Hard Decisions and Hard Science: Research Needs for Coral Reef Management

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The proceedings of the International Coral Reef Symposia provide illuminating snapshots of how coral reef professionals spend their time. Of the 179 papers from the Miami meetings published in 1977, less than 5 percent explicitly focused on the role of man or management.[1] Twenty years and five symposia later, over 25 percent of the 318 papers published for the Panama meetings addressed these themes.[2] This enormous growth reflects the belated recognition that reefs worldwide are in trouble.[3] Although this crisis provides no cause for celebration, coral reef science will benefit from the attention that management issues receive—more informative remote sensing, development of coral culturing techniques, and otherwise undoable manipulative experiments (known as marine protected areas) are but a few examples that emerged from the Panama meetings.

Is reef science, then, just a parasite of management? To be sure, most of the problems reefs face come down to the problem of managing people rather than corals.[4] Nevertheless, I will argue here that many crucial pieces of information are missing, and that any politically unpopular but necessary measure is doomed without good science to support it.

Models for Reef Management: How the Simple Becomes Complex

The Intersection of Biology and Economics

In order to defend reefs economically, the marginal costs of reducing stress on reefs must be less than the marginal benefits associated with so doing. Calculating the economic costs of treating sewage, not fishing, or not building are fairly straightforward, and have been used for years to support policies that are detrimental to reefs. More recently, economic analyses of the benefits associated with maintaining or improving the health of reefs have made important strides.[5] To use such analyses, however, we must make biological as well as economic assumptions. For example, we can estimate the economic costs of improving water quality or the economic benefits of increasing coral cover, but we also need to understand the biological relationship between water quality and coral cover to determine if an increase in income from tourism will cover the costs of water treatment facilities (figure 1). While it is tempting to assume simple biological relationships, such assumptions are rarely if ever justified.

Thresholds and the Precautionary Principle

Humans preferentially think of the world in linear terms: if changing the thermostat setting by five notches changes the temperature by five degrees, we expect 10 notches to result in a 10degree change. Nevertheless, "the straw that breaks the camel's back" is also a well known phrase. The camel teaches two important lessons: the effect of any single straw cannot be

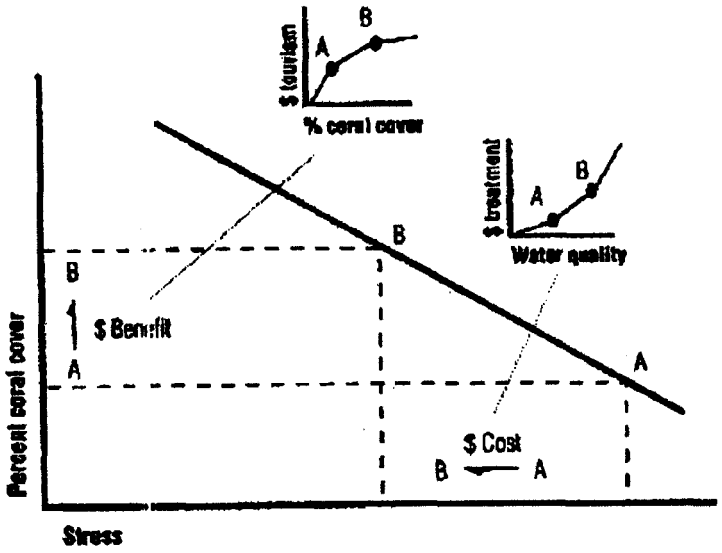

Figure 1.
Interrelationship between economic and biological analyses
Note: Gaining support for reef-friendly policies. Improving the status of reefs typically involves demonstrating that the cost of reducing stress on reefs is justified by the benefits associated with improved coral cover. For example, should a community invest in wastewater treatment in order to improve water quality, in order to to enhance coral growth, in order to increase tourism? To decide, one must know the economic cost of achieving different levels of water quality (small graph to right), the economic benefits from tourism from improving coral growth (small graph to left), as well as the biological relationship between water quality (or stress generally) and coral cover (main graph).

predicted from the effect of the previous straw, and simply removing the back-breaking straw does not solve the problem of the crippled camel.

The biological world (and for that matter the physical world, such as climate) is dominated by such nonlinear relationships and their resulting thresholds and multiple stable states (figure 2).[6] The history of reefs on the north coast of Jamaica provides a vivid example of what can go wrong when we ignore this fact. These reefs have been severely overfished for centuries, but until recently the corals themselves looked quite healthy.[7] Those of us doing our PhDs during the 1970s recognized and regretted the absence of grouper and snapper but did not worry about the future of the staghorn coral *Acorpora* or the star coral *Montastraea*. We were wrong to be complacent, for overfishing almost certainly prevented normal recovery from two natural disturbances in the 1980s: a major hurricane and the demise of a dominant sea urchin herbivore because of disease.[8] Low densities of urchins and the resulting replacement of corals by algae have persisted well beyond our initial expectations, for reasons that remain unclear.[9]

The implications of these basic realities should make managers and the public nervous for several reasons. First, removing a stress does not automatically lead to recovery, so that damage once done is often not readily undone. Second, even if one has perfect information about the present (that is, where one is on the curve of figure 2), not all stress is under human control. Synergy between natural acute disturbances and chronic human stress makes living on the precipice an extremely risky strategy. Finally, it is not easy to tell scientifically where on the curve one currently sits. We know that so called pristine reefs with their prehuman component of large predators and herbivores no longer exist,[10] but when does the relationship between overfishing plus eutrophication versus reef health reach a critical point? Simply monitoring the abundance of corals is unlikely to pro-

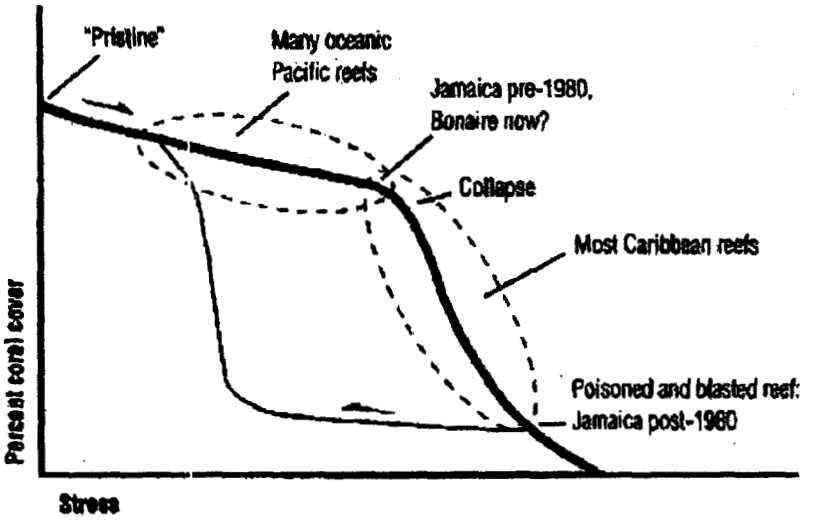

Figure 2.
Threshold effects
Note: The relationship between reef stress and coral cover is typically nonlinear. Consequently, coral cover is often a relatively insensitive measure of stress for many reefs, and a small increase in stress level can result in a large decline in reef health. Moreover, the response of reefs to increasing stress (thick "collapse"line) is not necessarily the same as the response to decreasing stress (thin "recovery" line), so subsequent recovery is often more prolonged than initial collapse.

tect us from disaster, since once the corals themselves start to collapse in numbers the game may well be over. Thus the precautionary principle[11] —stay away from the precipice—is as relevant to the management of coral reefs as it is to the design of bridges. Unfortunately, we know vastly more about the physics underlying bridge safety than about the biology underlying reef safety.

Ecological Externalities

The theory of metapopulations provides sobering albeit preliminary indications of what might be in store. Stated simply, organisms persist thanks to a patchwork of environments, to which they recruit and from which they go extinct. If you substantially reduce the number of patches, then the number of species will automatically decline. One clear prediction of these models is that species that are ecological dominants but poor recruiters will be particularly hard hit. As a consequence, the future of major Caribbean reef builders such as *Montastraea* and *Acropora* looks far from secure. Moreover, it takes time for the entire process to play itself out, so that we already owe an "extinction debt" of unknown size because of past reef destruction.

Lessons of the Ozone Hole

The Montreal Protocol provides a striking, even if imperfect, example of what can be achieved in environmental protection when parties agree. Why have we as a planet responded to the threat of ozone depletion, but failed to protect reefs (and natural resources generally)? Clearly the scale of the potential threat to health, the limited number of producers of ozone-depleting chemicals, and the relatively modest per person cost of reducing their use are a big part of the explanation. But the role of science cannot be underestimated. Models and eventually data dearly identified the nature of the threat and what was needed to mitigate it; in the absence of this information, I would argue, no action would have been

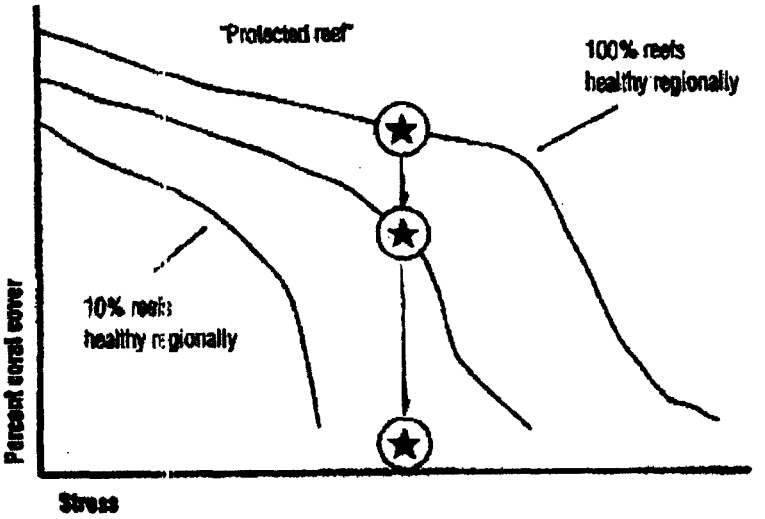

Figure 3.
The effect of ecological externalities
Note: Even excellent local protection from overfishing and eutrophication may not be enough to protect reefs if they are imbedded in regionally catastrophic reef loss.

taken. We may be reaching a similar point in climate change policy.

Marine scientists have recently argued that no-take marine reserves need to be increased from the current 0.25 percent to 20 percent of ocean surface area. They are almost certainly right, but we currently lack the numbers to support such an estimate. Without such support, costly proposals will be dismissed as the ecological equivalent of "voodoo economics," even taking the precautionary principle into account. The shrinkage of marine reserves within the Florida Keys Marine Sanctuary from the 10 percent originally proposed to the 0.5 percent eventually enacted is a clear example of this point. Doing something now is clearly much, much better than doing nothing, so this is not an argument for inaction. But we should also be wary of fooling ourselves with success stories that buy time but are ultimately doomed to failure. Hard decisions require hard science, and successful long-term management without it is an illusion.

Almost all of these points have been made before in the context of coral reef management, but they apparently bear repeating. There are currently no plans to include the role of scientific research in the inaugural International Tropical Marine Ecosystems Management Symposium (R. Kenchington, personal communication.), and a summary document for the Global Coral Reef Monitoring Network states that "we know sufficient about the biology, geology and physics of coral reefs to implement sustainable management." How can this be true, when, for example, we cannot reliably discriminate coral species, estimate the dispersal distances of their larvae, calculate the densities needed for successful spawning, or identify their important pathogens? Coral reefs will be the real losers if cross-fertilization between science and management falls victim to short-sighted rivalry between research and other needs.

Acknowledgments

Marea Hatziolos, Anthony Hooten, and Jeremy Jackson made many helpful suggestions, and the Smithsonian Institution has supported my research on coral reefs for many years.

References

1. Taylor, D. L., ed. 1977. *Proceedings: Third International Coral Reef Symposium,* Miami. Rosenstiel School of Marine and Atmospheric Science.

2. Lessios, H. A., and I. G. Macintyre.1997. *Proceedings of the Eighth International Coral Reef Symposium,* Balboa, Panama: Smithsonian Tropical Research Institute.

3. Wilkinson, C. R. 1992. "Coral Reefs Are Facing Widespread Devastation: Can We Prevent This through Sustainable Management Practices?" *Proceedings of the Seventh International Coral Reef Symposium,* 1: 11–21. Ginsburg, R. N., ed. 1994. *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards and History,* 1993. Miami: Rosenstiel School of Marine and Atmospheric Science.

4. Meffe, G., and C. R. Carroll. 1994. *Principles of Conservation Biology.* Sunderland, Mass.: Sinauer Press.

5. Cesar, Herman. 1996. "Economic Analysis of Indonesian Coral Reefs." World Bank Environmental Department Paper, Environmental Economic Series. Agricultural Operations, Country Department III, East Asia and Pacific Region and Environment Department, Washington, D.C.

6. May, R. M. 1977. "Thresholds and Breakpoints in Ecosystems with a Multiplicity of Stable States." *Nature* 269: 471-77. Knowlton, N. 1992. "Thresholds and Multiple Stable States in Coral Reef Community Dynamics. *American Zoology* 32: 674-82.

7. Jackson, J. B. C. 1997. "Reefs since Columbus." *Proceedings of the Eighth International Coral Reef Symposium* 1: 97–105.

8. Hughes, T. P . 1994. "Catastrophes, Phase Shifts, and Large-Scale Degradation of a Caribbean Coral Reef." *Science* 265: 1547-51.

9. Lessios, H. A. 1995. "Diadema antillarum 10 Years after Mass Mortality: Still Rare, Despite Help from a Competitor." *Proceedings of the Royal Society, London* B 259: 331-7.

10. Jackson, J. B. C. 1997. cited above.

11. Freestone, David, and Ellen Hey, 1995. *The Precautionary Principle and International Law : The Challenge of Implementation* (International Environmental Law and Policy Series, vol. 31.) Kluwer Law International.

12. Roberts, C. M. 1997. "Connectivity and Management of Caribbean Coral Reefs." *Science* 278: 1454-7.

13. Nee, S., and R. M. May. 1992. "Dynamics of Metapopulations: Habitat Destruction and Competitive Coexistence." *Journal of Animal Ecology* 61: 37–40.

14. Tilman, D., R. M. May, C. L. Lehman, and M. A. Nowak.1994. "Habitat Destruction and the Extinction Debt." *Nature* 371: 65-6.

15. UNEP (United Nations Environment Programme). 1996. *Handbook for the International Treaties for the Protection of the Ozone Layer: The Vienna Convention (1985), The Montreal Protocol (1987).* Nariobi, Kenya: Ozone Secretariat, United Nations Environmental Programme.

16. ____ 1996. *Handbook for the International Treaties for the Protection of the Ozone Layer: The Vienna Convention (1985)*. Cited above.

17. Maby, N., S. Hall, C. Smith, and S. Gupta. 1997. *Argument in the Greenhouse: The International Economics of Controlling Global Warming*. Global Environment Change Series. New York: Roudedge.

18. Schmidt, K. F. 1997. "'No-take' Zones Spark Fisheries Debate." *Science* 277: 489-91.

19. Ogden, J. C. 1997. "Marine Managers Look Upstream for Connections."*Science* 278: 1414-5.

20. Jackson, J. B. C. 1995. "The Role of Science in Coral Reef Conservation and Management." In *Partnership Building and Framework Development: Report of the ICRI Workshop*. Dumaguete City, Philippines.

21. Wilkinson, C., and Salvat, B. 1998. "The Global Coral Reef Monitoring Network: Reversing the Decline of the World's Reefs." In M. E. Hatziolos and others, eds., *Coral Reefs: Challenges and Opportunities for Sustainable Management*. Washington, D.C.: World Bank.