Tracking changes on a reef in the US Virgin Islands with videography and SONAR: a new approach

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Abstract Live coral and other benthic organisms were monitored along transects at Newfound Reef, St. John, US Virgin Islands, in March 1999, March 2000, and April 2000 using a digital video camera and an underwater position-locating system. In March 1999, twenty, independent transects (10 m long) were selected randomly as a subset of the "population" of all possible transects in the forereef, based on superimposing a uniformly spaced 10 m x 10 m (virtual) grid over the study site. These transects were videotaped in March 1999 and March 2000, and benthic components (reef organisms and substrate) were identified and quantified using random dots applied to still video images. A second set of randomly selected transects was videotaped in April 2000. From March 1999 to March 2000, mean cover of live coral decreased significantly from 18.0 $\pm$ 6.3 (SD) to 13.9 $\pm$ 6.1 (SD), a decline of over 20%. Mean cover of macroalgae, dead coral with algal turf, and other categories did not change significantly. The decrease in coral cover may be the result of chronic coral disease or damage from two hurricanes in the fall of 1999. No differences in mean coral cover or cover by other categories were found between March 1999 and April 2000, or between March and April 2000. Statistical analysis revealed that revisiting the same transects produced better power and ability to document change than sampling different sets of random transects each time.

Introduction

Given significant evidence of reef degradation from around the world (Wilkinson 2000), effective programs for monitoring reef systems are urgently needed. Furthermore, President Clinton’s Executive Order 13089 of June 1998 mandates “a comprehensive program to map and monitor US coral reefs” and calls for “research aimed at identifying the major causes and consequences of degradation of coral reef ecosystems.” Monitoring provides a context for experimental research. A variety of monitoring techniques is now available. Each method has advantages and disadvantages, and the selection of the best approach depends primarily on the objectives and the available resources (Rogers et al.

1994). Recent technological advances in underwater photography (both still and video) and in precisely locating sampling sites (e.g., with Global Positioning Systems or SONAR) offer significant improvements over previous methods for tracking changes on reefs. (Other advances in remote sensing and hyperspectral imagery also appear promising, but our focus here is on in-water assessments of the benthic components of reef communities.)

In this paper, we describe a new approach that combines videography and random selection of transects to monitor changes in coral cover and cover by other organisms at Newfound Reef, St. John, US Virgin Islands. A substantial effort was made to select and locate random transects. The selection of sample points (e.g., quadrats, or transects) within a study area is an important and often overlooked aspect of monitoring. Although numerous manuals on coral reef monitoring recommend random sampling, none to date addresses exactly how to locate, and potentially re-locate, random positions within a study site. (Note that here we are *not* referring to random selection of the study site itself, but rather the selection of sampling units *within* that site.) Few monitoring programs have sampling designs based on random sampling. Roger Green (1979) stated, "Putting samples in 'representative' or 'typical' places is <u>not</u> random sampling". With haphazard sampling, the locations of samples are determined using random numbers for distances and directions from a previous point, and the location of each sample is dependent upon the previous sample (i.e., auto-correlated). With random sampling, each sample is independent, i.e. has an equal probability of being selected. Given large enough sample sizes, haphazard sampling may produce results similar to random sampling. However, it is not strictly appropriate to analyze data from haphazardly selected sampling units with statistical methods requiring independent sampling. Interpretation of such data may lead to erroneous conclusions or assumptions.

Random sampling isn't simple or inexpensive, and working underwater with the inherent variability found in coral reef systems presents many challenges. Where available, Global Positioning Systems (GPS and Differential-GPS) have made it possible to locate a randomly selected position on the water, yet translating that surface location, repeatedly and with accuracy, below the water without causing damage to the benthos via dropping weighted markers, etc., is rarely feasible**.** We have developed an approach that allows selection and re-location of random transects with sub-meter positioning accuracy.

Methods

Study site

The study site is a fringing reef that parallels the outer shores of Newfound Bay, off the northeastern coast of St. John, USVI (Fig. 1). A sand channel passes from the bay through the reef crest and extends into deeper water, roughly dividing the forereef zone into an eastern and western portion. Transects were distributed within a 13,768 square meter area of the eastern forereef that was roughly rectangular, with a North-South axis of about 200 m and an East-West axis of about 75 m. Forty stony coral species grow here with the *Montastraea annularis* complex the most abundant. Newfound Bay has an undeveloped watershed and is relatively undisturbed by human activities.

Videotaping randomly selected transects

Living coral cover and cover by other organisms and substrate were monitored along the same set of randomly selected transects (n=20) in March 1999 and March 2000. In April 2000, a second set of randomly selected transects (n=20) was also videotaped. The depth of the transects ranged from 6 m to 9.5 m.

The method consists of two primary components: 1) a SONAR-based underwater position-locating system (Aqua Map ™ by Desert Star Systems) that enables random selection and location of the transects, and 2) a digital video camera to videotape reef transects.

The Aqua Map™ survey system was used to map the perimeter of the study site, calculate the study site area in square meters, define the population of sample points within the site, randomly select a number of points from that population which represent the origins of the transects, and locate (and re-locate) these points during initial and subsequent surveys. The Aqua Map™ system includes one mobile diver station (hand-held computer) with SONAR transducer, three baseline stations/transponders, and supporting software. Transects were selected from a population of all possible transects (in this case, n=120) determined by superimposing a uniformly spaced 10 m by 10 m (virtual) grid over the study site.

To film the transects, a diver used a SONY DVX-1000 digital video camera with a wide-angle lens inside an underwater housing (Stingray™ by Light and Motion Industries). The diver videotaped while swimming ~30 seconds per meter along the transect holding the camera perpendicular to the substrate from a height of ~40 cm, filming a "swath" or belt transect that is ~ 40 cm wide. This rate of filming and distance above the bottom provided the best resolution for detailed identification of substrate components, while making efficient use of field time. No video lights were used during filming. Aronson and Swanson (1997) experimented with the use of lights to improve benthic identifications, concluding they were unnecessary (even with a Hi-8 camera) to 9 m depth.

Back in the office, each tape was played to "capture" adjacent, non-overlapping frames as still images. Each transect was depicted by about 30 unique frames, or images**,** which were saved in a computer file. Random dots were placed on each frame during a process that used Microsoft Excel and Adobe Photoshop. The process was automated by WinBatch for Windows, a batch-processing program. After the images were dotted, an analyst identified the benthic components under the dots while viewing the frames in Adobe Photoshop. The same observer (JM) made all the identifications. These data were used to calculate percent cover of benthic categories (see Miller and Rogers 2000 for further details).

The following categories were identified from the video tapes: stony corals (to species), gorgonians, sponges, zoanthids, macroalgae, dead coral with algae, coralline algae, sand/pavement/rubble, other living organisms, and "unknown". The category "unknown" refers to substrate that cannot be identified with confidence. A guide to identification (see Miller and Rogers 2000) was used to increase consistency in identifications.

The entire process from first visiting a study site to completing the filming of twenty randomly selected transects takes 4-5 days. This includes 2-3 days for the SONAR testing and mapping, and two days for videotaping (diving 2-3 dives per day, 60-80 minutes per dive). Analysis requires 60-75 minutes per transect. Therefore, a site with 20 ten-meter transects can be completely analyzed in 3-5 days.

Statistical analyses

A paired t-test and a Student's t-test were used to compare percent cover by category from the identical transects in March 1999 and March 2000. A Student's t-test was also used to compare mean cover by category from the March 1999 transects with corresponding values from the second set of randomly selected transects surveyed in

April 2000 and to compare the results from March 2000 and April 2000. (The data did not require transformation.) A power analysis was conducted on the same comparisons listed above (March 1999 vs. 2000; March 1999 vs. April 2000; March 2000 and April 2000). To further evaluate the power of comparisons based on non-paired transects**,** we compared our 20 March 1999 transects to 20 random subsets of 20 transects selected from the overall sampling effort in 2000 (n=40). Additionally, an evaluation of the standard error of the means (Bros and Cowell 1987) was conducted on the 40 random transects from 2000 to evaluate the number of transects necessary to represent the study site.

Results

In March 1999, the mean percent of living coral along the 20 transects was 18.0 $\pm$ 6.3 (SD) (Table 1), with a range of 28.1 to 8.3. All other benthic components had mean values of less than 10% except macroalgae, dead coral with algae, and sand/pavement/rubble. In March 2000, the mean percent of living coral was 13.9 $\pm$ 6.1 (SD) (Table 1), with a range of 27.4 to 4.4. Corresponding values for macroalgae, dead coral with algae, sand/pavement/rubble, and all other categories were similar to March 1999 (Table 1).

Table 1. Mean percent cover of live coral and other benthic categories.
SD = standard deviation. n = 20 transects for each sampling period.

	March 1999		March 2000		April 2000	
CATEGORY	Mean %	(SD)	Mean %	(SD)	Mean %	(SD)
Coral	18.0	6.3	13.9	6.1	14.8	9.4
Macroalgae	15.4	6.9	16.8	9.7	5.1	3.8
Gorgonians	7.6	2.8	7.0	3.0	6.4	4.4
Sponges	2.2	1.7	1.6	1.1	1.1	1.0
Dead coral w/ algae	40.4	7.6	43.5	7.0	44.9	8.2
Sand, pavement, rubble	14.6	6.2	14.9	9.8	23.0	15.9

Note: the other identifiable categories equalled <1.0 %

Cover by live coral declined in every transect, and a paired t-test for March 1999 and 2000 showed a significant decrease in mean coral cover ($p<.001$). No other significant differences were found for any of the other categories. The Student's t-tests revealed a significant difference between mean percent coral cover between March 1999 and 2000 ($p=.04$), but no differences between March and April 2000, or March 1999 vs. April 2000. The power analysis for mean coral cover showed the paired t-test had good power and the non-paired Student's t-test poor power (Table 2). Mean percent cover by macroalgae in April 2000 (5.1 ± 3.8) was significantly lower than in March 1999 and March 2000. Given the significant increase in the sand, pavement, rubble category in April 2000, it is likely that the lower macroalgal cover exposed these other substrate types (Tables 1 and 2).

Table 2. Summary of t-test and Power analysis by category for sampling periods. Bold values represent significance at $p<.1$, and good power at $P>.9$. (Two tailed power analysis, $\alpha=.1$, $\beta=.1$)

	March 1999 vs. March 2000				March 2000 vs. April 2000		March 1999 vs. April 2000	
	Paired		Student's		Student's		Student's	
	p-value	Power	p-value	Power	p-value	Power	p-value	Power
Coral	**.001**	**1**	**.04**	.66	.70	.12	.32	.34
Macroalgae	.54	.16	.60	.08	**0**	**.98**	**0**	**.99**
Gorgonian	.28	.29	.49	.10	.64	.14	.30	.27
Sponge	.16	.41	.23	.24	.20	.46	**.03**	.75
Dead Coral with Algae	.17	.40	.20	.25	.55	.16	**.08**	.53
Sand, Pavement, Rubble	.85	.11	.93	.05	**.06**	**.96**	**.03**	.67

The series of t-tests between mean coral cover from March 1999 transects and from 20 randomly selected subsets of the 2000 data showed 10 comparisons with significant differences and 10 with no significant differences, further confirming the poor power when transects are not paired. We found that in order to obtain acceptable statistical power, using different sets of random samples each sampling period, 75 transects would have to be used.

Discussion

Advantages and disadvantages of the video method

We believe that this new approach to monitoring coral reefs offers many advantages over previous ones. Several researchers have successfully used video to monitor coral reefs noting that it is an efficient method for quantitatively sampling large areas of benthos that provides a permanent, archivable record (Carleton and Done 1995, Aronson and Murdoch 1997, Vogt et al. 1997, Wheaton et al. 1998). Some investigators working in the Pacific have found that taxonomic resolution is reduced with video methods (e.g. Carleton and Done 1995, Vogt et al. 1997). This appears to be a function of filming speed, distance from the bottom, and the greater benthic complexity and taxonomic diversity in the Pacific vs. the Caribbean/Western Atlantic rather than an inherent limitation of the method. Video monitoring in Florida and the Caribbean has shown that digital cameras can provide adequate resolution to identify most corals, and some sponges, macroalgae, gorgonians and zoanthids to species (Aronson et al. 1994, Wheaton et al. 1998, Rogers and Miller in press). However, it can be difficult to differentiate macroalgae (primarily *Dictyota* spp., *Lobophora variegata*, *Schizothix spp.*) from turf algae, and coralline algae can sometimes be hard to distinguish. Wheaton et al. (1998) chose to lump turf algae (our "dead coral with algae" category) into a single category with sand and all other non-living substrate because of inconsistencies in identifications by different analysts. We recommend making every effort to differentiate macroalgae from "dead coral with algae" because macroalgae are often indicators of reef degradation (e.g., from sewage and heavy fishing pressure).

Rogers and Miller (in press) compare the video technique to the chain transect method used in CARICOMP and other monitoring programs. While noting that the method is more appropriate for monitoring stony corals and other encrusting organisms than for some other categories, for example, upright, non-encrusting sponges and gorgonians (Bohnsack 1979), and that some problems with identification can arise because of poor resolution in the images, they point out that with the chain transect method the diver must be able to identify all of the benthic components in the field. In contrast, a competent diver with no expertise in reef organism identification can film the selected transects.

Changes in coral cover at Newfound Reef

The significant loss of mean percent coral cover from 18.0 $\pm$ 6.3 (SD) in March 1999 to 13.9 $\pm$ 6.1 (SD) in March 2000 represents a 23 % loss. Although the exact cause of the coral mortality is uncertain, several factors are theorized to have played a role. Two hurricanes passed near St. John in 1999. Hurricane Jose, a minimal Category 1 storm struck on October 21, and Hurricane Lenny, an unusual east-moving, Category 3 storm, passed 80 kilometers to the south of St. John on November 19. Both storms produced significant ground swells, with Lenny producing a large northeast swell for a week, certainly capable of producing physical damage to reefs. Although we dove at the study site following these storms and noted only limited damage, the storms probably contributed to the coral mortality observed in the transects surveyed in March 2000.

The coral disease plague type II (Richardson et al. 1998) has been observed at this site since 1997. Although no points of active disease were quantified during the video analysis, (i.e. no random points fell upon diseased corals), we were able to use the video record to simultaneously compare the same transects from March 1999 and 2000. We noted occurrences of active plague type II in transects from both periods, and where individual coral colonies could be directly compared, numerous small (centimeter) to large (~30 centimeter) areas of living coral tissue had died and were now covered with turf algae. In some cases, entire colonies or fragments were covered by turf algae. This qualitative ability, to review video data from previous years, demonstrates the usefulness of the video technique in providing a permanent record of reef conditions and in preserving information that can be obtained from the tapes in the future.

Resurveying of permanent transects vs. surveying of non-permanent transects to monitor trends

The selection of random, independent transects satisfies the criteria for rigorous statistical analysis and increases the likelihood that the data will be representative of the study site. The position-locating system allows researchers to return to the same transects for future monitoring without the need for installation of permanent markers for each transect. There is continuing debate over the value of re-surveying permanent randomly selected transects vs. surveying of a new set of (randomly-selected) transects on each occasion when monitoring changes on coral reefs over time. The Aqua Map™ system gave us the ability to explore both of these approaches. It enabled us to return precisely to our initial set of transects, as well as to select an additional set for comparison. Both sampling designs have merit, and will give similar results if the transects are truly representative of the study site, and if a large enough sample size is used. Direct transect by transect comparison (March 1999-2000) using a paired t-test produced acceptable power, and revealed significant change in coral cover. However, comparing mean percent coral cover values obtained from the March 1999 transects to a different set of 20 random transects in April 2000 had poor statistical power, and revealed no significant difference in mean percent live coral cover. To obtain acceptable statistical power using different sets of random samples each sampling period, a very large number (75) of transects would be required, adding eight extra days in the field and 12 to 15 days of video analysis. Re-sampling of permanent transects has the potential to detect change more effectively because the time involved and the variability inherent in choosing additional sets of transects will be reduced. We believe that this new approach to monitoring coral reefs, based on videotaping of permanent, randomly selected transects, provides the opportunity to track changes on coral reefs with greater confidence.

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List of Figures

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