Characterizing spatial and temporal reef fisheries in Chinchorro Bank Biosphere Reserve, northern Mesoamerican Reef System

Caracterización espacial y temporal de la pesquería en la Reserva de la Biosfera Banco Chinchorro, norte del Sistema Arrecifal Mesoamericano

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ABSTRACT

The main objective of this paper was to create a baseline for the spatial and temporal characterization of fisheries in the Chinchorro Bank Biosphere Reserve. Monthly records of one of three fishing cooperatives in the area were taken between August 2004 and June 2005. The individual length and weight of each fish species were recorded per boat. Catch per unit effort (CPUE) was calculated as kilograms per fisherman per hour (kg-fisherman$^{-1}$-hr$^{-1}$). CPUE values for *Epinephelus striatus*, *Mycteroperca bonaci*, *Lachnolaimus maximus* and *Sphyraena barracuda* were highest in the “Nortes” (northerly-winds) season due to increased fishing effort and to the fact that they were apparently caught in spawning aggregation sites. Generally, fishing at Chinchorro Bank exerts low to moderate ecological impact because fishing gear restrictions and fisheries are closely linked to the extraction of spiny lobster, a resource with a higher aggregated-value in contrast to reef fisheries.

Key words: Management, reef fisheries, Mexico, Chinchorro Bank, Biosphere reserve.

RESUMEN

El objetivo principal de este artículo fue crear la línea base para la caracterización espacial y temporal de la pesquería en la Reserva de la Biosfera Banco Chinchorro. Registros mensuales de la captura de escama en una de las tres cooperativas en el área de estudio fueron realizados entre agosto de 2004 y junio de 2005. La longitud y el peso de los individuos de las especies de peces fueron registradas por embarcación. La Captura por Unidad de Esfuerzo (CPUE) fue calculada como kilogramo por pescador por hora de pesca (kg-pescador$^{-1}$-hr$^{-1}$). *Epinephelus striatus*, *Mycteroperca bonaci*, *Lachnolaimus maximus* and *Sphyraena barracuda* presentaron los valores más altos de la CPUE en la época de “Nortes”, lo cual está asociado al incremento en el esfuerzo de pesca y a su aparición en sitios de agregación de reproducción. Generalmente la pesca en Banco Chinchorro representa un impacto ecológico bajo debido a las restricciones en los artes de pesca y a que la principal actividad pesquera está dirigida hacia la langosta, un recurso con un valor agregado similar a la pesca de escama.

Palabras clave: Manejo, pesquería arrecifal, México, Banco Chinchorro, Reserva de la Biosfera.
INTRODUCTION

Coastal development in the Caribbean poses a major threat to coral reef ecosystems and mangroves. Coastal areas of the Mexican Caribbean are no exception and to avoid coral reef degradation by massive tourism and over-fishing, Mexican federal and state governments have been working to establish marine protected areas in the Caribbean to protect mangroves and coral ecosystems. Chinchorro Bank Biosphere Reserve (CHBBR) is considered to be a priority conservation area. Coral reef systems of CHBBR support many different species, which are the main component of fisheries in the area. These fisheries are generally small-scale, artisanal and multi-specific; however, economic progress, growing coastal tourism and increased population have led to greater competition for fishery resources and possible over-fishing.

Fisheries on the CHBBR are closely linked to the extraction of spiny lobster, Panulirus argus (Latreille, 1804) and queen conch, Strombus gigas (Linneaus, 1758); however, the reef fisheries operate all year round, including the spawning aggregations of different fish species. Despite their socio-economic and ecological importance, reef fisheries off Chinchorro Bank are poorly documented. Nevertheless, it is known that in the Mesoamerican Reef System (MAR), within which the CHBBR is located, there are 68 commercially important fish species from 31 genera and 16 families (WWF, 2006). The majority of the studies in the MAR have been conducted on the impact of fisheries on the spawning aggregations of different fish species from Serranidae (e.g. Epinephelus striatus Bloch, 1792) and Lutjanidae (e.g. Lutjanus analis Cuvier, 1828) families (Aguilar-Perera & Aguilar-Dávila, 1996; Sala et al., 2001; Aguilar-Perera, 2006; Graham et al., 2008). Recently, several studies on fisheries in Belize have reported signs of fishing down the food web, caused by low lobster and conch catches, resulting in the finfish being increasingly targeted (Gibson & Hoare, 2006; Coleman, 2008). This highlights the need for knowledge on what is being fished and where. Which are the main fishing zones? In which seasons is maximum fishing effort exerted? Which species are being exploited and where are fish spawning aggregations located?

The main objective of this paper is to create a baseline for the spatial and temporal characterization of fisheries in order to improve scientific guidance for managing the CHBBR.

MATERIALS AND METHODS

Chinchorro bank is one of the most important platform reefs of the Caribbean. It was declared a Biosphere Reserve in 1996, making it a marine protected area under Mexican law. The CHBBR is located in southeast Mexico (18°47', 18°23' N; 87°14', 87°27' W, Fig. 1), in the state of Quintana Roo, approximately 39 km offshore from Mahahual (Jordán & Merino, 1987).

The CHBBR is exploited by three fishing cooperatives, but, due to the complexity of simultaneously sampling catches from all three, samples were only taken from the largest one: Langosteros del Caribe. Each of the fishermen of this cooperative operates a boat all around the reef and throughout the year, fishing lobster and finfish. At the end of a day of fishing every fisherman downloads and stores their capture in a "mother" ship. Catches from each fisherman were recorded directly on the mother ship. Records were taken for one week each month between August 2004 and June 2005. All cooperative boats were surveyed daily throughout the week and their entire catch was registered per boat. Each fish species, its abundance and individual length (cm) and weight (g) were recorded. Fish length was measured from the anterior extreme of the head (mouth closed) to the end of the caudal fin (i.e. total length or TL), and weight was measured with a 20 kg-capacity scale. Additional data such as fishing zone, fishing gear, number of fishermen, and fishing time were obtained via an interview with the boat’s captain.

Habitat characteristics of principal fishing areas were obtained by recording the benthic coverage via the video transect method (Aronson & Swanson, 1988). Several stations were positioned in different fishing areas around the reef. At each sampling station a geo-referenced (point) 50 m long transect was laid over the substrate to serve as a guide for recording. Video transect recordings were processed by viewing them on a high-definition monitor and freezing the image at determined intervals. A series of 13 points distributed systematically on the screen were overlaid on the frozen frame, and the benthic organisms at these points identified according to morphostructural groups (MSG): scleractinian corals, hydrocorals, octocorals, sponges, algae, and seagrass.

Production and species composition. Catch data were used to extrapolate an estimation of total coral reef production ($Y$) using the equation (Luchavez et al., 1984):

$$ Y = \frac{CD}{dA} * 1000 $$

Where $C$ is total recorded catch, $d$ is the number of days sampled (45 days), $D$ is the number of days fished per year (305 days) and $A$ is the reef area where catches were obtained ($238$ km$^2$). Only 305 days were included in the analysis because no reef fish were caught in July and September (all fishing effort was focused on the spiny lobster), and severe weather (primarily winter storms) occasionally prevented navigation.

Spatial and temporal arrangement of fisheries. Catch per unit effort (CPUE) was calculated as kilograms per fisherman per hour of catch (kg-fisherman$^{-1}$ · hr$^{-1}$). Each fish species was captured by using a specific fishing tool (harpoon or hand line) over the entire period of the study. These data were grouped into $30$ fishing quad-
Figure 1. Geographical location of the Chincorro Bank Biosphere Reserve (■ denote fishing sites and the studied fishing quadrants (□ quadrant without fishing; □ quadrant with fishing).
rants within the reef system because catch per fisherman was not spatially explicit. From a preliminary study, the average fishing area that a fisherman covers to obtain his catch was acquired. Fifteen random fishermen’s boats were traced using a GPS to estimate mean fishing area. Quadrant size was based on the approximate fishing area covered by one boat per trip (Fig. 1).

Determination of fishing zones based on the CPUE per quadrant for the ten most commercially important species was carried out with non-parametric multidimensional scaling (MDS) using the Bray-Curtis similarity index (Clarke & Warwick, 2001). This was followed by a similarity percentage analysis (SIMPER; Clarke & Warwick, 2001) to identify species that discriminate between fishing zones. All multivariate techniques were carried out using the PRIMER v6 program. In order to perform a seasonal analysis of fishing effort, the CPUE was calculated for three climatic seasons: rainy (July-October), “Nortes” (northerly-winds) (November-February) and dry (March-June).

A two-way ANOVA was applied without replication (Zar, 1999) in order to determine differences in the CPUE and size of organisms of the commercially important species for each fishing zone and climatic season. Tukey’s HSD was used as a post-hoc multiple comparison test (Zar, 1999). Data were tested for normal distribution using the Shapiro - Wilk test (Sokal & Rohlf, 1995) and for homogeneity of variance using Levene’s test. The data which did not meet the assumptions for the application of an ANOVA were log transformed (x).

The procedure employed by Marquet et al. (1995) was used to determine the relationship between the CPUE and morphostructural benthic groups. This consisted in determining the slope of the upper limit (maximum CPUE values) of the relationship between CPUE and live substrate cover, which could be an indicator of energy availability in reef systems. This procedure involves dividing the X-axis into intervals of equal width and registering the maximum value of the response variable (CPUE) of the fishing quadrants along the X-axis for each interval. Subsequently, simple linear regressions (r²) and Pearson correlations (r) were used to relate these two variables.

An ANOVA was applied to determine the significance of the relationship between MSG coverage and CPUE values (Zar, 1999).

**RESULTS**

Production and species composition. Based on annual catch and the presence of three fishing cooperatives in the CHBBR, total production for the entire reef system was estimated to be 0.6579 t·km⁻²·yr⁻¹. The reef area covered by the fishing zones used by fishermen was calculated to be 238 km², considering an 18 m iso-bath. A total of 37 species from 13 families were identified from 176 fishing trips. Four families were the most representative and corresponded to 87.88% of the total catch (Table 1): Lutjanidae (36.42%), Serranidae (27.01%), Balistidae (14.76%) and Labridae (9.69%). Balistidae, Serranidae and Labridae species were captured using spear, while Sphyraenidae species were captured using hand lines. In the case of the Lutjanidae species, *Lutjanus analis* and *Lutjanus griseus* were captured using spear, whereas *Lutjanus vivanus* and *Ocyurus chrysurus* were captured using hand lines (Table 1).

Spatial and temporal arrangement of fisheries. The results of the MDS, using the CPUE in the area of the CHBBR, divides the reef system into seven fishing zones (Fig. 2A-B). In zones 1, 2, 4 and 5, quadrants were located within the lagoon with some patch reefs formed mainly by scleractinian corals, octocorals, hydrocorals, sponges, algae, and seagrass, whereas in zone 7 the quadrants were generally covered by scleractinian corals, octocorals, hydrocorals, sponges and algae. Using a 90 % cumulative percentage for different species per zone, the SIMPER indicated hogfish, *Lachnolaimus maximus* (Walbaum, 1792); *E. striatus*, black grouper, *Mycteroperca bonaci* (Poey, 1860); *L. analis*, silk snapper, *Lutjanus vivanus* (Cuvier, 1828); and yellowtail snapper, *Ocyurus chrysurus* (Bloch, 1791) to be diagnostic species for different fishing zones (Table 2). Analysis of the CPUE by fishing zone with the ANOVA showed differences between *L. analis* and *L. vivanus*; the highest values for *L. analis* were presented in zone 7 (mean = 3.14 ± 3.66 S.D.) in relation to zones 2 (mean = 0.98 ± 1.34 S.D.) and 5 (mean = 0.82 ± 0.83 S.D.), and the highest values for *L. vivanus* were presented in zone 6 (mean = 1.79 ± 0.53 S.D.) in comparison with zones 2 (mean = 1.65 ± 0.88 S.D.) and 7 (mean = 1.03 ± 0.88 S.D.).

The temporal analysis of the CPUE showed significant differences between *L. analis* and *L. vivanus*; the highest values for *L. analis* were presented in zone 7 (mean = 44.87 ± 4.22 S.D.) and 2 (mean = 47.47 ± 3.24 S.D.) as opposed to zone 1 (mean = 35.55 ± 2.65 S.D.) (Table 1; Fig. 4). The temporal analysis of the CPUE showed significant differences between climatic seasons. The greatest CPUE values for *E. striatus*, *M. bonaci*, *L. maximus* and great barracuda, *Sphyraena barracuda* (Edwards, 1771) were presented in the “Nortes” season (Table 1; Fig. 4), whereas for *L. analis* the greatest CPUE value was recorded during the dry season. *Balistes capriscus* was only captured in February, during the “Nortes” season. The temporal analysis of the size of individuals was significantly different for *L. analis* in the dry season (Table 1; Fig. 4).

The CPUE was significantly related to the cover of scleractinian coral and sponges (p < 0.01), although these variables explained only 37 and 38% of the total variation, respectively (Fig. 5).
Table 1. Main species caught in Banco Chinchorro and results of a two-way ANOVA on the comparisons of average CPUE (kg-fisherman\(^{-1}\) - hr\(^{-1}\)) and size (cm) of the fish. Significant \(p\)-values (< 0.05) are indicated in bold.

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<th>Catch (%)</th>
<th>Average Size (±S.D.)</th>
<th>Average CPUE (±S.D.)</th>
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<td>0.60</td>
<td>0.8376</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Season</td>
<td>40</td>
<td>1.70</td>
<td>0.2124</td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION**

**Production and species composition.** Three potential causes of low yield estimates for the CHBBR are: 1) a low number of fishermen due to control by the authorities of the reserve limiting the number of fishermen per cooperative; 2) fishermen focus most of their effort on the spiny lobster fishery; and 3) the use of scuba diving or nets for any fishing activity is prohibited. These factors may also be resulting in the exploitation of fewer species (37 species) compared to Grovers Reef and the MAR region where 57 and 68 species respectively, are normally exploited (WWF, 2006; Coleman, 2008). The annual production estimates made here are different from those reported in Cuba (1.4 t km\(^{-2}\) yr\(^{-1}\)) (Claro et al., 1994);
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and on the Lesser Antilles (4.0 t km$^{-2}$ yr$^{-1}$) (Gobert, 1990). A reef system’s production depends on a number of factors (e.g. depth, coral cover, fishing area, methodology, etc.), however fishing effort is by far the most important (Arias-Gonzalez et al., 1994; Costa et al., 2003). The species in the sample are characteristic of the fauna exploited at other sites in the Caribbean and Gulf of Mexico (Munro, 1983; Butler et al., 1993; Claro et al., 1994; Coleman et al., 2000; Schmitter-Soto et al., 2000). Of the 10 species analyzed the great majority correspond to piscivorous or carnivorous species, and none correspond to parrotfish or other herbivorous species, as is the more common in areas of overfishing such as Mexican fringing reefs (pers. obs.) and Belize coral reefs (Gibson & Hoare, 2006; Coleman, 2008) where fishing down the food web is increasingly notable.

**Spatial and temporal arrangement of the fishery.** In many reef systems in the Atlantic, the variability of the CPUE and the distri-
plex reef development is evident with abundant colonies of gorgonians. These are the first records of reproduction aggregation sites for these two species in the Mexican Caribbean.

The differences in size of the individuals of *O. chrysurus* captured using a hand line may be due to the fact that this species was fished in different types of habitat. The sites with fish catches of smaller sizes are located in shallow habitats within the reef lagoon, which can serve as a shelter, while larger organisms were fished in deeper areas in the southern zone of the reef lagoon and in the windward region, which present more complex reef structures in the CHBBR (Jordán & Merino, 1987). In various studies this species, in its juvenile state, has been observed to present a very high dependency on shallow habitats (mangroves, seagrasses and small reef structures, whereas the adult organisms have been found in reefs of greater structural complexity in deeper waters (Nagelkerken et al., 2000; Nagelkerken et al., 2002; Mumby et al., 2004; Nagelkerken & van der Velde, 2004a; Nagelkerken & van der Velde, 2004b; Adams et al., 2006).

The fishing activity of the spiny lobster also apparently influenced the differences in fishing effort during the climatic seasons. The start of the lobster fishing season and the greatest fishing effort was in July, corresponding to the rainy season. Between November and February (Nortes) lobster catch became scarce and effort increased towards finfish. After the lobster fishing season from March to June (dry), many boats did not go out to fish because the capture of finfish is not highly profitable.

Figure 3A-C. Comparison (ANOVA) results of the CPUE for *L. analis* (A) y *L. vivanus* (B) and fish size for *O. chrysurus* (C). Letters (a and b) identify averages that differed significantly between fishing zone according to Tukey’s Test. The asterisk indicates the quadrant where the spawning aggregation is being fished.
Figure 4a-f. Average values (±Standard deviation) of the CPUE and fish size of the five most important fish species. Letters (a and b) identify averages that differed significantly between climatic seasons according to Tukey’s HSD Test.
Figure 5a-f. Relationship among the CPUE of the ten most important fish species and the benthic morphostructural groups (MSG) ($r^2$ = regression; $r$ = Pearson correlation; ANOVA, $p < 0.01$).
Throughout the Caribbean Sea, certain species present gregarious habits during their reproductive activity (AguilAr-PererA 
& Aguilar-DávilA, 1996; Garcia-Cagide & Garcia, 1996; Domeier & Colin, 1997; Crabtree & Bullock, 1998; Aguilar-PererA, 2006; Hey-
man & Kjerfve, 2008). In this study, exploitation of E. striatus, L. maximus and M. bonaci was shown during their spawning ag-
ggregation events, which are presented during the Nortes season. For E. striatus spawning aggregation sites have been reported 
inside the study area during the Nortes season (Aguilar-PererA & Aguilar-DávilA, 1996; Aguilar-PererA, 2006); whereas the spawn-
ing seasons of S. barracuda are not known, although, in the study area organisms with mature gonads were found during the 
"Nortes" season.

Most studies on spawning aggregations of Lutjanus analis in reefs of the Atlantic have found that from May to July; this spe-
cies presents this gregarious behaviour in specific sites (Domeier et al., 1996; Lindeman et al., 2000; Burton et al., 2005; Graham et 
al., 2008; Claro et al., 2009). For Balistes capriscus there is little information on its spawning aggregation period, however, it has 
been reported between November and August (Bernardes & Dias, 2000; Sedberry et al., 2006).

In general, the results suggest that fishing activity in the area of study is directed towards the resource that offers the max-
imum economic benefit (i.e. lobster) and the minimum fishing ef-
fort (i.e. spawning aggregations), which influences the capture of 
commercially important fish. In this context, resource managers 
at CHBBR are currently locating the spawning areas of these species in order to protect them and thus ensure the supply of 
recruits. They are also searching for alternative sources of income for fishermen, such as ecotourism, marine fish culture and 
exploitation of pelagic species, which are all more profitable than direct fishing of aggregations. For example, in an evaluation of 
the economic impact of fishing the grouper aggregation on Glover’s Reef, Belize, Sala et al. (2001) found that ecotourism income from 
the aggregation was 20 times greater than that generated from 
extracting the resource.

The positive relationship between CPUE and the cover of scleractinian corals and sponges was due to the combination of 
deeper habitats in the southern lagoon and the reef system edge, generally located in fishing zone 7, which has the highest struc-
tural complexity and consequently greater microhabitat diversity. The benthic organisms that contribute most to the structural complex-
ity in Caribbean reefs are scleractinian corals and sponges (Opresko, 1973; Alcolado & Herrera, 1989; González-Sansón et al., 1997; 
González, 1999; Jordán-Dahlgren, 2002; Ruiz-Zarate et al., 2003; Caballero et al., 2004). Depth may also be affecting cover in 
these areas since many studies show higher scleractinian coral 
and sponge abundances in environments between 6 and 30 m depth (e.g. Goreau, 1959; Huston, 1985; Graus & Macintyre, 1989; 

Management implications. Considering the classification by Russ 
(1991), the impact of fishing in the CHBBR is low to moderate be-
cause: 1) it uses selective equipment (speargun) and occasionally a 
hand line; 2) the majority of the species caught are top predators 
and belong to the snapper-grouper complex, since these species 
are highly valued in the market; and 3) fishing is the only activ-
ity that affects the fish communities and their habitats. However, 
this investigation proves that the principal species fished are ex-
ploded in their spawning aggregation seasons. This is a common 
ocurrence in the Caribbean and a great number of records exist 
that indicate that this fishing strategy is harmful to the populations 
since it causes the extirpation of reef fish spawning aggregations 
(e.g., Sadovy & Eklund, 1999) and changes to the reproductive 
population structure, such as decreases in mean fish size (e.g., 
Sadovy, 1994), abundance (e.g., Claro et al., 2001), genetic diver-
sity (e.g., Chapman et al., 1999) and alterations in aggregation 
sex ratio (e.g., Koenig et al., 1996). For this reason, a strategy for 
reducing fishing impact would be the seasonal closure of their 
spawning sites. This measure could be accompanied by catch 
control policies in the landing locations. Personal observations 
dicate that fishermen are starting to fish parrot and angel fish 
and shell them as fillets of grouper or snapper. Finally, although this 
study presents a general overview of the current state of fishing, 
it is important to focus studies at the population level for the spe-
cies of greatest commercial importance and to perform studies at 
ecosystem level, analyzing indicators that could measure fishing 
stress within fish communities (Pikitch et al., 2004).

ACKNOWLEDGEMENTS

This research was financially supported by Fondos Mixtos CONA-
CYT (Ref. QROO-2003-C02-13020). The authors thank members of 
the Langosteros del Caribe Fishing Cooperative and the Chinchorro 
Bank Biosphere Reserve personnel for their cooperation in the 
field work.

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Recibido: 13 de mayo de 2010.

Aceptado: 22 de julio 2011.