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# 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 including: 1) Who is going to do the monitoring and analysis, and what resources are (should be) available to support it? 2) What natural and anthropogenic impacts are expected? 3) What natural variation in population parameters is expected? 4) What are the spatial and temporal scales of interest? 5) What variables (population levels, physiological status) are most important to monitor from economic, social, and ecological perspectives? 6) What variables can be monitored most efficiently in terms of useful information content per unit of monitoring effort? 7) What quantitative and null hypotheses can be used to test whether a change is statistically significant? 8) What sampling design (temporal and spatial) including controls will be used? What statistical procedures will be used to test the hypotheses? 9) What level of change is ecologically significant? 10) How will the cause of a significant change be determined? 11 ) What options are there for management action in response to a change, and what level of reef change should trigger a change in management? 12) What quality assurance procedures are needed to ensure that the data are correct? 13) What are the deficiencies of the design and how will they be dealt with? Once these questions have been answered, a useful, cost-effective monitoring program can be set up.

## Introduction

Monitoring coral reefs is one type of Environmental Monitoring and Audit (EM&A), a system that has evolved from environmental impact assessments (EIAs). The design of a practical, useful EM & A plan involves art as well as science. There is no one correct design, and there are many incorrect ones. A poorly designed EM & A 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. As part of the EM&A 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 EM&A plan with a more general management plan for the area.

Surprisingly little advice has been written about the subject of EM&A plan design, particularly with respect to coral reefs. 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). 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). The monitoring program used in the US Virgin Islands is described by Rogers (1993) and that on the Great Barrier Reef is explained 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 concise set of methods designed to be taught to dive instructors has been developed by McManus et al. (1997).

There is a great deal of literature available 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 BACI, that meet the assumptions of parametric statistics, particularly ANOVA (e.g. see Underwood, 1993). As an alternative, R.M. Warwick and colleagues at Plymouth Marine Laboratory, UK have promoted the use of multivariate statistical designs, particularly ordination. Their journal publications and the instruction manual for their Primer statistical package contain much useful advice (Clarke and Warwick, 1997). To determine which EM&A design will be most suitable for Hawaii, it is helpful to consider 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** |
|---|---|---|
| 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.

**What types of monitoring are needed in Hawaii?**

There are two types of monitoring that could be useful in Hawaii: 1) intensive detailed, species-specific monitoring carried out 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, submitted). 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. Because coral reefs are found almost everywhere in Hawaii, and because they are subject to heavy use by local communities, there are hundreds of individual coral reef areas in Hawaii that deserve to be monitoring stations. 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 grades 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 | • Slow, and often not available when needed<br>• May be reluctant to come to a conclusion<br>• Little incentive to participate unless allowed to pursue a basic research objective<br>• May need different specialists for e.g. corals and fish<br>• Often unfamiliar with QA | • High quality results<br>• Medium cost<br>• 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 | • May need different specialists for e.g. corals and fish<br>• Expensive | • Medium to high quality results<br>• Results produced on time, within budget<br>• Willing to offer conclusions based on available data<br>• May keep track of latest reports from academic research<br>• 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 | • Usually too busy to get in the water<br>• Little time to read academic journals | • Medium to high quality results<br>• Results buried under paperwork<br>• Willing to offer conclusions based on available data<br>• Familiar with QA |
| State junior scientist/ technicians | Family-level and some detailed species-specific census and stock assessment, ecological assessment, some problem solving | • Too few to do all the work required<br>• Many other duties<br>• May lack of experience to interpret data<br>• May not be up to date on latest ecological theories | • Medium to high quality results<br>• Results on time<br>• Familiar with QA |
| Community members (scuba divers and snorklers) | Family-level and some detailed species-specific census and stock assessment | • Require training<br>• May require team scientist during surveys<br>• Different levels of experience<br>• Available only at certain times | • Medium to high quality results if survey is appropriate for skills level<br>• Cheap, enthusiastic, good PR<br>• 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 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. 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 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.

**What are the temporal and spatial scales of interest?**

Although some island residents may occasionally feel trapped, 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. 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 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 a mini-EIA type review to determine what natural and anthropogenic changes are expected to occur, and to what extent they might be expected to affect populations of ecologically or socio-economically important organisms. This information 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" can be added at sites with special conditions.

All available literature should be reviewed to seek information on natural population variation over time. 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 to be expected over say, a ten-year period, it is difficult to design an Action Plan that is based on changes in populations.

**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 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.

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.

**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. 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.

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.

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

It is useful to consider 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. Only with long-term monitoring will it be possible to determine the natural range of variation of each parameter.

**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. 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.

**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, can not 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 responsibilities.

**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 an increased frequency or number of locations for monitoring, the alerting of a team of specialists (rapid response team) to investigate, and a listing of 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 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 and control are now standard procedures in most commercial enterprise. 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.

**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.

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