OPINION

The Folly of Coral Restoration Programs Following Natural Disturbances in the Florida Keys National Marine Sanctuary

by William F. Precht, Richard B. Aronson, Steven L. Miller, Brian D. Keller and Billy Causey

Research should focus on human-induced losses of coral reefs and species.

Coral reefs around the world have changed dramatically over the past few decades. Many forms of stress and disturbance—separately and in combination—are changing the face of reefs, including both natural forces (hyper- and hypothermic stress, disease, and storms) and anthropogenic factors (for example, ship groundings, pollution, and overfishing). It is obvious that this resource needs protection and that many anthropogenic causes can be reduced or avoided by implementation of scientifically based management programs.

At the present rate of destruction, reef ecosystems will likely suffer continued significant degradation, possibly to the point of irreversible decline. In the Florida Keys National Marine Sanctuary (FKNMS), one possible course of action is to attempt to restore all damaged and disturbed reefs to fully functional ecosystems at a rate resulting in no net loss of ecosystem value (that is, the rate of reef destruction will be offset by rate of reef repair; Precht and others 2001). To date, most coral reef restoration programs within the FKNMS have focused on the physical damage caused by humans, although there has also been a call for intervening and restoring reefs affected by natural disturbances. It may be futile, however, to attempt such restoration projects in the latter category because natural disturbances generally occur at such a large scale that ameliorating their effects is often impossible. Here we evaluate the prospects of restoring reefs following natural disturbances given our understanding of the biology of the affected corals and the history of the Florida reef tract.

Historical Background

Before the late 1970s, two species of acroporid corals were the primary builders of coral reefs along the Florida reef tract. Acroporids have since undergone a regional decline, with losses of 95 percent or more in some areas during the past few decades (Precht and others 2002, Precht and Miller in press). The thickly branching elkhorn coral (*Acropora palmata*) was previously dominant at the shallowest depths on the reef (0-15 ft or 0-5 m depth). The more thinly branching

Ecological Restoration, Vol. 23, No. 1, 2005 ISSN 1522-4740 E-ISSN 1543-4079

staghorn coral (*A. cervicornis*) also grew at these shallow depths in more protected areas, and was dominant at intermediate depths (about 15-75 ft or 5-25 m) (Adey and Burke 1977, Geister 1977, Hubbard 1988). In the case of elkhorn coral, extremely rapid growth and asexual propagation favored the buildup of dense stands that were resistant to all but the most extreme storms. These coral forests grew above, and ultimately shaded out, most other corals (Porter 1974, Jackson 1991). The more fragile staghorn coral had similar life-history traits, enabling the species to outgrow other corals and form monospecific thickets (Tunnicliffe 1981).

There are a number of factors responsible for the recent *Acropora* decline with white-band disease, temperature stress, predation, and severe hurricanes being some of the most significant in reducing populations both locally and regionally (Aronson and Precht 2001a, 2001b). In Florida, it is well documented that *Acropora* populations are dynamic at the scale of individual reefs, and they have been extremely volatile during the past century (Mayer 1902, Shinn 1976, Enos 1977, Davis 1982, Shinn and others 1989, Jaap and Sargent 1994, Jaap 1998). The current Caribbean-wide decline of acroporids, however, appears to be unprecedented in at least the last few thousand years (Aronson and Precht 1997, Aronson and others 2002, Wapnick and others 2004) and possibly longer (Greenstein and others 1998, Pandolfi and Jackson 2001; but see Rogers and others 2002, Shinn and others 2003). The authors of many studies conclude that the recent regional demise of the acroporids may be without geological precedent, thereby implicating human interference as the cause of this change (Stokstad 2001).

The Role of Biology in Reef Management

Against this background of acroporid loss, it is relevant to ask, "What is required for coral reef recovery to occur in the Florida Keys?" And as a follow-up, "Is there a role for management in the recovery or restoration process?" Regarding the first question, we fully believe that coral recovery in all of the habitats it previously occupied in Florida is possible at the decadal scale given the previously prolific growth rates of the acroporids (Shinn 1966, 1976), and presuming the potential still exists for successful establishment of cohorts from sexual reproduction or fragmentation of branches (Precht and Miller in press). This latter expectation is not unreasonable because remnant populations of both species clearly exist throughout their geographic range, including Florida. Recent observations in the Keys show that localized acroporid thickets can develop sporadically from these remnant populations (Vargas-Ángel 2003a, 2003b).

Our present knowledge of the biology and geology of the acroporids along the Florida reef tract suggests that restoration following natural disturbances is not appropriate.

Another key question is, "What factors are likely to limit recovery or constrain restoration?" One limitation is reproductive potential. A heavy dependence on asexual propagation in the acroporids comes at the expense of larval production (Hughes 1989, Knowlton 1992). When they do reproduce sexually, elkhorn and staghorn corals are broadcast spawners, releasing their eggs into the water column for fertilization and development. Because these corals are now rare and too far apart for high fertilization success, they are experiencing an Allee effect (Knowlton 1992). Low levels of sexual recruitment by the acroporids have slowed their recovery at most Caribbean localities, including Florida (Aronson and Precht 2001a, 2001b).

In addition to the issues associated with life-history and reproductive traits, disease pathogens are still present (Precht and Aronson 1997, Santavy and others 2001, Patterson and others 2002), cold-weather fronts occur with regular frequency, global warming and bleaching events are increasing in intensity and frequency, hurricanes and severe storms that can set back reef development still occur, and predators are continuing to take their toll on remnant populations (Knowlton and others 1988, 1990; Bruckner and others 1997; Miller 2001). Moreover, all of these effects are exacerbated by each other and by other stressors (Hughes 1989, 1994; Knowlton 1992; Hughes and Connell 1999). Suitable substrate may also limit larval recruitment where algal populations remain high (Hughes and Tanner 2000).

To Restore or Not to Restore?

Because the acroporids were previously the dominant shallow-water coral species in the Keys, and because there is still uncertainty as to the role of natural and anthropogenic stressors in their demise, an argument can be made that we should continue research to obtain the knowledge and skills sufficient to attempt restoration (Kojis and Quinn 1994, 2001; Bruckner 2002; Bruckner and Hourigan 2002; Miller 2002). While acquiring basic information about the life history and ecology of these two species should remain a high priority, along with continuing monitoring programs to evaluate relative causes of mortality and the potential recovery of remnant populations, we believe that restoration is presently not a realistic management goal for *Acropora* species throughout their range in Florida.

Natural recovery may occur at some scale, but it must be recognized that substantial natural variability previously existed in the spatial and temporal distribution of *Acropora*-dominated reefs in recent and historical times (Precht and Miller in press). Specifically, in Florida, research has been performed on the effect of season and coral size on staghorn coral transplant success (Chilcoat and Fitt 2003). These experiments have shown high levels of mortality when the corals are transplanted during the summer months (G. Chilcoat and W. Fitt, pers. comm.). Furthermore, present-day processes including winter cold fronts, disease outbreaks and severe storms, continue to hinder the sustained development of acroporid-dominated reefs. Management to restore acroporids, therefore, must always be constrained by the boundaries of historical conditions and the scales of recurring natural disturbances inherent to the system (Landres and others 1999, Jameson and others 2002). Besides, it would be prohibitively expensive to repair reefs crippled by the negative synergistic effects of different types of stressors, such as severe storms, global warming, and emergent diseases (Knowlton 2001).

Many people believe, however, that it is necessary to restore coral reefs following natural disturbances because of their ecologic and economic importance. As a result, garden-type experiments have been attempted, especially after severe storms (Bruckner 2002). Under all but the most extreme conditions, however, hurricanes themselves can be favorable to the propagation and expansion of acroporid-dominated communities by promoting asexual reproduction via storm-generated fragments (Shinn 1966, 1976; Gilmore and Hall 1976; Highsmith and others 1980; Tunnicliffe 1981; Highsmith 1982; Fong and Lirman 1995; Lirman and Fong 1997; Lirman 2000). Vargas-Ángel and colleagues (2003a) investigated the costs and benefits to staghorn coral populations off the east coast of Florida and concluded that the ability of the species to recover rapidly from physical damage is a key factor in its ecological persistence. Likewise, Edwards and Clark (1999) suggested that natural recovery processes are likely to be sufficient for branching acroporids and that transplantation should be viewed only as a tool of last resort. They specifically argued that transplanting these fast-growing species ignores evidence that they survive transplantation and relocation poorly. Furthermore, geological investigation at Looe Key in the FKNMS has revealed that this reef system has been expanding in a landward direction for thousands of years, due primarily to the fragmentation, transport and reestablishment of *Acropora*-dominated communities following storms (Shinn and others 1981). In other words, attempts to recover and restore acroporid fragments generated by storms are contrary to what we know of the biology and geology of the species!

Nevertheless, such projects have been implemented under the premise that the broken branch fragments would otherwise have suffered greater mortality. One such example is an *Acropora* nursery program established by a volunteer group at Western Sambo Reef in February 1998 (Quirolo 2002). Their efforts were in response to a severe winter storm—The Ground Hog Day Storm of 1998—that injured remnant stands of elkhorn coral. Divers recovered 49 broken coral branch fragments and attached them to circular concrete pads, forming "*Acropora* rosettes." Seven months later, Hurricane Georges (pronounced Zhorzh) ravaged the middle and lower Florida Keys, including Western Sambo Reef, moving all of the rosettes from their positions. Only nine pieces of the transplanted *Acropora* survived this storm—a loss of 82 percent (J. Harold Hudson, pers. comm.). This grassroots effort to restore storm-induced coral fragments may have had some positive benefits in terms of mobilizing public support for corals and coral restoration, but the results demonstrate the ecological folly of such restoration attempts. Even worse, any short-term gains in public awareness could ultimately undermine more credible scientific approaches to management because the promised reef restoration did not succeed.

Conclusions

Understanding the complex life-history strategies employed by reef corals and the causes of their mortality is vital to developing successful management programs. Our present knowledge of the biology and geology of the acroporids along the Florida reef tract suggests that restoration following natural disturbances is not appropriate. These corals will likely exhibit positive growth if left to their own devices following natural disturbances, especially storms. However, we do recommend continued scientific research on the restoration of *Acropora* species throughout their range, including Florida. This need should be especially focused on human-induced injuries that are mechanical in nature because it is the most tractable problem.

Restoration of reef corals is an expensive proposition that requires multidisciplinary approaches, including science, management, and advocacy. We implore managers to evaluate the benefits of proposed restoration programs carefully before undertaking such costly ventures. Recognizing that the future of *Acropora*-dominated reefs in Florida remains unclear, we must focus our time and resources on managing and restoring those things we can, and understanding those we cannot.

Acknowledgments

We thank A. Bruckner, W. Goodwin, J.H. Hudson, M. Miller, E. Mueller, N. Quinn, and R. Vidra for conversations that helped us focus our ideas. This paper is the outgrowth of a presentation on Ethical Dilemmas in Ecological Restoration given at the 15th Annual Conference of the Society for Ecological Restoration International, Austin, Texas, in November 2003. This is Contribution No. 359 of the Dauphin Island Sea Lab.

References

Adey, W.H. and R.B. Burke. 1977. Holocene bioherms of Lesser Antilles: Geologic control of development. Pages 67-82 *in* S.H. Frost, M. P. Weiss and J.B. Saunders (eds.), Reefs and related carbonates: Ecology and sedimentology. Tulsa, Oklahoma: Studies in Geology No. 4, American Association of Petroleum Geologists.

Aronson, R.B., I.G. Macintyre, W.F. Precht, C.M. Wapnick and T.J.T. Murdoch. 2002. The expanding scale of species turnover events on coral reefs in Belize. *Ecological Monographs* 72:233-249.

Aronson, R.B. and W.F. Precht. 1997. Stasis, biological disturbance, and community structure of a Holocene coral reef. *Paleobiology* 23:326-346.

__. 2001a. Evolutionary paleoecology of Caribbean coral reefs. Pages 171-223 *in* W.D. Allmon and D. J. Bottjer (eds.), Evolutionary paleoecology: The ecological context of macroevolutionary change. New York: Columbia University Press.

__. 2001b. White-band disease and the changing face of Caribbean coral reefs. *Hydrobiologia* 460:25-38.

Bruckner, A.W., editor. 2002. Proceedings of the Caribbean *Acropora* workshop: Potential application of the U.S. Endangered Species Act as a conservation strategy.

NOAA Technical Memorandum NMFS-OPR-24.
Bruckner, A.W. and T.F. Hourigan. 2002. Proactive management for conservation of *Acropora cervicornis* and *Acropora palmata:* application of the U.S. Endangered Species Act. *Proceedings of the 9th International Coral Reef Symposium* 2:661-665.
Bruckner, R.J., A.W. Bruckner and E.H. Williams, Jr. 1997. Life history strategies of *Coralliophila abbreviata* Lamarck (Gastropoda: Coralliophilidae) on the southwest coast of Puerto Rico. *Proceedings of the 8th International Coral Reef Symposium* 1:627-632.
Chilcoat, G.C. and W. K.Fitt. 2003. Effect of season and coral size on the growth rate and survival of transplanted *Acropora cervicornis* in the Caribbean. Page 27 *in* the Abstracts of the 7th International Conference on Coelenterate Biology.
Davis, G.E. 1982. A century of natural change in coral distribution at the Dry Tortugas: A comparison of reef maps from 1881 and 1976. *Bulletin Marine Science* 32:608-623.
Edwards, A.J. and S. Clark. 1999. Coral transplantation: A useful management tool or misguided meddling? *Marine Pollution Bulletin* 37:474-487.
Enos, P. 1977. Holocene sediment accumulations of the south Florida shelf margin. Pages 1-130 *in* P. Enos and R. D. Perkins (eds.), Quaternary sedimentation in South Florida, Memoir 147. Boulder, CO: Geological Society of America.
Fong, P. and D. Lirman. 1995. Hurricanes cause population expansion of the branching coral *Acropora palmata* (Scleractinia): Wound healing and growth patterns of asexual recruits. *Marine Ecology* 16:317-335.
Geister, J. 1977. The influence of wave exposure on the ecological zonation of Caribbean coral reefs. *Proceedings of the 3rd International Coral Reef Symposium* 1:23-29.
Gilmore, M. D. and B.R. Hall. 1976. Life history, growth habits, and constructional roles of *Acropora cervicornis* in the patch reef environment. *Journal of Sedimentary Petrology* 40:519-522.
Greenstein, B.J., H.A. Curran and J.M. Pandolfi. 1998. Shifting ecological baselines and the demise of *Acropora cervicornis* in the Western Atlantic and Caribbean Province: A Pleistocene perspective. *Coral Reefs* 17:249-261.
Highsmith, R.C. 1982. Reproduction by fragmentation in corals. *Marine Ecology Progress Series* 7:207-226.
Highsmith, R.C., A.C. Riggs and C.M. D'Antonio. 1980. Survival of hurricane-generated coral fragments and a disturbance model of reef calcification/growth rates. *Oecologia* 46:322-329.
Hubbard, D.K. 1988. Controls of modern and fossil reef development: Common ground for biological and geological research. *Proceedings of the 6th International Coral Reef Symposium* 1:243-252.
Hughes, T.P. 1989. Community structure and diversity of coral reefs: The role of history. *Ecology* 70:275-279.
__. 1994. Catastrophes, phase shifts and large-scale degradation of a Caribbean coral reef. *Science* 265:1547-1551.
Hughes, T.P. and J.H. Connell. 1999. Multiple stressors on coral reefs: A long-term perspective. *Limnology and Oceanography* 44:932-940.
Hughes, T.P. and J.E. Tanner. 2000. Recruitment failure, life histories, and long-term decline of Caribbean corals. *Ecology* 81:2250-2263.
Jaap, W.C. 1998. Boom-bust cycles in *Acropora*. *Reef Encounter* 23:12-13.
Jaap, W.C. and F.J. Sargent. 1994. The status of the remnant population of *Acropora palmata* (Lamarck, 1816) at Dry Tortugas National Park, Florida, with a discussion of possible causes of changes since 1881. Pages 101-105 *in* R.N. Ginsburg (compiler), Proceedings of the colloquium on global aspects of coral reefs: Health, hazards and history. Miami: Rosenstiel School of Marine and Atmospheric Science, University of Miami.
Jackson, J.B.C. 1991. Adaptation and diversity of reef corals. *BioScience* 41:475-482.
Jameson, S.C., M.H. Tupper and J.M. Ridley. 2002. The three screen doors: Can marine "protected" areas be effective? *Marine Pollution Bulletin* 44:1177-1183.
Knowlton, N. 1992. Thresholds and multiple stable states in coral reef community dynamics. *American Zoologist* 32:674-682.
__. 2001. The future of coral reefs. *Proceedings of the National Academy Sciences, U.S.A.* 98:5419-5425.
Knowlton, N., J.C. Lang and B.D. Keller. 1988. Fates of staghorn coral isolates on hurricane-damaged reefs in Jamaica: The role of predators. *Proceedings of the 6th International Coral Reef Symposium* 2:83-88.
__. 1990. Case study of natural population collapse: Post-hurricane predation on Jamaican corals. *Smithsonian Contributions to the Marine Sciences* 31:1-25.
Kojis, B.L. and N.J. Quinn. 1994. Biological limits to Caribbean reef recovery: A comparison with western South Pacific reefs. Pages 353-359 *in* R.N. Ginsburg (compiler), Proceedings of the colloquium on global aspects of coral reefs: Health, hazards and history. Miami: Rosenstiel School of Marine and Atmospheric Science, University of Miami.
__. 2001. The importance of regional differences in hard coral recruitment rates for determining the need for coral restoration. *Bulletin of Marine Science* 69:967-974.
Landres, P., P. Morgan and F. Swanson. 1999. Overview of the use of natural variability in managing ecological systems. *Ecological Applications* 9:1279-1288.
Lirman, D. 2000. Fragmentation in the branching coral *Acropora palmata* (Lamarck): Growth, survivorship, and reproduction of colonies and fragments. *Journal of Experimental Marine Biology and Ecology* 251:41-57.
Lirman, D. and P. Fong. 1997. Patterns of damage to the branching coral *Acropora palmata* following Hurricane Andrew: Damage and survivorship of hurricane-generated asexual recruits. *Journal of Coastal Research* 13:67-72.
Mayer, A. 1902. The Tortugas as a station for research in biology. *Science* 17:190-192.
Miller, M.W. 2001. Corallivorus snail removal: Evaluation of impact on *Acropora palmata*. *Coral Reefs* 19:293-295.
__. (compiler). 2002. *Acropora* corals in Florida: Status, trends, conservation, and prospects for recovery. Pages 59-70 in A. Bruckner (ed.), Proceedings of the Caribbean *Acropora* workshop: Potential application of the U.S. Endangered Species Act as a conservation strategy. NOAA Technical Memorandum NMFS-OPR-24.
Pandolfi, J.M. and J.B.C. Jackson. 2001. Community structure of Pleistocene coral reefs of Curaçao, Netherlands Antilles. *Ecological Monographs* 71:49-67.
Patterson, K.L., J.W. Porter, K.B. Ritchie, S.W. Polson, E. Mueller, E.C. Peters, D.L. Santavy and G.W. Smith. 2002. The etiology of white pox, a lethal disease of the Caribbean elkhorn coral, *Acropora palmata*. *Proceedings of the National Academy Sciences, U.S.A.* 99:8725-8730.
Porter, J.W., 1974. Community structure of coral reefs on opposite sides of the Isthmus of Panama. *Science* 186:543-545.
Precht, W.F. and R.B. Aronson. 1997. White band disease in the Florida Keys–a continuing concern. *Reef Encounter* 22:14-16.
Precht, W.F., R.B. Aronson and D.W. Swanson. 2001. Improving scientific decision making in the restoration of ship-grounding sites on coral reefs. *Bulletin of Marine Science* 69:1001-1012.
Precht, W.F., A.W. Bruckner, R.B. Aronson and R.J. Bruckner. 2002. Endangered acroporid corals of the Caribbean. *Coral Reefs* 21:41-42.
Precht, W.F. and S. Miller. In press. Ecological shifts along the Florida reef tract: The past as a key to the future. *In* R.B. Aronson (ed.), Geological approaches to coral reef ecology. New York: Springer-Verlag.
Quirolo, D. 2002. The role of a nonprofit organization, Reef Relief, in protecting coral reefs. Pages 895-913 *in* J.W. Porter and K.G. Porter (eds.), The Everglades, Florida Bay, and coral reefs of the Florida Keys: An ecosystem sourcebook. Boca Raton, FL: CRC Press.
Rogers, C., W. Gladfelter, D. Hubbard, E. Gladfelter, J. Bythell, R. Dunsmore, C. Loomis, B. Devine, Z. Hillis-Starr and B. Phillips. 2002. *Acropora* in the US Virgin Islands: A wake or an awakening? Pages 95-

118 in A. Bruckner (ed.), Proceedings of the Caribbean *Acropora* workshop: Potential application of the U.S. Endangered Species Act as a conservation strategy. NOAA Technical Memorandum NMFS-OPR-24.

Santavy, D.L., E. Mueller, E.C. Peters, L. MacLaughlin, J.W. Porter, K.L. Patterson and J. Campbell. 2001. Quantitative assessment of coral diseases in the Florida Keys: Strategy and methodology. *Hydrobiologia* 460:39-52.

Shinn, E.A. 1966. Coral growth rate, an environmental indicator. *Journal of Paleontology* 40:233-240.

__. 1976. Coral reef recovery in Florida and the Persian Gulf. *Environmental Geology* 1:241-254.

Shinn, E.A., J.H. Hudson, D.M. Robbin and B.H. Lidz. 1981. Spurs and grooves revisited: Construction versus erosion, Looe Key Reef, Florida. *Proceedings of the 4th International Coral Reef Symposium* 1:475-483.

Shinn, E.A., B.H. Lidz, J.L. Kindinger, J.H. Hudson and R.B. Halley. 1989. *Reefs of Florida and the Dry Tortugas. Field trip guidebook T176*. Washington, D.C.: American Geophysical Union.

Shinn, E.A., C.D. Reich, T.D. Hickey and B.H. Lidz. 2003. Staghorn tempestites in the Florida Keys. *Coral Reefs* 22:91-97.

Stokstad, E. 2001. Humans to blame for coral loss. *Science* 293:593.

Tunnicliffe, V. 1981. Breakage and propagation of the stony coral *Acropora cervicornis*. *Proceedings of the National Academy of Sciences*, U.S.A. 78:2427-2431.

Vargas-Ángel, B., J.D. Thomas and S.M. Hoke. 2003a. Fragmentation in *Acropora cervicornis:* Survivorship, extension rates, and sexual reproduction off the coast of Fort Lauderdale, Florida, USA. Page 26 *in* Abstracts of the 7th International Conference on Coelenterate Biology.

__. 2003b. High-latitude *Acropora cervicornis* thickets off Fort Lauderdale, Florida, USA. *Coral Reefs* 22:465-474.

Wapnick, C., W.F. Precht and R.B. Aronson. 2004. Millennial-scale dynamics of staghorn coral in Discovery Bay, Jamaica. *Ecology Letters* 7:1-8.

William F. Precht is the Ecological Sciences Program Manager with the Ecological Sciences Program, PBS&J, 2001 NW 107th Avenue, Miami, FL 33172, 305/592-7275, bprecht@pbsj.com.

Richard B. Aronson is a senior marine scientist at the Dauphin Island Sea Lab, 101 Bienville Boulevard, Dauphin Island, AL 36528.

Steven L. Miller is a professor with the Center for Marine Science and NOAA's National Undersea Research Center, The University of North Carolina at Wilmington, 515 Caribbean Drive, Key Largo, FL 33037.

Brian D. Keller is the Research Coordinator with the Florida Keys National Marine Sanctuary, NOAA, P.O. Box 500368, Marathon, FL 33050.

Billy Causey is the Sanctuary Superintendent with the Florida Keys National Marine Sanctuary, NOAA, P.O. Box 500368, Marathon, FL 33050.