Contrast in the density and biomass of fish in a reef system with different fishing intensity in the Mexican Caribbean (#106576)

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Contrast in the density and biomass of fish in a reef system with different fishing intensity in the Mexican Caribbean

Jose Manuel Jose Manuel Castro Perez [Corresp., 1] , **Carmen A Villegas Sánchez** [1] , **Alejandro Medina Quej** [1] , **Rigoberto Rosas Luis** [1] , **Jesús Ernesto Arias González** [2]

[1] División de Estudios de Posgrado e Investigación, Tecnológico Nacional de México/Instituto Tecnológico de Chetumal, Chetumal, Q.R., Mexico

[2] Centro de Investigación y Estudios Avanzados del I.P.N-Unidad Mérida, Merida, Yucatán, Mexico

Corresponding Author: Jose Manuel Jose Manuel Castro Perez
Email address: jose.cp@chetumal.tecnm.mx

A wide range of fish species are caught in reef fisheries. However, fishing efforts tend to be highly selective in favor of large species, which generally have low population growth rates, making them more vulnerable to overfishing. When the decline of large predators occurs, fishing efforts start to focus on catching species from lower trophic levels, which can cause a trophic cascade effect.The objective of this research was to detect changes in the density and biomass of fish communities in areas with different fishing intensity in the study area.This study was carried out in Banco Chinchorro in the Mexican Caribbean and analyze the effect of fishing intensity on fish density and biomass, comparing data obtained from visual censuses with dependent information of the fishery. Evidence was found of a relationship between high fishing exploitation and low levels of density and biomass for *Epinephelus striatus, E. guttatus and Lachnolaimus maximus*. The decline of predators of non-commercial species had no effect on the density and biomass of these species. Both the density and biomass of the fish in the areas studied were influenced by the presence of algae, octocorals, hydrocorals and by variations in the CPUE.This study detected that density and biomass have decreased in some species belonging to the Serranidae and Lutjanidae families in areas with high fishing intensity. On the other hand, little evidence was found that the density and total biomass of families of noncommercially important species increased through the decline of their predators. Finally, although attempts were made to reduce the effect of structural complexity on the density and biomass of fish species, it was found that certain benthic groups and CPUE explained the observed changes in the density and biomass of fish assemblages.

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José M. Castro-Pérez[1], Carmen A. Villegas-Sánchez[1], Alejandro Medina-Quej[1], Rigoberto Rosas-Luis[2] and Jesús E. Arias-González[3].

1. Tecnológico Nacional de México/Instituto Tecnológico de Chetumal, Chetumal Quintana Roo, México.

2. Cátedras CONACyT. Tecnológico Nacional de México /Instituto Tecnológico de Chetumal, Chetumal Quintana Roo, México.

3. Centro de Investigación y Estudios Avanzados del I.P.N-Unidad Mérida, Yucatán, México.

Corresponding Author:
José M. Castro-Pérez[1]

Tecnológico Nacional de México/Instituto Tecnológico de Chetumal, Chetumal Quintana Roo, México.

Email address: jose.cp@chetumal.tecnm.mx.

Abstract

A wide range of fish species are caught in reef fisheries. However, fishing efforts tend to be highly selective in favor of large species, which generally have low population growth rates, making them more vulnerable to overfishing. When the decline of large predators occurs, fishing efforts start to focus on catching species from lower trophic levels, which can cause a trophic cascade effect.The objective of this research was to detect changes in the density and biomass of fish communities in areas with different fishing intensity in the study area.This study was carried out in Banco Chinchorro in the Mexican Caribbean and analyze the effect of fishing intensity on fish density and biomass, comparing data obtained from visual censuses with dependent information of the fishery. Evidence was found of a relationship between high fishing exploitation and low levels of density and biomass for *Epinephelus striatus, E. guttatus and Lachnolaimus maximus*. The decline of predators of non-commercial species had no effect on the density and biomass of these species. Both the density and biomass of the fish in the areas studied were influenced by the presence of algae, octocorals, hydrocorals and by variations in the CPUE.This study detected that density and biomass have decreased in some species belonging to the Serranidae and Lutjanidae families in areas with high fishing intensity. On the other hand, little evidence was found that the density and total biomass of families of noncommercially important species increased through the decline of their predators. Finally, although attempts were made to reduce the effect of structural complexity on the density and biomass of fish species, it was found that certain benthic groups and CPUE explained the observed changes in the density and biomass of fish assemblages.

Keywords: **c**oral reef; artisanal fishing; fish assemblage structure; Banco Chinchorro biosphere reserve; México.

Introduction

The increase in global fishing levels has generated environmental problems that are of public interest (*Pauly et al., 2002*). There is wide recognition that fish stocks throughout the world are under stress because of overfishing, coastal development, human population growth and climate change (*Savo, Morton & Lepofsky, 2017*; *Russ et al., 2021*).

Small-scale fisheries, including those in reef systems, are an important source of livelihood and food security for more than 1 billion people worldwide (*Adam et al., 2015*; *Babcock, Tewfik & Burns-Perez, 2018*). In the western Caribbean, more than a million people depend on the integrity and health of the Mesoamerican Reef System (MRS) for their livelihoods. The national economies of four countries (Belize, Guatemala, Honduras, and Mexico) benefit substantially from reef fishery resources and attractiveness as international tourist destinations (*Zeller, Graham & Harper, 2011*); however, there have been few studies on the effects of fisheries on reef fish communities (*Pauly et al., 2002*; *Adam et al., 2015*).

Although a wide range of fish species are caught in reef fisheries, fishing efforts tend to be highly selective in favor of large species, which generally have low rates of population growth, making them more vulnerable to overfishing (*Sadovy de Mitcheson et al., 2013*). Commercial species often include higher predators, such as serranids (groupers), lutjanids (snappers) and balistids (trigger fish). The decline of these species can increase the abundance of prey, which in turn influences the base of the food chain (*Mumby et al., 2006*; *Ruppert et al., 2017*). When the decline of large predators occurs, fishing efforts start to focus on catching species from lower trophic levels, which can cause a trophic cascade effect (*Jackson et al., 2001*; *Mumby et al., 2006*, *2012*). On the other hand, in recent years, it has been found that coral bleaching in large areas of reefs due to the effect of climate change (*Hoegh-Guldberg et al., 2018*) and the increase in the frequency or intensity of environmental disturbances such as hurricanes (*Knutson et al., 2010*) has much more direct effects on fish (*Graham et al., 2020*) and on benthos (*Hughes et al., 2018*; *Russ et al., 2021*) than fishing. The coral reef systems of the Banco Chinchorro Biosphere Reserve (BCBR) support many different species, which are the main component of fisheries in the area. These fisheries are generally small-scale, artisanal and multispecific; however, economic progress, increasing coastal tourism, and an increase in human population have led to greater competition for fishing resources and possible overfishing. Most of the fishermen live in the City of Chetumal, but spend 15 to 30 days in Cayo Centro in the RBBC to carry out their fishing activities. Approximately 41 motor boats powered by an outboard motor operate in the study area. The capture is made daily and freediving equipment is used for it.

The fisheries in the BCBR are closely associated with the extraction of the spiny lobster (*Panulirus argus*) and the queen conch (*Aliger gigas*), although several species of fish are also caught throughout the year, including fishing conducted during spawning aggregations of different species, such as *Lutjanus analis* and *Baliste capriscus* (*Castro-Pérez, González & Arias-González, 2011*). The federal and state governments of Mexico declared the BCBR a marine protected area on July 19, 1996, with the purpose of conserving and protecting mangrove and coral ecosystems. However, the management program that was established for these purposes was carried out with few scientific studies of the flora and fauna in this complex reef. However, to improve the fishing management plans in marine protected areas, it is necessary to incorporate technical and scientific opinions as well as the knowledge of users and handlers.

Although this study analyzed data obtained from sampling carried out in 2007 and 2008, the resulting information is of great relevance because there is currently no information on the effect of fishing activity on fish communities in the study area, mainly due to how difficult the sampling logistics are to carry out this type of study. For this reason, the present research aims to detect changes in the density and biomass of fish communities in areas with different fishing intensity, so the proposed hypothesis is that fishing reduces the density and biomass of the main fish species in the BCBR.

Materials & methods

Area of study

The BCBR is part of the Mesoamerican Reef System, which covers 1000 km along the coasts of Honduras, Guatemala, Belize and Mexico, and it is located in southeastern Mexico in the state of Quintana Roo, 42 km from the Mahahual coast (18°47’- 18°23’ N & 87°14’ - 87°27’ W). This reef was declared a marine protected area under the category of biosphere reserve in 1996. (Fig. 1A). Oval in shape, the BCBR covers an area of approximately 814.2 km^2 (45 km long and 18 km wide) and is composed of three cays: *Cayo Norte* (0.4 km^2), *Cayo Centro* (5.4 km^2), and *Cayo Lobos* (0.1 km^2) (*Chávez & Hidalgo, 1984*; *Jordán & Martin*, 1987). The reef lagoon covers approximately 553.7 km^2, with depths ranging from 2 to 12 m and gradually decreases from south to north (*González et al., 2003*).

Data collection.

Sampling of the fishery.

To identify areas with different fishing intensities in the study area, only the Langosteros del Caribe cooperative of the three that operate there was sampled, due to the complexity of working in all of them at the same time, for this purpose a monthly record was kept of the fish species caught between August 2007 and June 2008. During one week each month, the catches from the boats that arrived at the vessel that received the product were recorded. The weight was measured with a top loading balance with a capacity of 20 kg and an accuracy of 5 g. The fishing locations were recorded by consulting the position with the captain and using a map of the study area divided into 36 fishing quadrats (Fig. 1C). The CPUE was calculated as kilograms of fish caught per fisherman per hour ($kg \cdot fisherman^{-1} \cdot hr^{-1}$) for each quadrant.

Sampling of fish communities

Visual censuses were used to record the abundance and size of the reef fish using the linear transect technique proposed by *Brock (1954)*. Five visual censuses (replicas) were carried out at each sampling station, during the same day and time. Within a 50 m transect, the observer recorded the species detected within a distance of 2 m on each side and 5 m in front of the transect. For each observation, the diver recorded the abundance per species and estimated the total length of the fish. Fish lengths were estimated in 1 cm intervals for fish 0 to 10 cm TL and in 5 cm intervals for fish >10 cm TL. Samples were collected in August and September 2008 at 130 stations throughout the study area (Fig. 1B).

Sampling of the benthic groups in the reef habitats

The benthic cover was estimated to evaluate the characteristics of the habitat on the same date and in the sampling stations where the biological data of the reef fishes were obtained. A video camera was used to film the benthic substrate at each sampling station along five linear 50 m transects, with the footage then analyzed by stopping the image at specific time intervals until 40 frames were obtained. In each frame, at a series of 13 marked points (520 points per transect) that were systematically distributed around the monitor, the benthic organisms were identified according to six higher levels, known as morphostructural groups (MSG): scleractinian corals; octocorals; hydrocorals; algae; seagrass; and sponges (*Arias-González et al., 2011*).

It is important to mention that in the years in which biological sampling was carried out, the Natural Commission for Protected Natural Areas (CONANP) did not grant permission to carry out research activities without collecting or handling specimens of species not considered at risk within the Banco Chinchorro Biosphere Reserve. However, this working group currently has permission (Oficio No. F00.9/DRBBCH/151/2024) to carry out research work.

Data analysis

Areas with different fishing intensities

Castro-Pérez, González & Arias-González (2011) identified seven fishing zones in the BCBR using the CPUE values for fish of commercial importance in 30 fishing quadrants because in 6 six quadrants, no catches were recorded (Fig. 1C). In the present study, to reduce the effect of the structural complexity of the benthos on the density and biomass of the fish, 21 fishing quadrants were used, located mainly on the reef slope and in the southern section of the reef lagoon, which are characterized by high structural complexity. Combining the CPUE data of the 10 commercially important species of the 21 quadrants and the zones identified by *Castro-Pérez, González & Arias-González (2011)*, we classified the area into the following zones: Zone 1 (Quadrants 4, 34 and 36); Zone 2 (Quadrant 5); Zone 5 (Quadrant 25); and Zone 7 (Quadrants 2, 10, 15, 19, 21, 23, 24, 26, 27, 28, 29, 30, 31, 32, 33 and 35). Similarity was calculated using the Bray–Curtis index. The similarity coefficients were used to construct the similarity dendrogram; subsequently, data were permutated 999 times for a distribution to determine ANOSIM's R statistic (R = 0 is identical, R = -1 or 1 is most divergent), which facilitated the discovery of patterns among the quadrats and, thus, the detection of areas with different fishing intensities. Both analyses were performed with PRIMER 6.0 software (*Clarke & Gorley, 2001*).

Changes in the density and biomass of fish species due to fishing

The density (individuals/100 m^2) and biomass (kilogram/100 m^2) of each of the species were estimated to determine changes in these variables due to the fishing of species of commercial and non-commercial importance using data obtained from censuses visuals. The fish biomass was calculated via the exponential function $W = aL^b$, where W is the weight in kilograms, L is the length obtained from the length intervals and a and b are the constants from the length-weight relationship obtained from both *Claro & García-Arteaga (1994)* and *FishBase*. The average density and total biomass of commercially and noncommercially important species were compared among areas with different fishing intensities (detected via the similarity dendrogram) by means of a one-way analysis of variance (ANOVA). Subsequently, a multiple range test (Fisher's least significant difference, or LSD) (*Zar, 1999*) was applied to ascertain which areas presented differences. The data were log(x)-transformed to fulfill both normality assumptions (Shapiro–Wilk test) and homoscedasticity (Levene's test) (*Zar, 1999*). The same statistical tests were used to verify the average density and biomass differences among areas with different exploitation levels for each of the eight species caught with the most frequency in the study area: *Epinephelus striatus*, *Epinephelus guttatus*, *Lachnolaimus maximus*, *Lutjanus analis*, *Lutjanus griseus*, *Mycteroperca bonaci*, *Ocyurus chrysurus*, and *Sphyraena barracuda* (*Castro-Pérez, González & Arias-González, 2011*). Moreover, differences in the average density and biomass of the noncommercial species were tested among areas of different fishing intensities, with species grouped into twelve families: Acanthuridae, Balistidae, Chaetodontidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Malacanthidae, Mullidae, Pomacanthidae, Scaridae, and Serranidae.

Relationship of density and biomass of commercially important species with fishing pressure and benthic variables

The fish assemblages found in the different visual transects can vary for at least three reasons: fishing effort, differences in environmental conditions, and random variation (*Clua & Legendre, 2008*). Two redundancy analyses (RDA) were carried out using the CANOCO v4.5 program (*Ter Braak & Smilauer, 2002*), which separately related the density and biomass of the eight commercially important fish species with the coverage data for the different benthic morphostructural groups and the CPUE values for the species of greatest commercial interest. These multivariate methods were applied following the gradient length criterion, the species response models pertaining to the environment and the linear-type CPUE data. The density and biomass values were transformed via the Hellinger distance (*Legendre & Gallagher, 2001*), while the statistical significance was tested by means of Monte Carlo permutations (N = 9999).

Results

Areas with different fishing intensities

Based on the dendrogram using the CPUE values of the most commercially important species, the formation of three groups was detected with a similarity index of 60 % (Fig. 2A). The ANOSIM test provided statistical support to determine that the three groups were different in their composition and abundance ($R = 0.99$; $P < 0.05$). Considering this spatial separation and the distribution of the CPUE values for these quadrants, it was observed that Group 1 included quadrants that mainly belonged to the reef lagoon in the southern section of the study area (Cayo Lobos), which presented high CPUE values. Group 2 was formed by quadrats located on the reef slope, with intermediate CPUE values, while Group 3 generally contained quadrats located on the reef slope, with high CPUE values. In accordance with the above and to detect changes in the density and biomass of the fish species caused by the fishing activity, three areas with different fishing intensities were classified in the BCBR: moderate level fishing in the fore reef (FRMLF); High Level Fore Reef Fishing (FRHLF); and deep-sea fishing in reef lagoons (RLHLF) (Fig. 2B).

Changes in the density and biomass of fish species due to fishing

Analysis of the group of commercially important species among the areas of different fishing intensities revealed that the average density and biomass values showed significant differences (one-way ANOVA, $P < 0.05$). The analysis with the multiple range test showed that the highest values for these variables were recorded in the moderate fishing area and differed (LSD, $P < 0.05$) from the density and biomass of fish found in the high fishing areas (FRHLF and RLHLF), which were similar (LSD, $P > 0.05$) (Fig. 3A). The analysis of the group of noncommercial species did not reveal differences between the density and biomass values for the areas that presented different fishing efforts (one-way ANOVA, $P > 0.05$) (Fig. 3B).

The individual analysis of the eight commercially important species found that *E. guttatus*, *E. striatus* and *L. maximus* showed significant differences in their density and biomass values (one-way ANOVA, $P < 0.05$). The LSD test showed a decrease in the values of these variables in the high fishing areas, which did not show significant differences between them ($P > 0.05$) but differed ($P < 0.05$) from the moderate fishing zone (FRMLF) that showed high values of density and biomass of these species (Fig. 4).

The density and biomass per family of noncommercial species in the areas with different fishing intensities did not show significant differences (one-way ANOVA, $P > 0.05$), except for the Scaridae family (one-way ANOVA, $P < 0.05$). The analysis with the LSD test showed that the lowest values of density and biomass were present in the moderate fishing zone, but it differed ($P < 0.05$) from the zones where the highest catches occurred (FRHLF and RLHLF), which were statistically similar ($P > 0.05$) (Fig. 5).

Relationship of density and biomass of commercially important species with fishing pressure and benthic variables

The results of the redundancy analysis (RDA) showed low correlations (0.32 to 0.45) between the benthic coverage (seagrass, octocorals, hydrocorals and algae) and the CPUE fishing variable with the density and biomass of commercially important fish species. The percentage of variance explained was 78.1 to 88.0.

The arrangement of the density and environmental variables in the RDA undertaken in the present study revealed that along the first axis, the seagrass cover was associated with the quadrats belonging to the FRMLF and RLHLF areas and had a positive relationship with the density of *S. barracuda* and *L. griseus*. The hydrocoral cover was related to the quadrats in the FRHLF area. The octocoral cover and the grouped CPUE quadrats in the FRHLF area were detected along the second axis, with these variables revealing a strong positive association with the density of *O. chrysurus*. Algae cover was linked to the quadrats in the FRMLF area (C4 and C2), presenting a positive relationship with *B. capriscus* and a negative relationship with the density of *L. analis* (Fig. 6A).

Finally, the RDA results for both biomass and environmental variables showed that the first axis separated the quadrats with greater coverage of algae in the left part of the order where the quadrats belonging to the FRMLF area were grouped (C4 and C21), presenting a negative relationship with *L. analis* biomass. The second axis showed that the octocoral, hydrocoral and CPUE cover was associated with the quadrats mainly pertaining to the FRHLF area, showing a negative relationship among the CPUE results, the hydrocorals and the biomass of the species *E. striatus*, *E. guttatus*, *L. griseus* and *S. barracuda* (Fig. 6B).

Discussion

Areas with different fishing intensities

This study used CPUE values to detect and analyze three areas with different fishing intensities within the BCBR to identify changes in the biomass and density of reef fish. Although the fishing quadrats of the areas were found in structurally complex habitats, their location and type of habitat within the system influenced their fishing intensity. The quadrats of the areas with high intensities of fish exploitation (FRHLF and RLHLF) were located mainly on the reef slope and the southern part of the reef lagoon (*Cayo Lobos*), where a great variety of habitats provide the fishing communities a greater surface area in which to search for the target resource, namely, the spiny lobster. In contrast, the quadrats in the area with the least fishing intensity (FRMLF) were located primarily in the middle and northern part of the reef complex, in which fishing efforts are carried out less frequently.

Changes in the density and biomass of fish species due to fishing

The results of the present study provide evidence that fishing activity has caused detectable changes in the density and biomass of commercially important fish species in the BCBR. The low density and biomass of the commercial species in the areas of high fishing intensity reflect the extraction of top predators, such as species belonging to the Serranidae and Lutjanidae families. This may be related to the selectivity of the fishing equipment used in the reef complex, which usually consists of harpoons (*Castro-Pérez, González & Arias-González, 2011*), via which the fishermen catch the most expensive and in-demand species in local markets (*Mumby et al., 2012*; *Kadison et al., 2017*). Therefore, the reduction of the species most valuable to fishing communities may be imminent, leading to the exploitation of other less important species, such as scarids, balistids and pomacanthids. Various studies have found that the decrease in the density and biomass of carnivorous and piscivorous species (Serranidae, Lutjanidae and Caranidae) is caused by an increase in fishing pressure (*Friedlander & DeMartini, 2002*; *Williams et al., 2011*; *Valdivia, Cox & Bruno, 2017*). However, it cannot be ruled out that other factors could be intervening in the changes in these biological variables, such as the effects of climate change and hurricanes on their habitats (*Graham et al., 2020*; *Russ et al., 2021*).

Individual analysis of the eight commercially important species found that *E. striatus*, *E. guttatus* and *L. maximus* showed a decrease in density and biomass in areas with high fishing intensity. The latter can be attributed to the fact that these species have a high economic value in local markets (US$ 7.79 kg-1), and for this reason, they are caught all year round throughout the reef system through selective fishing, although the highest captures of the first two species were in November, December and January (*J. Castro, 2011, pers. comm.*), months in which these species have been documented to aggregate for reproduction (*Aguilar-Perera & Aguilar-Davila, 1996*; *Sala, Ballesteros & Starr, 2001*); *Dahlgren et al., 2016*). It has been reported in several locations in the Caribbean that these three species form an essential part of the small-scale fishery (*Sadovy* *de Mitcheson et al., 2013*; *Sherman et al., 2018*). *E. striatus* and *E. guttatus* have been highly exploited due to their reproductive aggregations that facilitate their capture at predictable sites and seasons (*Sadovy De Mitcheson et al., 2013*; *Cheung et al., 2013*; *Sherman et al., 2017*), which is why *E. striatus* is currently listed as threatened by the International Union for Conservation of Nature Red List (IUCN), while *E. guttatus* is considered a minor concern. *L. maximus* is a monandric and protogynous hermaphroditic species (*McBride & Johnson, 2007*), characteristics that have led to a decrease in its population due to overfishing (*Ault, Smith & Bohnsack, 2005*); therefore, at the regional level, this condition is classified as vulnerable by the IUCN.

In the Mexican Caribbean, there is little information on the biology and fisheries of many commercially important species; therefore, there is an urgent need to implement fisheries management and regulation strategies for these species. The only federal law concerning commercially important fish species in the study area is for the Nassau grouper *E. striatus*, which is a species that is associated with the closed season for the Red grouper *Epinephelus morio* and other species of grouper from the Gulf of Mexico and Caribbean Sea, which runs from 01 February to 31 March of each year.

The present research found little evidence that the density and total biomass of families of noncommercially important species increased through the elimination of their predators. This may be due to the small number of predatory species that are captured in the BCBR, causing a moderate indirect effect on the prey populations (*Jennings & Polunin, 1997*; *Roff et al., 2016*).

The differences in the density and biomass values found in the Scaridae family between areas with different fishing intensities may be linked to the size of the organisms that make up the family. These organisms are generally large in size (e.g., *Scarus vetula* and *Sparisoma viride*), causing them to be less susceptible to predation. In this reef system, organisms (*E. striatus*, *M. bonaci*, *L. analis* and *S. barracuda*) that are capable of consuming large prey are eliminated, leaving smaller predatory species (mesopredators) limited in their capacity to prey on larger organisms. This may have caused an increase in the density and biomass of the scarids in the highly fished areas (FRHLF and RLHLF). While some studies have found that families of large-bodied organisms are more vulnerable to fishing than families of smaller organisms (*Friedlander & DeMartini, 2002*; *Hawkins & Roberts, 2004*), there is little scientific evidence that species of the Scaridae family are being caught in the BCBR. The foregoing is the result of the implementation of awareness programs on the protection of parrotfish by the authorities of the reserve toward fishermen. These species are currently on the list of protected species in the Official Mexican Standard NOM-059-SEMARNAT.

Relationship of density and biomass of commercially important species with fishing pressure and benthic variables

The density and biomass of the main commercially important fish species in the areas with different fishing intensities were mainly influenced by the presence of algae, octocorals, hydrocorals and CPUE. Although some of these benthic groups contributed to the structural complexity of the reefs, the most important component was the scleractinian corals, which showed no association with the biological variables of the fish species. This was because the fishing quadrants were located on reefs with high structural complexity. Although attempts were made to reduce the effect of structural complexity on the density and biomass of fish species (*Luckhurst & Luckhurst, 1978*; *Chabanet et al., 1997*; *Darling, 2017*), it was found that certain benthic groups and CPUE explained the observed changes in the density and biomass of fish assemblages in the BCBR. The effect of fishing was based on the negative relationship found between CPUE and the density and biomass of highly exploited species such as *E. striatus*, *E. guttatus*, *L. griseus* and *S. barracuda*.

Although there was a detectable effect of fishing on certain commercially important fish species, there was no evidence that this activity affected the structure of the fish community (top-down trophic cascade effect) that could cause a phase change of benthic groups, as found on highly exploited reefs (*Jackson et al., 2001*; *Mumby et al., 2006*; *Mumby & Steneck, 2008*). *Castro-Pérez, González & Arias-González (2011)* mentioned that reef-fish fishing in this reserve was moderate because the target species was usually the spiny lobster *Panulirus argus* and fish were only occasionally caught. However, it should be considered that various authors have found that certain environmental disturbances are associated with the degradation of reefs that directly affect the structure of the fish community (bottom-up effect) (*Graham et al., 2020*; *Russ et al., 2021*), such as ocean acidity (*Kleypas & Yates, 2009*; *Veron, 2011*), coral bleaching, (*Hughes et al., 2018*) and hurricanes (*Knutson et al., 2010*) caused mainly by climate change. For this reason, it is important to establish management and conservation measures for the main fish species of commercial importance in these protected areas to counteract the effect of these environmental disturbances on these species, since these environmental phenomena cannot be excluded in protected areas (*Jones et al., 2004*). In a recent study comparing protected and nonprotected reef areas after hurricanes, high fish biomass was found in protected areas, in contrast to areas in which fishing was not regulated (*McClure et al., 2020*).

Conclusion

In the BCBR throughout the year, the largest fishing exploitation is for the spiny lobster, but in the months when this crustacean begins to be scarce, the fishermen focus their greatest fishing efforts on the main species of commercially important fish. Due to the above, this study has detected evidence that the density and biomass have decreased in some species belonging to the Serranidae and Lutjanidae families in areas with high fishing intensity, therefore, there is an urgent need to implement fisheries management and regulation strategies for these species. On the other hand, little evidence was found that the density and total biomass of families of noncommercially important species increased through the elimination of their predators. This may be due to the small number of predatory species that are captured in the BCBR, causing a moderate indirect effect on the prey populations. Finally, although attempts were made to reduce the effect of structural complexity on the density and biomass of fish species, it was found that certain benthic groups and CPUE explained the observed changes in the density and biomass of fish assemblages in the BCBR.

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Figure 1

(A) Location of the study area. (B) Distribution of the sampling stations for fish and benthic organisms. (C) scheme of the fishing quadrats.

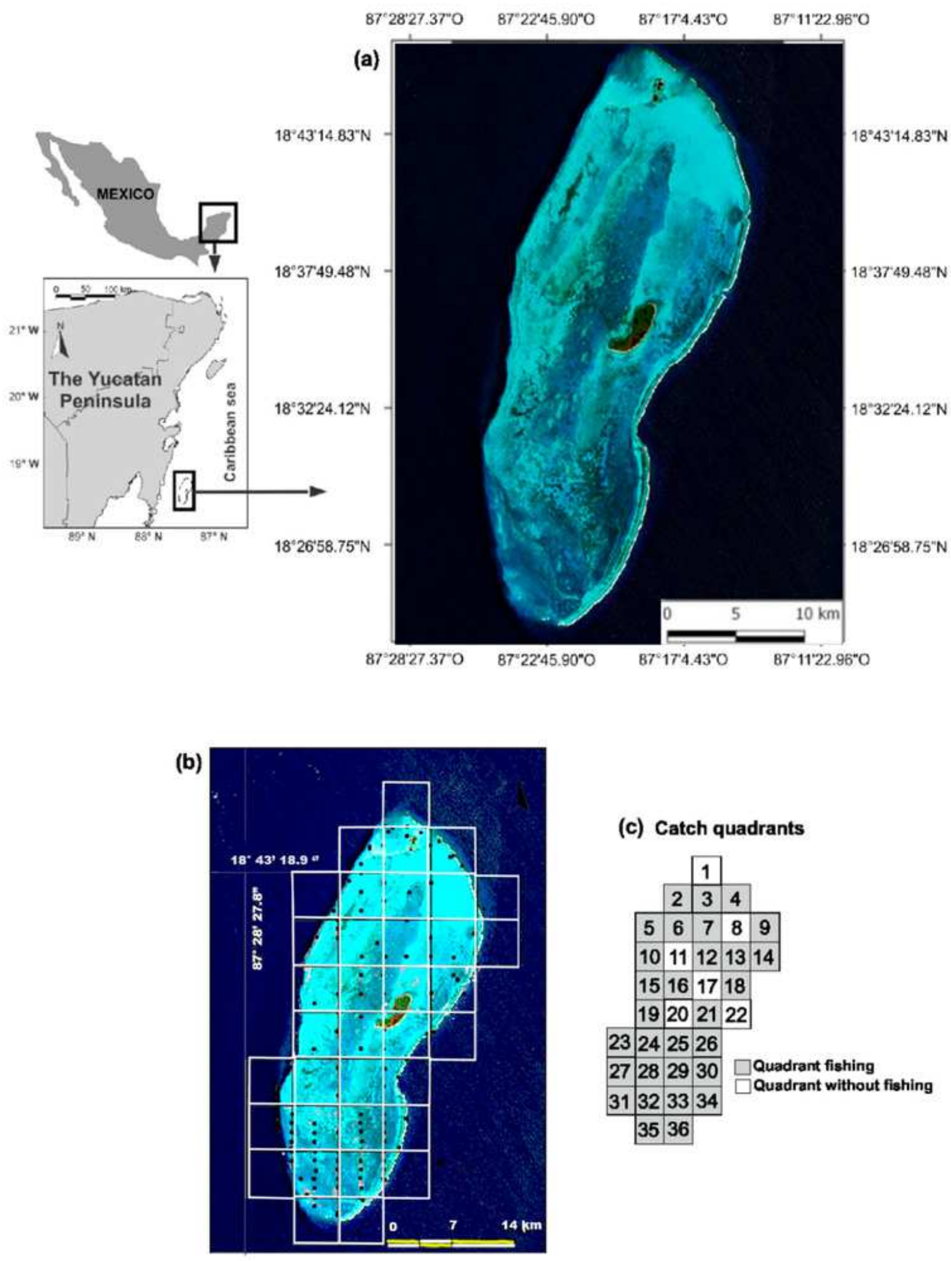

(a)
87°28'27.37"O
87°22'45.90"O
87°17'4.43"O
87°11'22.96"O
18°43'14.83"N
18°37'49.48"N
18°32'24.12"N
18°26'58.75"N
MEXICO
The Yucatan Peninsula
Caribbean sea
21° W
20° W
19° W
89° N
88° N
87° N
0 5 10 km
(b)
18° 43' 18.9"
87° 28' 27.8"
0 7 14 km
(c) Catch quadrants
Quadrant fishing
Quadrant without fishing

Figure 2

(A) Dendrogram obtained from the Bray–Curtis similarity coefficients and used for identifying quadrats with different fishing intensities based on the CPUE data. (B) Location of the areas with different fishing intensities.

FRMLF = forereef moderate-level fishing; FRHLF = fore-reef high-level fishing; and RLHLF = reef lagoon high-level fishing.

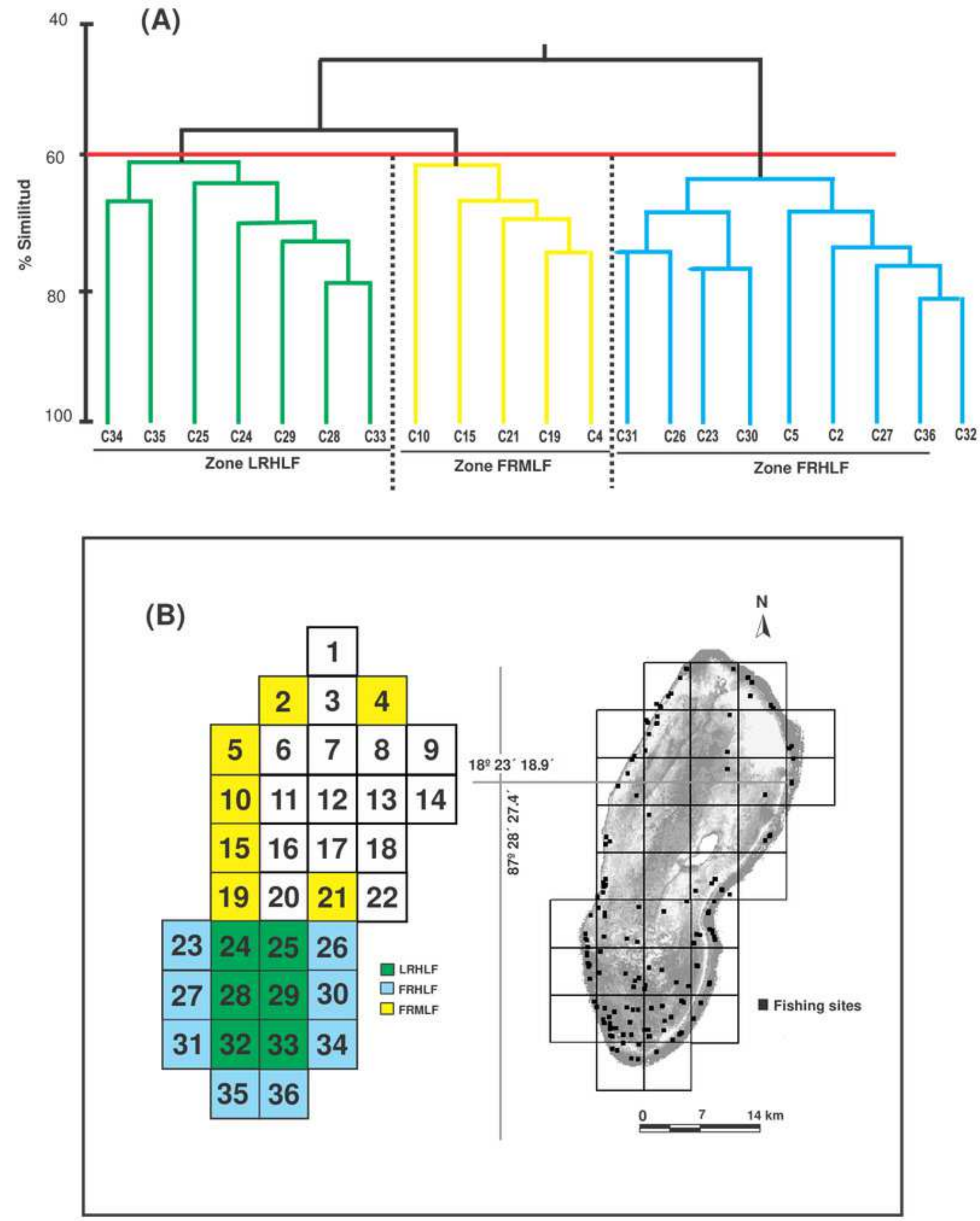
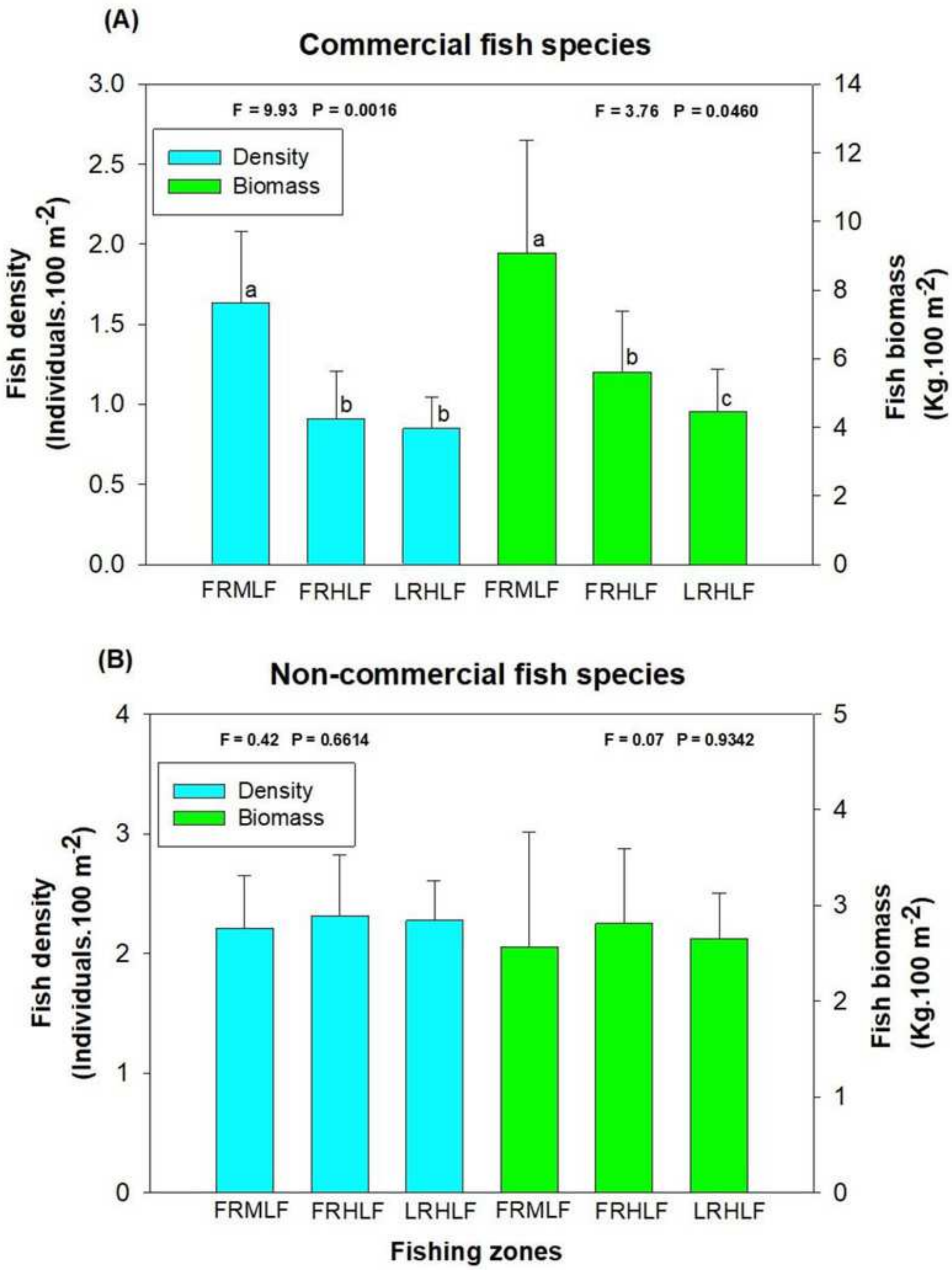

(A)
% Similitud
40
60
80
100
C34 C35 C25 C24 C29 C28 C33 C10 C15 C21 C19 C4 C31 C26 C23 C30 C5 C2 C27 C36 C32
Zone LRHLF
Zone FRMLF
Zone FRHLF
(B)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
LRHLF
FRHLF
FRMLF
N
18º 23´ 18.9´
87º 28´ 27.4´
Fishing sites
0 7 14 km

Figure 3

Comparison of the average (± SE) density and biomass among areas with different fishing intensities. (A) commercial species. (B) noncommercial species.

The homogeneous groups (LSD test, $P > 0.05$) are shown by the same letters for each treatment (areas): FRMLF = forereef moderate-level fishing; FRHLF = forereef high-level fishing; and RLHLF = reef lagoon high-level fishing.



(A)
Commercial fish species
F = 9.93 P = 0.0016
F = 3.76 P = 0.0460
Density
Biomass
Fish density (Individuals.100 m-2)
Fish biomass (Kg.100 m-2)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
14
12
10
8
6
4
2
0
a
b
b
a
b
c
FRMLF
FRHLF
LRHLF
FRMLF
FRHLF
LRHLF
(B)
Non-commercial fish species
F = 0.42 P = 0.6614
F = 0.07 P = 0.9342
Density
Biomass
Fish density (Individuals.100 m-2)
Fish biomass (Kg.100 m-2)
4
3
2
1
0
5
4
3
2
1
0
FRMLF
FRHLF
LRHLF
FRMLF
FRHLF
LRHLF
Fishing zones

Figure 4

Comparison of the average (± SE) density and biomass per species of commercial importance among areas with different fishing intensities.

The homogeneous groups (LSD test, $p > 0.05$) are shown by the same letters for each treatment (areas): FRMLF = forereef moderate-level fishing; FRHLF = forereef high-level fishing; and RLHLF = reef lagoon high-level fishing.

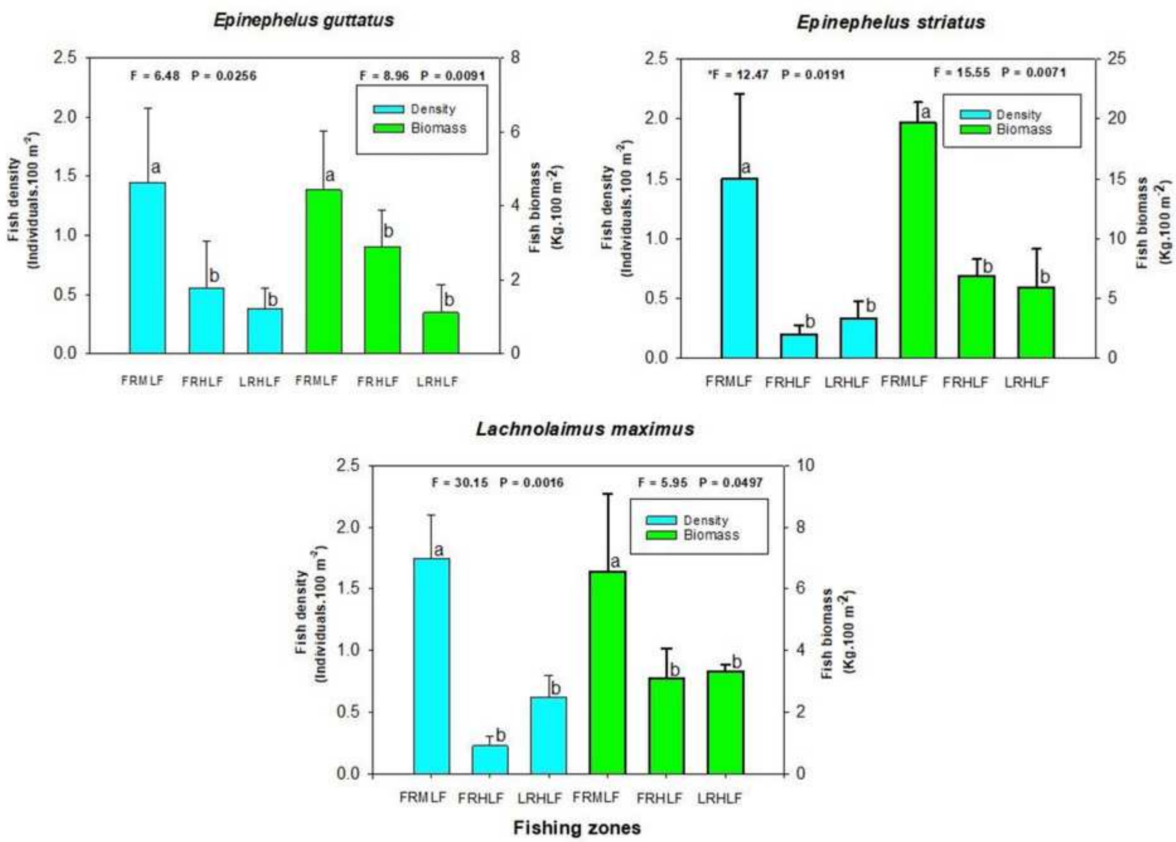

Epinephelus guttatus
F = 6.48 P = 0.0256
F = 8.96 P = 0.0091
Density
Biomass
Fish density (Individuals.100 m-2)
Fish biomass (Kg.100 m-2)
FRMLF FRHLF LRHLF FRMLF FRHLF LRHLF
Epinephelus striatus
*F = 12.47 P = 0.0191
F = 15.55 P = 0.0071
Lachnolaimus maximus
F = 30.15 P = 0.0016
F = 5.95 P = 0.0497
Fishing zones

Figure 5

Comparison of the average (± SE) density and biomass of the *Scaridae* family caught among the areas with different fishing intensities.

The homogeneous groups (LSD test, $p > 0.05$) are shown by the same letters for each treatment (areas): FRMLF = forereef moderate-level fishing; FRHLF = forereef high-level fishing; and RLHLF = reef lagoon high-level fishing.

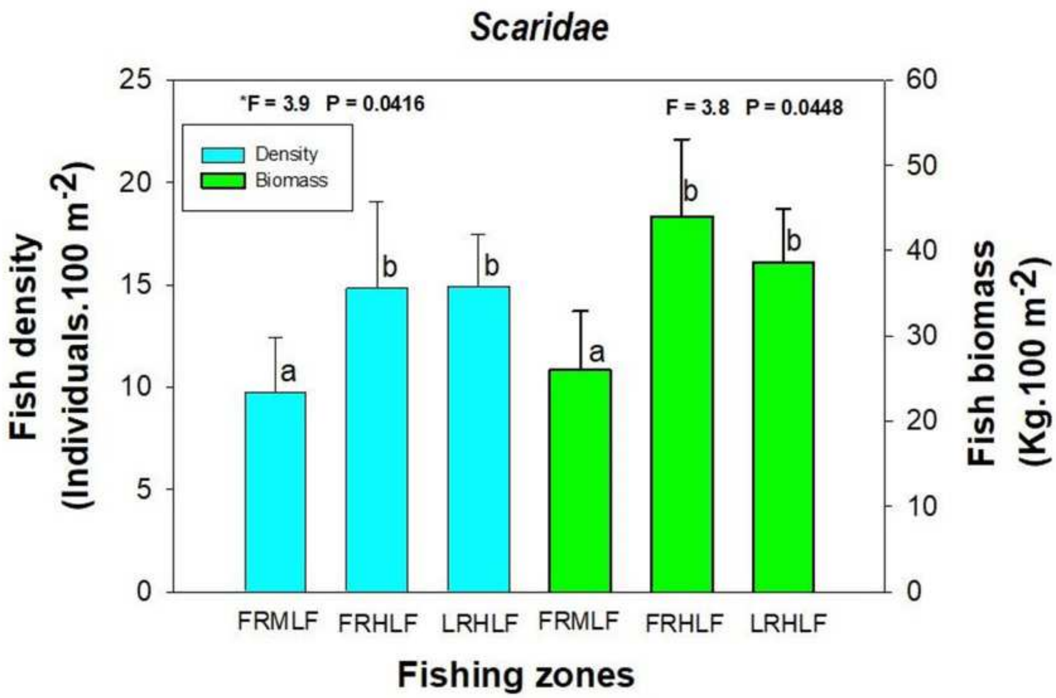
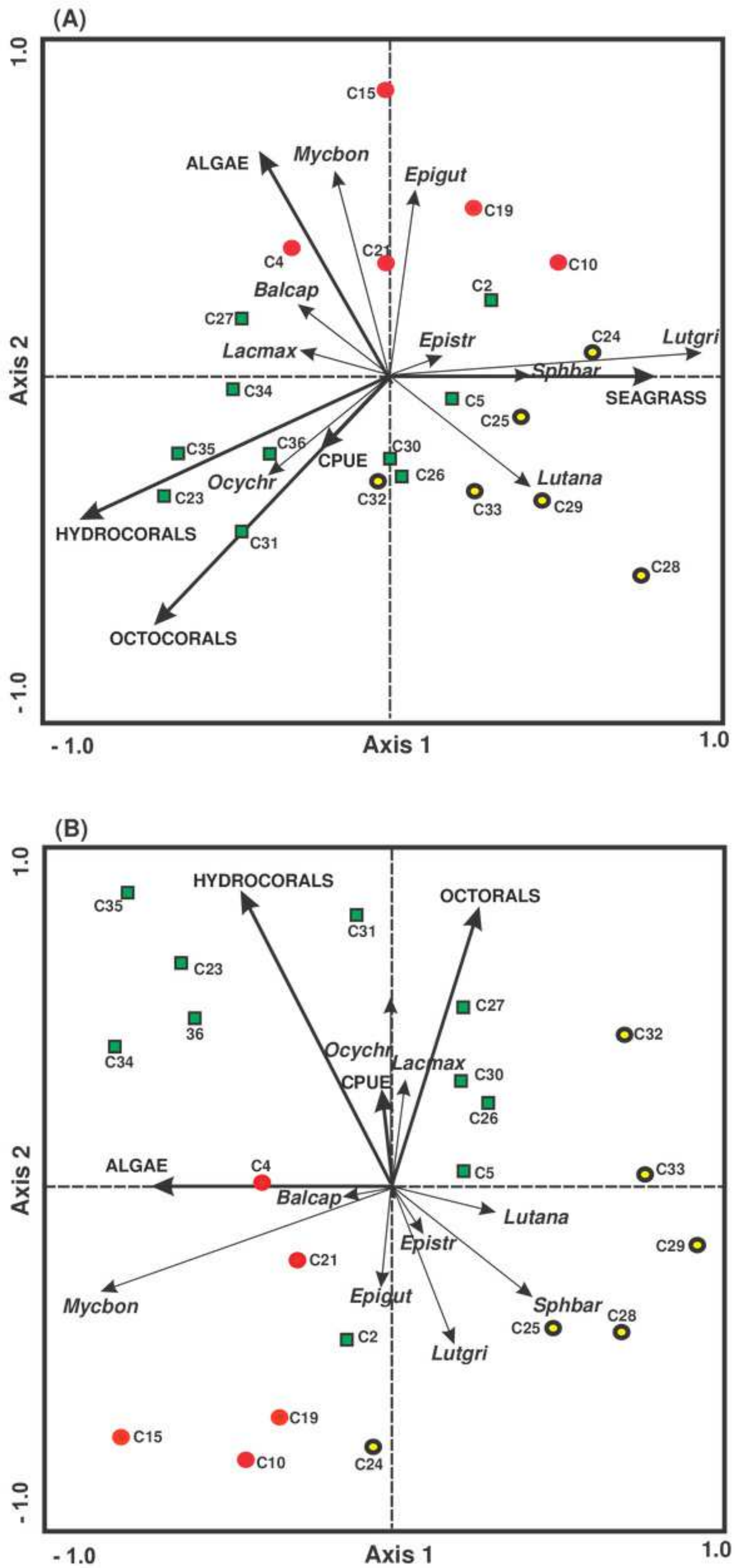

Scaridae
*F = 3.9 P = 0.0416
F = 3.8 P = 0.0448
Density
Biomass
Fish density (Individuals.100 m-2)
Fish biomass (Kg.100 m-2)
0
5
10
15
20
25
0
10
20
30
40
50
60
a
b
b
a
b
b
FRMLF
FRHLF
LRHLF
FRMLF
FRHLF
LRHLF
Fishing zones

Figure 6

Ordination of the RDA data for the density (A) and biomass (B) of commercial fish with benthic coverage (fishing quadrats) and the variable of fishing (CPUE) in the BCBR. The symbols represent the areas with different fishing intensities: (red circle) FRM

The abbreviations corresponding to the species are the following: *Balcap* (*Balistes capriscus*); *Epigut* (*Epinephelus guttatus*); *Epistr* (*Epinephelus striatus*); *Lacmax* (*Lachnolaimus maximus*); *Lutana* (*Lutjanus analis*); *Lutgri* (*Lutjanus griseus*); *Mycbon* (*Mycteroperca bonaci*); *Ocychr* (*Ocyurus Chrysurus*); and *Sphbar* (*Sphyraena barracuda*). The letter C = fishing quadrat; FRMLF = forereef moderate-level fishing; FRHLF = forereef high-level fishing; and RLHLF = reef lagoon high-level fishing.


(A)
1.0
- 1.0
Axis 2
Axis 1
- 1.0
1.0
C15
ALGAE
Mycbon
Epigut
C19
C21
C4
C10
C2
Balcap
C27
Epistr
C24
Lutgri
Lacmax
Sphbar
SEAGRASS
C34
C5
C25
C35
C36
CPUE
C30
C26
Ocychr
Lutana
C32
C33
C29
C23
HYDROCORALS
C31
C28
OCTOCORALS
(B)
1.0
- 1.0
Axis 2
Axis 1
- 1.0
1.0
C35
HYDROCORALS
C31
OCTORALS
C23
C27
36
C32
C34
Ocychr
Lacmax
C30
CPUE
C26
ALGAE
C4
C5
C33
Balcap
Lutana
Epistr
C29
C21
Epigut
Sphbar
Mycbon
C25
C28
C2
Lutgri
C19
C15
C10
C24