

**A COMPARISON OF CORAL REEF MONITORING METHODS  
IN USE AT MARINE RESERVES IN BELIZE AND THE BAHAMAS**

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## I. INTRODUCTION

The monitoring of coral reef habitats and the rich biodiversity that they harbor has proved a challenging but essential task in the management of tropical Marine Protected Areas (MPAs). Over the past 50 years, a plethora of sampling methods designed to monitor the ecological integrity (i.e., “health”) of coral reefs have been developed. While there is no general agreement on any single best coral reef monitoring method or associated suite of methods, it is widely conceded that to be of practical benefit, sampling protocols must (1) measure meaningful and biological parameters with sufficient accuracy and precision to meet monitoring goals, and at the same time (2) be of practical use to most MPA managers, many of whom operate in an institutional framework of severe budgetary, equipment, and personnel limitations.

This paper compares two different field methods presently used to monitor the integrity of coral reefs, along with selected associated fishery resources, in two different Caribbean nations: Belize and The Bahamas. In The Bahamas, a rapid assessment protocol (*Cinetransect* method), based upon the use of timed video transects, has been adapted by the Fisheries Department for use in the monitoring and management of coral reef habitats and associated fish assemblages within an emerging nationwide system of fully protected Marine Reserves. In Belize, the coral reef monitoring protocols described herein are integral components of a broader, atoll-scale monitoring program (LAMP) that measures a variety of meteorological, oceanographic, and biological parameters across coral reefs and other (non-reef) atoll habitat-types. For purposes of direct standardized comparison with the Bahamian coral reef monitoring methods, only the coral reef monitoring portion of the larger LAMP program is discussed here. A summary overview of the complete LAMP program is presented in Appendix 1.

Each of the monitoring protocols compared offer MPA managers the ability to measure and monitor a variety of coral reef attributes, and to also monitor selected reef-associated fish populations. By comparing the methods, results and practicality of these two different methodological approaches to monitoring coral reef health, it is hoped that this paper provide coral reef managers throughout the wider Caribbean with additional monitoring options. This work was carried out under the auspices of a NOAA coral reef conservation grant # NA03NOS4630226 (International Coral Reef Conservation Program) made to the Wildlife Conservation Society.

## II. SUMMARY DESCRIPTIONS OF CORAL REEF MONITORING METHODS

**A. LAMP METHODOLOGY (Belize).** (LAMP uses different, independent protocols for collecting data on reef substrates versus fisheries.)

### 1. Reef Substrate Monitoring.

a. Equipment: Three 30-m fiberglass measuring tapes; 4 stainless steel pegs; underwater writing slates & pencils.

b. Methods: One 30-m transect is positioned on the fore reef at about 10 m depth, oriented in a seaward-shoreward direction. From this, five replicate 10-m transects are positioned to radiate perpendicularly at randomly selected points (CARICOMP Methods Manual, Levels 1 & 2). SCUBA divers survey each of the five replicate transects, recording data on underwater slates. For each transect, data recorded include:

(i) *Substratum category* - Substratum categories recorded for living benthic organisms intercepting the transect line include: algae, hard corals, soft corals, sponges, other organisms, and nonliving substrates. Where possible, taxonomic identity of organisms intercepting the transect are also recorded to genus and species (Appendix 1D).

(ii) *Positional measurement* - the position and extent of each transect overlying each particular substratum category is recorded. These can then later be used to calculate an estimate of the relative proportion of the various substratum categories present at each site

(iii) *Incidence of disease* - Incidence and types of coral diseases are identified using provided photo ID charts.

(iv) *Rugosity* is calculated by measuring the ratio of the root 10-m tape held taut to the length of tape fitted closely along the contours of the substratum.

(v) *Sea urchin survey* - sea urchin species are identified and counted in three random circles around each 10-m transect line, using a line of 1.78 m radius with a lead dive weight tied to one end. This results in 15 10-m<sup>2</sup> quadrats per sampling site.

## **2. Fisheries Monitoring.**

A. Equipment: 2 sticks marked in cm; 2 pair calipers; 2 transect tapes; 2 writing slates

B. Methods: For spiny lobsters and fishes, surveys begin at the reef wall edge. The surveys are conducted by two divers swimming parallel to each other, about 5 m apart. The divers swim into the current for 30 minutes, turn 90 degrees and swim 10 m up the forereef slope (“shoreward”), then turn 90° once more and swim back with the current for 30 minutes (Acosta & Robertson 2003). Abundance is calculated as a quasi “catch-per-unit effort (CPUE)”, defined as the number of animals found/man hour of searching.

(i) *Spiny lobsters:* Two species of spiny lobsters (*Panulirus argus*; *P. guttatus*) are surveyed. All crevices are visually searched for subadults and adults, and all algal clumps inspected for juveniles. Measurements and observations can often be taken if the animals are approached slowly, including: (1) carapace length (estimated using the marked sticks), (2) sex (of adults, using external dimorphic characters), and 3) presence of egg masses (on adult females).

(ii) *Fishes:* Five commercially valuable fish species are visually censused on forereef sites. These are: mutton snapper (*Lutjanus analis*), hogfish (*Lachnolaimus maximus*), queen triggerfish (*Balistes vetula*), Nassau grouper (*Epinephelus striatus*), and black grouper (*Mycteroperca bonaci*). All individuals of these species sighted are counted and identified, and this information is recorded on underwater slates. The total length of each individual sighted is repeatedly estimated from a 3 m distance until an estimate of

acceptable precision (within +/- 2 cm) is obtained in 3 consecutive tries. (*NOTE: A report on the results of the fisheries monitoring carried out at Glover's reef as part of this present project is included in Appendix 2.*)

## **B. CINETRANSECT METHODOLOGY (The Bahamas).**

Since introduction of the method in 1970, the use of Cinetransects has proven a highly practical and efficient means of simultaneously surveying/monitoring reef substrates as well as associated fish assemblages in both tropical and temperate marine environments waters (Alevizon and Brooks 1975; Ebeling et al. 1980 a,b; Larson and DiMartini 1984; Alevizon and Greene 1989; Parker et al. 1994; Alevizon and Porter 2002).

### **1. Data Collection**

Cinetransects are obtained by a SCUBA diver using a high quality hand-held digital camera in an underwater housing. Once the survey begins, the camera is continuously triggered for the duration of the transect (2.75 minutes). The camera is usually pointed in the direction of travel and angled downward at about 30° from the horizontal, but is panned as necessary to record all fishes sighted within an approximate 180° arc centered in the direction of travel (i.e., about 90° either side of the diver's swimming path ) and extending outward about 4 m from the camera. The swimming path is not restricted to a fixed or pre-determined route. Rather, the diver wanders about the monitoring site while swimming at a comfortable and sustainable standardized speed about 1-2 m above the substrate. The only restrictions on the diver's swimming path are to stay within the monitoring site boundaries (i.e., above reef habitat), and not re-cross the same area twice during a single transect.

In this manner, a set of samples covering a relatively large area of reef is quickly generated. Twenty 2.75 minute Cinetransects will provide a high quality permanent record of about 3,600 m<sup>2</sup> of reef substrate. A "tunnel" of water with a volume of about 9600 m<sup>3</sup> is simultaneously recorded for fish censuses. This provides a far different perspective (and for some community

attributes a far more "representative" picture) of the reef community than might be gained from alternate survey methods that focus efforts upon far smaller areas (i.e., small quadrats; a few fixed line intercept transects). In terms of substrate survey and characterization, this basic approach is somewhat analogous to the manta tow survey method (AIMS 1997) developed and widely used for rapidly evaluating large reef areas in the Pacific. However, with Cinetransects, smaller areas are more thoroughly scrutinized, a permanent visual record is obtained, and data extraction/analyses are accomplished in the laboratory (Manta tows require instantaneous *in situ* interpretation and recording of environmental variables).

Cinetransects are not designed or intended to provide information on the full diversity of fishes present in complex reef habitats. Rather, Cinetransects are used as an efficient and practical way to quickly and simultaneously accumulate quantitative information on a select subset (larger, more visible, and diurnally active species) of the larger reef fish assemblage at hand. The subset of fishes targeted by Cinetransect surveys includes species representing all major categories of reef fish feeding types: planktivores, herbivores, benthic carnivores, and large piscivores. The 30-40 species thus included may be considered a reasonable "indicator" assemblage, capable of signaling systematic changes in the composition and/or trophic structure of the more extensive fish fauna at large (Alevizon and Brooks 1975; Ebeling et al. 1980 a,b).

## **2. Data Processing**

a. Reef substrates: Cinetransects are capable of providing quantitative data on the physical and biological characteristics of reef substrates filmed (Ebeling et al. 1980 a,b; Larson and DeMartini 1984; Alevizon and Porter 2002). For the analysis of Cinetransects used to monitor Bahamian reefs, a digital, single-frame-extraction analytical technique (and related software) already developed for such applications is employed. Here, frames are "grabbed" from the videotape at uniform time intervals and the resulting images transferred to CD ROM (digital) files. This library of images is then viewed as a gallery of consecutive frames, and abutting frames with minimal overlap (defined as images with 15% or less area in common) are selected for counting. Random points are generated for each image. These random points are stored on the CD ROM along with the image itself and are recalled every time the frame is displayed. A dedicated

macro, *Point-Count for Coral Reefs* (Wheaton et.al., 2001) is then used to score the image. The macro displays ten random points on each image, Using “hot-button” keys, the substrate category under each point is entered. Substrate categories are then quantified in terms of relative abundance (% cover). The four categories used in the monitoring of Bahamian reefs include (1) “hard” (scleractinian) corals, (2) octocorals (3) macro-algae, and (4) unidentified substrate. These broad categories are used because in many cases positive identification of these organisms to species is not feasible from the images.

b. Fishes: Cinetransects are reviewed in the laboratory. A high quality playback unit (Panasonic DV2000 digital video cassette deck) with stop action and slow motion capabilities is used to count all fishes that can be clearly identified on the digital tapes. Most of the species targeted by the Cinetransect surveys can be positively identified at the species level when present within about a 180° arc centered on the diver’s direction of travel, and extending about 4m outward from the camera. Suites of species that are problematic (in terms of positive identification at the species level) are identified instead at the generic level. In Bahamian waters, such groups typically include certain of the damselfishes (*Eupomacentrus spp.*), small wrasses (*Halichoeres spp.*), serranids (*Mycteroperca spp.*; *Epinephelus spp.*), and porgies (*Calamus spp.*).

### **III. DISCUSSION**

#### **A. BACKGROUND**

Protection and maintenance of *ecological integrity* is often the primary management goal of Marine Reserve management programs. Ecological integrity can be defined as an *unimpaired* condition in which ecosystems show little or no influence from human actions (Karr and Chu, 1999). Ecosystems with a high degree of integrity are often labeled as natural or pristine. *Natural* ecosystems, by definition, would continue to function in essentially the same way if humans were removed (Anderson 1991). Ecological integrity is inherently a holistic concept that includes both *structural* ecosystem attributes (e.g., composition, abundance, and distribution of native species and communities) as well as *functional* attributes (i.e., essential ecological

processes). It follows that management strategies and policies aimed at maintaining ecological integrity attempt to ensure that the natural biodiversity *and* essential ecological processes of the protected ecosystem remain intact, and free (as is practically possible) from adverse human impacts.

Ecological monitoring is a key element in the protection of ecological integrity. Monitoring in this sense has a number of critical objectives, including: (1) detecting and evaluating changes in ecological condition; (2) achieving better understanding of ecosystem structure and function; (3) assessing progress towards achieving management goals and objectives; and (4) identifying and addressing local stressors. Because many key ecosystem structural and functional attributes of large and complex natural ecosystems like coral reefs cannot be measured directly, a comprehensive suite of practical surrogate measures, or *ecological indicators*, must be selected and monitored to collectively reflect the essence of ecological integrity. Selection of the most effective and applicable indicators for a given ecosystem involves choosing those that are both biologically/ecologically meaningful, as well as practically measured, given the resources and goals of the management program.

Identification of both practical and robust quantitative indicators of ecological integrity for coral reef ecosystems is an issue of paramount concern to coral reef managers, and one that has occupied coral reefs scientists for over 40 years without full resolution. Nonetheless, there is widespread agreement among reef scientists that a substantive loss of live coral cover is the single most obvious and common manifestation of coral reef ecosystem degradation throughout the world. A progressive shift from coral-dominated to algal-dominated substrates represents the most common pattern of large-scale change reported for coral reefs of the greater Caribbean region over the last 35 years, and most likely signifies a serious decline in the ecological integrity of the coral reefs so afflicted (e.g., Done 1992, Hughes 1994, Lewis 1986, McClanahan and Muthiga 1998, Steneck and Detheir 1994; Alevizon and Porter 2002). Such changes are not likely reversible in the near term; most available evidence indicates that coral reefs of the greater Caribbean region show little propensity to recover from coral declines of large magnitude (Connell 1997).

Thus, it is not surprising that (change in) “% live coral cover” has become the single most widely used and accepted indicator of coral reef health on a world wide basis. Both the LAMP and Cinetransect methods described herein rely on this indicator as a primary measure of ecological integrity. While a number of other parameters are often monitored in local or regional programs, greater uncertainty remain regarding the interpretation of changes in these.

## **B. BENTHIC MONITORING PROTOCOLS COMPARED**

The LAMP (Belize) and Cinetransect (The Bahamas) protocols for monitoring coral reefs measure overlapping, but not identical, suites of ecological indicators (Table 1) Both the LAMP and Cinetransect monitoring methods are quite capable of detecting sufficiently small changes (<10%) in live coral cover to warrant their use as a primary method for monitoring coral reefs. As might be expected, each of these reef monitoring methods has its advantages and disadvantages.

The LAMP methodology is inherently capable of producing a good deal more detail than is the Cinetransects method in terms of substrate composition. The Cinetransect method provides reliable quantitative information on only the broadest of substrate categories (i.e., hard corals, soft corals, macro algae). However, the LAMP method can often provide resolution to genus/species if the samplers are sufficiently trained and experienced. Carlton and Done (1995) also noted that the primary limitation of video transects is a reduced taxonomic resolution of the substrate. Additionally, LAMP data is compatible with data produced by regional members of the Caribbean Coastal Marine Productivity (CARICOMP) program, a comprehensive monitoring plan for the Caribbean basin. Finally, unlike the LAMP procedure for surveying coral reef substrates, Cinetransects are not well suited to surveying lagoonal patch reefs of the Caribbean, many of which are too small to be practically surveyed by this technique.

In general, the LAMP methodology is more time-consuming in terms of field sampling, and requires substantially greater training and experience for the divers who actually collect data. For LAMP divers, executing the monitoring protocol requires training courses for field personnel, and the ability to recognize and identify and distinguish between closely related species *in situ*.

In contrast, the filming of Cinetransects require minimal training (<2 hours) in order to produce results compatible with Cinetransects filmed by others. Direct tests of the Cinetransect method have shown no detectable differences in results obtained by different, properly trained camera operators (Ebeling et al. 1980b). Although field personnel who actually obtain Cinetransects are not required to count or identify organisms, the person(s) reviewing and extracting data from the tapes or films obviously must be able to do so, and these individuals require a good deal more extensive training than do the divers.

In a relevant (to this paper) study, Brown et. al., (1999) conducted a comparative test of alternate benthic sampling techniques for coral reefs in Hawaii. As part of that study, time and monetary constraints were examined to determine the optimum sampling protocol. Analysis revealed that digital video collected more data per unit time than visual estimation (and other) techniques, but was also the most expensive option considered. Still, the authors concluded that since field time underwater is generally the principal limiting factor in coral reef monitoring, then the quantity of field data collected outweighs the expense. In addition, digital video also enable archiving of the data for later re-analysis to address additional questions.

In the same study, Brown et. al., (1999) choose fixed transects (as used by LAMP) over randomized transects (e.g., Cinetransects) for several reasons, the most relevant of which is that randomized sampling of transects will inherently have less power to detect differences in coral cover as reefs change over time. This is because the random protocol measures inherent spatial variation at each sampling period, which adds variance associated with spatial heterogeneity of the reef to changes or patterns that are time-related (Green and Smith, 1997). Also, using a repeated measures ANOVA design with fixed transects can provide additional information on population and community structure that is difficult to obtain with random transects (Connell *et al.* 1997).

### **C. FISH/FISHERIES MONITORING PROTOCOLS COMPARED**

Far greater differences are apparent between the LAMP and Cinetransect methodologies in monitoring fish/fisheries than in the monitoring reef substrates (Table 1). The Cinetransect

protocol monitors an “indicator assemblage” of some 30 to 40 species in order to assess changes in the overall reef fish assemblage at hand. Here, the relative abundance of species and other community-type parameters are used as indicators of ecological integrity, as discussed above. In contrast, the LAMP protocol utilizes population densities of a relative few valued fisheries species as indicators of the “productivity” of the ecosystem, in terms of output of commercially valued products.

Quantitative estimates of populations of fishes or invertebrates that are comparatively rare and/or widely and patchily dispersed (e.g., grouper, spiny lobster) are best obtained by surveying much larger areas of reef than need to be surveyed for analysis of reef substrates. Thus, for target organisms such as grouper and spiny lobster, the LAMP fisheries survey protocol is far more suitable than Cintransect surveys. The LAMP fishery data is also of greater utility in analyzing regional fishery trends, since the fisheries survey methods used by lamp are standardized with those used by the Florida Fish and Wildlife Conservation Commission (FWCC) for the same target species.

Cintransect sampling of fishes is designed to monitor a community level change, as well as helping coral reef scientists and managers achieve better understanding of ecosystem structure and function. Shifts in the composition of reef substrates inherently involve alterations in the nature, availability and distribution of benthic food resources, as well as shelter sites, used by some reef fishes. Such changes might likely result in changes in associated reef fish assemblages, a result that has been documented or inferred in a number of field studies (Hobson 1974; Randall 1967; Smith and Tyler 1973, 1975; Bell and Galzin 1984; Syms and Jones 2000). However, due to the complexity of the problem and the notable lack of long-term data from single monitoring sites, the nature and variability of such relationships are by no means clear.

Because the Cintransect method simultaneously samples benthic parameters and fishes on the same transect, direct analyses of relationships between substrate habitat variables and fish assemblages within the confines of a particular monitoring site are enabled. In contrast, although conducted in the same general reef area, the LAMP protocol samples areas of substantially different extent for benthic versus fish surveys. Therefore, the utility of LAMP in attempting to

correlate temporal changes in target fisheries with temporal changes in benthic habitat variables at a given monitoring site is far more limited.

#### **IV. CONCLUSIONS AND RECOMMENDATIONS**

This paper discusses and compares two options in terms of coral reef monitoring programs in active use within the greater Caribbean region. In many ways, the two methodologies presented here should be viewed as complementary rather than competing, for they were designed for somewhat different applications. Cinetransects offer the advantages of a rapid assessment method that can quickly survey both reef substrates and fishes over a substantial area (Table 1). Data gathering can be accomplished by divers with minimal training in obtaining survey data, and a permanent record of the habitat surveyed is obtained. The LAMP methodology, although requiring substantially more in-water time and a higher degree of training of field personnel, provides better taxonomic resolution of reef substrates, a better ability to detect small changes in reef substrates, useful data on particularly valued fisheries of the region, and data that is compatible with established regional programs within the wider Caribbean region.

Selection of the most appropriate protocol for monitoring coral reefs within any particular MPA should be driven by the goals of the management program, the resources (monetary, personnel, etc.) available, and the nature, distribution, and abundance of coral reef habitat within the MPA in question. There is no one “best” method, nor any “one-size-fits-all” monitoring technique for coral reefs. In some cases, the choice of an established reef monitoring method may be clear. In other cases, it may be useful to combine portions of different established monitoring protocols as best fits the needs and resources of the particular program. In unusual cases, it may be necessary to develop entirely new protocols to address atypical management needs and/or resource restrictions. Hopefully, the description and discussion of the methods presented here will provide coral reef managers of the wider Caribbean with a greater range of reef monitoring options.

**TABLE 1.** Summary comparison of two coral reef monitoring methods. Results are standardized by reference to one-time monitoring (sampling) of a single forereef site.

<b>VARIABLE</b>	<b>CINETRANSECT</b>	<b>LAMP</b>
<b>Substrate parameters monitored</b>	% cover of: hard corals; octocorals; macroalgae.	% cover of: corals; sponges; urchins; macroalgae
<b>Area covered per site (substrate sampling)</b>	~ 3600 m <sup>2</sup> (twenty 2.75 minute transects)	50m <sup>2</sup> (five 10 x 1m transects)
<b>Fishery parameters monitored</b>	relative abundance of selected suite of ~ 30-40 species	Abundance of spiny lobster; five valued finfish species
<b>Water column volume sampled per site (fish sampling)</b>	~ 9600 m <sup>3</sup> (with 20 transects)	N/A (abundance estimates based upon time rather than area searched)
<b># field personnel required for field surveys</b>	Three (one boat tender, two divers)	Three ( one boat tender, two divers)
<b>Type/size vessel required</b>	16 foot skiff (with dive platform)	16 foot skiff (with dive platform)
<b>Cost of specialized field equipment needed for data collection</b>	~ \$3500 (digital videocam, accessories, underwater housing)	< \$100
<b>Data recording format</b>	Digital video images	Underwater slates

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**APPENDIX 1.** Summary description of the overall LAMP program used to monitor multiple habitats within the Glover's Reef atoll system, Belize.

## **I. INTRODUCTION**

The **Long-term Atoll Monitoring Program (LAMP)** consists of an integrated series of protocols for monitoring physical and biological parameters at Glover's Reef atoll, Belize. The program measures a variety of (1) meteorological (temperature, precipitation), (2) oceanographic (temperature, salinity, turbidity), and (3) biological (chlorophyll, corals, urchins, fisheries, seagrass, mangrove) parameters. Most of the sampling protocols employed by LAMP are based upon sampling protocols developed for the Caribbean Coastal Marine Productivity (CARICOMP) program, a comprehensive, long-term plan for research and monitoring in the Caribbean basin; thus LAMP generates data compatible with the existing CARICOMP dataset.

The schedule for time-series measurements includes continuous, daily, weekly, monthly, biannual, and annual monitoring. Physical measurements (meteorological; oceanographic) are made along a generalized offshore-lagoon transect on a set schedule: (1) daily at the laboratory site (air temperature; cumulative rainfall); (2) weekly at three sites from the fore reef, back reef, and mid-lagoon (water temperature, salinity, and turbidity); and (3) continuous automatic temperature measurements at depth at three sites.

Biological monitoring is aimed at identifying trends in productivity in relation to environmental conditions across the Caribbean basin. Monthly measurement of larval recruitment using plankton nets is conducted from permanent plankton net stations in two major cuts in the reef crest. Biannual measurements of seagrass (*Thalassia testudinum*) standing crop biomass and total biomass is made at sampling sites established on the back reef. At each sampling site, horizontal light extinction is measured at the seagrass level using a Secchi disc. Annual mangrove sampling in three 10x10m plots results in measurements of diameter-at-breast-height, basal area, and biomass. Coral community monitoring takes place annually, and consists of replicate 10-m transects, and fishery surveys, at both fore and patch reef sites. Data is gathered on substrate category, rugosity, and taxonomic identity of selected benthic organisms.

## **II. PHYSICAL MONITORING**

Water measurements are made along a generalized transect from windward to leeward sides of the atoll on a set schedule: 1) daily air temperature and cumulative 24-hr rainfall at the laboratory site; 2) weekly seawater temperature, salinity, conductivity and turbidity using an SCT meter at the windward forereef, seagrass backreef, and lagoon; 3) continuous automatic temperature measurements using underwater dataloggers at 15-m depth in the lagoon and forereef and 2-m depth in seagrass. Data are recorded initially on water-proof paper, then periodically transferred to the data spreadsheet kept by the Station Manager at the Middle Cay laboratory.

### III. BIOLOGICAL MONITORING

Monitoring of biological communities is aimed at identifying status and trends in productivity and community structure in association with environmental conditions over time. Community-specific monitoring protocols, conducted in each of the three dominant community-types of the Glovers Reef Atoll ecosystem, are complimented by fisheries surveys targeting a number of commercially valued species in a variety of habitats.

**A. Seagrass Community.** Turtle grass *Thalassia testudinum* beds are monitored by measurements of standing crop biomass (leaves and bundle sheath) and total biomass (standing crop and belowground biomass) from sediment cores. Materials are sorted by seagrass species, fleshy brown macroalgae, fleshy green macroalgae, and calcareous macroalgae. Sampling is conducted during times of maximum day length (June) and minimum day length (December) at two sampling sites on the eastern backreef and western backreef.

**B. Mangrove Community.** The mangrove community (red mangrove *Rhizophora mangle*, black mangrove *Avicennia germinans*, white mangrove *Laguncularia racemosa*) is surveyed at fixed sites on Middle Cay. Trees are permanently marked (using paint or tape) at a point 1.5 m above ground, and the circumference is measured to calculate diameter-at-breast-height (dbh). For large *Rhizophora* with prop roots higher than 1.5 m above ground, each tall prop root is measured. Sapling growth is surveyed in 5 1-m<sup>2</sup> fixed subplots within each plot; all saplings are tagged, identified, and measured as described above. Measurements are taken on an annual basis during December.

**C. Coral Reef Community.** Corals and the associated benthic community, including sea urchins, are surveyed on patch reef and forereef sites. Surveys are conducted on the windward and leeward forereefs at the 10 m depth contour. One 30-m transect line is laid on the forereef downslope, from which 5 replicate 10-m transects radiate perpendicularly at random depth contours. Data include positional measurement, substratum category, taxonomic identity, and incidence of coral disease (white band, black band, bleaching). Positional measurements represent the area covered by a particular substratum type. Taxonomic identity is recorded to genus + species where identifiable and includes all living benthic organisms intercepting the transect line. Sea urchin species are identified and counted in 3 random circles around each 10-m transect line, using a line of 1.78 m radius with a lead dive weight tied to one end. This results in 15 10-m<sup>2</sup> quadrats per sampling site. Finally, rugosity is calculated by measuring the ratio of the 10-m tape held taut to the length of tape fitted closely along the contours of the substratum. Patch reefs are surveyed in the Conservation Zone and in the General Use Zone. Twelve 10-m replicate transects are measured in each zone, including the windward edge of the patch reef, the windward, and the center of the patch reef. Surveys are conducted once annually during summer. Detailed methods are described McClanahan and Muthiga (1989), McClanahan (1999), and Rogers et al. (2001).

**D. Fisheries Monitoring.** Standard (Florida Fish and Wildlife Conservation Commission) survey methods are used for several commercially-valuable species including spiny lobsters (*Panulirus argus*; *P. guttatus*), queen conch (*Strombus gigas*), mutton snapper (*Lutjanus analis*), hogfish (*Lachnolamnus maximus*), queen triggerfish (*Balistes vetula*), Nassau grouper

(*Epinephelus striatus*), black grouper (*Mycteroperca bonaci*). The sampling protocol is described in detail elsewhere for lobster (Acosta 1999; Acosta and Robertson 2003) and conch (Acosta 2002). Measurements include size (carapace length or shell length), sex of adults using external dimorphic characters, and presence of egg masses on adult females. Surveys are stratified in primary habitat: lobsters on patch reefs and the forereef; conch in seagrass or sand-algal backreef habitat. Fishes are visually surveyed on patch reefs and on the forereef sites. Estimates of total length (snout to tail fork) of fish are made from < 3 m, and abundance is calculated as catch per unit effort (CPUE). Surveys are conducted at quarterly intervals.

## **APPENDIX 2. PRELIMINARY RESULTS OF A LONG-TERM, FISHERY-INDEPENDENT MONITORING PROGRAM AT GLOVER'S REEF MARINE RESERVE**

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### **INTRODUCTION**

Glover's Reef Marine Reserve (GRMR), the third largest marine protected area in Belize, is composed of three main management areas (Gibson 2003). The Wilderness Zone (270 ha) is the most strictly protected with no extractive and recreational activities permitted. In the Conservation Zone, which represents the largest 'no take' area in Belize encompassing 7,077 ha, and 20% of the reserve, no fishing is allowed with the exception of subsistence and catch-and-release sport fishing. Traditional fishing is allowed in the General Use Zone (26,170 ha), but no traps, nets and long lines are permitted. A special reserve (1,550 ha) recently established to protect the Nassau grouper spawning site located on the northeast corner of the Atoll is also closed to all fishing.

Fishing is one of the most important economic activities in Belize, and several regulations have been passed over the years in an attempt to ensure that the industry is sustainable over the long-term. The marine protected area (MPA) system is expected to contribute to sustainable fisheries by providing refuge areas that export fish to adjacent fished areas (Bohnsack 1990). The increase in abundance and size of reef fish in the 'no take' zones of MPAs (Polunin & Roberts 1993) supports this theory of export via two mechanisms: (1) emigration of fish from the refuge area to surrounding fished areas (the 'spillover' effect), and (2) dispersal of larvae from the abundant larger individuals within the refuge (Hatcher *et al.* 1995).

Long-term monitoring is required to determine the status of these commercially-exploited stocks within our MPAs. One method is direct fishery monitoring that involves sampling fishermen's catch or landings. This method alone, however, is not adequate to monitor the status of a fishery. To obtain a full picture, fishery-independent monitoring is also required, which involves sampling of the target species in their natural habitat. This type of monitoring is particularly important in MPAs, which provide the opportunity to compare the effect of 'no take' zones with areas that are impacted by fishing.

A program of fishery-independent monitoring was carried out over a period of several years by Dr. Charles Acosta within the Glover's Reef Marine Reserve, which clearly illustrated the potential of the MPA to serve as a harvest refuge in sustaining and increasing stocks of commercial fisheries species. Based on his model, due to protection from fishing the expected

increases in populations of lobster and conch in the Conservation Zone are 250% and 420%, respectively (Acosta 2002).

We recently re-introduced this long-term monitoring program at Glover's on a systematic basis and present our preliminary results for approximately one year, from July 2004 to May 2005.

## METHODS AND RESULTS

The monitoring methods are described in the manual developed by Acosta (2003) and involve counts of lobster (*Panulirus argus*), conch (*Strombus gigas*) and five finfish species (*Epinephelus striatus*, *Mycteroperca bonaci*, *Lachnolaimus maximus*, *Lutjanus analis*, and *Balistes vetula*) along either transects or in timed surveys, yielding a measure of catch-per-unit-effort (CPUE). The CPUE can then be converted to density per unit area of habitat. Morphometric data are recorded for all species surveyed, as well as the presence of egg masses for lobster and conch. In our survey we expanded the sampling to include 33 stratified, randomly selected sites, which are located in all habitats and in both the Conservation Zone (CZ)<sup>1</sup> and General Use Zone (GUZ). The GPS coordinates were collected for each site and used to develop a map of the permanent sampling stations (see Fig. 1). At each station, habitat class, depth, visibility, salinity, conductivity, temperature, and date and time were also recorded. The four datasets collected in July 2004, October 2004, March 2005 and May 2005 were stored in separate Excel spreadsheets for finfish, conch and lobster and then analyzed using SPSS software.

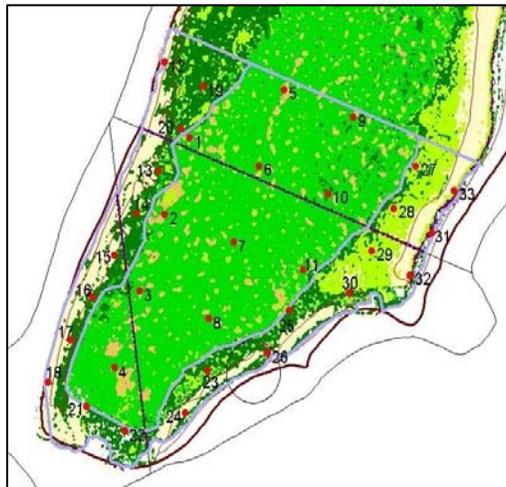


Fig. 1: Map showing the 33 sampling station, located in both the General Use and Conservation Zones

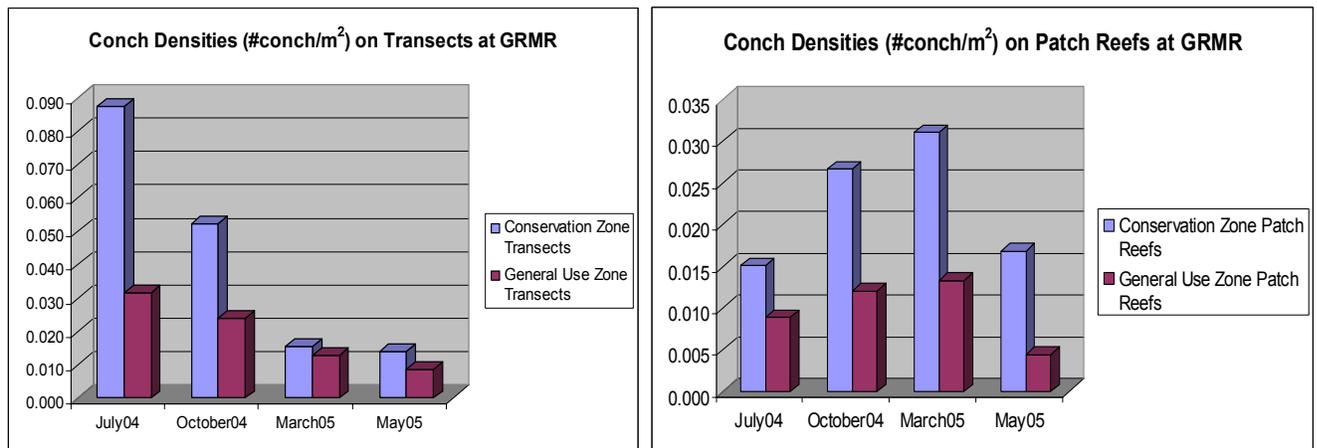
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<sup>1</sup> The Conservation and Wilderness Zones were combined for the analysis.

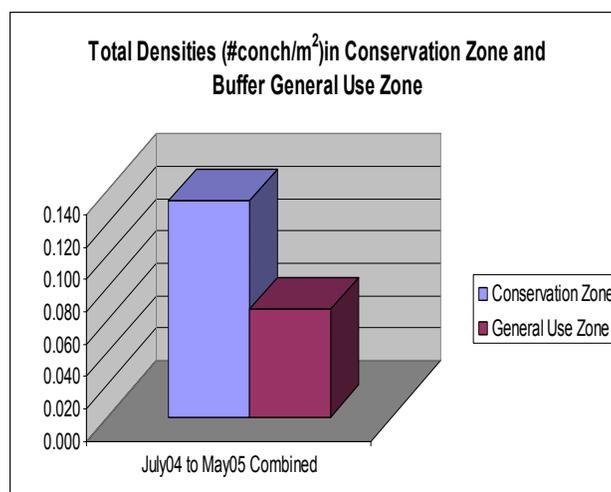
## Conch

The analysis included calculating densities of conch according to habitat (sea grass beds and sand flats or transects vs patch reefs), time of year, and management regime (CZ vs GUZ), and average shell length according to management zone.

As shown in the graphs below, conch were abundant along transects at the end of the closed season (July to October) and decreased in numbers until May. Densities appeared to increase in July, at the beginning of the closed season. The decline in numbers during the closed season indicates that illegal fishing is possibly taking place in the CZ and GUZ. The trend differs on the patch reefs and densities are also lower compared to those along transects. For both habitats, however, the densities are higher in the CZ than the GUZ.



The mean density of conch in the CZ, for the combined datasets and with a shell length greater than 110mm, was 0.11 conch/m<sup>2</sup>. This meets the level predicted by Acosta (2002). In contrast, the mean density in the GUZ was 0.05 conch/m<sup>2</sup>.

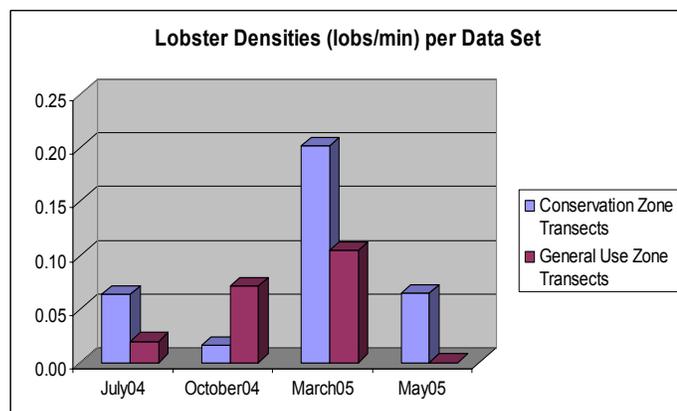
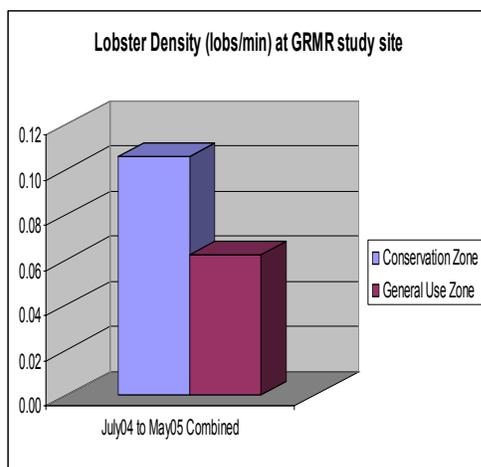


A t-test showed that the mean shell length of conch in the CZ (174.7 mm) was significantly larger than the mean size in the GUZ (153.3 mm) ( $p=0.000$ ).

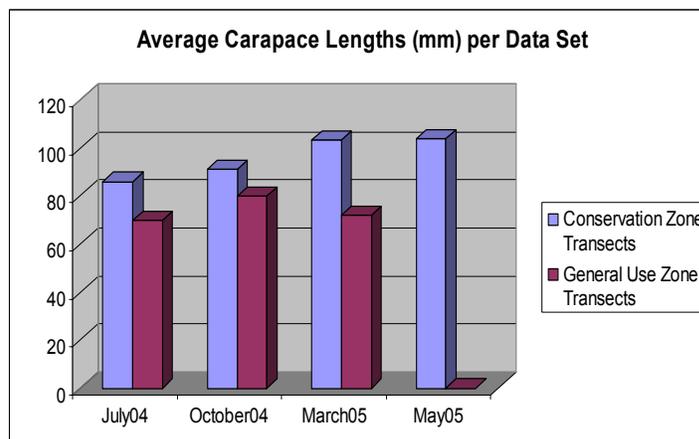
The relation between shell length and lip thickness indicates that immature conch can be legally harvested under the current size limit regulation of 7 inches or 177.8mm. Conch without a lip (lip thickness = 0) are considered immature. Of the total sample of immature conch, 18.1% had a shell length greater than or equal to the legal limit of 177.8 mm. Therefore almost a fifth of legally harvested conch are likely to be immature.

### Lobster

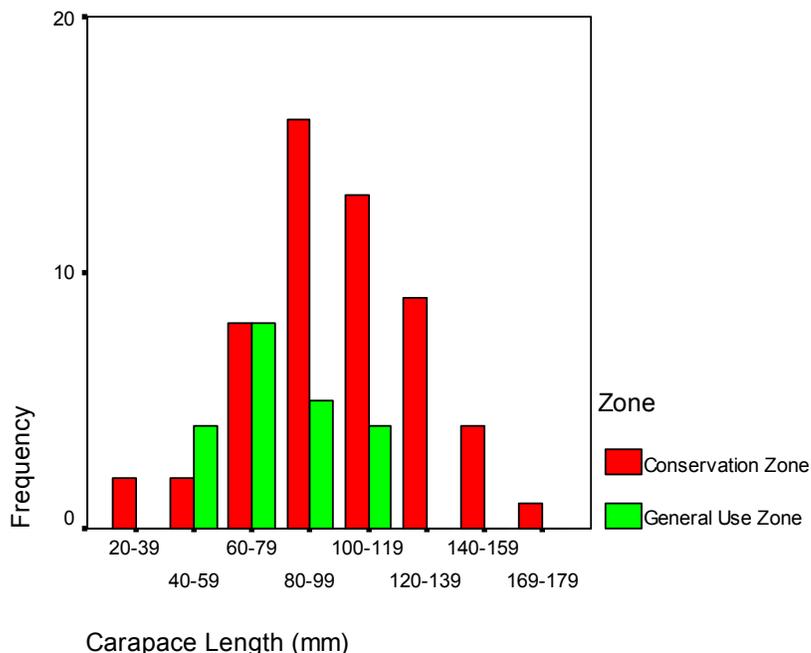
The data analysis for lobster included densities according to management zone and season, average carapace length according to zone, and size frequency to illustrate population structure.



The results show that total lobster densities were twice as high in the CZ than the GUZ. Furthermore, the seasonal change in density shows that some protection is probably being afforded in the middle of the lobster closed season (15 Feb – 14 Jun), but poaching is possibly occurring before the season starts (e.g. in May). The numbers were also noticeably depleted in the CZ in October, which coincides with the opening of the conch season when fishing pressure increases.



The average carapace length of lobsters in the CZ (95.1 mm) was significantly larger than in the GUZ (74.3 mm) (t-test,  $p=0.004$ ).



The most frequent size class in the CZ was 80 – 99mm, and in the GUZ it was 60 – 79mm (legal size = 76.2mm). In the GUZ the population was shifted towards smaller size classes or juveniles, and in the CZ it was shifted towards adults.

### Finfish

The finfish analysis included calculations of density and average size per species according to zone. As can be seen in the table below, the most common fish was the hogfish (*Lachnolaimus maximus*) and the species with the lowest frequency was the queen triggerfish (*Balistes vetula*).

Species	Frequency (n)	Percent
Black grouper	15	5.4
Hog fish	132	47.7
Mutton snapper	82	29.6
Nassau grouper	45	16.2
Queen triggerfish	3	1.1
Total	277	100

Density (# fish/100m <sup>2</sup> )	Hogfish	Mutton snapper	Nassau grouper
Conservation zone	3.2	1.8	1.0
General use zone	1.0	0.7	0.4
Total (CZ +GUZ)	2.2	1.4	0.8

Densities for all species, except for the queen triggerfish which was only observed in the GUZ, were higher in the CZ than in the GUZ.

Hogfish	Conservation zone	General use zone
N	94	38
Mean fork length (cm)	28.1	28.5
Mutton snapper		
N	53	29
Mean	33.4	32.4
Nassau grouper		
N	29	16
Mean	26.2	28.8

The average size of Nassau groupers (*Epinephelus striatus*) shows that mainly juveniles (< 36.8 cm) were observed. Average sizes of all species were similar in both zones. The sample sizes for the black grouper and queen triggerfish were too small, 15 and 3 respectively, for further analysis to be completed. Nevertheless, the few black groupers observed were larger on average in the CZ.

## DISCUSSION

Our preliminary results show that, although densities and average sizes of conch and lobster were higher in the CZ than the GUZ, the seasonal densities fluctuate widely possibly indicating that enforcement of the fisheries regulations needs to be strengthened in both zones.

Importantly, the results also revealed that the current legal shell length size limit for conch is allowing a significant proportion of immature conch to be harvested. Further studies are needed to estimate the volume of legal take of immature conch and its impact on the fishery.

Finally, the majority of Nassau grouper observed appeared to be juveniles, which are very vulnerable to spear fishing. Consideration needs to be given to protect them to ensure the restoration of the Nassau grouper population at Glover's Reef.

We plan to continue the monitoring in the future, working in collaboration with the staff of the marine reserve.

## **ACKNOWLEDGEMENTS**

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