Ecological Indicators 46 (2014) 454–465

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

# An analysis of indicators for the detection of effects of marine reserve protection on fish communities

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ARTICLE INFO

*Article history:*
Received 5 December 2012
Received in revised form 3 July 2014
Accepted 6 July 2014

*Keywords:*
Marine reserve
Fisheries management
Commercial fish species
BACI experimental design
Coral reef
Local ecological knowledge

ABSTRACT

We investigated the effects of marine reserve protection on fish and benthic communities at Glover's Reef Marine Reserve, Belize, using a broad suite of indicators. Responses of fish species to protection were highly variable, and therefore indicators calculated at the fish community level were ambiguous. According to 11 of 13 community-level indicators, sites located within the no-take zone fared more poorly over time than did sites in the surrounding fished area. However, we were able to detect positive reserve effects using a newly-proposed pair of indicators, which take into account spatial distribution of different species at the time of the no-take zone implementation. These indicators showed that species subject to low fishing pressure increased inside and to a lesser extent outside the no-take zone, while species subject to higher levels of fishing pressure increased in the no-take zone but decreased in the fished area. Indicators of changes in the fish community were not correlated with those related to the benthic community, and we suggest that indicators be carefully selected to match management objectives. We also find that positive reserve effects based on present-day data (e.g., higher abundances of commercial species inside the no-take zone versus outside) were often not associated with increases in fish densities over time, and suggest caution when interpreting abundance patterns in the absence of historical data. We recommend that similar studies be carried out at a variety of reserve sites, to test our proposed indicators and increase our understanding of community-level responses to fisheries closures.

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## 1. Introduction

Effective monitoring is essential to understand the responses of ecosystems to management interventions, and to provide a robust scientific basis for further regulation or mitigation efforts. A significant and growing body of literature has assessed the effects of marine reserves, and a number of indicators of marine reserve effectiveness have been proposed (Bunce et al., 2000; Pomeroy et al., 2004; McField and Kramer, 2007). However, there is a distinct lack of research dedicated to assessing the performance of these indicators (Beliaeff and Pelletier, 2011), which are assumed to represent some state or function of the ecosystem. An absence of knowledge on which indicators most effectively track changes in marine ecosystems hinders managers and policymakers from making informed decisions (Samhouri et al., 2009).

An indicator may be defined as a qualitative or quantitative variable derived from data or observations, and is used to measure the ability of a management action to move an ecosystem toward a desired state as defined by specific management objectives (Pelletier et al., 2005). Management objectives, such as increasing biodiversity or fishery catches, may be defined as reference points, or specific values of indicators that are to be targeted or avoided (Sainsbury and Sumaila, 2003). Thus, the distance between the present observed value of an indicator and its reference point is a measure of how well management objectives are being achieved. Reference points may also be defined to establish limits that, when reached, call for further management action. In order to be effective, an indicator should lead to appropriate management decisions while minimizing the risk of error in its interpretation (Beliaeff and Pelletier, 2011).

The issue of deciding upon an indicator to represent changes in ecosystem states is not a minor one, as the ultimate choice can have major influences on management outcomes. For example, Peterman (1990) discussed the dangers of ignoring the issue of statistical power in fisheries management applications, and showed how use of tests with low power may lead to faulty conclusions and costly management errors. In addition to adequate statistical

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http://dx.doi.org/10.1016/j.ecolind.2014.07.006
1470-160X/Published by Elsevier Ltd.

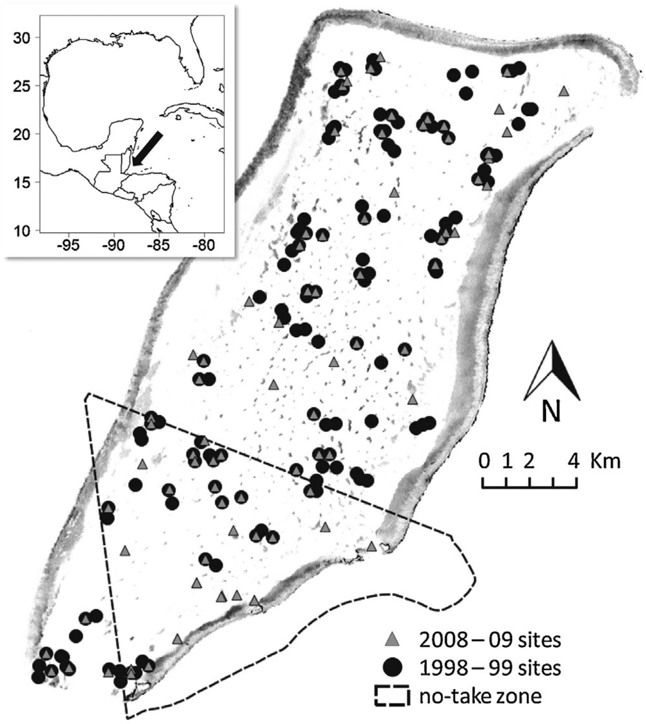


**Fig. 1.** Satellite image of Glover's Reef Atoll, Belize, with patch reefs and shallow sand banks appearing in gray.

power, other desirable attributes of indicators include: applicability to different geographical areas and spatial scales, repeatability, sensitivity to ecosystem stressors, predictability, simplicity, and cost-effectiveness (Beliaeff and Pelletier, 2011; Niemeijer and de Groot, 2008 and references within). Rarely can a single indicator track all changes of interest in an ecosystem, yet time and money are wasted in tracking two or more highly correlated indicators (Samhouri et al., 2009; Rochet and Trenkel, 2003; Shin et al., 2005). Unfortunately, the indicator selection process is usually arbitrary, and formal selection criteria for paring down suites of indicators are still under development (Niemeijer and de Groot, 2008). Thus, there is an urgent need to not only focus on the suitability of individual indicators for purposes of monitoring, but also on interrelationships between sets of indicators.

In this study, we investigate the effects of reserve protection on finfishes and benthic habitat at the Glover's Reef Marine Reserve in Belize. We calculate a suite of commonly used indicators of marine reserve effectiveness and explore interrelationships between these indicators. Additionally, we propose a new pair of indicators which we demonstrate can more easily detect the effects of reserve protection on commercially-fished species. We then highlight where our findings might be applicable to other reserves, and discuss where gaps in knowledge on effective monitoring exist.

## 2. Methods

### 2.1. Study site

The Glover's Reef Marine Reserve (GRMR) is located on Glover's Reef Atoll, 25 km east of the Mesoamerican Barrier Reef. Approximately one-fifth of the 35,000-ha atoll is designated as a no-take zone, and enforcement of the zone began in 1998 (Garaway and Esteban, 2002; Fig. 1). The focus of this study is on the atoll's lagoon, which contains over 800 patch reefs of varying spatial configurations and habitat composition types (Wallace, 1975). Previous studies using acoustic telemetry data for several grouper and shark species showed that these species exhibited high site fidelity, and suggest that individuals are not moving to and from the atoll (Chapman et al., 2005; Starr et al., 2007). Because maximum body length is correlated with home range size (Kramer and Chapman, 1999), immigration and emigration of other smaller-bodied species is expected to be limited, and Glover's atoll likely represents a closed system with respect to adult fish movements. A distinct group of fishers from mainland Belize use the atoll, and numbers of fishers and gear types have remained relatively stable since reserve implementation (Lizama, 2006). A 2004 survey identified around 100 fishers at the atoll from three different mainland villages (Gibson et al., 2006), and typical gear types are handline and spear gun.

### 2.2. Data sources

An underwater visual survey of finfish and benthic communities was carried out at the inception of the no-take reserve in 1998 and 1999 at 150 patch reef sites (Thoney, 2001), and we repeated this survey from 2008 to 2009 at 87 sites (56 of which were exact replicates of the previous survey; Fig. 1). For both surveys, fish abundance data for a suite of 42 species (Table 1) were collected using the stationary point survey method (Bohnsack and Bannerot, 1986) using a 5 m cylinder radius, with five replicates per patch located on the N, E, S, and W sides of the patch at the 3 m contour and center of the patch. In 1998–1999, benthic cover of patch reefs was determined using the line intercept transect method (cover recorded every 10 cm along 10 m transects, four replicates per patch). In 2008–2009, this method was modified to reduce diving time through the use of digital photography. Images were taken 0.5 m above the benthos at 2 m intervals along two transects spanning the long and short axes of the patch, and percent coverage of benthic organisms was calculated using random point intercept methods in CPCe software (Kohler and Gill, 2006). More details are described in Karnauskas et al. (2011).

Human perspectives on changes in fish abundance were assessed through interviews with 32 individuals who had been working at the reserve since its implementation. Individual face-to-face interviews were administered in either English or Spanish by the first author from May to June 2010. These interviews were carried out through opportunistic sampling at Glover's Reef, either on the cayes (small barrier islands) with residents, reserve managers, and tour operators, or onboard the fishing boats of fishers who were actively working. Additionally, we interviewed five foreign scientists who had conducted research activities at Glover's Reef over the past ten years via email. Temporal trends were assessed by presenting interviewees with a list of 24 of the most frequently-targeted commercial species, and asking whether the individual had perceived a large decrease, decrease, no change, increase, or large increase in each species over the past 10 years (with a "don't know" option). Fishers were asked whether or not each species was a fish that they actively targeted. The common name of each species was given, and the interviewer also pointed to a color photograph of each species, to ensure that no misidentification occurred.

### 2.3. Indicator development

We searched the peer-reviewed and grey literature for publications dealing with assessment of marine reserves, and developed a list of indicators that have been used to measure reserve effectiveness (Table 2). Using the comprehensive data sets for the GRMR, we calculated as many of these indicators as was possible from our available data (see Table 2 for formulas). In addition, we proposed a new pair of indicators that we hypothesized would be informative for describing trends in fish populations. Indicators were only calculated based on the fishery-independent