

What is the Purpose of Monitoring Coral Reefs in Hawaii?

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Abstract

Before embarking on an ecological monitoring program, it is important to define the objectives. The monitoring program can then be designed to fulfill those objectives. If the purpose of monitoring is to assist resource managers, then a number of important questions should be considered during the design process. Once these questions have been answered, a useful, cost-effective monitoring program can be set up. The model that appears to be having the most success in different parts of the world is one involving at least two tiers of differing resolution. At a small number of sites, high intensity monitoring is carried out at frequent intervals and using species level identification. At a larger number of sites, a broader brush approach such as Reef Check is taken, and typically the monitoring is carried out by a combination of scientists and members of the community. The broad brush results are not only useful to fill in geographically, but also provide an early warning system should more detailed surveys be needed.

Introduction

Monitoring coral reefs to serve management is one type of Environmental Monitoring and Audit (EM&A), a system that has evolved from environmental impact assessments (EIAs). EM&A plans are typically used to check the status of the environment during a development project, such as road or building construction. The monitoring results are checked or audited to determine if changes in the environment are due to the project, and if so what action can be taken to prevent further change. When considering how to monitor coral reefs for conservation purposes, the EM&A model is useful.

The design of a practical, useful monitoring plan involves art as well as science. There is no one correct design, and there are many incorrect ones. A poorly designed monitoring plan can be costly, wasteful, and may produce meaningless, misleading or incorrect results. To avoid these pitfalls, it is essential to follow a rigorous design process that includes consideration of a series of questions about the purpose and content of the project, as well as a detailed review of available data and/or a pilot study to determine key factors. While it may not be possible to answer all the questions posed, it is important to at least define what is not knowable. As part of the monitoring plan, it is essential to include a flexible Action Plan which lists what specific activities may be undertaken if a particular change is detected in the ecosystem. It is important to integrate the monitoring plan with a more general management plan for the area.

While there is good advice available on the many methods available for coral reef monitoring, surprisingly little has been written on the subject of how to choose a suite

of methods to design a complete monitoring and audit program for reefs that will provide the information needed to manage them. A major vacuum is in the area of how to interpret various types of results and what management actions are feasible. The subject of sampling design and statistics for environmental biologists is thoroughly covered by Green (1979). The application of EIA techniques to coastal areas is reviewed by Carpenter and Maragos (1989). The results of a conference on monitoring methods includes much useful information Crosby (1996). Oxley (1997) has presented a summary of important design considerations with respect to coral reefs. Short but useful guidance is given in the UNEP publication “Staff Training Materials for the Management of Marine Protected Areas,” especially Training Session 8.2 (Kenchington and Ch’ng, 1994). Several other UN publications on monitoring include Stoddart and Johannes (1978), Dahl (1981), UNESCO (1984), UNEP/IAEA/IOC (1991), UNEP (1993), UNEP/AIMS (1993). Methods for use in the Caribbean are described in CARICOMP (1991), by Rogers (1993) and Aronson et al, (1995). Those for the Great Barrier Reef are detailed in Oliver et. al, (1995). An extensive menu of marine monitoring methods for both reefs and non-reef areas in the Pacific is provided in English et al, (1997). The use of volunteers and non-professionals in monitoring programs was reviewed by Wells (1995). A set of methods designed to be taught to dive instructors has been developed by McManus et al. (1997). Reef Check methods are described by Hodgson (in press).

There is much literature on ecological sampling design and statistical analysis. Numerous publications by A.J. Underwood and colleagues at Sydney University have covered the statistical aspects of using complex sampling designs such as “before-after, control-impact” or BACI, that meet the assumptions of parametric statistics, particularly ANOVA (e.g. see Underwood, 1993). BACI designs tend to be very complex and can be costly, however, they are the most rigorous available. As an alternative, R.M. Warwick and colleagues at Plymouth Marine Laboratory, UK have promoted the use of multivariate statistical designs, particularly ordination, as a basis for analysis, that allows the sampling design to be relatively simple and inexpensive. Their journal publications and the instruction manual for their Primer statistical package contain much useful advice (Clarke and Warwick, 1997). The final choice of a sampling design for Hawaii will depend on the objectives defined by the government, and the resources available. To begin to consider which monitoring design will be most suitable for Hawaii, it is helpful to discuss possible answers to the following questions.

Who should design a monitoring plan for Hawaii?

There are major differences in philosophy and practice between managers and academic scientists. Some of these differences are shown below in Table 1.

Table 1. Different perspectives on research and monitoring (after Kenchington and Ch’ng, 1994)

Subject area	Academic scientist’s view	Manager’s view
Starting point	Hypothesis	A plan
Main goal of work	New scientific understanding	Solutions
Timeframe	As required to get answer	Short-term

Basis for decisions	“Good” data	Data, values, laws, opinions, costs
Expectations	Additional study always needed	Definite answer required to make decisions
Focus	Details	Broad brush
Bias in decision-making	Rely on biology, chemistry and physics	Include politics and socio-economics
Mode of operation	Do research to gain knowledge	Do research to support decisions for management
Constraints	Not enough data	Data, politics, socio-economics, cost

Because of these fundamental differences, scientists are not the best people to design a monitoring plan. The monitoring plan should be designed as part of an overall management plan that serves the needs of the entire community. The plan should be designed by resource managers who take advice from a multidisciplinary advisory committee including academic and non-academic scientists, businessmen, and other stakeholders in the community. The resource managers must decide on the specific objectives of the monitoring program within the broad goals of enabling them to sustainably manage coral reefs.

What types of monitoring are needed in Hawaii?

There are two types of monitoring that could be useful in Hawaii: 1) high resolution or intensive detailed, species-specific monitoring carried out frequently by well-trained technicians and marine scientists; and 2) less intensive, less specific, community-based monitoring carried out by trained members of the public, and led by a qualified marine scientist. The Reef Check program is an example of the second type of monitoring (Hodgson, in press). In addition, traditional basic and applied coral reef research should continue to be carried out by academic and other scientists. Often, the lines between these three types of field work will be indistinct, therefore, the more communication between these different groups, the less overlap and waste will result.

Who should do the monitoring and analysis?

There is never sufficient funding to carry out all of the monitoring and analysis that would provide a complete picture of natural resources in a timely manner. Fringing coral reefs are found along most coasts of the Hawaiian Islands, and because they are subject to heavy use by local fishermen, divers, etc, there are hundreds of individual coral reef areas in Hawaii that deserve to be monitored. But the state alone does not have sufficient technical staff nor funds to monitor such a large number of sites even once per year. Given the current economic crisis in Hawaii, it is a good time to consider how to do more with less. The types of monitoring that can be handled by different types of surveyors, their advantages and disadvantages are given in Table 2.

Table 2. Types of monitoring carried out by different categories of surveyors and their positive and negative attributes

Surveyor	Can carry out:	Limitation	Advantage
Academic scientist	Detailed species-specific census and stock assessment, ecological assessment, problem solving, analysis with respect to diverse academic sources of information	<ul style="list-style-type: none"> • Slow, and often not available when needed • May be reluctant to come to a conclusion • Little incentive to participate unless allowed to pursue a basic research objective • May need different specialists for e.g. corals and fish • Often unfamiliar with QA 	<ul style="list-style-type: none"> • High quality results • Medium cost • Managers get latest reports from academic research
Commercial consultant	Detailed species-specific census and stock assessment, ecological assessment, problem solving, analysis with respect to diverse academic sources of information	<ul style="list-style-type: none"> • May need different specialists for e.g. corals and fish • Expensive 	<ul style="list-style-type: none"> • Medium to high quality results • Results produced on time, within budget • Willing to offer conclusions based on available data • May keep track of latest reports from academic research • Familiar with QA
State senior scientist	Detailed species-specific census and stock assessment, ecological assessment, problem solving, analysis with respect to diverse academic sources of information	<ul style="list-style-type: none"> • Usually too busy to get in the water • Little time to read academic journals 	<ul style="list-style-type: none"> • Medium to high quality results • Results buried under paperwork • Willing to offer conclusions based on available data • Familiar with QA
State junior scientist/ technicians	Family-level and some detailed species-specific census and stock assessment, ecological assessment, some problem solving	<ul style="list-style-type: none"> • Too few to do all the work required • Many other duties • May lack of experience to interpret data • May not be up to date on latest ecological theories 	<ul style="list-style-type: none"> • Medium to high quality results • Results on time • Familiar with QA
Community members (scuba divers and snorklers)	Family-level and some detailed species-specific census and stock assessment	<ul style="list-style-type: none"> • Require training • May require team scientist during surveys • Different levels of experience • Available only at certain times 	<ul style="list-style-type: none"> • Medium to high quality results if survey is appropriate for skills level • Cheap, enthusiastic, good PR • Participation gives a sense of ownership supports marine conservation

A sensible approach for Hawaii is to design a monitoring program with different levels of detail and intensity that can be carried out using a combination of the above types of surveyors. Given the numbers of recreational divers, and the strong support for marine conservation in Hawaii, the state is in a far better position than anywhere else in the world to carry out a cost-effective, detailed, multi-tier monitoring program involving scientists, state employees, students, and recreational divers. While high-intensity monitoring has one goal – to produce high-quality data, community-based monitoring (monitoring that is carried out by non-scientists in the local community) has a second goal, and that is, to increase support and understanding for marine management. Successful implementation of a community-based monitoring program such as Reef Check, can increase public support for government management programs and has the potential to dramatically decrease the costs of enforcement. Community-based management of marine resources is a Polynesian tradition that was only recently lost in suburban Hawaii.

What resources are available to support the monitoring program?

The state has limited resources available to support a coral reef monitoring program. At most a few tens of sites can be monitored intensively by the existing government researchers. By using volunteer labor in combination with state workers, consultants and academics, the value of the state's investment in monitoring and management will be increased many fold. In addition, by using volunteers, particularly students or community groups, it is possible to attract cash and in-kind cost-sharing for training, surveys etc. In 1997, the first Reef Check global coral reef survey was carried out on a completely volunteer basis and an estimated US\$2 million was provided in cash, in-kind services (hotel rooms, airplane tickets, boat transport), materials, and labor. By using an "adopt-a-reef" program and other community involvement methods, volunteers can play a major role in monitoring and management of Hawaiian reefs. By joining in the Reef Check annual global survey, participants also will be able to quickly see how "their reef" compares to others around the world, and following repeated surveys, whether management measures are working or not. Details of the program may be found at: www.ust.hk/~webrc/ReefCheck/reef.html.

Given the large numbers of people who could potentially be involved in community-based monitoring programs in Hawaii, it will be useful for the state to collaborate with one or more NGOs such as Save Our Seas, Sierra Club or The Nature Conservancy, to handle the coordination aspects of the training and surveys. The high number of potential teams in Hawaii would allow a large number of sites (hundreds) to be surveyed at least annually. This organizational structure then will free up academic and other scientists, and state staff to carry out and manage the more intensive sampling at selected sites of high interest and to handle the analysis and interpretation of results. The latter operation should be a task for a multidisciplinary team from academia, commercial consulting and the government. An external reviewer from outside Hawaii would also be a valuable investment. The program presently operating in Western Australia is comparable. Hawaii should learn from such existing examples of successful programs. The model that appears to be emerging is one involving a tiered set of a few intensively monitored sites in combination with a larger number sites monitored in a less intense, broad-brush manner such as Reef Check.

What are the temporal and spatial scales of interest?

Hawaii covers a large area. How will it be possible to capture sufficient information about reefs throughout the state with the limited resources available?

It is safe to assume that the scale of interest to most people is the condition of their favorite dive or fishing spot. Few people living in Makaha will be overly concerned about the reefs in Poipu. While it would be a mistake to only choose monitoring stations based on usage, it is not possible nor sensible to monitor equally everywhere. It is equally impossible and would not be sensible to monitor all locations at the same frequency. Sites such as Hanauma Bay, that are subject to continuous impacts from tourists and divers should be monitored to some degree a frequent intervals – certainly once per month and ideally once per week. Sites where impacts are not expected at frequent intervals could be surveyed once or twice per year for coral, and quarterly for fish and mobile invertebrates. One approach to designing the monitoring station network is to first mark up a map with high priority sites, and then medium and low priority sites. By using a tiered monitoring design (see below) with different levels of intensity (frequency, number of parameters and level of taxonomy) at different locations, the high intensity stations can be located at high priority locations, with lower intensity stations at medium and low priority sites.

What natural and anthropogenic impacts, and what natural variation in population parameters are expected?

For each study site, it will be important to carry out an assessment of all available information from the scientific literature, technical reports, and from interviews with fishermen and divers to determine what natural and anthropogenic changes are likely to occur (storm waves, runoff, impacts from fishing, boating, pollution, divers etc), and to what extent they might be expected to affect populations of ecologically or socio-economically important organisms. Even in the absence of human impacts, populations of marine animals are notoriously unstable and may vary dramatically over time due to natural events such as poor recruitment, storms etc. Without knowing what level of variation is typical over say, a ten-year period, it is difficult to design an Action Plan that is triggered when specific changes in populations take place.

Pilot studies may be very useful to determine the short-term “noise” in population sizes of important organisms. Such studies are also very helpful for assessing methods and designs. Many grand monitoring schemes have quickly fallen apart when tested under real field conditions.

The available information on reefs should be reviewed for the whole state. The review will help determine what parameters (physical, chemical and biological) should be monitored. It will be useful to have a set of “core methods” to be used at every site so that comparisons can be made, and “additional methods” that can be added at sites with special conditions. Possible parameters are considered below.

What variables are most important to monitor from economic, social, and ecological perspectives? What attributes are most important to monitor (population levels, physiological status of organisms)?

It will be important to include a basic set of physical and chemical indicators of the state of the reef environment in the monitoring program because when a change occurs, that data can make it possible to rule in or out certain causes. Typical useful parameters for intensive monitoring stations would include temperature, salinity, pH, turbidity and oxygen. These measurements can be made with a standard commercial probe and can now be supplemented with an automated chlorophyll and nutrient analyzer.

There are thousands of species of animals, plants and other life forms on Hawaiian coral reefs. Choosing a core set of “indicators” is essential for a cost-effective and meaningful monitoring program. Some potential indicators may be important economically, but less important ecologically. For example, it can be imagined that some species such as the ulua (trevally) or lobster could be harvested down to low levels on a reef without having much impact on other parts of the reef system, perhaps due to a related species moving in to take up its ecological role. But a low level of ulua or lobster could have a significant economic impact on fishermen. In Hawaii, it will be useful to include both ecologically and economically important organisms in the list of indicator organisms.

Each species has a variety of physiological states some of which can be measured e.g. normal and bleached corals, diseased or undiseased fish, live-dead coral cover ratio and partial mortality of colonies. Bioindicators at the organismal and biochemical levels (biomarkers) are now commonly used around the world to assist in the process of monitoring change in the environment. It may be useful for Hawaii to test out the usefulness of some of these physiological indicators as part of the overall monitoring program.

The list of Reef Check indicators for Hawaii is a good starting point for a list of indicator organisms. When the Reef Check program was designed, the criteria for choosing indicators species were: ease of identification, high-value organism, and a high information content with respect to human impacts. The Hawaiian Reef Check fish indicators are: Butterfly fish, Taape Blueline snapper, Roi (Peacock grouper), Ulua (Jacks), Wekeá (Yellow goatfish), Uhu (Parrotfish) >20cm, Lau'ipala (Yellow tang), Puhī (Moray eel), Umaumalei *Naso literatus*. The invertebrates are: Banded coral shrimp (*Stenopus hispidus*), Black urchin (*Echinothrix diadema*), Pencil urchin (*Heterocentrotus mammilatus*), Sea cucumber (edible only), Crown-of-thorns star (*Acanthaster*), Triton shell (*Charonia tritonis*), Lobster, Cowry shells, Collocor urchin *Tripneustes*. In addition, the percentage of the reef covered by the following living and non-living substrate types is recorded: Hard coral, Soft coral, Dead coral, Fleishy seaweed, Sponge, Rock, Rubble, Sand, Silt/clay, Other.

What variables can be monitored most efficiently in terms of useful information content per unit of monitoring effort?

Unfortunately, the origins of scientific monitoring of reefs lie in traditional community ecology that was aimed at understanding relationships among different species. A number of these methods have survived until today and are best avoided as an unnecessary waste of effort. For example, many monitoring programs have included

coral growth forms as one parameter to be measured. Coral growth forms are a very useful descriptive feature of reefs. And yet it is difficult to imagine when a management decision would be taken based on a change in percentage cover of coral growth forms. If no management decision can be made based on a shift in growth forms, there is no point in recording this data *for the purpose of a monitoring program to serve management*. Many monitoring programs differentiate between zoanthids, soft corals and sea anemones. If shifts among these three categories will not result in a management action, then there is no reason to differentiate them in the monitoring program. Many ecologists will swear that it is necessary to record taxonomy to the species level to understand a system. But given typical resource limitations, this is not practical in many cases. Much recent research has indicated that monitoring at the genus or even family level provides a similar answer to that produced from much more costly and time-consuming species level data (Clarke and Warwick, 1997). Taken to its extreme, Johannes (1998) has argued that many management decisions can be made with no quantitative data. More importantly, when problems are detected at a broad level, it is always possible to refine monitoring to a more detailed, intensive level to try to determine a cause of a change.

Given the limited time, staff and money available for monitoring, it is essential to formally consider which parameters provide value for money. Just as fisheries scientists may calculate catch-per-unit-effort (CPUE), so it is possible to record information content-per-unit-effort (ICPUE). From this perspective, lobster have a high ICPUE because they are a highly sought after, valuable marine species. Their absence from an area previously known for lobster may indicate high lobster fishing pressure. The standard Reef Check core methods have been adapted for Hawaii by the inclusion of local high-value species. Additional species could be added for increased information.

Obviously, the selection of methods will determine the time, effort and cost to obtain the data of interest. There is a clear trend towards modifying methods to become more efficient. So-called "Rapid Assessment" protocols have been devised, but some of these are in fact very time consuming. The Reef Check program uses a combination of belt and line transects to record fish, invertebrates and substrate types. Point sampling is used because this is one of the quickest methods underwater. One survey can be completed in two hours. For Reef Check, it is recommended that a full set of still photos and a video be obtained of the transect and surrounding area. Such photographs and video can be very useful in answering unexpected questions that crop up long after the survey is completed. The ability to identify organisms in videos and photos is limited, however. In Reef Check surveys, this information is supplemented by a site description including a series of questions that is aimed at gathering anecdotal information such as perceived impacts of fishing.

What quantitative and null hypotheses will be useful to test statistically?

It is useful to consider null hypotheses for what we expect the natural range of variation to be on reefs. This can be the basis for the Action Plan that guides management, however, it should not be the only basis. Univariate measures such as a 25% reduction in a species of butterflyfish should be examined in light of a suite of other parameters that could point to a process and a cause. The manager should not be locked into taking an action that is not necessary. In management, it is very dangerous

and costly mistake to adopt a “no change expected” null hypothesis. As noted above, all populations change due to natural causes. Quite often, changes due to natural causes, e.g. storms, can be quite large in comparison to anthropogenic changes due to e.g. sedimentation, divers, pollution etc. Unfortunately, all these changes are additive. Generally, what is of interest is to detect anthropogenic changes that indicate that the reef is moving in an unsustainable direction.

**What sampling design (temporal and spatial) including controls will be used?
What statistical procedures will be used to test the hypotheses?**

It is important to consider the sampling design needs with respect to detecting change, particularly if the sampling design is meant to produce results that are to be assessed using parametric statistics such as ANOVA. A statistician should be involved in the design from the beginning. Multiple control stations are required, and sufficient replication is needed across all levels of the sampling design. If the goal is to detect change at a particular reef, then replicates within that reef will be needed. A nested or hierarchical design is a useful solution (Oxley, 1997). The same concerns with space are applicable to time. If an annual comparison is required, then temporal replication is required at a smaller time interval to reveal any sub-annual variation. Random, stratified sampling is usually most appropriate for coral reefs due to clear zonation patterns. Usually, a combination of univariate and multivariate analyses is most illuminating. For example, a univariate approach may be used with a single organism such as a species of lobster, while a multivariate ordination approach may be most useful for assessing overall reef health. An excellent example of a combined approach is given by the Great Barrier Reef monitoring program (Oliver et al, 1995). Numerous personal computer packages are now available at reasonable cost that can handle very complex multivariate tests with large matrices.

What level of change is ecologically significant?

It is quite possible for a change to be statistically significant without being ecologically significant. This can occur when there is a relatively small but uniform increase at many sites in a large sample. The change may be a seasonal change or due to some other natural factor that is not something that a manager should be concerned about. On the other hand, changes may occur that are clearly ecologically significant, but due to the sampling design, cannot be shown to be statistically significant. Therefore it is important to not only plan to rely on a statistical interpretation of change but also **to decide in advance** what levels of changes would be considered *ecologically* significant in Hawaii. For example, what decrease in the live:dead coral ratio, or what increase in partial coral mortality or decrease in a fish populations should be considered sufficient cause for alarm. By formally going through this decision-making process about what changes are considered important, before changes occur, a decision matrix can be developed that gives managers a clear idea of their objectives.

How will the cause of a significant change be determined?

Although strictly speaking not part of the monitoring plan, but rather the Action Plan, it is clearly important to have a mechanism in place to try to determine the cause of a statistically and/or ecologically important change in the reef. The procedures may

include increasing the frequency or number of locations for monitoring, alerting a team of specialists (rapid response team) to investigate, and listing the methods that could be employed. Unless such a system is planned well in advance, a major change could occur and be finished long before a response could be assembled.

What options are there for management action in response to a change, and what level of reef change should trigger a change in management?

As part of the Action Plan, once a change has been detected at a reef, and a cause has been suspected or determined, it is useful to have a prepared plan listing possible options for management decisions. For example, if a decrease in certain fish species is detected, one response might be to close the area to fishing. If partial mortality of corals has increased at a popular dive site for tourists, and it is suspected that tourists are partially to blame, then restrictions could be placed on the number of tourists visiting each day.

There are many types of changes that could be traced to “natural variation.” It is important not to invoke an inappropriate and possibly expensive management action in response to a natural change. Therefore, it is critically important to avoid locking the manager into a particular management action in response to a given change. That is, the Action Plan should be designed as a menu of possible actions that allow the manager the flexibility to make a management decision based on all available evidence.

What quality assurance procedures are needed to ensure that the data are correct?

Quality assurance (QA) and control (QC) are now standard procedures in most commercial enterprise. QA essentially refers to ensuring there is a plan for all activity, and a paper trail so that if a mistake is made, it can be traced to someone and rectified. QC refers to ensuring the quality of a product, in this case monitoring data and reports. QA and QC are regulated by the International Standards Organization (ISO) and certification to their standards is a huge and costly undertaking. A typical QA manual for a small EIA job fills a 10 cm thick binder with detailed instructions for every aspect of work. Industrial strength QA/QC is inappropriate for most monitoring programs. Instead, a practical QA/QC system should be designed that meets the needs of the program without drowning staff in procedures and forms. The QA/QC system should be formalized in the form of a QA/QC manual. The fundamental objective of the system should be to enable the project manager to minimize errors and to track them when they occur, so that they can be corrected.

Data management is an important aspect of QA/QC. Standard procedures should be written down and all data sheets should include a signature line. Data transfer and storage procedures need to be specified including automated and manual error checking. Calibration procedures for all equipment should be specified, including the use of blank samples for water testing. The methods used for pollution testing should be very carefully designed to ensure that contamination in the field or lab cannot occur. For example, the use of metal objects for the collection, storage or testing of samples for heavy metal analysis is not permitted. Finally, a safety plan should be written down that provides clear guidelines for dealing with emergencies of different types.

What are the deficiencies of the design and how will they be dealt with?

There is no such thing as a perfect monitoring program and it is useful to review the program and identify deficiencies on an annual basis so that contingency plans can be made to fill gaps. The monitoring program should be sufficiently flexible to allow it to be altered as needed in the future to take into account any new information or needs.

Conclusions

If the objective of monitoring in Hawaii is to allow sustainable management of reefs, there is a flexible model available. The model that appears to be having the most success in different parts of the world is one involving at least two tiers. At a small number of sites, high intensity monitoring is carried out at frequent intervals and using species level identification. At a larger number of sites, a broader brush approach such as Reef Check is taken, and typically the monitoring is carried out by a combination of scientists and members of the community. The broad brush results are not only useful to fill in the picture geographically, but they also provide an early warning system indicating when more detailed surveys are needed. Most importantly, the use of community-based method builds up local support for management measures that result from the monitoring. Without this community support, enforcement costs will remain high, and the management plan that is the justification for the monitoring program, will fail.

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