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Research Article

Comparison of catch, CPUE and length distribution of spawning aggregations of mutton snapper (*Lutjanus analis*) and grey triggerfish (*Balistes capriscus*) on a Mesoamerican coral reef

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ABSTRACT. This study evaluates the habitat characteristics, fishing effort, and production, as well as changes in the individuals, such as changes in size frequency, of the spawning aggregations of mutton snapper *Lutjanus analis* and grey triggerfish *Balistes capriscus*, caught in the Chinchorro Bank Biosphere Reserve (CBBR), Mexico. The mutton snapper aggregation was located in coral patches, while the spawning aggregation of grey triggerfish was located on the windward terrace of the reef flat. Fishery data was obtained for the duration of the spawning event in 2008, with a total of 5 days for mutton snapper and 4 days for grey triggerfish. The fishery recorded a total of 830 mutton snappers, with individual sizes ranging from 40 to 77 cm in fork length (FL). Individual size and catch per unit effort (CPUE) decreased through time, with the lowest values presented at the end of the 5 days. In contrast, a total of 665 grey triggerfish were recorded in the catch, ranging from 45 to 61 cm (FL) with the largest sizes caught at the end of the fishing period, concurrently with the lowest CPUE. A lack of governance allowed both species to be harvested during their spawning aggregations. The creation of an international body composed of fishers, managers, conservationists, and scientists from the countries belonging to the Mesoamerican Reef System is urgently required to look for agreements in conservation and management strategies of these commercially important species.

Keywords: artisanal fisheries, spawning aggregations, coral reef fishes, management, marine protected area, Mexico.

INTRODUCTION

Aggregations of tens of thousands of individuals of the same species, which occur at the same time and location for spawning, are a vital phase in the life histories of many reef fish (Colin *et al*., 2003; Sadovy de Mitcheson *et al*., 2008). Aggregation fishing poses unique threats since once found, aggregations are particularly easy to relocate and heavy fishing can rapidly remove a significant proportion of assembled individuals with potentially severe implications for reproductive and economic outputs (Sadovy, 1994; Sadovy & Domeier, 2005). A global database by the Society for the Conservation of Reef Fish Aggregations (SCRFA) shows that within exploited aggregations of known history (n = 140), over 60% show evidence of declines in density, almost 20% may have ceased to form, while the remaining 20% show stability or, in a few cases, may increase (Russell *et al*., 2014).

Historical evidence documented in several locations of the Caribbean points to a local and regional pattern of overexploitation, including the extirpation of reef fish spawning aggregations in areas where they used to occur (*e.g.*, Sadovy & Eklund, 1999; Paz & Grimshaw, 2001; Sadovy *et al*., 2003; Aguilar-Perera, 2006; Graham *et al*., 2008). The effects of fishing on these aggregations include changes in the structure of the reproductive population, such as alterations in the sex

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ratio (Koenig *et al*., 1996), a reduction in mean individual size (*e.g*., Sadovy, 1994; Graham *et al*., 2008), and declines in abundance (*e.g*., Claro *et al*., 2001) and genetic diversity (Chapman *et al*., 1999; Carson *et al*., 2011). Increased fishing effort and reduced catches are often observed following intense fishing activity targeting reef fish spawning aggregations (Beets & Friedlander, 1998; Matos-Caraballo *et al*., 2006). Recent research has focused on the spatial location of reef fish spawning aggregations and on recording the exact dates when these spawning events occur to establish management strategies (Kobara & Heyman, 2010). The identification of spawning activity during these aggregations may be assessed through two types of signals: direct and indirect. Direct signals provide unambiguous evidence of the occurrence of a spawning aggregation. They include direct observation, documentation of courtship behavior, and witnessing the spawning time during scuba diving at spawning sites. Indirect signals require additional supporting information to confirm the reproductive character of the aggregation. Examples of indirect signals include a swollen abdomen in the females, a change in the breeding color pattern, or a significant increase in relative abundance or a sharp rise in commercial catches at specific times of year and fishing areas (Colin *et al*., 2003; Heyman *et al*., 2004). In areas where spawning aggregations are not exploited, and their spatial location is unknown, an alternative approach is to identify spawning aggregation sites based on geomorphologic features of the habitat (Heyman *et al*., 2004; Boomhower *et al*., 2010; Kobara & Heyman, 2010; Gleason *et al*., 2011).

Despite recent progress in studies of reef fish spawning aggregations in the Caribbean, there is still little information on the dynamics of the spawning patterns and the effects of fishing on these aggregations at local scales in many reef systems (Sadovy de Mitcheson *et al*., 2008; Granados-Dieseldorff *et al*., 2013). As a result, fisheries management approaches to fish spawning aggregations have been based on emerging information on these resources, which has led to the establishment of marine protected areas (MPA) as a preventive protection strategy (Botsford *et al*., 1997; Palumbi, 2003). There are many cases of successful recovery of populations and fisheries in areas with strong support from fishers, where they participate in the monitoring and management of the spawning aggregations (Aburto-Oropeza *et al*., 2011; Hamilton *et al*., 2011; Granados-Dieseldorff *et al*., 2013). Several of these fishers have been involved in including spawning sites within marine protected areas (Berkes, 2007; Karras & Agar, 2009; Aburto-Oropeza *et al*., 2011; Edgar *et al*., 2014). In other regions, fishers have also supported the establishment of spatial and temporal closures to protect the spawning aggregations, allowing them to catch other species during these periods or in these spawning sites. However, in some cases, the involvement of fishers in the management and conservation processes inside and outside of MPAs has not been given much consideration (Castilla & Defeo, 2005; Hilborn, 2011).

In the western Caribbean, fishers from Mexico, Belize, Guatemala and Honduras traditionally harvest spawning aggregations of groupers (Epinephelidae) and snappers (Lutjanidae) over high relief areas of the fore reef (Craig, 1966; Castro-Pérez *et al*., 2011; Heyman & Granados-Dieseldorff, 2012). The mutton snapper *Lutjanus analis* is the most commercially important species of the Lutjanidae family (Bortone & Williams, 1986; Claro, 2001). Likewise, harvesting of the spawning aggregation of grey triggerfish *Balistes capriscus* has also been recorded, which is sometimes sold as Nassau grouper *Epinephelus striatus* fillet at local markets (Castro-Pérez *et al*., 2011). Despite the economic importance of these two species, there is no regional information on 1) the characteristics of the sites where these spawning aggregations occur, and 2) the amount harvested and the economic benefits for local fishers. This study evaluated the habitat characteristics of sites where spawning aggregations of mutton snapper and grey triggerfish were identified by locating their geographic positions in a supervised classification of benthic habitat. It also assessed daily fishing indicators, including catch, catch per unit effort (CPUE) and individual sizes of these spawning aggregations in the Chinchorro Bank Biosphere Reserve (CBBR) in Mexico. The objective was to generate knowledge that can be used for improving the management plan of the CBBR and also to provide an essential baseline for comparing with fishing variables with the purpose of evaluating the exploitation status of the reproductive aggregations.

MATERIALS AND METHODS

Study area

The CBBR covers part of the Mesoamerican Reef System (MRS), which extends 1,000 km along the coasts of Honduras, Guatemala, Belize, and Mexico. It was declared a Biosphere Reserve in 1996 (marine protected area) under Mexican law. The CBBR is located in southeast Mexico, in the state of Quintana Roo, approximately 39 km offshore from the coastal town of Mahahual (18º47'N, 87º14'W) (Fig. 1). The bank itself is oval in shape, has a surface area of approximately 814.29 km^2 (45 km long by 18 km wide) and encompasses three keys: Cayo Norte (0.42 km^2),

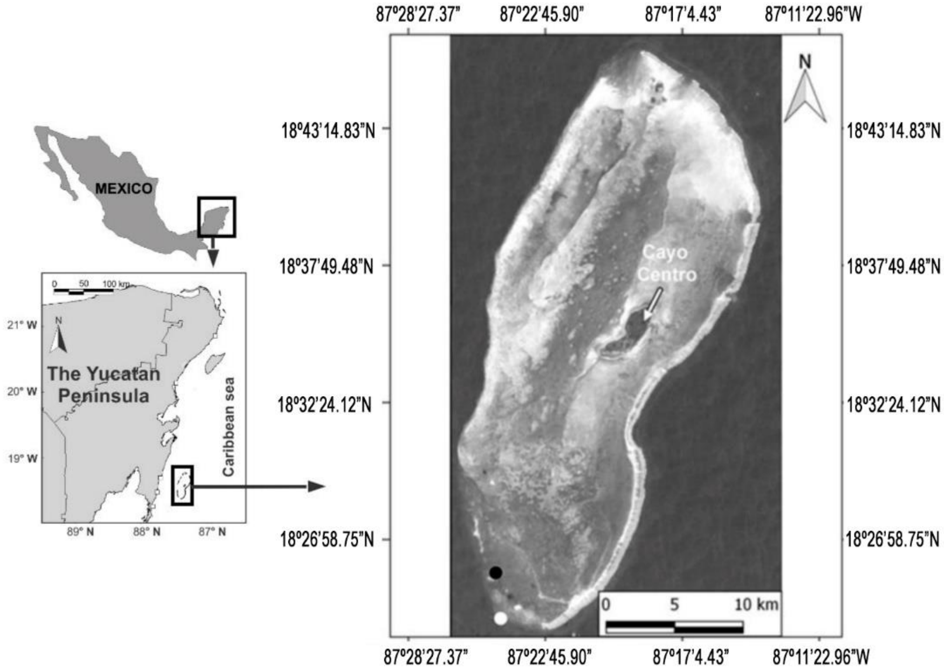

Figure 1. Study area and spawning aggregation sites of *Lutjanus analis* (○) and *Balistes capriscus* (●) in the CBBR, Mexican Caribbean.

Cayo Centro (5.41 km²), and Cayo Lobos (0.13 km²) (Chávez & Hidalgo, 1984; Jordán & Merino, 1987). The reef lagoon covers approximately 553.79 km², with depths varying from 2 to 10 m and a general decrease in depth from south to north. Coral patches occur throughout the reef lagoon, but are more numerous in the south and only occur in the central portion of the northern lagoon. Coral ridges are numerous in the south and absent in the north. The reef lagoon contains three core zones: Cayo Lobos, with 6.79 km^2, intended for the protection of staghorn coral; Cayo Centro, with an area of 12.64 km^2 and Rabios Lagoon, which was designed to protect the typical ecosystems of the CBBR. Together these zones have an area of 45.88 km^2 and represent 3.17% of the total area of the reserve (De Jesús-Navarrete, 2001). In 2013 the federal government established a fishing refuge zone called 40 cañones (122.57 km^2) in the CBBR to add a complementary management measure for the conservation and sustainable exploitation of the species of fishing interest.

Fisheries on the Chinchorro Bank reef

In the CBBR, fishing cooperatives (Langosteros del Caribe, Andrés Quintana Roo, and Pescadores de Banco Chinchorro) are currently allowed to carry out fishing activities based mainly on catching queen conch *Strombus gigas*, spiny lobster *Panulirus argus*, and demersal and pelagic fish. The fishery dynamics in the CBBR are mainly influenced by the harvest of spiny lobster, the reproductive behavior of several species of fish and weather conditions. The spiny lobster fishing season begins on 1st July and ends on the last day of February, with maximum fishing effort in July. Subsequently, fishers redirect their fishing effort to species of groupers, snappers, and barracuda, as the product becomes scarcer, based on their economic importance in local markets (Castro-Pérez *et al*., 2011). Many of these fishes are harvested during their spawning periods. Weather conditions, such as northerly and south-easterly winds, often hinder fishing activity.

Mutton snapper and grey triggerfish fisheries are developed when these species aggregate to spawn on the CBBR reefs. Mutton snapper fishing is performed around the full moon during a period of 5 to 10 days in May, while grey triggerfish fishing is carried out during the new moon in February, covering approximately 6 to 8 days of fishing. Fishers travel daily between 15 and 20 km from their base camp on Cayo Centro to the sites where spawning aggregations occur, located in the southern zone of the reef complex (Fig. 1) to harvest both species.

Habitat characteristics of spawning aggregation sites

To assess the habitat characteristics of the spawning aggregation sites, 235 sampling stations were used to characterize the benthic substrate. In each sampling station, the benthic community was surveyed by recording it using an underwater video camera at a distance of 40 cm perpendicular to the substrate along each 50 m transects. Each video transect was then sampled using 40 frames and 13 systematically dispersed points (520 points per transect). Data were grouped into the following major benthic categories: massive coral, branched coral, encrusting coral, dead coral, octocoral, hydrocoral, macroalgae, algal turf, sponge, calcareous material, and sand. With this information and a Landsat TM satellite image from the year 2000, a supervised classification image of the habitat types was produced in a Geographic Information System (GIS). Subsequently, the aggregation sites were spatially located on the habitat classification image. Finally, where the aggregations were found, a description of the characteristics of the benthic communities (relative coverage %) of the habitat was made.

Fisheries data

The fishery data was obtained from 5 boats which exploited the spawning aggregations of mutton snapper and grey triggerfish daily; the 5 boats were different for the fishery of each species. The boats used were made of fiberglass with a carrying capacity of 1 ton and used an outboard engine with a power between 40 and 60 HP. Two or three fishers manned these boats. Mutton snapper information was gathered during the fishing activities conducted from 20 to 24 May 2008 during the full moon phase. In contrast, the harvest of the grey triggerfish began one day before the new moon. Fishing was carried out during the day and lasted 4 days (5 to 8 February 2008). The fishing technique used to catch mutton snapper was a hand line, whereas a harpoon was used for grey triggerfish. Fishers carried out prospecting surveys, to avoid unnecessary costs, by free diving at the spawning sites one week beforehand to ensure that they were fishing during abundance peaks in the spawning aggregations for both species.

Full information on total catch and individual fork length (cm) and weight (g) were taken from all boats throughout the entire fishing season. Fish length was measured with an ichthiometer from the tip of the snout (with the mouth closed) to the midpoint of the caudal fin (fork length or FL), and weight was measured with a top loading balance with a capacity of 20 kg. Additionally, information on the number of fishers and departure and return times were obtained by applying a questionnaire to all boat captains, the catch per unit effort (CPUE) was estimated as kg per boat per fishing day (kg boat^{-1} day^{-1}) to compare the dail catchy production from each spawning aggregation.

The mutton snapper total production, obtained through catch records from the National Aquaculture and Fishing Commission (CONAPESCA) (taking into account the 41 boats and 92 fishers that operate in the area), was used to estimate the equivalent catch proportion of the spawning aggregation, during the 5 days of fishing, relative to the total catch of this species in the CBBR during the year. Similarly, to estimate the economic benefit to fishers, the current market value of a kilogram (kg) of mutton snapper for the year when the study was carried out was considered. On the other hand, considering that the catch of grey triggerfish is sold as fillets, a relationship between fish weight per boat and fillet weight was performed over the 4 days. Likewise, to estimate the proportion of the triggerfish spawning aggregation concerning the total fillet production in the CBBR, the total fillet yield was obtained from the CONAPESCA catch records; however this value corresponded to the catch of two species: white margate *Haemulon album* and grey triggerfish. Therefore, the fillet production value corresponding only to grey triggerfish had to be estimated.

Data analysis

Catch, income and fishing effort

A one-way analysis of variance (ANOVA) was used to assess daily differences in CPUE and organism length for mutton snapper and grey triggerfish spawning aggregations. Subsequently, a Fisher's LSD test for multiple ranges was used (Zar, 1999). Data were Log (x) transformed to meet assumptions of normality (Shapiro-Wilk test) and homoscedasticity (Levene's test) (Zar, 1999). Finally, to determine the proportion of the catch of the grey triggerfish spawning aggregation marketed as fish fillet, a simple linear regression was performed between individual weight and the weight obtained as fillets per boat.

RESULTS

Habitat characteristics of spawning aggregation sites

The mutton snapper habitat was characterised as being a continuous area of coral with a significant percentage of macroalgae (69.4%), followed by branched coral (12.9%), sand (7.5%), dead coral (4.6%), octocoral (3.8%), massive coral (0.6%), algal turf (0.6%), sponge (0.4%) and hydrocoral (0.2%) (Fig. 2a). The habitat of the grey triggerfish aggregation site was characterised by patches of coral composed of sand (35.2%), calcareous material (24%), macroalgae (18.1%), octocoral (14.4%), sponge (3.5%), massive coral (2.7%),

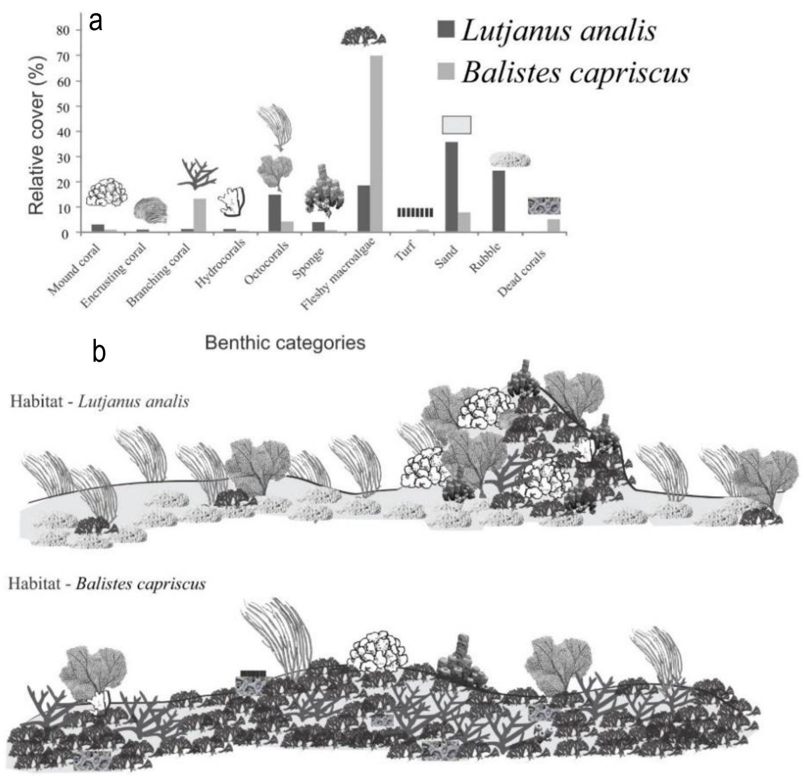

Figure 2. Percentage of benthic categories at sites where spawning aggregations were present.

branched coral (0.8%), hydrocoral (0.8%), and encrusting coral (0.6%) (Fig. 2b).

Individual size and CPUE

A total of 830 mutton snappers were recorded in the spawning aggregation catches during the five fishing days. Individuals landed ranged in size between 40 and 77 cm FL (60.47 ± 6.30 cm. mean ± SD), FL. Throughout the fishing days, the most represented individual sizes in the spawning aggregation were in the 50-59 and 60-63 cm FL intervals (Fig. 3a). The largest sizes were observed in the first three days of fishing (ANOVA, $P < 0.05$), which significantly differed from the other two days (LSD test, $P < 0.05$) (Fig. 3a). In regards to grey triggerfish, 665 individuals were landed during the four days of the full fishing season. Length frequencies ranged between 45 and 61 cm FL (52.70 ± 3.50 cm) (Fig. 3b). Significant differences in the size of individuals were found between fishing days (ANOVA, $P < 0.05$). A systematic increase in the mean size of fish captured was observed through time, ranging from 47.47 ± 0.11 cm on the first day to 57.81 ± 0.13 cm on the last day (Fig. 3b).

The overall CPUE estimated for mutton snapper was 116.71 ± 51.85 kg boat^{-1} day^{-1}. Significant differences in CPUE were found among days (ANOVA, $P < 0.05$). The first fishing day presented the highest values (194.16 ± 43.73 kg boat^{-1} day^{-1}) and the last day the lowest (68.09 ± 6.52 kg boat^{-1} day^{-1}) (Fig. 4a). Short-term trends in CPUE followed a monotonic exponential decrease of the form $y = a \times b^{(-x)}$. For the grey triggerfish, CPUE was 83.95 ± 23.22 kg boat^{-1} day^{-1}, and significant differences were found between days (ANOVA, $P < 0.05$). The highest values were estimated for the second and third days (97.35 ± 9.36 and 103.65 ± 13.81 kg boat^{-1} day^{-1}, respectively) and the lowest on the last fishing day (51.23 ± 6.21 kg boat^{-1} day^{-1}) (Fig. 4b).

Catch and income

During the 5 days of mutton snapper fishing, a total of 2,318 kg of fish were landed, representing 42% of the total catch in the CBBR (5,491 kg). This estimate was based on records of catches registered by the National Aquaculture and Fishing Commission (CONAPESCA) for that year, taking into account all boats and fishers in the study area. Based on prices per kg of whole fish in 2008 (US$ 6.27 kg^{-1}), mutton snapper aggregation fishing equated to a sum of US$ 14,533, while the estimate for total production was US$ 34,429.

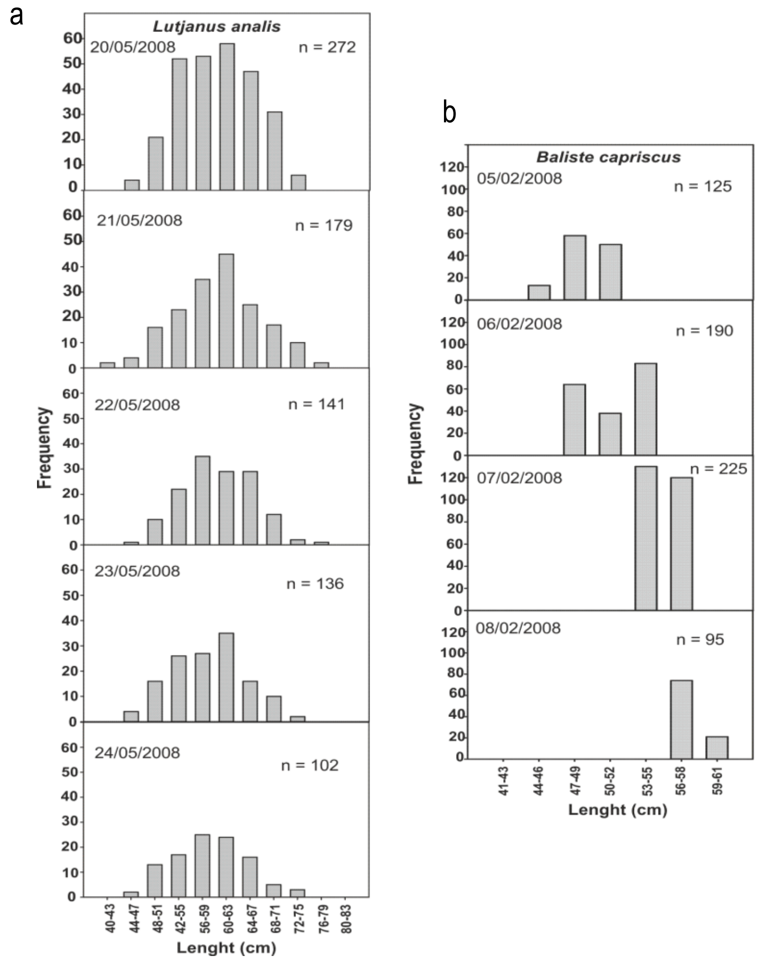

Figure 3. Daily length frequency distributions of a) the mutton snapper *Lutjanus analis*, and b) the grey triggerfish *Balistes capriscus* in their spawning aggregation fisheries in the CBBR, Mexico.

Concerning grey triggerfish, a total of 1,679 kg of whole fish were caught in the spawning aggregation during the four fishing days. Given that this product is sold as fish fillet, this catch provided a total of 589 kg of fillet. The weight of individuals per boat showed a positive linear relationship with the weight of fillet obtained ($R^2 = 0.9824$; $P < 0.001$). With this linear regression model, it was estimated that 100 kg of whole fish provided 40 kg of fish fillet (40% of the catch per boat). In the study area, there is a general record of the quantity of fillet obtained from white margate *Haemulon album* and grey triggerfish (2,866 kg) caught throughout the year, which indicates that spawning aggregation fishing of grey triggerfish contributes to 20.55% of the annual fillet production. Taking into account the price per kg of fillet (US$ 6.72 kg^{-1}), the spawning aggregation catch of grey triggerfish equated to US$ 3,958, while the estimate of total fillet production per year was US$ 19,260.

DISCUSSION

The grey triggerfish spawning aggregation site was located within the reef lagoon and was characterized by small reef promontories with a predominance of macroalgae surrounded by sandy areas with seagrasses within a depth range of 3 to 6 m. The area where the mutton snapper spawning aggregation occurred was located on a terrace close to the reef crest in the windward area at depths ranging from 12 to 14 m, which corresponds to a flat reef zone composed mainly of macroalgae and branching corals. The mutton snapper spawning aggregation was found in a shallower area than other spawning aggregations recorded for this species in other Caribbean reef systems (Lindeman *et al*., 2000; Claro & Lindeman, 2004; Burton *et al*., 2005; Heyman & Kjerfve, 2008; Claro *et al*., 2009; Gleason *et al*., 2011) likely linked to the fishing intensity on the reefs studied. The spawning aggregation recorded in this study experiences low fishing intensity compared

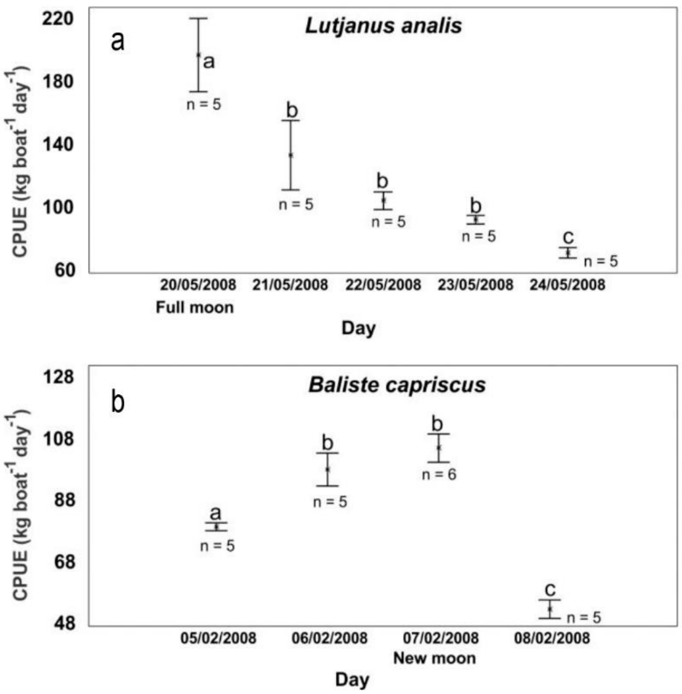

Figure 4. Daily CPUE trends in the spawning aggregations of a) the mutton snapper *Lutjanus analis*, and b) the grey triggerfish *Balistes capriscus* in the CBBR. Letters (a, b and c) indicate significant differences (Fisher's LSD).

to other reefs in the Caribbean because few fishers know the location of the site and they do not generally reveal this information. Regarding this, Aguilar-Perera & Aguilar-Dávila (1996) studied the Nassau grouper spawning aggregation in the Mexican Caribbean and suggested that spawning aggregations may move to deeper sites far from fishing pressure. However, this hypothesis requires further testing.

A comparison of indicators with mutton snapper spawning aggregations at Gladden Spit in Belize (Graham *et al*., 2008; Granados-Dieseldorff *et al*., 2013) showed that 830 individuals were caught in the study area, whilst Graham *et al*. (2008) reported a mean of 1,273 ± 611 individuals in the 2000-2006 fishing period, excluding the year 2005. Granados-Dieseldorff *et al*. (2013) recorded 1,146 ± 805 individuals at the same reef in the 1999-2011 period excluding the years 2002 and 2010. The two previous studies carried out at Gladden Spit analyzed the catch of daily landings from boats between March and June each year during their study periods, keeping records of the catches over 10 to 14 days each month when the peaks in abundance were greatest due to the spawning of this species. In the study by Graham *et al*. (2008), the number of boats where daily fishing records were obtained ranged from 5 to 7, whereas in the study by Granados-Dieseldorff *et al*. (2013) it ranged from 3 to 15.

The size of the organisms recorded in the CBBR was larger than those found in the two studies on spawning aggregation fishing at Gladden Spit. Graham *et al*. (2008) found a mean of 55.4 ± 1.0 cm FL for females and 52.3 ± 0.89 cm FL for males, while Granados-Dieseldorff *et al*. (2013) recorded individuals between 49 and 57 cm FL. The overall mean CPUE in this study was also higher than that found by Granados-Dieseldorff *et al*. (2013) (68.13 ± 37.52 kg boat^{-1} day^{-1}). The analyzed indicators could suggest that the mutton snapper spawning aggregation in the CBBR is less exploited than that of Gladden Spit. Probably because a) the spawning aggregation occurs in the closed season for spiny lobster and fishers only fish at the aggregation during the time when this activity is profitable (4 to 7 days), b) very few fishers know the location of the aggregation site and they are protective of this knowledge which has been passed down from generation to generation. There is no data in the MRS concerning the grey triggerfish, which precludes the estimation of its exploitation status.

Daily variability of CPUE in the spawning aggregation for both species in the study area may be due to: 1) the moment in time when the organisms are caught, and the order in which individuals arrived at the spawning sites, or 2) the removal of organisms by fishing. The presence of larger-sized organisms at the beginning of the fishing season could be related to the first arrival of more experienced organisms at the spawning sites. It has been documented that knowledge on finding spawning sites can be transmitted from older organisms to younger ones (Warner, 1988, 1990). Therefore, intensive fishing of these older, more experienced organisms could result in a permanent loss of the spawning site, even after the recovery of the stock (Sadovy & Domeier, 2005), or may disrupt spawning migrations when the inexperienced recruits can no longer learn from the experienced fish (Corten, 2001). In a study on the experimental removal of bluehead wrasse (*Thalassoma bifasciatum*) aggregations, followed by the introduction of a new population of identical structure (number and sexual ratio), revealed that the previously used sites were not as likely to be chosen by the new population as other potentially identified sites (Warner, 1988). Similarly, the removal of the more advanced age classes during the spawning period will increase the truncation of age and change in the size structure (Lambert, 1990; Marteinsdottir & Thorarinsson, 1998; Wright & Trippel, 2009), reducing the proportion of large and older fish (Trippel *et al*., 2005; Kennedy *et al*., 2007; Green, 2008; Raventos & Planes, 2008; Kjesbu, 2009), which produce larger eggs per unit body weight than the smaller females. It is believed that the larger eggs have a higher survival advantage at the start of their life since they result in larger neonates, which are physiologically more likely to survive (Kjesbu *et al*., 1996; Raventos & MacPherson, 2005; Raventos & Planes, 2008).

Implications for management

A lack of governance persists in the CBBR, which has allowed the harvest of mutton snapper and grey triggerfish during their spawning aggregation periods and there is no regulation of fisheries outside their spawning periods. The only federal law concerning commercially important fish species in the study area is for Nassau grouper, which is a species that is associated with the closed season for Red grouper *Epinephelus morio* and other species of grouper from the Gulf of Mexico and the Caribbean Sea, which runs from 16 February to 15 March of each year.

The following recommendations are proposed to manage these populations: a) implementation of closed seasons during the reproductive period, and increased surveillance to prevent illegal fishing, b) establishment of minimum individual catch sizes, c) use of hand lines only, given that the harpoon is more selective of larger-sized fish, d) implementation of a community-based monitoring program directed at gathering information on individual sizes and CPUE with the aim of evaluating these spawning aggregations. Finally, the creation of an international body composed of fishers, managers, conservationists, and scientists from countries belonging to the MRS is urgently required to look for agreements in conservation and management strategies for these commercially important species.

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