The simplest solution is not collecting geographically explicit survey data. This, however, would profoundly inhibit the analysis of land use decision-making. The alternative of collecting fine-grained linked data but not releasing it to the broader scientific community also would inhibit scientific progress. Introducing a substantial amount of random error or spatial transformations in a public data set would reduce the ability to identify specific households with certainty, but it also would diminish the scientific value of the data.

The classic solution, favoured by census agencies around the globe, is to aggregate up to geographic units that contain a sufficiently large number of households so that no single household can be identified. The drawback is that using such aggregated data to make inferences at the household level runs aground the ecological correlation fallacy. An alternative solution, now used for data sets with contextual data, is to release the linked data only after a researcher has assured that the confidentiality of respondents will be protected. One problem with this solution for fine-grain, spatially linked data is that the ease with which a researcher could find a respondent is considerably simpler than with the usual contextual variables. The alternative of inviting interested researchers to spend time at the institution that collected the data allows the original investigators some measure of insuring that confidentiality is protected, but not a failsafe assurance.

Finally, a solution that has been discussed, but to the best of my knowledge, never implemented, is to keep the data at an institution that will protect the confidentiality of respondents, allow interested researchers to have access to fine-grain, geographically explicit data on the host institution's computer system, and then have a system that screens output to insure that individual respondents cannot be identified from the totality of output generated by the outside researcher. For example, an outside researcher might create new variables based on the available data, use these variables in a statistical model, and have the results returned to the researcher. Such a solution is untested and is likely to be expensive. Considerable effort would be needed to implement and test such a system, but if available, it would serve to reduce the conflict among the three reasonable goals enunciated at the beginning of this article.

REFERENCES to this article are included in the electronic version of Update 02/02 on the IHDP website at www.ihdp.org/update0202/references.htm

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MONITORING CORAL REEFS: ECOSYSTEMS IN CRISIS

An invitation to collaboration between social and natural scientists and resource managers

BY ARTHUR L. DAHL

➤ **Coral reefs are complex, dynamic and highly productive** ecosystems of great importance to tropical coastal populations as a subsistence and commercial food source, as a tourism and recreation resource, and as a builder of coastlines and islands. Recent estimates put the total area of shallow coral reefs at 284,300 square kilometres along the coasts of 80 countries (1).

Despite their biological complexity and the difficulties of access in the coastal zone, there are now several decades of experience in monitoring coral reefs that have demonstrated both stability and change in coral reef ecosystems. The monitoring methodologies used range from complex scientific approaches (2) to simple methods practical for widespread use by non-specialists (3, 4). The results have documented increasing human impacts, extreme population variations, and the extensive decline of many coral reef areas.

Over the last five years, the rate of decline in coral reefs has reached crisis proportions. Coral reefs appear to be the first major ecosystem to show large-scale impacts from rising atmospheric carbon dioxide and global climate change. The widespread bleaching of corals during the 1998 El Nino resulted in up to 90% mortality of living corals on some reefs in all the oceans, even in such remote areas as the Maldives and Belize (5), and not all areas have shown significant recovery. Further bleaching events have been reported, including one early in 2002 on the Australian Great Barrier Reef. In response, international and non-governmental organizations have joined together in the International Coral Reef Action Network (ICRAN), a collaborative effort to reverse the decline in coral reefs through practical action in the field in the Caribbean, the East Asian Seas, Eastern Africa and the South Pacific, and hopefully later in all coral reef regions.

One element of ICRAN is monitoring and assessing the state of coral reefs, both globally through the Global Coral Reef Monitoring Network, and at the specific sites where improved protection and management are being put in place. Managers need to know if their actions are having an effect on the reefs. Local fishers and other users will be more apt to adopt and respect fisheries regulations if they see the results in larger fish stocks and better catches. The tourist industry needs to know if the beautiful reefs that attract tourists from around the world are being degraded by visitor impact. Monitoring can contribute to meeting all these needs.

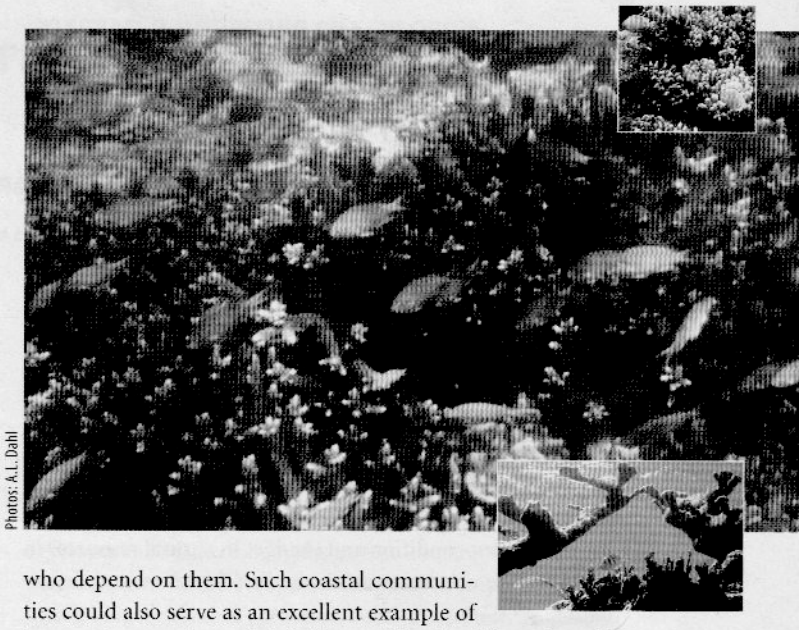
For coral reefs, a multi-level approach to monitoring is applied. The Reef Check programme has developed simple monitoring protocols that can be implemented by amateurs

like diving clubs and local fishing communities. These can provide general measures of reef status in many locations that could never be reached by scientific surveys. The Global Coral Reef Monitoring Network is implemented largely through coral reef scientists in marine laboratories, academic institutions and governments, often as an extension of their research and management activities. It does not apply a single standard protocol, although standard methods are available (2), but synthesizes the results from various monitoring programmes into periodic assessments of the Status of the Coral Reefs of the World (5). In addition, satellite remote sensing now generates regular data on oceanographic and meteorological conditions affecting coral reefs, such as the near-real-time NOAA Coral Reef Watch for hotspots associated with coral bleaching. At a fourth level, there are now plans for a GEF/World Bank led targeted research programme on coral reefs that will include some sites intensively monitored over several years to develop a better understanding of coral reef ecosystem dynamics at various temporal scales.

All of these monitoring programmes emphasize the biological and physical characteristics of coral reefs. While the ICRAN approach includes managing the socio-economic aspects of community-resource interactions (6), what is still largely lacking is comparable monitoring of the socio-economic status of the people that use, and communities that depend on, coral reef resources. Many of the impacts presently degrading coral reefs result from human actions at the local level, such as over-fishing, destructive fishing with dynamite or cyanide, urban pollution, run-off from agricultural areas, deforestation and erosion, siltation from coastal construction, changes in freshwater run-off, etc. The consequences are often disastrous for local people who rely on reefs for their subsistence or livelihood, but these human impacts are not being measured. Similarly, efforts to establish marine protected areas, to enforce fishing regulations, or to manage tourism impacts may produce improvements in local well-being. If these were better documented through socio-economic monitoring programmes, the political pressure to implement sustainable reef resource management would increase.

Other dimensions of ICRAN may also be of wider research interest. Studies have been initiated to determine the economic valuation of coral reef resources and services, but these need to be expanded to meet widespread demand. The relationship between improved natural resource management and poverty alleviation might be studied more easily in the framework of ICRAN field activities involving poor local communities. There is also potential to study the dynamics of community involvement in the management of their own environmental resources. We have anecdotal evidence of benefits, but appropriate research and monitoring programmes could provide more concrete documentation.

The ICRAN programme would therefore like to encourage researchers in the social sciences to consider establishing monitoring programmes in the coastal populations and communities adjacent to ICRAN demonstration and target sites, where it might be possible to develop correlations between resource management actions on the coral reefs and the health, economic development and welfare of people



Photos: A.L. Dahl

who depend on them. Such coastal communities could also serve as an excellent example of human impacts from global change. The bleaching of corals and their subsequent frequent mortality provides a clear local indicator of global change impacts on essential resources that can then be correlated with human consequences. The present efforts to map the risks of coral bleaching, to provide early warning of bleaching events and to monitor the consequences for local coral reef ecosystems provide an excellent starting point for work on the human dimensions of the problem.

Such research would support the approach that ICRAN and other coral reef programmes are taking to respond to the crisis in coral reefs. While there may be little that can be done in the short term to protect corals from the effects of rising carbon dioxide, global warming and climate change, much can be done to reduce other stresses on coral reefs with local causes. ICRAN is selecting reef sites that demonstrate good local reef management practices and using them as training sites for reef users and managers from other areas that need similar improved management. This would hopefully replicate these good examples of resource management at more and more sites. The emphasis is on using community-based approaches wherever appropriate. Maintaining as much as possible of the natural resilience of reef ecosystems should give these reefs a better chance to recover from and/or adapt to the unavoidable effects of global change. Otherwise the predictions of the pessimists that coral reefs may no longer exist as reef-building ecosystems in 50 years may be realised. A strong monitoring programme that documents trends in both reef health and human well-being can help to build support for the action necessary to save coral reefs.

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