CONSERVATION AND SUSTAINABLE USE OF THE MESOAMERICAN BARRIER REEF SYSTEM (MBRS) IN MÉXICO, BELIZE, GUATEMALA AND HONDURAS

Recommendations for a Synoptic Monitoring Program in the Mesoamerican Barrier Reef Region.

Second Regional Report on Coral Reef Ecology to MBRS/SAM PCU

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Executive Summary

1.1 Existing protocols

This 2nd Report on Coral Reef Ecology reviews the requirements for a region-wide Synoptic Monitoring Program (SMP), considers the methods used in the various monitoring protocols in use in the region, and provides suggestions for the structure of the SMP. We point out early that there is no one correct way to monitor coral reef ecosystems, but that there are incorrect, or rather, ineffective ways of monitoring. Crucial to deciding the methodology to be used, is to be clear on the purposes for which the SMP is being established. In our review of the protocols in use in the region, we emphasize their methodological similarities and differences. We include the recently developed CONANP protocol in this comparison. Although the copy we had access to remains an incomplete methodological description, it appears to be overly ambitious for routine application at a number of locations. Other protocols are inadequate because the methods used are too crude, or the levels of replication insufficient. Others are too demanding on monitoring staff, and the practice differs considerably from the methodology as set down. Nevertheless, each contains good suggestions, and it seems pointless to start the process of building a monitoring protocol from scratch.

1.2 Need to continue a broadly participatory approach to develop the SMP

Development of the SMP, until now, has been by means of a broadly participatory process. We believe it is fundamental that this process be continued, and strengthened if that is possible. To be a sustained, successful monitoring program, providing a database of real value to management decisions, the SMP must be implemented and managed by a region-wide team of individuals who know what the SMP is for, and who have a stake in its success. In turn, they must be supported in this by their supervisors and the administrative structures through which they report. An SMP that fails this crucial test is not worth developing, because it will fade and die as have so many monitoring programs in the past.

RECOMMENDATION 1
We propose that the participatory, inclusive procedure followed until now continue with one or more targeted workshops, including key user individuals, to finalize the design of the SMP. These workshops will specify the purpose(s) of the SMP, confirm the methodologies to be used, establish mechanisms for review, revision, and growth of the SMP, and mechanisms to ensure data get to the regional EIS, and are available to be used. They will simultaneously have an educative role, ensuring that participants in the SMP have the needed understanding and commitment to it.

1.3 Selection of monitoring locations, and sites

We consider the need to select a representative set of locations in which to implement the SMP. Some 23 locations have already been provisionally identified as monitoring sites. This set contains a number of inadequacies, and will have to be expanded if the SMP is to produce data representative of the region. We provide some suggestions for additional locations, but stress that the decisions to be made must be made by those who will implement the SMP.

RECOMMENDATION 2
The set of 23 monitoring locations identified to date must be expanded if the SMP is to yield a database of value for decision support, or for assessment of regional ecosystem 'health'.

RECOMMENDATION 3
We recommend serious consideration of the following locations as possible additions to the set included in the SMP:

Location	Features	Personnel available (?)
Isla Contoy, Mexico	protected area, northern limit of MBRS region	MPA staff
Puerto Morelos, Mexico	CARICOMP site, protected status pending	UNAM
Akumal, Mexico	fringing reef, not protected	CEA staff (local NGO)
Cozumel, Mexico	protected area	MPA staff
Mahahual, Mexico	fringing reef, not protected	MPA staff, Chinchorro
Turneffe Islands, Belize	CARICOMP site, not protected	UB IMS staff, Calabash
Lighthouse Reef, Belize	some protected areas	Belize Audobon NGO
Carrie Bow Cay, Belize	CARICOMP site, not protected	Smithsonian staff
Dangriga, Belize	CPACC site, unprotected, coastal	Belize Fisheries?
Cayos Cochinos, Honduras	CARICOMP site, protected	HCRF staff (local NGO)

In addition, at least two locations on Roatan (at least one not protected), and two additional unprotected locations in the central portion of the Belize Barrier Reef should be selected, using information on availability of personnel and logistics to facilitate monitoring.

At each monitoring location, there are likely to be sites representing various habitats. The design of the SMP will need to define the habitats to be monitored, in order for there to be consistency across the region. We suggest five distinct habitats that could be included, however additional ones, or a completely different set could be chosen depending on the need for data. We also propose a simple terminology: monitoring Locations throughout the region, within which there are monitoring Sites. We stipulate that each Site must fall within a single monitoring Habitat, and we recommend that there should be at least two Sites representing each Habitat sampled at a Location. Not all Habitats will occur in all Locations. We also suggest that while it may be desirable to select Sites in at least a quasi-random manner from within the available habitat space, we recognize that other monitoring programs already exist in the region, and there will be an advantage in co-locating Sites. (It follows that every effort should be made to integrate the SMP with existing environmental monitoring programs, including storing a copy of the monitoring data from other programs in the regional database that the SMP will generate.)

RECOMMENDATION 4
The ecological component of the SMP will recognize five Habitats: 1) mangrove forest, 2) seagrass bed, and three coral reef habitats: 3) shallow, back-reef (leeward) habitats in 1-5m depth, 4) shallow fore-reef (windward) habitats in 1-5m depth, and 5) deep fore-reef habitats in 8-15m depth. Each monitoring Site will include a single Habitat.

RECOMMENDATION 5
Each Location will include one or more Habitats. In each Habitat to be monitored at that Location, *at least* 2 replicate Sites will be chosen. Selection procedures will follow Woodley (1999), but exceptions can be made for Sites that are of specific management interest, or already used in other monitoring programs.

1.4 Consistency, frequency, replication of measurements

Important aspects of sampling design are sometimes ignored in the implementation of monitoring programs, with the result that the data have diminished value. These are considered in Recommendations 6-10. We outline the importance of methodological consistency throughout the region, and through time, while recognizing that a long-term monitoring program will be ineffective if it does not have the flexibility to adapt new, improved methods, or add new criteria to be monitored. What is essential is an on-going management structure for the SMP that will ensure reasonable consistency, while permitting the development, validation and cross-calibration that must occur if new methods are to be introduced. Given that the SMP will be implemented in a region that includes several on-going programs, there may be valid reasons for some regional variation in methods. We discuss examples of legitimate need for variation in methods.

We also discuss the need for a region-wide, consistent monitoring schedule, and recommend a single, annual monitoring of every Site within a short period of time. We advocate that provision exist for additional, supplementary monitoring when unexpected but significant disturbances occur, or at Sites of particular management interest.

The questions of replication, and sample placement are dealt with next. We stress that there are important statistical consequences of taking certain decisions, and that there are costs and benefits associated with all decisions on replication and sample placement. We make recommendations to provide guidance. There is no one set of 'correct' decisions to be made, and the important thing is that these decisions must be made explicitly, and implemented across the full region.

RECOMMENDATION 6
At each Location, methods used, as well as measurements made, must be reported, and included in the database. Where alternate methods that measure a particular attribute (such as coral percentage cover) are being used among Locations, they must have been rigorously cross-correlated, so that the measurements made are equivalent.

RECOMMENDATION 7
The Synoptic Monitoring Program will consist of a single, annual, sampling at every Site in the region, at a time of year agreed among the participants as most amenable to field activities. Sampling at all Sites should be constrained to a short time (1-2 months maximum), and should occur during the same time interval in each successive year. Certain easily accessible Sites (Category 1) may be monitored more frequently for certain attributes.

RECOMMENDATION 8
From time to time, unpredictable events (hurricanes, major bleaching episodes, oil spills) will occur in the region. An effort should be made to document the impact of such events by making extra monitoring visits to Sites, perhaps using a reduced protocol. Some Locations believed not to have been impacted should be included. It will be important to coordinate among Locations to ensure that the same protocol components are being used at each.

RECOMMENDATION 9
All measurements made within Sites must be replicated. The level of replication can differ among measurements, but should be uniform across Sites and years for each measurement. The level of replication must be decided in a cost-benefit process, using existing data and past experience to decide the level of replication that can be afforded, and that will yield data with adequate precision.

RECOMMENDATION 10
Where replicate data are collected using the placement of quadrats or transects within a Site, placement should be haphazard on each sampling occasion, and permanent fixed quadrats or transects should be avoided.

1.5 Methods for use at coral reef Sites

Our next 8 Recommendations concern the monitoring to be done at coral reef Sites. Ecological monitoring of coral reefs is substantially more advanced than is that of seagrass r mangrove habitats. Nevertheless, the methods used are not well developed, and in many instances practice does not follow written methodology faithfully. A database is only as good as the data entered, and the SMP will only be of value for management if the data have been collected using clearly defined methods, rigorously applied. Our first recommendation (# 11) is for a 'Visit Record' made at each Site that records a number of essential pieces of information, including who did the monitoring on that day. We consider in turn the monitoring of corals and other sessile organisms, mobile invertebrates, and fish. We note the near total lack of attention to measurements of production (as recruitment), rather than standing stock. The dynamics of a system (its health?) cannot be assessed by measuring abundances of component species, or their percentage cover over the substratum. We recommend serious efforts to implement monitoring of coral and fish recruitment in the SMP. We also comment on the advantages and disadvantages of use of video transect techniques, and recommend ways to cross-correlate data derived from simpler point-intercept techniques with video data. We do not recommend routine application of video techniques for several reasons, not least being that preoccupation with the equipment may lessen attention to important aspects of conditions at the Site while in the field.

While issues of water quality are widely recognized as important throughout the region, there is very little attention to this in any of the existing monitoring protocols with the exception of CARICOMP. We discuss the problems inherent in monitoring water quality, given that trace contaminants have their negative effects on biota as a cumulative effect over time. Concentrations in the water column on the day the Site is visited may show nothing to be amiss, and very sophisticated procedures are needed for measuring the trace levels that can be deleterious. There are no easy answers here, but we suggest two simple proxies for aspects of water quality that would, in our opinion, be of much greater value than annual analysis of water samples. We return to this issue in Recommendations 22 and 23.

RECOMMENDATION 11
At each visit to a Site, details should be recorded defining date and time of visit, personnel, weather conditions, and any unusual observations. The weather data may be as simple as a one-word description, but air temperature, sea state and wind should be noted, and it may be worthwhile to record water temperature, salinity, and turbidity. In addition, this Visit Record should record what monitoring methods were used, and how many replicates of each method were completed.

RECOMMENDATION 12
A transect method should be adopted to measure percentage cover of corals, at the genus level initially. In addition to percentage cover, coral attributes such as size distribution, mortality index, and frequency of coral diseases should be measured, using the same transects to define the population examined. The AGRRA protocol for corals may be the appropriate set of procedures to adopt, although serious consideration could be given to replacing its line-intercept technique for quantifying percentage cover with a point-intercept approach.

RECOMMENDATION 13
A controlled field experiment should be done to establish whether video records can provide data beyond percentage cover of corals, or whether it is feasible to gather these additional data using AGRRA methods at the same time that video transects are being swam.

RECOMMENDATION 14
The opportunity to extend coral monitoring to include monitoring of coral recruitment in the MBRS region should be taken up. This monitoring may best be done at a subset of sites, chosen because they are under sufficient surveillance that settlement plates will be likely to remain undisturbed between monitoring trips. Training in recognition of juvenile corals would be needed, and if this is included as a component of the SMP, it may best be initiated with the assistance of experts from the academic community who would play a leadership role at least through the first two years of data collection.

RECOMMENDATION 15
A region-wide, uniform, list of targeted fish species, and other mobile invertebrates should be identified, and monitoring procedures appropriate to determining abundances of these should be agreed to. A smaller list, and a greater level of replication of transects will improve the reliability of data. The procedures adopted by AGRRA provide a good guide for effective monitoring of fish abundances.

RECOMMENDATION 16
A small set of suitable species (conspicuous as new recruits, and settling at the time of year monitoring will occur) of reef fishes should be selected, and monitored to determine recruitment rates. This set should be monitored in a standard way, using 1m wide transects at all coral reef Sites in the region.

RECOMMENDATION 17
At selected (Category 1) Sites, tube traps should be deployed permanently, and sampled monthly to provide a record of sedimentation, and of rates of delivery of planktonic food and propagules. The sediments collected can be partitioned into terriginous and reef-derived, providing information on the extent of impact from the coast. At all coral reef Sites, horizontal Secchi disk readings should be taken on each visit, following CARICOMP procedures, as an index of degree of turbidity.

RECOMMENDATION 18
At all coral reef Sites, the extent of algal growth will be quantified by a suitable method, as an indirect measurement of the level of nutrification. Possible methods include a) growth over 2 weeks on clean glazed tiles deployed on the substratum and protected from grazing, and b) quantification of turf algal abundance using the procedures of the AGRRA protocol.

1.6 Monitoring of seagrass and mangrove Sites

Because monitoring of seagrass and mangrove habitats is far less developed than that of coral reefs, we recommend that monitoring initially be patterned on the CARICOMP protocol. This is the only one being used in the region that makes a substantive effort to monitor these habitats. We suggest, however, that the CARICOMP procedures need to be bolstered by a coordinated effort to collect remotely sensed data that will allow determination of extent of these habitats, and density of plants within them. This remotely sensed data should be collected on a regular schedule, perhaps every 3 years. Again, there should be provision in the SMP to provide additional remote monitoring following major disturbances such as hurricanes. Finally, we suggest a deliberate structural arrangement that will create a 'Seagrass Working Group' and a 'Mangrove Working Group' within the SMP, charged with the development of new and improved monitoring methods in these important habitats.

RECOMMENDATION 19
At all mangrove and seagrass Sites, the components of the CARICOMP protocol that measure standing biomass, age/size structure, and production of the component plant species should be applied.

RECOMMENDATION 20
Remotely sensed data must be obtained at the start of the SMP that will permit determination of the spatial extent and density of plants at all seagrass and mangrove Sites. This remote sampling should be repeated on a schedule of at least once every 3 years, and provision should exist for quick re-survey following major disturbances such as hurricanes. Whether this remote sampling is by aerial reconnaissance, or by satellite should be decided on a cost-benefit basis, as should the decision whether this survey is exclusively to provide data on mangrove and seagrass Sites, or a part of a region-wide program of up-dating of habitat distributions.

RECOMMENDATION 21
As part of the on-going communication among monitoring teams that will be essential to the success of the SMP, it may be useful to identify those Locations in which mangroves or seagrass beds are particularly abundant, and to form a sub-committee charged to explore ways to enhance the effectiveness of monitoring of these systems.

1.7 Research collaborations

Our final two Recommendations recognize the need for development and testing of methods during the life of the SMP. We recognize an immediate need to improve our capacity to track water quality within the region, and advocate the use of biomonitoring proxies for this. We strongly recommend the provision of funds for a small grants program to support research on this topic within the academic and research community of the region. We also recommend establishment of mechanisms to provide for a long-term collaboration between the implementers of the SMP and the academic and research community, as a way to ensure the SMP will be able to adapt and grow as demands on it change in future years.

RECOMMENDATION 22
Coinciding with the commencement of the SMP, MBRS/SAM funds should be provided in a competitive, small grant program to support members of the regional academic community to investigate potential biomonitoring methods that will provide proxies for aspects of water quality such as pesticide residues, heavy metals, nutrients, and so on, that will use species native to and readily available in the region, and that could be deployed as part of the SMP.

RECOMMENDATION 23
The SMP should be structured in a way that will promote collaboration between monitoring teams and members of the academic community. This collaboration will facilitate the development, testing, and cross-calibration of methodologies that will be essential if the SMP is to endure.

The Report concludes with a list of references cited, and with appendices on equipment needs for the SMP, and detailing the methodology used by each monitoring protocol we discuss.

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2 Introduction

This report makes recommendations for the implementation of the planned Synoptic Monitoring Program of the MBRS/SAM project. The Synoptic Monitoring Program will generate a region-wide database of information concerning the condition of the environments of the Mesoamerican Barrier Reef System and associated ecological systems in the coastal waters of Mexico, Belize, Guatemala and Honduras. The data generated will be housed in a geo-referenced database that will be a central part of the Regional Environmental Information System also being developed under the MBRS/SAM project. While we anticipate that this geo-referenced database will include a broad range of physical, ecological, climatic, socio-economic and other types of data, this report concerns recommendations for the ecological monitoring to be done within the Synoptic Monitoring Program (SMP). Other consultants are making recommendations concerning the monitoring of pollution, and the collection of socio-economic data.

Coral reef associated ecosystems in the region include mangroves, seagrass beds, coastal lagoons, estuaries and other coastal wetlands that may have an impact on the health of the reefs. This report will consider the collection of information on structure and community dynamics, importance of the areas as sources or sinks for recruitment of corals, fish and other important community components, relationships among ecosystems and factors that influence ecosystem dynamics and help determine their state. The objective of this report is to facilitate the design of the ecological component of a Synoptic Monitoring Program, which, once implemented, will provide decision makers with a clearer understanding of the status of the MBRS and the trends in its condition over time. Our goal is to make recommendations that will help define the priorities for monitoring the various ecosystems, i.e.: coral reef, mangrove, seagrass beds and other related wetlands in the MBRS region.

3 Criteria for Design of the Synoptic Monitoring Program

3.1 Purpose of the Synoptic Monitoring Program

The SMP is to be one of the cornerstones of the MBRS project. It will be a region-wide coordinated, long-term program of environmental monitoring, and should result in a database of considerable value that will be maintained and augmented by continued monitoring long after the completion of the MBRS project. There are three possible functions for the SMP, all of which could be important in the MBRS region. These are:

- To produce an environmental database that will be used to inform and support management decisions throughout the region. This would aid local managers, and national management agencies, while fostering a regional perspective on environmental management.

- To produce an environmental database providing a region-wide measure of the 'health' of the coastal marine ecosystems, particularly coral reefs, seagrass beds and mangrove forests. This would focus attention of managers on the need for a regional perspective, and would inform the four nations concerning their success in sustaining these critically valuable, interrelated, and shared environmental resources.

- To provide individuals and groups an opportunity for monitoring activities, and/or access to monitoring data, both of which will result in raised awareness of environmental issues in the coastal marine environments of the region.

3.2 Requirements for the Design

These three possible functions impose specific requirements on the design of the SMP. The first requires data that are reliable, precise, and adequately replicated in space and time. These data must be collected at geographic locations that are relevant to management decisions: locations under active management, locations 'upstream' where events or processes are likely to occur that will affect management decisions elsewhere, and control locations that are neither actively managed nor likely to be negatively impacting downstream sites. All three kinds of locations must be included in the monitoring program for it to be effective.

The second function requires data that are reliable, precise, and adequately replicated in space and time. These data must be collected at habitats and locations that are representative of the entire MBRS region. This requires sites to be well distributed with respect to ecosystem (reef, seagrass, mangrove, estuary), to geographic location, and to level of management, including sites with no active management and actively managed sites.

The third function only requires data that are easily collected, even by volunteer groups, and at a large number of locations, however the data do not need a high level of reliability or precision. Methods should be inexpensive and easy to learn. Sites should be representative of the habitats in the region but may be biased in terms of accessibility or habitat (i.e. a focus on reefs).

3.3 Flexibility and Inclusiveness

The design of the SMP will benefit if two additional general factors are considered. First, it is not necessary or appropriate that a single monitoring procedure be applied in a monolithic way at all monitoring sites. In noting this possibility of flexibility, however, we must remember that it is essential that the methods used to collect specific data at particular sites be known, and, so far as possible, be kept consistent over the long term. Nevertheless, some flexibility is possible, even to the extent that simple monitoring activities established primarily to serve function 3) could serve as an 'early warning' system, used to mobilize more intensive, technically demanding and expensive monitoring at 'trouble spots'.

Second, the design of the SMP should actively seek to include existing monitoring activity throughout the region, by co-locating at existing CARICOMP, CPACC, and other established monitoring sites, and by encouraging mirrored inclusion on the regional EIS of the data gathered at those sites for those other monitoring programs. As PCU personnel have indicated, the value of the environmental database will be diminished if the SMP is established without taking advantage of existing monitoring programs, and the acceptance of the SMP could be compromised if it does not embrace on-going monitoring activities. **In general, in coral reef regions worldwide, there has been very substantial waste of resources and effort in establishing monitoring programs that run for 2-3 years and then die when interest declines, funding dries up, or novel monitoring approaches and new initiatives capture attention.** While we refuse to predict the deaths of currently existing programs, it wastes valuable existing data if each new program is established as if no pre-existing data or programs exist.

3.4 The need for Consensus and Commitment to the SMP

As noted in our First Report, we are concerned that the implementation of the SMP be successful, and that the program will be sustained and useful over the long term. Despite the occurrence of numerous monitoring programs in this region in the past, and the wide experience with monitoring exercises of many individuals in the management community, there is a substantial need to improve capacity to a) design and implement, and b) comprehend the value of an effective monitoring program. Existing deficiencies are:

- a failure of most individuals who monitor to think regionally instead of locally,
- their lack of understanding of the principles of environmental sampling, or of the need for sampling procedures that are either kept constant, or are carefully and rigorously cross-correlated, over both space and time, and
- a failure of most agencies and governments that support monitoring programs to value the process, or the product, sufficiently to ensure it is sustained and the data used and disseminated.

The success of the SMP depends on four things: a clear and agreed purpose for the SMP, adequate coverage of the MBRS region, adequate monitoring methods, and enthusiastic endorsement/adoption by the user community. To achieve this endorsement, the development of the SMP must continue to be by means of the open participatory process that the PCU has initiated, while ensuring that adequate methodology and site distribution are implemented.

RECOMMENDATION 1
We propose that the participatory, inclusive procedure followed until now continue with one or more targeted workshops, including key user individuals, to finalize the design of the SMP. These workshops will specify the purpose(s) of the SMP, confirm the methodologies to be used, establish mechanisms for review, revision, and growth of the SMP, and mechanisms to ensure data get to the regional EIS, and are available to be used. They will simultaneously have an educative role, ensuring that participants in the SMP have the needed understanding and commitment to it.

4 Monitoring Methodology

4.1 Comparison of existing protocols

Rogers et al. (1994) provide a broad overview of the objectives, design, and methodology of coral reef monitoring programs. This report focuses on specific programs and the specific needs of the MBRS region, and we recommend their more general manual as a complimentary reference. A number of monitoring protocols have been developed for use in coral reef environments, while much less attention has been paid to monitoring condition of seagrass or mangrove environments. The first, extensive and sustained coral reef monitoring program (the AIMS Great Barrier Reef program) was initiated to quantify abundances of *Acanthaster planci* (Crown-of-thorns starfish), and extent of coral damage due to outbreaks of this predator. These objectives helped define the measurements to be made, and the procedures used to make them. A monitoring program devised without clear objectives will lack focus, and the data obtained will not be valued, even by the individuals who collected them. Objectives, however, are not universal, and specific objectives will demand particular measurements, and thus, a particular protocol.

One effective approach to developing the SMP would be to define specific objectives, and use these to determine which items need to be measured. Then procedures could be developed that would be used to obtain those measurements. This approach would build a protocol for the SMP that was clearly driven by the program objectives.

We recommend that the objectives of the SMP must define what needs to be measured, however it seems unwise to develop a suite of totally new methods specifically for the SMP. We prefer an alternative approach that recognizes that several protocols already exist, and that many individuals in the region have experience with one or more of them. A judicious selection from existing methods will build a protocol satisfying the objectives of the SMP while taking advantage of an existing reservoir of familiarity with monitoring procedures.

In adopting this approach, we must take care. Much effort can be wasted in debating the relative merits of existing protocols, especially if the focus of that debate is not informed by the objectives of the SMP, and is restricted to the attributes they measure, rather than the attributes that are ignored. We also believe it is more important to agree on the attributes than on the methods used to measure them. However, before attempting to pick from among alternative protocols, we must understand the existing protocols, and the attributes they measure.

The protocols for coral reefs pay most attention to sessile benthic organisms, chiefly corals, and focus effort on deriving estimates of abundances of specific taxa or functional groups. The abundance estimates are usually as percentage cover. Some protocols collect data on abundances of fishes, usually of selected species, and occasionally of other mobile fauna (lobster, conch, starfish, urchins). In recent years, there have been modifications to protocols to include information on prevalence of coral diseases, and bleaching.

Any monitoring of dynamics of populations has been notably absent from coral reef protocols, although the CARICOMP protocol monitors primary production in seagrass and mangrove habitats. Nor has monitoring of water quality, or more particularly, of the impacts of nutrients or contaminants, been common.

In this section, we provide a detailed comparison of the major coral reef monitoring protocols that have been used in the Caribbean, including the recently proposed CONANP protocol. We also include the AIMS protocol. A summary of features of these protocols is in Tables 1-3, and detailed descriptions are in Appendix Three. Our intention is to provide the information necessary for an informed decision among protocols, or, if a consensus is not possible, the information needed to cross-calibrate competing methodologies. We focus initially on attributes of the biotic community that are best sampled with a transect or quadrat approach. We then deal with other attributes that should be included, but which will require alternative sampling procedures. The section closes with a look at the much more limited information on methods for monitoring seagrass beds and mangrove forests.

4.1.1 Abundances of sessile biota

Protocols of GCRMN and AIMS begin their monitoring of sessile biota with a manta tow around the reef perimeter to provide a coarse yet spatially comprehensive picture of the whole of the reef system. This is a valuable approach that perhaps should be used more widely. A reef-wide survey will be more likely to detect severe but localized impacts that have a low probability of falling within a specific sampling site or transect within the reef. Importantly, a reef-wide survey might also detect epidemic problems early (e.g. coral diseases, storm damage, outbreaks of native or introduced species) and will enable better monitoring of their effects and spread before they become ubiquitous.

Beyond the manta tow, the higher resolution monitoring methods for sessile biota differ among protocols, although all quantify abundances as percentage cover (Table 1). While the point-intercept transect technique is a widely used benthic sampling method in coral reef ecology, only Reef Check currently uses this approach, although CPACC uses a related approach in analyzing the video data from its belt transects. AGRRA, CARICOMP and GCRMN use line-intercept transects, wherein percent coverage along a line is recorded rather than substrate categories under specific points (AGRRA quantifies only living coral using this method, and does not discriminate among species). Line-intercept data can provide useful information on the size and arrangement of particular microhabitat patches, in addition to simply their overall abundance. The CARICOMP protocol records the sequence of substrates, not simply overall percent cover.

There seems to be an advantage in the CARICOMP and GCRMN line-intercept approaches. They provide a more comprehensive picture of habitat structure along a transect, and have a higher probability of detecting rare benthos (although limited taxonomic resolution can negate this latter advantage). Nevertheless, Segal and Castro (2001) show that both point- and line-intercept approaches can yield comparable community composition data, provided that the former use a sufficient number of points. Both methods can detect benthos with less than 2% cover. Furthermore, line-intercept transects entail greater subjectivity and/or error in estimating proportional cover along the line, and are more time-consuming per transect surveyed. Although the level of replication (number of transects) specified by Reef Check for point-intercept transects (n = 4 per site) is actually less than that for AGRRA (n = 6 or more per site) and CARICOMP (n = 5 per sub-area) line-intercept approaches, there is the potential to survey many more transects when only collecting point data. (Decisions on level of replication are important and complex. They are discussed in 4.4.2.)

Provided image resolution is sufficiently high, video transect techniques such as those used by CPACC and AIMS are advantageous in their ability to collect much more data per unit of dive time and to store the images permanently for subsequent re-analysis. Of course, video transect approaches also incur much higher costs associated with equipment and skills, and much of the field time saved is spent in the lab extracting data from the images. At present, there has been no assessment of the relative advantages and drawbacks of the various methodologies in terms of statistical features such as precision and resolving power and therefore ability to describe patterns and monitor change. (Segal and Castro (2001) did not include video transects.) However, existing CPACC or AIMS video transect images could be used to simulate point- and line-intercept approaches on the same transect and compare these methods with one another and with the video methods. This could help suggest the best approach, or at least the extent to which data collected by different methods can be compared and integrated.

Quadrat methods are also commonly used in benthic ecology, but are not prevalent in the various Caribbean monitoring protocols in use. GCRMN encourages permanent quadrats be established as a supplement to the primary transect sampling program, but provides little specific information regarding methods for monitoring them. AGRRA uses quadrats systematically placed along its transects to collect targeted algal data. Because these quadrats are systematically placed in areas largely free of living corals, they provide a measure of the proportional coverage of various algae and of sand and pavement *in places free of living corals*. These data will *not* be comparable with data on coverage of these biota or substrata collected using standard point-intercept (Reef Check, CPACC), or line-intercept (GCRMN, CARICOMP) methods.

In contrast to other protocols, the proposed CONANP protocol uses 1m^2 quadrats, subdivided by a grid of monofilament spaced 10cm apart, as the primary benthic monitoring method. These are positioned consecutively to form 20m x 1m belt transects. Percent cover of live coral species and of algae are recorded, but the method for estimating cover (point-intercept or subjective estimation for each grid square, or for the whole quadrat) is not specified. Percent cover estimates from this protocol could be compared with those derived from other protocols using the point-intercept, line-intercept and video methods. However, lack of methodological detail in the description of the CONANP protocol makes it impossible to assess its relative precision or accuracy.

Table 1. Monitoring methods for coral reef benthos.

Program	Method	Depth	Replicates	Notes
AGRRA	10m haphazard line transects	1-5m + 8-15m (=Sites)	≥ 6 transects/site	% coverage under total line, using line intercept method..
	individual live colony measurements		all colonies touching transect, & >10 cm diameter (50/site minimum)	diameter of colony. % “recently dead” & “long dead”. notes on disease and bleaching. # of territorial pomacentrids.
	25x25cm quadrats for algal cover		5/transect (30/site minimum)	targets patches w/ abundant algae. % cover of specific algal types. height of macroalgae.
CARICOMP	10m permanent line transects (randomly chosen at first visit)	10 ± 3m	5/subarea (=site)	% coverage of substrate types, using line intercept method. Genus or species level resolution if possible. rugosity using chain method.
CONANP protocol	Contiguous 1 m^2 quadrats along a 20 m belt transect (haphazardly placed?)	Undefined?	Undefined?	1 m^2 quadrats subdivided by 10 cm grid to monitor % cover of sessile benthos.
	0.25 m^2 quadrats within belt		Undefined?	recruitment of scleractinian corals
CPACC	20m x 40cm random video transects	varies w/ reef type	20 per site	% coverage of substrate types, using 10 random dots applied to independent frames (see Rogers and Miller 2001). point-intercept is back-up method (how many points?).

Table 1. continued.

Program	Method	Depth	Reps	Notes
GCRMN	manta tow	Snorkeler towed above upper reef slope	≥ 9 x 2 min tows, depends on size of reef	broad picture of % cover live/dead/soft corals, damage, etc.
	20m haphazard line transects	3-6m + 10m (if possible)	5 per depth zone at site	record 'lifeforms' or spp. using point intercept method
	1 x 1m permanent quadrats	3-5m	not specified	benthos cover photographed or marked on slates. recruitment plates can be set near quadrats.
REEF				benthos not surveyed.
Reef Check	20m haphazard line transects	3m + 10m	4 per depth zone	follows fish survey. % coverage using point intercept method, sample at 0.5m intervals. uses substrate categories (i.e. no morphs, genera, species, etc.)
AIMS	50m x 25cm video transects	6-9m	5 per site	hard coral, soft coral and algal % cover estimated from 200 random points per video transect. hard corals identified to finest taxonomic resolution possible.

4.1.2 Other attributes of sessile biota

Several protocols collect information beyond coverage of sessile species. AGRRA collects structural data for all live hard coral colonies >10cm in diameter and under the transect line. Species, diameter, height, and percentage of the colony that is living, recently dead, or long dead are measured for each colony. Occurrences of diseases are also recorded on each colony. The CONANP protocol identifies species, size metrics (colony height and diameter), percentage recently and long dead, occurrence of diseases and bleaching as important variables to monitor for specific coral colonies. This would be useful information on coral population structure and community composition that only AGRRA addresses at present. However, the CONANP protocol does not describe how these data are to be collected.

4.1.3 Mobile biota other than fish

The various protocols handle collection of data on mobile invertebrates in a variety of ways (Table 2). Mostly these are ignored, or simply included when estimating cover of sessile taxa (this is a potential problem if mobile invertebrates are sufficiently abundant that they obscure sessile biota so that coverage of these is underestimated). There is considerable variation in practice, if not among protocols, concerning how such data are recorded.

Certain specific taxa are counted in all protocols except GCRMN and REEF (although there is an invertebrate RDT being tested by the REEF organization in the Pacific Northwest of the U.S.A.). The AGRRA and CARICOMP protocols specify a count of *Diadema* within a 1m wide belt transect superimposed on each line transect, but record no other invertebrates. Transect width is estimated using a 1m T-bar. AGRRA also records number of territorial *Stegastes* spp. damselfishes associated with each sampled coral colony, as a way of estimating the level of herbivory in the vicinity of each colony. The CPACC protocol includes a count of all urchin species made on each transect, independent of the video run. The CONANP protocol includes density and size of conch and density of *Diadema* urchins among the categories to be recorded in the quadrats. The AIMS protocol records abundance of *Acanthaster* during manta tows.

4.1.4 Sampling of fish

The CARICOMP and CPACC protocols do not include sampling of fish. The other protocols all sample abundances of fish species. The AGRRA, Reef Check and AIMS protocols all define the species to be included in the underwater fish surveys, while the GCRMN and REEF protocols include all species of reef fishes. All except the REEF protocol use belt transects on which abundances are quantified, although AGRRA combines use of transects with use of the REEF Roving Diver Technique (RDT) to build a species list. Among protocols, transects differ in dimensions, number, and placement relative to the benthic sampling. The AGRRA protocol advocates swimming out the transect line behind the diver to minimize prior disturbance to the fish, and estimates transect width using a 1m wide T-bar. Other protocols estimate transect width by eye, a less accurate method especially when rare fish are sighted (Table 3).

Table 2. Monitoring methods for coral reef mobile invertebrates.

Program	Method	Depth	Replicates	Species	Notes
AGRRA	10 x 1m belt transects	1-5m + 8-15m (=Sites)	≥ 6 per site	*Diadema*	swum on benthos transects w/ width guide device.
CARICOMP	10 x 1m permanent transects	10 ± 3m	5 per subarea	*Diadema*	swum on benthos transects w/ width guide device.
CONANP protocol	1 m^2 quadrats along a 20 m transect (haphazard?)	Undefined?	Undefined?	Urchins and conch	Species included in sessile benthos surveys.
CPACC	20 x 1m random transects	Varies w/ reef type	20	Urchins	swum on benthos transects (but not done by video).
GCRMN					Not surveyed.
REEF					Invertebrate survey based on fish RDT implemented in Pacific Northwest, but not yet in tropics.
Reef Check	20 x 5m transects	3m + 10m	4 per depth	Variety of crustaceans, mollusks, echinoderms	Follows fish surveys on same transects.
AIMS	manta tows	Snorkeler at surface above forereef	2 min intervals as needed to cover reef perimeter	*Acanthaster planci*	Record number, and size class of all observed.

Table 3. Monitoring methods for coral reef fishes.

Program	Method	Depth	Replicates	Species	Notes
AGRRA	30 x 2m transects (w/ 1m T-bar to help estimate width)	1-5m + 8-15m (=Sites)	≥ 10 depth (=site)	large visible families	Count of selected species only
	Roving Diver Technique		1/dive	All species	Done after transects. Based on REEF, but time specified (30-60 min).
CARICOMP					Fish not surveyed.
CONANP protocol	5 m diameter Bohnsack point census, *or* 10 min free swim	Undefined	1	All species	Point census or free swim done initially to compile species list to be used on transects.
	50 x 2 m transects	Undefined	Undefined	Defined list.	Count specified species.
CPACC					Fish not surveyed.
GCRMN	50 x 5 x 5m haphazard transects	3-6m + 10m (if possible)	3 per depth	All species	Count all species.
REEF	Roving Diver Technique (diver roves at dive site)	Any, but at site defined by boat.	1 per dive	All species	Restricted to 100m radius. Builds species list, crude abundance estimates.
Reef Check	20 x 5 x 5m haphazard transects	3m + 10m	4 per depth	Large visible species	Count selected species..
AIMS	50 x 5m & 50 x 1m transects	6-9m	5 per site	Large species + pomacentrids	Count specified large species on 5m transects, damselfish on 1m transects.

The CONANP protocol recommends use of an initial point census using a 5m diameter 'point' (Bohnsack and Bannerot, 1986), or a 10 minute timed swim to compile a list of all species present in the area. It is not clear whether this is done once, or on every monitoring occasion, nor whether differences in species lists among locations are a concern. This list defines the species to be counted on 50m x 2m belt transects.

By defining specific species to be sampled, the AGRRA, Reef Check and AIMS protocols have attempted to improve the reliability and precision of the data collected. In each case, species selected are ones that are similar enough in size and habits that they can be searched for simultaneously. The inclusion of all species is not necessarily a problem in the case of REEF because its RDT method allows the diver to repeatedly cover areas within a site employing a variety of search techniques as necessary to locate different taxa. For example, a diver would likely first scan broadly and higher in the water column for large, mobile fishes, then progressively narrow the breadth and height of the search to target small and/or cryptic species. GCRMN, on the other hand, uses relatively large transects (50x5m), which are known to be biased against small and/or cryptic fishes (e.g. Fowler 1987; Bellwood and Alcala 1988; Ackerman and Bellwood 2000). A width of 2.5m either side of the diver is beyond the range at which small species can be reliably detected. Also, search strategies for large and visible fishes (i.e. focus ahead of diver higher in water column) are very different from those for small and/or cryptic fishes (i.e. focus near and below diver). This will further decrease the probability of locating even those small fishes located along the center line. The CONANP protocol has similar problems, although the narrower transect width will tend to bias against the larger species. Among locations, spatial differences in reef complexity will lead to much greater differences in the probability of counting small species than large species using the wide GCRMN transects. **If taxa of a range of sizes and habits are to be included, monitoring programs should follow the lead of AIMS and employ multiple transect sizes tailored to particular groups of fishes.**

The focal species defined for AGRRA are not easily sampled on transects as narrow as the 30m x 2m transects specified for that protocol because they are predominantly large and active fish. Residence time in transects is greater for wider transects such as those used by GCRMN, Reef Check and AIMS, and this should result in less error, particularly with less experienced personnel. Adequate training is particularly important when monitoring fish. Narrow transects (50x2m) are also proposed for the CONANP program. Still, the narrow transects used by AGRRA and the CONANP program have a big advantage over wider transects: their widths are more accurately estimated, so that counts are more accurately converted to densities of fish. Although transect length differs more than twofold between GCRMN/AIMS (50m) and Reef Check (20m), transect length has been shown to have much lower effects than transect width on density estimates of larger fishes (McCormick and Choat 1987; Mapstone and Ayling 1998).

There seems to be an inherent preference among coral reef fish researchers for sampling methods that use prescribed sampling areas (i.e. belt transects) rather than those that do not strictly control for the area surveyed. These permit calculation of abundance as densities. However, the RDT data are likely especially useful for documenting presence of rare species that are prone to be missed by transect sampling programs. For example, the first report on the Reef Check program suggests that Nassau grouper *Epinephelus striatus* are absent from 142 of 162 reefs surveyed (88%; Pennisi 2002). However, the four 20x5m transects sampled in a Reef Check survey cover only 400 m^2 of reef. In contrast, an RDT survey with a 100m radius would cover approximately 31,000 m^2 of reef, or more than 70 times as much area. Newman et al. (1997) conducted censuses of approximately 4000 m^2 on the central Great Barrier Reef and found that mean densities of many large groupers were much less than 1 per census. This would yield a high probability of 0 counts in surveys covering only 400 m^2. Thus, the likelihood of detecting a rare species by the REEF/AGRRA RDT method would be much greater than the Reef Check surveys and would give a better picture of local extinction. In fact, a potential extension of the REEF/AGRRA RDT methodology might be enlist local dive guides in surveying rare species while leading dive groups. Dive guides could not survey all species due to their leadership responsibilities, but regular incidental reports of rare species would be a simple yet useful service. The CONANP protocol also uses free search techniques to compile its initial species lists, but the extent of these searches (5m diameter cylinder or 10 min swim) is unlikely to cover sufficient area to locate very rare species. These approaches will therefore not yield the same advantages as the RDT in documenting presence of rare species.

Several protocols go beyond abundance estimates for some or all species. The REEF protocol yields only crude estimates of relative abundance, but builds a comprehensive species list for each Site and some estimates of size distribution (Schmitt and Sullivan 1996). AGRRA collects estimates of fish size as well as number, and uses the RDT method to build a species list. The CONANP protocol recommends collection of data on size, trophic structure and biomass for specific key or commercially important species, but methods for doing this are not identified.

4.1.5 Placement and replication

The protocols differ in procedures for placement of sampling units (transects or quadrats), and in the level of replication within sites that they recommend. CARICOMP, and the AIMS protocol use permanent fixed transects (originally haphazardly placed), AGRRA, GCRMN, and Reef Check all use haphazard transects, and CPACC uses random transects. CONANP does not specify how transects are to be established. Replication varies from 4 transects per Site (Reef Check) to 20 (CPACC), and ***all programs except CPACC are likely inadequately replicated to generate abundance data with reasonable levels of precision*** (see Section 4.4.2).

The depth strata used by the various Caribbean protocols are generally comparable. AGRRA, GCRMN and Reef Check all sample in shallow depths (1-6m). AGRRA, CARICOMP and Reef Check regularly sample deeper waters (8-15m), and GCRMN encourages sampling at 10m if possible. Therefore, CARICOMP data do not cover shallow habitats and GCRMN might not cover deeper habitats. The REEF/AGRRA RDT does not specify a target depth, but data for particular depths could be extracted to facilitate comparisons with the other methods. The AGRRA use of RDT is intended to be in the vicinity of the boat anchored at the reference Site, so should be within the area of the line and belt transects. CPACC depths vary among a series of defined reef types, so some will overlap with depths sampled by the other programs. The CONANP protocol does not specify monitoring depths. Because all of the methodologies are based upon SCUBA diving, maximum depth will generally be restricted. However, reef habitat is much more abundant in deeper water within the Caribbean than in shallower systems like the Great Barrier Reef. Deep-water populations might exist in a natural refuge from disturbance and harvest, and might be important sources of replenishment for shallower areas. Therefore, occasional sampling of deeper reef habitat, perhaps by methods other than SCUBA (e.g. remote cameras for benthos, traps for fishes and mobile invertebrates), should be considered for future inclusion as an additional component of the SMP.

4.2 Coral reef attributes not included in existing protocols

Existing protocols for coral reef monitoring focus on patterns of abundance of various components of the biota. Conspicuously missing are estimates of population dynamics. To truly assess the 'health' of an ecological community, there needs to be information on its current success in replenishing its biota. Among existing protocols, AGRRA is unique in attempting to approach this for corals as a formal part of the protocol. By recording sizes of colonies along each transect, AGRRA yields data on size distribution that could be used to generate a size-based demography, and the data on percentages of the colony that are recently dead and long dead could provide additional demographic data. GCRMN suggests the setting out of tile settlement plates at monitoring sites to collect information on coral recruitment, but this is not being routinely done. The CONANP protocol recommends use of $0.25m^2$ quadrats to search for juvenile corals, but procedures are not specified. None of the existing programs specifically monitor recruitment of fishes, although AGRRA and REEF protocols include data on size distribution, and the CONANP protocol also recommends gathering data on size. Recruitment of many fish species is relatively easy to monitor and should be addressed, especially in order to assess replenishment differences among MPAs and outside their boundaries.

Existing protocols make little attempt to monitor water quality, sediment load, turbidity, or possible impacts of nutrients or contaminants on reef biota. At present, only CARICOMP and the Belizean CZMI conduct water quality monitoring. The CONANP protocol proposes water quality monitoring as well, and the AIMS long-term monitoring program provides another approach for comparison.

There are two important considerations when evaluating a water quality monitoring program. Firstly, a broad range of physical and chemical parameters should be measured. Changes in nitrate concentration, phosphate concentration, temperature, salinity and other variables can occur independently of one another owing to different sources of the changes, and their effects can also vary. So, monitoring of only one or a few variables cannot serve as a proxy for all and important environmental characteristics might be overlooked. Secondly, monitoring must account for the fact that properties of water masses are both transitory and dynamic. Specific variables can fluctuate widely in space and time. Importantly, drastic changes can occur within very narrow time frames as a result of episodic meteorological events. For example, tropical storms can cause severe flooding and run-off that can raise temperatures, lower salinity, increase turbidity and deliver land-based nutrients. These changes might dissipate quickly, but effects incurred during the event (e.g. coral bleaching) might persist. Therefore, direct sampling of physical and chemical variables will need to be very intensive in order to document these ephemeral changes with sufficient precision. In fact, frequently the weather conditions that create the important fluxes in water quality also preclude sampling, and the spike in water condition is not detected when monitoring next occurs.

The CARICOMP protocol collects water quality data with the finest temporal resolution of any existing or proposed protocol. Temperature, salinity and turbidity (using Secchi discs) are measured on a weekly basis. Furthermore, CARICOMP also compiles complementary continuous records of temperature using data loggers. This is the minimum sampling frequency that will be required to directly measure water quality. Unfortunately, the protocol does not address important chemical properties beyond salinity.

AIMS and CONANP protocols have the opposite shortcoming to CARICOMP. These methodologies measure a much wider array of variables (chlorophyll, nitrates, phosphates, silicates, dissolved oxygen and others), but do so too infrequently. AIMS only collects water quality data once per year, while CONANP proposes to sample on four occasions per year. Given the inherently ephemeral nature of many physical and chemical traits but their potentially persistent effects, measurement of these variables needs to be much more frequent.

The CZMI approach currently achieves the best of both worlds. CZMI monitors water quality on a monthly basis, which is much more regular than AIMS or CONANP. Although this is less frequently than the weekly monitoring of temperature, salinity and turbidity and continuous monitoring of temperature by CARICOMP, the range of variables addressed by CZMI is much more extensive than CARICOMP and is similar to the scope of the AIMS and CONANP protocols. Still, even monthly monitoring is likely to be inadequate. A recent study by Andrefouet et al. (2002) tracked the dynamics of plumes in the MBRS generated by Hurricane Mitch and subsequent terrestrial run-off. They found that even fairly large plumes could dissipate in as little as two weeks. When these plumes dissipate, associated physical and chemical changes might also dissipate. It is therefore probable that an important environmental event could come and go undetected in between monthly sampling, although it might have lasting and important effects on resident biota.

Sale et al. (1999) recommended that bioindicators be used within the MBRS region to track the biological consequences of physical and chemical changes and to serve as a record of longer-term patterns. In 1984, the U.S. NOAA developed Mussel Watch as part of its National Status and Trends Program. Mussel Watch deploys strategically placed groups of mussels (Mytilidae) to serve as bioindicators of water quality [see Lauentstein and Cantillo (1993) for a summary of Mussel Watch methods, and Lauenstein and Daskalakis (1999) for a summary of Mussel Watch results]. As filter feeding sessile bivalves, mussels accumulate most water-borne chemicals in their soft tissues and will therefore record trends over weeks, months or years. This is in contrast to 'snapshot' water samples, which only provide information on immediate water quality. In addition, because they concentrate the chemicals, the analysis of the mussel tissues does not have to be as sensitive as it would if the water column itself were being measured. Approaches like Mussel Watch directly address the question of interest in environmental management – effects of pollutants on organisms – while providing a long-term record that does not require regular fieldwork. Although mussels are not prevalent in the Caribbean, native filter-feeding bivalves such as file clams (*Lima lima*), oysters (*Isognomon radiatus*), and tellins (*Tellina radiata*) could also serve as bioindicator species. Since its inception, Mussel Watch has spread internationally, including to developing countries such as Malaysia. This shows that the approach is broadly applicable.

Algal growth plates reflect the influx of the key nutrients that determine primary productivity while providing a direct measure of the effects of these changes on a critical component of coral reef benthos and represent another potential bioindicator approach. This is particularly so if the plates are protected from grazing, spatial variation in which can confound interpretation of algal biomass data.

Yund et al. (1991) describe a sampling method that modifies tube traps used to monitor sedimentation in order to also monitor recruitment of invertebrate larvae. Tube traps are simply vertical tubes open at the top and closed at the bottom. They create a volume of still and protected water into which sediments fall and remain, thus providing an undisturbed record of sedimentation. By filling the base of the trap with formalin, larvae settling into that volume will be killed, retained and preserved. Sedimentation and recruitment are both largely overlooked in existing monitoring protocols, and tube traps modified following the design of Yund et al. can be a simple and inexpensive approach that does not require extensive field or laboratory costs. The approach is analogous to monitoring using bioindicators in that the traps can be deployed and left to passively collect and store information over any time period of interest, after which they would be retrieved and the contents analyzed.

4.3 Monitoring of seagrass and mangrove systems

In contrast to the array of coral reef monitoring programs in place throughout the Caribbean, monitoring of equally important seagrass and mangrove ecosystems is rare. This is despite that fact that, in addition to being important in their own right, seagrasses and mangroves can serve as important nursery grounds for coral reef fishes and other organisms (reviewed by Beck et al. 2001). Only CARICOMP presently includes seagrass beds and mangrove forests within its monitoring program (see CARICOMP protocol, Appendix Three). This is a critical facet of regional ecological monitoring that needs to be implemented more widely in the MBRS. CARICOMP monitoring of seagrasses and mangroves includes the water quality monitoring described in Section 3.2 in addition to habitat-specific biological monitoring. The CARICOMP protocol is particularly thorough in its description of methods, and in its attention to questions of sampling design, including site selection, placement of sampling effort, and level of replication. These are just as important in these non-reef habitats, and when methods do not involve transects, as they are when transects are being deployed on reefs.

CARCIOMP monitoring of seagrasses and mangroves includes collection of detailed data on biomass and productivity. For seagrasses, this involves coring to obtain cross-sectional samples of both aboveground and belowground biomass and direct measurement of leaf growth and leaf area. Additionally, seagrass samples are analyzed for carbon, nitrogen and phosphorus content. Estimation of mangrove biomass is more complicated and involves estimation of population size and stage (i.e. seedlings, saplings, adults) structure. Mangrove productivity is monitored by both direct measurement of growth in height, diameter and weight of individual trees and by analysis of litterfall. In contrast to the various coral reef monitoring programs, which largely examine reef status, the CARICOMP seagrass and mangrove monitoring methods provide more detailed information on ecological processes and system dynamics.

Monitoring of seagrasses and mangroves by CARICOMP provides useful information on area-specific biomass, structure and productivity, but little information on overall coverage of habitat and changes in that coverage. The coral reef monitoring programs likewise do not address spatial coverage, but this is likely to be more temporally stable for hard-bottom habitats like coral reefs (though their composition might change). Both mangroves and especially seagrasses can be readily dislodged by severe weather events. Mangroves are also known to be subject to diseases. Natural perturbations such as these, as well as anthropogenic disturbances such as oil spills, can cause the distribution of these habitats to expand, contract and shift in space. The CARICOMP methodology calls for inclusion of spatial coverage data in its enhanced work plan, but such data are difficult to compile 'on the ground'. However, periodic remote sensing can provide distribution and spatial coverage data that can be coupled with the detailed biomass and productivity data currently being collected (see Mumby et al. 1999).

5 Proposal for design of the SMP

5.1 Introduction

The following sections are a carefully considered proposal for design of the SMP. We consider in turn the number and distribution of monitoring locations, the distribution of monitoring sites within locations, and the monitoring methods to be applied. Modification and subsequent adoption of these elements of the SMP will be most effectively done if targeted workshops involving key players continue to be used as the mode of action (Recommendation 1).

5.2 Distribution of monitoring locations for the SMP

Some 23 locations have been proposed at which the SMP will be implemented. Many of these are complex enough in habitat diversity, and of sufficient size, that there will presumably be more than one monitoring site within each. We focus initially on the adequacy of distribution of these locations. They include the 15 priority protected areas agreed to for implementation of the program for monitoring MPA management effectiveness. The remaining 8 locations include one additional protected, and one other coral reef site, two major river mouths, and four ports or harbors.

This set of locations appears to be deficient in several ways:

- There are no locations identified in the northern 250km of the Quintana Roo coastline, yet this is the most heavily used portion of the MBRS region for tourism.

- There is only one coral reef location that is not yet protected (Caye Caulker includes a recently declared Marine Reserve, but on-the-ground protection remains minimal). There needs to be a set of unprotected sites distributed throughout the region; otherwise it will never be possible to demonstrate that management protection is having any effect.

- Other than Caye Caulker and Belize River, there are no locations identified in the northern half of the Belize Barrier Reef and coastal lagoon between Hol Chan and South Water Caye. Nor are there any locations identified on Turneffe Islands or Lighthouse Reef.

- There is only one location (Turtle Harbor) in the Bay Islands – it is nearly at the western-most end of the group. This is the only coral reef location identified in Honduran waters.

- Only one of five CARICOMP sites in the region (Hol Chan) is proposed as a location (Puerto Morelos, Calabash Cay, Carrie Bow Cay, and Cayos Cochinos omitted). Dangriga is also not included, but is one of three CPACC sites in the region (Hol Chan and Glovers Reef are the others).

RECOMMENDATION 2
The set of 23 monitoring locations identified to date must be expanded if the SMP is to yield a database of value for decision support, or for assessment of regional ecosystem 'health'.

Expansion of the number of monitoring locations introduces some additional costs for monitoring, both in field equipment and data management needs, and in personnel time (but see comments below). We propose these key criteria for the location-selection process:

- Are there personnel accessible to the location able to do the required monitoring, and is their participation endorsed by their managers? If all monitoring within a country is to be done by a single 'monitoring team', does that team have access to that location, and sufficient person-days available to include it?

- Does the new location help address one or more of the deficiencies identified in the current list of 23 sites?

- Does inclusion of the new location take advantage of monitoring activity under other projects? (A summary of current programs in the region is provided in Appendix Two.)

- Can the scope of monitoring activity at each location be reduced in order to accommodate a greater number of monitoring locations?

While additional/other locations may be appropriately included, we recommend at minimum the addition of the following:

RECOMMENDATION 3
We recommend serious consideration of the following locations as possible additions to the set included in the SMP:

Location	Features	Personnel available (?)
Isla Contoy, Mexico	**protected area, northern limit of MBRS region**	**MPA staff**
Puerto Morelos, Mexico	**CARICOMP site, protected status pending**	**UNAM**
Akumal, Mexico	**fringing reef, not protected**	**CEA staff (local NGO)**
Cozumel, Mexico	**protected area**	**MPA staff**
Mahahual, Mexico	**fringing reef, not protected**	**MPA staff, Chinchorro**
Turneffe Islands, Belize	**CARICOMP site, not protected**	**UB IMS staff, Calabash**
Lighthouse Reef, Belize	**some protected areas**	**Belize Audobon NGO**
Carrie Bow Cay, Belize	**CARICOMP site, not protected**	**Smithsonian staff**
Dangriga, Belize	**CPACC site, unprotected, coastal**	**Belize Fisheries?**
Cayos Cochinos, Honduras	**CARICOMP site, protected**	**HCRF staff (local NGO)**

In addition, at least two locations on Roatan (at least one not protected), and two additional unprotected locations in the central portion of the Belize Barrier Reef should be selected, using information on availability of personnel and logistics to facilitate monitoring.

Recommendation 3 leaves coverage sparce in much of the region. For example, a substantial gap exists in México between Mahahual and Akumal, (however, we understand it may be possible to obtain monitoring program data from the Sian Ka'an Biosphere Reserve to help close this). If Recommendation 3 is fully supported, or if it is augmented by further additions, the number of locations for the SMP is increased to 37 or more. This represents an added cost, but perhaps not a major increase in program costs, because costs depend more on needs for equipment and logistic support, and availability of personnel – factors that are strongly influenced by frequency and nature of monitoring. For a region of the size and complexity of the MBRS, 37 monitoring locations is a modest density, and the resulting database would have little value if no adjustments were made to the original set of 23 locations.

In this regard, a useful comparison can be made with the AIMS Monitoring Program on the Great Barrier Reef. On an extensive reef system stretching along 1600km of coast (compared to about 800km from the eastern Bay Islands, west and then north to Isla Contoy), the AIMS program annually surveys 49 reefs, and assesses an additional 61 by manta tow only, for a total of 110 reefs. The AIMS program does not survey coastal mangroves, estuaries, or other non-reef habitats. At each surveyed reef, fish and benthic communities are sampled with replicate transects at each of a number of sites depending on the size of the reef.

5.3 Selection of monitoring sites within locations

The identified locations vary in size from small MPAs such as Hol Chan (411 ha) to much larger ones. They vary also in the types and diversity of habitats included. We assume that more than one monitoring site will be established at each location. Monitoring sites must be carefully chosen because they will be the permanent locations at which monitoring data will be collected. (While it should be possible to add new monitoring sites in the future, dropping sites will usually not be desirable, and sites should not be thought of as temporary.)

We use the terminology and procedures of Woodley (1999), except that he uses 'Area' in place of 'Location'. That is, within each Location, there will be one or more 'Habitats' to be monitored. Within each monitored 'Habitat', there will be a number of potential monitoring 'Sites', of which certain ones will be selected. At each selected Site, monitoring activities will be done. The spatial extent of a monitoring Site is somewhat arbitrary, however, each Site will exist at a single GPS location, and one rule of thumb for gauging the size of a Site (from AGRRA Protocol, 2000) is that a Site is that area conveniently worked by divers when the boat is moored at the GPS location defining it (about 200 x 200m). Here we are concerned with the procedures for selecting Sites.

In order to build an effective regional SMP, it is necessary to agree first on the kinds of habitats to monitor, and to endeavor to monitor representative Sites for each of these Habitats at every Location. Some Locations may lack certain Habitats. We suggest 5 different Habitats, including 3 coral reef habitats widely sampled by other monitoring programs. This recommendation is only a guide. The individuals who will implement the SMP must make this decision.

RECOMMENDATION 4
The ecological component of the SMP will recognize five Habitats: 1) mangrove forest, 2) seagrass bed, and three coral reef habitats: 3) shallow, back-reef (leeward) habitats in 1-5m depth, 4) shallow fore-reef (windward) habitats in 1-5m depth, and 5) deep fore-reef habitats in 8-15m depth. Each monitoring Site will include a single Habitat.

Site selection will be best done by individuals knowledgeable about the specific Location, and will benefit if good habitat maps are available. (In fact, the provision of detailed habitat maps for each Location should be a high priority, to be achieved before Sites are selected for monitoring.) The goal should be to choose Sites that are representative of each Habitat at the Location. Woodley (1999) advocates selection of

Sites using a formal stratified random design. There are important statistical advantages if Sites have been selected in a stratified random design. However, we recognize that, since many locations will be places with some degree of management, there may be sites that will be of particular interest to the managers. Specific sites that are in use by on-going monitoring projects, or are of particular interest for local management for other reasons, should be chosen as Sites for the SMP. (The proposed subdivision of coral reef Habitats closely approximates that used in CPACC, in CARICOMP, and in AGRRA.).

RECOMMENDATION 5
Each Location will include one or more Habitats. In each Habitat to be monitored at that Location, *at least* 2 replicate Sites will be chosen. Selection procedures will follow Woodley (1999), but exceptions can be made for Sites that are of specific management interest, or already used in other monitoring programs.

These Recommendations should be used by the monitoring team responsible for each Location, but in consultation with monitoring teams from elsewhere in the region. The objective is to select a well-distributed set of replicate Sites, within Habitats, within Locations throughout the region of the MBRS. Locations containing extensive patches of habitat will demand more than 2 replicate Sites per Habitat if the monitoring data are to be representative of the full Location. If coral reef Habitats are being monitored, shallow and deep fore-reef Sites should be co-located for logistic ease, but will still have separate GPS locations.

Note that Recommendations 4 and 5 do NOT require that each monitoring Location include all 5 Habitats, nor that a fixed number of Sites per Location be monitored. Decisions on number of Habitats, and number of Sites of each type will be made at each Location, by those responsible for the monitoring program, and those (if any) who manage that Location. However, early in the life of the SMP, there should be an evaluation of the adequacy of monitoring proposed at each Location, carried out in the course of an implementation/training workshop (see Recommendation 1).

5.4 Adoption of the Sampling Regime to be applied at each Site

The SMP will monitor selected environmental attributes at each Site, using agreed methodology, and on a regular schedule. Schedule and methodology should be uniform across the region, and through successive years, with the proviso that, ***in exceptional circumstances, differences in methodology among Locations, or changes in methodology through time are permissible so long as certain conditions are maintained.*** These can be stated in a firm recommendation:

RECOMMENDATION 6
At each Location, methods used, as well as measurements made, must be reported, and included in the database. Where alternate methods that measure a particular attribute (such as coral percentage cover) are being used among Locations, they must have been rigorously cross-correlated, so that the measurements made are equivalent.

Recommendation 6 does not suggest that differences in methodology among locations do not matter. It recognizes that there may be legitimate reasons for using different methods, or for changing methods, and that, so long as these methods have been cross-correlated this can be done. One example of a legitimate reason could be that a particular Site is being monitored as part of an existing monitoring program (such as CARICOMP or CPACC), and that this program is continuing, or that the local staff are experienced in the methods of that program, and have the equipment needed to continue it.

Selection of a sampling regime results from a series of decisions driven by three things: the environmental attributes about which information is required, the frequency with which data on these attributes is required, and the resources available to implement the monitoring program. There is no single correct regime, although there are monitoring programs that are more comprehensive, or that yield more precise data, than others.

5.4.1 The monitoring schedule

There are seasonal variations in abundance and age distribution of most tropical marine organisms. Many organisms restrict their reproduction to a particular season, while some produce offspring throughout the year. Weather conditions also vary seasonally, making fieldwork at some Sites more difficult at some times of the year. In the MBRS region, there are a rainy and a dry season annually. For all these reasons, it is imperative that the SMP be based on a monitoring schedule that is uniform across Locations.

More frequent sampling provides a richer monitoring database, but at increased cost in personnel time. Further, some processes, such as the growth of corals, are relatively slow, and attributes they affect, such as coral percentage cover, usually change only slowly. For these reasons, we believe a single annual sampling effort will be adequate for most purposes, at a time of year when weather conditions are most likely to favor fieldwork. Sampling at all Locations should be constrained to a narrow monitoring season of one to two months that is uniform throughout the region.

Certain attributes cannot be adequately monitored using a single annual visit to each Site. Water quality data, in particular, would be of little value if collected once annually. We anticipate that some such attributes will be included in the program, and recognize that these may be monitored more extensively but only at Sites that are readily accessible by local participants in the program. ***Such Sites may be thought of as 'high intensity' or 'Category I' Sites, and it may be appropriate, at the start of the program, to identify such Sites, and ensure there is a reasonable distribution of them through the region.*** (Category II Sites would get comprehensive annual monitoring only.)

Environmental conditions are also affected by non-seasonal disturbances such as hurricanes and other unpredictable weather events. ***Valuable information on the effects of major disturbances can best be gained by conducting 'extra' monitoring immediately following such events.*** Such 'extra' monitoring would ideally include all Locations in the region, and must include some Sites and Locations not expected to have been heavily impacted by the event. This 'extra' monitoring might include only a subset of the methods employed in the annual monitoring period, chosen because these will be most likely to show the effects of the disturbance. When the monitoring protocol is to be reduced in this way, it will be best if that is done uniformly across Locations, rather than haphazardly. Effective communication among monitoring teams will be vital (see Recommendation 1).

RECOMMENDATION 7
The Synoptic Monitoring Program will consist of a single, annual, sampling at every Site in the region, at a time of year agreed among the participants as most amenable to field activities. Sampling at all Sites should be constrained to a short time (1-2 months maximum), and should occur during the same time interval in each successive year. Certain easily accessible Sites (Category 1) may be monitored more frequently for certain attributes.

RECOMMENDATION 8
From time to time, unpredictable events (hurricanes, major bleaching episodes, oil spills) will occur in the region. An effort should be made to document the impact of such events by making extra monitoring visits to Sites, perhaps using a reduced protocol. Some Locations believed not to have been impacted must be included. It will be important to coordinate among Locations to ensure that the same protocol components are being used at each.

5.4.2 Replication within Sites

The monitoring protocol to be adopted, as uniformly as possible, across the region, will include a variety of sampling methods. These methods may require water samples, or samples of biota or sediments to be taken, or they may involve some field quantification in quadrats or transects. Regardless of the method, decisions must be made concerning the number of replicate data per Site. These decisions should guide the field effort at each Site, so that the resulting SMP database reports the same levels of replication among Sites and among years.

In any environmental sampling exercise, there is no single correct level of replication to be observed. The use of 2, 5, 10, 25, 13 or 7 replicate samples are all 'correct', because every one of them provides the information needed to estimate within-Site variability (or Error). Collection of a single sample, however, is wrong, because no estimate of within-Site error can be made from a single measurement.

The decision of the level of replication to employ is a cost-benefit judgement. It is more expensive in time and materials to collect more replicates, but the resulting estimate of error is more precise. Green and Smith (1997) provide a detailed discussion of how to conduct a formal power analysis to evaluate the likely effectiveness of a monitoring program. As an example, they used the Bermuda CARICOMP data on percentage cover of coral, and showed that the power was weak, but could be substantially improved if the level of replication was increased from 5 to 10 transects per Site. ***In general, we believe that under-replication has been a widespread and unfortunate feature in most coral reef monitoring protocols, given the considerable spatial variability in the data being measured.***

To implement a monitoring program with a level of replication that will yield data of poor precision is a massively wasteful exercise, because the resulting database will be of minimal use for management decision support. Most existing protocols (Tables 1-3) set a minimum number of replicate transects that is too low to provide precise information on changes in abundance of fish, or in percentage cover of corals. A monitoring program that cannot statistically confirm the loss of fish or corals at a Site until that loss exceeds 50% of the population is not very helpful to managers. That degree of change will be evident to observant individuals without any quantitative measurements being necessary!

RECOMMENDATION 9
All measurements made within Sites must be replicated. The level of replication can differ among measurements, but should be uniform across Sites and years for each measurement. The level of replication must be decided in a cost-benefit process, using existing data and past experience to decide the level of replication that can be afforded, and that will yield data with adequate precision.

5.4.3 Fixed, random, or haphazard transects

The monitoring protocol adopted at coral reef Sites will include a number of measurements made using transects or quadrats. There seems considerable confusion concerning the merits of fixed, versus randomly or haphazardly placed transects or quadrats. (Haphazard placement is quasi-random, but without formal randomization procedures. A good example of haphazard placement is tossing the quadrat over your shoulder, or, more realistically, dropping the quadrat from the boat, as a way of choosing a sampling location.) In addition to differences in actual data collection methodologies, the various monitoring protocols that have been developed differ in their methods for placing sampling units (i.e. transects or quadrats). CARICOMP and AIMS use permanent fixed transects (originally haphazardly placed), AGRRA, GCRMN and Reef Check all use haphazard transects, and CPACC uses random transects. The Mexican program, recently developed by CONANP, does not specify how transects are to be established.

Although formal randomization is more statistically valid, there are likely no appreciable differences in the placement methods used by AGRRA, GCRMN, CPACC and Reef Check. However, there is a significant difference between random or haphazard placement and fixed transects in terms of the questions that can be asked and the analytical approaches that must be employed. In particular, random or haphazard transects only allow Site-level patterns and changes to be discerned. Yet while fixed transects also allow micro-site patterns and changes to be tracked, they require repeated measures techniques at the analysis stage to examine overall Site-level changes, because individual transect data are not independent through time. Although permanent transects seem intuitively more useful, we differ with Green and Smith (1997), and believe that they should be avoided. Their ability to describe Site-level trends is limited if Site x Time interactions exist (a likely possibility). In addition, the logistical constraints of establishing and maintaining fixed transects can also be substantial in a region where fishers are quick to scavenge anything left in shallow water that seems useful. A transect approximately placed on the 'same' site as last year, is **not** a fixed transect. Nor is it haphazard or random!

RECOMMENDATION 10
Where replicate data are collected using the placement of quadrats or transects within a Site, placement should be haphazard on each sampling occasion, and permanent fixed quadrats or transects should be avoided.

5.4.4 Other sampling to be done at each Site

With the exception of CARICOMP, established protocols are largely silent about measurements to make at each Site, other than those taken from quadrats or transects. We believe that the SMP cannot be that limited, and suggest that a major early task must be to decide what measurements to make at each monitoring visit to a Site, and how to make them. In coral reef sites, a number of different measurements will be made on transects, but there will be other measurements made, and decisions about replication, and procedure have to be made for these as well. In mangrove and seagrass sites, quite different measurements may be made, and transects may play a much smaller role in the methodology. The topic of which measurements to make, and how, is dealt with in the next section. Here we suggest a suite of important information that should be recorded for every Site, on every monitoring visit.

RECOMMENDATION 11
At each visit to a Site, details should be recorded defining date and time of visit, personnel, weather conditions, and any unusual observations. The weather data may be as simple as a one-word description, but air temperature, sea state and wind should be noted, and it may be worthwhile to record water temperature, salinity, and turbidity. In addition, this Visit Record should record what monitoring methods were used, and how many replicates of each method were completed.

The purpose of compiling the Visit Record, which should be entered into the regional database along with the actual data, is as a check that the sampling that was supposed to take place did occur. Weather and water quality measurements will be of limited value given that visits will be infrequent (see Section 3.2). Data on personnel, methods used and actual level of replication will help ensure that data are treated appropriately when used at some future date. ***Observations made on a manta tow survey at each visit could be included in the Visit Record.***

5.5 Attributes to be monitored

The most critical decisions to make in establishing the SMP may be to decide on the suite of attributes to be monitored. We will review factors that should be considered in making these decisions by considering coral reef Sites, seagrass Sites, and mangrove Sites separately. We discuss water quality issues separately to these.

5.5.1 Coral reef sites

In common with the majority of existing protocols, it will be very likely that the Synoptic Monitoring Program will include a variety of measurements on corals, on fish, and on other selected biota. Many of these measurements can be made using transect and/or manta tow procedures. Others may require other approaches.

5.5.1.1 Measurements of corals

We believe that percentage cover of living coral is a useful attribute that must be monitored, however, we think that a number of additional attributes of the coral community should also be recorded. The relatively low diversity of the Caribbean certainly permits recording coral abundance at the genus level, and we would encourage efforts to ensure that all participants could record accurately at the species level. We recommend a serious examination of the AGRRA protocol for methods to record percentage cover of corals, and methods for recording several other important attributes of the coral community: size distribution, an index of mortality (measuring percentage recently dead, and long dead, as well as percentage alive), frequency of coral diseases.

RECOMMENDATION 12
A transect method should be adopted to measure percentage cover of corals, at the genus level initially. In addition to percentage cover, coral attributes such as size distribution, mortality rate, extent of bleaching, and frequency of coral diseases should be measured, using the same transects to define the population examined. The AGRRA protocol for corals may be the appropriate set of procedures to adopt, although serious consideration could be given to replacing its line-intercept technique for quantifying percentage cover with a point-intercept approach.

On-going projects such as CPACC, are using video transects to assess coral cover. These have the advantage of relatively rapid data collection, and the apparent added benefit of a permanent record of what was present. We believe this benefit to be over-stated. Implementers of the SMP should explore whether the other desirable attributes of the coral community can be extracted from video data, or whether it is feasible to collect these data from the same locations as the video transects, but not using video to do so. We do not recommend routine use of video transects for the SMP because of equipment costs, potential loss of data through equipment failure in remote locations, and because ***a focus on video sampling may diminish attention to the corals, and their health while personnel are at the field site***. Digital still cameras also may provide a very useful way of collecting coral data, and should be explored as an alternate, cheaper way of making a permanent record of coral community condition if that record is seen as of high priority.

RECOMMENDATION 13
A controlled field experiment should be done to establish whether video records can provide data beyond percentage cover of corals, or whether it is feasible to gather these additional data using AGRRA methods at the same time that video transects are being swam.

The general lack of attention to population or community dynamics that has characterized coral reef monitoring programs is most unfortunate. AGRRA's relatively crude index of mortality stands alone. Knowledge of coral recruitment becomes more important when corals are subjected to greater stresses through climate change and associated bleaching, and through diseases. These increased stresses increase mortality rates and make the ability to recruit and re-establish more important than it would have been otherwise. The SMP has the opportunity of introducing a coordinated, regional-scale monitoring of coral recruitment. Required would be agreement that this was worthwhile, the deployment of frames to hold tile settling plates, and deployment of plates at each site, for collection 1 and 2 years later.

RECOMMENDATION 14
The opportunity to extend coral monitoring to include monitoring of coral recruitment in the MBRS region should be taken up. This monitoring may best be done at a subset of sites (Category I), chosen because they are under sufficient surveillance that settlement plates will be likely to remain undisturbed between monitoring trips. Training in recognition of juvenile corals would be needed, and if this is included as a component of the SMP, it may best be initiated with the assistance of experts from the academic community who would play a leadership role at least through the first two years of data collection.

5.5.1.2 Measurements of fish and other fauna

At coral reef sites, monitoring should include some fish species, and some other non-coral biota. Transect procedures will be appropriate for recording abundances, and other data on these fauna. ***Attempting to record abundances of all visible fish species is not worthwhile, unless significant effort, involving multiple methods, is to be expended.*** Instead, it will be appropriate to decide which species are to be monitored, and then devise procedures that best fit those species. Monitoring of small, relatively un-fished species has some important advantages in situations where fishing pressures are high, while there will be considerable interest in also monitoring certain, larger, charismatic, or commercially important species. Non-fish species of economic value, such as lobster and conch should also be considered monitoring targets.

RECOMMENDATION 15
A region-wide, uniform, list of targeted fish species, and other mobile invertebrates should be identified, and monitoring procedures appropriate to determining abundances of these should be agreed to. A smaller list, and a greater level of replication of transects will improve the reliability of data. The procedures adopted by AGRRA provide a good guide for effective monitoring of fish abundances.

The approved list of monitored species does not prevent individuals monitoring additional species of concern at particular Locations. However, it does preclude monitoring these additional species within the same visual transect counts for the agreed list. Precision of fish counts depends upon the number of species being counted simultaneously. We also recommend against attempting to classify fish to size categories (other than adult and juvenile) while counting them. There is a limit to the number of tasks that can be done well at the same time.

We strongly encourage a decision to include a program to monitor recruitment of juvenile reef fish of selected species. The simplest procedure for doing so is to use narrow transects, 1m wide, that can be superimposed on the transects swam for adults. The species to choose will depend on the time of year during which monitoring activities will take place. There is now considerable experience in the science community concerning effective ways to monitor fish recruitment (eg. Tolimieri et al. 1998). It will be particularly valuable to see how recruitment rates vary among Sites and Locations within this region.

RECOMMENDATION 16
A small set of suitable species (conspicuous as new recruits, and settling at the time of year monitoring will occur) of reef fishes should be selected, and monitored to determine recruitment rates. This set should be monitored in a standard way, using 1m wide transects at all coral reef Sites in the region.

Current research in the region, by Sale, Arias and others, is providing a good database of suitable species to monitor for recruitment. In addition, we are gaining information using genetics and otolith microchemistry that may enable us to determine the source locations for fish recruiting to particular sites. If those who implement the SMP consider fish recruitment an important measure of system 'health', it may be possible to plan for targeted genetic and microchemical analysis of fish collected at monitoring sites, in order to establish the degree of connectivity among local populations throughout the region. Such a study would probably not become a continuing part of the SMP, but the collection of specimens could easily be done as part of the monitoring procedures.

Monitoring of fish recruitment is not as technically difficult as monitoring of coral recruitment, but ***it may be worthwhile for one or more members of the academic community to play a leadership role in ensuring that recruitment monitoring is undertaken in an effective way.*** Integration of the SMP with on-going, or newly initiated research projects in such fields is an effective way of demonstrating the usefulness of the database being constructed.

5.5.1.3 Other monitoring measurements at coral reef sites.

Nutrification, sedimentation, and contamination by other anthropogenic pollutants are major forms of negative pressure on coral reef ecosystems. The monitoring protocol developed for coral reef Sites should be able to monitor these forms of disturbance. CARICOMP, among established protocols, considers these indirectly by recording horizontal secchi disk visibility at each site. This is a simple, and easily implemented procedure, however, as noted in 3.2 there is limited value in an infrequent measurement of turbidity. We recommend including these measurements at each site, but we recommend supplementing with an alternative procedure that will integrate the turbidity over time. This is by the use of 'tube traps' (Yund et al. 1991) to collect sediment over time at selected sites (because the tube traps would have to be maintained, and protected from vandalism). Tube traps permitted to sample for a month at a time could provide a monthly record of sedimentation, nature of the sediments (terriginous or reef-derived), and a monthly record of rate of arrival of zooplankton and phytoplankton, thus providing direct indices of rates of sedimentation and rates of supply of planktonic food and propagules. Tube traps are easily built out of standard PVC plumbing materials, and the sorting of contents requires only a microscope. Indeed, with public support to help minimize vandalism, it may be possible to deploy these quite widely through the region.

RECOMMENDATION 17
At selected (Category 1) Sites, tube traps should be deployed permanently, and sampled monthly to provide a record of sedimentation, and of rates of delivery of planktonic food and propagules. The sediments collected can be partitioned into terriginous and reef-derived, providing information on the extent of impact from the coast. At all coral reef Sites, horizontal Secchi disk readings should be taken on each visit, following CARICOMP procedures, as an index of degree of turbidity.

Water samples could be taken at each visit to coral reef Sites, but an annual water sample is of little real value in tracking nutrification, or presence of contaminants. Nor do we see great value in annual measurements of water temperature, salinity, oxygen content and so on, as discussed in 3.2. We suggest two indirect ways to assess aspects of water quality. The first is by means of simple quantification of algal production at the site. The second makes use of a suitable species as a biomonitor of contaminants. We recommend supplementing these methods at a small number of (Category I) Sites in close proximity to permanent staff by the installation of continuously recording instrumentation to measure temperature, salinity, and a range of chemicals included in seawater. If continuously recording instrumentation is not feasible, use of Hydrolab or similar instruments on a frequent (i.e. preferably weekly) sampling schedule, would be a useful alternative.

RECOMMENDATION 18
At all coral reef Sites, the extent of algal growth will be quantified by a suitable method, as an indirect measurement of the level of nutrification. Possible methods include a) growth over 2 weeks on clean glazed tiles deployed on the substratum and protected from grazing, and b) quantification of turf algal abundance using the procedures of the AGRRA protocol.

The former method is more direct, but requires two visits to the Site. The latter method is applicable to all sites. If both methods are to be used, it will be necessary to experimentally cross-correlate them.

Mussel-watch has been very successful in using mussels as biomonitors of a variety of contaminants in estuarine waters. There is a need to identify suitable equivalents to mussels that could serve as routine biomonitors for use in the region. We discuss this further in Section 4.5.3, after considering procedures at seagrass and mangrove Sites.

5.5.2 Monitoring of seagrass and mangrove sites

As noted in Section 3.3, only CARICOMP among existing protocols provides methodology for monitoring of seagrass or mangrove sites. These are both environments that are structured by a small suite of species of plants, and monitoring of ecosystem 'health' appears likely to be adequately done by focusing effort on these core species. This is the approach that CARICOMP takes, with additional sampling to record aspects of water quality. Sampling of fish species would be a logical addition if there were a decision to make the SMP more comprehensive than this.

The CARICOMP protocol samples both seagrass and mangrove species with an emphasis on their productivity, although measurements of plant size and shoot density are included for seagrasses, and more elaborate forestry approaches are applied to mangrove forests to characterize the forest in terms of size and age distribution of trees at the site. All procedures are straightforward, and use relatively simple equipment, and could be applied through the region as part of the SMP.

RECOMMENDATION 19
At all mangrove and seagrass Sites, the components of the CARICOMP protocol that measure standing biomass, age/size structure, and production of the component plant species should be applied.

In addition to this sampling of the primary structuring agents in each system, seagrass and mangrove Sites should be monitored for the same aspects of water quality as are to be monitored in coral reef Sites. Thus, a 'Visit Record' should be completed for each Site (Recommendation 11), turbidity should be quantified using Secchi disk, and, where possible, using 'tube traps' (Recommendation 17) to integrate sedimentation over time. In addition, it will be useful to duplicate the monitoring of algal production using settlement plates (Recommendation 18) in these Sites as well as at coral reef Sites.

Critical to the 'health' of mangrove and seagrass systems is the spatial extent of patches of that ecosystem, and whether patches are growing or declining. Methods for doing this are not included in the CARICOMP protocol. We suggest a remote-sensing approach to quantify spatial extent at each Site or Location, with repeated sampling on a schedule of every 3 years or more frequently. The opportunity for rapid re-assessment following major perturbations such as hurricanes should be planned for, using this approach.

Remote sensing methods are numerous, and range from purchase of satellite imagery, to flying of appropriately equipped small planes at low altitude. We believe it will be vital for the completeness of the regional EIS to obtain detailed satellite imagery for the entire region at the start of the SMP, and to update this imagery on a decadal or more frequent schedule. This imagery could provide the data needed to assess growth and decline of the primary structuring plants in mangrove and seagrass sites. More carefully targeted aerial surveys could supplement or replace this imagery, so that the monitoring of these Sites could be done more frequently. ***The remotely sensed data will provide information on spatial extent, and density of plants, and on whether boundaries are advancing, stable or retreating over time.***

RECOMMENDATION 20
Remotely sensed data must be obtained at the start of the SMP that will permit determination of the spatial extent and density of plants at all seagrass and mangrove Sites. This remote sampling should be repeated on a schedule of at least once every 3 years, and provision should exist for quick re-survey following major disturbances such as hurricanes. Whether this remote sampling is by aerial reconnaissance, or by satellite should be decided on a cost-benefit basis, as should the decision whether this survey is exclusively to provide data on mangrove and

seagrass Sites, or a part of a region-wide program of up-dating of habitat distributions.

Since there has been far less attention given to monitoring mangrove and seagrass sites than coral reef sites in recent years, this is an area in which the SMP can develop clearly new initiatives and contribute to wider understanding of these important habitats. It will be appropriate for Managers and participants in the SMP whose responsibilities include Locations with mangrove and seagrass sites to consider ways to augment the sampling outlined here in appropriate ways.

RECOMMENDATION 21
As part of the on-going communication among monitoring teams that will be essential to the success of the SMP, it may be useful to identify those Locations in which mangroves or seagrass beds are particularly abundant, and to form a sub-committee charged to explore ways to enhance the effectiveness of monitoring of these systems.

5.5.3 Development of new methodologies

A long-term region-wide SMP will develop new methodologies over time to be successful. If it remains static, failing to adopt new, improved procedures, or failing to monitor new factors and track new threats, it will die. The SMP should be structured in a way that will foster the development and testing of new procedures, and then their careful consideration for implementation within the formal, annual monitoring program.

Development and testing of methods is research***. It can be done by the monitoring teams, but it will probably benefit from the involvement, with them, of members of the academic community, who have the expertise to undertake such development and testing using appropriate, experimental and analytical procedures.*** Most of this research can be carried out entirely within the region, and this developmental activity will play a useful role in the training of graduate students, while helping to improve the SMP.

In this report, we have noted several different occasions where there will be a need for formal testing or comparison of methods, or for the simpler task of determining an appropriate level of replication for a particular method. Development of strong links between the SMP and the region's academic community will greatly facilitate these tasks, and will lead to appropriate collaboration in the development of new methods.

One important area where this collaboration is needed immediately is in the development of appropriate biomonitor techniques as proxies for water quality testing. It will not be possible to collect water samples at all sites, on a frequency that would make the data useful for assessing impacts of herbicides, heavy metals, freshwater run-off, or other terrestrial contamination on the biota of these coastal ecosystems. Appropriate biomonitor procedures will make possible the monitoring of such negative impacts indirectly. ***Given the great lack of attention to issues of water quality throughout the region, this component of the SMP should be seen as of very high priority.*** We suggest that MBRS/SAM funds be allocated specifically to fund research by scientists from academic or research institutions in the region with the goal of developing new biomonitor approaches, using species that occur naturally in the coastal waters of the region. These funds should not be in the form of contracts to produce a specific biomonitor – nobody knows what species will prove most effective in providing a proxy for which aspect of water quality. Instead, they should be as small grants for targeted research. The Mussel Watch program, discussed in Section 3.2, is one effective use of biomonitoring. So is the use of algal growth on tiles as an index of nutrification. Such methods can be simple, inexpensive, easily deployed, yet still able to demonstrate where there are issues of concern regarding water quality.

RECOMMENDATION 22
Coinciding with the commencement of the SMP, MBRS/SAM funds should be provided in a competitive, small grant program to support members of the regional academic community to investigate potential biomonitoring methods that will provide proxies for aspects of water quality such as pesticide residues, heavy metals, nutrients, and so on, that will use species native to and readily available in the region, and that could be deployed as part of the SMP.

RECOMMENDATION 23
The SMP should be structured in a way that will promote collaboration between monitoring teams and members of the academic community. This collaboration will facilitate the development, testing, and cross-calibration of methodologies that will be essential if the SMP is to endure.

This final recommendation brings us back to the beginning. To be effective and sustained, the Synoptic Monitoring Program must be a living, evolving entity. It must have sufficient stability of methods that the database will be useful for spatial and temporal comparisons. It must have sufficient flexibility to be able to address new issues as they arise, and to be able to recognize when methods need to be improved. This flexibility cannot be written into a method manual. ***It will develop as a consequence of the way the SMP is established, and the way it is operated.*** To be effective, the SMP must be implemented by people who believe in its value and can justify its expense to others. The participatory, inclusive approach that has been used until now, and the establishment of a management structure that will ensure that approach continues will be critical to the success of this exciting venture.

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7 Appendices

7.1 Appendix One: Equipment and supplies needed for Synoptic Monitoring Program

The majority of the components of the SMP as recommended in this report require simple field equipment such as tape measures, quadrats, underwater slates and waterproof data forms. Dive equipment, and boats and outboard motors may also need to be procured. Good quality portable GPS instruments will be the most elaborate essential field instruments. Water samplers, secchi disks, and, potentially Hydrolab or similar instrumentation will be required for those Sites at which water quality is to be monitored directly. Other items such as settlement tiles and tube traps, are not available commercially, and must be manufactured from hardware store supplies. Our recommendations rely on simple methods using inexpensive equipment largely because our experience has been that these methods work, and monitoring schedules are not interrupted by equipment malfunction or loss. The SMP must generate data from all Sites regularly and on schedule in so far as possible. Simple equipment helps make this happen.

This modest suite of equipment should be added to with items such as digital still cameras, digital video cameras, if it is the considered opinion that these are warranted. We consider them desirable extras, rather than essential components. Simple laptop computers rugged enough to go into the field may help speed the transfer of data from underwater paper to digital form, but machines with the latest accessories and capabilities are not required. We would consider these ahead of cameras. Computers used in the field will have a short life.

Access to remotely sensed data will require instrumentation and purchase of data. Whether it is seen as a cost for the SMP or for the REIS, computers suitable for storing and manipulating field data, and for connection to the REIS must be obtained.

Supplies budgets will need to be more substantial than equipment budgets. There are going to be travel costs, costs for fuel, and for SCUBA fills, and if there is not money to cover these, the monitoring equipment will sit unused. In addition, the equipment needs will not be satisfied once in Year 1. Many (most) of the items required will need to be replaced regularly due to loss, damage and normal use.

7.2 Appendix Two: Monitoring programs in progress in the Mesoamerican region.

7.2.1 CARICOMP

There are five CARICOMP sites in the region: Puerto Morelos, México (monitored by UNAM); Hol Chan, Calabash Caye, and Carrie Bow Caye, Belize (monitored by Fisheries Department, University of Belize, and Smithsonian Institution respectively); and Cayos Cochinos, Honduras (monitored by Honduras Coral Reef Foundation). Monitoring has not been continuous at all sites, but valuable data over several years are available.

7.2.2 CPACC

Within the region, only Belize is a participant in CPACC. However, in Belize, the Fisheries Department and CZMI have each commenced monitoring of 3 sites: Coral Gardens, Caye Chapel and Gallows Point (monitored by CZMI), and at Hol Chan, South Water Caye and Glovers (monitored by Fisheries Dept.)

7.2.3 Water quality monitoring

In Belize, the CZMI has been monitoring water quality at a number of sites within the Belize lagoon since the late 1990s. Samples are collected monthly from about 70 sites, and subjected to a suite of chemical analyses. This is the only water quality monitoring other than monitoring for human health concerns in the coastal waters of the region.

7.2.4 Baseline environmental data

Throughout the region, management agencies have collected baseline data on sites under management. Sometimes the intention has been to implement monitoring, but in many cases monitoring is not sustained beyond a second or third visit to sites. If accessible, these scattered data could be of value for the SMP. At present, in México, CONANP is commencing monitoring within marine areas under their management. In Belize, most MPAs will have received some baseline data collection from the agencies responsible for their management. In Guatemala, FUNDARY and FUNDAECO may have baseline data on the areas they manage. In Honduras, SECTUR, through its program PMAIB, has baseline information on marine resources of Roatan. They have surveyed reef sites, assessed water quality and used the CARICOMP approach, or similar, to assess mangrove productivity. They are commencing a monitoring program to build on these baseline data. In addition, BICA has baseline data for Sandy Bay, Roatan, and Turtle Harbor, Utila, while RIMS has initiated monitoring of sedimentation at Sandy Bay.

7.2.5 AGRRA Surveys

The AGRRA program has held several training workshops in the region that are usually followed by collection of baseline data at a number of 'home' sites following the workshop. Data should be available through the AGRRA website as well as from the agencies doing the surveys. In some instances this effort has led to subsequent AGRRA monitoring at those sites. In addition, Dr. Phil Kramer conducted an extensive post-Mitch survey of coral health throughout the region using a modification of the AGRRA method.

7.3 Appendix Three: Protocols used for monitoring coral reefs

7.3.1 AGRRA

7.3.2 CARICOMP

7.3.3 CONANP

7.3.4 CPACC

7.3.5 GCRMN

7.3.6 REEF

7.3.7 Reef Check

7.3.8 AIMS (not used in the Caribbean)