

Sampling May be Haphazardous to Your Reef Monitoring Program

Caroline S. Rogers
US Geological Survey
Biological Resources Division
P.O. Box 710
St. John, USVI 00830
(340) 693-8950 phone
(340) 693-9500 fax
caroline_rogers@usgs.gov

Key Words: reef, monitoring, coral, video, random

Abstract. Because of the difficulty of collecting data underwater and the time and depth constraints imposed by Scuba diving, most monitoring programs designed to document changes in coral reefs over time have been lacking in spatial scale and statistical rigor. Although reef scientists understand the importance of random sampling, few if any monitoring programs have sampling designs based on random selection of study sites. If our goal is to accurately assess the changes on coral reefs on a local, regional or global scale we must have confidence in the data we are depending on. This paper describes a statistically rigorous approach to sampling of coral cover based on the videotaping of randomly selected transects on coral reefs and compares this video method to the more widely-used linear chain transect method.

Introduction

Recent assessments of the status of coral reefs worldwide have painted a grim picture of reef degradation. By one estimate, 10% of the reefs have been destroyed, 60% will be lost within the next 40 years, and only 30% of the reefs can be considered stable (Wilkinson 1992). Some scientists argue that existing data are inadequate to draw these far-reaching conclusions, pointing out that most of the world's reefs have not been evaluated. There is not even general agreement about the areal extent of these marine ecosystems—a recent estimate of 225,000 km² (Spalding and Grenfell 1997) compares to one widely cited previous estimate of 600,000 km² (Smith 1978). The discrepancy is at least partly attributable to different opinions on what constitutes a “reef”. Any generalization about current status and trends in reef systems can only be as good as the data upon which it is based, and high quality data from a sufficient number of widely distributed sites are not available.

Reef scientists recognize the need to increase the spatial and temporal scale of their examinations and to use more rigorous statistical approaches to address these pressing concerns about reef change on a global basis. Interest in long-term monitoring of reefs has grown in recent years as a result of several international symposia and initiatives which have called for greater understanding of coral reef ecosystems, but few long-term data sets exist for these critical ecosystems. In a recent review of quantitative studies of coral abundance, Dr. Joseph Connell was able to find only 23 studies of four or more years in duration, and data were available for only three locations from the Eastern Caribbean: the US Virgin Islands (including our data from reefs off St. John), the Netherlands Antilles, and Barbados (Connell 1997). Most of these studies were conducted on a very small spatial scale. Whether our intention is to generalize about the current status of coral reefs (specifically, the amount of living coral) on a local, regional or global basis or to determine if and how they are changing over time, we must be certain that the data we are collecting are representative of the areas about which we are making conclusions. We also have to avoid inappropriate extrapolation from small areas and small data sets to larger geographic areas.

Although numerous manuals on coral reef monitoring recommend random selection of study sites (or quadrats, transects, etc.), none to date addresses exactly how these sites will be selected (English et al. 1994, Oxley 1994, Rogers et al. 1994). Few if any

monitoring programs have sampling designs based on **random** site selections. As Roger Green notes, "Putting samples in "representative" or "typical" places is not random sampling" (Green 1979). Because of logistic, financial, and time constraints, most scientists have used **haphazard** sampling in which the diver surveys a portion of the reef, e.g., a transect, and then swims a random number of fin kicks or meters away to the subsequent sampling site, and so forth. In this case, the location of each transect is dependent on the one which precedes it, i.e., the sampling units are not independent of each other. In addition, only one portion of the reef zone of interest may be included in the sampling. In contrast, truly random sampling ensures that each transect (sampling unit) has an equal probability of being selected for examination. The inherent variability (patchiness) in coral reef structure presents real challenges for sampling of these ecosystems. How can we be sure that our sampling is random and that it meets the criteria for rigorous statistical analysis?

The purpose of this paper is to propose a statistically rigorous approach to sampling of coral cover based on the videotaping of randomly selected transects on reefs selected for monitoring. It is an attempt to address the shortcomings of previous studies which have lacked sufficient spatial scale and statistical rigor. Although we are just now starting to test this approach on the reefs we study, we feel it warrants consideration by others, especially those who are just setting up reef monitoring programs. It involves random selection of locations for transects which will be videotaped with a digital video camera in an underwater housing to provide data on cover by reef organisms. (The details of the statistical treatment of the data collected with this method will not be discussed here.) In addition, we briefly compare the video method to the more widely-used linear chain transect method and discuss some of the disadvantages and advantages of each. Specifically, our purpose has been to develop a statistically defensible protocol for monitoring coral cover on reefs around St. John, US Virgin Islands. We want to test the following null hypothesis: H_0 = There is no change in total hard coral cover within the lower forereef zone on selected reefs around St. John over time. We want to determine the magnitude of differences in mean coral cover that can be detected between years at the same study site, given samples of fixed size and a prescribed level of statistical significance.

Several parameters can be used to describe the structure of a particular reef, including coral cover, density of colonies, condition of colonies, and size frequency distributions. We have decided to emphasize monitoring of coral cover (as well as algal cover) for several reasons. Most of the stresses which affect corals around St. John cause loss of coral tissue. If the corals fail to recover, the affected areas will be rapidly colonized by algae. Major stresses therefore will result in a decrease in the amount of "cover" of living coral on the reef and, usually, an increase in the amount of algae.

Because this protocol is being developed for the National Park Service (which administers Virgin Islands National Park on St. John) we are especially interested in being able to document the effects of anthropogenic (i.e., more "manageable") stresses. However, St. John has experienced several severe hurricanes in the last 2 decades, and

these storms and coral diseases have reduced coral cover on the reefs, rendering them more susceptible to detrimental human activities (e.g., Rogers et al. 1997). Monitoring should provide information on the responses of the reefs to a combination of natural and human stresses and should help to differentiate natural rates of change from those induced by humans.

Video Method

Rationale for using the video method

Given the complexity of coral reefs, their 3-dimensional relief or topography, and high diversity of organisms, a combination of photographic and non-photographic methods and different sampling approaches are required to assess changes in their structure over time (see Rogers et al. 1994). The primary method we used in the past was linear chain transects at fixed transects. We have now decided to use underwater video method for monitoring of reefs around St. John. This method is based on methods described in detail in Aronson et al. (1994) and Wheaton et al. (1996). Benthic cover is calculated from unique digital images of transects using acetate overlays containing random points or using an image analysis program.

Because Scuba diving imposes severe depth and time constraints on scientists attempting to collect data, most reef monitoring studies have been based on very small areas. Use of video cameras has given us the opportunity to efficiently collect larger amounts of certain types of data, giving increased return for the time spent underwater (see Carleton and Done 1995). For example, it takes less than 15 minutes to record a video transect 20 m long but sometimes over 4 hours to collect information along the same transect using the linear chain transect method. Although the chain transect method provides data on the 3-dimensionality of the reef surface and on organisms which are not visible from a vantage point directly above the reef (the "planar" view recorded with video), it is not suitable for collecting data over a large spatial scale. The video method requires a skilled diver but no expertise in identification of reef organisms, the basis of the chain transect method. In other words, it can be used by non-scientists. The video method can provide a substantial amount of useful information while minimizing a diver's time in the water, and unlike most other methods, provides an archivable, visual record of the reef. Video transect images can be stored on write-to CD or DVD. It is now possible to use image analysis (and associated point count software, such as that developed by Dr. Phil Dustan's group at the College of Charleston, South Carolina) to store the identification of the substrate associated with each pixel. Archived images can be sent to other researchers, and the same image and pixels can be identified for quality control.

Disadvantages of the video method

In spite of its numerous advantages, the video method has its limitations. Changes in the amount of living coral recorded with still photography or video are changes in the amount of living coral tissue visible in planar (2-dimensional) view. This technique will

under-represent colonies with a more vertical morphology (e.g., pillar coral) and is more suitable for monitoring reef zones with species exhibiting encrusting and hemispherical morphologies. The video method is not appropriate for monitoring recruitment of hard corals because resolution is not adequate to provide images of recruits less than about 4 cm in diameter. Some investigators working with analog video cameras on reefs in Florida have observed that it can be very difficult to differentiate macroscopic algae ("macroalgae") from algal "turf" species because of the planar perspective and quality of the image. (The digital camera we propose to use provides better image quality.) Also, in areas with high sedimentation rates, sediment particles may obscure the underlying algae resulting in underestimates of the algal cover. These are important considerations given that increases in macroalgae are considered one of the clearest indications of severe stress to reefs. Image analysis can take a very considerable amount of time (an estimated 2 or more hours per 20 m transect) whereas chain transect data can be processed relatively quickly.

Sampling methods and designs

Here we describe the approach we intend to take on reefs off St. John. At each of our study sites, we plan to define a statistical population (in this case, a population of transects) composed of spatial units of sampling that are limited to locations within the reef zone. We define the population to be sampled at each reef by superimposing a uniformly-spaced (virtual) grid of locations based on 10-m intervals between all locations. The population therefore comprises a finite number of locations on the reef that must be identified using GPS technology or an underwater surveying system (see below). To ensure that sample units in the population are non-overlapping, each unit is defined as a 10-m transect of fixed width that begins at one of the locations on the uniformly-spaced grid and is oriented in the same direction as every other transect. (It is generally best to sample along depth contours because depth exerts a major control on reef development. Changes in cover and species composition often occur with changes in depth.) Although compass orientation remains the same for all transects within a population, it may differ among study sites. For example, an exception to common compass orientation is needed where spur-and-groove reef formations can result in unacceptably large differences in depth of a single transect. At such locations, it is essential to develop an unambiguous set of instructions that allows divers to select compass orientation during the survey without producing overlapping transects or including sand channels in the videotransects. (For example, one rule might be that each diver ensures that there is 10 m of hard bottom along a depth contour, and if this is not the case, an alternate site must be selected.) These "rules" must be sufficient to ensure that all divers will make the same decisions.

Implementation of the sampling design

Here we describe the approach we plan to take at one of our study sites, Newfound Bay, in greater detail in an attempt to clarify several of the points raised above. Newfound

Bay is on the north side of St. John. The reef in this bay has a well-defined and extensive lower forereef zone located seaward of the reef crest and the upper forereef zone. The lower forereef slopes gradually from a depth of about 15' to a depth of 30', where the slope increases abruptly until a flat, sandy plain is reached in about 45-50' of water. The lower forereef zone in Newfound Bay actually comprises two distinct areas (eastern and western) that are separated by a sand channel. We are proposing to sample the western forereef zone.

The western forereef is about 250 m (= distance alongshore) x 90 m (= distance offshore). We plan to begin by defining the boundaries of the reef zone we want to sample. We then define the population (of transects) by superimposing a uniformly-spaced grid of locations based on 10-m intervals between all locations. A 10-m transect is associated with each location. All transects will be oriented parallel to shore and point in the same direction to ensure that they are non-overlapping. This also limits the range of depths that may be encountered within a single transect. In a perfectly rectangular reef we would expect a statistical population of about 250 transects $(=(250/10)*(90/10+1))$ to fit within the perimeter; however, the actual population size of the western forereef will obviously depend on its shape.

Prior to the actual survey of the western forereef, a pilot survey will be used to determine whether the population should be stratified by depth intervals. In the pilot survey duplicate 10-m transects will be videorecorded at depths of 15, 25, and 35'. Transect locations will be selected haphazardly, attempting to include portions of the forereef that are representative. Based on the results of the pilot survey, the population of transects (for the entire reef zone or for the shallow and deeper zones) will be identified. Randomly selected transects will be sampled, analyzed for substrate composition (cover), and analyzed statistically.

Once the results of the pilot survey have been analyzed, we will collect videorecordings of a random sample of n transects taken from the population of N transects as follows. In advance of the survey we know the spatial coordinates, say (x_i, y_i) , for each of the N transects ($i = 1, \dots, N$) relative to one another and within the limitations of the GPS (or other underwater surveying system). By randomly permuting the sequence of integers $(1, 2, \dots, N)$ and selecting the first n elements of the permutation, we obtain a simple random sample of n transects. Next, divers will be sent to make a videorecording of a 10-m transect (delimited by surveying tape) at each of the n locations. The actual order in which the n randomly selected transects are videotaped will be chosen to minimize the time spent underwater and the time needed to move from one transect location to another.

The locations of the transects to be sampled are determined prior to the diver entering the water. Where differential GPS technology is available, buoys attached to weights can be placed at the latitude and longitude of the randomly selected positions which mark the beginning of each transect. This method is only feasible when sufficiently accurate GPS is available. Also, it is difficult to translate the surface coordinates accurately to the locations on the bottom. An additional concern is the potential for damaging reef

organisms when lowering the weights attached to the buoys. There are also (expensive!) underwater surveying systems (e.g., Desert Star's Aqua Map system) which depend on use of SONAR signals from fixed reference units (baseline stations) and a mobile unit carried by a diver which makes location of the next transect to be sampled much more efficient. We plan to test such a system in the near future.

Comparisons of data collected with the linear chain transect and video methods

It is useful to briefly compare the results from the video method with the widely-used, less expensive chain transect method. The chain transect method (described in detail Rogers et al. 1994) and videotransect methods do not sample the same portion of the reef. The former involves counting of all surfaces (organisms, substrate, etc.) directly under a line while the latter records a video of a swath of the bottom about 45 cm wide. The chain method provides an estimate of the cover of the 3-dimensional reef surface while the video method gives a planar view. Here we compare the results of both of these methods to measure cover by corals and other substrate along five 20 m permanent transects at Newfound Bay (Table 1). The study site, in 25', is a forereef zone dominated by Montastraea annularis. Estimates of total coral cover and cover by the dominant coral species were surprisingly close. Although all values for macroalgae were less than 10%, the video method consistently gave higher values. In some cases, it was difficult to distinguish macroalgae from algal turf species in the video. (This can easily be done by a diver using the chain method.) Only gorgonian holdfasts are sampled with the chain method while any of the gorgonian in the video camera's field of view can be included in the sample. Consequently, cover by gorgonians is much higher using the video method. (Note that large gorgonians can obscure organisms beneath them.) Because the chain method involves measuring surfaces which are not visible in the planar view and these surfaces typically have algal covered dead coral, we would expect the category which we refer to as "dead coral with algae" to be higher with the chain method. However, the two methods show no significant difference between mean values for this category. Of course, this discussion is only cursory, and more work must be done to adequately characterize the differences between these methods (see CARICOMP 1997, Green and Smith 1997). Reefs dominated by branching coral species would probably give somewhat different results.

Conclusions

The selection of an appropriate sampling design and method must be driven by the specific purpose of the monitoring and the available resources. In addition, variations in the overall physical configuration (morphology) of the reef to be sampled may necessitate modifications or use of a different method altogether. The purpose of this paper has been to propose an approach to sampling of coral cover which is based on the videotaping of randomly selected transects. Roger Green points out, "It requires effort to ensure that sampling is random" (Green 1979). The question is, can we afford the time and expense to do random sampling? Can we afford not to? How much confidence can we have in

the conclusions we draw from sampling which is haphazard ? We have learned a lot about coral reefs in spite of the limitations of our previous approaches to sampling and a lack of statistical rigor. The difficulty and expense have to be weighed against the quality of the data which are collected. We suggest that people who are designing reef monitoring programs to track changes in coral cover over time *consider* using the video method at randomly selected transects. We hope that this paper will stimulate lively debate about this approach!

Acknowledgements

My thanks to Jeff Miller, Ginger Garrison, Ellen Gorman and Rob Waara for many hours of hard work collecting reef data with video and chain transect methods. Special thanks to Jeff Miller for his meticulous work analyzing the videotransects and producing Table 1 and to Ginger Garrison for analysis of the chain transect data. I am grateful to Bob Dorazio for his substantial contributions on sampling design. Jeff Miller and Ginger Garrison made many helpful comments on the manuscript.

References

Aronson RB, Edmunds PJ, Precht WF, Swanson DW, Levitan DR (1994) Large scale, long-term monitoring of Caribbean coral reefs: simple, quick, inexpensive techniques. Atoll Research Bulletin 421: 1-19

CARICOMP (1997) CARICOMP monitoring of coral reefs. Proc of the 8th Int Coral Reef Sym1: 651-656

Carleton JH, Done T (1995) Quantitative video sampling of coral reef benthos: large-scale application. Coral Reefs 14: 35-46

Connell JH (1997) Disturbance and recovery of coral assemblages. Coral Reefs 16, Suppl.:S101-S113

English S, Wilkinson C, Baker V (eds) (1994) Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science. Townsville, Australia. 368 pp

Green RH (1979) Sampling design and statistical methods for environmental biologists. Wiley, New York. 257 pp

Green RH, Smith SR (1997) Sample program design and environmental impact assessment on coral reefs. Proc of the 8th Int Coral Reef Sym 2: 1459-1464

Oxley, WG (1994) Sampling design and monitoring. In: English S, Wilkinson C, Baker V (eds) Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science. Townsville, Australia. pp299-312

Rogers C, Garrison G, Grober-Dunsmore R (1997) A fishy story about hurricanes and herbivory: seven years of research on a reef in St. John, U.S. Virgin Islands. Proc. 8th Int Coral Reef Sym 1: 555-560

Rogers C, Garrison G, Grober R., Hillis Z-M., Franke MA (1994) Coral reef monitoring manual for the Caribbean and Western Atlantic. National Park Service. 100 pp. including photographs

Smith SV (1978) Coral-reef area and the contributions of reefs to processes and resources of the world's oceans. Nature 273: 225-226.

Spalding M, Grenfell AM (1997) New estimates of global and regional coral reef areas. Coral Reefs 16: 225-230.

Wheaton JL, Jaap WC, Dustan P, Porter J (1996) Coral reef hard bottom monitoring project. Annual and 4th Quarterly Report. Florida Keys National Marine Sanctuary Water Quality Protection Plan. 30 pp

Wilkinson CR (1992) Coral reefs of the world are facing widespread devastation: can we prevent this through sustainable management practices? Proc. of the 7th Int Coral Reef Sym 1: 11-21

Ccattach\hawaii.doc

Table 1: Comparison of data on cover by reef organisms and substrate at Newfound Bay using chain transects and video method.

CATEGORY	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5		Mean (SE)	
	chain	video	chain	video	chain	video	chain	video	chain	video	chain	video
CORAL	18.7	16.5	24.7	23.5	26.6	31.4	29.4	31.8	28.5	26.6	25.6 (4.3)	26.0 (6.4)
Montastraea annularis	10.7	11.2	20.1	18.7	21.1	22.9	15.5	16.8	16.0	19.1	16.7 (4.1)	17.7 (4.3)
GORGONIANS	1.3	14.3	1.3	10.1	0.8	8.2	1.2	8.1	0.3	4.6	1.0 (0.4)	9.1 (3.6)
SPONGES	2.7	2.3	3.4	2.0	2.8	0.6	2.7	1.8	3.6	2.7	3.0 (0.4)	1.9 (0.8)
ZOANTHIDS	0.1	0.2	0.7	0.2	0.0	0.0	0.0	0.0	0.6	0.0	0.3 (0.3)	0.1 (0.1)
MACROALGAE	2.7	7.4	5.1	9.5	5.3	8.8	3.4	7.3	4.8	6.1	4.3 (1.1)	7.8 (1.4)
OTHER, LIVE	0.2	0.0	0.8	0.0	0.0	0.2	0.3	0.2	0.2	0.0	0.3 (0.3)	0.1 (0.1)
DCA	46.1	48.6	34.4	49.5	37.8	38.8	39.4	43.8	35.5	49.7	38.6 (4.6)	46.1 (4.7)
SAND	18.6	7.9	21.5	4.2	24.2	11.5	16.0	5.7	16.1	8.4	19.3 (3.6)	7.5 (2.8)
UNKNOWN	na	2.7	na	1.0	na	0.4	na	1.2	na	1.9		

NOTE: "DCA" refers to dead coral with turf algae. Also includes rubble, pavement and coralline algae.

"UNKNOWN" refers to indistinguishable sample points.

Author: Caroline Rogers at NBS-REMOTE

Date: 06/01/98 10:48 AM

Priority: Normal

TO: Brendalee Phillips at NBS-REMOTE

Subject: paper for reef workshop

----- Message Contents -----

Hi--

I am attaching a copy of the paper I prepared for a reef monitoring workshop in Hawaii June 8-10. (ginger is going to it--leaving this Saturday). Jeff will e mail you the Table which goes with it. Please show it to Zandy and read it when you get a chance. I think it might help clarify the approach we are trying to get to monitor coral cover.

Cheers-

Caroline