Fisheries Research 208 (2018) 70–85

Contents lists available at ScienceDirect

Fisheries Research

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

Fish community and single-species indicators provide evidence of unsustainable practices in a multi-gear reef fishery

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ARTICLE INFO

Handled by B. Arara

Keywords:
Coral reef fisheries
Data-poor fisheries
Length-frequency
Overfishing indicators
Spawning aggregations

ABSTRACT

Using information on the species composition and length-frequencies of fish caught in the spear and hook and line fisheries of Glover's Reef Marine Reserve, Belize, we evaluated changes between 2004–2010 and 2011–2017 in single-species and ecosystem sustainability indicators. The two gears differed in species caught, and both changed species composition between time periods, with the line fishers targeting smaller species, and the spear fishers responding to a parrotfish ban by catching more snappers and small groupers, as well as grey angels. Both gears caught smaller fish in 2011–2017 compared to 2004–2010, indicating overfishing. Species often caught immature were black grouper, Nassau grouper and mutton snapper with spears, and black snapper with lines. Most fish of other species were mature, but many were smaller than the optimal size for harvest. Fishing mortality rates were higher than natural mortality rates for most species in both gears in both time periods, whether calculated from average length or by length-based spawning potential ratio (LBSPR), implying that most populations were experiencing overfishing. Many species also had a low spawning potential ratio, implying a high probability that they were overfished. In general, many species were subject to unsustainable levels of fishing, and, according to the Froese indicators, some would benefit from size limits to protect immature individuals. These results are supported despite uncertainty in life history parameters for fishes in Belize, and differences between data poor assessment methods.

1. Introduction

Small-scale fisheries, including fisheries around tropical coral reefs, are an important source of livelihood and food security for often-impoverished coastal communities worldwide (Andrew et al., 2007; Newton et al., 2007). Thus, improving the sustainability of these fisheries is a necessary step toward poverty alleviation (Bene et al., 2010). In the Western Caribbean, over one million local people are directly dependent on the integrity and health of the Mesoamerican Reef system for their livelihood, and the national economies of four countries (Belize, Guatemala, Honduras, and Mexico) substantially benefit from the reef's fisheries resources and appeal as an international tourist destination (Zeller et al., 2011). Therefore, the sustainable management of small-scale fisheries associated with the Mesoamerican Reef system, much of which falls within the territorial waters of Belize, is imperative in light of food security and income generation as well as maintaining biodiversity and other essential ecosystem services. However, small-scale fisheries are difficult to assess and manage because they lack the quantity and/or quality of data needed for conventional stock assessment and have limited enforcement capacity across dynamic multi-species and multi-gear systems (Costello et al., 2012).

A first step in assessing the status of a small-scale fishery is to evaluate the species and length composition of the catch. Samples of species composition and length-frequencies may be easier to obtain than time series of total catch or abundance. Thus, length-based methods are commonly used for assessing the sustainability of data-limited fisheries, and to evaluate changes in status over time (Dowling et al., 2016). Such information can be used to evaluate whether large-scale community shifts have occurred, such as changes in the trophic level of fish that are caught, or a shift toward smaller species or smaller individuals, which can indicate unsustainable exploitation rates (Hobday et al., 2011; Rochet and Trenkel, 2003). Differences between gears may be important for designing management strategies that take into account the species and size selectivity of each component of the fishery.

For individual species that are commonly caught, the length composition of the catch can be informative about whether the fishery is focused on small or immature individuals (Froese, 2004), and whether

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https://doi.org/10.1016/j.fishres.2018.07.003
Received 20 December 2017; Received in revised form 27 June 2018; Accepted 7 July 2018

Table 1
Details on the symbols used in the analysis. Indicators are given separately in Table 2.

Symbol	Units	Defination	Source, method and use
Calculated from species composition data			
N		Number of fish identified to species in the catch	Used to calculate Simpson diversity
n_j		Number of fish of species j in the catch.	Used to calculate Simpson diversity
Calculated from length composition data			
L_c	cm	Length fully recruited into fishery	Calculated from mode of length frequency distribution (Babcock et al., 2013)
L_λ	cm	Maximum fully recruited length in fishery	Observed maximum length in the catch, excluding any outliers more than a few cm larger than the rest of the distribution. (See Supplement for details)
SL_{50}	cm	Length at 50% selection in logistic selectivity curve	Estimated by LBSPR function in R (Hordyk et al., 2015b)
SL_{95}	cm	Length at 95% selection in logistic selectivity curve	Estimated by LBSPR function in R (Hordyk et al., 2015b)
Taken from the literature or given an assumed value			
CV(L)		CV in length at age	Assumed equal to 0.1
K		von Bertalanffy growth coefficient	From literature (Table 3 and Supplement), has Monte Carlo distribution
L_m	cm	Median length at first reproduction	From literature (Table 3 and Supplement), has Monte Carlo distribution
L_{max}	cm	Maximum observed length	From literature (Table 3 and Supplement), assumed constant
L_∞	cm	Asymptotic length in the von Bertalanffy growth curve	From literature (Table 3 and Supplement), has Monte Carlo distribution
$t_{\max}$	yr	Maximum observed age	From literature (Table 3 and Supplement), assumed constant
Calculated from literature values for each Monte Carlo draw			
L_{opt}	cm	Optimal length, at which the total biomass of a cohort is maximized	$L_{opt} = \frac{3L_\infty}{(3+M/K)}$ (Beverton, 1992) or $log_{10}(L_{opt}) = 1.053 \bullet log_{10}(L_m)–0.0565$ (Froese and Binohlan, 2000)
M	yr^{-1}	Natural mortality rate	$M = 4.899t_{max}^{-0.916}$ or $M = 4.188K^{0.73}\,(10L_\infty)^{-0.33}$ where L_∞ is in cm (Then et al., 2015) or $M = \frac{-\ln(0.05)}{t_{max}}$ (Ault et al., 2008)
Calculated from data and parameters for each Monte Carlo and bootstrap draw			
$\bar{L}$	cm	Mean length of fish between L_c and L_λ	Needed to calculate Z (Ehrhardt and Ault, 1992)
Z	yr^{-1}	Total morality, calculated from $\bar{L}$	$\left(\frac{L_\infty - L_\lambda}{L_\infty - L_c}\right)^{\frac{Z}{K}} = \frac{Z(L_c - \bar{L}) + K(L_\infty - \bar{L})}{Z(L_\lambda - \bar{L}) + K(L_\infty - \bar{L})}$ (Ehrhardt and Ault, 1992) calculated iteratively using nlminb function in R.
F	yr^{-1}	Fishing mortality rate	$F = Z\text{-}M$

the population is overfished, defined as being below a biomass threshold (Cope and Punt, 2009). Given information about growth and natural mortality rates, length-frequencies can be also used to estimate fishing mortality rates (Beverton and Holt, 1957; Ehrhardt and Ault, 1992; Hordyk et al., 2015b), where a fishing mortality rate (F) larger than the natural mortality rate (M, i.e. $F/M > 1$) is an indicator that the population is experiencing overfishing (See Table 1 for definitions of all parameters, and Table 2 for the indicators). Length-based spawning potential ratio (LBSPR) (Hordyk et al., 2015b, 2016) is a methodology that can be used to estimate both fishing mortality rates and spawning potential ratio (SPR). SPR, defined as the current spawning stock biomass (SSB) relative to the unfished SSB, is a metric of whether the population is overfished, with values less than 0.3–0.5 (depending on the life history of the fish population) indicative of overfished status (Goodyear, 1993).

Using data collected by the Wildlife Conservation Society (WCS) between 2004 and 2011 at Glover's Reef, Belize, Babcock et al. (2013) applied several length-based methods to determine whether the spear component of the fishery was sustainable (Ault et al., 1998, 2005, 2008; Cope and Punt, 2009; Ehrhardt and Ault, 1992; Froese, 2004), and also used a range of multispecies indicators to evaluate the ecosystem impacts of the fishery (Rochet and Trenkel, 2003). Because life history data were not available from Belize, they used a Monte Carlo method to include uncertainty about the values of life history parameters in the estimates of status, along with bootstrapping to estimate the sampling error. The objective of this paper is to expand the analysis of Babcock et al. (2013) by: (1) using multivariate statistics to compare the species composition caught in the spear versus hook and line gears over time; (2) including six more years of data through May 2017 to calculate sustainability indicators; (3) calculating the indicators for the hook and line gear as well as the spear gear; (4) updating the life history data used to calculate the indicators; and (5) adding the LBSPR method (Hordyk et al., 2015b) to estimate both SPR and F/M.

2. Methods

2.1. Study site and data collection

Glover's reef (16°44′ N, 87°48′ W) is an atoll 25 km to the east of the Belize barrier reef, which is designated as a multi-zone marine reserve (i.e. marine protected area) (Tewfik et al., 2017). Approximately one fifth of the atoll is a replenishment zone (i.e. no-take area), while the remainder of the atoll is zoned as general use where commercial fishing is only allowed by licensed users and under a set of regulations enforced by the Belize Fisheries Department. The regulations within Glover's atoll include a ban on gillnets, traps, artificial habitats (i.e. shades to attract lobsters) and longlines in addition to other fishing regulations that apply throughout Belize (Government of Belize, 2003; Tewfik et al., 2017). Since 2009 regulations specific to finfish in Belize include a ban on catching herbivorous fish (specifically parrotfish and surgeonfish) and a minimum and maximum size limit (50–74 cm total length) for the Nassau grouper (Government of Belize, 2009). Beginning in 2011, the Belize Fisheries Department implemented a pilot study for the spatial management of fishing grounds, called the "Managed Access Program", at Glover's Reef, which restricted fishing rights to individuals who have traditionally used Glover's Reef through a new electronic licensing system. The fishers at Glover's Reef originate mainly from Sarteneja, in Northern Belize, and Hopkins on the mainland opposite Glover's Reef (Grant, 2004; Tewfik et al., 2017). The Sarteneja fishers come to the atoll aboard 10–15 m sailboats, and then disperse in 4–7 dories per sailboat to fish individually for finfish using either spear gun or Hawaiian sling gear (hereafter both referred to as spear fishing), or to free-dive for conch or lobster mostly within the atoll's lagoon and associated patch reefs but occasionally on the fore-reef (Tewfik et al., 2017). More rarely they also fish with hook and line. The fishermen from Hopkins tend to use 7–10 m skiffs with outboard motors, and typically have a crew size of two or three and fish for