Priorities for Caribbean Coral Reef Research

Scientific Needs for Integrated Coastal Management and Fisheries

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In the early nineties scientists and managers came to a general consensus that the three major stressors on Caribbean reefs were siltation, overfishing and nutrient enrichment (Ginsburg 1994). As the sources of these stresses often originate from land-based activities, reef protection requires a fully integrated coastal management approach (Gibson *et al.* 1998; Salm *et al.* 2001), often requiring international co-operation. In recent years threats associated with global climate change, such as coral bleaching, have greatly impacted many reefs and added to the complexity of management

Although the management approaches required to protect coral reefs mainly pertain to the management of people (Olsen 1997; Hatcher 1999), the decisions made must be based on good science. The interconnectedness of the components of the system is paramount, as was clearly demonstrated in the work carried out on the north coast of Jamaica in which overfishing indirectly resulted in the inability of corals to recover after a natural disturbance (Hughes, T.P. 1994; Knowlton 1998). In view of this ecological complexity, it is even more imperative that science is applied to management, and where knowledge is lacking that the precautionary principle be applied (Knowlton 1998). However, in developing countries where the pressure for economic growth and development is high, there is an urgent need for assistance in making the 'best' decisions in absence of full quantitative data, and in an effort to best fulfill multiple objectives (Fernandes *et al.* 1999).

Scientific needs to inform integrated management of coral reefs include improved understanding of how the ecosystem functions, how it responds to natural and anthropogenic changes, and also the effects of management strategies implemented (McField 2001). Evaluating effectiveness of management requires the selection of indicators that relate to specific management objectives (Olsen 1997). The identification and formalizing of such an evaluation process would be helpful to managers. As Hatcher (1999) noted, monitoring, multiple use zoning as used in many marine protected areas, and decision support systems should underpin most reef management programmes. These require analysis of the social, economic and institutional issues in relation to a reef (Olsen 1997), and thus need to be site specific. Thus, broad concepts developed from studies at specific sites cannot always be successfully applied to reefs having very different environmental settings and histories (McField 2001), or to areas with different cultural and socio-economic backgrounds (Olsen 1997; Hatcher 1999). Some priority needs that would be useful to coastal managers are hereby suggested.

Marine protected areas (MPAs) are generally recognized as being at the centre of integrated coastal management (ICM) efforts, but there are many unanswered questions about their optimum size, location and general effectiveness. In terms of size, although some recommendations have been made (e.g. Bohnsack 1990), the accurate percentage cover of 'no take' area required for a particular reef is still largely unknown. The factors involved depend to some extent on the organisms being targeted for protection. For example, Acosta and Robertson (2000) have recommended changes to the boundaries of a MPA in Belize based on the movement of spiny lobster. In addition, more research is needed to demonstrate clearly the role of MPAs in fisheries management, for example their potential to export fish, maintain levels of spawning biomass, and their ability to protect spawning aggregations included within their boundaries. The theoretical benefits of increased herbivory in MPAs contributing to reduced macroalgal cover have recently been tested in Belize through several different experimental or analytical approaches (McClanahan *et al.* 2001; McField 2001; Williams & Polunin 2001) although the combined results have not been conclusive. MPA networks should include areas of 'downstream reefs,' but to ensure this connectivity between MPAs many more studies are required on current patterns, dispersal paths, larval durations and

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settlement requirements, and also on initiating MPAs across borders (Russ 1996; Roberts 1997). Research has been proposed to identify coral reef areas that show resilience to bleaching events, and these critical areas can then be included within MPAs. In general, a great deal more work is required to determine with confidence, the most effective MPA network for a particular reef system, bearing in mind that MPAs are often costly to run successfully. The interactions between nutrients, algal dominance on reefs, herbivory, and coral cover are very complex (McCook 1999; Aronson & Precht 2000; Williams & Polunin 2001). Many Caribbean reefs are experiencing a phase shift from coral cover to algal cover (Hughes 1994; McClanahan & Muthiga 1998; McClanahan *et al* 1999). Although studies have shown that overfishing of herbivorous fishes is not the only factor causing an abundance of macroalgae (Williams & Polunin 2001), it would be useful to investigate whether re-introducing and protecting herbivores (e.g. parrot fish, *Diadema*) on such reefs would be successful.

The effect of fishing on reefs is very complex and more studies are required, for example, to develop the ability to predict its role in causing shifts in the ecosystem (Jennings and Polunin 1996). Different fisheries management strategies could be tested, such as the harvesting of mainly pelagic species which rely on external sources of food, or fishing at all trophic levels thus using a broader resource base. MPAs could provide the sites for such studies to be carried out. Refined modeling techniques could assist in determining fish yields under different strategies, using more appropriate catch and effort data that also includes information on invertebrates and plants (Jennings & Polunin 1996). More needs to be known about reef algae (reproduction, dispersal and recruitment), coral–algal interactions, bioindicators of reef nutrient status and the advantages of using stable isotope analysis of coral tissue (Risk & Risk 1997; McCook 1999).

A better understanding is required of the impacts of chronic stresses, such as sedimentation and nutrification, which may be low under stable conditions, but which may adversely affect coral recovery in times of major disturbances such as bleaching and hurricanes. This type of evidence would be useful to managers in gaining the necessary support for the need to reduce human impacts. The results of monitoring can be used in public awareness and education programs to generate the necessary community support (Hatcher 1999). Nevertheless, these impacts are the chronic, gradual ones which are often difficult to demonstrate cause-and-effect to decision makers. Recent work, however, is attempting to develop a multivariate approach to address this need (McField 2001). In contrast, the more dramatic impacts of storms and bleaching, such as the 48% decline in coral cover experienced in Belize (McField in press) are clearly noticeable in the short term, and can frustrate local efforts because they occur outside the control and limit of national management responsibility.

Many of the human impacts result from land-based activities, and much more research still needs to carried out in basic areas, such as determining the potential of mangroves to absorb nutrients from effluent discharge from sewage ponds and aquaculture farms, developing low-tech water reuse systems for shrimp farms, identifying the main causes of increased sediment yield at the scale of individual farms, assessing the effect of farming practices on nutrient loading in the coastal zone, and determining the influence of river run-off on reefs (Done 1995; Nunny *et al.* 2001). From these studies, improved land management practices can be recommended.

Determining the most relevant scale of potential impacts on reefs is a particularly complicated task for scientists, but critical for managers needing to know whether concern over nutrient enrichment should be focused on localized septic runoff, regional fluvial/agricultural discharges, or global dust storms.

Dive tourism is a major activity on many reefs in the Caribbean. However, determining carrying capacity is a prerequisite for limiting dives per site, and this is often difficult to assess. Although some work has been carried out (Hawkins & Roberts 1997; Jameson *et al.* 1999, Hawkins *et al.* 1999) more assistance from scientists is required in determining optimum sites for installing mooring buoys, the size of groups of divers per site, the effectiveness of rotating sites as a management measure, and the type of monitoring required. In Belize a mooring buoy impact project is currently underway at Lighthouse Reef and another study is planned for Hol Chan marine reserve, our most heavily visited site.

Simple methods for valuing reefs are required and may depend on use of a reef for tourism, fisheries productivity, and biodiversity. The criteria for determining the value need to be worked out so that managers can assess the consequences of loss of a reef put at risk by a development, or damaged as a result of ship groundings, etc. Such a 'value' can be used as a basis for the design of environmentally friendly development and land use practices (Done 1995). Fernandes *et al.* (1999) have used a multiple criteria analysis framework that assesses the multiple objectives of management—economic, social, and ecological—many of which may be conflicting. This integrated systematic assessment seems to be worthy of more research as it incorporates both quantitative and qualitative data and includes provision for community participation. The technique has some flaws, but further work could possibly make it more robust and usable by managers. One such evaluation was recently initiated at Lighthouse Reef in Belize with researchers from the University of Stockholm. Socio-economic analyses are critical to placing conservation measures into an economic context, understandable to developers and the general public.

Assessment and monitoring are basic elements of ICM, laying the scientific foundation for sustainable reef management (Wells *et al.* 1996). Surveys and assessment provide information on the extent and status of the system to be managed, identifying areas of high biodiversity. It is essential to have baseline data on the status of the system to be managed, and to measure or monitor changes over time in response to various impacts and management interventions. Monitoring should focus on the most likely sources of stress and thus lead to the most appropriate mitigation programmes (Risk 1999). More research is required to determine simple, cost-effective, and community-based methods, preferably developed for monitoring special indicator species (Risk & Risk 1997). Several potential indicator species (e.g. sponges, stomatopods) have been identified, but few have been rigorously tested (Turner 1995). More focus should be placed on monitoring techniques for determining recruitment rates and factors affecting recruitment, thus helping to accurately predict the recovery time of degraded reefs. However, much time and energy can be wasted on lengthy discussions/disagreements over monitoring methods, which could be better spent in collecting the information. More work is also needed on determining factors affecting spawning of corals and dispersal of larvae. Once again, this will require more research on currents of the region, particularly on local near-shore currents (Roberts 1997). Such studies could help identify those reef areas that are dependent on local management measures to maintain fisheries and biodiversity, in contrast to those that have an 'upstream' or external larval supply (Roberts 1997). A wide range of research needs could be pursued that are interdisciplinary, integrating the efforts of natural and social scientists, and which could result in support from decision makers for adaptive management for the protection of the region's coral reefs. Managers must also work within the local cultural and political climate to implement their management decisions, which may prove difficult for reasons beyond the realm of science.

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