to *Acropora* conservation, and new initiatives needed to protect these species; and 4) information and research needs to better understand and address the threats these species face, and predict the likelihood of recovery.

This document includes four working group reports, white papers from Florida, Puerto Rico and the U.S. Virgin Islands, abstracts from the talks, restoration approaches applied to these corals, background information used to list these species as Candidates for the ESA, and a reference compilation of literature specific for Caribbean Acroporids. The Executive Summary highlights the major outcomes and conclusions from the workshop, including the specific resolutions of each working group. These Proceedings should provide the information needed to complete a full status review on these species and make a listing determination for the ESA.

[1]*Acropora prolifera* is mentioned in several reports and abstracts throughout these proceedings, but it was not listed as a candidate species for the ESA and was not considered a separate species during this workshop. Vollmer and Palumbi (2002) present data that demonstrate that *A. prolifera* is a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*.

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EXECUTIVE SUMMARY

The widespread degradation and loss of the main reef-building corals, elkhorn coral and staghorn coral, on coral reefs throughout the Caribbean was the focus of a three-day workshop held at the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS). The workshop was sponsored by the National Oceanic and Atmospheric Administration (NOAA Fisheries) to obtain status reports about the distribution and abundance of these corals in Florida, Puerto Rico, the U.S. Virgin Islands, and the wider Caribbean. Workshop participants included coral reef biologists, ecologists and geologists, resource managers and policy experts from the U.S. and Caribbean, with representation by Federal, State, Territorial governments, universities and non-government organizations.

Elkhorn and staghorn corals are the two major reef building corals in Florida and throughout the Caribbean that once formed dense thickets at shallow and intermediate depths, contributing significantly to reef growth, island formation, coastal protection, fisheries habitat and biodiversity. Their decline has changed many coral reefs from spectacular three-dimensional living structures to flat "parking lot" stretches of seascape. Reports heard at the workshop added to the building body of evidence that elkhorn and staghorn corals have declined significantly in abundance from their historical levels and throughout their range across the Caribbean region. Disease outbreaks were identified as a major cause of coral loss, but habitat degradation, storm damage, coral bleaching, outbreaks of predators, competition by encrusting and bioeroding organisms, physical damage from anchoring and ship groundings, and other human impacts have also killed large amounts of coral. As recently as the 1980s these corals were a common feature of many reef environments, where they formed dense thickets and extensive stands of healthy, fast-growing coral. The loss of these species will result in a major loss of reef function and structure and may contribute to accelerated coastal erosion.

Elkhorn (*Acropora palmata*) and staghorn (*Acropora cervicornis*) corals were added to the Candidate Species List of the Endangered Species Act (ESA) in 1999 by NOAA's National Marine Fisheries Service (NMFS)[1]. The main intent of the workshop was to gather additional information on the status of these corals, evaluate how effective existing measures are at protecting these species, and propose additional conservation strategies that need to be implemented to restore these species. Four working groups were established and charged with evaluating the: 1) status and trends of elkhorn and staghorn coral populations and threats affecting surviving corals; 2) biology and ecology of the species as it affects future trends and potential rebuilding of the species; 3) management options to conserve the species; and 4) information needs to aid in their conservation. In addition to the specific recommendations developed by the working groups, all participants agreed that a major, well-organized effort is needed to systematically identify the causes of the decline, pull together what's been done, and determine exactly what needs to be done to halt the loss of these species; improve the ecological and physical conditions of these reefs so they can once again support elkhorn coral and staghorn coral populations; and develop strategies to promote coral recruitment and restore degraded coral populations.

The workshop participants concluded that recent information is available on their status from 60-75% of all reefs where these species occur. Both species still occupy their historic range, although localized range reductions and extirpations have occurred. Most populations have experienced losses of 80-98% of their 1970s baseline, although healthy stands are still found in a few locations and limited recovery through sexual

[1]*Acropora prolifera* is mentioned in several reports and abstracts throughout these proceedings, but it was not listed as a candidate species for the ESA and was not considered a separate species during this workshop. Vollmer and Palumbi (2002) present data that demonstrate that *A. prolifera* is a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*.

recruitment and/or regrowth of fragments has been observed. Over the last year *A. palmata* populations in a number of locations have been stable, although at only 5% of their historical abundance. There are numerous sites where additional populations are highly vulnerable to extirpations over the next 5-20 years. On a regional scale, there have been few signs of recovery since the initial decline. However, through the development and implementation of management actions that alleviate or minimize the threats impacting these species, there is a high potential for recovery.

Caribbean Acroporids have several unique life history strategies that can allow colonies to persist and recover under the right environmental conditions. Although they exhibit infrequent or sporadic sexual recruitment, these species can rapidly recolonize an area through a process known as fragmentation. A certain frequency and intensity of storms is thought to be important in maintaining and rebuilding local populations by breaking and dispersing branches, which can reattach and regrow. However, in many locations, populations have been reduced to such an extent that the potential for recovery through regrowth of fragments is limited and recovery is dependent on recruitment of sexually-produced larvae. Unfortunately, fertilization success may also decline as these and other sessile benthic broadcast spawners are likely to exhibit density dependent reproduction. In addition, genetic variability of remaining colonies may be drastically reduced which can have positive short- term (locally-adapted disturbance resistance populations) but negative long-term (ie. genetic introgression) implications.

Although participants felt there was sufficient information available on the status and trends of these species and the threats they face to make a decision whether an ESA listing is justified, they identified numerous information gaps. Key research needs include studies on 1) the biology of these species, with an emphasis on reproduction; 2) geologic time scales and linkages among past die-offs and the recent decline with respect to the importance of natural versus anthropogenic disturbances; 3) etiology and epizootiology of coral diseases; 4) genetic studies including linkages among populations, genetic exchange between populations, and effect of disturbance on genetic diversity; 5) scientific information on demographic parameters and habitat-based variables; and 6) evaluation of strategies to enhance recovery, including propagation and transplantation into degraded areas and techniques to mitigate threats. One of the key needs that is currently lacking is a model for modular (colonial) organisms capable of providing a reliable method to predict the current risk these species face and potential for this to continue into the future. Emphasis needs to be placed on the development of a model that incorporates demographic parameters, life history traits, and threats.

The overall conclusion of all participants of the workshop was that 1) both *Acropora palmata* and *A. cervicornis* have been severely reduced throughout their range; 2) these species have many mechanisms for recovering from physical damage including the development of new colonies from fragments; 3) there is limited recovery occurring in some areas through both sexual and asexual recruitment; but 4) it is not clear that these species will be successful at recovering to their former extent without specific management interventions, given the current assault from the overall, unprecedented combination of stresses, including biotic factors (predation and disease), mass bleaching events, physical damage from hurricanes, anchorings, and ship groundings, and degraded water quality. These corals are critical components of Caribbean coral reef ecosystems and both the structural and ecological roles of *Acropora* spp. are unique and cannot be filled by other species. Therefore it is essential that management initiatives are undertaken to address the threats affecting these corals, protect remaining populations, and rebuild and recover degraded populations. Conservation efforts are likely to be most effective when each coral population is considered independently, and any conservation action takes into account the preservation of a high genetic diversity. *Acropora palmata* and *A. cervicornis* could benefit from the protection the ESA affords and the listing will provide valuable added protection for many other reef species dependent on them.

Summary of Resolutions from the Biology and Ecology Working Group

1. The structural and ecological roles of Acroporid corals in the Caribbean are unique and can not be filled by other coral species. Their rapid accretion rates and structural complexity are unmatched. The loss of these characterstics will likely result in a significant loss of reef function and structure. At present, there is no indication that any other Caribbean coral species can replace the important role that Acroporid corals play within reef communities of the region.

2. Two sources of disturbance, diseases and storms, were identified as the main contributors to the regional decline of *Acropora* spp. In addition, sources of mortality such as chemical pollution and space competition from excavating sponges, were identified as “emerging issues” where more research is needed to fully predict their impacts.

3. White-band disease, which affects both *Acropora palmata* and *A. cervicornis*, is believed to have been the principal cause of mortality in these species throughout the Caribbean region in the past two decades.

4. Acroporid corals may require a certain storm frequency to be able maintain and expand populations through asexual recruitment when sexual recruitment is limited. However, a frequent occurrence of storms or a particularly intense hurricane may impact colony and fragment survival.

5. For Acroporid corals, which exhibit reportedly sporadic or limited sexual recruitment, asexual reproduction can play a major role in maintaining local populations. However, as population abundance decreases or disturbance patterns increase to the point where remaining coral populations are no longer able to survive and propagate by asexual means, the relative importance of sexual reproduction and recruitment increases. Anecdotal evidence and observations made by reef researchers at several locations throughout the region indicate that both *A. palmata* and *A. cervicornis* do indeed recruit sexually onto reefs and that in several instances populations that have experienced major declines (< 90%) are presently showing signs of recovery from newly settled sexual recruits.

6. The information available on patterns of asexual propagation has shown that, under the right environmental conditions, fragmentation followed by fragment stabilization, survivorship, and regrowth can provide an efficient mechanism for maintaining and expanding Acroporid populations. However, while fragmentation followed by fragment stabilization and growth may have been sufficient to maintain and expand Acroporid populations in the past, recent patterns of regional decline have increased the reliance of these species on sexual recruitment as a means of establishing and sustaining populations. Accordingly, the regional recovery of Acroporid populations will depend largely on the future success of sexual recruitment.

7. The scientific capability to assess the potential for recovery of *Acropora* spp. populations by sexual propagation of surviving populations is seriously impaired at present by the general lack of knowledge of the different aspects of this process. This was identified as a key research area where efforts need to be allocated in the future to determine: 1) spatial and temporal patterns of gamete formation and release; 2) size-stage thresholds for gamete production; 3) within and among colony variability in gamete production; 4) fertilization patterns; 5) transport and duration of larval stages; 6) larval survivorship patterns; 7) settlement requirements and preferences of coral planulae; and 8) early survivorship and growth of sexual recruits.

8. In light of the recent drastic decline of these critical structural (foundation[1]) species, it is important that we understand the influence of disturbances on the genetic composition and genetic variability within and among Acroporid populations. Furthermore, faced with the uncertainty about their recovery and long-term status, it is important to determine whether these disturbances have modified underlying genetic variability, favoring locally adapted, disturbance-resistant populations. This information will be crucial to: 1) evaluate, based on present genetic structure, the potential impact of future disturbances, and 2) determine, based on prior genetic exchange, the recovery capability of local populations from remaining regional sources of propagules. Similarly, information on the clonal structure of the populations will aid in the decision making process on marine reserves and management plans by identifying specific locations and populations at risk based on factors such as genetic isolation and genetic structure.

9. The preliminary results highlighted here can have important conservation implications – namely, each coral population should be considered individually and any conservation strategy (esp. transplantation studies) should take into account preserving 'meaningful genetic diversity'.

Summary of Resolutions from the Status and Trends Working Group

1. Once dominant species on shallow reefs (0-15 m depth) throughout the greater Caribbean, Acroporid abundance has been drastically reduced in abundance and spatial dispersion. In many areas, previously densely populated subpopulations (or monospecific thickets) now consist of no or few individuals. Present and future likelihood of disturbance to their abundance and habitat remains high due to both natural and anthropogenic factors.

2. The status of Acroporids has changed significantly since the 1970s with a region wide decline occurring in the 1980s and subsequent localized declines during the 1990s. The 1970s represents a baseline for "stable, healthy" populations and the 1980s as a baseline of the regional decline primarily resulting from white-band disease. Additional shifting baselines are useful to understand local and current declines; for example, regional mortality from disease is compounded on a local scale by hurricanes, bleaching events, and outbreaks of predators.

3. *Acropora palmata* and *A. cervicornis* have experienced an unprecedented decline throughout their historic range since the 1980s, including both a significant reduction (loss of 80-98%) in the number of individuals and an extreme reduction in area of distribution. Neither species have recovered to their former abundance. Some local *A. palmata* populations have been stable over the last year with evidence of recovery and limited sexual recruitment (e.g., USVI). *Acropora cervicornis* experienced a more severe decline with no or few signs of recovery or sexual recruitment (except Broward County, FL). Acroporids have a high likelihood of localized extirpation and possible extinction on ecological time scales (10-100 yrs).

4. White-band disease (WBD) is believed to be the primary cause for the region wide Acroporid decline during the 1980s. Current factors causing mortality or stress are highly localized, with some areas showing greater susceptibility to disease (e.g., Florida Keys, Belize), predation (e.g., Florida Keys and Puerto Rico), and storms (e.g., US Virgin Islands). Given the declined state of Acroporids and the increase in the frequency and intensity of disturbances, these sensitive species are highly vulnerable to both natural and anthropogenic stressors, especially synergistic disturbances.

5. An estimated 60-75% of the entire Acroporid population has been examined and enough information is available to make a determination whether these species are threatened or endangered. Approximately 5%, and no more than 10% of the population resides within US waters. Several geographical areas where more information is needed include Bahamas (especially southern), Nicaragua, Pedro Banks, northern Cuba, Haiti, Banks off of Turks and Caicos, Saba Banks, eastern Caribbean, and Trinidad and Tobago.

6. The historic range of Acroporids is believed to be the same as the current range, although it is not possible to conclude with certainty given the current scientific inability to differentiate genetically distinct populations. Local range reductions and extirpations have occurred and it is believed some populations may be reproductively isolated. Given the extent of decline and vulnerability to extirpation, it is believed these corals remain threatened throughout their range.

7. To assist in the recovery of these species, more scientific information is needed on both demographic variables as well as habitat-based variables including 1) survival and fecundity by age and frequency distribution of ages (size or stage structure[2]); 2) reliance of populations on asexual vs sexual recruitment; 3) genetically distinct populations, minimum population sizes, and amount of genetic exchange between populations; 4) juvenile population dynamics (e.g., survivorship, growth rates); 5) importance of habitat variables to recruitment and adult survivorship (e.g., standing dead colonies, vertical relief, habitat condition, cross shelf position); and 6) location of "endmember" populations and those showing signs of recovery and/or sexual recruitment.

8. *Acropora palmata* and *A. cervicornis* warrant further listing under the Endangered Species Act (ESA) and could benefit from the protection the ESA affords. Acroporids are likely to qualify for listing as threatened or endangered species because of the significant reduction in their abundance and high likelihood for future population declines; the current loss of habitat and potential for future loss of range remains high; they are highly susceptible to severe population reductions due to disease and predation; there are few existing regulatory mechanisms to minimize further reductions or impacts; and both natural and anthropogenic factors are likely to affect their continued existence. The likelihood of extinction for both species could be reduced by alleviating threats and implementing strategies that promote their recovery. The listing of these species will provide valuable added protection to both corals, as well as the many other species dependent on them.

[1]Species of large effect fall into two general categories: 1) structural or foundation species, which provide most of the three-dimensional architecture in which other species find shelter and food; 2) keystone species, which by virtue of their high rates of consumption and their generalized diets, exercise disproportionate control over the distributions, population sizes, activities, and adaptive characteristics of many other species (Vermeij, 2001). Based on this definition, the workshop participants determined that *Acropora palmata* and *A. cervicornis* are (1) structural or foundation species.

[2]Stage structure refers to a particular life history stage of *Acropora* spp., including a sexual recruit, fragment and whole colony.

Summary of Resolutions from the Management Working Group

1. The existing regulatory framework in the U.S. and its territories, as well as in many Caribbean nations offers limited protection to Acroporid populations through 1) the establishment of parks, sanctuaries and reserves; 2) fishery management plans that limit or prohibit the take of corals; restrict the use of fishing gears that cause habitat damage and breakage of corals, especially no-take reserves; 3) federal, state and territorial programs to establish and maintain mooring buoys to minimize coral breakage associated with anchoring; and 4) coastal zone management strategies that address shoreline development, sewage treatment and discharge, and destruction of associated habitats such as mangroves. However, the existing regulatory structure is insufficient for most *Acropora* populations; additional measures are necessary to improve water quality, address coastal development, improve navigational aids, address habitat damage from anchoring, destructive fishing gears, and boat groundings, and enhance enforcement.

2. A variety of protected areas exist in Florida, USVI and Puerto Rico, including National Monuments, Sanctuaries, Reserves, and Wildlife Refuges. These and other areas are typically zoned for specific or multiple uses, often include no-take areas, and offer various protective measures such as a prohibition on extractive activities. However, in general, they encompass a relatively small portion of the total *Acropora* habitat, they offer limited protection from various environmental impacts such as water quality issues, and enforcement may be limited or lacking.

3. Over the last five years Florida, USVI, and Puerto Rico have made major conservation advances through the establishment of various types of marine reserves and proposals for new marine protected areas. Many of these have been established in coordination with initiatives to address habitat destruction through fishing gear regulations, installation of mooring buoys and navigational aids, no anchoring zones, improved wastewater treatment, and other measures.

4. Coral reefs and associated habitats provide fishery resources that represent a critical source of food, but increased rates of collection and associated habitat destruction are threatening the regenerative capacity of of these species and critical linkages among species, and in some cases are contributing to phase shifts. A number of management initiatives have been proposed including improved monitoring and protection for fishery resources; greater habitat protection through establishment of no-take MPAs and other efforts; measures to protect spawning populations; elimination of destructive fishing practices and gears; implementation of gear restrictions; and incorporation of ecosystem-scale considerations in Fishery Management Plans.

5. Coral diseases and coral predators need far more study. Managers need to know the causes of diseases affecting Acroporids, how diseases are transmitted, and any actions that can be taken to reduce their negative impacts on *Acropora* populations. Efforts should be made to determine the degree of disease resistance that exists among clones, and genetic mechanisms for resistance. Research is also needed to determine the efficacy of programs to control potential “pest” species such as *Coralliophila abbreviata* and *Stegastes planifrons*.

6. Pollution and sedimentation could be signficantly reduced by fully implementing existing authorities among various federal, state and territorial agencies, but this will require greater efforts to monitor existing water quality, expanded studies to determine the ecological relevance of various pollutants, and improved permitting mechanisms for development projects that affect coral reefs. Local partnerships among governments, land owners, industry and the public are necessary to implement measures to reduce land-based runoff and prevent discharge from known point sources.

7. Coral mariculture, aquaculture and other propagation techniques, along with transplantation, and reattachment of dislodged *Acropora* fragments may provide a feasible strategy to rebuild degraded *Acropora* populations. These efforts may be especially useful in areas for which natural recovery is unlikely (due to an absence of parent colonies or sexual recruits), and on a small scale to speed up recovery following a ship grounding. However, care must be taken to ensure that source coral populations are not degraded, genetic diversity is maintained, and potential introductions of pathogens or other invasives are avoided. In addition, restoration efforts should not be undertaken unless the source of the threat has been identified and addressed. Because we know very little about appropriate restoration strategies and potential long-term benefits, all restoration efforts should be undertaken using an experimental approach that includes measures to evaluate success.

8. A number of countries have taken key steps to protect coral reef ecosystems within their waters through the development of MPAs, implementation of Fishery Management Plans, and development of strategies to address water quality issues. However, these efforts need to be greatly expanded on a local to regional scale and substantial new initiatives are necessary. There is a need for improved sharing of information and technical assistance from the U.S.; greater efforts to educate the public and user groups regarding the importance of coral reef ecosystems, threats, and solutions; and better cooperation among different government agencies, non-government organizations, industry and the public.

9. Several regional and international fora, including CaMPAM, SPAW, ICRI, GCRMN, CITES, AGRRA and CARICOMP are available to assist in the regional and international protection of Acroporid corals through improved management, monitoring, and conservation. However, there are various limitations with these initiatives, such as funding and leadership problems, a capability to adopt measures that address important concerns but not necessarily the most critical concerns for these species, and limited public, government and/or industry support.

10. An ESA listing would provide additional necessary conservation mechanisms, above and beyond the existing tools available to resource managers. The listing could protect and restore these species while providing added benefits for associated species; it would provide for increased recognition and awareness of coral reefs, their importance and their vulnerable condition; and it would enhance our ability to fill information gaps through support for targeted research and monitoring. An ESA listing would also add additional burdens and costs for increased management, enforcement and permitting of activities. No single mechanism is likely to be sufficient to halt the decline of these corals and enhance their recovery. It is likely that managers will have to apply all of their tools to ensure recovery of these species, including application of the ESA.

Summary of Resolutions from the Information Needs Working Group

1. There is a need to compile existing maps, historical and current aerial photographs, bathymetric information, airborne sensor data and other types of information showing existing and potential *Acropora* habitats and associated terrestrial and marine habitats essential to the conservation of Acroporids. These data should be incorporated into a GIS database to delineate critical habitat and design appropriate conservation strategies to protect these areas. While a good deal of recent information is available from U.S. locations, there is a need for ground truthing of maps and improved resolution of maps, as well as a need for expanded mapping efforts in non-U.S. locations.

2. While sensor-based reef mapping technologies can provide high resolution information on the distribution of ecological communities, current technology does not provide a reliable tool to distinguish among species of corals or condition (live, dead or diseased or bleached colonies). Thus, the use of sensor-based mapping tools must be combined with underwater visual, video and photographic monitoring and assessment.

3. There is a need for larger, regional scale coring programs to compile a long-term record and compare this to present day changes.

4. We need to improve our understanding of the nature of recent regional declines in *Acropora* populations, and whether evidence for causes of past declines are preserved in the geochemistry of *Acropora* fossils, to determine whether the observed decline is part of a natural cyclical process for which natural recovery is likely, or whether anthropogenic stressors have exacerbated these processes and may inhibit recovery.

5. Reef restoration at any scale will have, at best, very limited success unless the causes of decline are understood and action is taken to reduce these threats.

6. Transplantation and propagation of *Acropora* colonies are viable tools to enhance recovery at local scales, but considerations such as appropriate selection of colonies and fragments, the potential effects on genetic structure of populations, and the potential benefits must be weighed against the probability of natural recovery, other management interventions, and likelihood of long-term success.

7. Efforts to enhance sexual recruitment may provide a useful tool to promote recovery of populations, but additional research is needed to understand different aspects of sexual reproduction, including basic information on reproductive biology, role of water circulation in transport of larvae, and larval settlement requirements.

8. Novel ecological restoration efforts, such as strategies to enhance herbivory, reduce predation pressure, eliminate pest species, and mitigate diseases may have benefits on a local scale, but it is critical that these efforts be undertaken using a science-based approach that incorporates efforts to understand ecological processes and potential impacts of human modification of these processes.

9. Greater efforts are needed to monitor and assess *Acropora* populations at local to regional scales, at time intervals appropriate to the process under investigation, including studies to follow individual colonies at various life stages exposed to different environmental conditions and anthropogenic stressors.

BACKGROUND

NMFS Coral Species and Ecosystem Conservation Project

In 1998, the National Marine Fisheries Service (NMFS; NOAA Fisheries) began an initial analysis of the major reef-building coral species to determine whether environmental or anthropogenic factors were threatening the survival of certain species in U.S. waters of the western Atlantic. Corals selected in this review were analyzed based on 1) their role in coral reef structure and function (e.g., reef growth, essential fish and invertebrate habitats, biodiversity and coastal protection); 2) species potentially threatened by anthropogenic and natural factors identified as criteria for the Endangered Species Act (ESA); and 3) species previously placed on the candidate species list for the ESA. This review includes nine species identified in 1991 as candidates for listing under the ESA that were removed in 1997. Although the 9 corals listed as candidates in 1991 had declined in some locations, they were removed from the candidate list because NMFS was not able to obtain sufficient information on their biological status and threats to the species to meet the higher scientific documentation required for inclusion on the 1997 candidates list (62 F.R. 37560).

For each species included in the 1998 review, information was compiled on the life history characteristics, habitat and distribution, historical abundance and extent of decline, threats, and existing management mechanisms using available scientific literature, grey literature and personal communications. This project identified two Caribbean species, *Acropora cervicornis* and *A. palmata* that were of immediate concern.

A. Addition of *Acropora palmata* and *A. cervicornis* to the Candidate Species List of the ESA

Using information collected through Phase I of the 1998 project, as well as information obtained during a public comment period, NMFS added two coral species, elkhorn coral (*Acropora palmata*) and staghorn coral *(Acropora cervicornis*) to the candidate species list of the Endangered Species Act in 1999 (Federal Register Vol. 64, No. 120, June 23, 1999 pp. 33466-33467). These species were determined to qualify for listing on the candidate species list because they had exhibited a significant decline in abundance or range from historical levels, and this decline was due to one or more of the threats used to list a species on the ESA, specifically disease outbreaks, predation, natural climatic conditions, and habitat degradation. Extensive, dense thickets of staghorn coral and elkhorn coral were a common feature of Caribbean reefs until the late 1970s or early 1980s, depending on the location. These species have progressively declined in abundance throughout their range over the last 25 years, beginning with the first reports of white-band disease from the USVI in 1977. Disturbances that contributed to the decline include disease outbreaks, storms and hurricanes, temperature extremes, bleaching, predation by snails, sedimentation, and other factors. The two major sources of mortality most commonly cited as the main cause of their demise are white-band disease and physical disturbance caused by storms and hurricanes. A summary of the initial biological assessment completed during the preliminary review of *Acropora cervicornis* and *A. palmata* for the purpose of determining whether these species should be added to the NMFS Candidate Species List is annotated at the end of this document in Appendix II.

B. Addressing Information Gaps

The preliminary status review used to justify listing these corals as candidate species for the ESA revealed large gaps in available information. Extensive occurrences of “standing dead” *Acropora palmata* have been reported along the Yucatan peninsula of Mexico, San Andreas, the Turks and Caicos and other locations, but often the cause of mortality or timing of the event is not known. Quantitative data documenting a widespread loss of *A. cervicornis* are available for Belize, Jamaica, the Netherland Antilles, Florida, and Colombia, but in many cases data are available for a small number of locations, often one or a few reefs. Extensive quantitative data for *A. palmata* are also available for Florida, USVI, Jamaica, and a few other locations; in most other locations the available information is largely anecdotal. This has hindered our ability to list these species on the ESA, primarily because a marine invertebrate listing has more stringent information requirements than that needed to justify a vertebrate species for listing.

1) Atlantic and Gulf Rapid Reef Assessment

In order to collect needed information on a regional scale, NMFS Office of Protected Resources is collaborating with the Atlantic and Gulf Rapid Reef Assessment (AGRRA) program to compile regional information on the status of these species using coral reef assessment data for 1998-2000. The AGRRA protocol has been applied to over 400 reefs in the western Atlantic including reefs in the Bahamas, Brazil, Bonaire, Caymen, Cuba, Curacao, Dutch Antilles, Flower Gardens, Honduras, Jamaica, Mexico, St. Vincent, Turks and Caicos, USVI and Venezuela. The objective of AGRRA is to develop a comprehensive database of the condition of reefs throughout the Atlantic and Gulf of Mexico, including 1) the condition of reefs near population centers versus those in remote locations and 2) the identification of luxurious reefs with high coral cover, an abundance of rare or threatened invertebrates or fishes, or an unusual morphology which makes them important candidates for conservation efforts. The benthic component of the protocol characterizes corals by species and records data on abundance, percent partial mortality, size frequency, condition, and recruitment. The AGRRA program and database represent the most comprehensive large scale assessment to date, with information that is essential to understanding the extent of decline and patterns of recovery for western Atlantic Acroporid corals from throughout the region.

2) New Information

In most locations throughout the Caribbean Acroporid populations have declined by 95% or more, although some degraded areas are showing positive signs of recovery. In the U.S. Virgin Islands, for example, some of the *Acropora palmata* reefs decimated by white-band disease (WBD) during the 1970's and 1980's appear to be recovering through continued growth and fragmentation of remaining colonies, and through new recruitment. Other areas, such as Andros Island, Bahamas appear to have avoided a major decline of *Acropora palmata* altogether and still contain extensive and healthy stands. Although many anecdotal reports indicate that there are still a number of elkhorn or staghorn coral thickets in excellent condition, major storm events or other disturbances can lead to the sudden demise of these corals, such as that which occurred in southwest Cuba in the fall of 2001.

It is impossible to appreciate the significance of reported Acroporid declines or comebacks without placing them into a larger spatial and temporal context. Studies focusing on geological time scales are increasingly attempting to determine how the taphonomic signatures of fossil reefs differ from modern reefs. Future studies hold promise at extending our understanding of ecological changes to coral reefs, and specifically Acroporid populations, on geologically relevant time scales. However, few studies are presently focusing on addressing questions over large spatial scales (i.e. 1000 km) regarding the distribution, abundance and connectivity of populations, causes and extent of mortality, and patterns of recruitment and recovery. This is partly because of the time and effort required to carry out an effective sampling design and the difficulty at obtaining financial support for these types of projects.

Through the NMFS Coral Conservation Program and the Office of Protected Resources, NMFS is supporting new or ongoing research programs with relevance to an ESA listing for *Acropora cervicornis* and *A. palmata*. The goals of these efforts are to address how much coral has been lost on a regional scale, the potential for recovery, and possible human interventions that may reduce the time required for natural recovery. This includes:

1) recent monitoring programs focusing on particular reefs for which there is historic information; new regional monitoring or assessment programs; and detailed monitoring of individual colonies and recruits to evaluate their potential survivorship and causes of mortality.

2) geological research to characterize the historic range and abundance of populations; to determine whether the recent decline is a unique occurrence over the last 10,000 years or whether there are gaps in the *Acropora* record that would indicate that these species have been extirpated at some earlier period; and to determine whether the threats affecting coral populations today were present in the past.

3) genetic studies to establish linkages within and among populations; the degree of reproductive isolation; and the importance of sexual reproduction as a possible strategy to enhance species persistence and promote recovery through recruitment from distant locations.

4) mapping efforts to characterize the extent of *Acropora* habitat and the current and historical abundance of these corals.

5) models to help evaluate relationships between life history characteristics, storm events and other disturbances on the resilience and persistence of these species.

6) novel techniques to propagate and transplant fragments into degraded areas; to improve habitat quality; to enhance sexual recruitment; and to address threats (i.e. predators).

WORKSHOP OBJECTIVES

Information from recent monitoring and assessment programs like AGRRA will be supplemented with data compiled during this International Caribbean *Acropora* workshop, with contributions from coral reef ecologists, biologists and geologists, as well as resource managers with expertise in corals. Participants were tasked with presenting an up-to-date review on the status and trends of these corals from reefs in the U.S. and the wider Caribbean, including threats, patterns of recovery, existing management actions designed to protect remaining "healthy" populations and restore/rehabilitate degraded populations, and additional conservation actions necessary to enhance recovery of these corals.

The bulk of the workshop involved four concurrent working groups that were tasked with:

1) evaluating the five primary factors used to evaluate an ESA listing, and the risk of extinction based on the known threats;
2) compiling various life history traits, demographic and genetic parameters that are available to assist in making a determination of the risk these species face and their potential for recovery;
3) reviewing existing international and domestic regulations and their adequacy and effectiveness at protecting and restoring these species;
4) evaluating the benefits/costs of a threatened or endangered ESA listing for *Acropora* spp., including the effect this would have on associated species and coral reef ecosystems;
5) identifying critical habitat designation essential to the conservation of these species;
6) proposing possible conservation strategies for degraded populations, including specific criteria that would be needed in a recovery plan; and
7) identifying uncertainty regarding the status, abundance and trends; the level of precaution necessary to reduce extinction risk; and research needs to fill information gaps.

Would Acroporid Corals Benefit from a Threatened or Endangered Listing on the ESA?

The working groups were tasked with evaluating existing information on the biology, status and trends and threats, and application of new tools, to determine whether Caribbean Acroporids have declined to an extent where 1) there are substantial risks from existing threats; 2) populations are predicted to continue to be affected by these threats; 3) populations are unlikely to recover without management interventions; or 4) populations are likely to undergo natural recovery under existing environmental conditions. The participants also discussed the adequacy of existing conservation and management measures, new measures that could be applied, and whether an ESA listing would help promote recovery. There are four specific items that need to be evaluated with regards to a possible listing decision:

A. Are Acroporids at risk of extinction or likely to become threatened with extinction in the foreseeable future?

B. Would a listing action reduce the risk of extinction?

C. Are other management mechanisms sufficient to protect these corals?

D. Do these species exhibit ecological characteristics that benefit other species, the ecosystem or associated ecosystems?

Considerations When Evaluating Whether these Species Qualify for an ESA Listing :

A. Factors considered when examining whether Acroporids are at risk of extinction or likely to become threatened with extinction in the foreseeable future:

- life history traits that increase or decrease the likelihood of extinction
- recent and projected trends in abundance and range
- current population size and composition
- range size and distribution
- reproductive capacity and recruitment potential
- degree of threat from disease and/or predation and other natural and anthropogenic stressors
- other biological or environmental parameters relevant to species survival
- models to predict the likelihood of extinction that incorporate demography, threats, and life history parameters for a sessile, colonial organism

B. Factors considered when evaluating whether a listing action would reduce the risk of extinction:

- minimize imminent extinction of these species and possibility of long-term extinction
- choose species that are most likely to benefit from protection under the ESA
- likelihood that a species will respond to management regime proposed under a recovery plan
- ease of completing required management actions

C. Factors considered regarding whether other management mechanisms are sufficient to protect these corals:

- existing tools resource managers have to protect and restore coral populations
- new mechanisms being considered, developed, or applied that will benefit these corals
- local, national and international (regional) mechanisms

D. Factors considered when evaluating whether these species exhibit ecological characteristics that benefit other species, the ecosystem or associated ecosystems:

- cover the most species possible per listing action
- target ESA listing actions to those species that have large influences on ecological processes within the ecosystem they inhabit
- choose “umbrella” species to convey benefits to associated species with shared habitats or threats

TERMS OF REFERENCE FOR THE WORKING GROUPS

Status and Trends Working Group

- Develop status reports for the Caribbean region, Florida, Puerto Rico, and the USVI.
- Identify and characterize the threats that have impacted populations, where these occur, and whether they are ongoing.
- Estimate the number and percentage of reefs (or survey areas) with remaining populations in excellent condition, including populations at the geographic limit of the species, and populations that could provide an important source of recruits due to their location.
- Estimate the percent of reefs where these corals have declined substantially from some historic level and the percent of reefs where substantial recovery is occurring.
- Characterize changes among populations within reefs (including the extent of expansion into new habitats/depths and/or shifts in distribution (i.e. loss of populations at certain depths), and factors that may have mediated these changes.
- Identify gaps in assessment and monitoring information (specific countries or locations where the coral is thought to occur, or once did occur but no recent information is available) and what is needed to obtain this information.
- Describe difficulties in assessing *Acropora* populations, colonies, fragments, sexual recruits, partial mortality, and other population parameters and how this can be overcome.
- Provide suggestions on the type of demographic parameters that should be included in a monitoring program and how these can be applied to a model to predict risk of extinction.

Biology and Ecology Working Group

- Evaluate life history traits and their relationships with population viability, persistence, and potential for recovery, including contribution of asexual and sexual reproduction, dispersal, potential for inbreeding, effect of fragmentation on growth and reproduction, and other consequences of life history traits.
- Assess ecological, biological, or physical factors that affect colony survival, relationships with life history traits and regenerative capacity, competitive ability, and resistance to stressors.
- Discuss possible implications of life history on the genetic structure of populations.
- Assess relationships among genetic diversity and morphological variation and fitness, survival, partial mortality, potential for recovery, and adaptive significance of these parameters.
- Identify information gaps regarding the biology, life history traits, taxonomy, genetics and what is needed to address these gaps.
- Evaluate the factors that need to be considered when developing restoration strategies based on the life history, biology, and ecology of these species.
- Identify life history traits that need to be incorporated into a population model to predict future trends and how you would quantify these.

Management Working Group

- Evaluate existing legislation, regulations, statutes, management approaches, and conservation initiatives that apply to coral reefs in U.S. waters (state/territorial/federal), in other countries, and regional initiatives, their effectiveness at protecting these corals and enhancing recovery potential, and where they are being applied.

- Identify measures that would enhance compliance with existing conservation and management strategies.

- Recommend additional measures that could be implemented on a local, national, and regional scale that are necessary to address threats affecting these species and can help rebuild populations, and where these need to be applied.

- Identify approaches to enhance national and regional collaboration.

- Evaluate the benefits/drawbacks of an ESA listing, locations where this listing would be most effective, and the type of issues that the listing would have to address to mitigate threats.

- Identify information needed (research, monitoring, restoration, etc.) by resource managers that would help assist managers in protecting remaining corals and rebuilding populations.

- Examine the potential implications of not taking additional steps to conserve these species and the reefs where they occur.

Information Acquisition Working Group

- Identify and evaluate monitoring approaches that have been applied or need to be applied to assess status and trends in these species, including ways to quantify abundance, cover, various life history stages (i.e fragments, sexual recruits, standing colonies), partial mortality, and other demographic parameters.

- Discuss the use of remote sensing and other survey techniques as a tool to identify and characterize critical habitat, including geographic locations and aerial extent of this habitat, as well as the historic range/ abundance of the species. Identify areas where this is being applied, problems with existing methodologies (i.e. are these tools capable of identifying habitat of deeper *A. cervicornis* populations; water clarity etc.), and additional needs.

- Examine and evaluate geological information obtained from coring, in terms of historical extent and range of these species, the ecological history of reefs and these corals, mortality events, causes of mortality, and whether recent mortality events and other ecological changes that affect the potential for recovery (i.e. phase shifts) are unique and possibly due to human impacts, or whether anthropogenic impacts are a minor factor.

- Identify and evaluate techniques to propagate these corals and to restore populations following disturbance events including transplantation of propagules, stabilization of fragments, and removal of "pest" species; where these approaches have been undertaken, their value and effectiveness, and problems with existing approaches.

- Develop criteria regarding appropriate strategies to develop coral nurseries, guidelines for collecting fragments for mariculture and aquaculture, and guidelines for transplantation and restoration efforts.

Report from the Biology and Ecology Working Group

Compiled by Diego Lirman

Working Group Members: Iliana Baums, John Bythell, Diego Lirman, Elizabeth Gladfelter, Margaret Miller, Erich Mueller, Antonio Ortiz, Paula Rueda, Bernardo Vargas, Mark Vermeij, S. Vollmer, and Ernesto Weil.

INTRODUCTION

The Working Group was charged with evaluating the life history characteristics and the genetic makeup of *Acropora* populations and how these factors influence the success of these species, including their ability to persist under varying environmental conditions and their ability to recover following a biotic or abiotic disturbance. The group was also charged with evaluating the importance of these species in terms of essential habitat for other species, reef construction and other factors. Finally, the group was asked to discuss the most appropriate conservation strategies to enhance recovery, based on the biology and ecology of these species.

1. The Role of Acroporid Corals as Essential Reef Habitat

Acroporid corals play a major role within reefs of the Caribbean reef communities by providing the geological, physical, and biological foundation for the development of numerous shallow reef communities (e.g., Adey, 1975; Hubbard et al., 1994; Aronson and Precht, 1997). Their recent decline (up to 95% mortality at some locations) within the last three decades has highlighted their critical ecological role within reefs where they have historically supported a very productive reef community that depends on these species directly for food and refuge (Table 1). Coring studies have documented the geologic importance of *Acropora* spp. as reef builders (e.g., Hubbard et al., 1994; Aronson et al., 2002). The fast growth rates of Acroporid species as well as the rapid accretion rates of *Acropora*-dominated reefs has allowed populations of these corals to keep up with sea level rise through the Holocene (although populations were drowned and replaced by other coral species at many locations) (Gladfelter et al., 1978).

The role of Acroporids as structural (or foundation)[1] species within reef communities has been well documented. Lirman (1999) showed an association between the distribution of fish schools composed mainly of grunts and snappers and *Acropora palmata* colonies. These schools, which often remain in the same location for extended periods, utilize the topography offered by the elkhorn branches as diurnal refuge. Fish aggregations not only composed a large portion of fish biomass on the reefs surveyed, but they could also contribute to the flux of materials from surrounding vegetated areas to the reef through their daily feeding migrations (Meyer et al., 1983; Parrish, 1987). The excretory products of these fish schools can also contribute to the productivity of corals and algae in the area surrounding their refuge (Nelson, 1985; Bray et al., 1986), and even stimulate coral growth by providing nitrogen supplements (Meyer and Shultz, 1985 a, b). Direct associations between Acroporid corals and other reef fishes such as damselfishes, squirrelfish, glassy sweepers, and many others have also been reported (e.g., Emery; 1973; Clarke, 1977; Itzkowitz, 1977; Gladfelter and Gladfelter, 1978; Waldner and Robertson, 1980; Meyer et al., 1983; Meyer and Shultz, 1985a, b; Thompson et al., 1990; Williams, 1991, Clarke, 1996). In addition, Acroporid corals provide essential habitat (i.e., food, refuge, recruitment habitat) for turtles, lobsters, crabs,

[1]Species of large effect fall into two general categories: 1) structural or foundation species, which provide most of the three-dimensional architecture in which other species find shelter and food; 2) keystone species, which by virtue of their high rates of consumption and their generalized diets, exercise disproportionate control over the distributions, population sizes, activities, and adaptive characteristics of many other species (Vermeij, 2001).

echinoids, and gastropods. These documented relationships suggest clearly that changes in the extent and composition of *Acropora* spp. populations can result in significant changes in associated reef fauna.

Resolution: ***The structural and ecological roles of Acroporid corals in the Caribbean are unique and can not be filled by other coral species. Their rapid accretion rates and structural complexity are unmatched. The loss of these characterstics will likely result in a significant loss of reef function and structure. At present, there is no indication that any other Caribbean coral species can replace the important role that Acroporid corals play within reef communities of the region.***

2. Disturbance and Acroporid Populations

At the recent *Acropora* Workshop, members of the biology and ecology working group discussed the response of Acroporid corals to multiple stressors. Based on published reports and personal observations, the patterns of susceptibility, resistance, and resilience of these important coral species to stress are summarized in Table 2. Within this table, both documented and potential sources of disturbance are included to highlight the possible impact of future disturbance on the recovery of Acroporid corals, and to indicate areas where active management practices can play a role in mitigating the impacts of stressors.

Resolution: ***Two sources of disturbance, diseases and storms, were identified as the main contributors to the regional decline of Acropora spp. In addition, sources of mortality such as chemical pollution and space competition from excavating sponges, were identified as "emerging issues" where more research is needed to fully predict their impacts.***

3. Coral Diseases

The drastic decline in the abundance and cover of Acroporids in the Caribbean due to white-band disease (WBD; a presumed bacterial infection specific to this group) has been documented by Gladfelter (1982), Bythell and Sheppard (1993), and Aronson and Precht (2000, 2001). Unlike other sources of disturbance with mainly localized impacts such as hurricanes, the impacts of WBD on Acroporid corals have been region-wide (reviewed by Aronson and Precht, 2000). This unprecedented decline has changed the structure of shallow coral reefs dramatically. The replacement of Acroporids by other coral species and/or macroalgae has modified historical reef zonation patterns once defined by the dominance of *Acropora palmata* at shallow fore reefs (0-5 m) and *A. cervicornis* at intermediate depths (5-25 m) (Geister, 1977; Adey, 1978; Aronson and Precht, 2000).

Resolution: ***White-band disease, which affects both Acropora palmata and A. cervicornis, is believed to have been the principal cause of mortality in these species throughout the Caribbean region in the past two decades.***

4. Hurricanes and Tropical Storms

The impacts of hurricanes and tropical storms on Acroporid species have been summarized by Harmelin-Vivien (1994), Lirman (1997), Aronson and Precht (2000), and others. Their branching morphology and their location within shallow, wave-exposed areas of reefs make Acroporids highly susceptible to physical disturbance. Fragmentation and dislodgment of *Acropora* spp. were reported after Hurricanes Hattie (Stoddart, 1963, 1965; Zea et al., 1998), Edith (Glynn et al., 1964), Gerta (Highsmith et al., 1980), Allen (Woodley et al., 1981), David and Frederic (Rogers et al., 1982), Hugo (Gladfelter, 1991), Joan (Zea et al., 1998), Gilbert (Kobluk and Lysenko, 1992; Jordan-Dahlgren and Rodriguez-Martinez, 1998), and Andrew (Lirman and Fong, 1996, 1997), as well as after Tropical Storms Bret (Van Veghel and Hoetjes, 1995) and Gordon (Lirman and Fong, 1997).

The direct and indirect impacts of storms on Acroporid populations can be significant in terms of tissue mortality, fragmentation, and colony dislodgment. However, the ability of *Acropora* spp. to form new colonies from fragments (e.g., Bowden-Kerby, 1997; Lirman, 2000), together with the reportedly low success of sexual recruitment in this species (Dustan, 1977; Bak and Engel, 1979; Hughes and Jackson, 1980, 1985; Rylaarsdam, 1983; Rosesmyth, 1984), suggest a strong connection between storm disturbance and persistence of this group.

Resolution: ***Acroporid corals may require a certain storm frequency to be able maintain and expand populations through asexual recruitment when sexual recruitment is limited. However, a frequent occurrence of storms, or a particularly intense hurricane may impact colony and fragment survival.***

5. Reproductive Characteristics of Acroporids

A. Sexual Reproduction

Coral colonies exist as modules (ramets) capable of surviving alone or in small groups. The sum of all ramets derived from a single zygote constitutes the coral's genet, which, unlike aclonal organisms, can exist as independent units that may experience diverse environmental conditions (Coates and Jackson, 1985; Heyward and Collins, 1985; Harper, 1985). *Acropora palmata* and *A. cervicornis* are broadcast spawning hermaphrodites with one reproductive cycle per year (Szmant, 1986; Steiner, 1995). Egg and sperm bundles are released into the water column for external fertilization. The positively buoyant gametes float to the surface where they can remain viable for up to 8 hrs. Histological work and nightly spawning observations indicate that the predicted spawning time for *A. palmata* is 2-4 nights after the full moon in Aug/Sept while *A. cervicornis* spawning has been observed 2–7 days after the full moon in July/August (Steiner, 1995; Szmant, pers. obs.Vargas-Angel & Thomas 2002, pers. obs). However, *Acropora* spp. appear to be much less predictable in their spawning activity than other well-studied groups (e.g., *Montastraea* spp.). For example, a histological study by Jaap et al. (unpublished) of *A. palmata* in the late 70's-early 80's showed no gonad development during 2 of the 5 yr study while all other species examined were consistent across years. Also, no *A. palmata* spawning was observed during the night 2-4 window in Aug 2000 in Key Largo, FL and in La Parguera, Puerto Rico (M. Miller and Szmant, pers. obs.). In Aug 2001, *A. palmata* spawning was observed in the Florida Keys but on night 5 after the full moon, one night "late" (M. Miller, pers. obs.).

A. palmata spawn has been successfully raised to settlement in laboratory and field enclosures (Szmant & M. Miller, unpubl). In the laboratory, competence of planktonic larvae was documented at 5 days. Zooxanthellae, perhaps taken up from conditioned reef rubble offered as settlement substrate, were observed in the tentacles of the initial settled polyps. However, the mechanism of zooxanthellae transfer or uptake is unknown at present. Successful cultures from spawn to settlement were made at Key Largo Dry Rocks, Florida in 1996 and 1997 (Szmant, pers. comm.).

Resolution: ***For Acroporid corals, which exhibit reportedly sporadic or limited sexual recruitment, asexual reproduction can play a major role in maintaining local populations. However, as population abundance decreases or disturbance patterns increase to the point where remaining coral populations are no longer able to survive and propagate by asexual means, the relative importance of sexual reproduction and recruitment increases.***

While the energetic investment in gamete production and release is apparent, sexual recruits of Acroporids were absent, or present in very low numbers, in several settlement studies, leading to the generally accepted conclusion that these species exhibit low levels of sexual reproductive success (e.g., Dustan, 1977; Bak and Engel, 1979; Hughes and Jackson, 1980, 1985; Rylaarsdam, 1983; Rosesmyth, 1984; Knowlton et al., 1990). Although this may still be true, researchers at the *Acropora* workshop believe that the observed patterns of limited sexual recruitment success may not represent necessarily a life-history characteristic of this group. In fact, it was concluded that the documented patterns may be an artifact of: 1) the methods used in these studies (i.e., settlement tiles that may not offer the appropriate settlement substrate for Acroporids), 2) the timing of most of these studies (i.e., after the onset of the regional decline of Acroporids when adult densities were drastically reduced), and 3) the duration of these studies (i.e., never long enough to capture stochastic settlement events).

Resolution: ***Anecdotal evidence and observations made by reef researchers at several locations throughout the region indicate that both A. palmata and A. cervicornis do indeed recruit sexually onto reefs and that in several instances (e.g., Tague Bay Reef and other north shore reefs of St. Croix, USVI, Gladfelter, pers. obs.) populations that have experienced major declines (< 90%) are presently showing signs of recovery from newly settled sexual recruits.***

B. Asexual reproduction

In contrast to the limited information available on the patterns of sexual reproduction and recruitment for Acroporid corals in the region, patterns of asexual reproduction through fragmentation are well documented, and several consequences of asexual reproduction have been suggested for corals (Table 3). The organization of coral colonies into modules allows the biomass of a genotype to increase beyond the mechanical limits of individual colonies by the formation of tissue isolates and fragments (Jackson, 1977; Hughes et al., 1992). When growth-rates decline with increasing colony size (e.g., Maragos, 1974; Loya, 1976; Hughes and Jackson, 1985), fragmentation may help maintain high growth-rates by “pruning” colonies, creating new, smaller units. The larger size of fragments compared to sexually produced coral planulae may result in higher survivorship after recruitment (Jackson, 1977) and the colonization of areas not suitable for larval development, such as soft-bottom habitats (Highsmith, 1982; Heyward and Collins, 1985). Within populations that experienced recent storms, *A. palmata* fragments can comprise a large percentage of ramets as well as cover a large percentage of the bottom (Highsmith, 1982; Lirman and Fong, 1997). Similarly, demographic studies of *A. cervicornis* distributed along the coastal waters off Fort Lauderdale, Florida revealed that fragments can comprise over 40% of the staghorn coral population at the study sites (Thomas et al., 2000; Vargas, unpub. results).

Asexual propagation through fragmentation is often concentrated in time and fragmentation followed by fragment stabilization can result in a rapid increase in ramet abundance and coral cover, leading to space monopolization by fragmenting coral species (Lirman and Fong, 1997; Lirman 2000a). Unlike sexual reproduction, which is highly seasonal for *Acropora palmata* and *A. cervicornis* (Szmant, 1986), fragmentation can take place year-round. Similarly, successful asexual reproduction of colonies can take place even at low colony abundance and does not require multiple colonies for gamete concentration and fertilization.

Despite these potential benefits of fragmentation, there are negative consequences associated with this process that need to be considered (Table 3). The final outcome of fragmentation may be a total increase in biomass after a period of growth (Clark and Edwards, 1995), but initial tissue losses and the reduction in colony size can produce negative consequences as colony size in cnidarians has been directly associated with survivorship, growth, and reproduction (e.g., Connell, 1973; Loya, 1976; Highsmith, 1982; Jackson, 1985; Karlson, 1986, 1988; Hughes and Connell, 1987; Lasker, 1990; Babcock, 1991; Hughes et al., 1992). The immediate tissue losses after fragmentation can be significant. Fragment survivorship is influenced by the type of substratum where fragments land. In Florida, fragments that landed on top of live elkhorn colonies fused to the underlying tissue rapidly and showed no signs of mortality. In contrast, fragments placed on sand lost 58% of their tissue within the first month and 71% after four months (Lirman, 2000a). Similarly, the survivorship of *A. cervicornis* fragments is strongly determined by the type of substratum and fragment size (Bowden-Kerby, 1997; Vargas, unp. results).

During fragmentation, skeletal lesions are formed on both the fragments and the source colonies, and the recovery of lesions has been shown to be a considerable energetic drain on the damaged colonies (Meesters 1996, 1997). Furthermore, since linear growth can not resume until lesions are recovered and axial polyps form, lesions can also reduce the growth rates of damaged colonies (Lirman, 2000b). Similarly, the colonization of lesions by bioeroders can weaken coral colonies (Hernandez-Ávila et al., 1977; Mitchell-Tapping, 1983).

Severe fragmentation, as commonly observed after storms, may limit future sexual reproduction by reducing the biomass of colonies and shifting the energy allocation of damaged colonies from reproduction to stabilization and regeneration (Van Veghel and Bak, 1994; Van Veghel and Hoetjes, 1995; Hall and Hughes, 1996). Lirman (2000a) showed that hurricane-damaged *A. palmata* colonies and fragments on Florida reefs did not produce gametes until five years after the initial disturbance. Also, the size and weight of fragments may limit their dispersal range (Williams, 1975; Wulff, 1985; Jackson, 1986), slowing the recovery of damaged areas where the cover of adult colonies has been reduced significantly (Aronson and Precht, 2001; Precht et al., 2002). In such cases, recovery will depend on the recruitment of sexual propagules produced in distant, undisturbed areas (Connell and Keough, 1985).

Resolution: ***The information available on patterns of asexual propagation has shown that, under the right environmental conditions, fragmentation followed by fragment stabilization, survivorship, and regrowth can provide an efficient mechanism for maintaining and expanding Acroporid populations. However, while fragmentation followed by fragment stabilization and growth may have been sufficient to maintain and expand Acroporid populations in the past, recent patterns of regional decline have increased the reliance of these species on sexual recruitment as a means of establishing and sustaining populations. Accordingly, the regional recovery of Acroporid populations will depend largely on the future success of sexual recruitment.***

6. Genetic Status of *Acropora* Populations

Acroporid populations showed a significant Caribbean-wide decrease in the 1980s attributed, at least in part, to the epizootic white-band disease, a disease specific to this genus (Antonius 1981; Gladfelter 1982; Peters 1993; Aronson and Precht, 2001). Moreover, the branching Acroporids are especially susceptible to the physical damage caused by storms that have resulted in significant additional losses (e.g., Woodley et al., 1981). Declines of up to 95% attributed to these and other stressors have been observed at locations throughout the region where Acroporids were once the dominant on shallow reef zones.

Resolution: ***In light of the recent drastic decline of these critical structural (foundation) species, it is important that we understand the influence of disturbances on the genetic composition and genetic variability within and among Acroporid populations. Furthermore, faced with the uncertainty about their recovery and long-term status it is important to determine whether these disturbances have modified underlying genetic variability, favoring locally adapted, disturbance-resistant populations. This information will be crucial to: 1) evaluate, based on present genetic structure, the potential impact of future disturbances, and 2) determine, based on prior genetic exchange, the recovery capability of local populations from remaining regional sources of propagules. Similarly, information on the clonal structure of the populations will aid in the decision making process on marine reserves and management plans by identifying specific locations and populations at risk based on factors such as genetic isolation and genetic structure.***

Acropora spp. in the region reproduce both sexually and asexually. Asexual reproduction, which is a common reproductive and propagative strategy in this group (e.g., Tunnicliffe, 1981; Highsmith, 1982; Lirman, 2000a), leads to the multiplication of a genotype and results in an assemblage of genetically identical individuals or clones (Carvalho, 1994). Asexual reproduction per se has no effect on allelic or genotypic frequencies in populations. It does not allow for genetic segregation and recombination, however, and so preserves the effects of selection, genetic drift, or founder effect on genetic diversity. In addition, *A. palmata* and *A. cervicornis* reproduce sexually by releasing egg-sperm bundles in the water (broadcast spawning; Szmant, 1986; Steiner, 1995). The pelagic life stage provides the opportunity for long-distance transport of larvae with the surface currents (Sheltema, 1977; Crisp, 1978).

The dominance of asexual reproduction combined with broadcast spawning may have significant implications on the damage and recovery patterns of Acroporid populations and has led to a prediction of small effective population size and low genotypic diversity within Acroporid populations. As early as 1983, Bak (1983) hypothesized that high asexual reproduction rates can lead to low genotypic diversity so that Acroporids are more susceptible to disease compared to non-branching species.

The effective population size (i.e., the number of breeding individuals) reaches a maximum when all genets contribute to the next generation. Acroporid populations are expected to have a small effective population size if both fertilization success of spawned gametes and the recruitment of larvae are highly stochastic and dependent upon local conditions. By chance, only a few individuals might contribute a large number of offspring to the next generation (sweepstake effect; Hedgecock, 1994a, b). Once colonies become rare, the distance between them might limit fertilization success (Allee effect) even further. This is important for already declining Acroporid populations because small effective population sizes are far more prone to extinction due to demographic stochasticity, reduction in gene diversity, or accumulation of deleterious mutations (Grosberg and Cunningham 2000). The consequences of asexual reproduction on genotypic diversity depend largely on the frequency of sexual recruitment and genet longevity. Empirical and theoretical studies have suggested that genotypic diversity at a local scale might decrease over time through elimination of genets by intraspecific competition or stochastic effects. In contrast, genotypic diversity might remain high if sexual recruits, however rare, have a long life span after establishment (McFadden, 1997).

Resolution: ***The scientific capability to assess the potential for recovery of Acropora spp. populations by sexual propagation of surviving populations is seriously impaired at present by the general lack of knowledge of the different aspects of this process. This was identified as a key research area where efforts need to be allocated in the future to determine: 1) spatial and temporal patterns of gamete formation and release, 2) size-stage thresholds for gamete production, 3) within and among colony variability in gamete production, 4) fertilization patterns, 5) transport and duration of larval stages, 6) larval survivorship patterns, 7) settlement requirements and preferences of coral planulae, and 8) early survivorship and growth of sexual recruits.***

In an early study to detect clonal identity with Acroporid populations, Neigel and Avise (1983) utilized self-recognition analyses to show that: 1) *A. cervicornis* clones do not extend further than 20m, 2) one clone may dominate areas of $10m^2$, and 3) clones are generally spatially discrete with tight boundaries. However, the genetic basis of tissue compatibility has since been challenged by studies showing fusion of electrophoretically distinct ramets. Analysis of protein (allozyme) and DNA markers show patterns from dominantly asexual to dominantly sexual reproduction in the Scleractinia. Even within the same species, contrasting reproductive behavior over large geographical scales is not exceptional (Harrison and Wallace, 1990).

The genetic structure of *A. palmata* populations is currently under investigation (Baums, in progress). Both clonal structure and reef connectivity will be estimated by combining highly variable, mendelian markers (microsatellites) with a nested sampling approach on a variety of spatial scales. Genetic analyses conducted by Vollmer and Palumbi (2002) clearly shows that the three Caribbean *Acropora* comprise a natural hybridization system with *A. prolifera* being a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*. While the parent species *A. cervicornis* and *A. palmata* are genetically distinct, rare backcrossing of *A. prolifera* with *A. cervicornis* allows for limited mitochondrial and nuclear introgression (Vollmer and Palumbi, 2002). As a result, the genome of *A. cervicornis* may be sprinkled with *A. palmata* genes. An important distinction for the status and conservation of *A. cervicornis* is that the genetic data show it is a distinct species or genetic lineage, despite its introgression. One avenue of their on-going research is to assess the potential role of genetic introgression on the relative fitness of various *A. cervicornis* genotypes. In addition, with the genetic markers used for the hybridization work, they are also characterizing levels of genetic diversity and population structure of *A. cervicornis* throughout the Caribbean. Preliminary data suggests there is population structure among islands, and potentially even over small spatial scales (ca. 20kms), and varying degrees of genetic diversity within local populations. In Puerto Rico, for example, they are finding surprisingly high levels of genetic diversity at some sites (ca. 1 genotype per 5m), while other sites appear to be dominated by a single clone.

Resolution: ***The preliminary results highlighted here can have important conservation implications – namely, each coral population should be considered individually and any conservation strategy (esp. transplantation studies) should take into account preserving 'meaningful genetic diversity'.***

Table 1. Contribution of Acroporid corals to the reef communities of the Caribbean region

- •• REEF-BUILDING / FRAMEWORK CONSTRUCTION
- •• CARBONATE DEPOSITION
- •• TOPOGRAPHICAL RELIEF / COMPLEXITY
- •• ESSENTIAL HABITAT FOR ASSOCIATED REEF SPECIES
- •• PROTECTION FROM EROSION / WAVE ACTION
- •• BIODIVERSITY
- •• MICROHABITAT DIVERSITY
- •• AESTHETICS
- •• SCIENTIFIC VALUE
- •• EDUCATIONAL VALUE
- •• RECREATIONAL VALUE
- •• COMMERCIAL VALUE

Table 2. Stressor-response characteristics of Acroporid corals in the Caribbean. The information included in this table is based on published reports and expert opinion recorded at the Caribbean Acroporid Workshop, April 16-18, 2002, Miami. While the information provided here emphasizes documented responses of Acroporid corals to stressors, it is recognized that stressors known to affect other coral species may influence Acroporids in similar fashion even when data to test this are not available. Similarly, while the direct effects of individual stressors are emphasized here, it is recognized that many stressors have indirect and synergistic effect pathways that need to be considered. Lastly, while the lethal effects of stressors are emphasized here, it is recognized that many of these stressors commonly have sub-lethal effects such as reduced calcification, growth, reduced reproductive output, and reduced recruitment that can have important consequences on the long-term survivorship of these species. Emerging issues are recognized as potentially important stressors for which limited information is available and more research is needed. Susceptibility: High, Medium, Low; Effects: Lethal (whole colony mortality), Partial (patchy tissue mortality), Minimum; Spatial Extent: Regional, Local; Resilience (i.e., time required to recover from impacts): High, Medium, Low; Effect Pathway: Direct, Indirect (mechanism). * Although bleaching is commonly recognized as a coral response to stress, it is included in this list due to the potential role of bacteria in causing this response.

Table 2. Stressor-response characteristics of Acroporid corals in the Caribbean.

STRESSORS	Susceptibility	Effects	Spatial Extent	Resilience	Effect Pathway
Diseases / Pathogens					
White Band Disease	High	Lethal	Regional	Low	Direct
Patchy Necrosis / White Pox	High	Partial	Local - Regional	Medium - High	Direct
Bleaching *	Low - High	Partial - Lethal	Local - Regional	Low	Direct
Physical Damage					
Storms	High	Minimum - Lethal	Local - Regional	Low - High	Direct
Groundings / Anchor Damage	Medium - High	Minimum - Lethal	Local	Medium - High	Direct
Competitors					
Snails (*Coralliophila abbreviata*)	Low - High (depend on population	Partial - Lethal	Local	Depends on extent of predation	Direct
Fireworms (*Hermodice carunculata*)	Low - Medium	Partial	Local	Medium	Direct
Damselfishes	Low - Medium	Partial	Local	Medium	Direct + Indirect (algal competition)
Parrotfish (*Sparisoma viride*)	Low - Medium (depend on population	Partial	Local	Low	Direct + Indirect (algal competition)
Bioeroders	Low - Medium	Partial	Local	Medium - High	Direct
Sea Urchins	Low	Minimum	Local	High	Direct + Indirect (fragmentation)
Clionid Sponges	High	Lethal	Local - Regional	Low	Direct
Macroalgae	Medium	Partial - Lethal	Local - Regional	Medium	Direct + Indirect (recruitment)
Temperature	Unknown	Lethal at extremes	Local-Regional	Low at extremes	Direct +Indirect (bleaching)
Irradiance	Unknown	Unknown	Local - Regional	Unknown	Direct (UV) + Indirect (bleaching)
Reduced Water Motion	Medium - High	Lethal if persistent	Local	Unknown	Direct + Indirect (bleaching)
Siltation	Medium	Partial	Local	Medium - High	Direct + Indirect (recruitment)
Salinity	Unknown	Unknown	Unknown	Unknown	Unknown
Nutrients	Unknown	Unknown	Local	Unknown	Direct + Indirect (recruitment, algal competition, bioerosion)
Solid Waste	Low	Partial	Local	Medium - High	Direct
Chemicals	Unknown	Unknown	Local - Regional (Emerging issue)	Unknown	Direct
Increased CO_2	Unknown	Unknown	Regional (Emerging issue)	Unknown	Indirect (calcification)

Table 3. Potential benefits and consequences of fragmentation and asexual reproduction of Acroporid species in the Caribbean.

POTENTIAL BENEFITS OF FRAGMENTATION

- RAPID SPACE MONOPOLIZATION
- REPRODUCTION IN ISOLATION (NO CROSSING)
- HIGH SURVIVORSHIP OF PROPAGULES
- REDUCED SEASONALITY
- INCREASED LOCAL ABUNDANCE
- INCREASED BIOMASS (AFTER REGROWTH)
- COMPETITIVE ADVANTAGE
- EXPANDED HABITAT SUITABILITY
- REEF EXPANSION / CREATION OF PRIMARY SPACE
- AVOIDANCE OF SIZE / SHAPE LIMITATIONS
- AVOIDANCE OF SENESCENCE
- INCREASED GENET SURVIVORSHIP

POTENTIAL CONSEQUENCES OF FRAGMENTATION

- TISSUE LOSSES
- LESION FORMATION
- REDUCED AVERAGE SIZE OF RAMETS
- REDUCED GROWTH RATES
- INCREASED MORTALITY RATES
- INCREASED SUSCEPTIBILITY TO STRESSORS
- INCREASED BIOEROSION
- REDUCED SEXUAL REPRODUCTIVE OUTPUT
- REDUCED PROPAGATION CAPABILITIES
- REDUCED GENETIC DIVERSITY

Report from the Status and Trends Working Group

Compiled by Patricia Richards Kramer

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EXECUTIVE SUMMARY

The Status working group (WG) summarized available information on the regional and local status of Caribbean Acroporids and discussed whether these species warranted further listing under the Endangered Species Act (ESA). They estimated 60-75% of the entire population has been examined (or at least observed) and concluded enough information was available to make a determination whether these species were threatened or endangered. The WG also estimated 5% (no more than 10%) of the population resides within US waters. The WG developed specific products including a "*Status Matrix*" and "*Status Map*" that included data on the distribution, status and threats to these species and a *Cross shelf matrix* to allow for a more comparable assessment of Acroporid populations. They identified several gaps in geographical information and prioritized areas to be assessed including Bahamas (especially southern), Nicaragua, Pedro Banks, northern Cuba, Haiti, Banks off of Turks and Caicos, Saba Banks, eastern Caribbean, and Trinidad and Tobago. The WG suggested that a combination of several population parameters be considered when assessing the status of Acroporid populations (e.g., abundance, partial mortality, size structure, survivorship, genetics) and recommended areas requiring additional research.

The WG agreed there has been a significant decline in Acroporid populations and discussed specific examples (Florida, Jamaica, Belize, Curacao, USVI) where greater than 80% loss (and up to 98%) occurred. The WG established the 1970s as a baseline for "stable, healthy" populations and the 1980s as a baseline of the regional decline. They noted additional shifting baselines were useful to understand local and current declines. The WG agreed it was both the overall reduction of populations throughout its historic range and fast rate of decline that makes these species vulnerable to extinction. They did not believe the geographical range (on ecological scale) had been contracted, although local range reductions had occurred. The WG identified and discussed various sources of mortality and agreed WBD had been the primary cause of decline, but current impacts were harder to determine.

The WG agreed there has been an overall decline over the last 10 years in *A. palmata*, with only small recovery trends. Over the last year (2001), several *A. palmata* populations are believed to be stable, but highly vulnerable to disturbance and further decline. The status of *A. cervicornis* has been a continuing decline with no or few signs of recovery over the last year or 10 years. Threats to both species remain high and since populations are subjected to numerous different stresses, any one severe disturbance event (or synergistic events) could lead to local extirpations and one or both species may be vulnerable to possible extinction.

The WG emphasized a key factor in recovering these species was to develop and implement actions that minimize further disturbance and increase population sizes. The WG concluded that *Acropora palmata* and *A. cervicornis* warranted further listing under the Endangered Species Act (ESA) and would benefit from the protection the ESA affords.

OVERVIEW

The goal of the Status working group (WG) was to begin to summarize available information on the status of Caribbean Acroporids at both regional and local scales and discuss those factors important in determining whether these species are threatened or endangered. They focused on five areas: 1) minimum and maximum population estimates; 2) trends; 3) historic and current range; 4) population parameters; and 5) recovery. As a first step, they discussed if there was enough information currently available to make the determination that these species were threatened or endangered. They estimated that over 60-75% of reefs in the Greater Caribbean has been assessed or monitored (within the last five years) with some type of survey. They suggested there may be some important populations in the 25-40% not yet observed (e.g., Cuba, Bahamas, Saba) important to the persistence of these species. They further estimated that at least 5% (and probably no more than 10%) of the entire Greater Caribbean population resides within US waters, and at least 80% of the reefs within US waters have been examined scientifically. Despite the information gaps, the WG agreed that sufficient information existed to make the determination whether these species are threatened or endangered.

1. Minimum and Maximum Population Estimates

A. Historical distribution and abundance

The WG discussed the historic distribution of Acroporids and how *A. palmata* and *A. cervicornis* were once dominant species commonly found throughout the greater Caribbean. They agreed that currently, northern-most *A. palmata* populations extended from southern Florida and the northern Bahamas (Abaco) region to their southern-most populations near Trinidad & Tobago (unlikely further south than this)-and the insular and coastal reefs of Venezuela and Colombia. Populations extended to their westernmost range in Veracruz Mexico to their easternmost point in Barbados. In the U.S., the WG noted the current northern-most limit for *Acropora palmata* was in Broward County, FL and the species was unlikely to occur in Palm Beach County. Given the coldwater temperatures (14-15 degrees in many winters) in the Flower Garden banks, the WG agreed it did not occur there. *Acropora cervicornis*, they noted, has a similar range except its northern limit was Palm Beach. The WG suggested efforts be made to confirm the current distribution of these species, especially northern and southern most occurrences.

To synthesize information on the status of Acroporids, particularly at specific locations throughout its range, the WG developed a "*Status Matrix*" (Table 1&2) and "*Status Map*" (Fig. 1) that included data on the distribution, status, and threats to these species. Distribution information included location of reef, extent of distribution, and reef type. Status data included recent trends, baseline used to determine status source of information, extent of decline, condition, coral cover, and sexual recruits. The level of threat was categorized into evidence of human impact, bleaching, hurricanes, disease, and damselfish, snail or other predation. Data was documented from source of information, data parameters measured, other surveys available, and gaps in information. Priorities for information needs were also listed. Members from the WG were able to provide preliminary information on Florida Keys and BNP, US Virgin Islands, St. Thomas, St. Croix, St. John, Puerto Rico, Dominican Republic, Cuba, Trinidad, Colombia, San Andres, Colombia (including San Andres), Gonaive Island, Jamaica, and Pedro Bank. The *Status Matrix* was formatted into a questionnaire and given to other workshop participants who were able to provide additional information on Belize, Netherlands Antilles (Aruba, Curacao, Bonaire), Tobago, Anguilla, British Virgin Islands, Broward County Florida, and Venezuela (Los Roques). The WG recommended the *Status Matrix* questionnaire be distributed to other experts in the region (e.g., through coral list server).

B. Habitat

The working group discussed general habitat requirements of Acroporids and factors that limited the distribution of both species. The WG also discussed the extent of different habitats occupied by these corals over the range of the species. They agreed that population densities of these species (particularly *A. palmata*) varied greatly throughout its region, and in addition, population abundances ranged from single, isolated individuals to large densely aggregated, monospecific thickets. The WG recognized the need for a more specific definition of a distinct population in order to compare the status of different areas, particularly without the current availability of information on genetically distinct populations. Therefore, the WG suggested a standardized classification scheme for Acroporid reef types (=population) and developed a draft *Cross shelf matri*x (similar to Lindeman et. al, 1998). The matrix included information they had available on the location of Acroporid reefs (e.g., country, latitude/longitude), cross shelf position of reef [innershelf=first emergent barrier or reef crest, midshelf=Reef crest, outer shelf (to ~30m), offshore (atolls and offshore)]; water depth, reef position or aspect (e.g., leeward, windward), and wave energy. The WG recommended the draft matrix be sent to other Acroporid experts throughout the region for completion. This would allow for a more comparable assessment of Acroporid reef types (=populations) throughout the region (i.e., comparing apples to apples) and the magnitude of a declining population in one area versus another area could be assessed in relation to the status of the species throughout its range.

Resolution: ***Once dominant species on shallow reefs (0-15 m depth) throughout the greater Caribbean, Acroporid abundance has been drastically reduced in abundance and spatial dispersion. In many areas, previously densely populated subpopulations (or monospecific thickets) now consist of no or few individuals (e.g., Los Roques Venezuela). Present and future likelihood of disturbance to their abundance and habitat remains high due to both natural and anthropogenic factors.***

2. Trends

A. Initial and shifting baselines

To determine extent and rate of decline of these species, the WG discussed how to establish a baseline for comparison purposes. For Caribbean Acroporids, the WG agreed there was at least 20 years of comparable information on these species, as well as geological data, and thus suggested the 1970s as a regional baseline (e.g., several workshop participants have personal observations of Acroporid populations from at least the 1970s). The WG believed the 1970 baseline represented the status of Acroporid populations in a “healthy, stable” state, and prior to any significant disturbance events, particularly the dramatic Acroporid die off due to white-band disease in the 1980s. The WG also believed the 1970s baseline and its representativeness of a “stable, healthy” population was further supported by presentations by Aronson and Hubbard that showed the geological record suggested that in the last ~10,000 years such population declines as the one related to the 1980s die off were at least rare and/or uncommon in the last 3000 years, thus suggesting that such die offs are unique or unprecedented.

In addition to the 1970s representing a “healthy” baseline, shifting baselines in relation to significant disturbance events were discussed due to their relevance in estimating the continuing decline of these species. The WG suggested there were two regional “disturbance baselines”; the first in the 1980s coinciding with the outbreak of white-band disease and *Diadema* die off and the second coinciding with high Acroporid mortality related to the 1998 coral bleaching event. On smaller scales, the WG suggested this baseline varied in relation to localized disturbance event(s) that may have had more significant impacts than regional disturbance events. For example, in the Virgin Islands, reoccurring and intense hurricanes have caused some of the most significant declines or alterations in Acroporid populations, and more so than the 1998 bleaching event.

Resolution: ***The status of Acroporids has changed significantly since the 1970s with a region wide decline occurring in the 1980s and subsequent declines during the 1990s. The 1970s represents a baseline for "stable, healthy" populations and the 1980s as a baseline of the regional decline primarily resulting from white-band disease. Additional shifting baselines are useful to understand local and current declines; for example, mortality from disease has been compounded on local populations by hurricanes, bleaching events, and outbreaks of predators.***

B. Extent of loss

To understand the overall loss of Acroporids, the WG examined both the extent and the rate of decline. Acroporid populations throughout the Caribbean declined dramatically in the 1970s-1980s and continued to decline in the 1990s until many populations were nearly gone. The extent of decline, including both a significant reduction (loss of 80-90%) in the abundance of individuals and an extreme reduction in area of distribution throughout its range, triggered the initial concern for the persistence of this species. Examples of widespread decline, where there was a loss of greater than 80% of population (and up to 98% in some areas) for both species included Florida, Jamaica, Belize, Curacao, and USVI. Because the number of individuals had declined to significantly low levels in such a fast timeframe (~10 years), the WG agreed it was both the overall reduction of populations throughout its historic range and fast rate of decline that makes these species vulnerable to extinction.

The WG discussed the current status (as compared to the importance of historic status) of several local populations and identified (where known) which populations were increasing, decreasing, stable, or unknown. Over the last 10 years (decadal scale), they suggested the overall trend of *A. palmata* has been a decline with small recovery trends. Over the last year (2001), several populations are believed to be stable, albeit at such low population densities that there is high enough vulnerability to stochastic disturbance to cause extinction. There is some evidence of recovery, as well as evidence of areas just recently examined (e.g., southcoast Cuba) that contain stable populations. The WG emphasized the status of many populations are unknown and may still be declining. For *A. cervicornis*, there has been a continual decline since the 1980's with no signs of recovery, although Broward county was noted as an exception. It is not known whether or not the few remaining populations are able to persist. For both species the degree of threat remains high. The WG noted that more information was needed especially in light of its uncertainty as a genetically distinct species. The matrix provides additional information on the status and stability of local populations.

Resolution: ***Acropora palmata and A. cervicornis have experienced an unprecedented decline throughout their historic range since the 1980s, including both a significant reduction (loss of 80-98%) in the number of individuals and an extreme reduction in area of distribution. Neither species have recovered to their former abundance. Some local A. palmata populations have been stable over the last year with evidence of recovery and limited sexual recruitment (e.g., USVI). Acropora cervicornis experienced a more severe decline with no or few signs of recovery or sexual recruitment (except Broward County, FL). Acroporids have a high likelihood of localized extirpation and possible extinction on ecological time scales (10-100 yrs).***

C. Sources of mortality

The WG discussed various sources of mortality and identified historic and current threats, as well as the degree of threat, for each country in the *Status Matrix*. The WG agreed that white-band disease (WBD) was the primary cause for the region wide decline of Acroporids, but current impacts are harder to determine. The working group also emphasized that many current factors causing mortality or stress were highly localized, including breakage by hurricanes/storms, temperature extremes (bleaching, cold-air outbreaks), disease, predation by invertebrates and fishes, algae overgrowth, and long-term exposure resulting from drops in sea level. Similarly, human impacts resulting in mortality or stress such as direct destruction by ship groundings/anchoring, dredging, and diving/snorkeling; nutrient loading often leading to macroalgal overgrowth; and reduced water clarity due to sedimentation, were also localized.

The WG suggested the sources of mortality or threats varied on both spatial and temporal scales and identified on the *Status Matrix* which locations had high, medium or low threats. They concluded that the information compiled in the *Status Matrix* suggested that current threats to Acroporids are very high for both anthropogenic effects and natural disturbances. They recommend that in order to assist resource managers, more data were needed on these threats, particularly synergistic effects from confounding disturbances, but more importantly, management actions were needed to alleviate or minimize further disturbance. It was emphasized that even Acroporid populations within marine reserves were still declining and remain at high risk.

The WG noted that certain locations appeared to be more severely affected by coral disease, although they did not know if there were any specific patterns for the Caribbean. For example, several Acroporid populations in Puerto Rico (e.g., Culebra) had more than 50% of colonies infected with WBD. These colonies subsequently died and became completely covered by algae and colonized by damselfish within two months. Acroporid reefs off of Key West were reported to have the highest incidence of WBD in the Florida Keys. In contrast, several *A. palmata* populations on Andros Island Bahamas and along the south coast of Cuba had less evidence of mortality from WBD. The WG discussed that the infectious nature of disease is unclear, particular how it relates to population abundance. It was not known if densely aggregated thickets were more susceptible to mortality than populations further distances apart or isolated individuals.

Mortality caused by snails was suggested by the WG as an additional and important concern, mainly because the incidence of mortality seemed to be increasing, although highly localized. Even though more studies today are focusing on snail-induced mortality, the WG noted the extent and rate of mortality caused by these snails, especially in comparison to other predators, was alarming. Damselfish predation was also suggested as an area of further investigation, particularly following coral mortality either from disease or bleaching.

Resolution: ***White-band disease (WBD) is believed to be the primary cause for the region wide Acroporid decline during the 1980s. Current factors causing mortality or stress are highly localized, with some areas showing greater susceptibility to disease (e.g., Florida Keys, Belize), predation (e.g., Florida Keys), and storms (e.g., US Virgin Islands). Given the declined state of Acroporids and the increase in the frequency and intensity of disturbances, these sensitive species are highly vulnerable to both natural and anthropogenic stressors, especially synergistic disturbances.***

D. Information gaps

The WG listed areas where little or no information was available or where the information was not readily available and recommended these as priorities for status surveys. These areas included (but not limited to, nor are they in any priority order): Haiti, Saba, Saba Bank, Nicaragua, Mushwar Bank and Silver Bank, Turks and Caicos (some AGRRA data), Pedro Banks, Serranilla Bank, Alicia Bank, Bajo Nuevo Bank, Bahamas (Aklins, Ragged Islands, Crooked Island, Long Island, Cat Island, southern Bahamas), Inagua, Meguana and Hawk's Die Reef (Bahamas); northern Bahama Bank; from N. Eleuthra to New Providence, Treasure Key, Grand Bahama, Mysteriosa Banks, Swan Islands, Rosa Linda Bank, Bay Islands, Costa Rica, and eastern Caribbean (although most islands have some ongoing monitoring programs such as St. Vincent, Barbados, St. Lucia and Martinique, and Guadeloupe).

Resolution: ***An estimated 60-75% of the entire Acroporid population has been examined and enough information is available to make a determination whether these species are threatened or endangered. Approximately 5%, and no more than 10% of the population resides within US waters. Several geographical areas where more information is needed include Bahamas (especially southern), Nicaragua, Pedro Banks, northern Cuba, Haiti, banks off of Turks and Caicos, Saba Banks, eastern Caribbean, and Trinidad and Tobago.***

3. Historic and Current Range

The WG discussed what portion of the historical range or distribution of the species had been lost and suggested that it was likely the overall range had remained the same since at least a few individuals were still present throughout its range. The WG emphasized that local reductions in range have occurred in several areas throughout the Caribbean. In addition some populations, especially those located at the extent of their range, may not be viable or able to persist given the severe reduction in abundance. The challenge in defining distinct populations, especially genetically distinct ones, made it difficult for the WG to conclude with certainty that there was no contraction of its geographical range or to determine if populations have been extirpated on smaller spatial scales. They did note examples from the literature and personal communications where populations at some study sites have been reported extirpated (e.g., southern Belize). The WG discussed how the *A. cervicornis* population in Broward County did not "exist" in the 1970s and suggested more information was needed on whether this species expanded its range or increased its population size. The WG did not know which was more important for the recovery of this species either maintaining the overall range extent or maintaining local viable populations and ensuring these do not go extinct.

Resolution: ***The historic range of Acroporids is believed to be the same as the current range, although it is not possible to conclude with certainty given the current scientific inability to differentiate genetically distinct populations. Local range reductions and extirpations have occurred and it is believed some populations may be reproductively isolated. Given the extent of decline and vulnerability to extirpation, it is believed these corals remain threatened throughout their range.***

4. Population Parameters

The WG discussed which population parameters were needed and available to help understand the status and trends of Acroporids, particularly in trying to quantify loss. The WG focused on factors that were available to help understand the population status at larger spatial scales since the Biology WG was discussing such life history parameters as survivorship, reproduction, and genetic information. The Status WG suggested that a combination of several parameters (and not just one single factor) be considered when assessing the status of Acroporid populations including amount of coral cover (both living and dead), number of individual colonies, colony size, percent coral mortality (both old and recent), proportion of living colonies versus standing dead colonies, reef structure (or complexity/vertical height), area cover/extent, areas with "luxuriant or healthy" populations, and areas with extirpated populations.

The WG mentioned that size related parameters and partial mortality data were needed since these corals were modular organisms. Besides a noticeable reduction in population sizes, reports (e.g., USVI) suggest individual colonies were smaller and often had partial mortality. The WG noted that percent live coral cover is how coral status has been historically assessed, but suggested there can be two contexts of coverage; one that describes how Acroporids occupy a certain range of reef area (areal extent), and second the density of individuals in a population. In addition, they emphasized the need to identify end member reefs (i.e., those that are the most degraded vs. those relatively pristine) as a way to characterize the viability of populations and potential for recovery (i.e., identify those reefs that are potential "re-seeders") and identified those they knew of in the Status matrix. They suggested a vertical index (e.g., colony heights, canopy complexity) needed to be characterized and its role in the population stability needed to be evaluated. The WG discussed that examining standing dead colonies in growth position, as is done in the AGRRA survey method, gives an indication of the historic population (where preserved) and importance as habitat to other reefal organisms. The degree of coral cover, colony density, and relief may also be good indicators of the suitability of an area to support recruitment.

The working group suggested directions for future research should address understanding these population parameters, particularly at larger spatial scales. They noted that more information was available for *A. palmata* than *A. cervicornis*, and emphasized that more information was needed for *A. cervicornis* especially since it has suffered the most dramatic decline. The WG recognized various population parameters have been measured by different surveyors (and methods), often making it difficult to compare data sets. They identified a few good standardized comparable data sets existed on a large scale (e.g., AGRRA, Caricomp), as well several local monitoring programs. The WG group did not have time to discuss the spawning, long distant dispersal, distribution of populations and proximity to each other, minimum population size, recruitment, or survivorship, but noted more information was also needed in these areas.

The WG agreed that there was not enough information on the genetic status of Acroporids to determine an effective population size. They emphasized it was important to understand if colonies were genetically different for Acroporids more so than for many other species due to their tendency for asexual reproduction. The WG suggested Acroporids may be at higher genetic "risk" than other species, therefore underscoring its endangerment status. Several research efforts are addressing the genetic question, but it was also recognized that there needed to be other measurable criteria (e.g., populations parameters discussed above) in lieu of these data until they become available.

On the last workshop day, the Status and Biology working groups (WGs) met and discussed Acroporid reproduction strategies and survival of recruits. The WGs agreed that both sexual and asexual recruitment appear to be highly localized. It was suggested that on local scales, populations can resist/recover if densities are high enough through both sexual and asexual reproduction, but as population size decreases, they rely more on sexual reproduction, which could be a limiting factor or problem for the many severely reduced populations. The WG did not know if Acroporids were less dependent upon sexual reproduction than other species, or if they were just unsuccessful at sexual reproduction. In addition, they questioned if sexual recruitment was more successful on live *Acropora* stands or areas with more standing dead colonies. The Broward county thickets of *Acropora* showed evidence that sexual recruitment can be very successful, although most recruitment studies have shown low recruits or a reduction in the number of recruits in recent years. In general though, the WG agreed that sexual recruitment rates were very low, yet it was not known how dependent local populations were on sexual recruitment. Since it is likely that some areas rely on sexual recruitment more than others, the WG suggested these areas should be identified. The WG said not enough information was known to estimate what percentage of a population was needed to reproduce sexually in order to support the entire population through sexual recruitment alone.

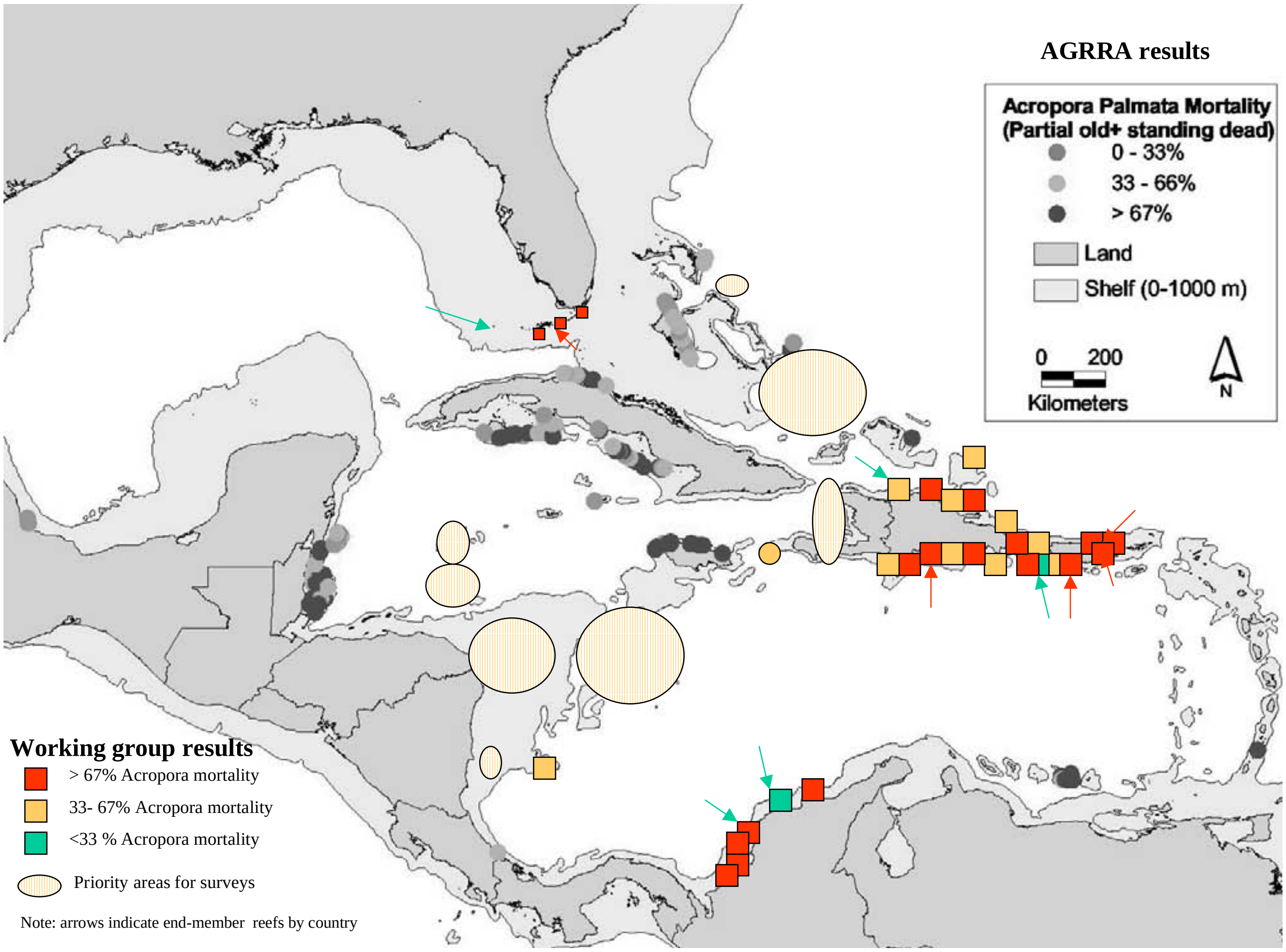
The WG also considered the difference in investment strategies between asexual vs. sexual reproduction. Data from the 1970s in the Keys showed that for a series of years *Acropora* did not show signs in their tissue of sexual reproduction, yet colonies were very abundant. Thus it was postulated that perhaps in the past, they only sexually reproduced every few years suggesting a lower investment in this life history strategy. It was emphasized that asexual recruitment was not equivalent to sexual recruitment in outcomes and consequences since the effects on the population as a whole are very different. The survivorship of juvenile corals was not known, although the WG suggested that survivorship is likely low, particularly of *A. cervicornis*. The WG suggested priority areas needing more data included juvenile population dynamics (e.g., survivorship, growth rates), differentiating sexual recruits vs. juveniles vs. crusts, and survivorship of individuals after establishment of colony.

Resolution*: To assist in the recovery of these species, more scientific information is needed on both demographic variables as well as habitat-based variables including 1) survival and fecundity by age (size or stage) and frequency distribution of ages (size or stage - fragment, whole colony, sexual recruit, etc.); 2) reliance of populations on asexual vs sexual recruitment; 3) genetically distinct populations, minimum population sizes, and amount of genetic exchange between populations; 4) juvenile population dynamics (e.g., survivorship, growth rates); 5) importance of habitat variables to recruitment and adult survivorship (e.g., standing dead colonies, vertical relief, habitat condition, cross shelf position); and 6) location of "endmember" populations and those showing signs of recovery and/or sexual recruitment.*

5. Recovery

The Status WG concluded its session by discussing several factors that needed to be considered when understanding the recovery of these species including status of the species, degree of threat, likelihood of persistence, reproduction, and adequate habitat. As mentioned above, the WG agreed that both *A. palmata* and *A. cervicornis* populations have been severely decimated. Over the last year, *A. palmata* has been stable, albeit at only at 5% of its historic baseline abundance. It was emphasized that the decline in *A. cervicornis* has been more severe and continues to decline. The WG emphasized that Acroporids are one of the more sensitive reef species and given the series of disturbance events, these species are highly susceptible to future disturbances. The WG noted that the frequency and intensity of disturbances (e.g., disease, hurricanes, bleaching, human impacts) in the Caribbean have increased in recent years, with several reefs affected by repeat and/or coinciding events. In addition, with sea surface temperatures predicted to continue to warm over the next 100 years, global climate change will play a critical role in influencing the frequency and magnitude of *El Niño-La Niña* bleaching-related events and hurricanes. Threats to both species remain high and since populations are subjected to so many different stresses, any one severe disturbance event (or synergistic events) could lead to local extirpation. They suggested these species will not recovery easily from extant populations, given the current level of threats. The WG suggested that

Fig. 1. Map of the wider Caribbean showing locations where *Acropora* spp. populations were examined, and the condition of those populations.



several local populations were vulnerable to extirpation over the next 5 years in some areas (e.g., southern Belize) and over the next 10-20 years (e.g., Florida Keys) in others, especially given the probability of continued and possible increase in disturbance. On a regional scale there have been a few signs of recovery (e.g., some areas in Colombia) since the initial decline (for *A. palmata*, not *A. cervicornis*), but overall the general trend has been a general decline since the baseline 1970s, thus making both species very vulnerable to extinction. The WG emphasized that these species, given their current declined state, were highly vulnerable to both natural and anthropogenic stressors (especially synergistic effects), and had a high likelihood of localized extirpation and possible extinction, although the time frame was difficult to pinpoint. They did note that the stochastic risk of extinction was high on an ecological/historic time scale (10-100 yrs).

Although more was known on the status and degree of threat of these species, the WG emphasized that more information was needed on how to contribute to their recovery. In addition to those already mentioned above, high priorities included documenting evidence of sexual recruitment, determining what constitutes good habitat for sexual reproduction (or minimum population sizes), and identifying sources of potential reseeding reefs. The WG discussed the problems of uncertainty and lack of information, but agreed that a primary goal was to provide information that will be useful to resource managers. The WG emphasized a key factor in the recovery of these species was to focus on developing and implementing management actions that will alleviate or minimize further disturbance to these species and that will contribute to their recovery. As a next step, the WG suggested that questionnaires similar to the Status matrix they developed be distributed to gather more information. The WG acknowledged the leading and proactive step by Colombian scientists to protect Acroporids by providing recommendations to their government to add Acroporids to their country list of endangered and threatened species. Based on observations of dead vs. live coral and similar to the IUCN criteria, the Colombian scientists recommended *A. cervicornis* be listed as "critical endangered"; and *A. palmata* as "endangered". It is expected that the Colombian government will accept and implement their recommendations.

To conclude, the WG agreed *Acropora palmata* and *A. cervicornis* warranted further listing under the Endangered Species Act (ESA) and could benefit from the protection the ESA affords. They suggested the likelihood of extinction could be reduced by alleviating threats to these species and implementing strategies that promote their recovery. They further emphasized the listing of these species would provide valuable added protection to the many other species dependent on them.

Resolution: ***Acropora palmata and A. cervicornis warrant further listing under the Endangered Species Act (ESA) and could benefit from the protection the ESA affords. Acroporids are likely to qualify for listing as threatened or endangered species because of the significant reduction in their abundance and high likelihood for future population declines; the current loss of habitat and potential for future loss of range remains high; they are highly susceptible to severe population reductions due to disease and predation; there are few existing regulatory mechanisms to minimize further reductions or impacts; and both natural and anthropogenic factors are likely to affect their continued existence. The likelihood of extinction for both species could be reduced by alleviating threats and implementing strategies that promote their recovery. The listing of these species will provide valuable added protection to the many other species dependent on them.***

Report from the Management Working Group

Compiled by Brian Keller

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INTRODUCTION

The Management Working Group was given the following tasks to address:

- Evaluate existing legislation, regulations, statutes, management approaches, and conservation initiatives that apply to coral reefs in U.S. waters (State/Territorial/Federal), in other countries, and regional initiatives; their effectiveness at protecting these corals and enhancing recovery potential; and where they are being applied.
- Identify measures that would enhance compliance with existing measures.
- Recommend additional measures that could be implemented on a local, national, and regional scale that are necessary to address threats affecting these species and can help rebuild populations, and where these need to be applied.
- Identify approaches to enhance national and regional collaboration.
- Evaluate the benefits/drawbacks of an Endangered Species Act (ESA) listing, locations where this listing would be most effective, and the type of issues that the listing would have to address to mitigate threats.
- Identify information needed (research, monitoring, restoration, and so on) by resource managers that would help assist managers in protecting remaining corals and rebuilding populations.
- Examine the potential implications of not taking additional steps to conserve these species and the reefs where they occur.

The working group included experience in the following places: U.S. (Florida Keys and Biscayne Bay), U.S. Virgin Islands, Puerto Rico, and Trinidad and Tobago; this report reflects this participation and the Working Group recognized that additional input would be required to make this report more representative of the Caribbean region.

1. Evaluation of Existing Regulatory Framework and Measures to Enhance Compliance

The existing regulatory framework is substantial in the U.S. and many Caribbean nations. Fishery Management Plans, National Parks and Monuments, and National Marine Sanctuaries in federal, state and territorial waters of the Gulf of Mexico, West Atlantic, and Caribbean are examples of management measures that have been taken to both directly and indirectly protect corals. Of importance to *Acropora* populations, most managed areas in state and federal waters now prohibit take of stony corals. Some areas provide mooring buoys to minimize physical damage to corals from anchoring. Additional measures include prohibition of the use of fishing gear in no-take zones and regulations against any direct physical impact to corals.

These regulations are necessary, but not sufficient, to protect *Acropora*. Often existing protective measures are insufficient as they may include protective measures established in one particular location (e.g., state or federal waters), but they do not apply to adjacent areas. In addition, there often is a general lack of political will and enforcement capacity. This is most often the case for many coastal zone issues, resulting in degradation of mangrove, seagrass, and coral reef habitats. A “common denominator” for these impacts is poor water quality, including elevated nutrient concentrations, persistently or periodically heavy sediment loads, and various chemical contaminants (e.g., pesticides, petroleum compounds, and mercury). In this regard, we must enhance public education and outreach, including how land-based activities impact coastal zones. Another potential measure is through fortified penalty structures, which should enhance compliance and restoration of ecosystem structure and function. This is a necessary context for all other, more-specific steps toward Acropora restoration. There is a need to re-evaluate current systems of navigational aids (charts, markers, and education) because of the prevalence of boat and ship groundings in some areas. Because of the shallow depth distribution of *A. palmata* in particular and *A. cervicornis* in some cases, reef groundings often damage at least one of these species. Improved navigational aids may help prevent some of this kind of damage.

Some steps toward improving water quality have been taken in some areas, and degraded water quality is widely recognized as a management issue. For example, in the Florida Keys, State waters have been designated as a no-discharge zone and pump-out facilities are widely distributed for boaters to use. In addition, the city of Key West, which processes nearly half of the wastewater produced in the Keys, now uses advanced wastewater treatment and injects this highly processed effluent into a deep, confined aquifer. Finally, the State has strict regulations regarding shoreline development, which protects mangrove and other critical nearshore habitats including patch reefs.

The existing regulatory structure allows penalties and fines to be imposed on violators. This enforcement capacity can only be as successful as political will and available resources allow. In most of the region, political will and resources are lacking, particularly in areas where tourism-based economies or long-term subsistence fishing dominate decision-making and implementation of management plans.

Resolution: ***The existing regulatory framework in the U.S. and its territories, as well as in many Caribbean nations offers limited protection to Acroporid populations through 1) the establishment of parks, sanctuaries, monuments, and reserves; 2) fishery management plans that limit or prohibit the take of corals; restrict the use of fishing gears that cause habitat damage and breakage of corals, especially in no-take reserves; 3) federal, state and territorial programs to establish and maintain mooring buoys to minimize coral breakage associated with anchoring; and 4) coastal zone management strategies that address shoreline development, sewage treatment and discharge, and destruction of associated habitats such as mangroves. However, the existing regulatory structure is insufficient for most Acropora populations; additional measures are necessary to improve water quality, address coastal development, improve navigational aids, address habitat damage from anchoring, destructive fishing gears, and boat groundings, and enhance enforcement.***

2. Evaluation of Existing Management Approaches and Conservation Initiatives in U.S. Waters.

The existing management approaches and conservation initiatives of most benefit to branching corals have focused on addressing physical impacts, including damage resulting from fishing gear, anchoring and ship groundings. Depending on zoning and regulations, marine protected areas (MPAs) help prevent damage from gear and groundings. Because all corals, particularly branching growth forms such as *Acropora* *palmata* and *A. cervicornis,* are susceptible to such impacts, MPAs can afford some immediate protection from this type of damage. As noted above, enforcement capacity generally is lacking, which compromises a central function of zoning plans; many resource managers emphasize the need for strengthening enforcement capacity. When they are effective, marine reserves prohibit all collection of marine life and other resources, with the goals of protecting biodiversity and sensitive habitats, and restoring ecosystem processes.

1. Florida

The John Pennekamp Coral Reef State Park was established in 1960 as the first coral reef MPA world-wide. The area of protection in the Upper Keys was extended by implementation of Key Largo National Marine Sanctuary in 1975. The Looe Key National Marine Sanctuary (1981) protected a significant coral reef in the Lower Keys.

Three National Parks have been designated in South Florida marine environments. Dry Tortugas (DRTO; 1992) and Biscayne (BISC; 1980) National Parks include significant coral reefs. Prior to the establishment of DRTO, the Fort Jefferson National Monument (1935) protected the area. In addition, Everglades National Park (EVER; 1947) includes much of Florida Bay, an important subtropical lagoon with vital ecological connections with the Florida Reef Tract.

The U.S. Fish and Wildlife Service manages several large National Wildlife Refuges that protect extensive areas of shallow hardbottom and seagrass environments in the Lower Keys, which also have important ecological connections with the Florida Reef Tract. Additional MPAs are managed by the State of Florida.

The U.S. Congress designated the Florida Keys National Marine Sanctuary (FKNMS) in 1990. The FKNMS covers nearly 10,000 km^2 surrounding the Florida Keys and Reef Tract, and encompasses many of the management areas noted above. It took six years to develop a management plan for the FKNMS, including a multiple-use zoning plan with 23 fully protected ("no-take") marine reserves. Another three years were required to develop a plan for the Tortugas Ecological Reserve, the largest marine reserve in the U.S. (518 km^2). Approximately 10% of coral reef environments in the Florida Keys are protected within marine reserves.

Corals in general are afforded a number of mechanisms of protection under the various Action Plans that comprise the FKNMS Management Plan, but there are no particular programs for *Acropora* spp. In practice, however, *Acropora* spp. receive particular attention in the form of tight restriction on collection of samples for research and restoration after damage from boat groundings and other sources.

The Florida Keys comprise an Area of Critical State Concern, with a Rate-of-Growth Ordinance for growth management and support for implementing comprehensive wastewater and stormwater treatment plans.

Cable corridors are being implemented to minimize damage to corals off southeastern Florida. Additionally, county and state agencies require transplantation and monitoring of corals potentially affected by cable deployment and other reef altering activities.

Additional protective measures include a 1990 designation of *Areas To Be Avoided* by ships longer than 50 m. Coincident with this step was a dramatic decline in large-vessel groundings in the FKNMS. The Florida Reef Tract, which lies within the sanctuary, is marked by eight RACON beacons, which transmit warnings to ship radar screens. The FKNMS also has an active program for waterway markers and maintains more than 400 mooring buoys, which help minimize anchor damage. Regulations are enforced by 17 officers equiped with vesssels up to 82’ in length, which supports cruises to the relatively remote Tortugas region. Finally, the FKNMS has an active program of education and outreach, which includes volunteers and staff (Team OCEAN) who provide boaters with information at sea.

Seven reefs dominated by *Acropora cervicornis* occur in nearshore waters off Fort Lauderdale. These reefs are being closely monitored, but have not been provided with particular protective measures.

2. U.S. Virgin Islands

Virgin Islands Coral Reef National Monument (VICR) was recently created and Buck Island Reef National Monument (BUIS) was recently expanded by the designation of thousands of acres of non-extractive zones (2000 Executive Order). These new and expanded National Monument designations afford total protection to 7% of the St. Croix shelf and 3% of the St. John/St. Thomas shelf. In December, 2002, the Virgin Islands Legislature passed Bill 12 approving establishment of the St. Croix East End Marine Park.

A program of mooring buoys managed by the National Park Service, non-governmental organizations (NGOs), and private dive operations provides additional protection from anchor damage to coral reef ecosystems including seagrass beds. In addition, a vessel management plan regulates numbers of vessels and uses allowed in Virgin Islands National Park (VIIS) waters. Thirteen Areas of Particular Concern, mostly including marine environments (particularly St. Croix coral reefs), are part of a Territorial zoning plan that theoretically should manage development to be environmentally sustainable.

The St. Croix petroleum refinery has an oil spill response team involving resource managers to help guide appropriate response strategies. Environmental Sensitivity Index maps (NOAA/U.S. Coast Guard) delineate coral reefs and other sensitive habitats and resources that could be impacted by an oil spill.

The Coastal Barrier Resource Act identifies sensitive areas such as coral reefs. There are 30 sites in the USVI that are designated as federal coastal barriers. This designation provides protection from development with federal funding or requiring federal action.

3. Puerto Rico

In Puerto Rico there exist several laws and proposed regulations that may aid in the conservation of corals. The most pertinent statute is the Law for the Protection, Conservation, and Management of Coral Reefs in Puerto Rico, Law 147. This law explicitly mandates the conservation and management of coral reefs in order to protect their functions and values. The Department of Natural and Environmental Resources (DNER), the agency in charge of implementing the law, will do so through a regulation that is currently being prepared. Law 147 provides for the creation of zoned areas in order to mitigate impacts from human activities. These zones include (1) Reef Recuperation Areas and (2) Ecologically Sensitive Areas. These zones will facilitate the DNER in controlling human activity that can directly impact *Acropora* spp. such as anchoring. Law 147 also directs the DNER to identify and mitigate threats to coral reefs from degraded water quality due to pollution. Law 147 will also require an Environmental Impact Statements (EIS) for projects or activities that can negatively affect coral reefs.

DNER is currently developing regulations to begin implementing Law 147. An interagency committee will be convened to coordinate government activities that may affect coral reefs.

Law 137 from 2000 directs the DNER to designate priority areas as marine reserves, including a minimum of 3 percent of the insular platform within 3 years (2003). Marine reserves are defined as areas where all extractive activities are prohibited in order to help recover depleted fishery resources and protect biodiversity, and can protect *Acropora* by preventing impacts from fishery gear. To date, two marine reserves, Reserva Natural Canal Luis Peña in Culebra, and Desecheo Island have been established.

There are also currently 13 natural reserves in Puerto Rico that have coral reefs within their boundaries. These are managed by the Puerto Rico Department of Natural and Environmental Resources (DNER). The Reserves are located on all coasts and offshore islands and provide an infrastructure for management measures to protect *Acropora* spp. populations. The DNER has been utilizing mooring buoys since 1990, principally in the Natural Reserves in Fajardo, Culebra, Guánica, and La Parguera. More information is needed on the location and status of *Acropora* spp. populations within the natural reserves in order to apply the conservation strategies, particularly those pertaining to direct impacts. It should be noted that natural reserves probably have minimal success in preventing impacts to coral reefs and *Acropora* spp. from degraded water quality because these impacts are not excluded by reserve boundaries.

Resolution: ***A variety of protected areas exist in Florida, USVI and Puerto Rico, including National Monuments, Sanctuaries, Reserves, and Wildlife Refuges. These and other areas are typically zoned for specific or multiple uses and often include no-take areas and offer various protective measures such as a prohibition on extractive activities. However, in general, they encompass a relatively small portion of the total Acropora habitat, they offer limited protection from various environmental impacts such as degraded water quality, and enforcement may be limited or lacking.***

3. Proposed New Initiatives for U.S. Reefs to Enhance Protection of Coral Reef Resources

While the nature and magnitude of human impacts to coral reefs vary among reefs and jurisdictions, many of the underlying activities are authorized and regulated under law and can be managed or mitigated using existing federal and state authorities, with programs tailored to local needs. Through the U.S. Coral Reef Task Force, federal and state agencies have agreed to pursue a comprehensive program focused on nine conservation strategies designed to reduce or eliminate the most significant threats to coral reefs. These include: 1) expansion and strengthening of marine protected areas; 2) reduction of impacts from extraction; 3) reduction of habitat destruction; 4) reduction of marine and land-based pollutants; 5) restoration for damaged reefs; 6) reduction of global threats; 7) reduction of impacts from international trade; 8) improved interagency accountability and coordination; and 9) expanded education and outreach for the public.

Many of the chief threats to coral reefs stem from human activities taking place on or near specific reef tracts. One of the most promising conservation tools to address these are marine protected areas that encompass and protect important habitats where harmful activities can be minimized through a system of marine zoning. Among the various types of MPAs, ecological reserves, or no-take zones, are particularly effective in maintaining biodiversity, productivity and ecological integrity, and for *Acropora* habitats may be most useful in protecting these corals from damage associated with particular types of fishing gear, anchoring and other physical stressors. Although a number of MPAs currently exist, there are multiple problems associated with these, including: 1) considerable gaps in coverage; 2) gaps in protection within existing sites; 3) limited degree of connection among protected areas; 4) designation and management under multiple jurisdictions (state, federal, territorial, local jurisdictions) with differences in purpose, scope and authority under each jurisdiction; 5) limited international cooperation; and 6) lack of consistent definitions to describe various levels of protection.

The U.S. Coral Reef Task Force has proposed a critical marine conservation goal for MPAs in the U.S. that includes 1) strengthening of protection within existing MPAs; 2) establishment of additional no-take ecological reserves with a goal of 20% of all representative U.S. coral reefs and associated habitats by 2010; 3) a national assessment of the remaining gaps in coverage; and 4) strengthened support for international cooperation to conserve global biodiversity.

Among U.S. Jurisdictions, proposals to strengthen existing MPA structure and develop new MPAs include:

1. Dry Tortugas National Park

The Park has proposed to implement a Research Natural Area (marine reserve) that would cover an area of approximately 158 km^2, including significant shallow coral reef environments.

2. U.S. Virgin Islands

The creation of the Virgin Islands Coral Reef National Monument (VICR) and the enlargement of Buck Island Reef National Monument are very significant for coral reef and associated habitat protection. Both monuments are awaiting a final review by the Government Accounting Office (Congress) before management actions can be implemented. VIIS will be developing a new General Management Plan in 2003, which will implement additional coral reef protection measures. VICR is also proposing to install a hurricane mooring system in Hurricane Hole that will protect the mangrove and coral communities from vessels using this area as a storm refuge.

The Territorial government is moving forward on the establishment of the East End Marine Park in St. Croix. This park will contain several no-take zones and coral resources in all zones will be protected.

There are a number of other marine reserves in the USVI that are basically “paper parks” because of lack of enforcement. Steps to take include educating residents and visitors, enforcing regulations, and employing more enforcement officers.

3. Puerto Rico

Law 137 from 2000 directs the Puerto Rico DNER to designate priority areas as marine reserves. Marine reserves are defined in this statute as areas where all extractive activities are prohibited in order to help recover depleted fishery resources and protect biodiversity. The law states that that three percent of the insular platform must be designated within 3 years (2003). This mechanism could be helpful in the conservation of *Acropora* spp. if it is determined that overfishing of coral reefs that is affecting survivorship of these corals. It has been hypothesized that overfishing of reef fish, octopus, and lobster may lead to an increased abundance of *Acropora* spp. predators such as the snail *Coralliophila abbreviata*. Currently there are two marine reserves in Puerto Rico, Reserva Natural Canal Luis Peña in Culebra and Desecheo Island. However, these two reserves only protect a very small percentage of the *Acropora* spp. populations in Puerto Rico.

Resolution: ***Over the last five years Florida, USVI, and Puerto Rico have made major conservation advances through the establishment of various types of marine reserves and proposals for new marine protected areas. Many of these have been established in coordination with initiatives to address habitat destruction through limitations on the use of destructive fishing gear, installation of mooring buoys and navigational aids, no anchoring zones, improved wastewater treatment, and other measures.***

4. Additional Measures Needed on a Local and National Scale

A. Strategies to address overfishing and fishery gear impacts

Strategies to address overfishing in coral reef ecosystems are necessary to mitigate problems associated with macroalgae abundance and cover, growing populations of corallivores, and other problems. Overfishing of herbivorous parrotfish and surgeonfish has contributed to increases in macroalgae, which may overgrow stony corals and can lead to reduced potential for recruitment of planula larvae. Also, removal of certain predatory fish such as groupers may contribute to an increase in three spot damselfish populations, which can further contribute to the loss of *Acropora* through the creation of algal gardens. Overfishing of a number of other invertebrate and fish species, such as lobsters, octopus, trunkfish and hogfish, may result in greater numbers of coral eating snails, and increased mortality to *Acropora*.

1. Florida

There needs to be considerable thought and discussion about reductions in fishing effort, such as a program to invest in reducing fishing fleets.

Further programs of outreach and education could be developed to better inform the public and decision-makers about how overfishing affects the condition of coral reefs and steps they can take to help improve the protection and conservation of coral reef ecosystems. We need to be more effective at communicating how marine reserves protect populations and habitats.

Penalties could be made more severe and additional resources could be directed toward enforcement. Penalty structures could be modified to include the rescinding of fishing permits and/or the confiscation of gear and vessels.

More marine reserves could be designed, discussed, and implemented, and the size of existing reserves could be increased. Communities and residents should take more of a “stewardship” approach to local waters and the resources they contain.

2. U.S. Virgin Islands

Overfishing is a large concern. It is necessary to enforce existing regulations, eliminate fishing in protected areas, protect spawning sites, and protect nursery habitats.

Losses of mangrove habitat exacerbate problems associated with overfishing. There is a pressing need to protect mangroves, which are already a protected species under VI law; control water quality in mangrove areas; re-site or replace aging sewage treatment systems; and enforce the use of vessel pump-out facilities and provide additional facilities.

3. Puerto Rico

There is widespread recognition of overfishing within Puerto Rico's nearshore coastal communities, especially among coral reefs. The concerns extend to both recreational fisheries and commercial fisheries, and also among certain types of destructive fishing gear (traps and gill nets). In addition, local fishers target lobsters and octopus in shallow water, often wading through and damaging *Acropora* habitat in the process of collection. A number of reef fishes and invertebrates that may be important in controlling corallivorous molluscs are presently overexploited, including lobster, octopus, trunkfish, hogfish and other species .

Puerto Rico, through DNER, has developed a new coral reef fisheries law and is currently developing regulations (Reglamento de Pesca de Puerto Rico). These will establish a variety of new measures, including restrictions on gear types, locations of fishing areas (and areas closed to fishing), permits for harvest, sizes, seasons and/or quotas for the harvest of commercially important species, and provisions for licensing. If adopted, these regulations will also prohibit spearfishing.

Resolution: ***Coral reefs and associated habitats provide fishery resources that represent a critical source of food, but increased rates of collection and associated habitat destruction are threatening the regenerative capacity of of these species and critical linkages among species and in some cases are contributing to phase shifts. A number of management initiatives have been proposed including improved monitoring and protection for fishery resources; greater habitat protection through establishment of no-take MPAs and other efforts; measures to protect spawning populations; elimination of destructive fishing practices and gears; implementation of gear restrictions; and incorporation of ecosystem-scale considerations in Fishery Management Plans.***

B. Diseases and predation

Although white-band disease, white pox, and other syndromes are recognized as important sources of mortality to elkhorn and staghorn coral, scientists and managers have very little information on the epizootiology and etiology of these diseases. Greater emphasis needs to be placed on 1) field monitoring programs to determine the temporal and spatial distribution, abundance and impact, and synergistic effects of other natural and anthropogenic stressors; and 2) laboratory studies to determine causative agents, role of other stressors in the proliferation and spread of these diseases, and host response. With this information, scientists and managers can begin to work toward the development of strategies to mitigate diseases, possibly by treating diseased colonies, addressing water quality issues and managing possible vectors for disease transmission. In addition, efforts are needed to determine whether there are disease resistant clones.

The recognition of significant predation by invertebrates and fishes has been acknowledged for Caribbean Acroporids primarily when coral prey abundance was diminished by other factors, and possibly in response to increased densities of predators. We need further research on corallivores such as *Coralliophila* and *Hermodice* and on the damaging effects of *Stegastes planifrons* algal-gardening behavior. Research is needed to help determine the efficacy of programs of *Coralliophila* and *Stegastes planifrons* control. In particular, managers need more information about the predators of these three species and other possible mechanisms for population controls. Small-scale corallivorous snail removal in remnant *Acropora palmata* populations undertaken in the Florida Keys was effective in preserving live tissue, but it is unclear whether this is an effective management strategy at a larger scale and the ramifications of such a manipulation in a complex coral reef community remain unknown.

Management strategies should include training programs to heighten awareness and alert resource managers of infestations and acute changes in reef communities. Any such efforts should be conducted as step-wise approaches in a plan for ecosystem restoration: action, result, and end product.

Resolution: ***Coral diseases and coral predators need far more study. Managers need to know the causes of diseases affecting Acroporids, how diseases are transmitted, and any actions that can be taken to reduce their negative impacts on Acropora populations. Efforts should be made to determine the degree of disease resistance that exists among clones and genetic mechanisms for resistance. Research is also needed to determine the efficacy of programs to control pest species such as Coralliophila abbreviata and Stegastes planifrons***

C. Pollution and sedimentation

Excessive sedimentation generated by coastal development, agriculture and dredging, increased nutrients from agriculture, sewage discharge and fertilizers, and discharge of oils and chemicals disrupt normal biological and ecological processes, kill benthic invertebrates, and artificially encourage growth of macroalgae. Acroporids are particularly sensitive to poor water quality, as they have a poorly developed mechanism to remove sediment from their branch surfaces and they require high light levels for photosynthesis.

1. Florida

There need to be increased non-point source pollution controls to reduce or eliminate upland sediment impacts to nearshore coral reefs, e.g., pave roads, construct sediment catchment basins, and utilize proper site drainage.

Given the recent designation of State waters as a no-discharge zone, expansion of this designation to include Federal waters (40% of the Sanctuary) has been proposed. Sanctuary staff are developing steps to protect and culture fragments of *Acropora* spp. rescued from boat-grounding sites and other damaged areas. They are exploring partnerships for the rehabilitation of coral fragments for future use in reef restoration projects. The Florida Keys has a Wastewater Treatment Master Plan that comprehensively defines future needs for treatment systems. This plan is being implemented, and a test project in one municipality will generate data on changes in nearshore water quality that result from the conversion from on-site sewage disposal systems (e.g., septic tanks and cess pits)to centralized treatment facilities.

2. Puerto Rico

Sedimentation and pollution are of growing concern to Puerto Rico's nearshore reefs. Law 147 directs the DNER to identify and mitigate threats to coral reefs from degraded water quality due to pollution.

Resolution: ***Pollution and sedimentation could be signficantly reduced by fully implementing existing authorities among various federal, state and territorial agencies, but this will require greater efforts to monitor existing water quality, expanded studies to determine the ecological relevance of various pollutants, and improved permitting mechanisms for development projects that affect coral reefs. Local partnerships among governments, land owners, industry and the public are necessary to implement measures to reduce land-based runoff and prevent discharge from known point sources.***

D. Reduce physical impacts to coral populations from anchoring and ship groundings

1. Florida

In 1997, NOAA designated Tortugas Bank as a no-anchoring zone for ships at least 50 meters long, however, foreign-flagged ships carrying international (non-NOAA) charts did not show this zone. In May 2002, the International Maritime Organization adopted a proposal to designate areas around the Florida Keys as a Particularly Sensitive Sea Area (PSSA). As one of the only PSSA's in the world, this designation (effective Dec.1 2002) will increase compliance with no anchoring and reduce the threat of groundings and spills.

Using vessel-grounding data from the Florida Keys National Marine Sanctuary, the U.S. Coast Guard installed new markers at a hard-hit shallow reef historically dominated by *Acropora palmata*.

E. Captive breeding programs and coral restoration approaches to rebuild *Acropora* populations

Captive breeding is a possible approach toward helping to rebuild *Acropora* populations. Aquarists have developed techniques to successfully maintain and propagate scleractinian corals in closed systems, and Acroporids are particularly amenable to culturing in grow-out systems placed on the sea floor. Some of the major concerns, that need to be evaluated from a management perspective, include sources of fragments for grow-out, impact of culturing on genetic diversity, and possibility of reestablishing Acroporid populations in degraded areas using cultured branches and colonies.

It is necessary to improve response and success of vessel grounding restoration projects through development of standard assessment procedures, notification protocols, and restoration approaches. Base resources should be available to respond and react to catastrophic injuries. Volunteer programs can provide assistance in the rescue, re-stabilization, and monitoring of injured coral colonies.

Restoration projects should be conducted using a hypothesis driven scientific approach whenever possible. Coral restoration is a relatively new approach to ecosystem management and is still in its infancy in regards to methods and strategies. We have much to learn about the best methods and substrata for reattachment of fragments produced by groundings, storms, and other events. For *Acropora*, a variety of approaches to stabilize fragments have been undertaken, ranging from reattachment using cement, epoxy, wire, and cable ties, however, cost and benefits of these approaches has not been evaluated. Development of successful methods should be done through designed experimental approaches that will allow for better decision making and project design.

Restoration projects should be monitored in ways to help inform management actions. Numerous restoration projects have been undertaken and can provide valuable information through long-term monitoring efforts, yet the outcome of these efforts is rarely reported. Monitoring projects should be designed to answer fundamental questions about the project's success as a function of the ecosystem as a whole.

1. Florida

Several restorations in response to ship groundings have been undertaken in Florida, including groundings within *Acropora* habitat. To date, three of these have involved stabilization and reattachment of branches/ colonies. A small-scale effort involving *A. palmata* was undertaken by the FKNMS in collaboration with Reef Relief, in which storm-generated *Acropora* branches were attached to cement rosettes placed in shallow water. Fragments generated by storms and from ship groundings are also being cultured by various laboratories, including Mote Marine Laboratory and the Florida Aquarium in Tampa.

2. Puerto Rico

A biological restoration following the grounding of the Fortuna Reefer vessel was undertaken off the east coast of Mona Island in 1997. A total of 1857 *A. palmata* branches were secured to reef substrate and to dead, standing *A. palmata* skeletons using stainless steel wire. In 2000, a mid course correction was undertaken, where surviving fragments were re-wired with heavy stainless wire and a small subset were also secured using cement. NOAA Fisheries has been monitoring the success of this effort.

In southwest Puerto Rico, a small NGO formed by University of Puerto Rico graduate students is propagating *A. cervicornis* fragments by attaching small branches to wire racks and growing these out in shallow reef sites. Fragments are collected from different reefs and reef zones, in attempt to maximize genetic and environmental variation. Pilot studies have been highly successful with high survivorship, rapid growth rates, and the enhancement of localized fish populations through creation of high relief substrate in non-coral areas. However, additional research and small-scale projects are needed to help determine whether this approach can be utilized on a large-enough scale to be of use to managers.

3. U.S. Virgin Islands

A small coral transplant project utilizing *Acropora palmata* and *A. cervicornis* is underway in the Virgin Islands National Park. The researchers are using cable ties to fasten naturally-occurring fragments of three fast growing species of coral to damaged reefs.

Resolution: ***Coral mariculture and aquaculture and other propagation techniques, along with transplantation, and reattachment of dislodged Acropora fragments, may provide a feasible strategy to rebuild degraded Acropora populations. These efforts may be especially useful in areas for which natural recovery is unlikely (due to an absence of parent colonies or sexual recruits), and on a small scale to speed up recovery following a ship grounding. However, care must be taken to ensure that source coral populations are not degraded, genetic diversity is maintained, and potential introductions of pathogens or other invasives are avoided. In addition, restoration efforts should not be undertaken unless the source of the threat has been identified and addressed. Because we know very little about appropriate restoration strategies and potential long-term benefits, all restoration efforts should be undertaken using an experimental approach that includes measures to evaluate the success.***

5. Evaluation of Management Measures Outside U.S. Waters

Any efforts to protect Acroporid coral populations in the U.S. would benefit from measures adopted in other countries, as coral populations are likely to be linked through sexual reproduction and dispersal of planula larvae. Measures proposed or existing in U.S. waters, including MPAs, Fishery Management Plans, and improved Coastal Zone Management strategies, also need to be implemented outside of the U.S. Also, new information on approaches to understand and address various stressors and enhance recovery of coral populations through propagation, transplantation and other ecological and biological restoration approaches should be shared with other countries.

Through a brief evaluation of existing measures outside of U.S. waters, protected areas were recognized as one of the key areas of emphasis; many countries have established MPAs, but these vary in scope, size and success. Also, a variety of fishery management strategies have been adopted, but there is a general consensus that greater emphasis needs to be placed on sustainable management of commercially important food fish and ornamental species. Perhaps one of the most widespread initiatives, most countries have implemented a system of mooring buoys to reduce anchor damage.

A number of limitations with existing management mechanisms were identified. Most importantly, in many cases management plans have been developed but not implemented; habitat destruction is occurring as a result of harmful fishing gears, dredging, and removal of mangroves; existing regulations are insufficient and protected areas are offered very limited protection due to a lack of enforcement capabilities; and strategies to address water quality need to be improved. Finally, it was noted that the agencies that have authority to address the most critical needs for *Acropora* often involve different branches of the government, and more cooperation between various regulatory agencies is critical .

Resolution: ***A number of countries have taken key steps to protect coral reef ecosystems within their waters through the development of MPAs, implementation of Fishery Management Plans, and development of strategies to address water quality issues. However, these efforts need to be greatly expanded on a local to regional scale and substantial new initiatives are necessary. There is a need for improved sharing of information and technical assistance from the U.S.; greater efforts to educate the public and user groups regarding the importance of coral reef ecosystems, threats, and solutions; and better cooperation among different government agencies, non-government organizations, industry and the public.***

6. Regional and Global Initiatives

A. Regional organizations

Regional organizations exist such as CaMPAM, a network for MPA managers in the Caribbean region. However, groups such as this generally lack funding and leadership. There is a need to get upper management of local conservation efforts more engaged in such regional-scale programs.

1. Coastal and Marine Productivity Networks (CARICOMP) and Atlantic and Gulf Rapid Reef Assessment (AGRRA)

CARICOMP and AGRRA have been contributing to a better understanding of the status of Caribbean Acroporids through their monitoring programs. Through their efforts we have been able to get recent information from close to half of all Caribbean nations. These efforts should be supported and expanded to enhance collection of data on the status and trends of these corals from throughout their range.

2. Specially Protected Areas and Wildlife in the Wider Caribbean Region (SPAW) protocol

The SPAW Programme supports activities for the protection and management of sensitive and highly valuable natural marine resources. This program is responsible for the regionalization of global conventions and initiatives such as the Convention on Biological Diversity (CBD), the International Coral Reef Initiative (ICRI), and the Global Coral Reef Monitoring Network (GCRMN). The goals include efforts to: 1) significantly increase the number of and improve the management of national protected areas and species in the region, including the development of biosphere reserves, where appropriate; 2) to develop a strong regional capability for the coordination of information exchange, training and technical assistance in support of national biodiversity conservation efforts; 3) to develop specific regional, as well as national management plans for endangered, threatened or vulnerable species; and 4) to coordinate the development and implementation of the Regional Programme for Specially Protected Areas and Wildlife in the Wider Caribbean, in keeping with the mandate of the SPAW Protocol.

B. International Protection

1. CITES

All stony corals are currently listed on Appendix II of the Convention on the International Trade in Endangered Species (CITES). This listing is designed to prevent the overexploitation of stony corals as a result of international trade by requiring that exporting countries issue permits for the trade in corals. These permits must include a finding that the species in trade was legally acquired and the trade in that species is not detrimental to the survival of the species in the wild. This listing does not offer protection for corals that are in domestic commerce.

2. International Maritime Organization

The delicate coral reefs along the Florida Keys have become the first internationally protected nautical zone in the United States. The 2,900-square-nautical-mile zone is designed to protect fragile coral from anchors, groundings and collisions from large international ships. The zone stretches from Biscayne National Park to the Dry Tortugas and encompasses all of the 2,500-square-nautical-mile Florida Keys National Marine Sanctuary. Future nautical charts are expected to show the zone , known as the " Florida Keys' Particularly Sensitive Sea Area".

Resolution: ***Several regional and international fora, including CaMPAM, SPAW, ICRI, GCRMN, CITES, AGRRA and CARICOMP are available to assist in the regional and international protection of Acroporid corals through improved management, monitoring, and conservation. However, there are various limitations with several of these initiatives, such as funding and leadership problems, a capability to adopt measures that address important concerns but not necessary the most critical concerns for these species, or limited public, government and/ or industry support.***

7. Potential Benefits and Drawbacks of ESA Listing

Threats to Acroporid corals pose difficult management problems that are currently addressed through a patchwork of federal, state and territorial regulatory and management programs. The most important programs involve managing state and federal parks, marine sanctuaries, commercial fisheries, offshore mineral development, and coastal zone development. In most cases, these efforts have been developed independently of one another, and they reflect strategies to protect certain areas, to conserve certain species or to provide broad protection. While existing programs provide meaningful and necessary protection, these programs have offered very limited protection for Acroporids, they have not always addressed management needs from an ecosystem perspective, and they have not adequately addressed priority conservation issues for these species.

A. Potential benefits of ESA listing include:

The ESA provides a means for conserving species that are threatened or in danger of extinction, and for the conservation of the habitats upon which those species depend. Once listed, the ESA mandates implementation of a recovery program capable of restoring a species in its natural habitat to a level at which it can sustain itself without further legal protection. The goals of the recovery program are to 1) identify the ecosystems and organisms that face the highest degree of threat; 2) determine actions necessary to reduce or eliminate the threats; and 3) implement strategies to recover the species.

Threatened species designation for *A. palmata* and *A. cervicornis* would result in a population-by-population approach to protection through critical habitat designations, with stronger penalty structures. Critical habitat designations could in turn be used to help improve water quality through a ridge-to-reef approach to improved coastal zone management, e.g., protection of mangrove, seagrass, and coral reef habitats.

Some other specific benefits of an ESA listing include:

- Critical habitat designation – protection and enforcement for areas occupied by *Acropora* as well as habitats essential to the survival of these species (e.g., associated mangroves and sea grass beds).

- Captive breeding through implementation of a recovery plan - scientific efforts to understand and improve mariculture, transplantation and other restoration approaches may be supported as a key strategy to rebuild populations.

- Increased attention and awareness – an ESA listing would focus attention on coral reefs, specifically Acroporid corals, raising awareness among public, legislators, and other public officials.

- Increased research funding- through development of a recovery plan one of the goals may be support for targeted research leading to an improved understanding of *Acropora* biology.

- Increased protection for all coral reef species - by protecting declining coral species such as *A. cervicornis* and *A. palmata* through the ESA, other species assemblages dependent on reefs will also benefit.

- Reduce impacts to *Acropora* habitats from development or dredging - Prevents projects funded, authorized or carried out by the Federal government if those activities would contribute to the degradation of habitat occupied by the species.

- Copy-cat effect- through an ESA listing, greater recognition may be raised for the protection of other key invertebrate species that are also declining.

B. Potential drawbacks of an ESA listing include:

- Enforcement of incidental damage would be difficult
- Additional steps for researchers to obtain permits
- Draws more attention to species
- Section 7 consultative requirements for any impacts
- Difficulty of defining "take"
- Captive breeding/aquaculture

7. Implications of Not Taking Additional Steps

There are numerous strategies that are needed to protect coral reef ecosystems and many of these can be implemented under existing authorities. However, no single mechanism is likely to be sufficient to halt the decline of these corals and enhance their recovery. It is likely that managers will have to apply all of their tools to ensure recovery of these species, including application of the ESA. An ESA listing as threatened or endangered would require the development and implementation of a recovery plan thereby reducing the likelihood of extinction by alleviating threats affecting these species and promoting strategies to increase population size.

Acropora palmata and *A. cervicornis* are the fastest growing framework-building corals in the Caribbean. Their demise over the past 10-20 years likely has resulted in reef erosion rates that exceed accretion. This, in turn, can lead to:

- Loss of shoreline protection
- Habitat and biodiversity loss
- Declining tourism as reefs lose structure and associated animals

Another implication of not taking additional steps for *Acropora* is that we may soon be faced with the next group of species that are rapidly declining from similar threats– *Montastraea* – the second-most important genus that has built Caribbean reefs for the past million years.

Resolution: ***An ESA listing would provide additional necessary conservation mechanisms, above and beyond the existing tools available to resource managers, to protect and restore these species while providing added benefits for associated species; it would provide for increased recognition and awareness of coral reefs, their importance and their vulnerable condition; and it would enhance our ability to fill information gaps through support for targeted research and monitoring. An ESA listing would also add additional burdens and costs for increased management, enforcement and permitting of activities. No single mechanism is likely to be sufficient to halt the decline of these corals and enhance their recovery. It is likely that managers will have to apply all of their tools to ensure recovery of these species, including application of the ESA.***

8. Additional Information Needs of Resource Managers

There is a critical need for standardization of collection, interpretation, and presentation of information. This standardization is necessary for direct comparisons of information from different sites, particularly ecological data.

A. Settlement and recruitment of Acropora

Resource managers need a better understanding of factors determining successful settlement and recruitment of *Acropora*. It is fairly well established that an intermediate level of grazing by *Diadema* results in higherdensities of coral spat, and it would be helpful to determine whether this is the case for *Acropora*. Ongoing research by Drs. Alina Szmant and Margaret Miller may help answer this question. Research by Dr. Bob Steneck has showed that a particular species of coralline red algae attracts a number of different coral spat in the Indo-Pacific. This alga occurs in the Caribbean, but we do not know whether this same effect occurs generally and for *Acropora* in particular.

B. Genetic linkages of populations

Metapopulation genetics of *Acropora* is a final topic in need of further research. There is an ongoing study of *A. palmata* in the Florida Keys and this is an area that recently has gained far more attention by scientists.

Report from the Information Needs Working Group

Compiled by John McManus
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INTRODUCTION

The goal of this working group was to make recommendations on how information needs can be met in support of recovery efforts and effective management of the corals *Acropora palmata* and *Acropora cervicornis*. These recommendations focus on the need to identify and quantify critical habitat, to quantify the current and historical extents of these species, to identify changes that have occurred over time in biological and geological time frames, and to determine the stability of their populations and the factors that influence this stability. Specific questions are addressed within four topical areas: A) remote sensing, aerial photography and geographic information systems (GIS); B) historical/geological questions and studies; C) strategies to enhance recovery; and D) research and monitoring needs.

1. Remote Sensing, Aerial Photography, and Geographic Information Systems (GIS).

A. *What types of information can we get on critical habitat, historical distribution and extent of Acroporid populations, and on the nature of their declines?*

We are concerned with critical habitat in several senses. First, we must identify and map the habitats that currently include living *Acropora*, and those that have done so in the recent past. It is likely that these will include most of the area that can potentially be colonized by *Acropora*. Further, in case one or more species of Caribbean *Acropora* are to be included on the U.S. Endangered Species Act, the capacity must exist for people to identify key areas of current *Acropora* growth, and to identify associated habitats on land and sea, that provide critical ecological links (adjacent forested watersheds, salt ponds, mangrove and sea grass communities, etc.), whose protection would be essential in conserving those key coral reefs.

In all cases, we need to gather together existing maps of current and historical *Acropora* distributions, as well as maps with a broad range of information from which potential *Acropora* habitats can be inferred, including maps of bathymetry, water quality, physical oceanography, and substrate type. These should be made available within a GIS system in order to facilitate quantitative inferences and overlay analysis as well as to provide access to the information to a wide audience. Local experts should be consulted, and data added from the presentations of the workshop participants and other sources to facilitate the inference process. Where feasible, layers should be incorporated into the GIS representing *Acropora* distributions as reported over time.

In light of the temporal and logistical constraints imposed, to assist with the process of identifying existing *Acropora* habitats, researchers will need to use existing aerial photography in conjunction with existing and new ground truth data. The availability of aerial photographs is very patchy throughout the region. There are some areas in which coral reefs have been mapped with multi- and hyperspectral data from air borne sensors, particularly in U.S. waters. In some areas of the Caribbean, very little mapping of coral reefs exists. For such areas, satellite mapping may be helpful. However, this would best be undertaken by groups that are already engaged in broad area reef mapping work, as experience at that scale is crucial in accurate data interpretation. In all cases, canvassing of local experts can be used to minimize the need for detailed ground-truthing and to provide supplemental information.

Resolution: ***There is a need to compile existing maps, historical and current aerial photographs, bathymetric information, airborne sensor data, and other types of information showing existing and potential Acropora habitats and associated terrestrial and marine habitats essential to the conservation of Acroporids. These data should be incorporated into a GIS database to delineate critical habitat and design appropriate conservation strategies to protect these areas. While a good deal of recent information is available from U.S. locations, there is a need for ground truthing of maps and improved resolution of maps as well as a need for expanded mapping efforts in non-U.S. locations.***

B. *What are the comparative advantages and limitations of the sensor-based mapping tools currently available?*

The major options for sensor-based reef mapping currently are satellite data, aerial photographs, airborne multi- and hyperspectral data, and acoustic data from watercraft. Additionally, airborne laser systems such as LIDAR can be used to provide high-resolution bathymetric information which, when used with other airborne sensor data, can provide extremely useful information on the distribution of ecological communities associated with coral reefs. The LIDAR and hyperspectral options are expensive in terms of initial investment. However, they are ultimately cost effective in terms of the wide range of purposes to which the data can be put to support effective reef management and conservation. We note, however, that none of the options can thus far reliably distinguish among species of coral in any but exceptional circumstances. The uses and limitations of each approach are listed below:

- Satellite
    - Poor resolution
    - Requires heavy ground-truthing
    - In U.S. waters and sporadically elsewhere
    - Gross area determination
- Aerial photos
    - Higher resolution
    - Intermediate ground-truthing
    - Require geometric correction
    - Require expensive processing and specific expertise
    - Most commonly used
    - Finer scale than satellites
- Multi- and Hyperspectral Airborne
    - Needs significant ground-truthing
    - Primarily used in US waters
- Lidar
    - Provides primarily depth information.
    - Best used in conjunction with other airborne data.
- Acoustic Mapping
    - Can establish coral presence/absence
    - Still in development

Resolution: ***While sensor-based reef mapping technologies can provide high resolution information on the distribution of ecological communities, current technology does not provide a reliable tool to distinguish among species of corals or condition (live, dead or diseased or bleached colonies). Thus, the use of sensor-based mapping tools must be combined with underwater visual, video, and photographic monitoring and assessment.***

2. Historical/Geological Questions and Studies

A. *How have populations of these corals changed over the last 10,000 years?*

Ecological observations suggest *Acropora* populations fluctuate on small scales of time and space. Location-specific cores and outcrops have revealed no evidence of population declines similar to that currently underway in at least the last 2500 years (late Holocene), at least in those sites. However, in parts of Florida and the USVI it appears that there have been gaps in the record. For instance, limited coring off Buck Island USVI suggests that the reef community was dominated by *Acropora palmata* over the last 7000 years, but it disappears from the reef system 3000 ybp and then reestablishes after nearly a 1000 year hiatus. There are suggestions that this is part of a regional pattern that is not explained by sea level changes or local oceanographic conditions. The occurrence of this event argues for a regional cause, such as a widespread outbreak of disease, yet this cannot be confirmed at this time.

Previous interruptions in growth were followed by recovery. However, this does not imply that we can necessarily expect recovery from the current population decline, because anthropogenic stresses are currently exacerbating the problem.

Resolution: ***There is a need for larger, regional scale coring programs to compile a long-term record and compare this to present day changes.***

B. *How well can we identify the causative agents for declines in the populations of Acropora?*

Plausible scenarios for some past, localized interruptions in *Acropora* growth can be inferred from considerations of local changes in sea level and antecedent topography. In other cases, the cause cannot be easily identified from those considerations. Further research on present day *Acropora* populations might potentially provide a basis for determining causes of past declines in their populations from evidence preserved in the geochemistry or in the composition and nature of the fossil assemblage. It is imperative to improve our understanding of the nature of the recent declines in *Acropora* populations throughout the Caribbean (white-band disease, predation by mobile fauna, hyper and hypo-thermic stress, land based sources of pollution, and others including interactions of natural and human induced stresses). In particular, we need to have a better understanding of the causes, mechanisms, and epizootiology of coral disease.

Resolution: ***We need to improve our understanding of the nature of recent regional declines in Acropora populations, and whether evidence for causes of past declines are preserved in the geochemistry of Acropora fossils to determine whether the observed decline is part of a natural cyclical process for which natural recovery is likely, or whether anthropogenic stressors have exacerbated these processes and may inhibit recovery.***

C. *What is the extent of existing geological information on Acropora and what should be recommended for further research?*

Current geological information relevant to *Acropora* is mostly location-specific. A complete geological picture of past occurrences would require core and outcrop sampling of Holocene deposits throughout its range at multiple spatial scales; these samples should be dated at a high resolution.

3. Strategies to Enhance Recovery

A. *What are the practical issues involved in the restoration of Acropora populations, including the potential usefulness of propagation and transplantation?*

The goals of mitigation or restoration must be established (e.g., how much should Acroporid cover be increased?) prior to any action. Eliminating or reducing the known anthropogenic causes of declines (including sedimentation, pollution, eutrophication, global warming, over fishing, ship groundings, etc.) is a prerequisite to restoration. Similarly, a greater understanding of causes and consequences of coral disease (white-band, white pox, and other emerging disease) is essential.

Resolution: ***Reef restoration at any scale will have, at best, very limited success unless the causes of decline are understood and action is taken to reduce these threats.***

Transplantation and propagation could enhance populations or limit further declines in small scales (e.g., ship grounding scars) due to the importance of fragmentation as a means of reproduction in *Acropora* species. However, it is important to avoid reducing natural genetic variability and altering the degree of local adaptation in subpopulations. Thus, we need information on the genetic structure of *Acropora* subpopulations and maps of previous distributions. This information should be used in selecting colonies for transplantation and in developing propagation programs. There is a high cost associated with applying these methods at large scales. These costs should be weighed against potential benefits, probability of long-term success, and other management options. Because of the complexity of reef ecology, there will always be a high level of uncertainty involved in any such management interventions. Any restoration options necessitate an adaptive management approach, with the understanding that each intervention is to be treated as an experiment and the intervention adjusted over time in response to periodic evaluations of the success or failure.

Resolution: ***Transplantation and propagation of Acropora colonies is a viable tool to enhance recovery at local scales, but considerations such as appropriate selection of colonies and fragments, the potential effects on genetic structure of populations, and the potential benefits must be weighed against the probability of natural recovery, other management interventions, and likelihood of long-term success.***

B. What is the potential usefulness of enhancing sexual reproduction and recruitment in Acropora?

Improving sexual reproduction and the recruitment of sexually produced planulae would require a greater understanding of the biology of *Acropora* species, with emphasis on the factors involved in determining the natural balance between asexual and sexual reproduction, and the cues involved in the settlement of planulae. More work is needed on demographic modeling to predict response of populations to future disturbances and stresses, and this should encompass a range of spatial and temporal scales.

Resolution: ***Efforts to enhance sexual recruitment may provide a useful tool to promote recovery of populations, but additional research is needed to understand different aspects of sexual reproduction, including basic information on reproductive biology, role of water circulation in transport of larvae, and larval settlement requirements.***

C. What other strategies should be considered to enhance the recovery of Acropora populations?

There are initial efforts to redistribute and propagate *Diadema* sea urchins so as to enhance herbivory in areas where *Acropora* settlement may be hampered by high densities of macroalgae. As with any such interventions, these efforts should include studies of the genetic variability and subpopulation structure of the sea urchin, and the operations should be designed to preserve this variability and structure. A variety of other potential strategies are under investigation. Progress on these could be greatly enhanced by a greater understanding of relevant ecological processes (ie. snail predation, damselfish interactions, fireworms).

Resolution: ***Novel ecological restoration efforts, such as strategies to enhance herbivory, reduce predation pressure, eliminate pest species, and mitigate diseases may have benefits on a local scale, but it is critical that these efforts be undertaken using a science-based approach that incorporates efforts to understand ecological processes and potential impacts of human modification of these processes.***

4. Research and monitoring needs

A. What are the needs with respect to the monitoring of Acropora populations, standing colonies, fragments and new recruits?

Assessment, mitigation and restoration activities, including creation of the demographic models discussed above, require monitoring of percent cover of *Acropora* species as well as counts per unit area of the different life stages (colonies, fragments, living coral crusts, and new recruits). Individual colonies at different life stages should be monitored in comparative studies across a range of environmental conditions including anthropogenic stresses. Monitoring should be carried out at multiple spatial scales over the next several decades at time intervals appropriate to the processes being investigated, and sampling design should be based on statistical power analysis. Monitoring should include assessments of abiotic parameters including potential pollutants and other factors that may enhance the decline of *Acropora* populations.

Resolution: ***Greater efforts are needed to monitor and assess Acropora populations at local to regional scales, at time intervals appropriate to the process under investigation, including studies to follow individual colonies at various life stages exposed to different environmental conditions and anthropogenic stressors.***

Acropora Corals in Florida: Status, Trends, Conservation, and Prospects for Recovery

Compiled by Margaret W. Miller with contributions from Walt C. Jaap, Mark Chiappone, Bernardo Vargas-Angel, Brian Keller, Richard B. Aronson, and Eugene A. Shinn

ABSTRACT

Despite representing the northern extent of *Acropora* spp. range in the Caribbean, most of the Florida reef line from Palm Beach through the Keys was built by these species. Climatic factors appear to have been important agents of *Acropora* loss within historic (century) time frames. In the recent past (1980-present), available quantitative evidence suggests dramatic declines occurred in *A. cervicornis* first (late 70's to 84) with collapse of *A. palmata* occurring later (1981-86). However, recent monitoring studies (1996-2001) show continued decline of remnant populations of *A. palmata*. Current trends in *A. cervicornis* in the Florida Keys are hard to assess given its exceedingly low abundance, except in Broward County, FL where recently discovered *A. cervicornis* thickets are thriving. While the State of Florida recognizes *A. palmata* and *A. cervicornis* as endangered species (Deyrup and Franz 1994), this designation carries no management implications. The current management plan of the FKNMS provides many strategies for coral conservation, among them minimizing the threat of vessel groundings and anchor damage, and prohibitions on collection, touching, and damage from fishery and recreational users. Although *Acropora* spp. are not explicitly given any special consideration, they are implicitly by Sanctuary management. Restoration approaches undertaken in the Florida Keys include rescue of fragments damaged by groundings and experimental work to culture broadcast-spawned larvae to re-seed natural substrates. Neither of these efforts have yet realized full success.

Geological history

Prior to the most recent moderate sea-level phase, Florida reef development proceeded under high sea-level conditions in the absence of the sensitive *Acropora* spp. These species were absent in Florida due to the inimical effects of Gulf waters flowing unimpeded from the shelf (now Florida Bay) over the reef tract. Slow-growing head corals built the Pleistocene Florida reefs. However, the spur-and-groove reef structures which we observe in the Florida Keys today as well as for the three-reef system from Palm Beach to northern Miami-Dade County are all constructions of *Acropora palmata* (Lighty 1977, Shinn 1988). The rapid growth of this species has allowed this impressive accretion on a short geological time frame, the last 6-7K years when sea level has been low. Early Holocene conditions were perhaps best conducive to rapid Acroporid colonization, but rising sea levels between 5 and 3 thousand years ago led to the demise of the reef system north of Fowey Rocks, and the die-off of Acroporid reef flats due to flooding and formation of Florida Bay.

Thus, although geological evidence suggests that coral reef formation has occurred in the absence of *Acropora* spp. in the distant past under high sea-level conditions, it is clear that future functional absence of these species will severely compromise the ability of Florida reefs to survive anticipated sea level rise (i.e., their ability to "keep up") in the not-too-distant future.

Long-term trends (100 yr)

The best observational/anecdotal evidence comes from the Dry Tortugas region (Agassiz 1882, Mayer 1902, Davis 1982, Jaap et al. 1989, Jaap and Sargent 1993, etc.). These observations suggest impressive decline of *A. palmata* occurred between 1881 and 1977 (prior to 1980's white-band disease epidemic) due to natural disturbances such as cold fronts, hurricanes, and "black water" events. Jaap and Sargent (1993) report overall loss of *A. palmata* cover in the Dry Tortugas from 44 hectares in 1881 (Agassiz 1882) to a low of ~200m^2 in 1977 to an area of 1400 m^2 by 1993. Less information is available regarding historical status of *A. cervicornis* in the Dry Tortugas, but it was al so significantly impacted by a severe cold front during the winter of 1976-77. Following the cold front, Davis (1982) reported ~91% loss of staghorn coral in Dry Tortugas. Jaap and Sargent (1993) suggest that disturbances in the Tortugas region (e.g. adverse water quality, possibly destructive storms) have rendered most habitats unsuitable for *Acropora* spp. and hence, makes full-scale recovery unlikely. However, comparisons between maps developed by Agassiz (1882) and those of Davis (1982) illustrated that staghorn coral occupied extensive areas of habitat previously dominated by gorgonians (octocoral-dominated hardgrounds), suggesting that phase shifts could occur on the order of decades.

Jaap (1998) reports alternating reef strata of *A. cervicornis/prolifera* and head corals visible in reef excavation created by a ship grounding in 1989, suggesting the repeated appearance/loss of staghorn corals over geological time scale in this region. Even over a shorter time scale (1965-2001), photo sequences by Shinn (Fig. 1) show rise and fall of *Acropora* growth in the vicinity of a focal head coral at Grecian Rocks, Key Largo, FKNMS.

Medium-term trends (early 1980s to mid-1990s)

Most published reports of *Acropora* spp. status come from this era (see Table 1, Fig 2). Dustan and Halas (1987) report in a monitoring study at Carysfort a slight increase in coverage by *A. palmata*, but an 18% decrease in coverage of *A. cervicornis* between 1974 and 1982. The *A. palmata* increase was accompanied by a decrease in mean colony size, indicating substantial fragmentation during the study period which the authors attribute largely to anthropogenic physical disturbance (boat groundings and visitor impacts). This suggests that any major white-band disease (WBD) impacts to *A. palmata* at Carysfort Reef probably occurred after 1982. However, the deeper reef terrace at Carysfort Reef, which was historically dominated by staghorn coral, suffered dramatic loss of this species, probably due to disease and predominantly after 1982. Szmant (pers comm) reports a complete loss of both species in the vicinity of the Carysfort tower between summer 1982 and a subsequent visit in April 1984.

Jaap et al. (unpublished) also found stable *A. palmata* populations at Elkhorn reef (Biscayne National Park) from 1977-81 and at Elbow and French reefs (Key Largo) from 1981-86. In contrast, disease and storms caused the demise of *A.cervicornis* at these same reefs. Jaap et al. (1987) reports a monitoring study of Molasses Reef during 1981-86 showing a drastic decline in *A. cervicornis* (96%) over the course of this study, but stable *A. palmata* abundance. Again, this suggests that the major *A. palmata* decline, at least in the Key Largo area took place after 1986. Jaap et al. (unpublished) also observed a complete loss (100%) of 175 colonies of *A. cervicornis* at French reef over the same time period, probably due to storms and/or disease.

Jaap et al. (unpublished) conducted a histological study of coral reproductive activity in Biscayne National Park from September 1977-May 1981. Active gonad development in *A. cervicornis* was observed in all years of the study. However, *A. palmata* failed to display gonad development in 1980.

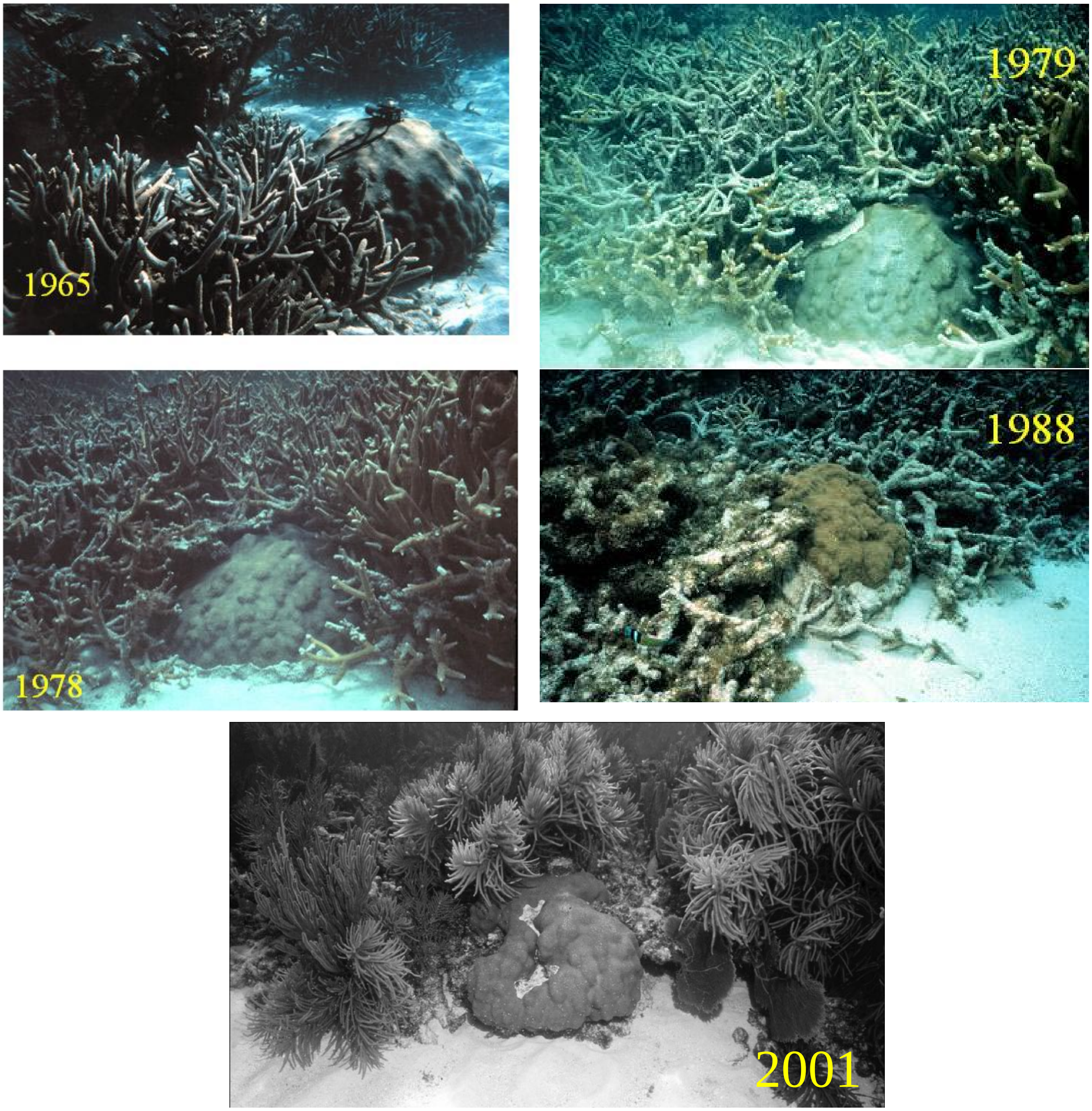

Figure 1. Photo sequence of a single head coral (*Montastraea faveolata*) at Grecian Rocks in the upper Florida Keys National Marine Sanctuary showing increase of *A.cervicornis* following 1965. The thicket was partially dead by 1978 and completely dead but standing by 1979. Between 1979 and 2001, gradual collapse of the thicket structure and colonization by octocorals is observed. Source: EA Shinn

Porter and Meier (1992) report overall loss of *A. palmata* cover (stability at one out of 7 stations) and a substantial decrease in colony size, particularly at Looe Key, over the period of 1984-91. The authors suggested that disease, mortality from bleaching, and algal overgrowth due to reduced urchin grazing were possible factors responsible for the decline.

Fig. 2

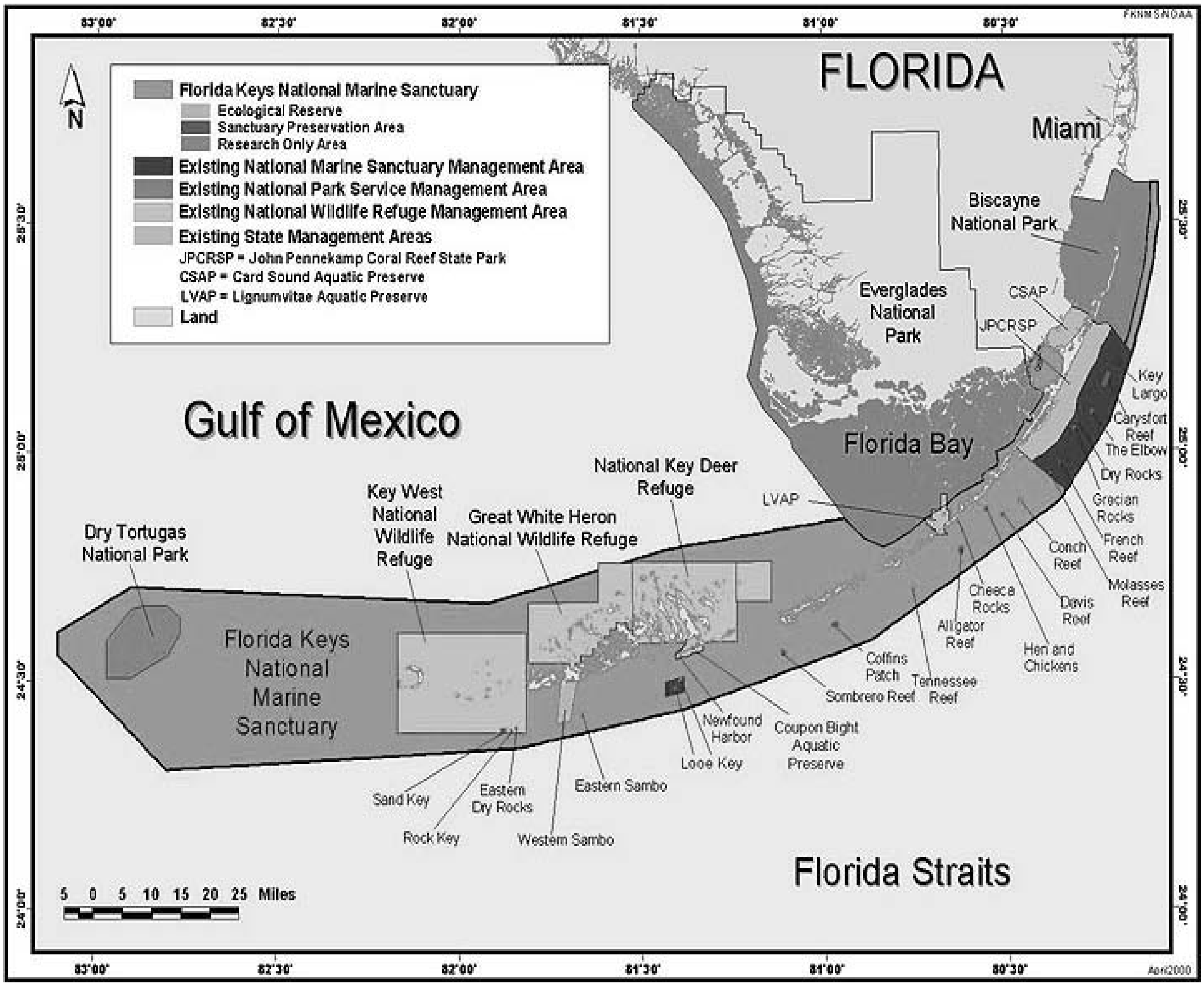

Fig. 2. Map of the region described in this paper. Major sites are numbered from northeast to southwest. Representative sites: 1) Broward County; 2) Ball Buoy, Biscayne National Park; 3) Molasses Reef, FKNMS; 4) Looe Key, FKNMS; 5) Dry Tortugas National Park; 6) Tortugas Bank, FKNMS.

A snapshot mapping study of Looe Key reef suggests areal (m^2) losses of ~93% and ~98% for *A. palmata* and *A. cervicornis*, respectively, between 1983 and 2000 (Miller et al. 2002a). Based on studies by Dustan and Halas (1987) and Jaap et al. (1987), it is quite likely that the 1983 baseline used in this study was already depressed, at least for *A. cervicornis*. A systematic survey of deeper reefs (13-19 m) along the entire Florida Reef Tract in 1995 found *A. cervicornis* to be present at only seven of 20 sites and never at more than 0.62% cover (Aronson and Murdoch, unpublished).

The species status of *Acropora prolifera* is under scrutiny[1], and its history is poorly documented. However, it has suffered population collapse equivalent to *A. cervicornis* and is very rare, being seen in a few locations in Dry Tortugas over the past decade (Jaap, pers. comm.).

[1]Vollmer and Palumbi (2002) present data that demonstrates that *A. prolifera* is a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*.

In summary, available quantitative information indicates that *A. cervicornis* underwent drastic decline in the late 1970s to early 1980s throughout the Florida Keys, although the information with the best temporal resolution comes from the Upper Keys. *A. palmata* decline seems to have been less severe through 1986, reported most commonly as a decline in colony size. *A. palmata* did show severe decline at Looe Key beginning in the late 1980s. There is very little monitoring information available between 1991 and 1996.

Short-term trends (mid-1990s to the present)

Several reef monitoring projects began in the Florida Keys in the mid to -late 1990s (1996 and 1998) which provide excellent quantitative data on coral (including *Acropora*) abundance and, in some cases, condition. Results from these projects are consistent in showing very low colony density and coverage patterns for both species. There is also evidence of *continued* decline in both species over the period from 1996 to 2001. The only exception to this pattern is the discovery of *A.cervicornis* thickets in Broward County, Florida, where monospecific stands appear to be thriving in nearshore hardbottom habitats.

A. Synoptic monitoring of Keys/Tortugas reefs (Chiappone, Swanson, S. Miller):

During 1999-2001, a rapid assessment of 260 sites were sampled in the region, including 204 sites from southwest of Key West to northern Key Largo and 56 sites in Dry Tortugas National Park, the Tortugas Bank, Riley's Hump, and south of the Marquesas Keys in a stratified random sampling scheme. Mean percent coverage for both *Acropora* species, as determined from surveys of 100 points for each of four transects per site, was low. In the Florida Keys, mean coverage by *A. cervicornis* was 0.049% among eight habitat types and did not vary significantly. Mean cover was greatest on high-relief spur and groove reefs (0.049%) and offshore patch reefs (0.045%). Mean coverage by *A. palmata* was even lower throughout the Florida Keys than its congener, even on many high-relief spur and groove reefs where it was formerly abundant. Among the eight habitat types surveyed, *A. palmata* was only recorded in high-relief spur and groove reefs where it was formerly abundant. Mean coverage in this habitat type was 0.158% and ranged from 0.158% in the lower Keys, 0.300% in the middle Keys, to 0.338% in the upper Keys.

The density of *Acropora* colonies was quantified in 25 m x 0.4 m or 10 m x 0.4 m transects. For *A. cervicornis*, mean colony densities among the eight habitat types were no greater than 0.052 colonies/m^2 and there were no significant differences detected in mean colony density among habitat types. Offshore and mid-channel channel patch reefs had the greatest mean densities (0.047-0.052 colonies/m^2). Within strip transect surveys, colonies of *A. palmata* were only found in the high-relief spur and groove habitat. The mean density estimate for this habitat type was 0.036 colonies/m^2, ranging among regions from 0.010/m^2 - 20.010/m^2 in the middle Keys, 0.015/m^2 -20.015/m^2 in the lower Keys, and 0.073/m^2 - 20.073/m^2 in the upper Keys. Patches of numerous colonies were evident at Sand Key, Eastern Dry Rocks, Molasses Reef, Sand Island, and Elbow Reef, most of which are within FKNMS no-fishing zones.

Because density estimates using 25 m x 0.4 m or 10 m x 0.4 m transects were so low for both *Acropora* species, the 2001 surveys also included larger and additional transects to assess densities. For the Florida Keys shallow fore reef, both spur and groove and hardbottom were surveyed from Key West to northern Key Largo at 2 m to 8 m depth. Densities were extremely patchy (Fig. 3) and despite the relatively large sample area, only 43 colonies of *A. cervicornis* and 302 colonies of *A. palmata* were recorded. Maximum densities for particular reefs were 2.25 colonies/m^2 for *A. cervicornis* and 12.13 colonies/m^2 for *A. palmata* (Fig. 3). In low-relief hard-bottom habitats, 50 *A. cervicornis* and 18 *A. palmata* colonies were encountered and were even more patchily distributed.

The prevalence of disease or disease-like conditions indicated relatively low prevalence of for both *Acropora* species, although few colonies were assessed during 1999-2001. Of the 31 *A. cervicornis* encountered, only one colony exhibited signs of possible recent disease. Three of the 18 colonies of *A. palmata* assessed exhibited either white band disease or signs of recent disease, evidenced by dead white skeleton. Not surprisingly, few juveniles for either *Acropora* species were encountered from the 260 Florida Keys sites. Reconnaissance surveys in several locations, however, did reveal some smaller colonies presumably derived from sexual recruitment, supported by the lack of nearby colonies.

Fig. 3

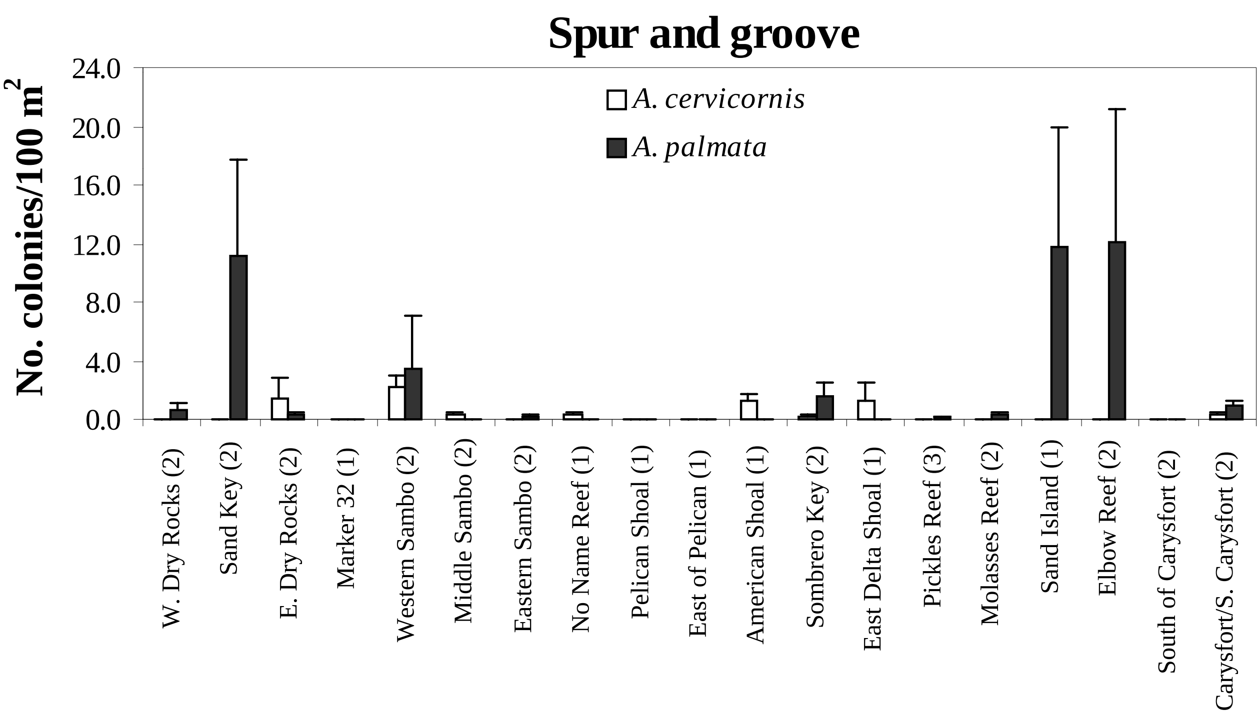

Fig.3. Mean density (no. colonies/100 m^2) of *Acropora cervicornis* and *A. palmata* on high-relief spur and groove reefs on the Florida Keys fore reef during 2001. Sites are arranged from southwest to northeast and error bars represent one standard error. Values in parentheses are the number of sites surveyed for each reef, with 400 m^2 surveyed for colony numbers per site. Source: Chiappone, Swanson, & S.Miller, (unpublished data).

B. Coral Reef Monitoring Program (Coral Reef Monitoring Program, Jaap et al.)

Begun in 1996, the Coral Reef Monitoring Program (CRMP) samples four 10 m permanent video transects at each of over 40 reef sites throughout the Florida Keys and Dry Tortugas. *A. palmata* occurred at five shallow reef sites out of the 40 sampled. The percent cover contributed by *A. palmata* at upper Keys Reefs was low at the beginning of the study (7.2-7.3% in 1996) and declined to less than 1% by 2000. *A. cervicornis* coverage was even lower, declining during 1996 to 2000 from 0.13% in 1996 to 0.03% in the upper Keys, from 0.26% to 0% in the middle Keys, and from 0.11% to 0.02% in the lower Keys. White Shoal, in the Dry Tortugas, is the only site that exhibited relatively stable coverage patterns of *A. cervicornis* (~2-3% cover).

C. Focal monitoring of Acropora palmata (M. Miller, et al.)

A dramatic decline in *A. palmata* abundance was observed at 6 focal patches in the Key Largo area since 1998 (mostly from 1998-1999) and little recovery since then (Miller et al. 2002b). This decline was most evident at sites where *A. palmata* occurs as sparse, individual colonies where total colony abundance fell by 77% between 1998 and 2001. This decline was less evident in denser thicket stands where mean colony density declined from 1.1 colonies/m^2 in 1998 to 0.8 colonies/m^2 in 2001. The incidence of white-band disease in this focal survey study was always less than 6% of colonies for each site and the mean prevalence for all sites was always < 3% of colonies (< 2% in 2001). Prevalence of three-spot damselfish (*Stegastes planifrons*) was much higher, ranging up to 70% of colonies at French Reef in 1998. The mean prevalence (n=6 sites) ranged from 30% to 40% for all survey years. The density of corallivorous gastropods (*Coralliophila abbreviata*) averaged over all surveyed colonies ranged from a mean of ~ 0.5 snails/ colony in 1998 to a maximum over 1 snail/ colony in 2000 and decrease back to ~0.8 in 2001.

D. Broward County Acropora cervicornis (Vargas et al.)

While the geographic range of *A. cervicornis* was always known to extend to Palm Beach County waters, the relatively recent discovery of thriving thickets in Broward County (Fig. 4) was exciting and unexpected, especially given the dismal state of *A. cervicornis* populations in seemingly less marginal areas further south in the Florida Keys. Extensive mapping activities reveal at least six sites with *A. cervicornis* thickets averaging 13% live tissue cover and with *A. cervicornis* colony densities ranging from 1.3-3 colonies/m^2. Recent ecological studies documented linear extension growth rates of 8-9 mm/month and broadcast spawning in this latitudinally marginal population. No occurrence of white-band disease has been observed in these populations.

In contrast, *A. palmata* is extremely rare in Broward County, Florida, and was probably never abundant since the demise of early Holocene reefs (Lighty et al. 1977, 1978 papers discuss the development and demise of the northern Dade to Palm Beach County relict reef system).

Fig. 4

Fig. 4. *Acropora cervicornis* thickets thriving in Broward County, FL. Source: B Vargas-Angel

E. Additional observations

Weaver (personal communication) reports a die-off (13% live cover to <1%) of an *A. cervicornis* thicket at Little Africa reef in the Dry Tortugas between 1995 and 1997. This die-off appears to be from disease, since there is still standing dead structure and a few small colonies/recruits in the surrounding rubble field persist. No recovery was observed at this site between 1997 and 2002.

Current status (May 2002) of *Acropora* spp. in the Dry Tortugas region includes very sparse occurrence of *A. cervicornis* (suffering from damage by threespot damselfish and some disease) on the Tortugas Bank. In 1993, the *A. palmata* patch included an area with high density and peripheral areas with rather low density of *A. palmata*. In May, 2002, the overall status is, *A. palmata* have declined in abundance (qualitative observation) and the higher density cluster is virtually non-existent. A nearby patch of *Acropora prolifera* seems to have expanded noticeably since 1993 and appears healthy and thriving (Jaap, pers. obs.). Interestingly, no corallivorous snails were found on any *Acropora* colonies in the Dry Tortugas in three days of searching in May 2002 (M. Miller pers. obs.).

Current conservation, management and restoration status

The major coral reef management entity in the region is the Florida Keys National Marine Sanctuary (FKNMS), with smaller marine areas administered by the National Park Service and the State of Florida. The FKNMS Management Plan contains 12 separate Action Plans (e.g. zoning, mooring buoys, restoration, channel marking, etc.), all of which contribute to varying degrees to coral protection. While *Acropora* spp. are not explicitly noted in the management plan, they implicitly receive special consideration in all Sanctuary management actions. Additional protective measures to be undertaken could include greater education and outreach effort, improved waterway markers, and harsher penalties, particularly at sites with remnant *A. palmata* populations that receive repeated vessel groundings.

Several management needs persist that could improve management and conservation of *Acropora* spp. populations in the FKNMS. These include more research on *Acropora* recruitment and propagation, distribution and abundance maps for extant *Acropora* populations, and greater capacity for episodic event response.

The FKNMS has undertaken several restoration efforts (and some partnerships with NGOs such as Reef Relief) regarding *Acropora palmata*, particularly in response to groundings in the lower Keys region. Rescue and re-attachment of grounding-generated fragments has had mixed success, in that subsequent storm events have destroyed some of the transplant/nursery structures. Recent research efforts at larval culture and settlement of *A. palmata* have had little success (Szmant and M. Miller, personal observations). Since 1998, two collections at mass-spawn have been accomplished (1998 and 2001 at Horseshoe Reef), but viable larval cultures failed to develop despite similar procedures as had produced successful cultures and settled recruits in past years from spawn collection made at Key Largo Dry Rocks (e.g. 1996). In 2000, no spawning by *A. palmata* was observed either in Key Largo (or in Puerto Rico) over the 3 night window in which spawning was predicted. No observations were made in 1999. One hypothesis is that the *A. palmata* population at Horseshoe reef may not retain sufficient genetic diversity to provide for successful fertilization in the collected cultures. Spawn-collection activities had been shifted to Horseshoe after 1998 when the population abundance at Key Largo Dry Rocks declined to the point of making nighttime spawn collection infeasible. Future efforts will seek to make *A. palmata* spawn collection at multiple sites to increase the likelihood of genetic diversity in the resulting cultures. The intention is to culture the larvae to the point of competence and then expose them to reef substrate to provide for enhanced *A. palmata* settlement/recruitment as a restoration/recovery measure.

Summary

It is clear that dramatic decline in both *A. palmata* and *A. cervicornis* has occurred in Florida over the past two decades and, in the case of *A. palmata* (for which current trend data is available) decline continues through 2001. It appears that noticeable recoveries of both species have occurred in the historical past in the Dry Tortugas region where the observational time line is over a century. Juveniles of both species are observed at a range of locations, but it is unclear whether they represent a trajectory of population increase as their fate is unclear. Current observations of disease incidence are low (~2-3% of colonies) but somewhat patchy in distribution. Active predation (by snails and fire worms) is observed on 10-30% of colonies in well-studied areas and is the most obvious chronic (and potentially manageable) threat. Little quantitative population benefit from restoration efforts to date has been documented.

Table 1: Site-specific condition of *Acropora palmata* in Florida. Sites are arranged from northeast to southwest and approximate location can be interpolated from the map in Fig. 2. po = personal observation; SP= snail prevalence (i.e. proportion of colonies infested by *Coralliophila abbreviata*); WBD=White-band disease, presence/absence or proportion of infected colonies; CRMP = Coral Reef Monitoring Project (Jaap et al.); other published sources listed in references. On opposite page.

Table 1. Site-specific condition of *Acropora palmata* in Florida.

Site	Trend	Time-frame	Current status	Extent of decline	Condition in 2001 (Predators,WBD)	Reproduction /recruitment?	Source
Elkhorn	Decline	70's-01	Rare	Very High	Snails present	Recruits ~20cm (cohort?) present	Jaap, Curry/M.Miller (po)
Elkhorn Control	Decline	1970's-2001					Jaap (po)
Ball Buoy	Decline	1970's-2001	Rare				Jaap. Curry (po)
Carysfort	Stable	1974-1982					Dustan&Halas1987
	Collapse	1982-84		Very high			Szmant po
	Decline	96-01					CRMP
South Carysfort	Decline	98-01	0.27 col m^{-2} in thicket	65% (density)	SP=0.25; 0.6 snail colony^{-1}		
Grecian	Decline	96-01					CRMP
Little Grecian	Stable	98-01	Decent Thicket (2)		SP=0.33; 1.1 snail colony^{-1}		M. Miller et al
KL Dry Rocks	Decline	70's-01	<20 colonies	Very High	Snails high; Some sexual recruits (2001) but with serious snail infestation		Jaap po M. Miller, po
Elbow	Decline	70's-01	~0.1 col m^{-2}				Jaap (po), Chiappone et al.
Horseshoe	Stable	98-01	Decent Thicket	Slight	SP=0.14; 0.3 snail colony^{-1}	Spawning observed in 2001, not 2000	M. Miller (2002b)
Sand Island	?	00-02	~0.1 col m^{-2}		WBD, heavy snail impact		Szmant (po), Chiappone et al.
French	Decline	98-01	<50 colonies	80% (# colonies)	SP=0.38; 1.1 snail colony^{-1}		M. Miller (2002b)
Molasses	Stable	81-86					Jaap et al
	Decline	96-01					CRMP
	Decline	98-01	Sparse colonies	76% (# colonies	SP=0.33; 0.93 snail colony^{-1}		M. Miller (2002b)
Pickles	Decline	96-01	<20 colonies	68% (# colonies)	SP=0.26; 0.83 snail colony^{-1}		M. Miller (2002b)
Sombrero	Decline	96-01	Virtually gone				CRMP
Looe	Decline	96-01					CRMP
		83-00		93% areal coverage	Snails present	Some small recruits	M. Miller et al. 2002a
Eastern Sambo	Decline	96-01					CRMP
Western Sambo	Decline	96-01	Decent Thicket				po
Middle Sambo	Decline	70's-01	11 colonies (2001)				M. Miller (po)
Rock Key	Decline	96-01					CRMP
Sand Key	Decline	96-01	~0.1 col m^{-2}				CRMP; Chiappone et al.
Eastern DR	Decline	70's					
Western DR	Decline	70's					
Dry	Stable	93-02	~600m2		No snails present, high		Jaap, M. Miller

Table 2. Site-specific information on *Acropora cervicornis* in south Florida. Sites are arranged from southwest to northeast and approximate location can be interpolated from the map in Fig. 2. ****Observation relates to Acropora prolifera*

Site	Trend	Time-frame	Current status	Extent of decline	Condition in 2001 (Predators,WBD)	Reproduction /recruitment?	Source
Little Africa, DT	Decline	95-01	~Absent	~100% from 95-97		-	Weaver (po)
****5-ft Channel, DT* ***A.prolifera***	*Increase*	*93-02*	*Large thicket*		*No snails, some colonies look pale*		*Jaap, MMiller (po)*
Tortugas Bank	?	96?	<1% live cover				Aronson, Keys Wide Cruise
Tortugas Bank	?	02	Scattered colonies	?	No snails, some WBD, some damselfish damage	Few sexual recruits observed	M. Miller (po)
White Shoal, DT			Scattered colonies				Jaap
Pulaski Shoal, DT	?	96?	<0.5% cover				Aronson, Keys Wide Cruise
28 ft. Shoal	?	96?	<0.5% cover				Aronson, Keys Wide Cruise
West Sambo	?	96?	<1% cover				Aronson, Keys Wide Cruise
Looe Key	Collapse	83-00		98% of areal cover	Snails present		Miller et al. (in press)
	?	96?	<0.5% cover				Aronson, Keys-wide cruise
No Name	?	96?	<0.5% cover				Aronson, Keys-wide cruise
Pickles	?	96?	<0.5% cover				Aronson, Keys-wide cruise
Molasses	Collapse	1981-86		96%			Jaap et al. (1987)
French	Collapse	1981-86		100%			Jaap et al. unpub.
Carysfort	Decline	1974-82		18%			Dustan and Halas (1987)
Broward County	Increase	1996-2002	13% cover		predators present	Spawning in 2001	Vargas-Angel et al.

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Distribution and Status of Acroporid Coral (Scleractinia) Populations in Puerto Rico

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ABSTRACT

Acroporid corals were important components of shallow fore reef and lagoonal habitats in coral reefs of the tropical western Atlantic and the Caribbean. An epizootic event of white-band disease (WBD) in the early 80's, produced extensive mass mortality of both species throughout their distribution range in the wider Caribbean. As a result, there were significant changes in community structure, loss of habitat and biodiversity. In the late 70's, extensive thickets of elkhorn coral *Acropora palmata* were present in 40 % of 35 reef localities surveyed around the island of Puerto Rico. Another 20 % of these reefs had dense patches and abundant colonies of staghorn coral *A. cervicornis*. The hybrid *A. prolifera* was present in many localities but it rarely formed dense thickets. Surveys of more than 100 coastal and offshore localities around the island during the last 20 years indicate a significant decline in populations of both species in most localities and recovery in others. Most of the high profile, dense thickets that formed the *Acropora* zones have disappeared, and only a few reefs localities, mostly in the southwest coast, have healthy, high density populations of *A. palmata*, *A. cervicornis* and *A. prolifera*. The primary cause of this significant decline in distribution and density of populations was the widespread white band disease (WBD) epizootic event of the early 80's. In following years however, surviving populations and colonies where hit by hurricanes, storms, bleaching, more disease, and an increasing deterioration of the environmental conditions around coastal coral reefs due to anthropogenic activities. Other, long-term natural factors, such as snail and fireworm predation, and damselfish territorial behavior, have caused increasing tissue mortality and the pre-emptive competition of corals by filamentous algae. In recent years, patchy necrosis and substrate monopolization by an aggressive, endolytic sponge, *Cliona langae*, have become important factors in the loss of live tissue in *A. palmata* along the southwest and west coasts, and the offshore islands. Deterioration of local environmental conditions (high sedimentation and turbidity), the occasional hurricane, persistent disease, and predation by snails and fireworms cause significant mortality in *A. cervicornis* and *A. prolifera*. Today however, signs of recovery can be observed in few localities for *A. palmata* and *A. cervicornis* mostly. Few extensive fields, abundant thickets, high densities of small colonies, and most importantly, many sexually produced recruits can be observed in many localities of the southwest coast and offshore islands. New protective legislation by the Department of Natural Resources in combination with the presence of healthy populations, the high growth rates of these species, and new sexual recruitment may provide a chance for some recovery in many localities.

[1]Vollmer and Palumbi (2002) present data that demonstrate that *A. prolifera* is a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*.

1. Historical perspective

Acroporid corals (*A. palmata* and *A. cervicornis*, and to a lesser degree, *A. prolifera*) were important components of shallow fore reef and lagoonal habitats in coral reefs of the tropical western Atlantic until the late 70's and early 80's. These species formed the famous *Acropora* zones, dense stands of high profile, spatially complex, monospecific thickets in shallow and intermediate depths in most Caribbean coral reefs (Vaugham, 1919; Goreau, 1959; Lewis, JB, 1960, 1965; Scatterday, JW, 1974; Ross, PJ, 1964, 1971; Glynn, 1973; Colin, 1978). In the late 70's and early 80's, a white-band disease (WBD) epizootic event caused extensive mass mortality of these species throughout their range with losses up to 95% (Gladfelter, 1982). The demise of *Acropora* spp. has resulted in significant changes in community structure, loss of habitat and biodiversity (Aronson and Precht, 2001). In many localities, acroporids have disappeared as a consequence of regional disease outbreaks, compounded locally by hurricanes, bleaching events, and a overall deterioration of local environmental conditions.

In Puerto Rico, Acroporid coral populations have declined significantly over the last two decades in almost all reef localities where they were formerly abundant. Dense and well developed thickets of both *A. palmata* and *A. cervicornis* were present on many reefs, patch reefs and shelf edge localities off the north-east, east, south, west and north west coast, and also the offshore islands of Mona, Vieques and Culebra (Fig. 1) (Almy and Carrión-Torres, 1963; McKenzie and Benton, 1972; Rogers, 1977; Goenaga and Cintrón, 1979; Boulon, 1980). Goenaga and Cintrón (1979) conducted island-wide surveys of 35 localities in 1978-79 (Fig. 1) and found 88% of all locations colonized by *A. palmata* and 52% by *A. cervicornis* colonies. Many reefs (40%) had high profile thickets with high colony densities, while 20-28% of the locations only had isolated colonies (Table 1).

Table 1. Abundance of acroporids in 35 coastal locations of Puerto Rico in 1978-79. Adapted from Goenaga and Cintrón (1979).

Condition	***A.palmata***	***A.cervicornis***
High profile thickets/dense patches	40%	20%
High colony density and few patches	20%	6%
Isolated colonies	20%	28%
Absence of Acropora spp.	12%	48%
Live cover	5-100%	

Some reefs however, were already showing signs of anthropogenic impacts such as high siltation and turbidity (Goenaga and Cintrón, 1979). Today, evidence of these species remains in many locations where standing dead skeletons of *A. palmata* and rubble piles of *A. cervicornis* can be seen. With the exception of few reefs in the southwest and isolated offshore locations, the dense, high profile, monospecific thickets of both species have disappeared from Puerto Rico coral reefs (unpublished data).

Although few long term data are available, the primary cause of the significant decline in population densities and distribution is thought to be an island wide outbreak of white-band disease in the early 1980's. In addition to disease, surviving colonies were hit by hurricanes and tropical storms, other types of disease, a concentration of predators, bleaching, and an increasing deterioration of the environment around coastal coral reefs due to anthropogenic activities (Table 2). For example, large stands of *A. palmata* on east coast reefs near Fajardo were decimated by WBD in the mid 1980's, and subsequently, hurricane Hugo (1989), caused almost total destruction to the remaining *A .palmata* thickets (Goenaga and Boulon, 1992). Hurricane David (1979) had devastating effects to *A. palmata* thickets on fore reef habitats throughout the south and west coast, with a high proportion of colonies being dislodged from the reef substrate and deposited onto the reef flat followed by high mortality (Vicente, 1993).

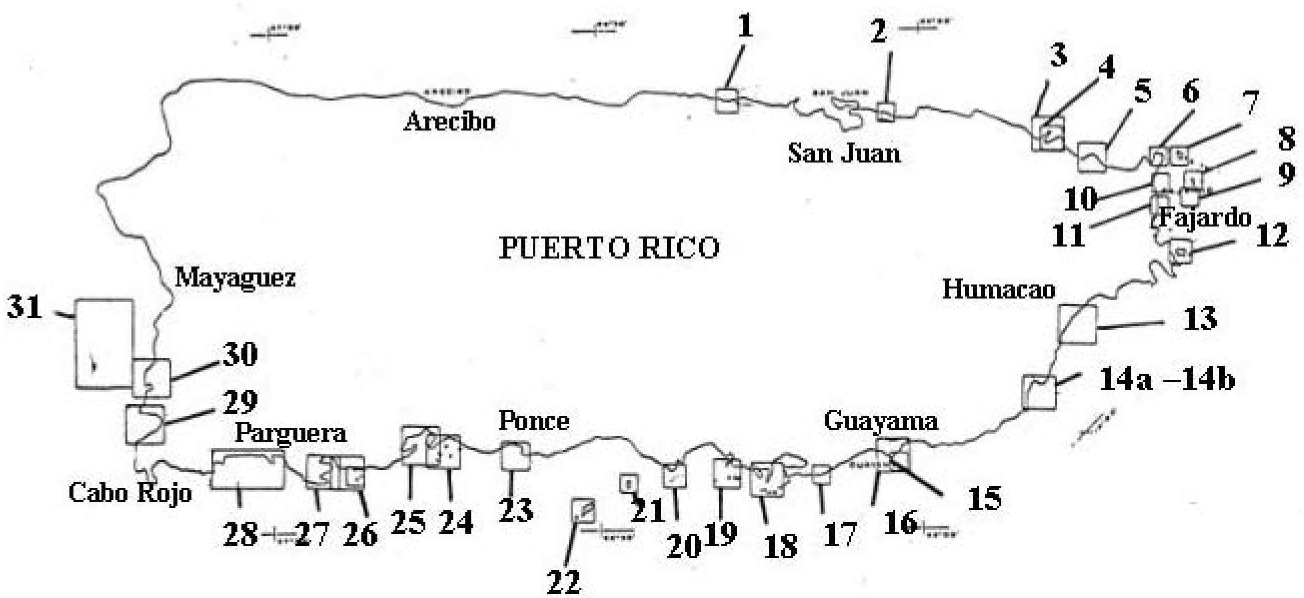


Figure 1. Map of Puerto Rico showing major coral reef areas surveyed (lines) by Goenaga and Cintrón (1979).

Then WBD hit in the early 80's and up to 30% of the colonies were reported to be affected in many reefs (Davis et al., 1986). During the 1990's a number of other coral reef areas (i.e., Islote Palominitos, Los Corchos Reef, Cayo Dákity, Playa Larga, Culebra) showed severe physical destruction of the *A. palmata* framework and *A. cervicornis* thickets as a result of several hurricanes [Louis (1995), Marilyn (1995), and George's (1998)] (Goenaga, 1990; Hernandez-Delgado, 2000). In the nineties WBD continues to affect *Acropora* populations throughout Puerto Rico, but disease prevalence is generally low (Bruckner et al., 1997; Bruckner and Bruckner, 1997, 2001; Williams et al., 1999; Weil et al., 2000; Weil, 2002). For instance, in one of the outer reefs studied by Davies (1986), remaining Acroporid populations were reported to have WBD on 8.5% of the living colonies by 1993 (Williams et al., 1999). In the absence of compounding impacts from disease and other factors, like those observed in the 1960's and 1970's, *Acropora* populations in Puerto Rico generally recovered from hurricane damage. Coral fragments produced by hurricane Edith in the early 1960's were observed to reattach and recover in many localities in the southwest (Glynn et al., 1964).

Other natural factors, such as damselfish (Pomacentridae) territorial behavior, are causing increasing tissue mortality and the pre-emptive competition of corals by filamentous algae (Hernández-Delgado, unpublished data). In addition, coral bleaching was documented in *Acropora* spp. in 1987, 1989, 1990, 1995 and 1998 (Williams et al., 1987; Goenaga et al., 1989; Goenaga and Canals, 1990; Winter et al., 1999; Weil, 2000), but associated mortality was not reported. Localized anthropogenic impacts (i.e., historic coral collection for souvenirs, reef trampling, snorkeling, SCUBA diving, anchoring, some fishing methods) have also caused some destruction of corals around Fajardo (Mckenzie and Benton, 1972; Torres, 1975; Hernández-Delgado, 1992). Ship groundings have caused significant mechanical destruction of *Acropora* assemblages in Los Corchos, Culebrita Island, Islote Palominitos, off Fajardo (Hernandez-Delgado, 2000), Guánica and Mona island (Bruckner and Bruckner, 2001). Military activities have caused some damage also in Culebra and Viéques (Antonious and Weiner, 1982; Hernández-Delgado, pers. obs.).

With few exceptions, most of these impacts have never been quantified. For example, quantitative information on the impact the Fortuna Reefer ship grounding in Mona island has been collected for over two years (Bruckner and Bruckner, 2001), the fates of storm generated fragments following Tropical storm Debbie and Hurricane Hortense in La Parguera were evaluated (Bruckner, unpublished data), and an ongoing project is evaluating the impact of Hurricane George's on *A. palmata* populations off La Parguera and Guánica (Ortiz, unpublished data). The impact of predation by the snail *Coralliophilla abbreviata* was assessed by Bruckner (2000). Ongoing anthropogenic degradation of coastal (urban development) and inland areas (deforestation) continue to affect the quality of the coastal reef environments (i.e. higher turbidity, high nutrient input, pesticides and herbicides, solid suspended material, high sedimentation rates, etc.), and may contribute to the decline of acroporids and coral reefs in general (Goenaga and Boulon, 1992; Hernandez-Delgado, 1992, 2000; Morelock, 2001).

2. Current status

Although there is very limited quantitative data regarding the current ecological status of Acroporids in Puerto Rico, a wealth of qualitative observations and information on their distribution and relative abundances have been collected over the years for many coral reefs in the east, southwest and west coasts, and some of the offshore islands. These data are good baseline information and provides a picture of the current status of Acroporid populations. Recent surveys of over 100 reefs along the coast and islands, indicate that Acroporid populations have continued to decline in some areas from persistent disease, storms, and sedimentation coupled with the poor coastal environmental conditions (high turbidity, sub-optimal water quality, etc.) and algal overgrowth (Appendices 1 and 2).

Many environmentally-degraded fringing coral reefs along the shoreline of Puerto Rico (i.e., Punta Picúa, Punta Miquillo; Río Grande, Guánica, La Parguera, Mayagüez) show large stands of dead *A. palmata* in their upright, growth position, suggesting mortality resulted from factors such as disease outbreaks, bleaching, siltation, algae competition, or a combination of any of these (Table 2), and not from physical damage associated with storms or hurricanes. Most frequently, total colony mortality does not occur from these factors, and high growth rates, capacity for tissue regeneration, asexual reproduction, and high survivorship of storm-generated fragments, seem to be playing an important role in maintaining some populations. A recent event of patchy necrosis in southwest reefs produced moderate levels of partial tissue mortality in a high proportion of colonies in a relatively short period of time (November 13-18, 2002). On average, between 35 and 74 % of all colonies of *A. palmata* in six reef areas were affected by this syndrome (Fig. 2). Average tissue loss varied between 14 and 17% of the colony surface area (Fig. 3) (Weil and Ruiz, unpublished data). This event happened after a period of extreme calm weather and seas

Table 2. Historical and current causes of tissue mortality (partial and/or total) of acroporid corals in Puerto Rico. Question mark indicates that factor needs to be verified.

Natural factors	Species	Anthropogenic Factors	Species
Disease		**Siltation**	Ap, Ac
White band-I and II	Ap, Ac	**Pollution**	Ap, Ac
White plague ?	Ap, Ac	**Ship and boat groundings**	Ap, Ac
Black band	Ac	**Eutrophication**	Ap, Ac
Bleaching	Ap, Ac	**Floating debris**	Ap, Ac
Patchy necrosis	Ap	**Divers**	Ap, Ac
Predation		**Anchors**	Ap, Ac
Snails	Ap, Ac		
Fireworm	Ac		
Parrotfish	Ap		
Damselfish	Ap, Ac		
Storms	Ap, Ac		
Clionid sponges	Ap		
Algae competition	Ap, Ac		

that lasted for approximately 15 days. Tissue mortality could also be associated with high residence time of fish and sea turtle feces on the surface of *A. palmata* colonies. Almost all colonies affected by patchy necrosis showed rapid regeneration of the lost tissue a week after the mortality. Follow-up surveys up to August of 2002 of the tagged colonies that suffered mortality in November of 2001 show total (100% new tissue cover) recovery of tissue in 98 - 100% of the injuries in all tagged colonies. Injuries that have not completely recovered show active growth margins but, a layer of turf algae and sediment seem to slow down the advance of the new growth (Weil & Ruiz, unpublished data).

2.a. Eastern coast

Over 90 localities have been surveyed in the last decade by various authors along the northeastern and eastern region of Puerto Rico. Hernnadez-Delgado surveyed 86 sites and compared the information with previous reports from the same sites (Table 3) (Appendix 1). Data were geographically sub-divided into four main areas: northern inshore, eastern inshore, eastern offshore close (<6 km), and eastern offshore remote (>6 km). This classification was originally based on a Bray-Curtis ordination analysis for coral species presence/absence data sets to classify coral reefs (Hernández-Delgado, 2000). *A. palmata* was an important component of coral reefs and coral communities in most of the sites (93%) of four major localities surveyed prior to 1980 (Almy and Carrión-Torres, 1963; Pressick ,1970; Mckenzie and Benton, 1972; Goenaga and Cintrón, 1979; Goenaga and Vicente, 1990; Goenaga and Boulon, 1992; Hernández-Delgado, 1992; and unpublished data). Today, however, *A. palmata* has been observed only in 36.7 % of these sites, as one moves across an anthropogenic stress gradient of water transparency, sedimentation and concentration of suspended solid material (Hernández-Delgado, 2000). The northern inshore localities showed the highest decline (68.4 %) and the offshore remote reefs (>6 km) the lowest *A. palmata* has but disappeared from 62 % of the sites in northern and eastern Puerto Rico where it used to be found in high densities many years ago. Surveys conducted in 1998 in the southwest coast of Culebra and northwest coast of Vieques islands showed scattered colonies of *A. palmata* in good health in these localities (Weil et al., 1998). *A. palmata* was more abundant in Vieques and showed higher colony densities than in Culebra.

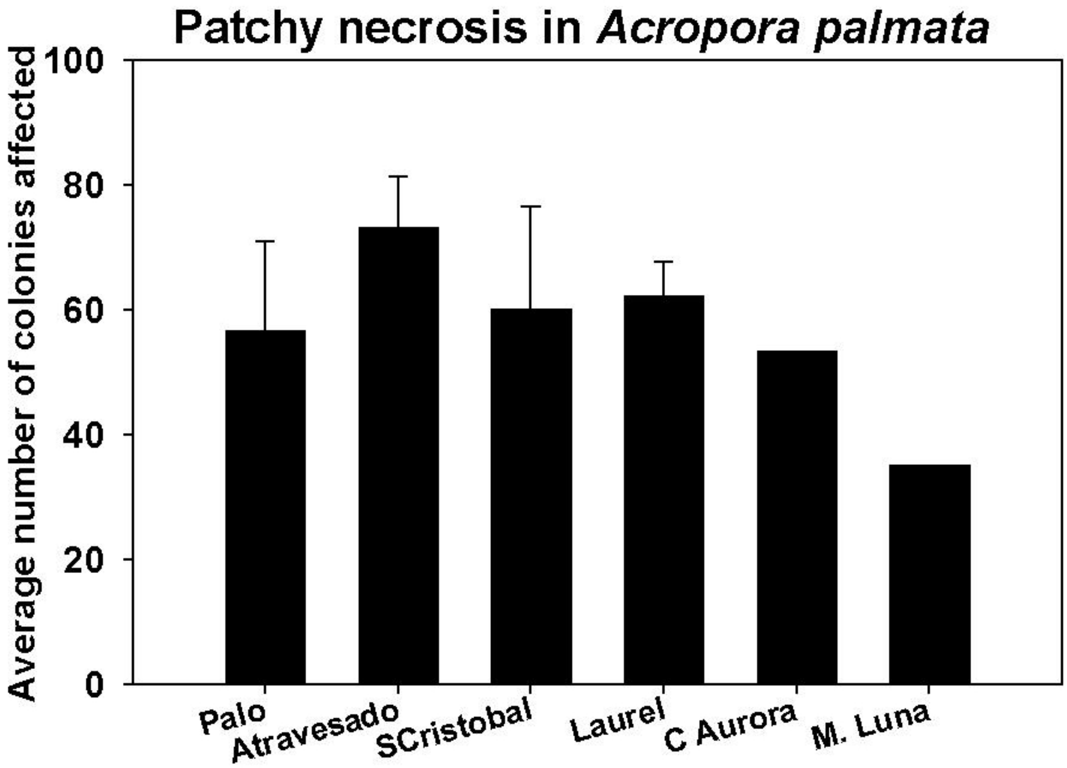


Figure 2. Average number of colonies of *A. palmata* affected by patchy necrosis in six coral reefs off La Parguera and Guánica. (Weil & Ruiz, unpublished data).

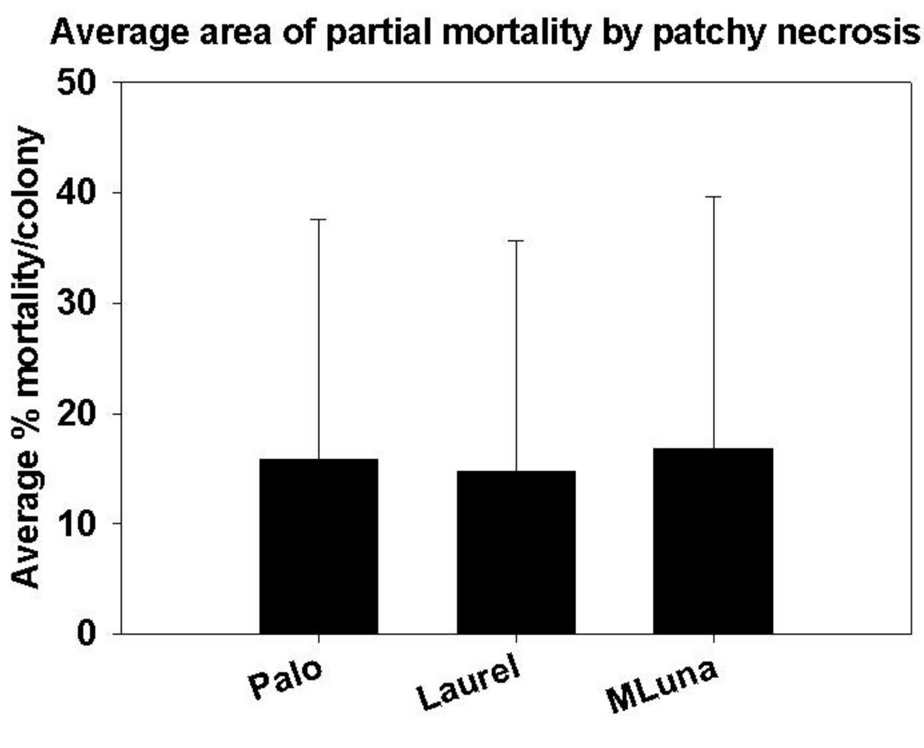
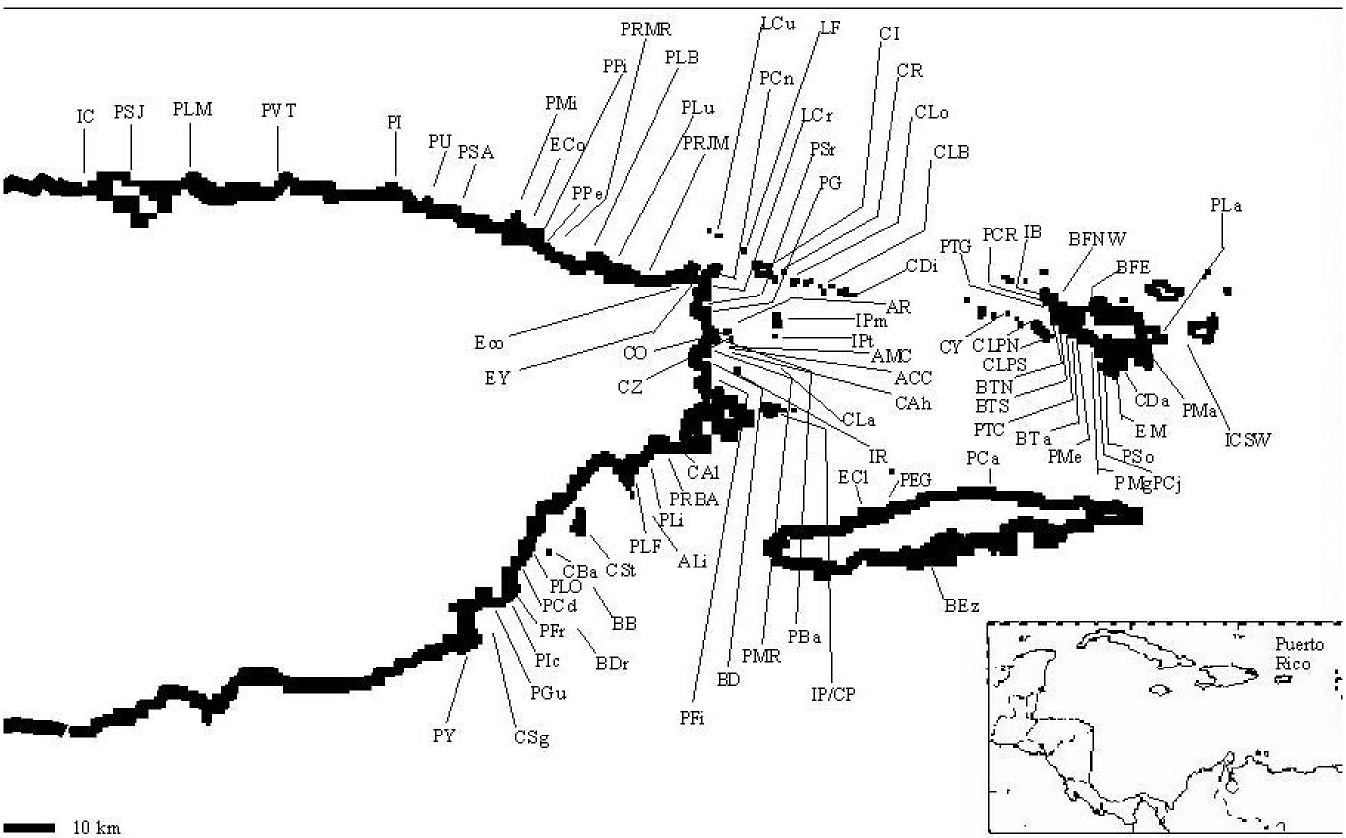


Figure 3. Average tissue loss in *A. palmata* by patchy necrosis in three coral reef areas with dense populations of the coral in La Parguera (Weil & Ruiz, unpublished data).

A .cervicornis, was documented from the northern and eastern reefs in past reports. It was present in 52.9% of the sites surveyed in the 1970's, but today, it is only found in 24% of these sites. It has disappeared from 43% of the eastern close offshore reefs, and from all the northern and eastern inshore sites. It is present in 100 % of the eastern offshore remote reefs, but it has decline in abundance. The hybrid *A. prolifera*, was rare in all of the four geographic localities. It disappeared from 100% of the northern reefs and from 60% of the eastern offshore close reefs. It disappeared also from 27% of the eastern offshore remote reefs. No colonies were ever documented in eastern inshore reefs. Recent surveys of two reefs in Culebra and northwest coats of Vieques islands, showed presence of isolated colonies and thickets of *A. cervicornis* (Weil et al., 1998) (Appendix 2). There were many small-sized thickets (10 x 5 m or less) of *A. cervicornis* in the southwestern side of Culebrita Island, but most of these where destroyed by recent hurricanes and disease outbreaks. Several isolated patches of *A. cervicornis* growing on Los Corchos Reef south of Culebrita Island are doing well (Hernández-Delgado, unpublished data). A WBD outbreak in August, 2001 caused partial to total colony mortality in 51% of the surveyed *A. cervicornis* colonies (n=118) within the Luis Peña Channel Marine Fishery Reserve, at Culebra (Hernández-Delgado, unpublished data). No current information is available for other localities in the the east coast of Puerto Rico or offshore islands. Low abundance of large mature colonies and low abundance or lack of juveniles, sexual recruits or reattached fragments is a clear indication that recovery is not occurring. Moreover, many recently dead colonies, and colonies showing partial tissue mortality are common sights in many of these localities. Despite the ability of Acroporid corals to regenerate tissue lesions (Matos-Caraballo, 1988) and grow fast, the combination of natural and anthropogenic factors may be preventing recovery in eastern reefs.

Figure 4. Map of the eastern section of Puerto Rico showing the location of 88 reef localities surveyed in the last 10 years. Many of these localities were surveyed in 1978-79 by Goenaga & Cintrón. List of localities can be found in Appendix 1. From Hernandez-Delgado (2000).



2.b. Southwest and western coasts

Acropora palmata

With few exceptions, *A. palmata* occurs at low densities from 0.5-5 m depth throughout the south and southwest coast of Puerto Rico. Colonies continue to experience partial mortality in many localities, however. This species is now rare below 5 m, but it can still be found in few, deep patch reefs and some locations on the shelf edge. High densities of medium to large colonies are common in at least two exposed reefs in La Parguera (Laurel and San Cristobal), and dense, high profile thickets pave the exposed fore reef of Atravesado (Appendix 2) (Bruckner et al., 1997; Weil, pers. obs.). No *A palmata* thickets were observed in extensive surveys from La Parguera to Ponce between 1995-1997, but medium size and few large colonies are common in some locations. Colonies were widely scattered (<1 colony every 5 m), or corals occurred in aggregates of less than 4 colonies (Bruckner and Morelock, unpublished data). Prevalence of corallivores and disease was high (Bruckner, unpublished data). High mortality was associated with Hurricane Georges (1998), and over 90% of coral was removed from Laurel, Pinnacles, Media Luna and Turrumote reefs off La Parguera (Bruckner, unpublished data, Ortiz, unpublished data). In 1999, disease affected an average 1.3% of all colonies of *A .palmata* in Turrumote, Media Luna and Laurel reefs off La Parguera (Weil, 2002), an apparent decline from previous years. Average live cover of this species on most reefs near La Parguera is now low or less than 1% (Williams, et al., 1999; Weil, unpublished data; Bruckner, unpublished data).

A recent problem is the mortality of *A. palmata* colonies by the intrusive colonization and fast advance of a brown, endolytic, clionid sponge (*Cliona langae*) (Fig 5). This sponge monopolizes much of the exposed reef substrate that was formerly occupied by live *A .palmata,* and it rapidly overgrows standing colonies and fragments. In 1999, an average 16 % of all colonies of *A. palmata* from three reefs in La Parguera, were attacked by the sponge. Average coral tissue mortality rate was 9 cm/year, which is faster than the coral's growth rate (Weil, 1999a,b and unpublished data). The sponge is resilient and in almost all cases, it kills the colony within a short period of time.

Small elkhorn coral thickets still occur on the west coast of Puerto Rico near Rincón (Steps Reef) and the northwest coast near Isabela (Shacks Reef) in 1-2 m depth. These populations were largely unaffected by disease or predation between 1994-1997 (Bruckner, pers. obs.). Unpublished data from August 1999 indicate that elkhorn thickets on fringing reef near Rincón (Tres Palmas and Steps) were still in excellent condition (EarthWatch report, 1999).

A. palmata has been virtually eliminated from other reefs near shore reefs of the west coast, especially near Mayagüez, possibly from anthropogenic disturbances (Morelock & Bruckner, unpublished data). One of the largest remaining healthy stands of elkhorn coral is located in 3-5 m deep in Bajo Gallardo reef, 13 km off the west coast. Coral disease outbreaks were observed during 1996 and 1997, however live coral cover remained high (30-90%), with corals in good shape with low incidence of recent mortality. Like many other shallow populations, this one was hit hard by Hurricane Georges, but remaining colonies and fragments recovered and/or reattached to the reef and were actively growing in 1999 (Earthwatch report, 1999).

Shallow areas of La Parguera were also hit hard by Georges, and in some areas nearly all *A. palmata* colonies were removed (Bruckner, pers. obs.). However, several reefs including Laurel and San Cristobal had a high number of remaining fragments which exhibited substantial growth by February of 1999 (Fig. 6) (Weil, pers. obs., Ortiz, unpublished data). Most colonies damaged by the Hurricane are now recovering

(Bruckner unpublished data, Earthwatch report, 1999; Ortiz, unpublished data). However, the survival of the fragments is being hampered by partial tissue mortality on the average of 46 % of the total live tissue in one year (Ortiz, unpublished data). Elkhorn coral thickets on fringing reefs near Rincón (Tres Palmas and Steps) were still in excellent condition in 1999, one year after Georges (Earthwatch report, 1999; Appendix 2). Populations of *A. palmata* on the southeast and west coast Mona island have been monitored in recent years. Two surveys in 1998 and two in 1999 indicate that in general, populations are in poor shape, with significant recent mortality, moderate-to-high incidence of disease, predation, algae and cyanobacteria overgrowth, and tissue loss caused by *Cliona* moving in (Bruckner, Earthwatch data, 1999; Bruckner and Bruckner, 2001; Weil, 1999a,b, unpublished data). Small thickets of *A. palmata* in fairly good shape exist to the north and south of the Fortuna Reefer restoration site in Mona island, although *Cliona*, patchy necrosis, white-band disease and neoplasia are affecting many of these colonies.

A recent study of the impact of snail predation on populations of acroporids indicate that they are playing an important role in the decline of acroporids in some reefs (Bruckner, 2000). Surveys of 12 reefs around La Parguera and the west coast found that snails were on 18 % of all colonies of *A. palmata* and that the average snail density on those colonies was 3.7 snails per colony. A larger proportion of colonies supported more snails in inshore reef habitats compared to exposed habitats. In some areas, up to 32 snails have been observed on a single colony. Also, larger snails have been recorded (which adds to more injury per snail) on *A. palmata* (Fig. 7) where they caused conspicuous feeding lesions and in several occasions, consumed entire colonies (Bruckner, 2000).

Acropora cervicornis* and *A. prolifera

Populations of *A. cervicornis* off the southwest coast of Puerto Rico are continuing to be impacted by WBD, predation, and other factors such as the occasional storm, which can be devastating. In 1996, white-band disease affected 0.5-10% of the colonies in four locations in La Parguera (Bruckner and Bruckner, 1997; Bruckner, unpublished data); disease prevalence varied seasonally, with a peak infection in August and September. In 1999, average disease incidence for *A. cervicornis* was 1.15 % in three reefs off La Parguera (Weil, 2002), an apparent decline from previous years.

Although there has been a substantial decline of *A. cervicornis* populations near la Parguera, abundant isolated colonies or small thickets can be found in several fringing and patch reefs in the area. High growth rates and some recruitment appear to exceed mortality in some localities, and dense and extensive fields have been able to reestablish (San Cristobal, Turrumote, Atravesado). The largest thickets of *A. cervicornis* (50 x 100 m) and *A. prolifera* (approximately 10 x 10 m) in the area are located on a shallow (1-3 m) sandy platform fringing the back lagoonal area on the northwest side of San Cristobal. Isolated colonies occur in western Puerto Rico, but no extensive thickets are known to remain. Small and healthy colonies were recently observed in several localities on the western platform (El Ron, Cabo Rojo, El Negro, Turmaline, Buyé). No current information is available for other localities.

Mujeres reef is a deep fringing reef in the southwest coast of Mona island. An extensive and healthy field of *A. cervicornis* (approximately 3,500 m^2 located between 12 and 15 m deep) was first observed in 1996 (R. Bruckner and E. Weil, pers. obs.). This population had no disease, few damselfish algal lawns, and few corallivores. It remained in good health during three subsequent surveys (Weil, unpublished data) until Hurricane Georges hit the island. Surveys during 1999-2001 revealed few remaining live colonies (Earthwatch report, 2001). Isolated colonies and small thickets can still be found along the southwest coast of Mona and around Mujeres reef. Some recovery has been noted (Bruckner, pers. obs.). Several small

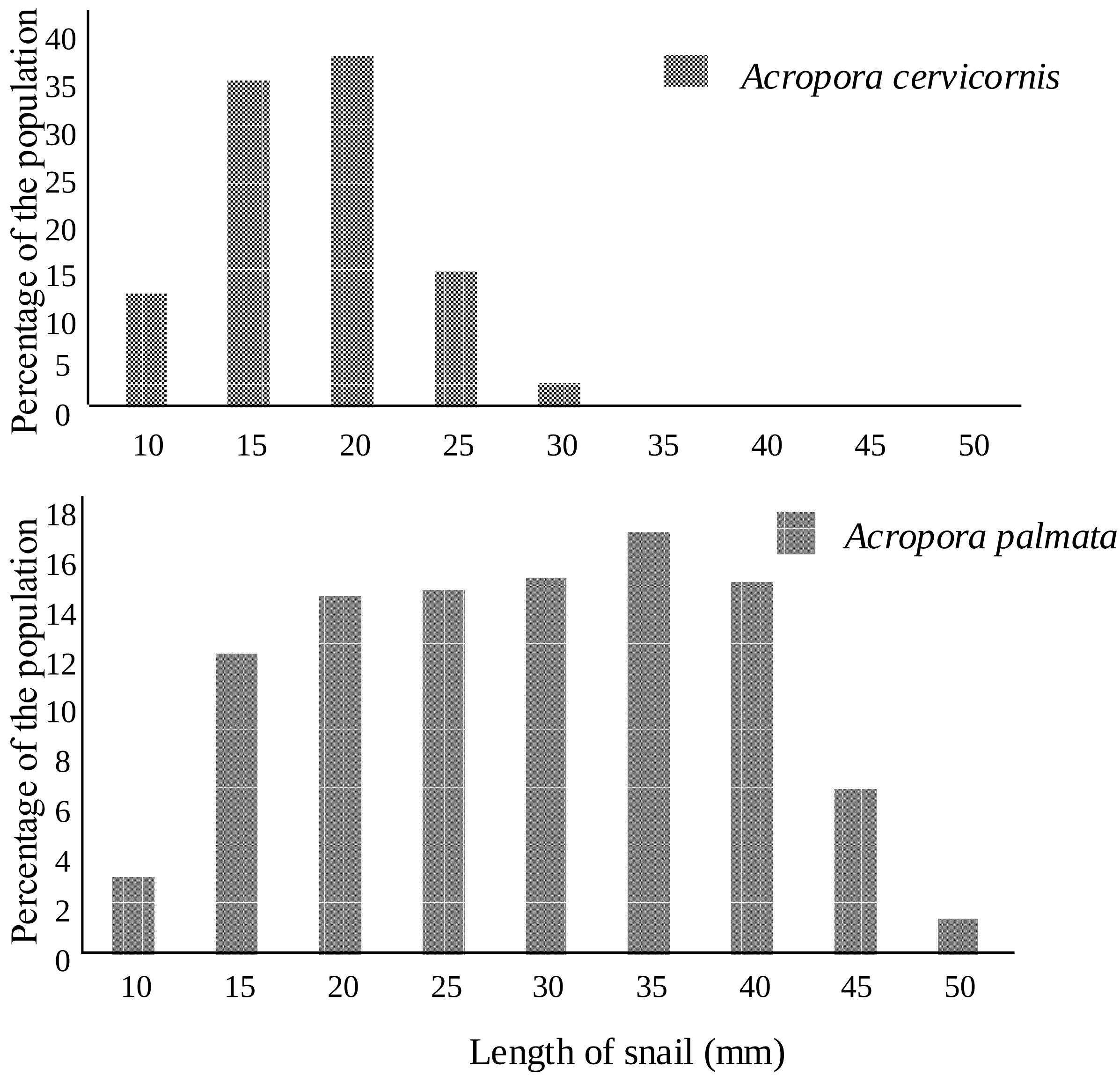


Figure 7. Shell length frequency distribution of *C. abbreviata* in acroporids from reefs off the southwest coast of Puerto Rico (from Bruckner, 2000).

colonies and few large colonies and small isolated thickets have been observed in surveys (1999-2002) conducted in the southwest coast of Desecheo island (3-22 m deep). Few of these were affected by WBD and no corallivores were observed. Significant accumulations of bioeroded and fouled *A .cervicornis* rubble in the area indicates that the species was abundant in the past (Weil, unpublished data).

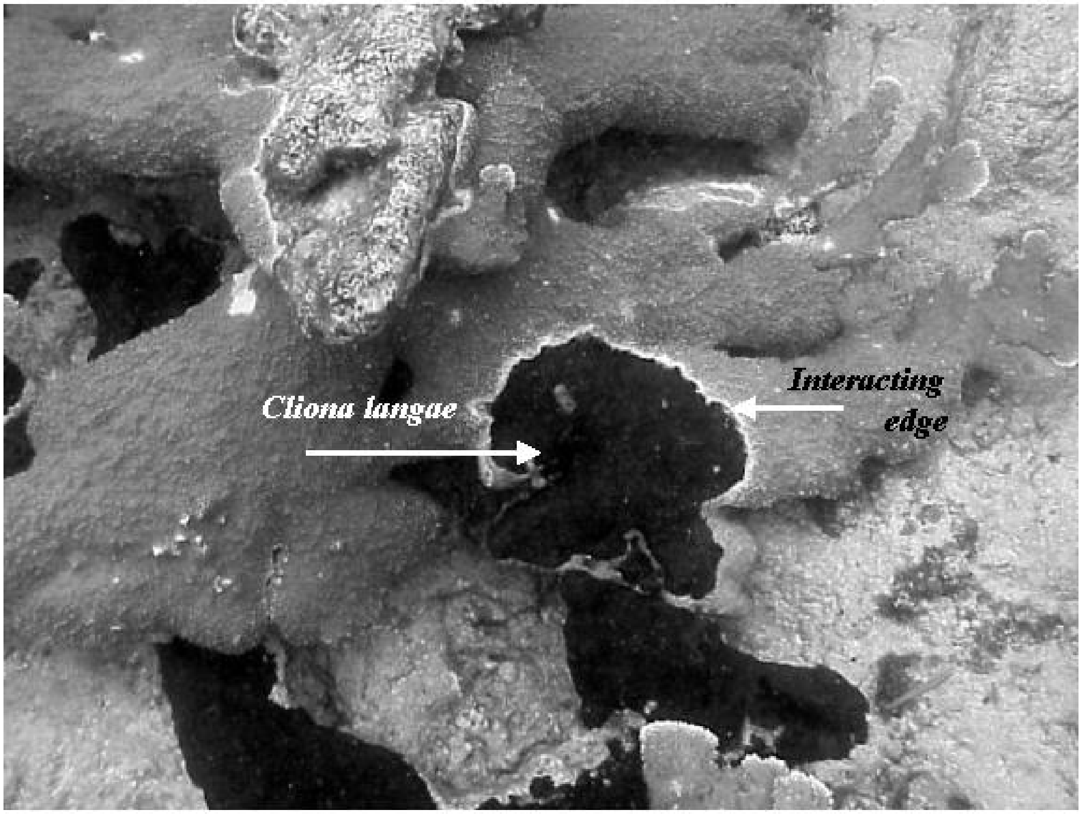
The Department of Natural Resources has conducted monitoring surveys in several reefs around Puerto Rico in the last three years. In 16 reefs surveyed in 2001, most of the transects sampled did not contain colonies of *A. cervicornis or A. palmata*. A total of 3 colonies were observed in 80 transects. The colonies ranged in size from 10 to 85 centimeters measured as the distance intercepted by the chain transect. The mean percent cover of *A. cervicornis* for the Canoas, Botes, and Media Luna reef sites was 1.7%, 0.5%, and 0.2% respectively. The overall mean percent cover for the 80 transects of the study is 0.15%. Additionally one of the colonies in Desecheo (21 kilometers west of Puerto Rico and frequently flushed by oceanic waters) was observed with white-band disease.

Table 3. Percent decline in the number of northeastern and eastern reef sites with *Acropora* spp. populations in the last 20 years.

Geographic province	Reefs Surveyed	Reefs with Acroporids old survey	Reefs with Acroporids today	Percent Change
Acropora palmata				
Northern inshore	19	19	6	68.4
Eastern inshore	18	15	7	53.3
Eastern offshore close	24	22	15	31.8
Eastern offshore remote	27	23	22	4.3
Total number of localities	85	79 (93 %)	50	36.7
Acropora cervicornis				
Northern inshore	19	2	0	100
Eastern inshore	18	3	0	100
Eastern offshore close	24	14	8	42.9
Eastern offshore remote	27	26	26	0
Total number of localities	85	45 (52.9 %)	34	24.4
Acropora prolifera				
Northern inshore	19	1	0	100
Eastern inshore	18	0	0	N.P.*
Eastern offshore close	24	5	2	60.1
Eastern offshore remote	27	11	8	27.3
Total number of localities	85	17 (20 %)	10	41.1

*N.P.= Not present in any survey.

Figure 5. Colony of *Acropora palmata* being killed by the endolytic sponge *Cliona langae* in Laurel reef, La Parguera, PR. (photo E.Weil)



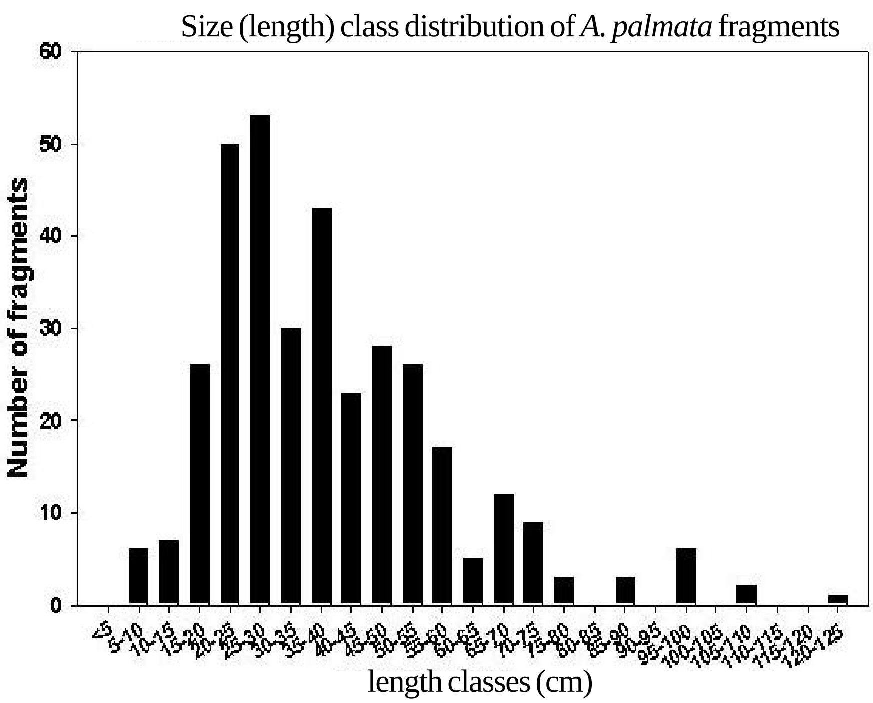


Figure 6. Size frequency distribution of *A. palmata* fragments one year after Hurricane Georges hit Puerto Rico in 1998 (Ortiz, unpublished data).

3. Management approaches in Puerto Rico DNER pertinent to conservation

3a. Existing and proposed regulations

Law for the Protection, Conservation, and Management of Coral Reefs in Puerto Rico (Law 147)

In Puerto Rico there exist several laws and proposed regulations that may aid in the conservation of corals. The most pertinent statute is the Law for the Protection, Conservation, and Management of Coral Reefs in Puerto Rico, is Law 147. This law explicitly mandates the conservation and management of coral reefs in order to protect their functions and values. The Department of Natural and Environmental Resources (DNER), the agency in charge of implementing the law, will do so through a regulation that is currently being prepared. Law 147 provides for the creation of zoned areas in order to mitigate impacts from human activities. These zones include (1) Reef Recuperation Areas and (2) Ecologically Sensitive Areas. Although the specifics are being worked out, these zones will facilitate the DNER in controlling human activity that can directly impact *Acropora* spp. such as anchoring. Law 147 also directs the DNER to identify and mitigate threats to coral reefs from degraded water quality due to pollution, a measure that can also be used to protect reefs with *Acropora* spp. In this regard, the law requires Environmental Impact Statements (EIS) for projects or activities that can negatively affect coral reefs. An interagency committee will be convened to coordinate government activities that may affect coral reefs.

Marine Reserves Law

Law 137 from 2000 directs the DNER to designate priority areas as marine reserves. Marine reserves are defined as areas where all extractive activities are prohibited in order to help recover depleted fishery resources and protect biodiversity. The law states that that 3 percent of the insular platform must be designated within 3 years (2003). This mechanism could be helpful in the conservation of *Acropora* spp. if it is determined that overfishing of coral reefs that is affecting survivorship of these corals. It has been hypothesized that overfishing of reef fish, octopus, and lobster may lead to an increased abundance of *Acropora* spp. predators. Currently there are two marine reserves in Puerto Rico, Reserva Natural Canal Luis Peña in Culebra, and Desecheo Island.

3b. Existing conservation strategies

Natural Reserves

There are currently 13 natural reserves in Puerto Rico that have coral reefs within their boundaries. The natural reserves are a logical setting to adopt the zoning measures mentioned above because of the available infrastructure and experience. Zoning strategies that regulate direct human impacts, such as no anchor zones, may be more easily applied due to the existing jurisdiction, although this remains to be seen. It should be noted that natural reserves probably have minimal success in preventing impacts to coral reefs and *Acropora* spp. from degraded water quality because these impacts are not excluded by reserve boundaries. More information is needed on the location and status of *Acropora* spp. populations within the natural reserves in order to apply the conservation strategies, particularly those pertaining to direct impacts.

Mooring buoys

Another existing strategy that may assist in the conservation of these species is the use of mooring buoys. The DNER has been utilizing this strategy since 1990 principally in Fajardo, Culebra, Guánica, and La Parguera. It is apparent that *Acropora* spp. are very vulnerable to anchor damage because of their branching growth form and their presence in shallow reef zones where anchoring is common. This strategy can be applied in cases where heavy anchoring is occurring on reefs with high abundance of these species. As mentioned above it is necessary to obtain more information on the location of reefs with existing *Acropora* spp. populations that may be important to their conservation.

Restoration projects

Currently there is a restoration project being conducted with *Acropora* spp. in southwest Puerto Rico. The restoration includes reefs on the southwest and west coast in its first stage. This project involves a coral nursery that uses fragments to propagate colonies for restoring populations. Specially designed structures to growth the fragments and transport them without major manipulations have been designed along to facilitate transport and placement once the fragments reach a certain size. One important aspect of this project is that it includes considerations and methods to preserve sufficient levels of natural genetic variation in the cultured fragments to increase genetic variability in the restored populations so it can respond to both short- and long-term changes in the environment. Fragments collected from different populations (well separated) in different areas of the southwest are cultured in the farm for future propagation to impacted areas in Puerto Rico or even, in other places within the Caribbean. As soon as the transplanted fragments reach sexual reproductive sizes in their final restoration site, the chances of increasing genetic combinations during the reproductive season of the population in the area also increases.

This project is now on its second phase. Preliminary results indicate that the overall survival of coral fragments, 10 months after transplanted, was 86.6% (n= 367), however, differences in the survival of different clones was observed. This could imply that some clones may be better adapted to survive and grow in a wild range of environmental conditions while other may be restricted to specific environmental conditions (light regime, sedimentation rates, water movement, etc.). Survival of fragments had also been affected by their manipulation and transportation, and by algae (*Ceramium nitens*) overgrowth. New methods were developed after the first movement of fragments and mortality during transportation has been reduced significantly. In the second phase, over 2,000 coral fragments have been transported with an overall survival rate of 99.6% one month after the fragments were transplanted into the reef area. Maintenance of the culturing devices every two weeks is needed to prevent algae overgrowth.

The overall linear growth (accumulate length of all branches), 10 months after transplantation, was 52.2 ± 4.6 cm (n= 318 initial fragments). High growth rates account for the fast linear extension of most fragments in the culturing devices with an overall net linear growth of 38.4 ± 4.5 cm. Other useful parameter in coral farming is the branchiness (number of branches produced over time). These measurements provide information to decide the number of fragments that will be harvested after one or two years. The overall number of branches produced, was 7.3 ± 1.8 branches per year. To calculate the expected number of corals to be harvested and propagated to restoration places, the number of initial fragments to be transplanted is multiplied by 7. However, after 10 months of coral growth, the branch lengths of those corals were too small to be harvest. From this previous work, we expect that 1.5 to 2 years of coral growth are needed to harvest the cultured coral fragments (branches).

4. Needs for Improving Conservation

Water quality

In order to improve the current conservation efforts there are some gaps in knowledge that need to be addressed. One important question is understanding how water quality impacts are affecting the persistence of *Acropora* spp. in Puerto Rico. Previous research has highlighted the degraded condition of many near-shore reefs in Puerto Rico (Goenaga and Cintron 1979; Goenaga and Boulon 1992; Hernandez-Delgado, 2000; Velazco et al., 1985). It is evident that there are multiple factors causing this degradation but there seems to be a general consensus that water quality impacts are a major force involved in this decline. Two major threats to water quality on coral reefs in Puerto Rico are high loads of suspended sediments and nutrient contamination, although direct evidence is only available implicating sediment impacts. Since it is probable that impacts from degraded water quality play a role in the health of these species, a logical step in conservation may be to determine thresholds in the important parameters in order to establish adequate standards.

Information on location and status

More information is needed on the location and condition of these species, particularly information on areas that may be important to conservation because of high abundance. Management efforts should compile all of the available information for Puerto Rico to determine where there are information gaps. Habitat maps are currently available from the NOAA/NOS biogeography program[1]. These could be useful for mapping and quantifying the existing *Acropora* spp. A methodology should be developed to aid in this quantification and it should provide for comparing abundances among reefs such that spatial priorities can be established.

Case study- Proposed Natural Reserve in Rincon

A situation that can be used to examine conservation strategies for *A. palmata* in Puerto Rico involves a fringing reef in Rincon with a high abundance of healthy colonies. Several years of monitoring has showed that the colonies at this site are some of the healthiest in the northwest (A. Bruckner, letter to DNER; Appendix III, this report). The adjacent coastal zone exhibits low levels of development although the reef experiences increases in turbidity from storm runoff (A. Bruckner, unpublished data. Letter to DNER). There are currently several large resort development projects proposed for the adjacent terrestrial areas. Possible threats from this type of development to the *A. palmata* include water quality degradation from increased run-off, and direct impacts from increased recreational activities. Several local NGO's have proposed the creation of a natural reserve encompassing the reef, adjacent marine habitats and available land areas, as mechanism to mitigate impacts. The strategy aims to use the natural reserve designation to prevent or minimize the development, although there is no evidence that this has been successful elsewhere. Any effort should strive to prevent the creation of a Paper Park by providing effective solutions. The best case scenario for this reef would be the avoidance of impacts by not doing the development projects. If this is not successful then the impacts should be minimized and mitigation should include monitoring programs to insure the *A. palmata* is not affected. Impacts from recreational activities could be managed with the use of zoned areas as provided by the Coral Reef Conservation Law. The question arises as to the role of ESA designation for this case in Rincon.

[1]NOAA/NOS NCCOS/Biogeography Program. 1305 East West Highway, Silver Spring, MD. 20910. 301-713-3028 x 144

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Appendix 1a. Distribution of *Acropora* spp. in northern inshore Puerto Rican coral reefs (based on presence/absence data).

Location	Historic (1970s)			Present (1999-2002)		
	A. pal	*A.cer*	*A.pro*	*A. pal*	*A.cer*	*A.pro*
Playa de Vega Baja	*			*		
Cerro Gordo, Vega Alta	*					
Isla de Cabras, Cataño	*					
Punta San Jorge, San Juan	*					
Punta Las Marías, Carolina	*			*		
Punta Vacía Talega, Loíza	*					
Punta Iglesias, Loíza	*					
Punta Uvero, Río Grande	*					
Punta San Agustín, Río Grande	*					
Punta Miquillo, Río Grande	*					
Ensenada Comezón, Río Grande	*					
Punta Picúa, Río Grande	*					
Punta Percha, Río Grande	*					
Patch reef off Río Grande	*					
Punta La Bandera, Luquillo	*			*		
Playa de Luquillo	*			*		
La Selva, Luquillo	*					
Playa El Convento, Fajardo	*	*		*		
Ensenada Yegua, Fajardo	*	*	*	*		
n=19	*19*	*2*	*1*	*6*	*0*	*0*

Appendix 1b. Distribution of *Acropora* spp. in eastern inshore Puerto Rican coral reefs (based on presence/absence data).

Location	Historic (1970s)			Present (1999-2002)		
	A. pal	*A.cer*	*A.pro*	*A. pal*	*A.cer*	*A.pro*
Playa Canalejo, Fajardo	*			*		
Playa Las Croabas, Fajardo	*					
Playa Sardinera, Fajardo	*					
Punta Gorda, Fajardo						
Punta Barrancas, Fajardo	*					
Punta Mata Redonda, Fajardo	*					
Bahía Demajagua, Fajardo	*					
Punta Figueras, Ceiba						
Cayo Algodones, Naguabo	*	*		*		
Patch reef off Bahía Algodones, Naguabo	*			*		
Punta Lima, Naguabo	*			*		
Playa Fanduca, Naguabo	*			*		
Playa Las Ochenta, Humacao						
Punta Candelero, Humacao	*	*		*		
Punta Fraile, Humacao	*	*		*		
Punta Icacos, Humacao	*					
Punta Guayanés, Yabucoa	*					
Punta Yegua, Yabucoa	*					
n=18	*15*	*3*	*0*	*7*	*0*	*0*

Appendix 1c. Distribution of *Acropora* spp. in eastern offshore close (<6 km) Puerto Rican coral reefs (based on presence/absence data).

Location	Historic (1970s)			Present (1999-2002)		
	A. pal	*A.cer*	*A.pro*	*A. pal*	*A.cer*	*A.pro*
Cayo Obispo, Fajardo	*	*				
Cayo Zancudo, Fajardo	*					
Arrecife Mata Caballos, Fajardo	*					
Arrecife Roncador, Fajardo	*	*	*	*		*
Arrecife Corona Carrillo, Fajardo	*					
Cayo Ahogado, Fajardo	*	*				
Isla de Ramos, Fajardo	*	*		*		
Isla Piñero/Cabeza de Perro, Ceiba	*	*		*		
Arrecife Lima, Naguabo	*			*		
Cayo Santiago, Humacao	*			*		
Cayo Batata, Humacao	*					
Bajo Blake, Humacao						
Bajo Drift, Humacao						
Cayo Sargento, Yabucoa	*	*				
Cayo Largo, Fajardo	*	*		*	*	
Las Cucarachas, Fajardo	*			*		
Los Farallones, Fajardo	*			*		
Cayo Icacos, Fajardo	*	*	*	*	*	
Cayo Ratones, Fajardo	*	*		*	*	
Cayo Lobo, Fajardo	*	*		*	*	
Islote Palominitos, Fajardo	*	*	*	*	*	
Isla Palominos, Fajardo	*	*	*	*	*	
Cayo La Blanquilla, Fajardo	*	*		*	*	
Cayo Diablo, Fajardo	*	*	*	*	*	*
n=24	*22*	*14*	*5*	*15*	*8*	*2*

Appendix 2. Relative abundances of acroporid corals and sexual recruits in several reef localities along the south and west of the main island and few offshore islands. (*** = abundant, ** =few patches and isolated colonies, * = isolated colonies).

Locality	Reef	Depth m	Latitude	Longitude	*A. palmata*	*A. cervicornis*	Sexual recruits
Guanica	Aurora	0.5 - 15	17° 56.652		**	*	*
	Coral	0.5 - 15			*	***	
Parguera	Corral	0.5 - 15			**	*	*
	Pinnacles W	1.5 - 20	17^3 55.973	67^3 00.726	*	*	*
	Pinnacles E	2 - 20	17^3 55.973	67^3 00.720	*	*	*
	Turrumote	0.5 - 20	17^3 56.061	67^3 01.066	**	**	*
	Mata la Gata	0.5 - 12	17^3 57.664	67^3 02.253	**		*
	Caracoles	0.5 - 12	17^3 57.65	67^3 02.175			
	Enrique	0.5 - 18	17^3 57.223	67^3 03.119	*	*	*
	Media Luna	0.5 - 20	17^3 56.092	67^3 02.952	*	*	*
	Laurel	0.5 - 18	17^3 56.581	67^3 03.296	**	**	*
	Mario	0.5 - 18	17^3 57.157	67^3 03.380	*	*	*
	Conserva	0.5 - 14	17^3 57.442	67^3 03.397	*	*	
	Long Reef	4 - 20	17^{3}55.439	67^3 00.962	*	*	*
	San Cristobal	0.5 - 18	17^3 56.581	67^3 04.673	**	**	*
	Atravesado	0.5 - 15	17^3 56.521	67^3 05.094	***	***	*
	El Palo	0.5 - 12	17^3 56.006	67^3 05.702	**	*	*
	Margarita	0.5 - 12	17^3 36.006	67^3 05.702	*	*	*
	Acuario	15 - 20			*	*	*
	Black Wall	17 - 30	17^3 58.569	67^3 04.175		*	
	Buoy site	17 - 30	17^3 53.304	66^3 59.074		*	*
	Shelf edge	17 - 30	17^3 52.104	66^3 61.104		*	
Cabo Rojo	El Ron	0.5-18			*	*	
	Buye	0.5-10	18° 08.068	67° 11.210	*		
Joyuda	El Negro	0.5-20	18^3 09.162	67^3 14.758	**	*	*
Mayaguez	Gallardo	1.5-18			***		
Rincon	Tres Palmas	1-3			**		
	Steps	1-3	18^3 21	67^3 15	**		
Aguadilla	El Natural	5-20			*		
Desecheo Is.	South Gardens	1-22	18^3 22.69	67^3 29.044	*	**	*
	West	1.5-18	18^3 22.740	67^{3}29.120	*		
Isabela	Shacks Reef	1-14			**		
Mona Island	Fortuna Reefer	1-12	18° 02	67° 51	**		*
	Pajaro	4-15	18° 03.930	67° 51.938	*	*	*
	Mujeres	10-20	18° 04.503	67° 56.278		*	*
	Sardinera	0.5-10	18° 05.410	67° 56.420	*		
	Carmelita	0.5-3	18° 05.650	67° 56.502	**		
Culebra	Culebra s-w	0.5-18	18° 29.330	65° 29.910	*	*	*
Vieques	Viequez n-w	0.5-18	18° 16.300	65° 42.200	*	*	*

Appendix 3: Letter to DNER on *Acropora palmata* populations at Steps Reef, Rincon

Vicente Quevedo
Natural Heritage Division
DNER
P.O. Box 9066600
Pta. De Tierra Station
San Juan, P.R. 00906-6600

Dear Mr. Quevedo,

I was recently informed that Puerto Rico’s Department of Natural and Environmental Resources (DNER) is considering the establishment of a marine natural reserve for Steps Beach and surrounding reefs off the west coast to offer protection for the benefit of the elkhorn reef system in Rincon. I would recommend implementing additional conservation measures for the coastal habitats near Steps and Tres Palmas, particularly because these areas support endangered and threatened wildlife, and also contains one of the few remaining healthy stands of elkhorn coral (*Acropora palmata*) left in the Caribbean. A large-scale development project in the cattle field immediately fronting Steps Reef is likely to cause substantial run-off during construction, and elevated nutrients and pollutants once the establishment is operational (as a result of increased sewage production and pesticides and fertilizers used on the surrounding grounds). Coral reefs are negatively affected by sediments, excessive nutrients and pollutants, and elkhorn corals are particularly sensitive to these types of stressors. A development project in this area may accelerate the decline in the health and productivity of the nearshore reefs, and possibly threaten the survival of elkhorn coral populations due to their limited tolerance to sedimentation and nutrient loading.

In support of further protection for Steps and Tres Palmas as a marine natural reserve, I am providing this information on the diversity, health and importance of two coral reefs located off the west coast of Puerto Rico near Rincon, Steps Reef and Tres Palmas. I conducted monthly surveys on Steps and Tres Palmas between 1994-1997, and annual surveys in 1998-2000. I am coral reef ecologist with the National Marine Fisheries Service. I received my Ph.D. from the University of Puerto Rico, Department of Marine Sciences in La Parguera, where I lived from 1994-1998. During the five years I lived in Puerto Rico, I spent 4-5 days per week diving on reefs off the northwest, west and south coast of Puerto Rico, and have continued to revisit these sites two times each year. For my research and dissertation I examined the effect of coral diseases and predators on important reef building corals. I collected information on different measures of coral reef health from the west and south coast near Aguadilla, Rincon, Desecheo, Mayaguez, Boqueron, La Parguera, Guayanilla, Guanica, and Ponce. I also established permanent study sites on the northwest coast (Aguadilla), southwest coast (off Parguera), the west coast at Steps and Tres Palmas (Rincon), and Mona Island, to conduct a detailed study of coral disease processes, long-term impacts, and synergistic effects of human activities. I have continued my research in Puerto Rico over the last three years under a study sponsored by Earthwatch “Saving Puerto Rico’s Reefs”. My studies focus on the effects of disease, predation and storm damage on the dominant and most important corals, including elkhorn coral, star coral and brain coral. I take a holistic approach to my research to obtain a snapshot of the health of the reef ecosystem using a modification of the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol (I examine corals as well as other indicators of reef health like fish abundance and size, type and biomass of algae, and present of key indicator organisms including commercially important species and keystone species). I also examine the long-term effect of these processes on coral survival, growth and new recruitment.

In the following document, I have provided a summary of the importance and role of elkhorn corals, their status throughout the region including Puerto Rico, threats that are impacting elkhorn coral populations, and measures that are needed to protect these corals. I am providing specific information on the elkhorn coral reef at Steps and Tres Palmas, based on my study between 1994-2000. I was unable to reexamine these sites in 2001 due to weather. It is important that these sites continue to be monitored to detect change in reef health. A detailed synoptic examination of the site in 2002 is recommended to quantify the extent, abundance and condition of the elkhorn population. I would be interested in conducting these studies but would need minimal support to conduct the work. If you have any questions about the following document, please contact me at andy.bruckner@noaa.gov.

Rincon's unusual elkhorn coral *Acropora palmata* thickets

Steps and Tres Palmas reefs are some of the best developed fringing coral reefs found off the west coast of Puerto Rico. The coastline at Rincon is fringed by a narrow sandy beach, with beach rock at the waters edge. Tres Palmas and Steps Reefs are two hardground areas, separated by a channel 50-150 m wide. The reefs start immediately seaward of the beach rock and slope from 0.5m to 8-10 m depth. The reef extends out for less than 200 m before terminating in a shallow sand flat (8-10 m depth). In shallow water (0.5-3 m depth) the reef is dominated by *Acropora palmata* with isolated brain, star and mustard hill corals. Elkhorn colonies form a dense stand that begins about 5 m offshore and extends seaward 20-30 m. The densest areas of elkhorn growth are near Steps and Tres Palmas, and colonies also occur at a lower density from just north of the marina to the dome. The deeper portion of the reefs (from 2-8 m) is dominated by *Diploria strigosa*, but many other massive and branching corals, sea fans, soft corals, and other invertebrates also occur here.[1]

A second reef begins from 250-400 m offshore. This reef is completely submerged, and slopes gradually seaward to about 70 feet. It is shallowest at the landward edge (0.5-2m) where the reef is colonized by isolated *A. palmata* colonies, and massive and plating corals dispersed over the remainder of the hardground areas. There is relatively high cover (25-40%) in moderate depths (15-20 m) and several large massive boulder corals and plating corals.

Background information on *Acropora palmata*

Life history: *Acropora palmata* is a fast-growing (5-10 cm/year linear branch extension) branching coral that forms dense thickets (stands) from 0.5-6 m depth in exposed fore reef environments. Colonies are also found in exposed back reef and deeper fore reef zones (to 18 m depth) at a lower abundance**,** provided that there is good circulation, high light, and low levels of sedimentation. Colonies are large and tree-like with exceptionally thick and sturdy branches up to 3 m in diameter. Elkhorn coral is an annual broadcast spawner (individual colonies release eggs and sperm bundles in August/ September) that produces millions of gametes, but this species exhibits very low rates of sexual recruitment. The main mode reproduction is believed to be asexual - colonies produce long branches that become very fragile and are easily dislodged during storms. These detached branches reattach to substrate and continue to grow, and damaged adult colonies regenerate injuries.

At Steps, Tres Palmas and other surrounding fringing reefs, sea conditions are generally calm from April through September, with periods of high wave action in winter. Colonies are often fragmented, and the reef substrate may be littered with branches, but these rapidly fuse to the substrate and begin sending up new branches (protobranches). This has allowed elkhorn populations to rapidly recover from storms; elkhorn coral populations have remained very dense, with colonies slowly expanding into deeper water and to neighboring areas.

Distribution and abundance: This species was formerly the dominant species on the shallow fore reef in the Florida Reef Tract, the Bahamas and throughout the Caribbean[2] , forming extensive, densely aggregated, monospecific thickets between low water level and 5-6 m depth, in wave-exposed and high surge reef zones.

Colonies of *A. palmata* occur throughout shallow nearshore reef environments of Puerto Rico, except for 1) locations on much of the north coast; 2) reef environments adjacent to major cities; and 3) reefs affected by discharge from large rivers. Elkhorn populations were formerly most abundant on the northwest coast near Jobos and Isabela; on the west coast near Rincon; south of Mayaguez to Boqueron; on reefs near La Parguera; fringing reefs near Guayanilla, Guanica, Ponce; isolated reefs near Punta Tuna; Fajardo and offshore emergent reefs, and the islands of Mona, Culebra and Vieques. Possibly the largest remaining stand of elkhorn coral in Puerto Rico is located at depths of 3-5 m on a submerged reef 15-20 km off Boqueron (Bajo Gullardo). During the 1970s and 1980s Goenaga conducted island-wide surveys of reefs; and his reports provide extensive information on known locations of *A. palmata* throughout Puerto Rico.

Success and limitations of life history and population recovery: The success this species has achieved is a result of its fast rate of growth, persistence of injured adults by rapid wound healing, and high rate of asexual recruitment of fragments (Gladfelter et al., 1978; Bak and Criens, 1981; Highsmith, 1982). *A. palmata* has adaptations for survival in shallow, high energy reef environments occupied by few other stony corals, but colonies are susceptible to breakage from physical forces associated with storms and high wave action. Branches that break off standing colonies fuse to the substrate and continue growing. This has allowed *A. palmata* to rapidly recolonize an area after a major disturbance and spread into new areas, especially habitats not suitable for settlement by sexually-produced larvae (Fong and Lirman, 1997). However, this mode of reproduction also limits the extent of spread of populations. Unlike *A. palmata*, colonies that reproduce sexually and have a high success of settlement and recruitment of planula larvae benefit from the ability to disperse to surrounding and distant reefs, as the larvae are carried by water currents. Because *A. palmata* exhibits limited ability to recruit sexually, damaged populations are unlikely to recover unless a local source of branches remains following the disturbance.

While storms may enhance the spread of *A. palmata* populations, recent observations indicate that initial mortality to colonies and fragments may be quite high, injured colonies and fragments exhibit reduced growth rates and declines in reproductive output, and damaged populations are susceptible to subsequent disturbances (Bruckner, unpubl. Data; Lirman, 1998). If populations of *A. palmata* were seriously damaged near Rincon, there is no other site within close proximity that could serve as a site for new recruits. Populations of elkhorn coral formerly existed on reefs surrounding the Mayaguez Bay, but these have largely disappeared as a result of poor water quality.

Importance of *Acropora palmata*

A. Storm damage: Elkhorn coral thickets reduce incoming wave energy, offering critical protection to coastlines. Loss of this species may negatively affect shorelines with mangrove and grass bed habitats which rely on calm water provided by these effective reef barriers. Fringing reefs with elkhorn thickets, like those found in Rincon, are also particularly important to coastal communities and the beach as they form a buffer that protects shorelines from erosion during storms. The loss of elkhorn thickets results in higher wave action reaching coastal environments, and this can lead to erosion and loss of nearshore grassbeds and mangroves. In Rincon, the elkhorn thickets front a narrow sandy beach. There is high wave action during winter. This is associated with offshore transport of sand, which accumulates among the corals on fringing reefs and in the surrounding area. Without the presence of a large stand of elkhorn coral, it is likely that much more sand will be carried offshore during periods of high wave action, and the beaches may eventually disappear.

B. Fisheries habitat: The high structural complexity produced by the interdigitated branches of *A. palmata* colonies provide essential fish habitat. Studies from Florida and the Virgin islands have shown that a higher number of lobsters, snappers, grunts, parrotfish and other large reef fish occur in areas with live stands of elkhorn coral. In many locations elkhorn populations have died, but erect skeletons (standing in place) may remain for 10-20 years. Dead colonies continue to provide high relief habitat utilized by a number of organisms. The skeletons are rapidly overgrown with algae and benthic invertebrates, and fish communities become dominated by schools of herbivorous fish like surgeonfish due to increased biomass of algae. Over time, however, the skeletons eventually collapse, eliminating high-relief topography and habitat for predatory fish and motile invertebrates.

C. Reef growth: Coral reefs were formerly dominated (prior to 1980s) by three species of coral - elkhorn coral (*A. palmata*), staghorn coral (*Acropora cervicornis*) and star coral (*Montastrea annularis* complex). *A. palmata* formed characteristic thickets in the shallowest, exposed areas, on fringing reefs and the outer portions of offshore reefs. These often extended along the coastline or the crest of the reef for several kilometers. *A. cervicornis* also forms thickets, but it occurs in intermediate depths (5-25 m) on the fore reef in areas with moderate to low amounts of wave action, and shallow calm back reef environments. *M. annularis* is a complex of three species of massive corals that occurs throughout most reef environments (it is uncommon in areas dominated by elkhorn coral). *M. annularis* grows very slowly and colonies may live for hundreds of years forming immense structures several meters tall.

The genus *Acropora* include the fastest growing scleractinian corals in the Indo-Pacific and Caribbean. Branch extension rates of 10-12 cm per year are common for the Caribbean species, which is approximately 10 times greater than massive reef-building corals. Gladfelter (1982) estimated a rate of reef accretion by elkhorn coral of 10.3 kg $CaCO_3/m^2/yr$; over 1000 years, shallow windward *A. palmata* reefs have grown upward close to 15 meters, keeping pace with rising sea level (Adey, 1975).

This growth results in a large accumulation of branches and rubble as a result of wave action that periodically prunes colonies. Some of these branches are carried to deep reef or soft bottom communities, where they accumulate and are cemented together. This creates additional habitat for fish, hard substrate for colonization by other corals, and also contributes to reef growth. In offshore populations of elkhorn coral, hurricanes will also break branches and carry these from the front of the reef to the back side, depositing them in a lower energy environment. These accumulate and slowly build new islands. Recently Dr. Ernest Williams and colleagues excavated several of the outer islands off La Parguera (Turrumote; Media Luna) and found that the entire island consists of elkhorn coral.

Threats: *A. palmata* once was the dominant scleractinian coral on high-energy, windward reefs of the tropical western Atlantic (Goreau, 1959; Almy and Carrion-Torres, 1963). Over the past two decades the density of this species has been greatly reduced throughout its range as a result of various anthropogenic and natural disturbances[3], especially white-band disease (WBD) epizootics and storm damage (Gladfelter, 1982; Peters, *et al*.,1983; Rogers, *et al*., 1982; Peters, 1993). A number of studies have shown that elkhorn reefs rapidly recovered from periodic storms and other short-term disturbances through regrowth of colony stumps and branch fragments. However, in many cases elkhorn populations are being impacted by a number of different stresses at the same time which have may a synergistic effect, compounding losses or preventing recovery.

Acropora palmata populations on the southwest coast of Puerto Rico have suffered similar losses to that reported from other parts of the Caribbean. These reefs have been impacted by relatively few hurricanes since the 1960's, the most severe of which were Hurricanes Edith (1963), David and Frederick (1979), Hortense (1996) and Georges (1998). While Hurricane Edith caused extensive destruction to *A. palmata* thickets, Glynn et al. (1964) observed high survivorship and continued growth among damaged colonies and fragments. Hurricanes David and Frederick also damaged *A. palmata* populations (Armstrong, 1983), however information on patterns of recovery is unavailable. I followed the fates of hurricane generated fragments on reefs near La Parguera after Tropical Storm Debbie (1994), Hurricane Hortense and Hurricane Georges (Bruckner, unpubl. Data). In my study area a high incidence of disease affected fragments after Debbie with mortality that exceeded 50% of the branches, and Hortense dislodged and overturned many of the remaining fragments. However, new fragments produced during Hortense exhibited fairly good survival until Hurricane Georges, which removed most remaining standing colonies and fragments generated by Hortense. Some sites in La Parguera have shown little recovery after 3 years. Although La Parguera has some of the best deep reef environments (e.g., shelf edge reefs) found in Puerto Rico (and these rival reefs found throughout the Caribbean), there is only one reef in the entire Parguera reef system that still has an extensive thicket of *A. palmata* (Morelock, pers. Comm.Bruckner, unpubl. data). in areas off La Parguera where this species once formed large thickets (shallow reef crest/ fore reef), only isolated colonies or small groups of colonies remain and many of these are affected by disease, *Cliona* overgrowth, and snail predation.

In Rincon, a number of broken colonies were observed after Hurricane Georges. Unlike La Parguera, most fragments remained near mother colonies and these did not die. One year later the fragments were firmly attached to the reef and had produced numerous small protobranches.

Like other Caribbean locations, observations from Puerto Rico suggest that coral disease has impacted this species in the past. On one reef near La Parguera, C. Goenaga observed an incidence of WBD which affected 20-33% of the *A. palmata* colonies in 1984 (Davis, *et al*.,1986). During the 1990's I have documented a slow, steady decline of remaining *A. palmata* thickets in La Parguera due to a combination of factors including disease and predation (Bruckner *et al*., 1997, unpubl. data). On the east coast of Puerto Rico, vast stretches of living *A. palmata* colonies were observed in 1979 in Fajardo, Culebra and Vieques. Populations near Fajardo were decimated by WBD in the 1980s, and Hurricane Hugo in 1989 caused almost total destruction to *A. palmata* thickets in eastern Culebro (Goenaga and Boulon, 1992). On 85 reefs off the east coast and associated islands, populations of elkhorn coral have continued to decline from disease, sedimentation, and algal overgrowth (Hernandez-Degado, pers. Comm).

Tolerance to terrestrial impacts: Elkhorn coral is an environmentally sensitive species that requires clear, high saline, well circulated water with moderate temperatures (25-29°C). *A. palmata* is intolerant of prolonged periods of high sedimentation; this species lacks a well developed ciliary mucus system found in sediment-tolerant species like *Porites astreoides* and *Montastraea cavernosa*. It can only tolerate short periods of increased water turbidity if the site is exposed regularly to moderate to high levels of wave action. Rogers (1983) found that even low doses of sediment accumulate on the flattened branch surfaces, resulting in rapid tissue necrosis; in addition, injuries regenerate more slowly at elevated sedimentation levels (Meesters and Bak, 1995). Rincon's reefs are affected by poor water quality conditions during the rainy season in summer due to run-off, but murky conditions generally persist for short periods and water clarity improving after a few days. In winter high wave action prevents accumulation of sediment on branches. Clearing of the land adjacent to Steps reef would cause a significant increase in run-off, which is likely to have a significant impact on nearshore elkhorn coral populations.

Natural disturbances: Coral disease is a major factor that has impacted this species since the 1970s (first reported in 1977 from St. Croix, USVI). White-band disease (WBD) spread throughout the Caribbean, with concurrent losses of 90-95% reported during the 1980s and early 1990s. White-band disease still affects *A. palmata* throughout its range and other new, white-type diseases (white pox; patchy necrosis) have been reported on this species in the 1990s. Elkhorn coral is one of only two coral species (other species is *A. cervicornis*) known to have experienced mass mortalities from disease.

Throughout its range, Caribbean-wide losses of *A. palmata* have been attributed primarily to WBD, with compounding (localized) effects from hurricanes, increased predation pressure, hypothermic stress, bleaching events, physical damage from ship groundings, and problems associated with increased nutrient and sediment loading**.** Two predators in particular, include the fireworm, *Hermodice carunculata* and the corallivorous gastropod, *Coralliophila abbreviata*, are a significant threat to elkhorn populations. While worms generally consume parts of individual branches, the gastropods are capable of denuding entire colonies of *A. palmata*. The pressure on remaining populations from coral predators may be increasing in many locations, because, even if snail and fireworm densities have not increased, they may occur at higher densities on individual corals because there are fewer corals remaining. However, recent work suggests that coral eating gastropods have become more prevalent and more voracious on reefs in Puerto Rico and the Florida Keys possibly as a result of overfishing of their predators, the octopus and spiny lobster (Bruckner et al., 1996; Szmant, pers. comm). Work by Bruckner et al. (1997) examined the population dynamics of snails on reefs in La Parguera, and the relative affect of snails on remaining populations. This study showed that individual snails will consume 5-25 square centimeters of tissue in one day and aggregates of snails eat entire colonies in as little as one month. It is interesting to note that the snails were much larger (30-50 mm) than those found on massive corals, and these were predominantly female (the snails change sex from male to female once they reach a certain size) suggesting that populations may continue to increase in abundance (larger females producea higher number of offspring) and contribute to the loss of remaining coral thickets near la Parguera.

Fortunately, Rincon populations of elkhorn coral currently do not face a substantial threat from coral diseases or predators at this time. Snails have been observed at high densities (2-25 snails per coral) on massive brain and star corals on these reefs, but the snails are very small (less than 1 cm). Over the duration of the study (1994-1997), only six standing elkhorn colonies have been affected by groups of snails and associated predation was minimal.

A low incidence of disease has been observed at Steps and Tres Palmas. Isolated colonies are periodically observed with white band, and patchy necrosis may be relatively common after extended periods of terrestrial runoff (May-July, during the rainy season water visibility may drop below 1 m and remain this way for several days). However, patchy necrosis most frequently affects fragments, colonies are not entirely killed, and branches begin to regenerate tissue off areas that were formerly affected by disease.

An outbreak of disease (patchy necrosis) was recorded on *Acropora palmata* at **Steps Reef** during 1996. The occurrence of the disease may be associated with high sediment loads that affected corals at the time of construction of a residential structure across the street from Steps. The construction project involved removal of all trees, and the land was bulldozed, exposing the underlying sediment. Unfortunately, this occurred during the rainy period in summer, and run-off was exacerbated. Fortunately, the amount of sediment run-off declined within a few weeks, and the disease outbreak subsided. However, this indicates that coral populations are very vulnerable in this location, and development of the land immediately in front of Steps may seriously compromise elkhorn coral populations, especially if construction coincides with the rainy season.

Conservation Measures: *A. palmata* is offered limited **protection by existing legislation** in U.S. waters: The Fishery Management Plan for Coral and Coral Reefs, developed in 1982 by the Gulf of Mexico and the South Atlantic Fisheries Management Councils provides direct protection in federal waters for acroporid corals (and other species). The FMP 1) prohibits the taking of stony coral or destruction of coral; 2) establishes a permit system for taking corals for scientific or educational purposes; 3) requires the return of stony corals taken incidently in other fisheries; and 4) prohibits the use of toxic chemicals in taking fish or other marine organisms. Other protected areas include National Parks (Florida: Dry Tortugas; Biscayne National Park and the U.S. Virgin Islands: Buck Island; St. John) and in the Florida Keys National Marine Sanctuary. It is illegal to damage, remove, collect, or sell *Acropora palmata* and other stony corals In State waters of Florida (State statute, in effect since the mid 1970s).

The Fishery Management Plan for Corals and Reef Associated Plants and Invertebrates of Puerto Rico and the USVI, July 1994, Caribbean Fishery Management Council regulates take of stony corals in federal waters around Puerto Rico: Harvest and possession of stony corals, octocorals, and live rock, whether dead or alive, are prohibited, except for the purpose of scientific research, education, and restoration. In territorial waters of Puerto Rico, DNER prohibits the harvest or take of corals (Law No. 83) for commercial purposes except under permit.

Potential impacts associated with a loss of elkhorn coral populations in Rincon: The disappearance of these coral thickets may ultimately affect the diversity and abundance of reef organisms, the rate of carbonate deposition and reef growth, and the skeletal contribution to coral cayes and boulder ramparts (Hernandez-Avila *et al*., 1977; Gladfelter *et al*., 1978; Williams, pers. comm.).

Reduced Diversity. In addition to the loss of one of the most important reef builders in the Caribbean, many organisms that rely on *A. palmata* for habitat, feeding areas, and refuge will disappear.

Tourism. Steps reef is a very popular site for snorkeling, due to the shallow water and close proximity to land. Steps is one of the few reefs in Puerto Rico accessible immediately off the shore.

Beach erosion. Loss of elkhorn coral would result in stronger waves reaching the shoreline, which will subsequently cause substantial increase in erosion of sand. Increased erosion of sediments will ultimately affect other benthic reefs invertebrates found slightly deeper than elkhorn coral and also those found on the outer reefs. In addition, increased erosion is likely to result in decreased water clarity which will affect the amount of light reaching photosynthetic reef organisms.

The U.S. Endangered Species Act: In the U.S. Federal Register Notice (FR Doc. 99-1011, 1/15/99; Vol. 64, no. 10) the National Marine Fishery Service (NMFS) has proposed to add two coral species, elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) as candidates for possible addition to the List of Endangered and Threatened species under the Endangered Species Act. These species are fast-growing, branching corals that form dense, high profile, monospecific stands at shallow and intermediate depths. Formerly, these were two of the three most important corals in the tropical western Atlantic, contributing significantly to reef growth and providing essential fishery habitat. During the last two decades, disease outbreaks and compounding (localized) factors such as hurricane damage, increased predation, hypothermia, boat groundings, sedimentation, and bleaching have resulted in widespread mortalities. Losses are well documented at several sites in the U.S. and throughout the Caribbean, where populations declined during the 1980s by up to 96%. To date, acroporid corals have not recovered to their former abundance. Low remaining population densities, a strong dependence on asexual recruitment by coral fragments, and limited potential for larval recruitment may hinder recovery of these species, given continuing losses from coral diseases, storms, and human impacts.

In this notice, NMFS is not proposing to list these corals as Threatened or Endangered species under the U.S. Endangered Species Act. The goals of the candidate species program are 1) to identify species that may qualify as candidates for possible addition to the List of Endangered and Threatened Species, 2) to assist in acquiring information needed to determine the status and trends of a species, and 3) to encourage voluntary efforts to help prevent listings. NMFS is seeking additional information on these species that would support or argue against inclusion on the candidate species list. This includes historic and current population abundances and distribution, assessments of threats, and existing and future protective measures that may assist in recovering these species.

Using information collected from an initial analysis of published information indicating that populations of *A. palmata* were in serious decline, and public comments generated from the Federal Register Notice proposing the candidate listing, NMFS added two coral species, elkhorn coral (*Acropora palmata*) and staghorn coral *(Acropora cervicornis*) to the candidate species list of the Endangered Species Act (Federal Register Vol. 64, No. 120, June 23, 1999 pp. 33466-33467).

[1]Stony corals recorded in study area at Steps and Tres Palmas reefs: *Acropora cervicornis, A. palmata, Montastraea faveolata, M. cavernosa, Porites astreoides, P. porites, Favia fragum, Agaricia agaricites, Diploria strigosa, D. clivosa, D. labyrinthiformis, Siderastrea siderea, Dendrogyra cylindricus, Colpophyllia natans*, *Dichocoenia stokesi, Meandrina meandrites*

[2]These species occur in Florida and throughout the Caribbean including the Antilles, the West Indies, Central and South America, including Mexico, Belize, Honduras, Nicaragua, Costa Rica, Panama and Columbia. Isolated populations occur in the southern portion of the Gulf of Mexico, near Veracruz, Mexico; the northern limit in 1992 was the Tuxpan Reef System, approx 29°N latitude; northern limit off the east coast of Florida is Biscayne National Park; the species is absent from Bermuda, the east coast of Florida, Florida Middle Grounds and Flower Garden Banks; the southern limit is Venezuela, in areas without freshwater runoff.

[3]White-band disease is the most significant source of mortality to *Acropora palmata* populations throughout the range over which this coral occurs, and populations have declined by as much as 90-95% as a result of disease. However, localized losses of *A. palmata* populations have also been associated with storm damage, ship groundings, predation, cold water events, flooding, bleaching, siltation, and algal and invertebrate overgrowth.

Acropora in the U.S. Virgin Islands: A Wake or an Awakening? A Status Report Prepared for the National Oceanographic and Atmospheric Administration

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ABSTRACT

Many shallow reefs in the US Virgin Islands (USVI) had extensive stands of *Acropora palmata* (elkhorn coral) before white band disease and hurricanes caused dramatic declines in the late 1970s and 1980s. *Acropora cervicornis* (staghorn coral) abundance also was reduced by storms and disease. None of the reefs that has been surveyed recently in the USVI has higher coral of these species than it did 25-30 years ago. Although *A. palmata* colonies appear to be increasing in number and size on many reefs, colonies are usually isolated from each other and few sites have dense areas with high elkhorn coral cover. Sexual recruitment has been successful at some sites. Many colonies are in very shallow water making them especially vulnerable to storms and land-based development.

INTRODUCTION

In the 1960s and 1970s, *Acropora palmata* (elkhorn coral) was the main reef-building coral at depths of less than 10 m in the US Virgin Islands, growing in nearly monospecific stands on the reef crest and in the upper and lower forereef zones of well developed fringing and bank barrier reefs and on isolated patch reefs (Fig. 1). Although elkhorn coral was the most abundant coral in these areas at that time, its density varied greatly.

Figure 1. Elkhorn coral at Buck Island Reef National Monument, 1966.

Acropora cervicornis (staghorn coral) was also abundant, although not often found in dense thickets or well-defined zones. *Acropora prolifera*, actually a hybrid between the two other *Acropora* spp. (Vollmer and Palumbi 2002), was very rare[1].

In the USVI in the mid 1970s and 1980s, white band disease (WBD) and hurricanes caused dramatic declines in *A. palmata* (Gladfelter 1982, Rogers et al. 1982) and apparently in the other *Acropora* species as well. In 1961, President John Kennedy designated Buck Island Reef National Monument, St. Croix, in recognition of its remarkable elkhorn barrier reef. The significance of the coral reefs around St. John was specifically mentioned in the 1962 legislation that added the marine portions to Virgin Islands National Park (established in 1956).

The presence of these two units of the National Park Service (NPS) and Fairleigh Dickinson University's West Indies Laboratory on St. Croix led to some of the earliest research on the *Acropora* spp. and associated reefs, including studies of disease (Gladfelter 1982; Davis et al. 1986); hurricane damage (Rogers et al. 1982; Hubbard et al. 1991); physiology, calcification and growth rates (Gladfelter W. 1982; Gladfelter E. 1983a, b, c; 1984; Gladfelter and Gladfelter 1979; Gladfelter et al. 1978, 1989); nutrient budgets (Bythell 1988, 1990); productivity (Rogers and Salesky 1979; Adey et al. 1981), relationships with reef fish assemblages (Gladfelter and Gladfelter 1978), and spatial distribution (Anderson et al. 1986; Beets et al. 1986; Bythell et al. 1989; Hubbard 1989).

This report is a compilation of historical and recent information on *Acropora* spp. in the US Virgin Islands (St. Croix, St. John and St. Thomas) based on qualitative observations and quantitative studies investigating a variety of scientific questions and conducted with a number of different methods and approaches appropriate to the question being asked. It does not include all the research results of studies on *Acropora*, but rather focuses on studies that document patterns of abundance and distribution, and on some of the mechanisms thought to be responsible for the observed patterns.

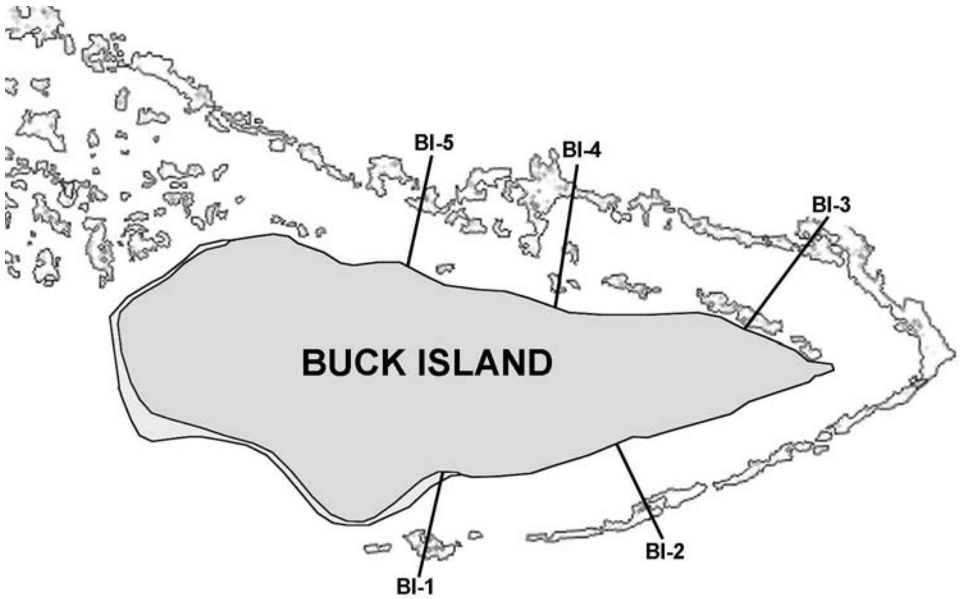
ST. CROIX

A substantial amount of information is available for *Acropora* spp. at Buck Island Reef National Monument (BIRNM), located 1.2 miles north of St. Croix. The most significant change to occur at BIRNM in the last three decades has been the demise of the *Acropora palmata* colonies that formed the shallow portions of the barrier reef. Bythell et al. (1989) summarized some of the major changes between 1976 and 1988, and their summary report on data from 1976, 1984 and 1988 is the basis for much of the following discussion (Gladfelter et al. 1977; Anderson et al. 1986). In 1976, five cross–reef transects were established at Buck Island, 3 on the north (BI-3, BI-4, BI-5) and 2 (BI-1, BI-2) on the south side (Fig. 2). At that time, the crest of the north and south bankbarrier reefs and the northern forereef was composed of greater than 50% live *A. palmata*.

Acropora palmata was the most abundant coral on the forereef slope down to the bank at a depth of 10-15 m in the north and east sections of the reef. In the south, this species was dominant to depths of 3-4 m. About 75% of the total live coral cover of 44% on the northern forereef slope was *A. palmata*. By 1984, when Anderson et al. (1986) surveyed the reef, the cover of *A. palmata* was dramatically reduced in the region of transect BI-3. In the forereef area, cover by hard corals was reduced to 20%, although *A. palmata* was still dominant (>10%). Anderson et al. (1986) reported patches of healthy elkhorn coral at this time with 80% live cover but also noted that most of the forereef had stands that were almost completely dead.

[1]Vollmer and Palumbi (2002) present data that demonstrate that *A. prolifera* is a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*.

Figure 2. Cross-reef transects established at Buck Island in 1976.

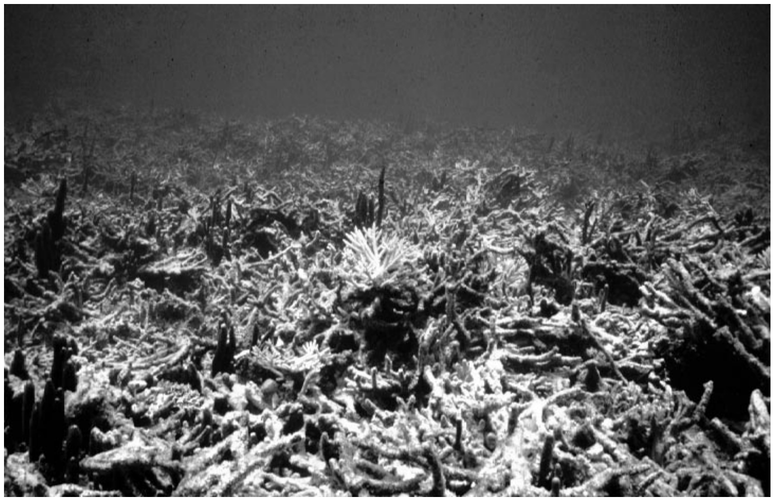


Surveys in the fall of 1988 confirmed many of the findings of Anderson et al. (1986), and showed additional declines in the *Acropora* spp. In 1988, live coral cover was less than 12% with only about 3% *A. palmata* on the forereef near transects BI-3 and BI-4. In contrast, along transect BI-5, *A. palmata* comprised 72% of the total cover of 27% on the upper forereef, suggesting that this area was less affected by the mass mortality which devastated most of the reef. This species was only rarely seen below a depth of 3-4 m on any part of the reef.

In 1976, *Acropora cervicornis* was noted in patches on the mixed coral/gorgonian bank seaward of the bank barrier reef and comprised 2% of the total coral cover of 27 %. Surveys in 1988 indicated virtual disappearance of this species on the north side of Buck Island and large reductions in abundance on the south side, although it comprised up to 2-3% of the coral cover in some localized areas off the southern reef (Bythell et al. 1989). *Acropora cervicornis* is now rare around St.Croix, at least in shallow water.

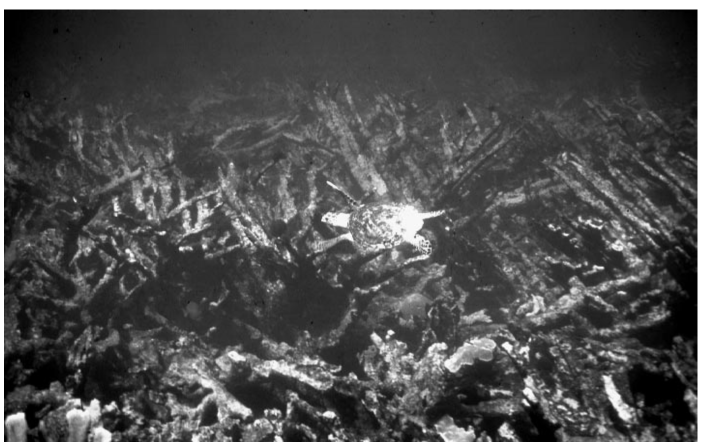
Acropora prolifera was not common around Buck Island in the 1970s, although in the lagoon off the east end of the island cover of this species reached about 60%. Bythell et al. (1989) suggested that this was perhaps the best-developed stand of this species on St. Croix. Anderson et al. (1985) noted thickets of mostly dead *A. prolifera* here in 1984. In fall 1988, cover of this species was less than 1% (Bythell et al. 1989) (Fig. 3).

Figure 3. Mostly dead thicket of *Acropora prolifera*, north backreef lagoon Buck Island, 1997.



The dramatic demise of the *Acropora* spp. at Buck Island in the 1970s and 1980s can largely be attributed to white-band disease (WBD) which affected many Caribbean reefs during this time period (Rogers 1985, Bythell and Sheppard 1993). The disease left extensive stands of these corals intact but dead (Fig. 4).

Figure 4. Intact dead *Acropora palmata* stand, east end Buck Island 1986.



White-Band Disease (WBD)

A 1973 report on Buck Island includes what is apparently the first reference to a condition later labeled "white band disease" by Dr. William Gladfelter. Photographs and a rough drawing show the distinctive narrow white band separating the living end of an elkhorn branch from the algal-encrusted dead base (Robinson 1973). In 1976, Gladfelter et al. (1977) found incidences of WBD at Buck Island but reported that only a few percent of the colonies in any area were affected. Impressive stands of living elkhorn were present at Buck Island at this time. Gladfelter began to measure the rate of progression of WBD on individual colonies and to monitor its effect on the populations of *A. palmata* on Buck Island and Tague

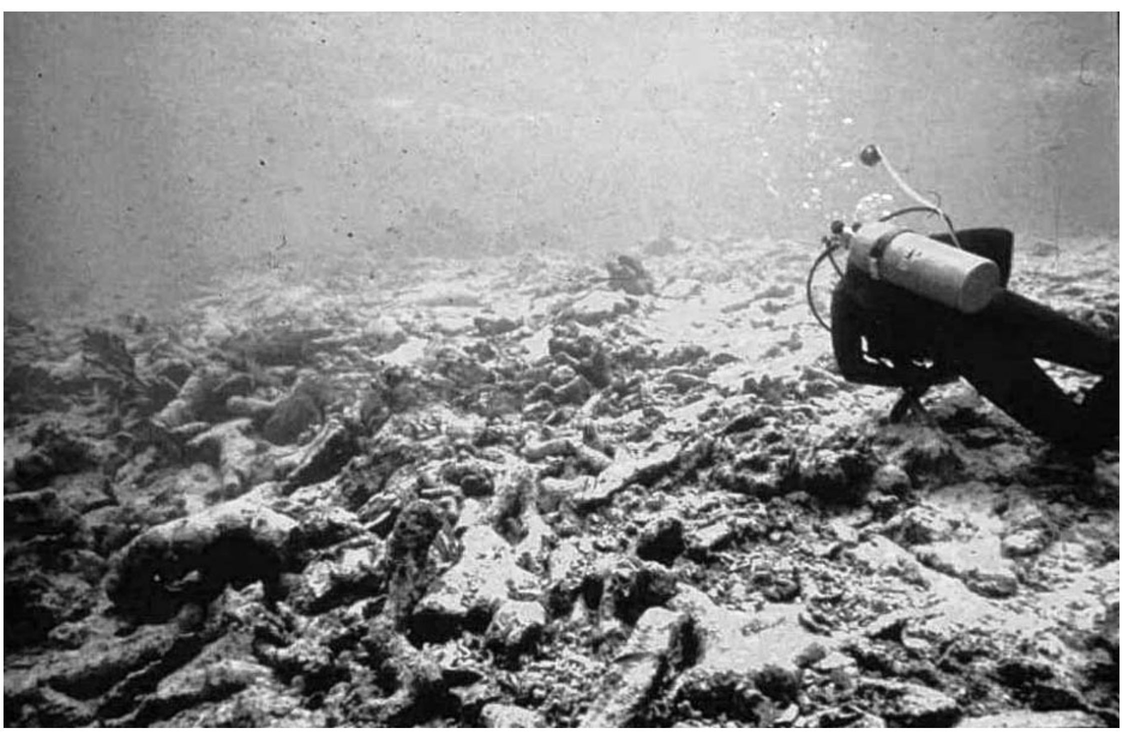
Bay Reefs (Gladfelter et al. 1977; Gladfelter 1982). The disease progressed at a rate of about 1 to 14 mm/day (with an average of c. 6 mm/day). Similarly, Davis et al. (1986) estimated a progression of 4-5 mm/day for the disease based on data from Buck Island.

Hurricanes

Hurricanes have also caused significant deterioration of coral reefs at Buck Island. In 1979, Hurricane David caused extensive physical damage to shallow elkhorn coral stands there (Rogers et al. 1982). Off the southeastern forereef, monitoring of storm-damaged elkhorn branches showed 66% of them were still alive11 months after the storm and many of these had begun healing and initiating new branches (Rogers et al. 1982). However, elkhorn coral recovery was hindered by white band disease which devastated this primary reef-builder (see above).

In 1989, Hurricane Hugo, an exceptionally powerful storm, caused further destruction (Fig. 5). The five cross-reef transects established in 1976 were re-surveyed (Gladfelter et al. 1991). The shallow forereef on the south side of Buck Island was reduced to pavement, and the coral rubble generated was transported up onto the reef crest, forming a raised berm 30 m landward of the crest (Hubbard et al. 1991). No *Acropora palmata* was recorded on the south reef in locations where it had previously been dominant. On the eastern shallow forereef *Acropora palmata* cover fell from 5% to 0.8% (Gladfelter et al. 1991) in an area that had once supported 85% cover of this species. The north reef at Buck Island was less severely damaged by Hurricane Hugo, but *Acropora palmata* populations were still reduced from approximately 1.8% to 1.0% cover on the forereef of transect BI-3, an area that had previously supported about 36% cover of this species (Gladfelter et al. 1991). These surveys clearly showed the effects of the storm, but most of the *Acropora* spp. mortality had already occurred. Interestingly, many of the *A. palmata* colonies killed by WBD remained upright, even in exposed areas like Buck Island Bar to the north.

Figure 5. Elkhorn coral fragments at Buck Island Reef National Monument after Hurricane Hugo (1989).



In 1988 more permanent monitoring sites were established at Buck Island (Bythell et al. 1992, 1993a). Although *Acropora* species were no longer a dominant part of the coral community at the start of this period, it can be seen that where they occurred there have been further reductions in cover over the past decade (Fig. 6), a period of unusually intense hurricane activity (Bythell et al. 2000a, b). One of the sites on the northern reef was established near cross-reef transect BI-5 (see above), and shows that hurricanes and disease have destroyed at least some of the stands that were still intact in 1988 (Bythell et al. 1989).

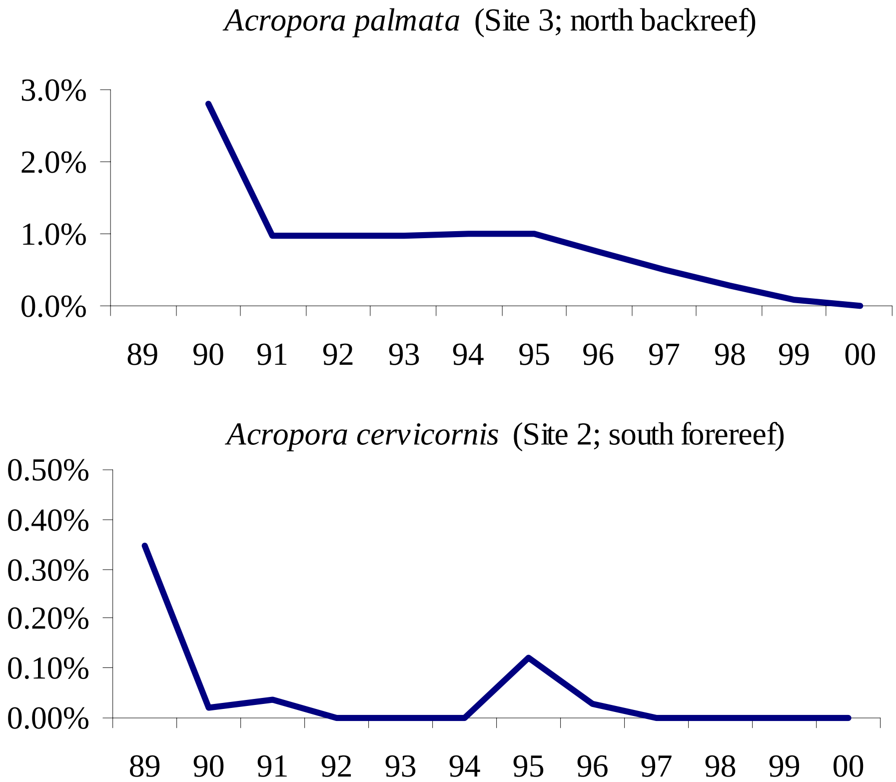


Figure 6. Reductions in cover of *Acropora palmata* and *A. cervicornis* on permanent transect monitoring sites at Buck Island over the past decade (Bythell et al. 2000a). No *Acropora* species were recorded on these transects in 2000.

Beginning in 1993, *Acropora palmata* colonies were observed in the southeast forereef in the area scraped clean by Hurricane Hugo, although they were only a minor component (0.4%) of the coral community recruiting to the area (Bythell et al. 1993a, 2000b). In 1995, after Hurricane Marilyn, some colonies were up to 1 to 2 m across but exhibited physical damage from the storm. Additional colonies have recruited to this area and appear to be in relatively good condition although they have been affected by subsequent storms and snail predation. West of Buck Island, numerous, large elkhorn colonies, some reaching 2 m across, can be found (Zandy Hillis-Starr, Brendalee Phillips, pers com.).

Recent monitoring of individual elkhorn colonies and surveys of spatial distribution

In January 2000, NPS biologists tagged colonies of *Acropora palmata* on the southeast forereef of Buck Island (less than 4 m deep). They have photographed them annually since then. All photographs are captured from video taken with a SONY DCR-VX700 Digital Handycam. Over this two year period, 14 colonies have grown noticeably or remained about the same in terms of total tissue cover, while 11 have lost live tissue (3 of these have died). Some of these colonies have exhibited very high rates of growth (as observed in photographs), apparently approaching the high end of the range reported previously at Buck Island (calculated as 4 to 11 cm/year in Gladfelter et al. 1978 and Rogers et al. 1982). *Coralliophila* snails were present on some colonies and actively feeding when examined in 2002 (One untagged colony in this area had 57 snails on it). Territorial damselfish were observed in photos of some colonies. Snorkel surveys conducted between February and August 2002 along the Buck Island forereef, both north and south, have shown an increase in the number of *Acropora palmata* colonies in water 1 – 10 m deep. The colonies range in size from several centimeters (sexual recruits) to large branching colonies over 2 m maximum dimension. Most sexual recruits have developed branches after settling on dead *A. palmata* structure, however there are also a number of "crusts" that are re-sheeting (reencrusting) dead *A. palmata* branches. Some of these crusts have spread into each other and have merged to cover, in one instance, an area over 5m long. In the backreef/lagoon entire *A. palmata* patch reefs that have been standing dead structure for years are now covered in living tissue. A rough visual estimate of the distribution of *A. palmata* colonies in the area of the 2000 *Acropora* tag site (south forereef) has recovered since Hurricane Hugo (1989) to maximum densities of 3 colonies per m^2. The majority of these colonies are smaller than 1 m. However, large colonies (>1 m) have increased in number as well, indicating survivorship of colonies first noted in 1993 and 1995 (Z. Hillis-Starr, pers. comm.).

In August-September 2002, the distribution of *A. palmata* colonies along Buck Island forereef was surveyed using a modification of the method developed by C. Rogers, B. Devine, and Christy Loomis (see below; Rogers et al. 2002). The colonies were divided into three size classes (small = 0-25 cm, medium = 26-100 cm, large >100 cm in maximum dimension), and their locations were recorded while snorkeling using handheld GPS units. To date an area of approximately 41,880 m^2 has been surveyed and 2,238 *A. palmata* colonies have been recorded (Fig. 7). Approximately 49 %, 35 %, and 16 % were in the small, medium, and large size classes, respectively (Fig. 8).

Other surveys of former elkhorn-dominated reefs around St. Croix and comparisons of past and present coral cover

In February, March and April 2002, W. Gladfelter surveyed selected reef zones around St. Croix that had been formerly dominated by *A. palmata*. Nine reef sites were surveyed in March 2002 to ascertain present cover and recent recruitment of *A. palmata*, and to compare current cover to cover during the 1970s-1990s. Three study sites were on the south shore (Robin Bay forereef; Isaacs Bay forereef; and Isaacs Bay backreef); three on the north shore (Tague Bay, Prtzl Reef; Tague Bay forereef, Romney Point; Channel Rock) and three off shore (eastern forereef Buck Island; Bythell's Reef; Friday Reef). At the eastern forereef of Buck Island, the study plot initiated in 1988 (Gladfelter 1991) was re-visited and the position and size (projected surface area, from photographs) of all live *A. palmata* colonies were recorded. At all sites percent cover (planar surface) of *A. palmata* was recorded. At some sites this was determined from measurements taken from photographic belt transects (Prtzl Reef, Romney Reef, Friday Reef, Buck Island forereef) while at other sites it was estimated from swimming several belt transects, approximately 50 m x 2 m, at a given site. At sites where photographic belt transects were made, size frequency distributions (made by measuring the maximum diameter of each colony) and colony density were also determined.

Figure 7. Distribution of *A. palmata* colonies around BIRNM eastern forereef, September 2002.

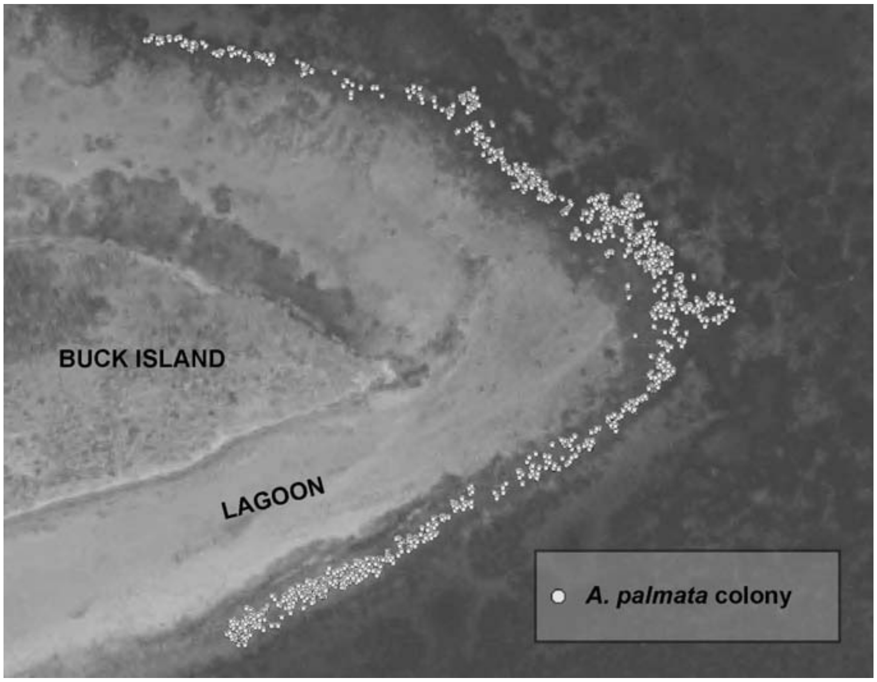


Figure 8. Distribution by size class of *A. palmata* colonies along the south forereef at BIRNM, September 2002.

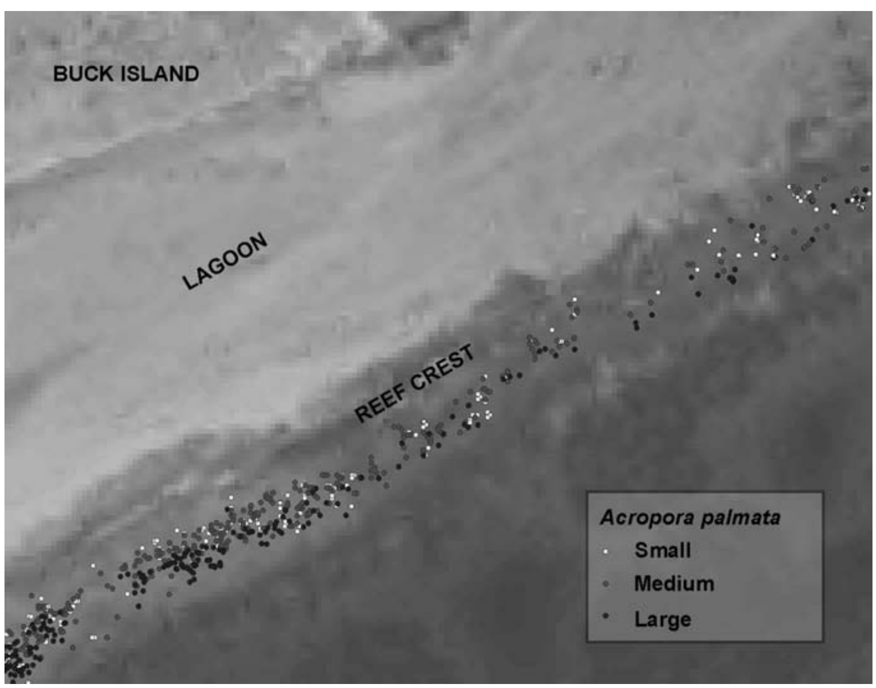


Table 1 compares past and present percent planar cover by *A. palmata*. Some of the previous values for cover were obtained from Adey et al. (1981) who used a chain transect method to determine cover of live tissue at several south shore sites (ranging from 10 to 66%) as well as vertical relief (1.9 to 3.0). Their data for cover were divided by their estimates for relief to arrive at a rough estimate of planar cover. Percent cover in the 1970s ranged from about 7-9% on the southern forereefs, to about 33% on the Isaac's backreef (estimated from Adey et al. 1981, and Gladfelter, pers. obs.). It was about 25-35% throughout much of the north shore and the offshore reef area (Gladfelter, pers. obs). Maximum documented cover was 62% on the eastern forereef of Buck Island (data calculated from 25 photoquadrats; Gladfelter et al. 1977), although in some relatively large areas the percent cover approached 100% (Fig. 9). Total live tissue cover was even higher, of course, as there were often several overlapping tiers of branches, covered on both sides. There was an average of 1.75 m^2 of live *A. palmata* tissue per m^2 of reef. The colonies in this forereef zone had extremely long branches oriented perpendicular to the approaching wave fronts (i.e. parallel to the direction of the prevailing waves). The largest colony measured (in 1988; Gladfelter, pers. obs.) had a length of 7.1 m.

Table 1. A comparison between the late-1970s and 2002 of percent planar surface cover of *Acropora palmata* at sites on St. Croix.

REEF NAME	mid-1970s % cover		2002 % cover
Southshore Reefs			
Robin fore reef		7%	<0.1%
Isaac fore reef		9%	<0.1%
Isaac back reef		33%	0.5-1.0%
Offshore Reefs			
Channel Rock	estimated	35%	0.1-0.5%
Friday Reef	estimated	35%	2.4%
Bythell's Reef	estimated	35%	0.5%
BI Barrier Eastern fore reef		62%	0.5-1.0%
Northshore Reefs			
Tague Bay FR (Romney)		47%	3.6%
Tague Bay (Prtzl Reef)	estimated	25%	1.4%

At present (2002), no reefs can be considered *A. palmata*-dominated as they were in the 1970s, yet all the surveyed sites show some live *A. palmata*, and some show evidence of at least two successful recruitment events in the past 10-15 years. Cover on the south forereefs is <0.1%. At the other sites, the cover ranges from 0.1 to 3.6%. Total live coral tissue reduction has been much greater than it may at first appear. For instance, in 1977, the percent cover in the Romney Point area was measured as 47% (Gladfelter 1982). It is now 3.6%, 7% of the late 1970s level. Yet the total surface area of live tissue is actually much less because the present colonies are small, and many are primarily crusts, rather than complex three-dimensional colonies. Previously, many colonies stood several meters above the substrate with live tissue covering not only the top and bottom of the branches, but also extending down to the base of the colony as well. Thus overall tissue reduction in the reef zones formally dominated by *Acropora palmata* is almost catastrophic, two orders of magnitude or greater.

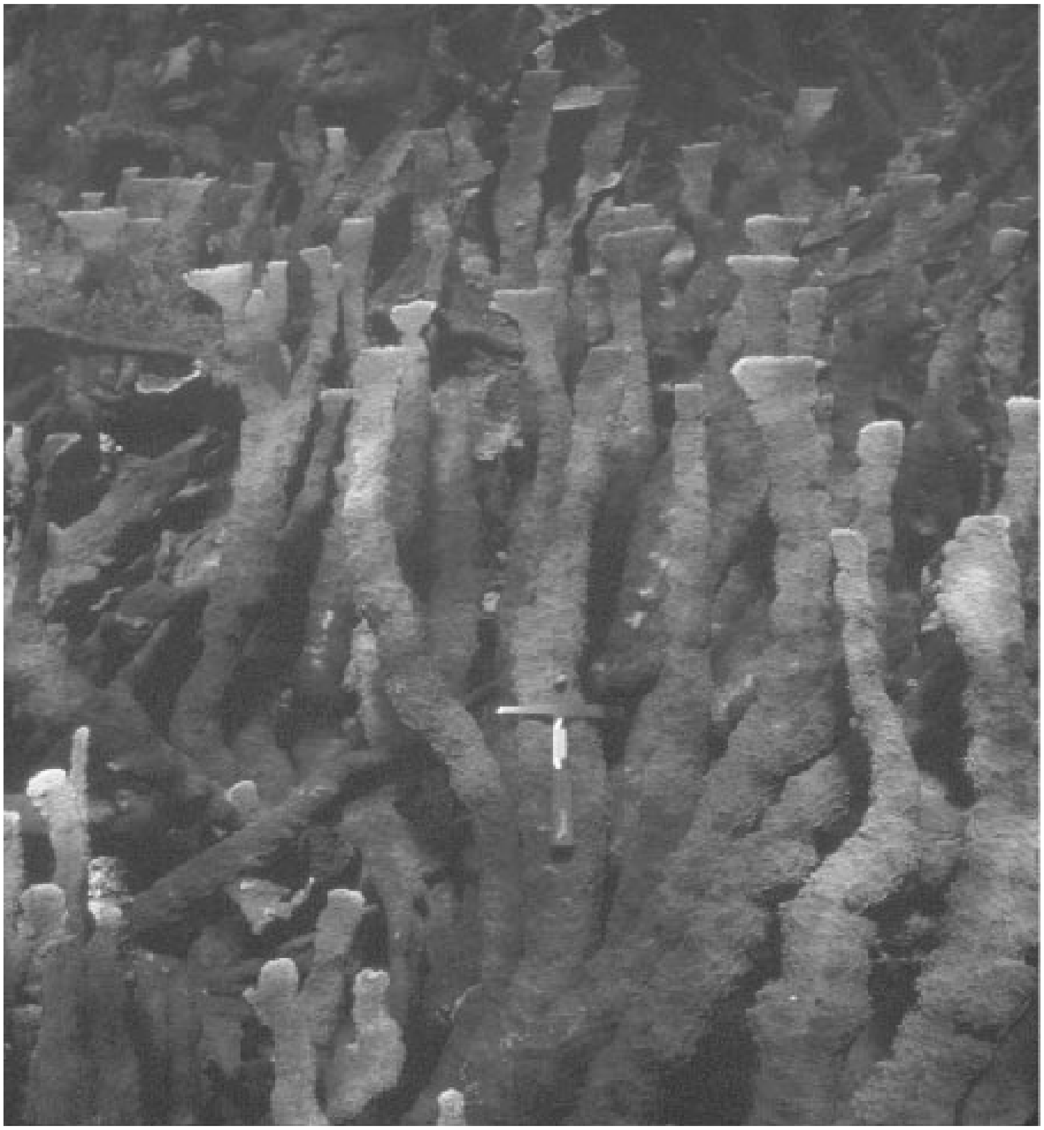


Figure 9. *Acropora palmata* colonies on the eastern forereef of Buck Island in 1977.

On the eastern forereef of Buck Island (in the 200 m^2 study plot; Table 2) there was a drastic reduction in total number of colonies from 1988 (106 colonies) to 2002 (10 colonies), and a reduction in total % planar cover, from 5% to 1%.   In 1989, the site was re-surveyed the weekend before Hurricane Hugo arrived. There were 104 colonies of which 98 remained from the 106 recorded in 1988 and six new ones (presumably 8 were lost to WBD).   In a 1990 survey several months after Hurricane Hugo, only 17 colonies were clearly recognizable as pre-Hugo, and many of these had been displaced and/or had a reduction in surface area; there were 33 colonies in the plot with a total planar cover of 0.8%.   In 1991, there were 61 colonies in the plot, over half of which were small, recent recruits.   After Hurricane Marilyn hit St. Croix in 1995, the plot was again surveyed, and only 33 colonies remained, of which only 7 were from the pre-Hugopopulation. Two other hurricanes, Georges (1998) and Lenny (1999) also hit St. Croix. In 2002, only 4 of the pre-Hugo colonies remained, although each had grown. The results of this study have some interesting implications for the genetic composition of any new population that may develop at this site. Only a very few, rather small colonies of the pre-Hugo population have survived. It would take years before they could repopulate this site asexually.   Even though the recruits from the 1990-1991 recruitment event appear to have died at this site, it apparently is an area capable of successful recruitment. A new population established at this site may well have a very different genetic make-up from the original population, as it will be primarily composed of sexual recruits (which may then grow, fragment, and expand their zone). On three sites, Prtzl Reef, Romney Reef, and Friday Reef, some parameters of population structure, size frequency and density data, were determined. Recruitment of *Acropora palmata* was first noticed in 1992 on Prtzl Reef, when many colonies of approximately 10-15 cm in height were observed (Gladfelter, pers. obs.). In 2002, this reef had many circular colonies, varying in size from new recruits (less than 10 cm in diameter) to colonies as large as 120 cm in diameter. As this site is only about 0.5 m to 1.0 m deep, it has been directly impacted by the many storms that have affected St. Croix in the past decade. Some of the colonies had obviously been overturned, but had re-cemented to the substrate and new branches were growing outwards and upwards. The Romney Point section of Tague Bay forereef had the most abundant *A. palmata* in the entire forereef zone (about 2 m depth). At its richest area, coral cover was 3.6%, the highest measured anywhere during this study. The colonies ranged from small crusts to large colonies almost 2 m in diameter. While there was some evidence of small colonies resulting from successful sexual recruitment, many of the colonies appeared to be the results of fragmentation and re-cementation. At Friday Reef, at a depth of 4.5 m, the colonies were circular, and all appeared to have been the result of successful sexual recruitment. Coral colonies measured from the photoquadrats ranged from small colonies up to 150 cm in diameter, with many around 80 cm. At both Prtzl Reef and Friday Reef, the present populations may be entirely derived from successful sexual recruitment. One recruitment episode may have been in 1990 (as at Buck Island) and another about a decade later.

Table 2. Fate of *Acropora palmata* colonies on Study Plot #1 (20 m x 10 m) on the eastern forereef of Buck Island, including percent planar surface cover, colony density and number (no.) of remaining pre-Hugo colonies.

YEAR	% cover	No. colonies/200m^2	No. pre-Hugo	NOTES
1977	62%			
1988	5%	106		
1989		104	98	8 lost to WBD/6 added
	HUGO			
1990	0.8%	33	17	displaced
1991		61		1990 recruitment
	MARILYN			
1996		33	7	Marilyn mortality?
	LENNY			
2002	1%	10	3	Lenny mortality?

Conclusions for St. Croix

- Populations of *A. palmata* which dominated reefs on the eastern half of St. Croix (with ca. 10% up to almost 100% planar cover, covering a total area of almost 10 km^2) in the late 1970s have been reduced to < 0.1% cover in many areas to a maximum of 3.6% by 2002.
- Several sites (on the order of hundreds of m^2) have numerous young, healthy *A. palmata* colonies, many of which are the result of more than one successful episode of sexual recruitment.
- Barring devastation by storms (for which the species has shown remarkable adaptations for survival), disease (WBD was very rarely observed in this current survey), or predators these populations appear capable of recovery in the future.
- Over half of the individual colonies of elkhorn coral that have been monitored since January 2000 at Buck Island have grown, some of them substantially, although some colonies have died.
- Recent surveys to determine the presence and distribution of *A. palmata* along Buck Island's barrier reef show dramatic signs of recovery of the species. Although there was a very patchy distribution of colonies, in the densest areas there was a maximum of 3 colonies per m^2 .

ST. JOHN

Reefs off St. John once dominated by *Acropora palmata* have been affected greatly by white band disease and hurricanes.

White-Band Disease

During surveys in early 1984, Beets et al. (1986) found WBD at seven sites off the northern shore of St. John, although it was not common at any location. At the time of their work, some stands of live elkhorn were still present on many of the reefs, but other areas had piles of storm-generated rubble and standing dead colonies probably killed by WBD. The most impressive stand of living elkhorn was found along the western shore of Haulover Bay off the island's north shore. This and other shallow reef areas are now graveyards of dead elkhorn coral, with branches and fragments interspersed among algal covered skeletons still in normal growth position.

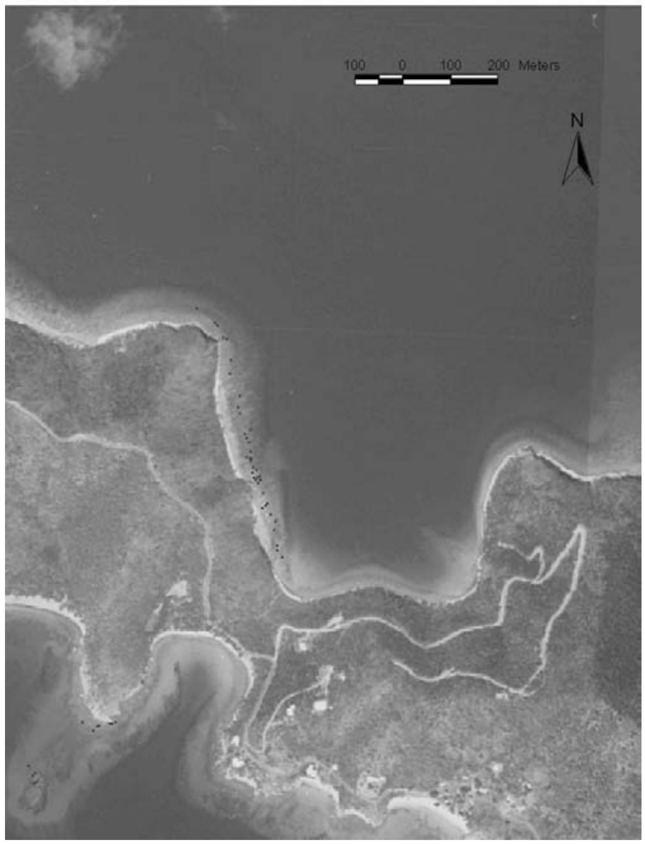
Hurricanes

Hurricanes David (1979) and Hugo (1989) caused severe destruction on the reefs of St. John. In Fish Bay and Reef Bay, powerful waves from Hurricane David smashed elkhorn colonies and deposited the fragments in ramparts on top of the reef crests (Beets et al. 1986). Even in the absence of major storms or other obvious stresses, shallow elkhorn reefs are particularly vulnerable. For example, 40 of the 50 elkhorn corals that were monitored over a seven month period in 1987 in Hawksnest Bay, St. John exhibited algal growth, tissue loss from corallivorous snails and other unknown predators, bleaching, and physical breakage (probably from boats and northern swells) (Rogers et al. 1988).

Recent surveys of *Acropora* spp. in St. John

Biologists and GIS-specialists from the US Geological Survey, National Park Service and the University of the Virgin Islands (and volunteers) are collaborating on surveys of *Acropora* spp. around the USVI (primarily around St. John and St. Thomas). They have developed a protocol for mapping and assessing the condition of elkhorn colonies based on recording GPS waypoints for each surveyed colony along with data on depth, size (estimated from 3 measurements), presence of disease and predators, percent dead, etc. Photographs are also taken of each colony, and all data are entered into a database. The GPS waypoints are mapped onto geo-referenced aerial photographs providing information on spatial patterns (see Figure 10; Rogers et al. 2002). Over time, they hope to be able to document if there is an increase in both the number and size of the elkhorn colonies. The protocol is more difficult to use when colonies are in dense stands (although such stands are now found at only 2 sites around St. John). However, the GPS unit can be used to delineate a polygon around the stand, and at least some of the desired data can be collected. Recent work to date around St. John has focused on elkhorn, although the same protocol is being used to survey *A. cervicornis* (staghorn).

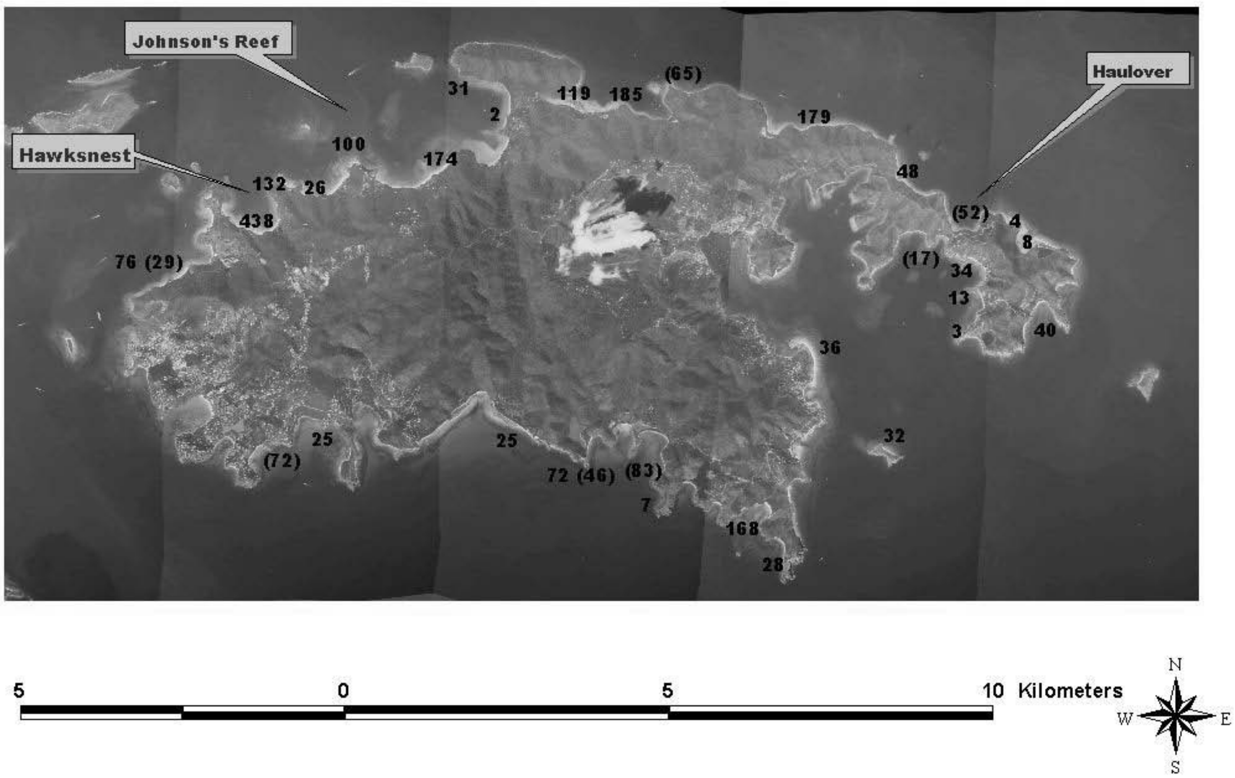
Figure 10. Aerial photograph of Haulover Bay with GPS waypoints indicating elkhorn locations in the western portion of the bay.



Surveys have been done around most of the island of St. John. Figure 11 reflects data collected from four different visual census methods and sources; the detailed method where GPS coordinates and data on colony condition are collected on individual colonies and three similar rapid assessment methods that collect limited data on colony size distribution and abundance. Values in Figure 11 reflect the total number of individual, discrete colonies along each section of coastline, combining data from all methods. Colonies range in size from several centimeters to 200 centimeters in greatest dimension. Numbers in parentheses indicate the abundance of colonies with detailed information. The other numbers refer to totals of individual colonies collected using rapid assessment methods. In some cases, colonies are aggregated and in other cases, colonies are scattered along a stretch of shoreline. Abundances are underestimates since many areas have not been sampled yet. Data were collected from May 2001-August 2002.

Preliminary analysis of data on 279 elkhorn colonies from 5 locations around St. John shows that many of the corals are relatively small (Fig. 12) and could have become established since Hurricane Hugo (1989) and Hurricane Marilyn (1995). New sexual recruits have definitely become established on reefs formerly dominated by elkhorn coral. Coral-eating snails were present on about 12% of the colonies surveyed. About 25% of the colonies were partially dead (1 to 85%). No active white-band disease was seen.

Figure 11. Distribution of elkhorn colonies around St. John.



These surveys of elkhorn coral around St. John show very patchy distribution, with Hawksnest Bay and Johnson's Reef having the highest amount of this species. At Hawksnest Bay, over 300 elkhorn colonies are growing on one patch reef. The elkhorn coral in this bay declined in the late 1980's and early 1990's presumably from a combination of white band disease and storm damage, although no quantitative data are available. A patch reef in the eastern part of this bay has very few living elkhorn colonies. Runoff following 18 inches of rain in a 24 hour period in April 1983 is most likely responsible for killing at least some of the coral in this portion of the bay (E. Gibney, pers. comm.) (Construction in this watershed had resulted in deposition of large amounts of sediment at the head of the gut that empties into eastern Hawksnest).
In 1999, numerous colonies of *A. palmata* were observed growing in western Hawksnest Bay. Hurricane Lenny in November 1999 and a January 2000 storm with extremely large swells destroyed some of these, although most colonies remain intact. In February 2000, 149 live colonies and 51 living fragments of elkhorn were recorded within an area of 100m^2 on one patch reef (Rogers 2000). The cover of live elkhorn in this small reef area was about 30%. The reef continues to be susceptible to runoff from the developed watershed above the bay. Storms, disease, predators and damage from boats continue to cause elkhorn colony mortality around St. John. In April 2002, an 85' ferry grounded on Johnson's Reef inside Virgin Islands National Park, causing extensive damage to living elkhorn colonies. Two other boats have hit this reef since then.

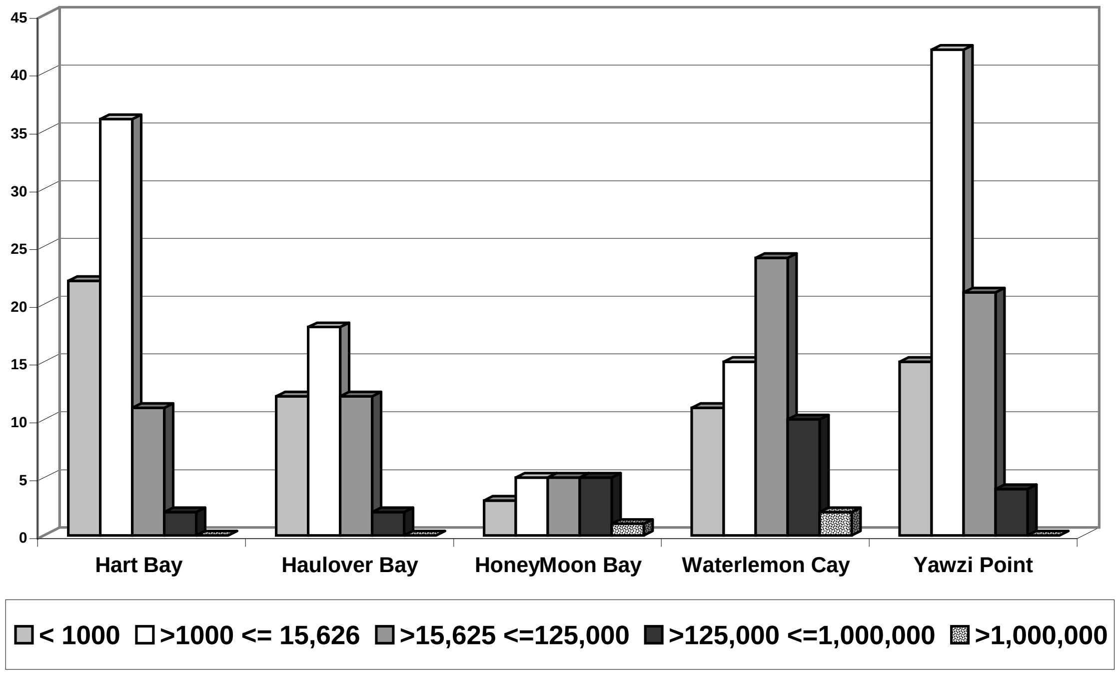


Figure 12. Size distribution of elkhorn colonies around St. John. Units are cm^3 (from multiplication of height, length and width measurements).

Acropora cervicornis

No detailed surveys of *Acropora cervicornis* have been done around St. John, but general observations document widespread, mostly isolated colonies in depths of at least 8m. No deeper surveys have been done specifically to quantify the abundance of this species around the island. No extensive "thickets" of this species are present, except in Saba Bay, off the east end of St. John. Hansen Bay, on the east end of St. John, has a high density of mostly isolated colonies (over 112 colonies in an area of about 6,950 m^2 on one patch reef (Rogers 2000). The cover of live elkhorn in this small reef area was about 30%. The reef continues to be susceptible to runoff from the developed watershed above the bay. Storms, disease, predators and damage from boats continue to cause elkhorn colony mortality around St. John. In April 2002, an 85' ferry grounded on Johnson's Reef inside Virgin Islands National Park, causing extensive damage to living elkhorn colonies. Two other boats have hit this reef since then). Damselfish territories and possibly white-band disease are frequently noted on staghorn corals.

Acropora prolifera

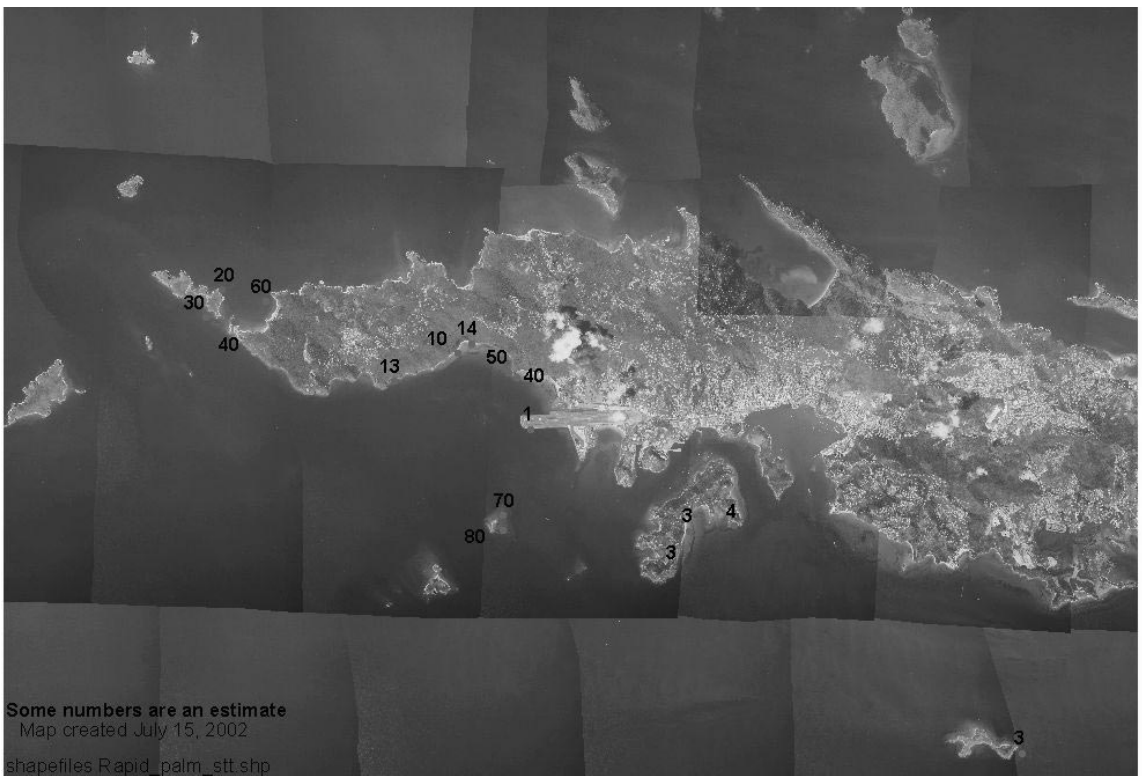
A single dense stand of this "species" has been videotaped in Saba Bay. There is no development in this watershed, but it is now for sale and any development of the steep upland areas will threaten survival of these shallow colonies.

ST. THOMAS

The existence of large *A. palmata* "ghosts" and fragments of *A. cervicornis* indicate that at one time these species were the main reef-building corals in the near shore areas of St. Thomas and outlying cays. These corals apparently succumbed to white-band disease and hurricanes. Live stands of *A. palmata* as well as dead, upright colonies can be found just south east of Buck Island (St. Thomas); east of Flat Cay, Hull Bay, Botany Bay; southeast and southwest of West Cay; northeast of the point of Little St. Thomas; and south-east and west of Black Point, Perseverance Bay and David Point (Fig. 13). There are smaller dead colonies of elkhorn as well as live individual colonies in the deeper waters (12 m) of the spur and groove reefs in Sprat Bay and Limestone Bay off Water Island.

It has been reported that extensive thickets of *Acropora cervicornis* existed near Buck Island at depths up to 17m before Hurricane Marilyn in 1995. This storm apparently destroyed these thickets. In June 2002 only a few staghorn colonies were seen in this area, and they appeared to have white-band disease.

Figure 13. The map shows areas that have been surveyed or have been reported to have *Acropora palmata* around St. Thomas as of July 2002.



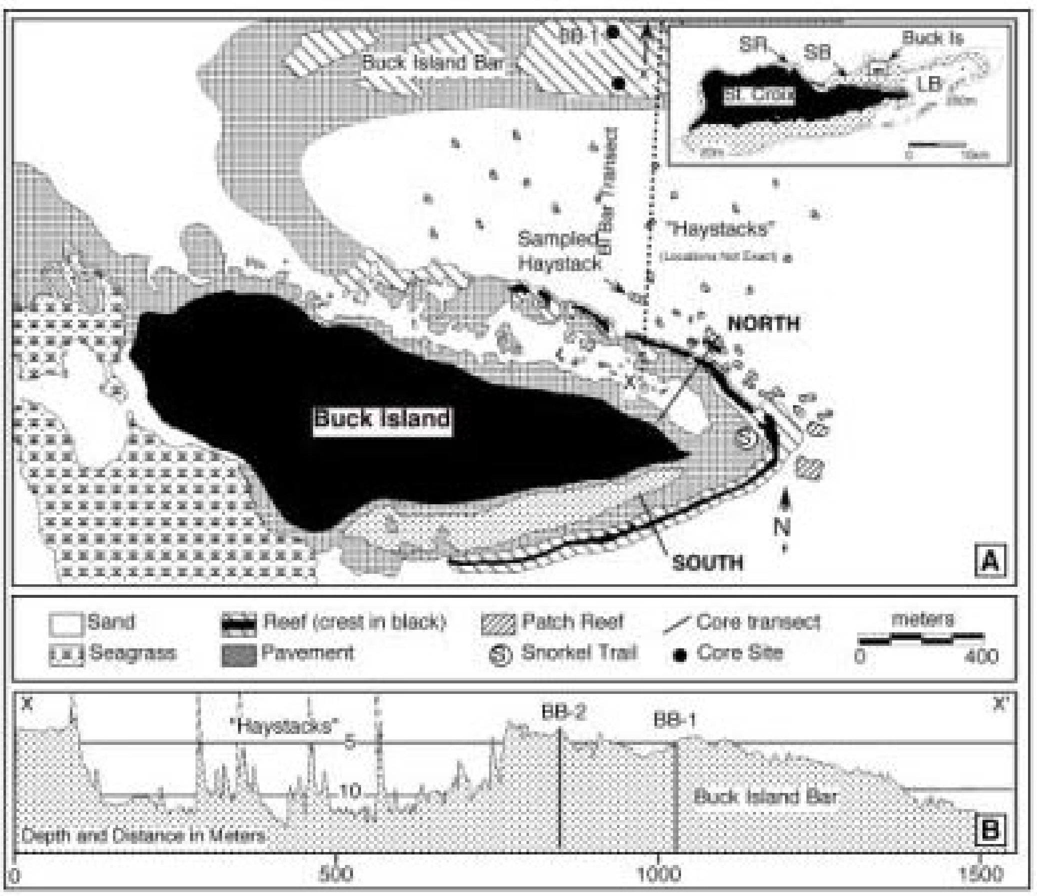
Recent surveys of *Acropora* spp.

Using a rapid assessment method, 448 elkhorn colonies were recorded from 16 locations around St. Thomas (Fig. 13). Of the colonies for which there is information on condition, 63 were healthy, 131 were "moderately" healthy, and 3 were mostly dead. Some of the most extensive elkhorn stands around St. Thomas are found in Botany Bay which is soon to be developed extensively.

LONGER-TERM PATTERNS: A GEOLOGICAL PERSPECTIVE

While the coral reef monitoring and research programs in the USVI, and particularly at Buck Island, provide some of the longest and most complete records of recent *A. palmata* history, they provide only a glimpse of longer-term patterns. Perhaps the greatest question with respect to the recent decline in abundance of this (and other) species is the relative importance of anthropogenic factors versus natural, cyclic change. Jackson (1992) and others have examined Pleistocene reefs and noted a zonation pattern similar to what was seen on Modern reefs prior to the early 1980's. It has been suggested that this fidelity of zonation reflects conditions 125,000 years ago that were more stable than those occurring today. It is tempting to conclude from this that the "more stable" Pleistocene reefs can be used to characterize "pre-anthropogenic conditions" and contrasted with the reef decline of recent decades. However, Jackson (1991) cautioned that apparent stability can change dramatically depending on either temporal or spatial scale. When viewed over longer periods (i.e., time averaging) or across greater distances, reef communities will appear more stable than the "chaos" that often characterizes community dynamics at the quadrat level. Thus, the question remains, "How do we use the recent geologic record as a backdrop for recent losses of *Acropora*?"

Figure 14. Map showing the location of coring transects across the northern and southern portions of Buck Island reef. The location of Buck Island relative to St. Croix is shown in the inset. A profile across Buck Island Bar showing core locations is provided below the map.



A coring investigation was conducted at Buck Island in 1989 and 1990 to document the Holocene development of the reef. Seven cores were taken along two transects that correspond to biological monitoring stations (BI- 3 on the north and BI- 2 to the south:Fig. 14). An additional core was recovered from Buck Island Bar on the exposed platform north of Buck Island.

If one compares the relative percent cover of the main coral species (and total coral abundance) in the cores to monitoring data from the same locations, a striking similarity exists between the time-averaged community structure over the past 7,000 years and the pre-WBD reef community. This is in line with Jackson's observations on Pleistocene reefs and strongly suggests that a reef community dominated by *A. palmata* has been the norm at Buck Island over the past seven millennia.

It is tempting to take these observations further and imply that this spatial persistence reflects temporal stability of the reef community. This similarity has in fact been cited as evidence that "the regional *Acropora* kill is without precedent in the late Holocene" (Aronson and Precht 2001). However, a closer examination of the data from the Buck Island cores and other Caribbean sites indicate that the situation is not this simple.

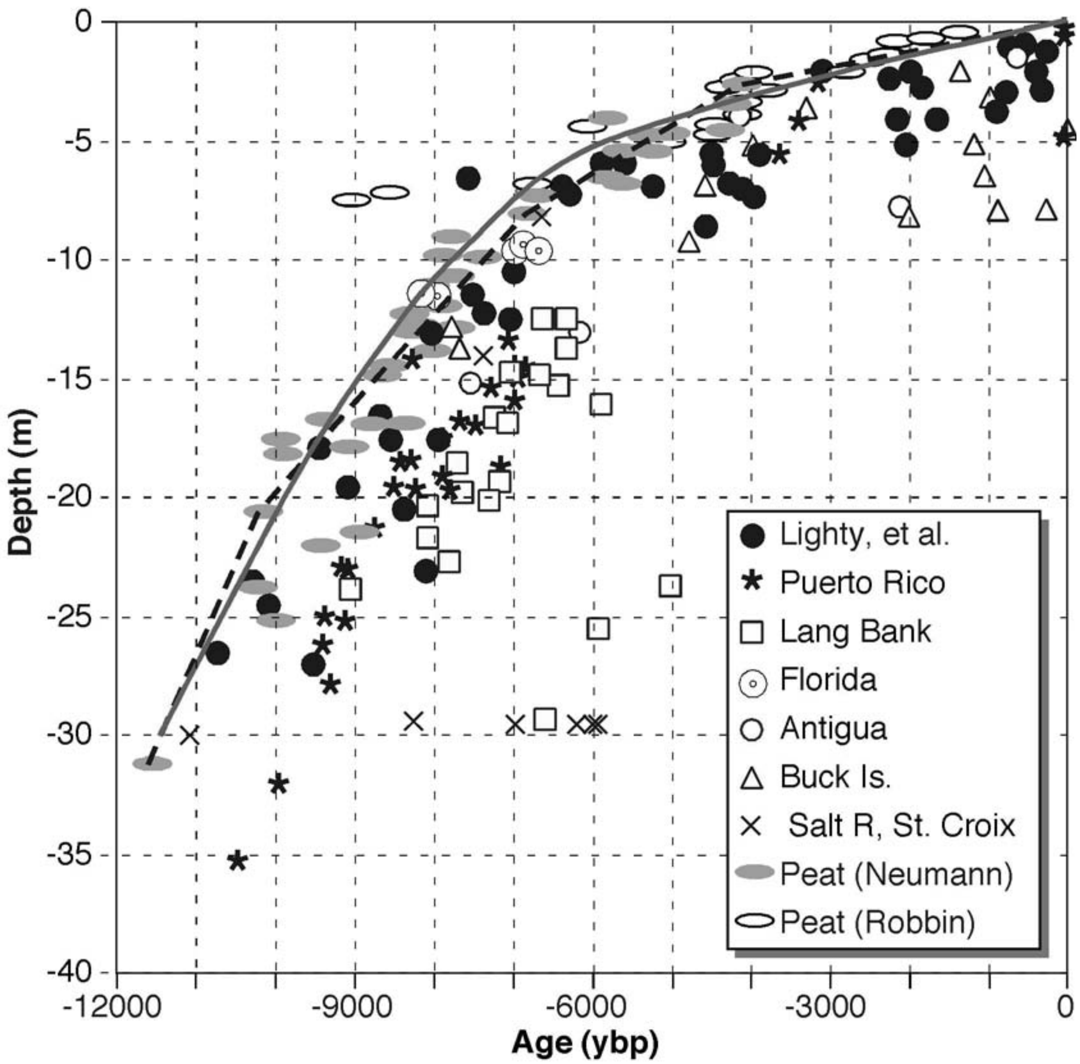
Early development at Buck Island was dominated by massive corals, despite oceanographic conditions seemingly more favorable for *Acropora* growth (i.e., clear, shallow water with active circulation). This pattern is also typical of the Florida Keys and other shallow reefs developing at this time. *Acropora palmata* eventually took over the reef crest but again disappeared from the Buck Island system around 3,000 years ago. It re-established after nearly a thousand year hiatus. If one compares this pattern to the larger Caribbean, it appears that the absence of *A. palmata* from Buck Island is part of a larger, regional pattern.

Figure 15 summarizes the pattern of *A. palmata* occurrence based on over 120 samples (ages are either calibrated $_{14}$C or U/Th determinations). Starting around 6,000 Cal bp ("calibrated years before present"), the abundance of *A. palmata* samples decreases dramatically (note that the flattened circles are mangrove peat dates and not coral dates). This corresponds to the time when Caribbean reefs that one would expect to have been dominated by *A. palmata* were not. Again, *A. palmata* is not seen between 3,000 and 2,000 Cal bp. This corresponds to the shift from *A. palmata* to massive corals at Buck Island.

The widespread occurrence of these gaps across the Caribbean argues for a regional or global cause. Sudden changes in sea level or local oceanographic conditions cannot explain the pattern. The confinement of the event to *A. palmata* and its broad impact are similar to the recent white-band disease outbreak. While an absolute link cannot be proven at this time, the occurrence of widespread *A. palmata* losses twice in the recent geologic past argue against such events being "unprecedented".

Whatever the cause for past outbreaks, anthropogenic factors have played an important role in recent reef decline and rising human exploitation of tropical coastal areas cannot continue without serious negative repercussions. The above discussion argues for a re-examination of our newfound confidence in separating natural from anthropogenic change. The geologic past provides an important long-term record against which present-day change can be considered. However, until we address spatial and temporal scaling problems inherent in comparing a time-averaged record created over thousands of years to monitoring records spanning at best three decades, accurately applying the ancient record will remain an elusive goal. In the balance lies our ability to make objective and scientifically grounded management decisions on a local, regional or global scale.

Figure 15. Plot of age and depth (relative to present sea level) of Caribbean *A. palmata* samples. The sealevel curves of Lighty et al (1981: solid) and Neumann (unpubl.) are also shown. Note the gaps in *A. palmata* starting at ca. 6,000 and 3,000 Cal bp. From Hubbard et al (2000, in press).



CONCLUSIONS

• None of the reefs that has recently been surveyed has a density or percent cover of elkhorn coral equivalent to what it had in the past. Overall tissue reduction in the reef zones formally dominated by *Acropora palmata* has been catastrophic, two orders of magnitude or greater. "Graveyards" of elkhorn, where detached dead branches of this species are interspersed among dead but standing colonies, are still visible on many reefs. However, at least at some locations around all three of the major islands, St. Thomas, St. Croix, and St. John, there is evidence that elkhorn coral is recovering. Maximum cover of elkhorn noted to date around St. John was 30% for a small area on Hawksnest Reef and 3.6% at Romney Reef off St. Croix.

• Staghorn coral is now relatively rare around St. Croix but numerous, mostly isolated colonies are common around St. John.

• Comparisons of previous and present values for percent cover will usually underestimate the actual declines in elkhorn because of the coral's complex morphology. This is because the present colonies are small, and many are primarily crusts, rather than complex three-dimensional colonies as in the past. Those colonies stood several meters above the substrate with live tissue covering not only the top and bottom of the branches, but extending down to the base of the colony as well.

• White-band disease has been more responsible for mortality of the *Acropora* spp. than any other factor in the USVI, although the physical damage from hurricanes has jeopardized recovery from this disease. No active WBD has been noted on elkhorn corals around St. John this year, and it was seen on only a few colonies around St. Croix. Staghorn corals often have freshly killed portions for which the cause is unknown. WBD appears to be responsible in some cases.

• Sexual recruitment of *A. palmata* has been successful at many locations.

• Although the *Acropora* spp. can reproduce effectively through fragmentation (Highsmith 1982), the storm-generated fragments of these species in the USVI have not survived and grown to replace the reefs decimated by disease and storms.

• Many of the new coral colonies are in very shallow water close to shore making them especially vulnerable to runoff from development, exposure at low tide, and storm surge. Many are exhibiting considerable losses to snail predation. It is not clear if recovery will continue.

• Although elkhorn coral has many mechanisms for recovering from physical damage, and fragments can develop into new colonies, it is not clear that it will be as successful at recovering from the current assault from the overall, unprecedented combination of stresses (including predation and disease).

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Threats to *Acropora* spp. in the Caribbean

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Mass mortalities of *Acropora palmata* and *Ac. cervicornis* on Caribbean reefs over the last three decades have caused drastic declines in coral cover throughout the region. Although hurricanes and cold-water events (in Florida and the Bahamas) have killed acroporids on some reefs, white-band disease has been the single most significant source of mortality on a regional level. Paleontological work in Belize suggests that the *Acropora* kill is without precedent in at least the last 3-4 Kyr. Analysis of 36 reef cores extracted from a 375-km^2 area of the central shelf lagoon showed that *Ac. cervicornis* dominated continuously for at least the last 3,000 yr. The lettuce coral *Agaricia tenuifolia* occasionally grew in small patches until the late 1980s. Within a decade, *Ac. cervicornis* was virtually eliminated by white-band disease. *Ag. tenuifolia* recruited to and grew on the dead coral branches and was the dominant coral by the mid-1990s. The scale of species turnover increased from tens of square meters or less to hundreds of square kilometers or more. Paleontological data from the Dominican Republic, St. Croix and the Bahamas support the hypothesis that the current situation is unprecedented on a millennial scale.

In fore reef environments, the establishment of damselfish territories and other localized mortality were responsible for variability at the smallest spatial and temporal scales (square meters, months to years) within populations of acroporids. Hurricane damage introduced variability at larger spatial and temporal scales (kilometers to tens of kilometers, years to 1-2 decades). The spatial scale of mortality of *Acropora* spp. has increased to a regional scale, virtually eliminating variation at a range of smaller spatial and temporal scales.

Current threats to remnant populations of *Acropora* include hurricanes, disease, corallivory, hyper- and hypothermic stress, sea-level rise and pollution. These threats generally act in combination rather than individually. The life history strategies of *Ac. palmata* and *Ac. cervicornis* are not conducive to rapid recovery from regional mass mortality. At present, agariciids and poritids are the most common corals colonizing the disturbed surfaces of reefs formerly occupied by acroporids.

Focal *Acropora* spp. Assessment in the Florida Keys

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This presentation will summarize two recent assessments of *Acropora* spp. status. The first involves population surveys of elkhorn coral, *Acropora palmata*, and its predator, the corallivorous snail *Coralliophila abbreviata*, in the Key Largo area. Surveys were conducted annually in May from 1998 to 2001 at six sites in the FKNMS; three no-take zones and three reference areas. At each survey, size and condition of each sampled coral colony was estimated as well as the number and size of its resident snails. A drastic decline in *A. palmata* populations was observed between May 1998 and May 1999, coinciding with a severe bleaching event and Hurricane Georges during summer/fall of 1998. All colonies in three patches (out of 10, ~200 colonies) sampled in 1998 suffered complete mortality by May 1999. Sampling at two sites in October 1998, after Hurricane Georges, confirmed that average sizes of standing colonies and of loose fragments had decreased while the abundance of fragments had increased. The total amount of live *A. palmata* (as measured by total # of colonies or by total "live area index") extant at three sites where all colonies were sampled declined drastically from 1998 to 1999 and has shown only marginal recovery from 1999 to 2001. The incidence of white band disease (WBD) in these *A. palmata* patches has been consistently low throughout the study, below 6% for any given site survey with zero incidence observed in many site surveys. The average incidence of WBD observed in 2001 was 2% of colonies (n=6 sites). The average density of corallivorous snails on *A. palmata* (#/*A. palmata* colony surveyed, n=6 sites) more than doubled from 1998-2000 but declined slightly between 2000 and 2001 (overall mean ~0.8 for 2001). Sites with low-density *A. palmata* stands (LD sites) had consistently more snails colony^{-1} (0.8-2.5) than sites with thickets (0.4-1.0). Meanwhile, the average size of snails on *A.palmata* declined between 1998 - 1999 and has rebounded somewhat by 2001. Published measurements of average snail consumption rate are ~1-2 (cm^{2}live *A.palmata* tissue)snail^{-1}d^{-1} with individual measurements ranging up to 6.5 (cm^{2}live *A.palmata* tissue)snail^{-1}d^{-1}.

The second assessment evaluated change in total *Acropora* spp. cover at Looe Key (lower Keys) over a longer time frame. In 2000 the occurrence and approximate size of all *A. palmata* and *A. cervicornis* colonies was recorded on scaled base maps of the spur and groove structure at Looe Key and compared to archival maps made with the same scaled base maps in 1983. Total areal loss for the mapped area was estimated at 93% for *A.palmata* and 98% for *A. cervicornis*. It is likely that considerable *Acropora* spp. loss had occurred prior to 1983, and is thus not included in these estimates.

Lastly, recent attempts at larval culture of *A.palmata* for restoration will be described.

Status of Acropora Corals in the Florida Keys: Habitat Utilization, Coverage, Colony Density, and Juvenile Recruitment

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As part of an ongoing, large-scale assessment and monitoring program in the Florida Keys, this study collected coverage and colony density data for *Acropora* corals in the region, including Dry Tortugas National Park and Tortugas Bank. The results presented are considered preliminary because our initial sampling program was not optimized for surveying the coverage and density of *Acropora* corals. During 1999-2001, a total of 260 sites were sampled in the region, including 204 sites from southwest of Key West to northern Key Largo (Figure 1) and 56 sites in Dry Tortugas National Park, the Tortugas Bank, Riley's Hump, and south of the Marquesas Keys (Figure 2). As part of our larger program, sampling was stratified with respect to habitat type, geographic region, and protection from fishing to ascertain spatial variations in mean percent coverage, species presence-absence, density of juveniles, and the density, size, and disease prevalence of colonies > 4 cm maximum diameter. In randomly selected sampling locations, 10m or 25 m transects were used for linear point-intercept estimates of cover, and 1 m swaths were surveyed for the presence and density of *Acropora* colonies. During 2001, larger transects (25 m x 2 m) were also used to obtain density estimates of both species. Eight habitat types were surveyed from nearshore to the deeper fore reef (15 m) and included mid-channel and offshore patch reefs, back reef rubble, high-relief spur and groove, low-relief hard-bottom, and low-relief spur and groove. Sites were further classified by geographic region into the lower, middle, and upper Keys.

Mean percent coverage for both *Acropora* species, as determined from surveys of 100 points for each of four transects per site, was low (Table 1 and Figure 3). In the Florida Keys, mean coverage by *A. cervicornis* was 0.049% among the eight habitat types and did not vary significantly. Mean cover was greatest on high-relief spur and groove reefs (0.049%) and offshore patch reefs (0.045%). Mean coverage by *A. palmata* was even lower throughout the Florida Keys than its congener, even on many high-relief spur and groove reefs where it was formerly abundant. Among the eight habitat types surveyed, *A. palmata* was only recorded in high-relief spur and groove. Mean coverage in this habitat type was 0.158% and ranged from 0.158% in the lower Keys, 0.300% in the middle Keys, to 0.338% in the upper Keys. The density of *Acropora* colonies was quantified in 25 m x 0.4 m or 10 m x 0.4 m transects. For *A. cervicornis*, mean colony densities among the eight habitat types were no greater than 0.052 colonies/m^2 and there were no significant differences detected in mean colony density among habitat types (Table 3). Offshore and mid-channel patch reefs had the greatest mean densities (0.047-0.052 colonies/m^2). Within strip transect surveys, colonies of *A. palmata* were only found in the high-relief spur and groove habitat. The mean density estimate for this habitat type was 0.036 colonies/m^2, ranging among regions from 0.010/m^2 in the middle Keys, 0.015/m^2 in the lower Keys, and 0.073/m^2 in the upper Keys. Patches of numerous colonies were evident at Sand Key, Eastern Dry Rocks, Molasses Reef, Sand Island, and Elbow Reef, most of which are within Sanctuary no-fishing zones.

The prevalence of disease or disease-like conditions indicated relatively low prevalence of for both *Acropora* species, although few colonies were assessed during 1999-2001 (Table 4). Of the 31 *A. cervicornis* encountered, only one colony exhibited signs of possible recent disease. Three of the 18 colonies of *A. palmata* assessed exhibited either white band disease or signs of recent disease, evidenced by dead white skeleton. Not surprisingly, few juveniles for either *Acropora* species were encountered from the 260 Florida Keys sites. Reconnaissance surveys in several locations, however, did reveal some smaller colonies presumably derived from sexual recruitment, supported by the lack of nearby colonies.

Because density estimates using 25 m x 0.4 m or 10 m x 0.4 m transects were so low for both *Acropora* species, the 2001 surveys also included larger and additional transects to assess densities (Tables 5-6). For the Florida Keys shallow fore reef, both spur and groove and hardbottom were surveyed from Key West to northern Key Largo at 2 m to 8 m depth. Densities were extremely patchy (Table 5 and Figure 4) and despite the relatively large sample area, only 43 colonies of *A. cervicornis* and 302 colonies of *A. palmata* were recorded. Maximum densities for particular reefs were 2.25 colonies/m^2 for *A. cervicornis* and 12.13 colonies/m^2 for *A. palmata* (Figure 4). In low-relief hard-bottom areas, 50 *A. cervicornis* and 18 *A. palmata* colonies were encountered and were even more patchily distributed.

Table 1. Mean percent coverage of *Acropora cervicornis* and *A. palmata* by habitat type and regional sector in the Florida Keys, 1999-2001 (Miller et al., NURC/UNCW).

Habitat/regional strata (no. sites)	*Acropora cervicornis*		*Acropora palmata*	
	Mean % cover	SE	Mean % cover	SE
Mid-channel patch reef (16)	0.016	0.022	---	---
Lower Keys (6)	---	---	---	---
Middle Keys (8)	---	---	---	---
Upper Keys (2)	0.125	0.145	---	---
Offshore patch reef (22)	0.045	0.052	---	---
Lower Keys (12)	0.083	0.128	---	---
Middle Keys (1)	---	---	---	---
Upper Keys (9)	---	---	---	---
Back reef rubble (7)	---	---	---	---
Lower Keys (7)	---	---	---	---
Inner line reef tract (4)	---	---	---	---
Upper Keys (4)	---	---	---	---
High-relief spur and groove (46)	0.049	0.089	0.158	0.174
Lower Keys (24)	0.073	0.158		
Middle Keys (5)	0.100	0.407	0.300	0.733
Upper Keys (17)	---	---	0.338	0.400
Low-relief hard-bottom (62)	0.012	0.014	---	---
Lower Keys (13)	0.058	0.060	---	---
Middle Keys (28)	---	---	---	---
Upper Keys (21)	---	---	---	---
Patchy hard-bottom in sand (8)	---	---	---	---
Lower Keys (1)	---	---	---	---
Middle Keys (6)	---	---	---	---
Upper Keys (1)	---	---	---	---
Low-relief spur and groove (39)	0.006	0.011	---	---
Lower Keys (25)	0.010	0.019	---	---
Middle Keys (11)	---	---	---	---
Upper Keys (3)	---	---	---	---

Table 2. Survey effort and number of *Acropora cervicornis* and *A. palmata* colonies sampled for colony density in the Florida Keys, 1999-2001 (Miller et al., NURC/UNCW).

Habitat/regional strata	**No. sites surveyed**	**Survey area (m^2)**	***A. cervicornis***	***A. palmata***
Mid-channel patch reef				
Lower Keys	6	34.8	---	---
Middle Keys	8	32.6	---	---
Upper Keys	2	12.4	6	---
Subtotal	16	79.8	6	---
Offshore patch reef				
Lower Keys	12	107.6	13	---
Middle Keys	1	5.6	---	---
Upper Keys	9	50.6	---	---
Subtotal	22	163.8	13	---
Back reef rubble				
Lower Keys	7	140.0	---	---
Inner line reef tract				
Upper Keys	4	61.0	---	---
High-relief spur and groove				
Lower Keys	24	283.7	3	2
Middle Keys	5	63.6	2	1
Upper Keys	17	194.7	1	15
Subtotal	46	542.0	6	18
Low-relief hard-bottom				
Lower Keys	13	230.4	4	---
Middle Keys	28	506.0	---	---
Upper Keys	21	403.6	---	---
Subtotal	62	1140.0	4	---
Patchy hard-bottom in sand				
Lower Keys	1	20.0	---	---
Middle Keys	6	110.0	---	---
Upper Keys	1	20.0	---	---
Subtotal	8	150.0	---	---
Low-relief spur and groove				
Lower Keys	25	558.7	2	---
Middle Keys	11	220.0	---	---
Upper Keys	3	60.0	---	---
Subtotal	39	838.7	2	---
Total	204	3115.3	31	18

Table 3. Mean density (no. colonies/m^2) of *Acropora* colonies (> 4 cm max. diameter) by habitat type and regional sector in the Florida Keys, 1999-2001 (Miller et al., NURC/UNCW).

Habitat/regional strata (no. sites)	*Acropora cervicornis*		*Acropora palmata*	
	Mean colonies/m^2	SE	Mean colonies/m^2	SE
Mid-channel patch reef (16)	0.047	0.047	---	---
Lower Keys (6)	---	---	---	---
Middle Keys (8)	---	---	---	---
Upper Keys (2)	0.375	0.375	---	---
Offshore patch reef (22)	0.052	0.031	---	---
Lower Keys (12)	0.094	0.055	---	---
Middle Keys (1)	---	---	---	---
Upper Keys (9)	---	---	---	---
Back reef rubble (7)	---	---	---	---
Lower Keys (7)	---	---	---	---
Inner line reef tract (4)	---	---	---	---
Upper Keys (4)	---	---	---	---
High-relief spur and groove (46)	0.009	0.004	0.036	0.025
Lower Keys (24)	0.010	0.006	0.015	0.015
Middle Keys (5)	0.020	0.020	0.010	0.010
Upper Keys (17)	0.005	0.005	0.073	0.064
Low-relief hard-bottom (62)	0.004	0.002	---	---
Lower Keys (13)	0.018	0.010	---	---
Middle Keys (28)	---	---	---	---
Upper Keys (21)	---	---	---	---
Patchy hard-bottom in sand (8)	---	---	---	---
Lower Keys (1)	---	---	---	---
Middle Keys (6)	---	---	---	---
Upper Keys (1)	---	---	---	---
Low-relief spur and groove (39)	0.003	0.002	---	---
Lower Keys (25)	0.004	0.003	---	---
Middle Keys (11)	---	---	---	---
Upper Keys (3)	---	---	---	---

Table 4. Proportional prevalence of *Acropora* corals affected by diseases in the Florida Keys, 1999-2001. N = total number of colonies sampled (Miller et al., NURC/UNCW).

Species	Condition	No. colonies affected	Prevalence (proportion)
A. cervicornis	Dead white skeleton	1	0.0323
	Non-diseased	30	0.9677
	Total	31	1.0000
A. palmata	Dead white skeleton	1	0.0556
	White band disease	2	0.1111
	Non-diseased	15	0.8333
	Total	18	1.0000

Table 5. Mean (± 1 SE) *Acropora* densities (no. colonies/100 m^2) in Florida Keys fore reef habitats (2-8 m depth) during 2001, using 25 m x 2 m transects. Sites are arranged from southwest to northeast and those marked with an asterisk are Sanctuary no-fishing zones.

Habitat type/region/site	**Area (m^2)**	***Acropora cervicornis***	***Acropora palmata***
		No. colonies/100 m^2	**No. colonies/100 m^2**
Western Dry Rocks	800	---	0.63 ± 0.50
Sand Key*	800	---	11.13 ± 6.62
Eastern Dry Rocks*	800	---	1.63 ± 1.36
Marker 32	400	---	---
Western Sambo Reef*	800	2.25 ± 0.80	3.50 ± 3.50
Middle Sambo Reef	800	0.25 ± 0.25	---
Eastern Sambo Reef*	800	---	0.13 ± 0.13
No Name Reef	400	0.13 ± 0.13	---
Pelican Shoal	400	---	---
East of Pelican Shoal	400	---	---
American Shoal	400	1.25 ± 0.48	---
Lower Keys Subtotal	6,800	0.54 ± 0.20	1.84 ± 0.94
Sombrero Key*	800	0.13 ± 0.13	1.50 ± 1.00
East Delta Shoal	400	1.25 ± 1.25	
Middle Keys Subtotal	1,200	0.50 ± 0.42	1.00 ± 0.69
Pickles Reef	1,200	---	0.08 ± 0.08
Molasses Reef*	800	---	0.25 ± 0.16
Sand Island	400	---	11.75 ± 8.25
Elbow Reef*	800	---	12.13 ± 9.08
South of S. Carysfort	800	---	---
Carysfort/S. Carysfort Reef	1,600	0.25 ± 0.25	1.13 ± 0.46
Upper Keys Subtotal	5,600	0.07 ± 0.07	2.88 ± 1.48
Spur and groove total	**13,600**	**0.35 ± 0.11**	**2.19 ± 1.77**
Marker 26	400	1.50 ± 1.50	---
Maryland Shoal	1,600	1.94 ± 0.52	---
East of Looe Key	400	---	---
West of Big Pine Shoal	400	---	---
Lower Keys Subtotal	2,800	1.32 ± 0.39	---
Delta Shoal	800	0.88 ± 0.64	---
Crocker Reef	800	---	---
Davis Reef*	800	---	0.13 ± 0.13
Little Conch Reef	800	1.38 ± 0.60	---
Southwest of Conch Reef	400	---	---
Conch Reef*	800	---	---
Northwest of Conch Reef	800	---	2.13 ± 2.13
Middle Keys Subtotal	5,200	0.25 ± 0.12	0.35 ± 0.33
Little Pickles Reef	400	---	---
Southwest of Molasses Reef	400	---	---
Northeast of French Reef	1,200	---	---
Dixie Shoal	800	---	---
Dixie Shoal	800	---	---
Upper Keys Subtotal	3,600	---	---
Hard-bottom total	**11,600**	**0.43 ± 0.12**	**0.16 ± 0.15**

Table 6. Mean (± 1 SE) density (no. colonies/100 m^2) of *A. cervicornis* in Florida Keys mid-channel and offshore patch reef habitats during 2001, using 10 m x 2 m transects. Sites are arranged from southwest to northeast and those marked with an asterisk are Sanctuary no-fishing zones.

Habitat type/site	**Region**	**Sample area (m^2)**	***Acropora cervicornis***
			No. colonies/100 m^2
Mid-channel patch reef			
South of Sunshine Key	Middle Keys	160	1.25 ± 1.25
East Washerwoman	Middle Keys	160	---
South of Vaca Key	Middle Keys	160	---
East of Marker 49	Middle Keys	160	0.63 ± 0.63
Turtle Shoal	Middle Keys	160	---
East Turtle Shoal	Middle Keys	160	---
Cheeca Rocks*	Middle Keys	320	---
South of Molasses Channel	Upper Keys	320	9.06 ± 5.24
Habitat subtotal		**1,600**	**2.00 ± 1.15**
Offshore patch reef			
Northwest of Davis Reef	Middle Keys	160	---
West of Pickles Reef	Upper Keys	160	---
West of Molasses Reef	Upper Keys	320	5.31 ± 2.97
White Banks/Dry Rocks	Upper Keys	320	---
East of Mosquito Bank	Upper Keys	160	---
South of Carysfort Reef	Upper Keys	160	---
West of Carysfort Reef*	Upper Keys	320	---
Habitat subtotal		**1,600**	**1.06 ± 0.67**
All patch reef types		**3,200**	**1.53 ± 0.67**

Figure 1. *Acropora* survey locations throughout the Florida Keys, 1999-2001.

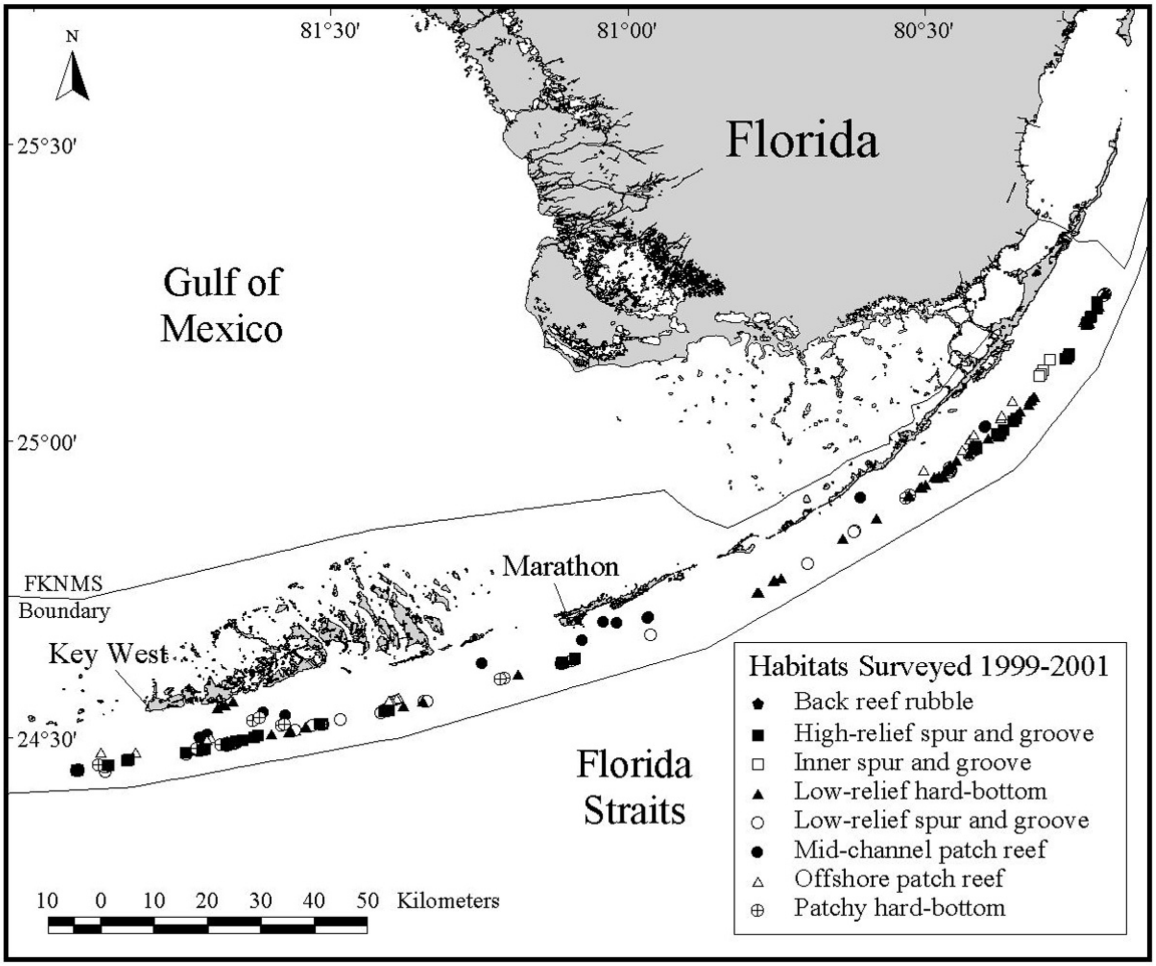


Figure 2. *Acropora* survey locations in the Tortugas, 1999-2000.

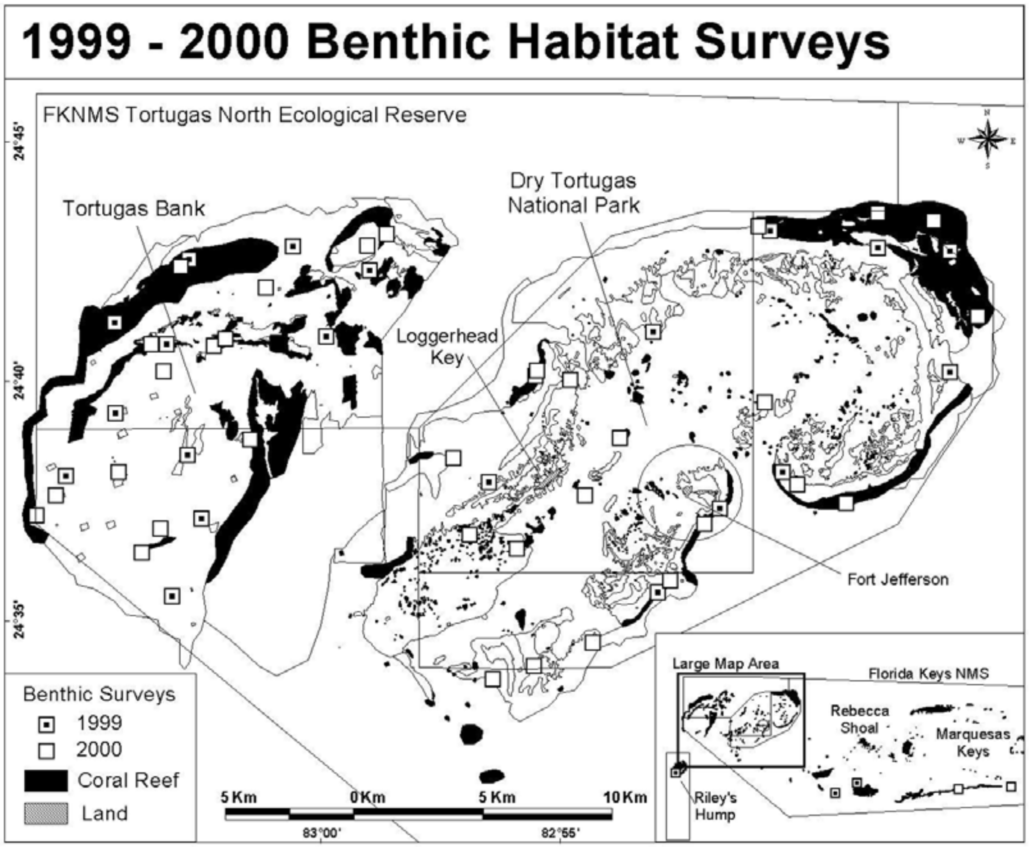
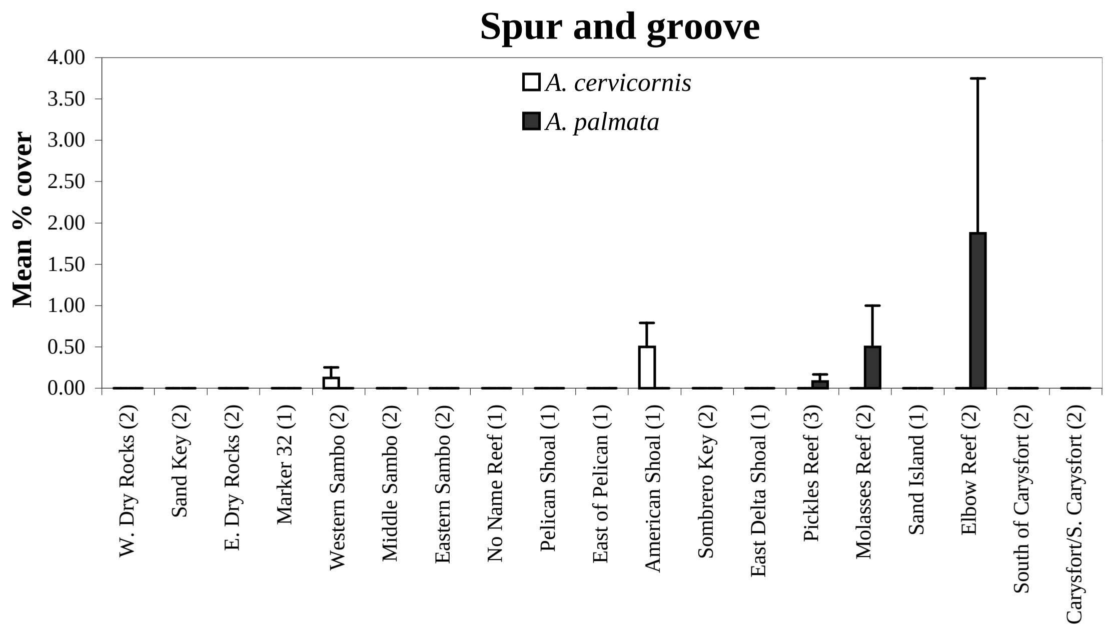


Figure 3. Mean percent cover of *Acropora cervicornis* and *A. palmata* on high-relief spur and groove reefs (top) and low-relief hard-bottom (bottom) on the Florida Keys fore reef during 2001. Sites are arranged from southwest to northeast and error bars represent one standard error. Values in parentheses are the number of sites surveyed for each reef, with 100 points surveyed along each of four 25 m transects per site.



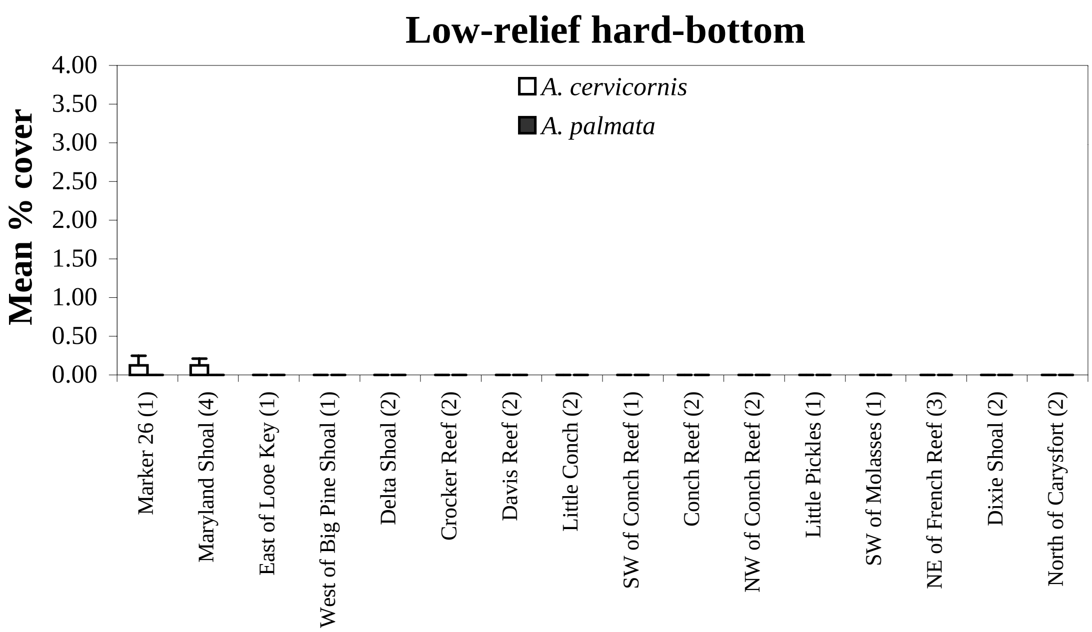
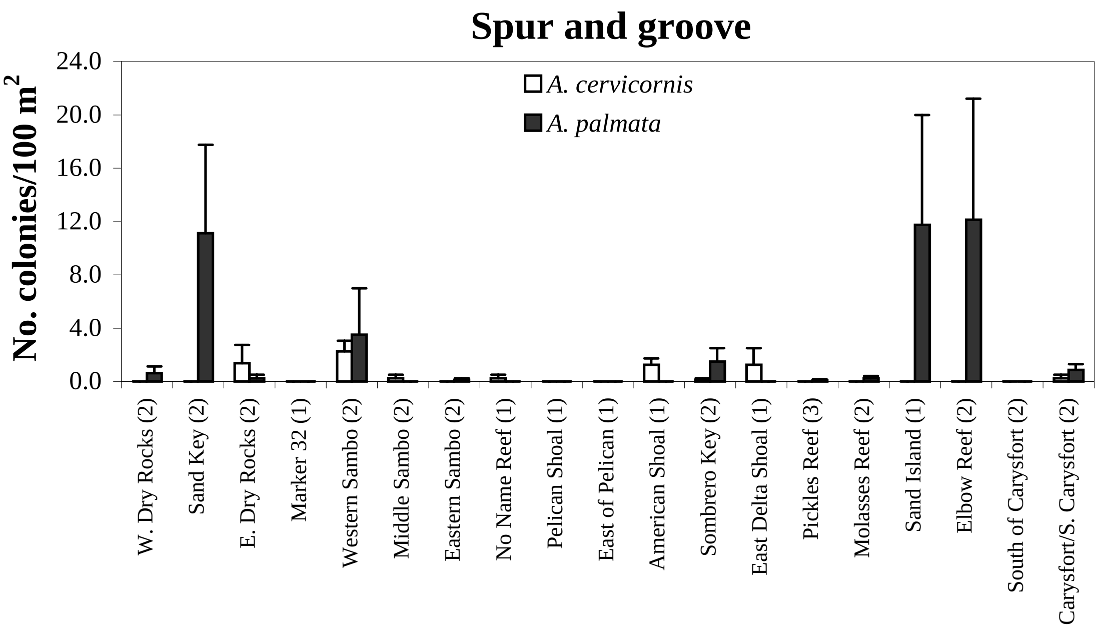
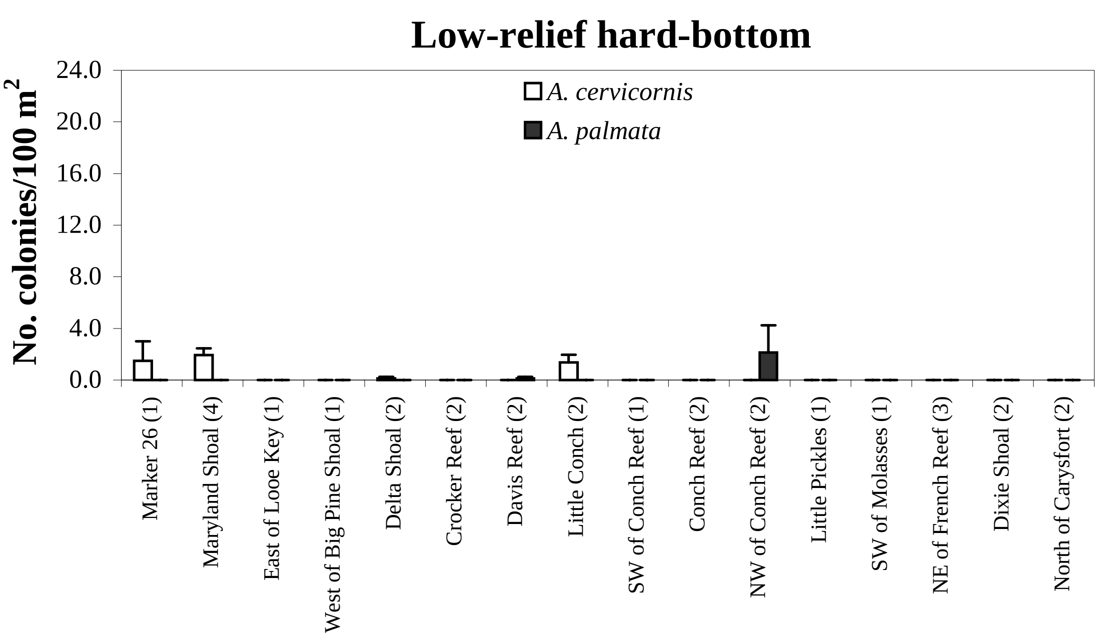


Figure 4. Mean density (no. colonies/100 m^2) of *Acropora cervicornis* and *A. palmata* on high-relief spur and groove reefs (top) and low-relief hard-bottom (bottom) on the Florida Keys fore reef during 2001. Sites are arranged from southwest to northeast and error bars represent one standard error. Values in parentheses are the number of sites surveyed for each reef, with 400 m^2 surveyed for colony numbers per site.





Acropora- A Review of Systematics, Taxonomy, Abundance, Distribution, Status, and Trends: Florida, 1881 - 2000

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Systematics

Phylum Cnidaria
- Class Anthozoa Ehrenberg, 1834
  - Subclass Zoantharia deBlainville, 1830
    - Order Scleractinia Bourne, 1900
      - Suborder Astrocoeniina Vaughan and Wells, 1943
        - Family Acroporidae Verrill, 1902
          - Genus *Acropora* Oken, 1815
            - *Acropora palmata* (Lamarck, 1816)
            - *Acropora cervicornis* (Lamarck, 1816)
            - *Acropora prolifera* (Lamarck, 1816)

Genus description:
Acropora: Branched, bushy, plate-like, sometimes encrusting. Axial and radial corallites on branches. Two cycles of septa (=12); porous corallite walls, corallites without columella. The type species is *Acropora muricata* (Linné 1758), missing, type locality unknown.

Geographic distribution: Pacific and Indian Oceans, Red Sea, Persian Gulf, Western Atlantic-Caribbean.

Stratigraphy: Eocene (58 x 10^6 YBP) to Recent

Veron and Wallace (1984) reported that there were 364 extant species of *Acropora*, 361 in the Indo Pacific and three in the western Atlantic. The three western Atlantic species, *A. palmata, A. cervicornis, and A. prolifera* are commonly referred to as elkhorn, staghorn, and fused staghorn corals.

Acropora palmata

Madrepora palmata Lamarck, 1816
Madrepora muricata forma palmata Brook 1893
Madrepora muricata Duerdan, 1899
Madrepora (Acropora) palmata Mayer, 1914
Acropora palmata (Lamarck) Vaughan, 1915
Acropora palmata (Lamarck) Wells and Lang, 1973
Acropora palmata (Lamarck) Veron 2000

Description: *Acropora palmata* is the largest of all *Acropora* species; colonies are up to four meters from branch tip to branch tip, two meters high, with a base trunk that is up to 40 cm in diameter. The base is firmly attached to the substrate. Branches are flat or less commonly round, tubular radial corallites are of various diameters and length. Brown to yellow-gold color.

Geographic distribution: Known from Dry Tortugas to Broward County in Florida. In the western Atlantic, *A. palmata* is known from the Bahamas, Greater and Lesser Antilles, Venezuela, Aruba, Bonaire, Curacao, Colombia, Panama, Nicaragua, Honduras, Belize, Mexico.

Stratigraphy: Late Pliocene to recent.

Bathymetry and habitat preference: Depth range is <1 to17 m, optimal range 1 to 5 m. The nominal habitat is the seaward face of a reef such as the spur and groove formations and seaward portion of the reef flat. Branch fragments are often found occupying back reef areas following storms; *A. palmata* may form extensive barrier reef structures such as in Belize, Greater Corn Island, and Roatan.

Reproduction and growth: *Acropora. palmata* is a hermaphroditic broadcast spawning species. The prime time for releasing eggs and sperm is in August and September. We documented that eggs, ova, and sperm were present in tissues (histological analysis) during June through August, 1978-1980. In 1977 and 1981, we did not see evidence of reproduction. Growth rate (branch extension) is 4 to 11 cm per year in Florida. A colony that was 2 meters in height would be 18 to 50 years old. The 4 cm rate is based on Vaughan's early studies in Tortugas and probably under estimates growth. *Acropora palmata* can rapidly spatially monopolize large areas by fragment propagation. Fragments cleaved from the colony may grow into new individuals (Highsmith et al., 1980; Bak and Criens, 1981; Tunnicliffe, 1981; Highsmith, 1982; Rogers et al., 1982; Tunnicliffe, 1984).

Acropora cervicornis

Madrepora cervicornis Lamarck, 1816
Madrepora cervicornis Pourtalés, 1871
Acropora cervicornis (Lamarck) Goreau and Wells, 1967
Acropora cervicornis (Lamarck) Veron, 2000

Description: *Acropora cervicornis*: Arborescent, tubular branches, distinct axial-tubular corallites at branch terminals and radial corallites distributed relatively uniformly on branches. Radial corallites often form bracts rather than tubes. Secondary branches diverge from primary branches at 30 to 90 degree angles. Specimens from deep water tend to have long and slender (about 1.5-cm in diameter) branches and fewer secondary branches. Branches of colonies from shallow water tend be thicker (about four cm in diameter) with a greater number of secondary branches. The color ranges from gold and yellow to brown. Colonies are often not firmly attached to the substrate. Branches may fuse to adjacent branches (anastomosis) forming a pretzel-like maze. Large thickets form a complex structure than may be two to three meters in height and 30 meters long (seen in Dry Tortugas in the early to mid 1970s).

Bathymetry: The species was reported to depths of 50 m off Discovery Bay, Jamaica (Goreau and Wells, 1967), but is more often seen in depths of 3 to 30 m in Florida.

Reproduction and growth: The species is a hermaphroditic, broadcast spawner. The ova, eggs, and sperm were seen during summer of 1978, 1979, and 1981; in 1979, there was active gonad generation from January through June (unpublished data). Propagation from fragments is common (Gilmore and Hall, 1976, Tunnicliffe, 1981). Growth rate for *A. cervicornis* is 4 to 12 cm per year. The species has a more rapid growth during warmer months in Florida (Jaap, 1974).

Acropora prolifera

Madrepora prolifera Lamarck, 1816
Madrepora prolifera (Lamarck) Pourtalés, 1871
Isopora muricata forma *prolifera* Vaughan, 1901
Acropora prolifera (Lamarck) Cairns et al. 1991

This species is the most enigmatic of the three. It is confused with *A. cervicornis* and poorly studied. The distribution includes Dry Tortugas, Yucatan, Belize, Jamaica, Columbia, Panama, and the Netherlands Antilles.

Florida status and trends

Acropora palmata:

Dry Tortugas- 1882 to 1993. Estimated area of coverage went from 109 acres (Agassiz, 1882), to 0.15 acres (Davis, 1982), to 0.35 acres (Jaap and Sargent, 1993).

Elkhorn Reef, Biscayne National Park, 1977 to 1981, *A. palmata* abundance ranged from 8 to 28 colonies (Figure 4) along three 25 m long transects from 1977 to 1981 (Jaap, 1983).
Key Largo- 1981 to 1986. At Elbow Reef, abundance ranged from 66 to 84 colonies within 16 one m^2 quadrats. At French reef, abundance ranged from 42 to 99 colonies within 26 one m^2 quadrats. At Molasses Reef, abundance ranged from 79 to 135 colonies within 25 one m^2 quadrats. The trend these reefs was very stable populations (Figures, 5-8).

Looe Key, 1983. Seventeen *Acropora palmata* colonies occurred in six quadrats on a spur, 2 to 7 m depth.

Coral Reef Monitoring Project, USEPA WQPP, 1996 to 2000, data from 160 video transects from north Key Largo to Smith Shoal. *A. palmata* occurred at five shallow reef sites. Data are processed by point count analyses, we identify benthos and substrate for approximately 600 points at each station, and there are four stations per reef. Percent cover data are computed from the relative number of points that were covering *A. palmata* colonies.

The percent cover contributed by *A. palmata* at upper Keys Reefs ranged from 7.23 percent in 1996 to 0.95 percent in 2000. In the lower Keys reefs, *A. palmata* cover ranged from 7.27 percent in 1996 to 0.85 percent in 2000 (Figures 10, 11).

Acropora cervicornis

In Dry Tortugas, Agassiz (1882) estimated *A. cervicornis* covered 1030 acres; Davis (1982) estimated coverage at 1181 acres. In 1976-77 a hypothermic event occurred, killing 90 to 95 percent of the population of *A. cervicornis* and *A. prolifera* at Dry Tortugas (Walker 1981, Porter et al., 1982). In 1983 there was a loss from a disease that caused significant losses of *A. cervicornis* (Peters et al., 1983).

In a study of several reefs in Biscayne National Park from 1977 to 1981 we saw a decile in abunce at Elkhorn Reef (N= 3 transects) of 32 to 15 colonies (Figure 4).

In a study at Key Largo Reefs from 1981 to 1986 we observed a decline of 175 to 0 colonies at French Reef and 120 to 3 colonies at Molasses Reef (Figures 7, 8).

In the CRMP study we observed declines: in the upper keys, *A. cervicornis* declined from 0.13 percent cover in 1996 to 0.03 percent in 2000, in the middle Keys, *A. cervicornis* declined from 0.26 percent cover in 1996 to 0.00 percent in 2000, and in the lower Keys. *A. cervicornis* declined from 0.11 percent cover in 1996 to 0.02 percent in 2000. In Dry Tortugas, at White Shoal, we saw a relatively stable abundance in *A. cervicornis* (Figures 12-15).

Causes for *Acropora* declines in Florida

Natural disturbances: hurricanes, hypothermia, hyperthermia, winter storms (1992 storm of the century).

Diseases: the white disease seen in *A. palmata* and in *A. cervicornis* can be very serious Gladfelter (1977) and Peters et al. (1983, 1986) report on the impact and causative pathogen.

Predators that feed on *Acropora* include the fire worm *Hermodice carunculata* (Marsden, 1960, Glynn, 1960); the gastropod *Coralliophilla abbreviata* (Brawley and Adey, 1981), the three spot damsel fish (Kaufman, 1977, Potts, 1977). Competitors for lebensraum (space): Fleshy algae (Lighty, 1981)

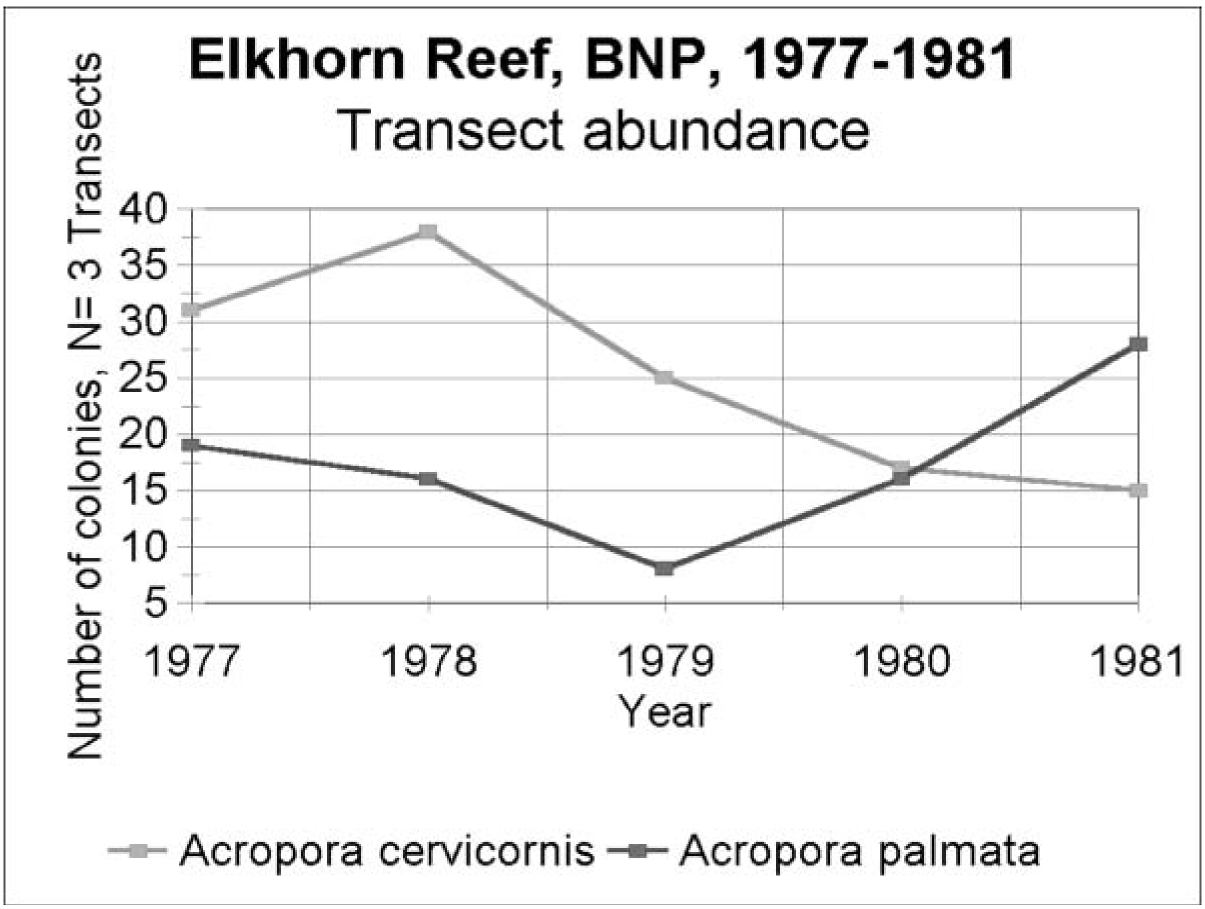


Figure 4. Abundance of *Acropora palmata* and *A. cervicornis* at Elkhorn Reef, Biscayne National Park, three 25 m long continuous line transects parallel to the depth contours (3 to 5 m depth).

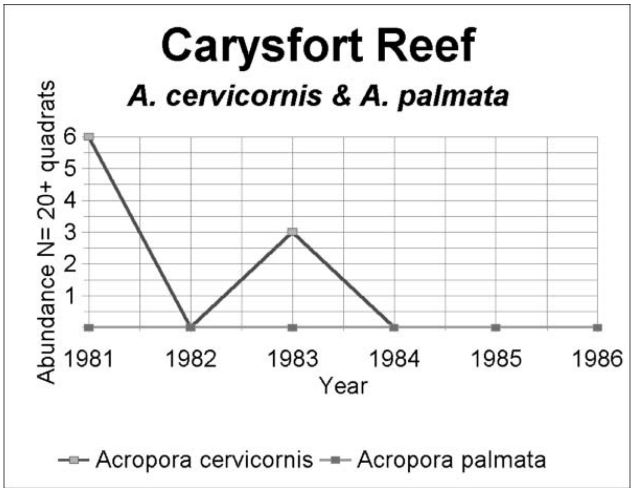


Figure 5. Abundance of *Acropora palmata* and *A. cervicornis*, Carysfort Reef, 1981-1986, based on inventory of 16 1m^2 quadrats per year.

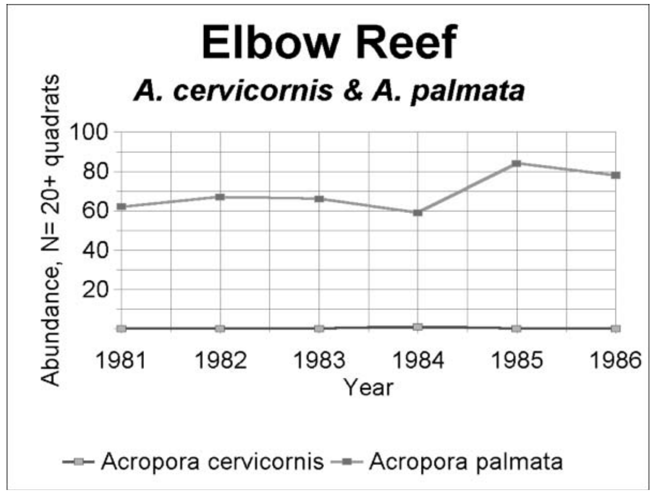


Figure 6. Abundance of *Acropora palmata* and *A. cervicornis*, Elbow Reef, 1981-1986, based on inventory of 26 1m^2 quadrats per year.

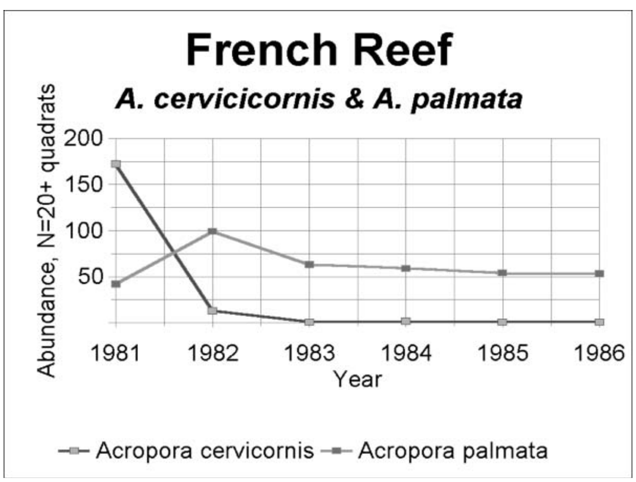


Figure 7. Abundance of *Acropora palmata* and *A. cervicornis*, French Reef, 1981-1986, based on inventory of 27 1m^2 quadrats per year.

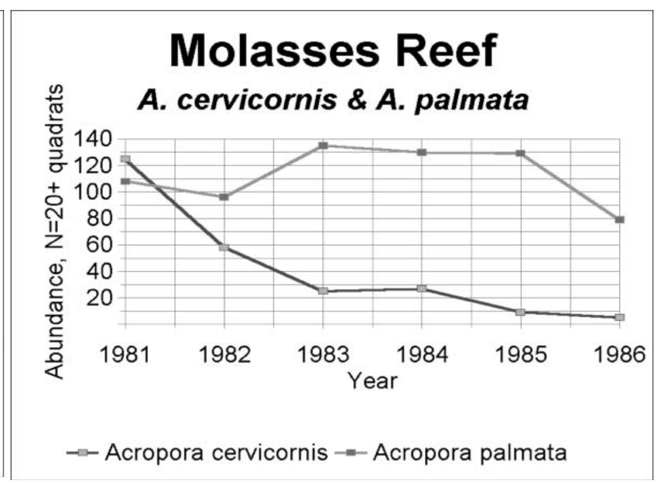


Figure 8. Abundance of *Acropora palmata* and *A. cervicornis*, Molasses Reef, 1981-1986, based on inventory of 25 1m^2 quadrats per year.

Figure 10. *Acropora palmata* cover at Upper Keys locations, 1996 to 2000, point count analysis of video images.

Acropora palmata, Upper Keys (n=7)

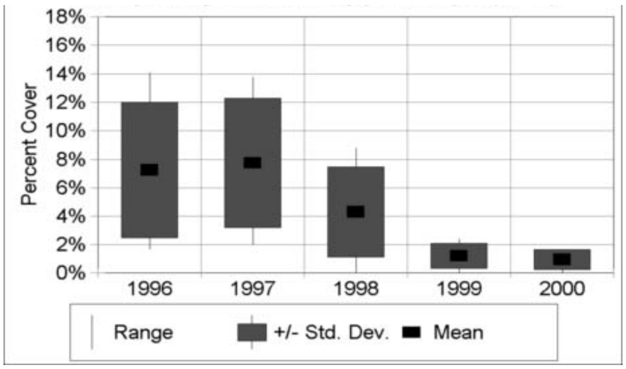
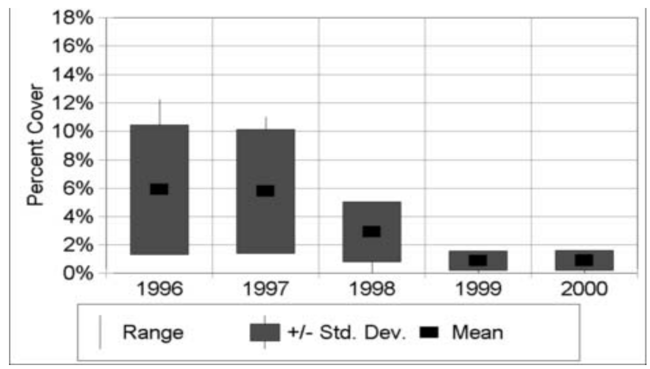


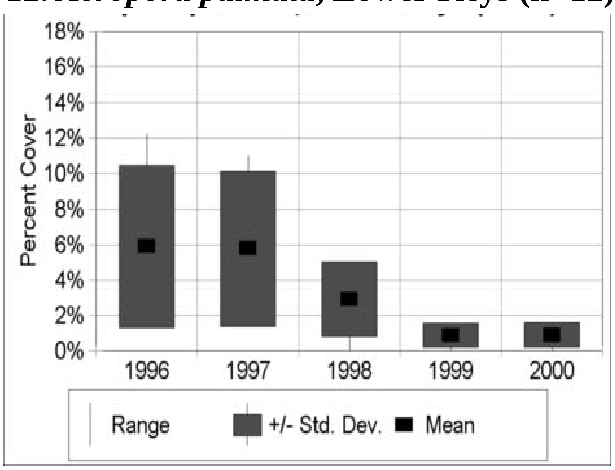
Figure 11. *Acropora palmata* cover at lower Keys locations, 1996 to 2000, point count analysis of video images

Acropora palmata, Lower Keys (n=12)

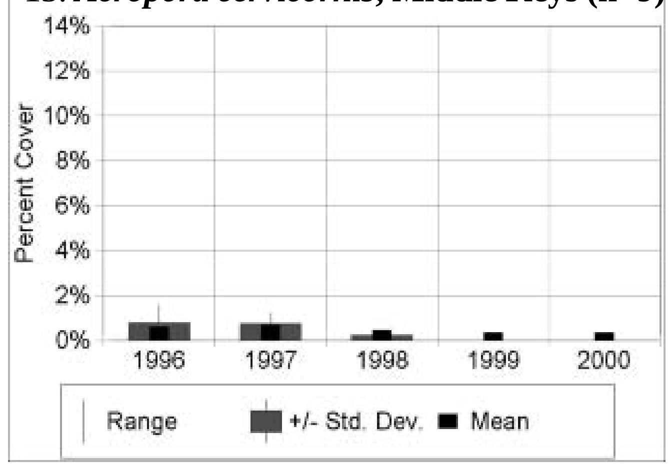


Figures 12-15, Percent cover by *A. cervicornis*, CRMP sites, upper keys, middle keys, lower keys, and Dry Tortugas, point count analyses of video images.

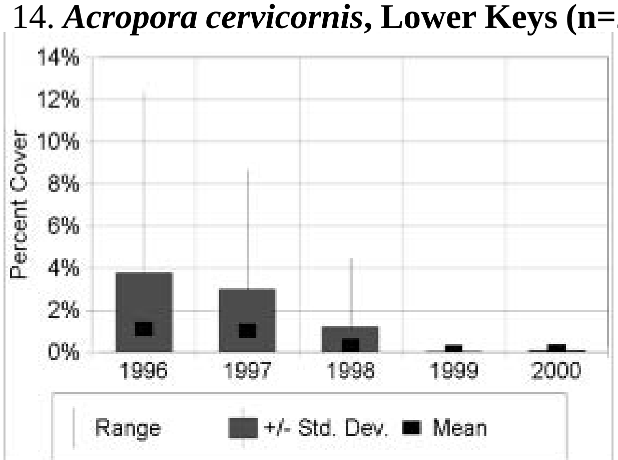
12. **_Acropora palmata_, Lower Keys (n=12)**



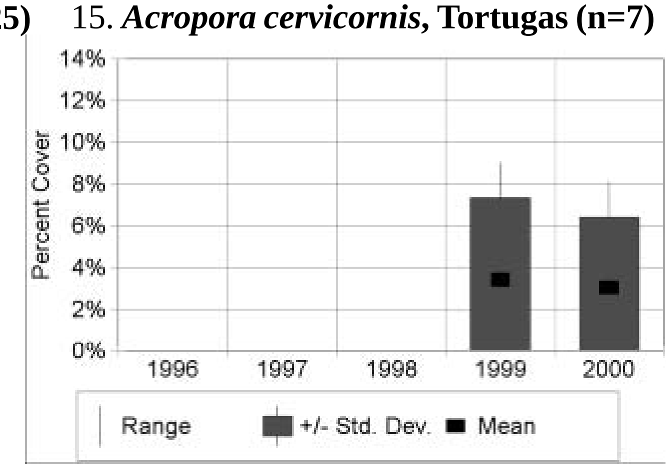
13. **_Acropora cervicornis_, Middle Keys (n=9)**



14. **_Acropora cervicornis_, Lower Keys (n=25)**



15. **_Acropora cervicornis_, Tortugas (n=7)**



Distribution, Population Ecology, and Reproductive Biology of *Acropora cervicornis* in Broward County, Florida. USA.

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During previous research by the National Coral Reef Institute (NCRI) aggregations of staghorn coral (*Acropora cervicornis*) were found distributed along the coastal waters off Fort Lauderdale. These corals appear to flourish beyond known temperature constraints and in the midst of significant anthropogenic stressors. The National Coral Reef Institute has established a basic research program aimed to investigate aspects of the population structure and propagation dynamics of this species off the coast of Broward County. Ongoing studies have located over a dozen sites with conspicuous staghorn coral aggregations. These occur between 600 and 800 m offshore in approximately 4–6 m depth. Patches range between 700 and 7000 m^2, and estimates of mean coral cover range from 5 and 30%, with *A. cervicornis* accounting for 87–97% of all scleractinians. Evidence of predation on *A. cervicornis* at the study sites is noticeable, mainly by the fire worm *Hermodice carunculata* and the gastropod *Coralliophila abbreviata*. Conversely, no incidence of white-band disease or bleaching of *A cervicornis* has been detected to date. Histological examinations have revealed progressive gametogenesis, and mass release of egg-sperm bundles was observed on the night of 6 August 2001, with a high proportion of colonies (~70%) spawning. Additional research interests include the study of disturbance dynamics, namely storm events and sedimentation. In light of the catastrophic demise of *A. cervicornis* throughout the Caribbean, the flourishing population off Fort Lauderdale is perhaps both the largest and northernmost aggregation of *A. cervicornis* in the continental U.S.A., and represent a potential source of propagules to repopulate/ replenish other previously impacted south Florida coral reef habitats.

Status of *Acropora* spp. Populations in Northern and Eastern Puerto Rican Coral Reefs

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Background

Acroporid coral populations have declined significantly in the northern and eastern Puerto Rican coral reefs during the last three decades. Almy and Carrión-Torres (1963), Mckenzie and Benton (1972), Goenaga and Cintrón (1979), and Hernández-Delgado (1992) listed the presence of *Acropora* spp. in different northeastern Puerto Rican reefs, where living colonies are now rarely seen or completely absent. For example, Goenaga and Cintrón (1979) informed large monotypic stands of *A. palmata* on Cayo Largo (Fajardo) and Cayo Batata (Humacao), with 90-100% living cover. These are actually long gone. The situation of the Acroporids in general in critical. Many environmentally-degraded fringing coral reef habitats along the shoreline of Puerto Rico (i.e., Punta Picúa, Punta Miquillo; Río Grande) show large stands of dead *A. palmata* on their growing position, which suggests that mortality might have been the result of disease outbreaks or other biological factor, in possible combination with poor water quality and high sedimentation rates. In addition, there are many coral reefs (i.e., Islote Palominitos, Los Corchos Reef, Cayo Dákity, Playa Larga; Culebra) which show severe physical destruction of the *A. palmata* framework as a result of the hurricane impacts (Goenaga, 1990). Major recent destructive hurricanes included David (August 31, 1979), Hugo (September 18, 1989), Louis (September 6, 1995), Marilyn (September 16, 1995), and Georges (September 21, 1998). It is the combined (cumulative, synergistic) effects of natural and anthropogenic factors which have caused this major decline.

Although there is a major lack of quantitative data regarding the ecological status of Acroporids in general in Puerto Rico, I was able to document the distribution of *A. palmata*, *A. cervicornis*, and *A. prolifera* along 88 northern and eastern Puerto Rican coral reefs in a presence/absence basis. Information was obtained from the available literature (reviewed by Hernández-Delgado, 2000) and from recent unpublished observations. Where possible, data was compared from previous reports and/or personal observations with recent reports or personal observations. Data was geographically sub-divided according to Hernández-Delgado (2000) into four provinces: northern inshore, eastern inshore, eastern offshore close (<6 km), and eastern offshore remote (>6 km). This classification was originally based on a Bray-Curtis ordination analysis for coral species presence/absence data sets to classify coral reefs (Hernández-Delgado, 2000).

Results

The variations in the frequency of observations (presence/absence data) of the three Atlantic *Acropora* species in northern and eastern Puerto Rican coral reefs was summarized in Table 1. Table 2 list all of the surveyed reefs. *Acropora palmata* was a major reef builder in most of the surveyed coral reefs (83-100%). However, at present it only was documented in 32 to 82% of the surveyed reefs as one moves across an anthropogenic environmental stress gradient. During the last three decades, this species has disappeared from 68% of the surveyed reefs from northern Puerto Rico. It has also disappeared from

53% of the eastern inshore reefs and from 32% of the offshore close (< 6 km) reefs. It has only disappeared from 4% of the offshore remote reefs (>6 km).

As for *A. cervicornis*, it was rarely documented from the northern and eastern reefs. In spite of that, it has become absent from 100% of the surveyed sites. It has also disappeared from 43% of the eastern offshore close reefs. No net changes in the frequency of observations was documented from eastern offshore remote reefs. However, it should be mentioned that, absolutely in all of the surveyed reefs from this province, *A. cervicornis* populations have declined significantly due to a combination of factors (discussed below).

As for *A. prolifera*, it was very rare in all of the four geographic provinces. It disappeared from 100% of the northern province reefs and from 60% of the eastern offshore close reefs. It disappeared also from 27% of the eastern offshore remote reefs. No colonies were ever documented in eastern inshore reefs.

Discussion

All of the surveyed coral reefs from northern and eastern Puerto Rico are showing unequivocal signs of declining *Acropora* populations. A combination of natural and anthropogenic factors could have cumulatively and/or synergistically affected their survival and distribution. Acute and highly localized natural factors such as White Band Disease (WBD) outbreaks, patchy necrosis, and predation by the coralivorous gastropod, *Coralliophila abbreviata*, and the fireworm, *Hermodice carunculata*, have been shown to contribute to the demise of *Acropora* spp. from Puerto Rican reefs. High densities of *C. abbreviata* have been also documented on coral reefs with only a few isolated surviving colonies of *A. palmata*. In addition, long-term natural factors, such as damselfish (Pomacentridae) territorial behavior has caused increasing tissue mortality and the pre-emptive outcompetition of corals by filamentous algae. Also, major acute phenomena, such as hurricanes, have caused a widespread destruction of *A. palmata* frameworks and of *A. cervicornis* thickets. Acute and highly localized anthropogenic impacts (i.e., historic coral collection for souvenirs, reef trampling, snorkeling, SCUBA diving, some fishing mehtods) have also caused a major destruction of corals. Also, severe acute anthropogenic impacts have caused major destruction of *Acropora* assemblages, including ship groundings (i.e., Los Corchos, Culebrita, Islote Palominitos) and military activities (i.e., Culebra, Vieques). Finally, major long-term anthropogenic degradation of water quality (i.e., higher turbidity, lower transparency, higher concentration of nutrients and solid suspended material) and higher sedimentation rates have largely contributed to the inshore coral reefs Acroporid corals decline.

Acropora in the U.S. Virgin Islands: A Wake or an Awakening?

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Many shallow coral reefs in the US Virgin Islands had impressive, nearly monospecific stands of elkhorn coral (*Acropora palmata*) in the late 1970s and early 1980s. A series of hurricanes and white band disease (first noted in 1973 at Buck Island Reef National Monument) decimated these stands. "Graveyards" of elkhorn, where detached dead branches of this species are interspersed among dead but standing colonies, are still visible. However, at least at some locations around all three of the major islands, St. Thomas, St. Croix, and St. John, there is evidence that elkhorn coral is recovering.

We have developed a protocol for mapping and assessing the condition of elkhorn colonies based on recording GPS waypoints for each surveyed colony along with data on depth, size, presence of disease and predators, percent dead, etc. Photographs are also taken of each colony, and all data are entered into a database. The GPS waypoints are mapped onto geo-referenced aerial photographs providing information on spatial patterns. Over time, we hope to be able to document if there is an increase in both the number and size of the elkhorn colonies. Our work to date has focused on elkhorn, although we have begun to use the same protocol for *A. cervicornis* (staghorn). Damselfish territories and possibly white band disease have been noted on staghorn corals. While the emphasis is on the corals, recovery of these morphologically complex species will presumably have effects on fishes and other associated organisms and communities, and these relationships should be explored.

Preliminary analysis of data on 279 elkhorn colonies from 5 locations around St. John shows that many of the corals are relatively small and could have become established since Hurricane Hugo (1989) and Hurricane Marilyn (1995). Coral-eating snails were present on about 12% of the colonies surveyed. About 25% of the colonies were partially dead (1 to 85%). No active white band disease was seen.

At Hawksnest Bay, over 300 elkhorn colonies are growing on one patch reef. The protocol is more difficult to use when colonies are in dense stands such as at this site. However, the GPS unit can be used to delineate a polygon around the stand, and at least some of the desired data can be collected.

Storms, disease, predators, and damage from boats continue to cause elkhorn colony mortality. (On April 7, 2002, an 85' ferry grounded on a reef inside Virgin Islands National Park causing extensive damage to living elkhorn colonies). Although this species has many mechanisms for recovering from physical damage, and fragments can develop into new colonies, it is not clear that it will be as successful at recovering from the current assault from an overall, unprecedented combination of stresses (including predation and disease).

Acropora palmata: Historical Status, Extent of Decline, and Projection for Recovery, on St. Croix Reefs

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The distribution of *Acropora palmata*-dominated reefs on the St. Croix shelf during the mid-1970s is summarized. These reefs totaled nearly 10 sq. km. in area. Surface coverage (defined as % of projected planar surface area) exceeded 70% in some areas (e.g. the forereef of Buck Island). In this zone there were actually several m^2 of live coral tissue per m^2 of reef due to the layering of branches. By the mid-1980s white band disease (WBD) had devastated populations of *A. palmata* everywhere on St. Croix, and surface coverage had decreased to a maximum of a few percent, but was less than 0.1% in many areas.

Following demise of the *A. palmata* population from WBD, a study was initiated in 1988 on a 200 sq. m quadrat on the eastern forereef of Buck Island to monitor individual coral colonies and to observe initial stages of recovery of the *A. palmata* population in the previously densely populated reef zone. This study plot was subsequently monitored in 1991, 1996 and 2002. In 1988, the population of *A. palmata* in this plot, although enormously reduced, had 5% surface coverage. It appeared to be healthy, recovering from destruction, and no WBD disease was observed. Hurricane Hugo in 1989 caused further reduction of the population to 0.8% in the study plot. Post-Hugo recruitment of *A. palmata* was first observed on the northeastern reefs of St. Croix in 1992, where numerous 10-15 cm high *A. palmata* colonies were observed on Prtzl Reef. Nine former *A. palmata*-dominated reef sites were surveyed in March 2002 to ascertain present coverage and recent recruitment of *A. palmata*, and where data exist, compared to prior coverage during the 1970s, 1980s or 1990s. Size-frequency distributions, densities and % (planar) surface cover were determined for four of these sites: % surface cover ranged from <0.1% for south shore forereefs to 1.4, 2.4 and 3.6% cover for three north shore reefs. The population structure, including the presence of recent recruits, as well as the healthy appearance of the colonies suggest young, healthy and actively growing populations of *A. palmata* on the north shore reefs that, barring devastation by storms, predators, or disease, appear to be on their way to recovery.

The Demise of *Acropora* in the Caribbean: A Tale of Two Reef Systems

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Over the past two decades, coral reefs in the Caribbean have changed dramatically. Reef-building corals have declined, and the cover of fleshy, noncoralline macroalgae has increased. Many authors have argued that the loss of herbivores has been the culprit in the community shift, while others have cited reef nitrification. It is our contention, however, that coral mortality especially the mortality of the *Acropora* is the crucial precursor to macroalgal dominance. For example, ten years after Hurricane Hattie devastated reefs from northern Belize in 1961, the once lush coral community was reduced to a layer of coral rubble covered by fleshy macroalgae. This was identical to the pattern observed on Jamaican reefs more than 20 years after the passage of Hurricane Allen (1980). In Jamaica, mortality of the *Acropora* was caused by storm-induced fragmentation followed by collateral mortality related to predation and disease. At research sites at Discovery Bay on the Jamaican north coast, coral cover has fallen from >50% in the late-1970's to <5% today, while macroalgal populations have risen from near 0% to >60% during the same period.

Acropora cervicornis was also the dominant space occupier at intermediate depths on the fore-reef (8-20 m) along the central portions of the Belizean barrier reef from at least as far back as the 1960's until the mid-1980's. Subsequently, *A. cervicornis* populations collapsed due primarily to mortality associated with white-band disease (WBD). At Carrie Bow Cay the location of the Smithsonian coral reef research station, coral cover dropped from 30-35% in the late 1970's to 12-20% in the 1990's. These losses were followed by concomitant increases in macroalgae (<5% in 1980 to >60% in the early 1990's). Populations of *A. palmata* have been decimated on these reefs from WBD as well.

Combing these ecological data from Jamaica and Belize with other reef areas from throughout the Caribbean reveal similar losses in *Acropora* dominated communities during essentially the same period. On a regional-scale, the mass mortality of Acroporid corals due to a variety of factors and especially WBD has been largely responsible for the present increases in macroalgae. These widespread biotic disturbances, which are still active today, have diminished coral populations, thereby opening space for colonization by algal species. These observations highlight the primacy of coral mortality in general, and disease induced mortally of the acroporids in particular, in changing the face of Caribbean Reefs.

These data also indicate that no form of local stewardship or management could have protected these *Acropora* dominated reef systems from these disturbances or changed the overall trajectory of coral loss. It is becoming increasingly more apparent that regional- and global-scale causes of reef decline are most important in structuring modern reef communities. Understanding the causal link between global change and reef demise are some of our most pressing ecological challenges for the future.

Status of *Acropora* Species on the Leeward Islands of the Netherlands Antilles

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The Leeward Islands of the Netherlands Antilles comprise Curaçao and Bonaire (12° 15' N, 68° 45' W). The islands measure 445 and 288 km^2 respectively and possess a sheltered south coast and a wind-exposed north coast. The oceanic islands lie 60 km off the coast of the South American mainland. Industrial development and immigration resulting in overpopulation during the 1970's imposed a great pressure on Curaçao's terrestrial and marine resources. The reefs of Curaçao are overfished as fish is a cheap source of nutrition. Bonaire remained free of such developments and presently depends on (eco)-tourism (i.e. diving tourism) as the main source of income. A currently effective marine park was established in 1979 protecting the reef to a depth of 60m.

Acropora species formed dominant constituents of the shallow (<10m) reef fauna and were found the entire southwest coast of both Curaçao and Bonaire until the 1981 mass die-off (VanDuyl 1985, Bak and Criens, 1981). The study by VanDuyl (1985) consists of an inventory of the benthic community along the south coasts of both island at a small spatial resolution (<1m^2) and therefore provides an excellent reference to quantify the decrease in *Acropora* cover over the last two decades. In 1980/1981 when the surveys for this work were carried out, *Acropora* species covered 7.94×10^6 m^2 of the reef bottom between 0 and 10m, which corresponds to 15.1 % bottom cover of the shallow reef terrace. Comparing these data with our observations made during the last four years, we estimated the decline in *Acropora* stands to be more than 98%. Local patches remain, however, where *Acropora* patches occurred in large stands covering the entire shallow reef terrace as dense bands (>20m width). These populations occur at exposed sites (i.e. the shoreline faces southeast, which is the direction from which refracted waves hit the island). The importance of water-movement for *Acropora* is also indicated by the north-south gradient that exists in the depth distribution of *A. palmata*. Towards the south exposure to increased water-movement caused (1) colonies to move towards deeper water and (2) branches become thicker and more robust. At extremely exposed sites (i.e. the most eastern tips of the islands) *A. palmata* colonies occur as thin sheets with small branches (<30cm) rising from its surface.

Especially on Bonaire small patches (<60m^2) of *A. cervicornis* occur which seem to be able to survive due to fast growth since they still suffer from white-band disease. Recruitment of the latter species is observed (> 4 individuals m^{-2}) at a few locations cleared by tropical storm Lenny in November 1999 providing solid substratum to settling planulae. The same storm damaged *A. cervicornis* stands at other sites around this island. On the north coasts of both islands enormous patches of *A. palmata* (> 1000m^2) are found and colonies seem unaffected by diseases or high levels of partial mortality (e.g. Boca Patrick). If *A. cervicornis* is also present the supposed hybrid *A. prolifera* (VanOppen et al. 2000) is frequently observed.

Acropora populations have decreased enormously over the last two decades and decline occurred at sites that suffered from increased industrial pollution and sites receiving oceanic water. The occurrence of populations that do well (i.e noticeable recruitment and absence of diseases) shows that these reefs are yet not degraded beyond the point-of-no-return. This indicates that the *Acropora* population at the Leeward Island of the Netherlands Antilles potentially harbors unexpected adaptive (genetic) variation, which allowed them, at least partially, to survive in the present day situation.

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Status of Acroporid Populations in Colombia

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According to a recently published base line study of coral reefs in Colombia (Díaz et al., 2000), the total extension of recent coral formations in Colombian maritime areas, both in the Caribbean and the western Pacific, is about 1,090 km^2, of which more than 99% are placed in the Caribbean. In the latter, only 1/3 of the coral reefs are found along the continental coast and shelf, most of them surrounding the offshore islands of the archipelagos of San Bernardo and Rosario. On the other hand, 2/3 of Colombian reefs are found in the oceanic archipelago of San Andrés and Providencia, in the southwestern part of the Caribbean, off the continental shelf of Nicaragua and Honduras. Here, coral formations comprise two barrier reefs surrounding the two major islands, five large atolls, and several coral banks. According to Geister´s typical ecological zonation of Caribbean reefs based on wave exposure zones, which includes a zone dominated by *Acropora palmata* in the highly exposed areas and an *A. cervicornis* dominated zone in medium exposed areas, the base line study estimated the total extension of *A. palmata*- dominated reefs in about 28 km^2 (2.6% of the total coral reef extension) and that of *A. Cervicornis*- dominated reefs in only 0.8 km^2 (0.07%). However, the relative cover of living tissue of both species in their respective zones is very variable from a reef area to another, ranging from nearly 90% in a few scattered patches to less than 15% in the majority of reefs.

Many of the *Acropora* dominated reefs, as they were described in the 1970´s from San Andrés and Providencia are currently reduced to cemetaries of broken skeletons covered by algae. The decline of *A. cervicornis* in this area has been estimated at 99% in the course of the last three decades, and that of *A. palmata* at about 75%. Even worse is the situation in most reef areas along the continental coast. In some areas like the San Bernardo and Rosario Islands, the decline of both species has attained levels of nearly 100%. Only in a few areas, such as Isla Arena and in some bays nearby Santa Marta, scattered small patches or isolated thickets of *Acropora* exhibit living cover over 50% and show even signs of recovery after the widespread mortalities occurred in the course of the last decades. The occurrence of scattered living thickets of *A. prolifera* has been recorded in several places in the Colombian Caribbean, in both oceanic and shelf reefs. A single record of *A. valida* from Gorgona Island off the Colombian Pacific coast has not yet been corroborated but, according to Glynn & Ault (2000), although the record may have been valid, this species appears to be now extinct in the eastern Pacific.

Two detailed studies about the status and health of *Acropora* reef habitats have been performed very recently in the Colombian Caribbean. One of them was carried out in May-December 2001 at several bays of the Tayrona Natural Park (TNP; central part of the northern coast of Colombia, continental reefs) and included mapping of all *Acropora* formations as well as assessments of their current composition, cover, health, and growth rates (Moreno-Bonilla et al, 2002.). The other evaluated only *A. palmata* populations within different geomorphological units of the San Andrés island reef complex (SAI; southwestern Caribbean, oceanic reefs), in January 2002 (Rueda and Acosta, 2002). Preliminary analysis of the results show that cover of reef surfaces at both *A. palmata* and *A. cervicornis* formations of the TNP are now strongly dominated by algae (means 80.6% and 79.4% respectively), while mean live coverage by these corals is very low (9.9% and 5.1% respectively). Average cover of live *A. palmata* in SAI is greater (14%), with a highest mean value in the fore-reef terrace (19%) and the lowest in the lagoon terrace (5%). In the TNP the ratio of live:dead coral is about 1:14 in the case of *A. cervicornis* and 1:7 in the case of *A. palmata*, based on cover estimates. This relationship is about 1:2 for *A. palmata* in SAI, based on volume estimates. Live populations of *A. palmata* and *A. cervicornis* in the TNP show a high incidence of partial mortality(29.7% and 58.8% respectively), *Stegastes planifrons* territories (55.8% and 58.1%) and *Coralliophila abbreviata* (22.3% and 51.2%). White pox disease is also frequent (18.1%) there in *A. palmata*, while algae overgrowth (72.5%) and fragmentation (54.4%) are common conditions in *A. cervicornis* as well. Partial mortality in SAI is found affecting about 2.7% of the *A. palmata* tissues, associated in part with bleaching, white pox disease and white patches. Linear growth estimates in healthy colonies of the TNP resulted in mean rates of 7.52 cm/year for *A. palmata* and 9.62 cm/year for *A. cervicornis*.

All three Caribbean *Acropora* species have been listed recently in the "red book" of threatened marine invertebrates of Colombia by a technical commission coordinated by the Ministry of the Environment (Mejía et al., 2002). *Acropora cervicornis* was considered as a critically endangered species in Colombia, while *A. palmata* was included as endangered, and *A. prolifera* as vulnerable, according to the IUCN categories.

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Status of the Acroporid Coral Species in the Dominican Republic

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Description of Coral Reef Areas

Most coral reefs of the Dominican Republic are fringing reefs. There are also two barrier reefs, numerous patch reefs, and four large offshore banks. In the eastern and northwestern coasts, broad coastal shallows platforms with barrier reefs are found, while in other places terrigeneous sediments produce high turbidity that prevents reefs from forming or growth. The increasing coastal development, pollution, untreated wastewater discharges and beach erosion have impacted living reef sites. Following is a report on the status of Acroporid species in the Dominican Republic.

Offshore Banks

The Silver Banks, Atlantic Ocean.

This is a shallow oceanic rise extending 3,740 km2. In it's northern portion a barrier reef has formed, composed of a series of patch reefs bound together near the surface, and extending some 30 km southeasterly. On its protected side, corals grow in column-like structures of cemented skeletons that ascend from the rubble and sandy bottom to the surface some 15 to 25 m upward. *A. palmata* is found occupying the top portion of these columns, as well as in the reef down to 6 m. The Acroporids found here are in bad conditions. The reef crest panorama is of a skeletal web of dead colonies of *A. palmata*. In places during 1984, there used to be large colonies of *A. palmata* (3 m tall), and dense growth of *A. cervicornis*, there is now rubble grounds around dead stands of palmatas. Turf algae, Rhodophytes, as well as Cyanobacter complex, and encrusting boring sponges grow on top of these remains. The recuperation of acroporidae in this reef is slow. In 1994 reports were received that *A. cervicornis* was budding, as well as the black sea urchin *Diadema antillarum* was reappearing.

Parque Nacional Montecristi Barrier Reef

Located in the northwestern coast, it is the largest reef of the country with 64.2 linear km. The coast is low-lying mountainous terrain of sedimentary origin, in a dry climate setting. The shoreline is almost all covered with red mangroves, followed by seagrass beds and several pocket beaches. This setting is protected by a barrier that varies in distance from shore (200 m to 3,000 m). The reef setting is varied, with high relief features and large living coral colonies are common with sizes exceeding 10 m in diameter.

Reef Lagoon

Coral patches (5 to 800 m2) are found with soft coral, associated mainly with *Montastraea annularis* complex and other rounded forms. Here *A. cervicornis* thrives.

Reef Flat and Back Reef

In areas closer to tidal channels the dominant species are *Porites* sp., and rounded forms. Nevertheless, *A. cervicornis*, *A. palmata*, and *Millepora complanata* are common.

Reef Crest

Skeletal remains of acroporids, poorly lithified, form the reef crest. A few young *A. palmata* can be found, but *Millepora* sp. is the dominant species. On the seaward side the basal structure of the crest is formed by large skeletons of *A. palmata* and *A. cervicornis*.

Outer Reefs

In exposed areas, there is evidence of a lower Palmata zone consisting mostly of large dead colonies of *A. palmata*. To deeper waters *A. cervicornis* is also found in good shape, growing in tidal channels throughout the extension of the reef.

Punta Rucia Offshore Keys

These keys are away from any terrigenous influences and freshwater discharges. In the breaker zone the dominant species found here are *A. palmata*, *Millepora* sp., *Montastraea annularis* complex, and *Diploria strigosa*. On the frontal reef at 12 m depth, a diverse coral community can be found were *A. palmata* stands among other species

Reefs Along the Reef Terraces of the Dominican Republic, (Atlantic Ocean)

Most of the coastline area are facing the easterly trade winds and its oceanic condition. The littoral zone drops abruptly to deeper waters (2-10 m). The bottom is composed of eroded carbonate rocks, covers by encrusting algae, and species adapted to harsh environs. The coral growth can include *A. palmata* forming small patches In the deeper sandy areas, small patches of *A. cervicornis* can be found. Most of the sites visited have presented these species coming back in association with healthy *Diadema antillarum* populations.

Fringing Reefs of Dominican Republic, (Atlantic Ocean)

The traditional land use has been agriculture. Recently tourism has increased coastal settlements near reef sites and beaches. The predominant reef structures are coral patches with low cover and few living corals. The few fringing reef of *A. palmata* and *Porites* sp. are now affected *A. palmata* skeletal are found covered with algae and sediments. *Millepora* sp. has since dominated the breaker zones. Nevertheless, the acroporids in the deeper water are still healthy. Another type of coastal feature is of intrusive igneous mountain slopes and terraces. The climate is very humid; the forest cover has turned into agricultural fields. The reefs here are of the fringing type very close to shore and in shallow waters where reef patches can be found. These are composed of skeletal remains of *A. palmata* covered by algae and sediments. On outer reefs, approximately 5 miles offshore shoals (15 m deep) of eroded carbonate terraces are found, with few corals species, but no acroporids.

Reefs at the Mona Passage of Dominican Republic

In the east facing the Mona Passage, is the Bávaro-El Macao-Punta Cana Barrier Reef System, extending almost continuously for 60 km. The coastline is sandy, followed by mangroves, coastal lagoons, and swamps. The reef lagoon can be as wide as 3.5 km (2-5 m deep) and typically has coral patches and seagrass beds. In the back reefs *Porites* sp., rounded forms and *A. cervicornis* are common species. *A. palmata* skeletons covered with algae in association with *Millepora* sp. dominates the windward side of the breaker zone, which is narrow and steep. At 4 m, there are large dead stands of *A. palmata* as well as large boulders of *Montastraea annularis* complex, and *Diploria* sp. In some sites, the breaker zone can be narrow and composed of very large compacted skeletons of *A. palmata* where algal cover is high and few live corals are present.

Reefs of Parque Nacional del Este

The reefs of this protected area are basically low relief systems, found either as fringing and small deep (20-30 m deep) patches. Most of them are in the leeward side protected by a landmass of Pleistocene and Recent reef terraces.

Fringing Reefs

At the 10 m contour the bottom is covered with skeletons of *A. palmata* which project to the surface. At the reef crests there are live colonies of *A. palmata, A. cervicornis, M. complanata*, and rounded forms. Sporadic coral congregations turn the narrow reef flat and converts itself into an *Acropora - Montastraea* zone, forming the breaker. The acroporids in the breaker zones are not very healthy mainly due to recent storms. At depth > 3 m, there are large colonies of *A. palmata*, in varying health conditions.

Low Relief Spur and Groove Communities

Here it is common to find large dead colonies of *A. palmata*, and underneath them, some broken branches with new growth. The presence of *D. antillarum* is noticeable. In several places new growth of *A. cervicornis* is commonly found.

Reefs of Parque Nacional del Este
Hard Bottom Carbonate Reef Flat Communities

In terms of diversity, they are dominated by turf and brown algae, and/or a co-dominated by algae and corals. The corals are more diverse in these communities, with 12 species, the most common being *A. palmata*, *Diploria clivosa*, *Porites astreoides*, and *Porites porites*.

Patch Reef Communities

These are located in protected waters on the western portion of the leeward side or inside the Catuano Passage, protected by the fringing reef and it's reef crest. In some cases *A. cervicornis* is found. Large (>2 m diam) colonies of *A. palmata* that serve as base structure for other species to settle are also found.

Fringing Reefs of the Southern Pleistocene Reef Terraces of the Dominican Republic (Caribbean Sea)

The southern coast has four major coastal features: Pleistocene reefs terraces, medium size river estuaries, shallow carbonates platforms, and terrigenous substrates. Reef formations can only be found in the shallow carbonates platforms, forming fringing systems. In the late 1980's, most of the fringing reefs associated with sheltered white sandy beaches have been used by the tourism industry and its secondary development, altering the natural settings. The breaker zone of these areas is very stressed and is now largely formed by dead loose remains of *A. palmata* and rounded forms covered by turf algae and sediments. The lower Palmata zone has also been affected receiving large amounts of sediments coming from the heavy activities that occur at the beach and lagoon regions of the reefs. At deeper sites (12 m), the reef is in good shape, including the acroporids found there.

Fringing Reefs of the Pleistocene Reef Terraces of the Dominican Republic (Caribbean Sea)

At the spur and groove formations in the base of the breakers zones (4-6 m deep), large colonies of *A. palmata* and *Montastraea annularis* complex still dominates, surrounded by several other species. Approximately 30% of the *A. palmata* (at Boca Chica site) withstood the Acroporid mortality event. Nevertheless, the seascape seems catastrophic, finding pieces of corals encrusted with algae and sponges littering the bottom. Between all this, small colonies of *A. palmata* appear. In deeper waters, at 20 m, a striking growth of *A. cervicornis* and other species can be found.

Fringing Reefs of the Terrigenous Southern Coast of the Dominican Republic. (Caribbean Sea)

In the sedimentary loose terrains this coasts lies in a dry climate setting, but several medium size rivers discharge in the region. Since mid 1980's, agricultural irrigation programs have altered this natural setting.

Places were reef developed, now have been transformed into estuarine zones. Waters are loaded with agricultural by-products, pesticides and fertilizes, as well as high with sediment loads. This situation has practically eliminated all of the standing live corals and reefs in the region. It is now rare to find living stands of *A. palmata* and *A. cervicornis*. Is also suspected that conditions for the rare *Acropora prolifera* are now gone. (Puerto Viejo reef is one of a few sites were it has been reported for the Dominican Republic).

Parque Nacional Jaragua

Parque Nacional Jaragua is located at the southwestern portion of the Dominican Republic in very dry climate. No rivers or surface runoff is found in these Pleistocene reef terraces. On its leeward coast, protected by high cliffs, sheltered long and white sandy beaches are common, followed by consolidated hard carbonate substrate where coral cover and density is high. There is not a well-developed fringing or bank reef in most of the zone, *A. palmata* is not a common species in this settings.

Development, Sedimentation, and Water Quality

It has inflicted major changes in the reef setting due to: deforestation, coastal urban development, dredging, agriculture irrigation projects, industrial development, and wastewater deposition without treatment.

Coral bleaching, mass mortalities, and other stresses.

There has not been a countrywide study of bleaching for the Dominican Republic. However, reports of its occurrence is more evident at the reef sites near major urban settlements, as well as those reefs which are more heavily visited or over fished such as: Puerto Plata, Sosúa, Las Terrenas, Macao, Bávaro, Guayacanes, Boca Chica, and La Caleta. The mass mortalities of *A. palmata* and *Diadema antillarum* were reported, as have been rare occurrence of coral and octocoral diseases.

Hurricanes and tropical storms.

Hurricanes and tropical storms are natural events common in Hispaniola. There have been more than 200 of these events recorded since the 15th century. These phenomena are more common for the Caribbean southern coast, rarely affecting the Atlantic coast. Nevertheless, all major reef sites have been affected by at least one of these events.

Overfishing

Overfishing is believed to be one of the major causes that has prevented the comeback of Dominican reefs. Overharvesting of commercially important species such as S*trombus* sp., *Panulirus* sp., and fishes of the Serranidae, Lutjanidae, and Scaridae families, is evident. Lately, there has been an increase in the harvesting of other reef creatures such as black corals, hermit crabs, ornamental reef fishes, starfish, sea urchins and live rocks for the souvenir and aquarium trade. In these later cases it has been introduced the use of chemical substances such as Clorox bleach, among others to harvest the ornamental species. This is affecting the corals and other non-target species as well.

Recent Legislation

Most of the activities related to non sustainable fishing practices, as well as industrial, agricultural and rural development, mentioned above, have been either prohibited or regulated by the recently promulgated Environmental Law 64/00 and several Presidential Decrees. Nevertheless the marine ecosystems management is not receiving the sufficient financial and political support needed to support and implement the mandates and policies, enforcement and education.

Status of Acroporids in the Mexican Atlantic

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Foreword: I have had the luck to be able to visit most, if not all, of the reefs in the mexican Atlantic at least twice in my coral reef researcher career, some 20 years now. This allow me to have an spatial overall view, but also some idea of trends, as comparative assessment of coral community structure has been one of the main tools of my work. I have to said this, so that you would be able to understand the background from where I am expressing my views regarding Acroporids status in Mexican reefs.

Coral Reef Distribution:

Coral reefs in México can be roughly grouped in three sets at the geographical scale: 1) SW Gulf of México reefs; 2) Campeche bank reefs, and 3) Caribbean reefs.

The SW Gulf reefs are close to shore (from 0.5 to 11.7km) and comprise three main reef sets (Veracruz-Antón Lizardo, Tuxpan and Isla Lobos reefs; Fig. 1) forming clusters of relatively proximal reefs; rising from depths of 25 to 35m and with shallow lagoons. These reefs are strongly influenced by large river discharges, carrying large amounts of suspended sediments and a wide array of pollutants. Campeche bank reefs are well-developed isolated banks lying 80 to 130km offshore in an oceanic climate far from terrestrial influences. Morphology among all these reefs varies widely. Along the Mexican Caribbean "extended fringing reefs" (barrier –like reef tracts separated from the coast by a well developed, but shallow lagoon) dominate the continental margin and the largest atoll-like reef in the Caribbean: Chinchorro reef is found on the southern section. Continental influence upon Caribbean reefs is negligible because the Yucatán peninsula is a karstic platform where rivers are mostly absent.

Acroporids distribution in the Mexican Atlantic:

Acropora palmata, *A. cervicornis* and *A. prolifera* are pan-Caribbean species and can be found anywhere in the region. This section therefore, addresses the reef areas or reef structures characterized by the ample dominance of any of these species.

1) SW GULF OF MÉXICO REEFS

Most reef in the Veracruz-Antón Lizardo reef system (southernmost SW Gulf reefs), had an extremely well developed *Acropora palmata* belt in the shallow windward forereef zone, from the reef crest down to 5 or 6m. Such belts were composed by monospecific, dense and continuous stands of very large colonies with a growth form typical of relatively high-energy environments. Northward, at Tuxpan reefs these *A. palmata* belts decrease in importance, although are still present. At Isla Lobos reefs the belts disappeared, and mostly scattered *A. palmata* colonies dominate the shallow, windward forereef.

In the leeward margin of many of these reefs very extensive beds of *A. cervicornis* could be found, as well as in some shallow protected areas.

Mortality:

Around the early 1970´s extensive mortality in the windward *A. palmata* belts and the leeward beds of *A. cervicornis* was evident by the mid 1970´s most of these colonies, if not all, have died. Their skeletons remained *in situ* in standing position.

Actual Status (Recovery):

Recovery is very limited, restricted to ends of reefs by the early 1990, but occurring in most of the SW Gulf reefs (Jordán-Dahlgren, 1992). Interestingly *A. palmata* recovery occurred mostly by "re-sheating" of new tissue over standing skeletons of the same species. This process consist of new tissue growth over large areas of a dead skeleton, without producing new branches, actually re-sheeting the old skeleton. Apparently, it happens with both surviving tissue (re-growth in this case) in a mostly dead colony and/or when a sexual propagule recruits to the dead skeleton (Jordán-Dahlgren, 1992). A phenomenon that we have witnessed in many instances afterwards.

By the year 2000 recovery is still relatively minor in these reefs, and a subjective estimation would be an increase on the order of 3 to 5% in living *A. palmata* cover, with high local variability. In Tuxpan reefs recovery had been apparently more widespread than at Veracruz-Antón Lizardo, but unfortunately locals had been extracting many of the new small colonies for souvenirs and trade. Recruits that undergo re-sheating are less affected by this practice.

2) CAMPECHE BANK REEFS:

A. palmata and *A. cervicornis* are important species in the shallow exposed and protected areas of most of these reefs. Logan (1969) describes massive stands of these two species in many Campeche bank reefs. My personal observations indicate that *A. palmata* formed belts (as described above) mostly in the semi-protected northern, and at times also, in the southern tip of these reefs. In protected areas *A. palmata* forms many inner and at times large patch reefs. The eastward shallow fore reef has been mostly barren of Acroporids during my observations. Also in protected areas, either inner or leeward, very extensive stands of *A. cervicornis* were common, from 25 to 30m deep to very shallow areas, even in the reef flats.

Mortality:

At an unknown period most of the *A. palmata* and *A. cervicornis* suffered massive mortalities in these reefs. The *A. palmata* skeletons have remained mostly *in situ* in standing position, but the *A. cervicornis* beds are now mostly gravel deposits.

Actual Status (Recovery):

Recovery is still limited, but evident in many reefs. We have quantitative data from 1995 and 2001, for two separated Campeche reefs, and clearly *A. palmata* is recovering at good rate wherever it occurs, both by re-sheeting and by new colony recolonization (data is still being processed). Recovery is not homogeneous in reefs areas or zones, instead is highly patchy. *A. prolifera* is relatively abundant in some shallow areas of these reefs. *A. cervicornis* seems to recover more slowly than *A. palmata*.

3) CARIBBEAN REEFS

A. palmata dominates the shallow reef environment along the reef tract. In many areas *A. palmata* reefs are highly conspicuous, like in the Siyan Ka´an biosphere area (Jordán-Dahlgren at al. 1994). But the condition and extent of the species stands varies widely (Jordán-Dahlgren, 1993). *A. cervicornis* was relatively abundant in the shallow protected areas along the reef tract some 20 to 15 years ago, but is a rare species nowadays. *A. prolifera* is not common, although at places is relatively abundant.

Mortality:

From the 1970´s to the late 1980´s *A. palmata* and *A. cervicornis* suffered mass mortalities in the mexican Caribbean reefs. *A. palmata* however, was never massively destroyed as relatively large areas of healthy stands alternated with areas of total mortality. Particularly in the central and southern parts of the reef system. This is in contrast to what may to have occurred in the Campeche Bank and SW Gulf reefs, where the Acroporids demise was overwhelmingly uniform. In the NE section of the coast *A. palmata* survived quite well, but no so *A. cervicornis* whose former large stands have disappeared from the time being. In 1988 the very large Hurricane Gilbert (also class V) landed in the NE coast and destroyed most of the *Acropora* stands.

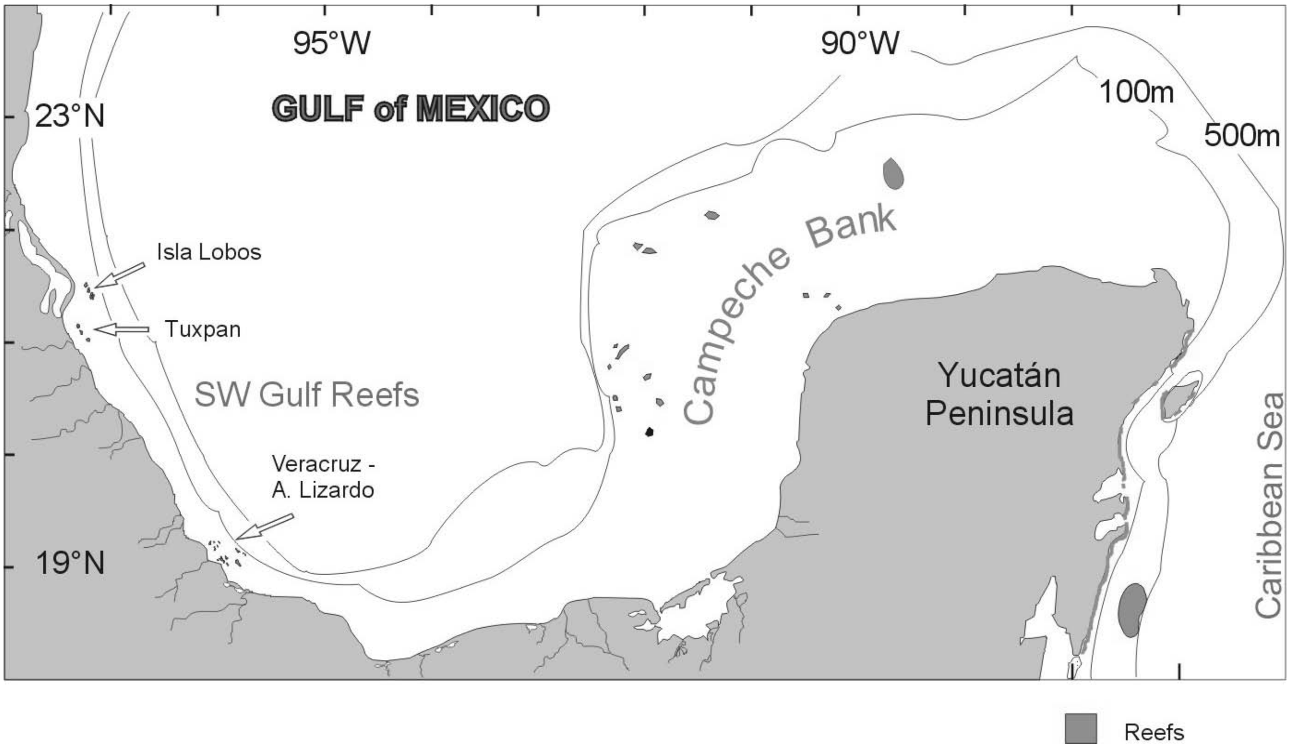
Actual Status (Recovery):

We only have reliable data for the NE Yucatán coast. But it now shows a fast pace of recovery after a long period (3 to 4 years) of no apparent recovery. Recovery is taking place in a highly patchy pattern where re-sheeting dominates recovery of old stands and by new colony colonization in many areas where prior to Gilbert hurricane there were no *A. palmata* stands (Jordán-Dahlgren and Rodríguez-Martínez, 1998). Other areas that used to have luxurious *A. palmata* stands, are still large piles of rubble, with no signs of recolonization. *A. cervicornis* is also becoming less rare, but still is in a phase

DISEASES:

Although recovery in terms of Acroporid cover seems to be well underway in some reefs, is still too early to address if full recovery in terms of dominance and covered reef area would be achieved anytime soon. Disease may slow the recovery process (white- band disease may be responsible for the demise of *Acropora* in the Caribbean), as many of the new colonies had signs of diseases such as white band and some colonies show necrotic patches (Rodríguez-Martínez et al., 2001). Data are still being collected and processed, but I may say now that at some reef sites, diseases are having a serious populational impact in the recovery process, whereas in others the effect seems to be reversible and still in others is negligible.

Fig. 1 Map showing reef localities in the Mexican Atlantic



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Mapping Marine Populations

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Landscape pattern analysis of the distribution of biological populations and community types has been well developed for terrestrial mapping for some time. Global Positioning Systems (GPS) are used routinely to provide accurate maps and locations of point and polygon features that can be imported into a GIS platform. The principles of landscape ecology and the study of ecosystem structure and change are being explored to understand the link between landscape pattern and ecosystem function. In the marine environment, mapping populations of organisms and understanding seascape patterns are considerably more difficult as a result of technical, equipment, access, depth, and visibility problems.

This presentation will describe a simple new Surface Water GPS methodology for mapping shallow reefs and near coastal species distributions. A group of partner agencies in the Virgin Islands; UVI, USGS and NPS, have worked to develop a low tech method of geo-referenced mapping in coastal waters. This technique is presently being used to map the distribution of Acroporid species, including size, depth, snail predation, disease and % live coral cover.

Using existing technology and adapting it to marine circumstances, highly accurate population distribution maps can be overlayed on digital images and benthic habitat maps creating the first maps of marine populations. A Garmin 12XL GPS unit placed inside an Aquapac waterproof case and attached to a small kickboard float is towed by a snorkeling swimmer. After locating a species of interest, a mark is made for a GPS waypoint and saved. Other field personnel record a digital still or video image and data about the colony is recorded on a standard field sheet.

After collecting both waypoint and track positions, the GPS is brought to the office where the track and waypoints are downloaded, converted to a textfile where data fields are added and then converted to a dbf file for import into Arcview GIS. This methodology opens a new approach to marine mapping by providing position data capable of being used at the scale of the local population to track change or recovery over time.

“Unprecedented” *Acropora* Die-Offs: 6,300 & 3,000 ybp

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In 1992, Jeremy Jackson observed that Pleistocene coral reefs exhibited general spatial stability. In contrast, monitoring and anecdotal observations have documented short-term variability and decline in reefs over recent decades. The result is an increased interest in the fossil record as a “pre-anthropogenic” frame of reference for conditions today. Proposals that recent disease outbreaks are “unprecedented” and largely anthropogenically induced are becoming increasingly common. This position requires three assumptions. First, changes in reef-community structure over periods of decades (i.e., monitoring records) can be identified in the fossil record. Second, spatial continuity of species and reef zones in the Pleistocene reflects uninterrupted temporal stability. Finally, examples of community disruption on the scale of the recent decimation of *Acropora* by white-band Disease do not exist in the Holocene record.

Cores through the shelf-edge reef communities off St. Croix, Puerto Rico and Florida reveal active *Acropora*-reef development starting around 10,000 ybp and ending suddenly between 7,000 and 6,300 ybp at all three sites. This is associated with a dramatic decrease in the number of *A. palmata* samples reported in the literature. Cores from a reef around Buck Island (U.S. Virgin Islands) reveal a species composition similar to that seen in monitoring records prior to the onset of WBD, implying that the “average” forereef community over the past 7,000 years was similar to what existed there before disease decimated *A. palmata* throughout the region. At 3,000 ybp, however, Acroporids disappeared at Buck Island, and community dominance shifted to massive corals. This corresponds to a second interval during which no *A. palmata* samples have been reported in the literature. While the overall pattern of reef development better matches the pre-WBD community at Buck Island, a more detailed look at the record implies a second Caribbean-wide interruption in the *A. palmata* record. Thus, spatial persistance is not necessarily equivalent to temporal continuity. Our cores have documented at least two regional gaps in the *A. palmata* record that appear analogous to the recent near-extirpation of the species by WBD. A re-examination of our new found confidence in separating natural from anthropogenic change seems in order.

Population Dynamics and Life-History Traits of *Acropora palmata*: Costs and Benefits of Fragmentation

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Several unique characteristics differentiate *Acropora palmata* from other coral species. Although *A. palmata* can be very susceptible to the physical disturbance caused by storms, it can also exhibit extraordinary regeneration and regrowth capabilities. The ability of *A. palmata* to form new colonies from storm-generated fragments, together with the reportedly low success of sexual recruitment in this species, suggest a strong connection between storm disturbance and survivorship and persistence of this species.

Here, I present the results from a simulation model developed to test the potential impacts of physical disturbance on elkhorn populations. This stage-based transition model identifies storm intensity and frequency as important factors influencing damage and recovery patterns of *Acropora palmata* populations. The simulations highlight an important trade-off between the primary and secondary negative impacts of storm damage and the need for this species to propagate asexually in light of its limited sexual recruitment success. After a severe storm, *A. palmata* populations can be numerically dominated by fragments and crusts. The shift in biomass from units with high survivorship (i.e., colonies) to units with higher mortality probabilities (i.e., fragments and crusts) can affect the recovery and long-term survivorship of disturbed populations.

Clearly, the difference between a storm being a destructive force or an external factor that promotes asexual propagation and population expansion is often a small one, and the balance between these two will ultimately influence the long-term survivorship of *A. palmata* populations already decimated by diseases and other stressors.

Genetics of *Acropora cervicornis*

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Since I am unable to attend the meeting, I thought I would summarize what the genetics of Caribbean *Acropora* says about the system and how this information might add to the conservation of *Acropora cervicornis*. Basically, I see three major questions that the genetics of *A. cervicornis* can answer: 1) Is *A. cervicornis* a discrete species (or evolutionary lineage), 2) How much gene flow exists between populations of *A. cervicornis* and what is the scale of any connectivity, and 3) How much genetic diversity exists within local populations and how may this relate to the corals ability to survive perturbations like bleaching, white-band, etc.?

1) The genetics clearly shows the three Caribbean *Acropora* (in review) are a natural hybridization system with *A. prolifera* being a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*. We have taken to calling *A. prolifera* immortal mules for their potential to propagate clonally through asexual fragmentation. Introgression is limited by hybrid infertility or inviability, but rare backcrossing of *A. prolifera* with *A. cervicornis* allows for the some mtDNA and nuclear introgression. For *A. cervicornis*, this means that its genome is likely sprinkled with *A. palmata* genes, and, while introgression in general appears rare, its extent is unknown at present. Surprisingly, introgressed mitochondrial haplotypes in *A. cervicornis* are quite common (ca. 20%) and distributed throughout the Caribbean, even though backcrosses occur ca. 1 every 10 generations. An important distinction for the status and conservation of *A. cervicornis* is that the genetic data show it is a distinct species or genetic lineage, despite this introgression. The gene flow between the species constitutes an interesting avenue of species research (which we are actively pursuing), but the introgression is functionally not affecting the independent evolutionary trajectory of the species. I would be happy to discuss this research with anyone interested at length via email (etc.) and/or furnish a copy of the manuscript in review once it comes out of its current state of limbo (hopefully soon).

2) We are also looking at the population structure and connectivity of *A. cervicornis* across the Caribbean using the markers (mtDNA control region in particular) that we have developed for the hybridization work. Preliminary data suggests population structure among islands and potentially even over small spatial scales (ca. 20kms). We are actively gathering this data, and would appreciate any samples especially from the southern Caribbean. This result is somewhat surprising, and has important conservation implications – namely that each population should be considered individually with the best potential for recovery coming from local populations and not larvae drifting in from afar. To me, it also suggests that any transplant studies should occur (when possible) with fragments from nearby populations since there may be potential for local adaptation that should be preserved. However, given the state of some populations, this may no longer be possible.

3) One major focus should also be on the amount of genetic or clonal diversity within populations. In Puerto Rico, we are finding surprisingly high levels of genetic diversity at some sites (ca. 1 genotype per 5m), whereas other sites appear to be dominated by a single clone. We are gathering similar data from sites in the Bahamas, Jamaica, and Panama. Amounts of genetic diversity in local populations has important evolutionary and ecological implications which we can discuss further. Some fruitful areas of research might be to see if genetic diversity correlates to a population's ability to survive perturbations like bleaching. We

are hoping to pursue these and related avenues with our approach. Yet, it could also be argued that populations are already perturbed given the white band epidemic. Nevertheless, I suggest that consideration should be given to this issue and any conservation strategy (esp. transplants) should take into account preserving meaningful genetic diversity.

I will stop here and conclude by saying, in my biased opinion, that including genetics will add greatly to any conservation strategy for *A. cervicornis*. Getting a very gross fingerprint of these corals (with PCR, sequencing, and RFLP) could be easily adapted for these purposes.

Genetic Status of *Acropora palmata* Populations in the Caribbean

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Acropora palmata populations showed a significant Caribbean-wide decrease in the 1980s together with their congener *A. cervicornis* and are still in a depressed state. It has been suggested that white-band disease (WBD), a disease specific to Acroporids (Antonius 1981; Gladfelter 1982; Peters 1993) is the primary cause of the recent mortality observed in wide areas of the Caribbean. It might have served as a strong selective agent, i.e. killing non-resistent genotypes and thereby reducing genetic variability. Additionally, Acroporids are particularly susceptible to hurricane breakage and have undergone major bleaching events in the last decade.

Clonal structure

A. palmata reproduces both sexually and asexually. Asexual reproduction can be the dominant mode of reproduction (Highsmith 1982). The high Acroporid cover of Caribbean reefs prior to the 1980s resulted from the combined effects of fragmentation and high growth rates.

Asexual reproduction leads to the multiplication of a particular genotype and results in an assemblage of genetically identical individuals that can function and survive on their own (Carvalho 1994), called a clone. Asexuality per se has no effect on allelic or genotypic frequencies in populations. It does not allow for genetic segregation and recombination, however, and so preserves the effects of selection, genetic drift, or founder effect on the genetic diversity. Bak (1983b) hypothesized that high asexual reproduction rates led to low genotypic diversity so that Acroporids were more susceptible to disease compared to non-branching species.

A. palmata reproduces sexually by releasing egg-sperm bundles in the water (broadcast spawning, Szmant 1986). Larvae settle out after about 1-2 weeks in the plankton. The pelagic life stage provides the opportunity for long-distance transport of larvae with the surface currents (Sheltema 1977; Crisp 1978).

The dominance of asexual reproduction combined with broadcast spawning has implications for the recovery potential of declining *A. palmata* populations. The breeding population size reaches its maximum if all genets contribute to the next generation. *A. palmata* is expected to have a small breeding population size: both fertilization success of spawned gametes and the recruitment of larvae is highly stochastic and dependent upon local conditions. By chance, only a few individuals might contribute a large number of offspring to the next generation (sweepstake effect, Hedgecock 1994a, b). Once colonies become rare, the distance between them might limit fertilization success (Allee effect) even further. Populations with small breeding population sizes are far more prone to extinction due to demographic stochasticity, reduction in gene diversity, or accumulation of deleterious mutations (see Grosberg and Cunningham 2000).

We need to understand the clonal structure of local *A. palmata* populations if we want to assess the status of this coral in the Caribbean. Several avenues have been pursued to detect clonal identity in Cnidaria. The first studies utilized self-recognition analyses (Neigel and Avise 1983) in *A. cervicornis*. This study found that *A. cervicornis* clones do not extend further than 20m. One clone may dominate areas of $10m^2$ and these clones are generally spatially discrete with tight boundaries. The genetic basis of tissue compatibility has since been challenged by studies showing fusion of electrophoretically distinct ramets. Analysis of protein (allozyme) and DNA markers show patterns from dominantly asexual to dominantly sexual reproduction in the Scleractinia. Even within the same species, contrasting reproductive behavior over large geographical scales is not exceptional (reviewed in Harrison and Wallace 1990). However, a lack of appropriate sampling design and the limited power of allozymes to resolve all genotypes limits the extend to which studies can be compared.

The consequences of asexual reproduction on genotypic diversity depend largely on the frequency of sexual recruitment and genet longevity. Empirical and theoretical studies have suggested that genotypic diversity at a local scale might decrease over time through elimination of genets by intraspecific competition or stochastic effects. In contrast, genotypic diversity might remain high if sexual recruits, however rare they might be, have a long life span after establishment occurred (McFadden 1997). In either case, interpopulation differences can be maintained (Hoffmann 1987).

Gene flow in the Caribbean

Opposing patterns of genetic population structure in the Caribbean have been predicted. High gene flow along major current paths (most recently Roberts 1997) may result in a gradient of genetic similarity, correlated within a current system, and would likely reduce subpopulation structure on small scales. Cowen et al. (2000) and others suggested that retention of larvae, aided by local current features, larval behavioral adaptations and high mortality rates should lead to highly subdivided populations. Studies of marine organisms demonstrate population patterns, from strongly structured to homogenous across the Caribbean basin. In the latter case, slight but significant microgeographic structure has been reported in the presence of high gene flow.

To date, there have been no studies on the population structure of Caribbean Scleractinia. However, geographic variation has been found in a number of Anthozoa in temperate and in tropical systems using allozyme and nuclear markers.

Burnett et al. (1995) predict that reef building corals show considerably more population structuring than has been described in strictly sexual species. The zoanthid *Zoanthus coppingeri is* only partly clonal but exhibits strong population structure between localities separated by only 50m, a consequence of random changes in gene frequencies as a result of low levels of gene flow. High clonal longevity and low sexual recruitment rates seem to maintain genetic differences over long periods.

If coral populations are largely self seeding and long-distance transport of larvae is a rare event, the Island Stepping Stone model predicts that genetic differentiation should increase with geographic distance with obvious management implications. Geographic and genetic distance were correlated in some cases.

Analysis of protein (allozyme) and DNA markers show patterns from dominantly asexual to dominantly sexual reproduction in the Scleractinia. Even within the same species, contrasting reproductive behavior over large geographical scales is not exceptional (reviewed in Harrison and Wallace 1990). However, a lack of appropriate sampling design and the limited power of allozymes to resolve all genotypes limits the extent to which studies can be compared.

Underlying the above discussion is the assumption that species with long lived planktonic larvae should have a higher dispersal potential than species with philotrophic, short lived, benthic or no larval stages. It cannot be ruled out that the failure to consistently relate reproductive strategies, with the amount of gene flow in marine organisms, is due to the shortcomings of the markers and the statistical methods, rather than lack of pattern. Additionally, the fundamental differences between clonal and non-clonal species, both in terms of genetic structure and spawning strategies, further complicate predictions and call for different experimental approaches. It is essential to test the ability of the chosen marker system to reliably differentiate between clones (ramets, identical by descent) and closely related individuals (genets, identical by state) to reach confident conclusions about population structure. Furthermore, broadcast spawning corals like *A. palmata* only spawn annually and do so synchronously Caribbean wide. Thus, the potential for larval retention in local current features is likely to be different and, as of now unpredictable, across the Caribbean basin. Lastly, long generation times and low sexual recruitment will likely result in different time scales of larval exchange rates compared to sexual species.

Genetic structure of *A. palmata* is currently under investigation. Both clonal structure and reef connectivity will be estimated by combining highly variable, mendelian markers (microsatellites) with a nested sampling approach on a variety of spatial scales.

Summary

The presumed dominance of asexual reproduction in *A. palmata* leads to a number of predictions, namely small breeding population size and low genotypic diversity within populations. Genet longevity and low sexual recruitment are expected to produce population substructure in the Caribbean. This substructure might not conform to geographic distance or cluster along major current patterns. Rather, it is expected to be influenced by the volatile nature of local currents and eddies. Failure to detect subpopulation structure does not exclude the possibility of extremely rare exchanges of sexual recruits between populations due to the presumed long generation times in *A. palmata*. In the latter case, conclusions derived from genetic studies about the population status and Caribbean reef connectivity will be limited. Nevertheless, information on the clonal structure of the populations will aid in the decision making process on marine reserves and management plans.

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Coral Farm: the First Step to Restore Reefs

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Puerto Rico Coral Farmers is a marine scientific group within Caborrojeños Pro Salud y Ambiente, Inc. (CPSA), a non-profit organization registered in the Puerto Rico State Department since 1991. The mission of our organization is to raise awareness on issues regarding the conservation and protection of our environment. CPSA has the support of several local and federal agencies, including the US Department of Commerce, Rural Economic Development, Environmental and Natural Resources Department, among others. At present, we are currently working with the National Fish & Wildlife Foundation to develop effective and low cost methodology to restore coral reefs.

Our goal is to implement methods for manipulating and enhancing depleted coral population through coral farming in the Southwest area of Puerto Rico, specifically in Cabo Rojo, Lajas, and Guánica. We have designed specific procedures to collect, transport and culture of several coral species that will be continually tested on this study. Coral Farming is a proposed plan to overcome part of the problem of reef deterioration in Puerto Rico and the Caribbean. Through the culture of a wide diversity of corals, we will be able to supply corals to deteriorated coral reefs, damaged by natural (storms, and disease) and human induced disturbances (ship grounding, pollution, military activities, among others.)

Our Partners

- Fish & Wildlife Foundation: Main partner that will provide the funding for the proposed project. Is the main sponsor of our current Reef Restoration Methodology Project (ending August 2001), where we developed the coral reef farming methodology, which will be implemented in a larger scale in the proposed project.
- Department of Natural Resources and Environment (DNRE), Guánica State Forest: Will provide storage facilities for the equipment and materials, and to prepare the coral culture device needed for the coral nurseries.
- Other partners: Local organizations such as the Ferré Rangel Foundation, and the Ford Motor Company Foundation have manifested their interest to collaborate in the proposed project, by providing additional funding to cover the costs of a vehicle to be used in the project (to transport heavy equipment, coral culture device, and trailer), and for an educational component, respectively.

Statement of the problem

In an effort to overcome the problem of coral reef deterioration, the active restoration of damaged coral reefs is now at the scope of most conservation efforts. Coral reef restoration is a relative new field of research that will become increasingly important for management purpose. Restoration techniques have the potential to accelerate the re-growth of a reef after disturbance and created new reef where none previously existed. The basic approach is to introduce new colonies of fast growing species into the reef. The establishment, growth, development and maturating of these colonies may increase larvae production and recruitment locally or the increase the number of colonies by the establishment of broken off fragments from transplanted colonies.

Despite the fact that some corals are known to survive after transplantation (Highsmith, 1982), some techniques have been proven not to be feasible options because of the following:

- **Negative effects on collection sites**: The majority of the work done in coral reef restoration projects involve the collection of the coral colonies from one site, transported and transplanted to a second site. Harriot and Fisk (1988) have documented the negative impacts of transplantation on the collection site, such as the reduction of coral population from healthy reefs, among others.
- **Highs cost, and low percent of survival of coral transplanted**: Cost/effectiveness is not measured in most of coral reef restoration project. For example, after the M/V Fortuna Reefer Vessel Grounding at Mona Island (Puerto Rico) the National Oceanic and Atmospheric Administration's Damage

Assessment and Restoration Program initiate an emergency coral reef restoration. After an expedited $1.25 million settlement funds to restore the reef less than 65 % of *Acropora palmata* fragments survived. Comparable results (68% after one year) were obtained without human intervention when hurricane Georges (September 22, 1998) passed through Puerto Rico, fragmenting many colonies of *A. palmata* in several reefs of La Parguera, southern Puerto Rico (Ortiz and Ruiz, 2000).

Farming corals (or coral nursery) is the best logical step in coral harvesting that will allow us to produce corals to be used on restoration projects. Our experience in coral farming has proved that coral nursery or coral culture is a useful tool in coral reef management. The coral nursery is based on the idea of the metapopulation concept. A metapopulation is a series of small, separate, populations united by some mechanism that allows genetic flow. In this scenario, even if the individual populations go extinct, other population survives and supply dispersing individuals who re-colonizes "extinct" patches (Harrison, 1991). By this concept, the coral culture of different species within the nursery sites may act as a source of corals to replenish extinct populations at different reefs. The proposed coral farm not only will increase the local genetic variability by the addition of new coral strains to the reef, it also will preserve coral strains (on coral nurseries) for future dispersion, including candidate species considered for the Endangered Species Act. For example, we have already successfully farmed *Acropora cervicornis* and *Acropora prolifera,* two of such threatened species.

Expected Results and Benefits

We will establish a total of 6 coral reef nurseries in three southwest towns: Cabo Rojo, Lajas and Guanica (2 nurseries in each town). Each of these nurseries will have at least 50 coral culture devices, for a total amount of 300. Initially, we will collect and culture in these device at least 8,400 coral fragments of different species. By the end of the second year, we expect to have harvested at least 30,000 fragments to be cultured in additional 1,440 new culture devices.

Outcomes

1. Implement effective methodologies for coral propagation and transplantation through human activities.
2. Increase of genetic diversity of local coral population by providing new, genetically different individuals .
3. To have farmed large and diverse amounts of corals, including threatened species of the *Acropora* genus, available to be used in future local reef restoration efforts.
4. Direct involvement of coral reef resource managers; island fishing communities and other non-government partners in coral reef restoration projects.
5. Integration of coral transplantation techniques in the management strategies for improving the fishery resources in Puerto Rico.
6. Increase public knowledge about the importance of coral reefs as essential habitats for marine life, and the joint efforts to preserve and restore damaged coral reefs.
7. Coral farms will also produce direct and indirect benefits to local areas by expanding habitats for marine invertebrates, ornamental and commercial fishes, and underwater attractions for snorkeling or SCUBA diving.

Our ultimate goal is to transfer our findings and experience in restoration and coral farming methodology to other Caribbean nations, as a sustainable method to increase coral populations

We propose the extensive use of experimental and proven methods of coral culture. All coral transplantation or cultured methods will be continually tested to determine the optimum approach. Each methodology will be tested and evaluated using appropriate experimental design. For example, experimental coral culture device will be set up in a complete randomized design. Triplicate coral culture device contained branches or fragments of one strain of each coral species will be randomly allocated within each coral nursery area. The number of coral fragments and its size within the experimental coral culture device will be recorded at the initiation of the project. Coral nursery sites will be visited periodically over the year period and the response variables to be measured are mortality rate of transplant, incremental growth, and colony conditions. All techniques (coral collection, transportation, transplantation, etc.) will be modified depending on previous results.

Coral Culture as a Conservation Tool for *Acropora* spp.

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During the past 20 years, aquarists have developed techniques to successfully maintain, and propagate, scleractinian corals in closed systems. Much of this was accomplished by hobbyists with the goal of creating "mini-reefs" for display. But the requirements for scleractinians were based on knowledge of coral biology, particularly their need for oligotrophic water and high irradiances. Scientists have also developed closed coral systems to better understand coral biology and their effects on community metabolism. The Acroporids are particularly amenable to culture because of their high growth rates and ease of asexual propagation. Coral model systems, such as the "microcolony," are the equivalent of lab rats and offer the potential to much more fully understand the complex physiological processes of corals and their symbiotic dinoflagellates. Closed-system culture offers opportunities to study diseases that affect acroporids (bleaching, white-band disease and patchy necrosis/white pox) in much more detail than possible in the field. Finally, such systems also offer a refuge of last resort for a genus that has seen dramatic population declines in much of the Greater Caribbean.

Management Measures for Corals and Coral Reef Ecosystems in the Florida Keys National Marine Sanctuary: Is the Existing Program Sufficient to Protect and Restore Acroporid Corals?

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Florida Keys National Marine Sanctuary

The Florida Keys National Marine Sanctuary is a nearly 10,000-km^2 marine protected area that was designated by Congress in 1990; its management plan was implemented in 1997 and consists of 12 action plans in four categories of protection: physical damage, environment/water quality, science/understanding, and penalties. A key aspect of the Sanctuary's management plan is the use of marine zoning to set aside areas for specific activities to balance commercial and recreational interests with the need for a sustainable ecosystem. In particular, there are 24 fully protected ("no-take") zones that help protect resources from overuse and separate conflicting uses. The Sanctuary's management plan includes multiple approaches to protecting live coral. Although *Acropora* spp. are not singled out within the plan, they receive special consideration in day-to-day operations. For example, there was a ban on collection of *Acropora* for research for several months following the damaging effects of Hurricane Georges in 1998.

Introduction to the U.S. Endangered Species Act

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BACKGROUND

The purposes of the Endangered Species Act are to provides a means to conserve ecosystems upon which endangered species and threatened species depend, to provide a program for the conservation of endangered and threatened species, and to take appropriate steps to recover a species.

Species' Listings Under the Endangered Species Act

The National Marine Fisheries Service (NMFS) is responsible for determining whether marine species, subspecies, or distinct population segments are threatened or endangered under the Endangered Species Act of 1973, as amended, 16 U.S.C. 1531 et seq. (ESA). To be considered for listing under the ESA, a group of organisms must constitute a "species," which is defined under section 3 of the ESA to include "any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature." NMFS has determined that, to qualify as a distinct population segment (DPS), a population (or group of populations) must be substantially reproductively isolated and represent an important component in the evolutionary legacy of the biological species. A population (or group of populations) meeting these criteria is considered to be an "evolutionarily significant unit" (ESU) (56 FR 58612, November 20, 1991). In its listing determinations to date, NMFS has treated an ESU as the equivalent of a DPS under the ESA.

Section 3 of the ESA defines an endangered species as "any species which is in danger of extinction throughout all or a significant portion of its range" and a threatened species as one "which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." The statute lists factors that may cause a species to be threatened or endangered (ESA section 4(a)(1)), but it does not provide further guidance on how NMFS is to determine the risk of extinction or the likelihood of endangerment.

Section 4(b)(1)(A) of the ESA requires NMFS to make listing determinations based solely on the best scientific and commercial data available after conducting a review of the status of the species and after taking into account efforts being made to protect the species. Accordingly, in making its listing determinations, NMFS first determines whether a population group constitutes a "species" under the ESA, and determines the species' status and the factors that have led to its decline. The status review provides background information on the species including taxonomy and biology, current and historic range, population information, habitat requirements, a summary of the threats faced by the species, a review of existing conservation measures, and a discussion of the activities that would be affected if the species were listed.

The process for determining whether a species should be listed is based solely on scientific information on the status of a species and specifically excludes potential economic impacts. The status is determined from an assessment of factors that may be contributing to decline including 1) habitat destruction or modification; 2) overexploitation; 3) disease or predation; 4) inadequacy of existing regulatory mechanisms; and 5) other factors affecting survival of the species. NMFS also assesses protective efforts being made to determine if they mitigate risks to the species.

Invertebrate listings

An amendment to the ESA in 1978 allows us only to list distinct populations of vertebrates. Marine invertebrates must be threatened or endangered throughout their range to be listed, because they are thought to have greater ranges and fecundity and a greater resilience to exploitation and environmental change than vertebrate species. Since most benthic inverts produce pelagic larvae with the potential for long-distance dispersal, these species are assumed to exhibit a high degree of interconnectivity through water circulation, and it is thought that a distant population in good condition can serve as a source of recruits to rehabilitate degraded populations.

Even though we are required to list all populations of an invertebrate species if we determine that they are threatened or endangered, the degree or type of protection these species receive can vary, depending on whether a species is listed as threatened or endangered. If we were only to list one or both of these corals as threatened we would subsequently issue regulations through a rule-making process that would specify what measures were necessary for the conservation of the species and where these measures would apply. In some cases these rules would only affect the species in state or territorial waters if the state has a cooperative endangered species agreement and the state feels that those measures are beneficial for the species. In contrast, if we were to list one or both of the corals as endangered all of the provisions of the ESA automatically apply, regardless of whether the species is in federal waters, or in state and territorial waters. So a threatened listing gives us much greater flexibility.

What does it mean to be listed

A. Critical Habitat

When we publish a final decision to list a species on the ESA we are required to designate critical habitat - Critical habitat includes specific areas that contain the physical, biological and environmental factors necessary to support the species, as well as areas that are not occupied by the species, but are essential for its conservation - for corals, this could include other reef environments, as well as mangroves and grassbeds.

B. Protective measures

By listing a species, we are required to protect that species and recover it to its former abundance or range, concentrating on areas that are critical to the species based on unique genetic diversity, areas with a documented high abundance, populations that may provide a significant source of recruits to other areas, and populations at the geographic limits of the species. The ESA also provides us with the tools to protect the habitat occupied by a listed species by prohibiting any activities that are funded, authorized, or carried out by the federal government if those activities are likely to contribute to the degradation of the habitat and jeopordize the survival of the species (section 7). For coral reefs, this measure would require permits for any activities involving dredging, coastal development projects, sand extraction and discharge of sediment near coral reef environments. The ESA (section 9) also makes it illegal to “harass, harm, pursue, shoot, wound, kill, trap, capture, or collect or engage in commerce in listed animals except by permit for conservation or scientific purposes”.   Harm has been defined to include “significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns including breeding, feeding, or sheltering”. A listing also increases federal aid to state and commonwealth conservation agencies with cooperative endangered species agreements. Most importantly, The ESA requires that we develop and implement a recovery program.

C. Recovery Programs

A recovery program includes a summary of information on a species and its life history, including information on taxonomy, population discreteness, population size and trends (including past and present size and future projections based on current trends), reproduction and recruitment rates, sources and rates of mortality, diet and feeding habits, movement patterns, habitat use patterns and critical habitat requirements. The threats affecting the species should be described in detail, as well as the overall objective of the recovery plan, the type of recovery actions, and an implementation schedule to achieve these actions. The goals of the recovery program are to determine actions necessary to reduce or eliminate the threats affecting the species and protect critical habitat essential for the survival of that species. The recovery program must also identify measurable criteria that will be used to down-list a species once it has recovered, and an analysis of the time and cost required for full recovery.

APPENDIX I: Restoration Approaches for *Acropora* in Florida, Puerto Rico and USVI

Coral reef restoration efforts in the United States have traditionally occurred in response to damage resulting from ship groundings, but recent efforts are underway to mitigate damage from other natural and anthropogenic factors. In the past, most restoration projects focused on stabilization and reconstruction of the reef structure followed by a reintroduction of benthic invertebrates. These projects have been conducted on a site by site basis, using a variety of different approaches and often including only limited science-based monitoring to evaluate the benefits of a particular technique.

NOAA's National Ocean Service (NOS) is currently developing a manual outlining techniques to conduct damage assessment following shipgroundings in coral reefs within the Florida Keys National Marine Sanctuary (FKNMS) that will improve our ability to determine the most cost effective and ecologically beneficial restoration program. More recently, pilot research projects in the Florida Keys are seeking to develop and evaluate new restoration techniques by targeting important ecological processes. This includes innovative experiments involving novel ecological restoration projects that seek to enhance sexual recruitment of important reef-building coral larvae; reestablish important missing ecosystem links such as the herbivorous sea urchin *D. antillarum,* as a tool to control the proliferation of harmful macroalgae; and approaches to control coral predators and coral diseases.

A. Restoration efforts by the Florida Keys National Marine Sanctuary for *Acropora*

Compiled by Anne McCarthy with contributions from Brian Keller, Harold Hudson, and Bill Goodwin

Over the last decade, staff from the Florida Keys National Marine Sanctuary (FKNMS or Sanctuary) have developed and applied techniques to restabilize (reattach to the seafloor) coral fragments fractured and dislodged mainly by vessel groundings and hurricane events. Since 1992, over fifteen moderate to major restoration projects have been initiated, overseen, or permitted by the FKNMS within State and Federal waters. Of these projects, three were efforts to restabilize colonies of Elkhorn Coral (*Acropora palmata*) damaged by vessel groundings in shallow reef areas of Carysfort Reef (1998), Western Sambo Reef (2001), and Rock Key Reef (2002). Techniques employed at these sites included an expansion anchor method used by Continental Shelf Associates, Inc. (Graham and Fitzgerald 1999), the deployment of "reef crowns" designed to simulate the natural surroundings and cradle dislodged *A. palmata* that was stabilized with concrete, and the direct cementing of fragments to the substrate using hydraulic cement. A fourth project was completed in 2000 in cooperation with Reef Relief (a Florida Keys non-governmental organization) and involved the re-transplantation of previously salvaged corals from a hurricane-damaged Western Sambo Reef into the denuded area of an early 1990's vessel grounding at the same reef.

At this time, there is limited information on the success of these restoration efforts. However, some preliminary observations of these sites have been made and indicate possible success of stabilization and survivorship using the "reef crowns" and direct cementation and poor success using the expansion anchor method (Bill Goodwin, personal communication). Until recently, the Damage Assessment and Restoration Program (DARP) consisted of only three employees for the entire FKNMS and therefore had limited capacity to monitor and evaluate success beyond qualitative observations. As the program grows, plans are being drafted to evaluate the success of the Western Sambo and Rock Key sites using numerous variables. The ultimate objective is to return these damaged areas back to their baseline (pre-injury) conditions.

Variables to be evaluated may include algal cover, evidence of cement toxicity on adjacent organisms, structural integrity of reef framework and other structures, growth and survivorship of transplanted or stabilized coral fragments, and recolonization of the site by typical reef-dwelling organisms other than corals (fish, crustaceans, other invertebrates).

Additional efforts to salvage grounding-generated coral fragments include the transfer of smaller fragments to aquaculture and marine research institutions for "rehabilitation" with an ultimate objective of returning them to the grounding site. Scientific research is also supported through this mechanism by supplying living tissue and minimizing collection of un-impacted corals. Recent "rescue" efforts resulted in mixed results. Several *A. palmata* fragments (too small for direct restabilization) were transported to Mote Marine Laboratory's Center for Tropical Research on Summerland Key and shipped to the Florida Aquarium in Tampa following a sailboat grounding on Rock Key. Within one to two days following transport, most of the fragments demonstrated rapid tissue loss and a condition termed "shut down reaction" or " rapid tissue necrosis" (Jane Hawkridge, personal communication). To verify the cause of this necrosis, tissue samples from these fragments were sent to a researcher studying this phenomenon for bacterial analysis. Two of the fragments shipped to the Florida Aquarium in Tampa have demonstrated positive results with recent reports of tissue growing over wounds and the substrate in the artificial system. Overall, these stressed fragments (which may not have otherwise survived) have provided "corals of opportunity" for researchers and potential opportunities for reintroduction of healthy colonies to degraded habitats following rehabilitation in a controlled system.

As the DARP grows and more time is allocated toward greater evaluation of restoration efforts in the Sanctuary, it is believed that responses to vessel groundings and hurricanes will adapt to meet the ecological needs of the impacted coral reefs. With this, methods used to restabilize and 'restore' these areas will also need to be revised as we discover which approaches work best in the various conditions encountered in Florida Keys reef environments.

B. Restoration efforts in Puerto Rico

Compiled by Andrew Bruckner

1. Fortuna Reefer Grounding, Mona Island, Puerto Rico

The Fortuna Reefer, a 327' merchant vessel, ran aground on the southeast coast of Mona Island in July 1997. The grounding and removal disturbed over 6 acres of shallow coral reef habitat dominated by large stands of elkhorn coral, *Acropora palmata*. NOAA's Damage Assessment and Restoration Program and the Commonwealth of Puerto Rico expedited a settlement amounting to US $1.25 million for primary and compensatory restoration, that included $650,000 to conduct an emergency coral restoration project within 2 months of the incident. The objectives of the emergency restoration were to reestablish the structural relief of the coral reef community and reduce coral mortality by securing loose *A. palmata* branches to relict reef substrates and standing elkhorn coral skeletons (NOAA, 1997a). Between September 24, 1997 and October 14, 1997, a team of 19 divers including marine engineers and biologists stabilized 1857 *A. palmata* coral fragments ranging in length from 15 cm to 3.4 m. Fragments were attached either to reef substrate or to dead, standing *A. palmata* skeletons. Stainless steel wire was used to secure fragments to the reef; wire was extended across a fragment and then wrapped around stainless steel nails that were cemented into holes drilled in the substrate (NOAA 1997; Iliff et al. 1999). Initial monitoring of the site showed that after two years, 57% of these fragments were alive, 26% were dead but still securely in place, and 17% were missing. Although the wire had several limitations, it was effective over the short term for holding fragments in place: a major hurricane impacted the site one year after the restoration was completed, and yet only 17% of the fragments were removed. In June, 2000 a mid-course correction was undertaken, where the living fragments were rewired, as the original wire has begun to corrode and break. This restoration represents a novel effort at securing elkhorn coral branches to the reef with wire.

2. Puerto Rico Coral Farmers

A comunity-based effort is underway to culture branches of *A. cervicornis* (and other species) for use in creating fish habitat in sandy areas, and for rehabilitating degraded areas. The emphasis of this project has been on the west and south coast, near Guanica, Parguera and Cabo Rojo, but there are interests in expanding it to Culebra. A more detailed description of this effort is included in the abstracts.

C. Restoration Efforts in the U.S. Virgin Islands

1. Virgin Islands National Park

A small coral transplant project is underway in the Virgin Islands National Park. The researchers are using cable ties to fasten naturally-occurring fragments of three fast growing species of coral to damaged reefs. They initially tried the two part putty epoxy which comes in a tube and hardens in 1-24 hours depending on literature or in-water experience. It only bonded if the skeleton and substrate were totally clean. The researchers have switched to cable ties, which appear to work very well. Fragments attached to dead coral skeleton had lower mortality than natural colonies of the same species. *Acropora palmata* and *A. cervicornis* have both overgrown the cable ties and they appear to be non-toxic (Ginger Garrison, personal communication).

Table 1. Comparison of restoration approaches used for *Acropora palmata* and *A. cervicornis*. Compiled by A. Bruckner.

Technique	Benefit	Drawback
Re-attachment of *A. palmata* fragments to the reef using stainless wire	rapid, cost effective, works in high surge areas	wire abrades tissue; wire becomes corroded and breaks; requires attachment point for wire
Re-attachment of *A. palmata* fragments to the reef using cable ties	rapid, cost effective, tissue readily grows over plastic	cable ties loosen under high surge
Re-attachment of *A. palmata* fragments to the reef with cement or epoxy	permanent attachment, does not cause tissue mortality, does not require specialized attachment point	costly, may not set rapidly, ineffective under high surge conditions; requires that both surfaces are clean and free of algae, encrusting inverts and sediment
Attachment of *A. palmata* fragments to bases (e.g., cement rosettes) that are placed on the reef	provides a base for attachment	requires manipulation out of water; rosettes must be attached to reef or they may be dislodged by high wave action
Attachment of *A. palmata* fragments to dead, standing colonies	provides a base for attachment; raises fragments off the bottom; may speed up recovery and reestablishment of standing colonies as tissue expands over skeleton	high likelihood of loss as skeletons may be bioeroded and will break during periods of high wave action; potential competition with bioeroding sponges (*Cliona*)
Collection of storm-generated fragments from sandy areas and placement on reef substrates	may enhance the survivorship of fragments following a storm; can be undertaken by volunteers	fragments may be removed during high wave action if there has not been sufficient time for them to reattach naturally
collection and grow-out of fragments on racks placed in shallow marine environments	may enhance survival and growth rates of fragments; elevates fragments above the substrate; provides a source of fragments for restoration	may reduce genetic diversity; can facilitate spread of disease or outbreak of predators
collection and grow-out of fragments in land-based aquaria	allows culturing under controlled environment; can provide a source of colonies for scientific studies	disease concerns; fragments may be acclimated to laboratory conditions and exhibit poor survivorship in the wild

APPENDIX II: Summary of Biological Information on *Acropora palmata* and *Acropora cervicornis*

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Acropora palmata

Description: Elkhorn coral is a large branching coral up to 3 m in diameter with exceptionally thick and sturdy branches. This species was formerly the dominant species on shallow, exposed reefs throughout the Caribbean and in the Florida Reef Tract, forming extensive, densely aggregated, monospecific thickets (stands) that develop during periods between storms (Adey and Burke, 1976; Woodley, 1992). The success this species has achieved is a result of its fast rate of growth, rapid wound healing by injured adults, high rate of survival of fragments, and ability of broken branches to cement to the substratum and continue growing (Gladfelter et al., 1978; Bak and Criens, 1981, Highsmith, 1982). Because of the high survivorship of fragmented branches, *A. palmata* was rapidly reestablished after a major disturbance, and colonies spread into neighboring areas not previously occupied by *A. palmata*, including sandy habitats not suitable for settlement by sexually-produced larvae (Lirman and Fong, 1997). In sheltered areas, and on reefs where storm disturbances are low, this species occurs as isolated colonies, primarily due to reduced likelihood of fragmentation, and the low recruitment success of sexually-produced larvae (Dustan, 1977; Rylaarsdam, 1983; Rosesmyth, 1984).

Preferred habitat: Elkhorn coral is found between low water level and 5-6 m depth, in wave-exposed and high surge reef zones (Adey and Burke, 1976); isolated colonies can be found to depths of 18 m, primarily in areas with low rates of sedimentation and high current. This is an environmentally sensitive species that requires clear, high saline, well circulated water with mean temperatures of 25-29^{o}C (Jaap et al., 1989). *A. palmata* is intolerant of sedimentation; this species is not found in areas with considerable runoff, river discharge or land erosion (Lewis, 1984), and populations will disappear from coral reefs exposed to sudden changes in temperature, salinity or water quality (Davis, 1982; Dustan and Halas, 1987).

Importance: *Acropora palmata* is a major reef-building species and the dominant coral on the shallow fore reef in the "palmata zone". Few other species coexist in this environment, due to the extreme fluctuation of environmental conditions. Dense thickets of elkhorn coral reduce incoming wave energy, offering critical protection to coastlines. Loss of this species may result in increased coastal erosion and may negatively affect shorelines with mangrove and grass bed habitats which rely on calm water provided by these effective coral barriers. Of the 60+ species of coral in the Caribbean, only three dominate present day coral reefs and the Pleistocene geological record: *A. palmata*, *A. cervicornis* and the *Montastraea annularis* "complex" (Jackson, 1992). *A. palmata* colonies contribute to the reef framework, and coral thickets account for some of the greatest measured reef growth rates (Goreau, 1959). Gladfelter (1982) estimated a rate of reef accretion by this species of 10.3 kg $CaCO_3/m^2/yr$; over 1000 years, shallow windward *A. palmata* reefs have grown upward close to 15 meters, keeping pace with rising sea level (Adey, 1975). This species also produces islands; boulder ramparts and coral cayes in exposed locations in the Caribbean islands are composed primarily of *A. palmata* skeletons (Williams et al., 1999). High structural complexity produced by the interdigitated branches of *A. palmata* colonies provide essential fish habitat; *A. palmata* thickets often contain a higher diversity of fish species than in comparable areas (Gladfelter and Gladfelter, 1978).

Species distribution: *A. palmata* is found on reefs in southern Florida and the Bahamas, and throughout the Caribbean, including the Antilles, the West Indies, Central and South America, including Mexico, Belize, Honduras, Nicaragua, Costa Rica, Panama and Columbia, and. Isolated populations occur in the southern portion of the Gulf of Mexico, near Veracruz, Mexico; the northern limit in 1992 was the Tuxpan Reef System, approx 29 N latitude (Jordan-Dahlgreen, 1992). *A. palmata* was one of the dominant reef-builders Barbados, but has virtually disappeared (Lewis, 1984). The southern limit is Venezuela (Los Roques) and the northeastern tip of Tobago. Elkhorn coral does not occur in Bermuda, the northern Gulf of Mexico, or the east coast of South America (Guyana, Surinam or Brazil). *Acropora palmata* prefers moderately high energy wave environments found along the windward sides of islands and banks generally always found within 5 m of sea level. Depending on the degree of wave energy, *A. palmata* colonies may grow either in the shallow fore reef, back reef or patch reef environments, however it usually forms either continuous or discontinuous crests. *Acropora cervicornis* prefers moderate-to-low energy environments and occurs in depths down to 20 m. It can occur in patch reef, back reef, reef crest, and fore reef habitats. Historically, populations of *A. palmata* and *A. cervicornis* populations occur throughout the greater Caribbean and have been documented as far back as the Pliocene. Northern-most populations occur in Florida off Broward County and the northern Bahamas region, and southern-most populations occur near Trinidad & Tobago, Venezuela and Columbia.

U.S. distribution: *A. palmata* coral occurs in Biscayne National Park, on the Florida Keys Reef Tract, off Puerto Rico and offshore islands, and on fringing reefs around the U.S. Virgin Islands. This species is absent from Flower Garden Banks, Florida Middle Grounds and Southeast Florida. The northern limit on the east coast of Florida is in the Biscayne National Park (Triumph Reef 25^{o} 29' N).

Growth: Branches increase in linear dimensions by 5-10 cm/year, depending on geographical location, temperature, horizontal position on the reef, depth, and environmental conditions. The greatest rate of growth occurs on the shallow fore reef during summer and early fall; reduced growth is reported during cold water periods, and in back reef environments (Gladfelter et al., 1978).

Life history adaptations: *Acropora palmata* has a high investment into persistence of adult colonies with modifications in growth patterns in response to wave stress and light intensity. Colonies in deep water have broad and flattened branches which are very fragile. On wave-exposed, shallow reefs, branches are fewer in number; branches become thicker, shorter and more cylindrical and are oriented at close to a 45^{o} angle, pointing into incoming currents and waves. In the back reef, colonies have broad, flattened branch tips, although branches are thicker in cross section when compared to deep-water colonies (Gladfelter, 1982). The skeleton is less porous and stronger than most massive corals, and porosity is lower towards the base and higher in branch tips (Chamberlain, 1978). Of all Caribbean corals, *A. palmata* exhibits the most rapid and efficient ability to regenerate tissue and skeleton over injuries (Bak, 1983), allowing this species to recover quickly from storm damage. *A palmata* is low on the aggressive hierarchy, experiencing tissue destruction if it contacts slow-growing massive corals (Lang, 1973). *Acropora palmata* outcompetes massive corals by growing above them, thereby reducing light penetration and water circulation water (Shinn, 1972).

Reproduction: Individual colonies of *A. palmata* produce both eggs and sperm which are broadcast into the water column for external fertilization. Egg and sperm bundles are positively buoyant, floating to surface and remaining viable for up to 8 hours after release. This species spawns 4-5 days after the full moon in August and/or in September. Although colonies have a high investment in gamete production, few larvae survive and sexual recruits are rare (Dustan, 1977; Bak and Engel, 1979; Rylaarsdam, 1983). Unlike

Indo-Pacific acroporids, the main mode of propagation of *A. palmata* is by colony fragmentation, enabling this species to colonize areas unsuitable for sexually produced larvae, and allowing rapid recovery following minor hurricanes and tropical storms.

Threats: The major sources of mortality to *A. palmata* responsible for the virtual elimination of this coral from the Caribbean over the past two decades has been white-band disease (Gladfelter, 1991). Other causes of mortality include natural factors such as breakage by hurricanes and tropical storms, predation by invertebrates and fish, hyper-and hypothermic stress, and bleaching episodes. Anthropogenic causes of mortality include nutrient loading and overgrowth by macroalgae, sedimentation and reduced water clarity, and physical damage from boat groundings and anchors. Although *A. palmata* has adaptations allowing it to inhabit shallow, high energy reefs, it is susceptible to breakage from physical forces associated with storms and hurricanes. Fragmentation was thought to be adaptive, with a high survivorship of hurricane-generated fragments and a rapid recovery of affected zones (Glynn et al., 1964; Highsmith, 1982). While storms may enhance the spread of *A. palmata* populations, recent observations indicate that initial mortality to colonies and fragments may be quite high, injured colonies and fragments exhibit reduced growth rates and declines in reproductive output, and damaged populations are susceptible to subsequent disturbances (Bruckner, unpubl. Data; Lirman, 1998). In Puerto Rico, populations damaged by storms have continued to decline, with a high incidence (40-60%) of fragment mortality within the first 90 days (Bruckner and Bruckner, unpubl. Data). Woodley (1992) suggested that the large monospecific stands of *A. palmata* described as a characteristic feature of Caribbean reefs (Goreau, 1959; Adey and Burke, 1976) may have developed only because of an unusually long interval (approximately 35 years in Jamaica) between major hurricanes.

Outbreaks of coral disease were first observed among *A. palmata* populations in St. Croix in the mid 1970s and disease epizootics have spread throughout the Caribbean over the past two decades. Up to 95% of the *A. palmata* disappeared over a ten year period from Tague Bay, St Croix as a result of **white-band disease** (WBD) and storm damage (Gladfelter, 1991). Goenaga reported 20-33 % of *A. palmata* affected with WBD on one reef near La Parguera PR in the early 1980s (Davis et al., 1986); disease epizootics were also reported in Florida (Jaap, 1984). *A. palmata* populations in Puerto Rico and elsewhere in the Caribbean continue to be afflicted by WBD (Bythell, 1993; Bruckner et al., 1997; Aronson and Precht, 1998; Williams et al., 1999). In addition to WBD, new diseases have emerged on *A. palmata*, including **white pox** (Williams, 1996) and **patchy necrosis** (Bruckner and Bruckner, 1997b). Tumors or **calicoblastic neoplasms** (raised, whitened, abnormal lumps on colony surfaces with distorted polipary structures) were first noted by Squires (1965) and their affect on growth and regeneration was examined in Curacao (Bak, 1983). Calicoblastic neoplasms were reported from Carysfort Reef in Florida in 1975 and Grecian Rocks, Florida in 1982, and they are known to occur sporadically, at low levels throughout the Caribbean (Peters et al., 1986). Neoplasms are thought to reduce the reproductive potential of coral, and they are susceptible to ulceration and invasion by filamentous algae; affected areas lack mucous secretory cells and are very porous, increasing vulnerability to sedimentation and wave stress (Peters et al., 1986).

Coral-eating **predators** including the fireworm, *Hermodice carunculata* and the corallivorous gastropod, *Coralliophila abbreviata* appear to have become more prevalent and cause more damage to *A. palmata* populations in Puerto Rico and the Florida Keys possibly as a result of overfishing of their predators, the octopus and spiny lobster (Bruckner et al., 1997b; Szmant, 1997), and possibly because their host populations have been greatly reduced, effectively concentrating predators (Knowlton et al., 1990). Territorial damselfish (*Stegastes planifrons*) bite repeatedly at the same location on *A. palmata* branches creating conspicuous lesions which are colonized by algae. Regeneration of these lesions is continually interrupted. As a result, the surrounding polyps secrete a wall of tissue and skeleton around the lesion, which extends vertically upward, resembling a chimney; this growth encloses the tufts of algae. Stoplight parrotfish (*Sparisoma viride*) also bite at elkhorn coral branches, removing tissue and underlying skeleton (Bruckner and Bruckner, 1998).

Death to large stands of *A. palmata* by **hypothermia** has been significant in the Dry Tortugas (Jaap and Sargent, 1993) and areas along the Florida Reef Tract with direct connections to the Florida Bay. *A. palmata* is vulnerable to **sedimentation** associated with increased runoff and river discharge, especially in areas with minimal wave action. Rogers (1983) found that even low doses of sediment accumulate on the flattened branch surfaces, resulting in rapid tissue necrosis; in addition, injuries regenerate more slowly at elevated sedimentation levels (Meesters and Bak, 1995). In areas with heavy commercial boat traffic and recreational use, *A. palmata* thickets are vulnerable to **boat groundings** and anchor damage, primarily because these corals are restricted to shallow water (Dustan and Halas, 1987).

Acropora cervicornis

Description: *Acropora cervicornis* (staghorn coral) is a branching coral with cylindrical branches ranging from a few centimeters to over two meters in length and height (Aronson and Precht, 1997). Colonies are yellow-brown in color and have distinct, protruding tubular corallites. The tip of each branch has an enlarged apical polyp which is often pale in color and is the actively growing portion of the colony. Colonies tend to branch trichotomously once each year, expanding in diameter 12 cm or more annually. The species often forms dense, localized thickets throughout its range. In these thickets, usually only the upper portions of the branches support living polyps; the bases of the colonies are often encrusted with algae and invertebrates and provide important habitat for damselfish, juvenile grunts and other species (Tunnicliffe, 1981).

Preferred habitat: Of the three Western Atlantic species of *Acropora*, this species occupies the most extensive range, occurring in back reef and fore reef environments from 0 to 30 m (Baker et al., 1997). The upper limit of *A. cervicornis* populations are defined by wave forces and the lower limit controlled possibly by suspended sediments and light availability (Dodge et al., 1974; Tunnicliffe, 1981). Fore reef zones at intermediate depths (5-25 m) were dominated by extensive monotypic stands of *A. cervicornis* until the mid 1980s (Aronson et al., 1998). Although branches tend to be fragile and easily broken, colonies are often most abundant in areas of intermediate to high water turbulence (Tunnicliffe, 1981).

Importance: *A. cervicornis* is one of the three most important reef building corals on Caribbean reefs today, and this species is often the dominant component in fore reef and lagoonal Pleistocene and Holocene deposits (Jackson, 1992; Stemann and Johnson, 1992; Greenstein et al., 1998). High population density, rapid growth rates and high partial mortality results in the accumulation of large amounts of *A. cervicornis* skeletal material (Gilmore and Hall, 1976). This rubble may remain in place, compacting to form an important component of the reef-framework. It may be transported and deposited at the base of the reef, or it may be broken down into smaller fragments by dissolution and bioerosion, to contribute to clastic material which fills spaces in the rigid framework of the reef (Tunnicliffe, 1983). The most rapid accretion rate for a Holocene reef dominated by *A. cervicornis* was 12 m per 1000 years at Alacran Reef, Mexico (Macintyre et al., 1977). The open framework of densely populated *A. cervicornis* thickets provides essential habitat for motile invertebrates and fishes; back reef populations are important habitat for juvenile grunts and other reef fishes.

Species distribution: *A. cervicornis* is found throughout the Florida Keys, the Bahamas, the Caribbean islands, and Central and South America, including Mexico, Belize, Honduras, Nicaragua, Costa Rica, Panama and Columbia. This coral occurs in the western Gulf of Mexico, to the Veracruz Reef System, but is absent from U.S. waters in the Gulf of Mexico, as well as Bermuda and the west coast of South America (Guyana, Surinam and Brazil).

U.S. Distribution: In U.S. territorial waters, this species occurs throughout the Florida Keys reef tract, the Dry Tortugas, Biscayne National Park and Southeast Florida reefs, extending north to Boca Raton. It also occurs in the U.S. Virgin Islands and Puerto Rico, and the associated islands of Mona, Desecheo, Culebra and Vieques. It is absent from Flower Garden Banks and the Florida Middle Grounds.

Growth (linear extension): Average annual growth rates for individual branches ranges from 3-15 centimeters, depending on geographical location and local environmental conditions. Under optimal conditions, growth rates of 11 cm per year are reported for Florida (Shinn, 1966), 7.1 cm for the U.S. V.I.(Gladfelter et al., 1978), and 12 cm for Jamaica, with a maximum annual growth for individual branches of over 20 cm/year (Tunnicliffe, 1983). In St Croix, Gladfelter (1984) did not observe any major changes in growth rates throughout the year; a 30-60% decline in rates of linear extension occurs during months in which water temperatures did not exceed 26^{o}C in Florida (Shinn, 1966). A reduction in growth rates is associated with extreme turbidity (Rogers, 1990).

Morphological adaptations: Branching morphology, combined with a rapid growth rate promotes colony proliferation and dominance of large areas, but may result in high susceptibility to physical disturbance. Unlike *A. palmata*, this species may fragment completely, sacrificing adults for the production of new asexual propagules. Vegetative propagation allows for the rapid establishment of new colonies throughout the year, unlike sexual larvae which are only produced once each year. Fragmentation may also provide an effective method of inhibiting competitors (Tunnicliffe, 1981). Wave exposure and depth affect colony morphology: colonies from shallow, exposed habitats are robust and have many short branches, while colonies in protected locations are taller and have fewer slender, elongate branches (Goreau et al., 1979). In addition, back reef colonies had a higher level of branching than fore reef colonies (Tunnicliffe, 1981). Aggressive, massive coral species such as *M. annularis* can digest *A. cervicornis* tissue when in contact, however *A. cervicornis* is able to out-compete these corals by growing above them, presumably through shading (Shinn, 1972). *A. cervicornis* populations have been found to contain two distinct algal symbionts which enables the coral host to occupy two competitively different photic habitats; at shallow depths the symbiont is similar to that found in *A. palmata*, while deep water populations contain a distantly-related symbiont (Baker et al., 1997).

Reproduction: *A. cervicornis* is a hermaphroditic broadcast (mass) spawner with an annual cycle of gametogenesis and release. In Puerto Rico, Steiner (1995) observed spawning 6 days after the August 1987 full moon. Persistence of this species appears to depend heavily on successful asexual reproduction, as larval recruitment is seldom observed (Knowlton et al., 1990; Hughes et al., 1992).

Threats: The major cause of mortality to *Acropora cervicornis* populations has been white-band disease, with synergistic effects from storm damage, predation, shading and sedimentation, mechanical abrasion, overgrowth and thermal shock (Knowlton et al., 1981; Tunnicliffe, 1981; Woodley et al., 1981; Rogers, 1983; Porter et al., 1982; Aronson and Precht, 1998). Although branching morphology and rapid growth rates allow this species to survive in areas with considerable sediment deposition, chronic elevated turbidity caused bleaching and reductions in growth (Rogers, 1983). The spread of *A. cervicornis* through asexual reproduction reduces genetic variability of populations, possibly increasing their susceptibility to disease (Bak, 1983). In Jamaica, WBD was observed on colonies prior to Hurricane Allen; extensive hurricane damage, disease and increased predation by corallivorous invertebrates caused a large scale decline during the early 1980s, and populations have failed to recover after nearly 20 years (Woodley et al., 1981; Knowlton et al., 1990). In other Caribbean localities outbreaks of WBD are believed to be the prominent factor contributing to a widespread disappearance of this species (Aronson and Precht, 1997). A second form of WBD (type II) has recently emerged among *A. cervicornis* populations; affected colonies bleach in a band which advances up the branch, and is followed by progressive tissue necrosis (Richie and Smith, 1998). The advance of white-band disease can be up to 5 mm/day, exceeding the growth of regenerating branches, which is approximately 0.3 mm/day (Davis et al., 1986).

A Caribbean-wide demise of this species as a result of anthropogenic and natural disturbances appears to be a unique event that contrasts with the long-term persistence of this taxon during Pleistocene and Holocene periods (Greenstein et al., 1998; Aronson et al., 1998). *Acropora cervicornis* may be experiencing an Allee effect; this species is now rare, and colonies may now be too far apart to ensure fertilization success, preventing reduced populations from becoming reestablished by sexual recruits (Knowlton, 1992).

APPENDIX III: WORKSHOP AGENDA

April 16, 2002, TUESDAY:

8:00-8:15 Welcome, introductions, workshop overview

8:15-8:30 Opening remarks by John McManus, Director, National Center For Caribbean Coral Reef Research (NCORE)

Session I: Status reports: historical extent, extent of loss, recent rate of loss, causes of mortality, and patterns of recovery

8:30-9:30 Regional status of *Acropora palmata* and *A. cervicornis*: results of 1998-2001 Atlantic and Gulf Rapid Reef Assessment (AGRRA) surveys from 22 countries (Phil Kramer)

9:30-10:00 Threats to *Acropora* spp. in the Caribbean (Rich Aronson)

10:00-10:15 Break

10:15-11:00 Status and trends of *A. palmata* and *A. cervicornis* in the Florida Keys
A. Key Largo (Margaret Miller)
B. Recent trends throughout the Keys (Mark Chiappone and Steven Miller)
C. Historical trends 1881-2000 (Walt Jaap)

11:00-11:15 Distribution, population ecology and reproductive biology of Acropora cervicornis in Broward County, Florida (Bernardo Vargas-Angel)

11:15-12:00 Status and trends of *A. palmata* and *A. cervicornis* in Puerto Rico
A. Status of *Acropora* spp. populations in northern and eastern Puerto Rican coral reefs (Edwin Hernandez)
B. South and west coast populations (Ernesto Weil)
C. DNER monitoring and management (Michael Nemith/Miguel Canals)

12:00-1:00 Lunch

1:00- 2:00 Status and trends of *A. palmata* and *A. cervicornis* in the USVI
A. Historical status, extent of decline and projection for recovery on St. Croix reefs. (William B. Gladfelter and Elizabeth H. Gladfelter)
B. The Status of Acropora in the USVI: A wake or an awakening? (Caroline Rogers)
C. Status in the NE Caribbean (Anguilla, BVI, St. Croix) and changes since the 1970s (John Bythell)

2:00-2:20 The demise of Acropora populations in the Caribbean: a tale of two reef systems (Bill Precht)

2:20-2:40 Status of *Acropora* species on the leeward islands of the Netherlands Antilles (Mark Vermeij/Rolf Bak)

2:40-3:00 Acroporid populations in the Dominican Republic (Francisco Geraldes)

3:00-3:15 Afternoon tea break

3:15-3:30 Status of Acroporid populations off Colombia (Jaime Garzon-Ferriera/Juan M. Diaz)

Session II: Application of research data on the biology, ecology and geology of these species and available management tools to develop an effective conservation program

3:30-3:45 Mapping marine populations: patterns in *Acropora* recovery (Barry Devine)

3:45-4:00 Unprecedented" *Acropora* Die-Offs: 6,300 & 3,000 ybp (Dennis Hubbard)

4:00-4:15 Population dynamics and life-history traits of *Acropora palmata*: costs and benefits of fragmentation (Diego Lirman)

4:15-4:30 Genetic Status of *Acropora palmata* populations in the Caribbean (Iliana Baums)

4:30-4:45 Management measures for corals and coral reef ecosystems in the FKNMS: Are existing and proposed regulations sufficient? (Brian Keller)

4:45-5:10 The U.S. Endangered Species Act: Application to reef-building corals (Andy Bruckner)

5:10-5:30 Closing comments, assignments to working groups, working group tasks

7:00-9:30 **Evening reception and buffet**

8:00-10:30 Evening presentations:
- Coral Farm: the first step to restore reefs *(Antonio Ortiz and Hector Ruiz)*
- Coral Culture as a Conservation Tool for *Acropora* spp. *(Erich Mueller)*
- *Acropora palmata* and *A. cervicornis* Video Footage
  - *USVI - Zandy Hillis-Starr, Denny Hubbard*
  - *St John Acropora populations - Jeff Miller, Caroline Rogers*
  - *Bonaire/Curaçao - Mark Vermeij*

April 17, 2002, WEDNESDAY:

8:30-12:00 Working group discussions

12:00-1:00 *Lunch*

1:00-2:00 Working group presentations (15 minutes each)

2:00-5:30 Working group begin drafting recommendations

April 18, 2002, THURSDAY:

8:30-10:00 Working groups finish write-ups

10:00-10:15 *Morning coffee*

10:15-12:00 Working group presentations and discussion

12:00-1:00 *Lunch*

1:00-2:00 Final discussion and wrap-up

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APPENDIX V: Acropora Literature

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