Short communication

Record of abundance, spatial distribution and gregarious behavior of invasive lionfish *Pterois* spp. (Scorpaeniformes: Scorpaenidae) in coral reefs of Banco Chinchorro Biosphere Reserve, southeast Mexico

ABSTRACT. The lionfish (*Pterois volitans/ P. miles*) is the first known species of marine fish to invade the Caribbean and Gulf of Mexico, and it is threatening the biodiversity of the region´s coral reefs. Its success as an invasive species is due to its high predation and fertility, fast growth and lack of predators. Its first record in Mexico was in 2009. To estimate their abundance, 22 sites were monitored around the reef of Banco Chinchorro Biosphere Reserve (BCBR) during 2013. Densities from 0 to 333 ind ha^{-1} (97.6 ± 140.2 ind ha^{-1}) and biomasses from 0 to 58.7 kg ha^{-1} (18.2 ± 29.9 kg ha^{-1}) were recorded, the highest so far in the Mexican Caribbean. In addition, two lionfish distribution zones were detected: Leeward reef (LR) and Windward reef (WR). LR was 4.6 and 3.9 times higher in density and biomass, respectively, than WR. The sizes found in the monitoring ranged from 5 to 40 cm of total length. Finally, a gregarious behavior was observed in 47.5% of the recorded fish. Our results suggest that, to prevent the development of large reservoirs of lionfish in the BCBR, management and control actions in areas of high lionfish abundance should be prioritized.

Keywords: *Pterois volitans***,** Lionfish, invasive species, Banco Chinchorro, Leeward reef, gregarious behavior, Mexican Caribbean.

Biological invasions are considered among the main causes of biodiversity loss (Challenger & Dirzo, 2009). The establishment of an invasive species can generate an imbalance in the environment, damage to the native community and economic losses (Aguirre-Muñoz *et al.*, 2009). So far, *Neopomacentrus cyanomus* and *Pterois volitans* / *miles* are confirmed species that have established themselves in the western Atlantic (Côté *et al.*, 2013; Robertson *et al.*, 2016b). In a mere three decades, *P. volitans* invaded and settled over 7.3 million km^2, comprising the coasts of Eastern United States, Caribbean Sea, and Gulf of Mexico (Côté *et al.*, 2013).

The invasion of lionfish is considered one of the greatest threats to biodiversity in the Atlantic (Hixon *et al.*, 2016), and it has reached higher densities than in its native area (Darling *et al.*, 2011;

Kulbicki *et al.*, 2012). Its presence on reefs has caused ecological impacts such as a decrease in the density and biomass of native fishes (Albins, 2015). It has the ability to compete for space and food with species of a similar trophic level (Albins, 2013). The direct effects of the lionfish could be combined with other stressors such as overfishing and pollution in the Caribbean reefs (Albins & Hixon, 2013), resulting in a biodiversity crisis.

In Banco Chinchorro, although the first lionfish (14 cm total length) was captured by a fisherman, nearly of Cayo Centro area at three m water depth on july 09, 2009, it is very likely that the invasion has begun years before the first sighting. The impacts of the rapid population establishment on Mexican coasts are largely unknown (Sabido-Itzá *et al.*, 2016b).

The objectives of this study are to describe the abundance (density and biomass), spatial distribution, size structure, and gregarious behavior of the lionfish in Banco Chinchorro Biosphere Reserve (BCBR). “Lionfish” and *Pterois* spp. refer to *P. volitans* and *P. miles*, due to the recent record of this last one in the area, noting that *P. volitans* dominate in abundance (Guzmán-Méndez *et al.*, 2017). This Marine Protected Area is considered a priority in the Mesoamerican Reef System region, so the results presented here are important in determining the course of monitoring and control efforts.

The Chinchorro reef system is located in the southeast of the Yucatan Peninsula, Mexico (18°47'-18°23'N, 87°14'-87°27'W) (Carricart-Ganivet & Beltrán-Torres, 1998), at 30.8 km from the mainland and is separated from the coast by a 1,000 m deep channel. In 1996, due to its ecological, fishing and cultural importance, it was declared a Biosphere Reserve by the Mexican government with an area of 144,360 ha, comprising reefs, islands, reef lagoon and adjacent ocean waters (INE, 2000) (Fig. 1).

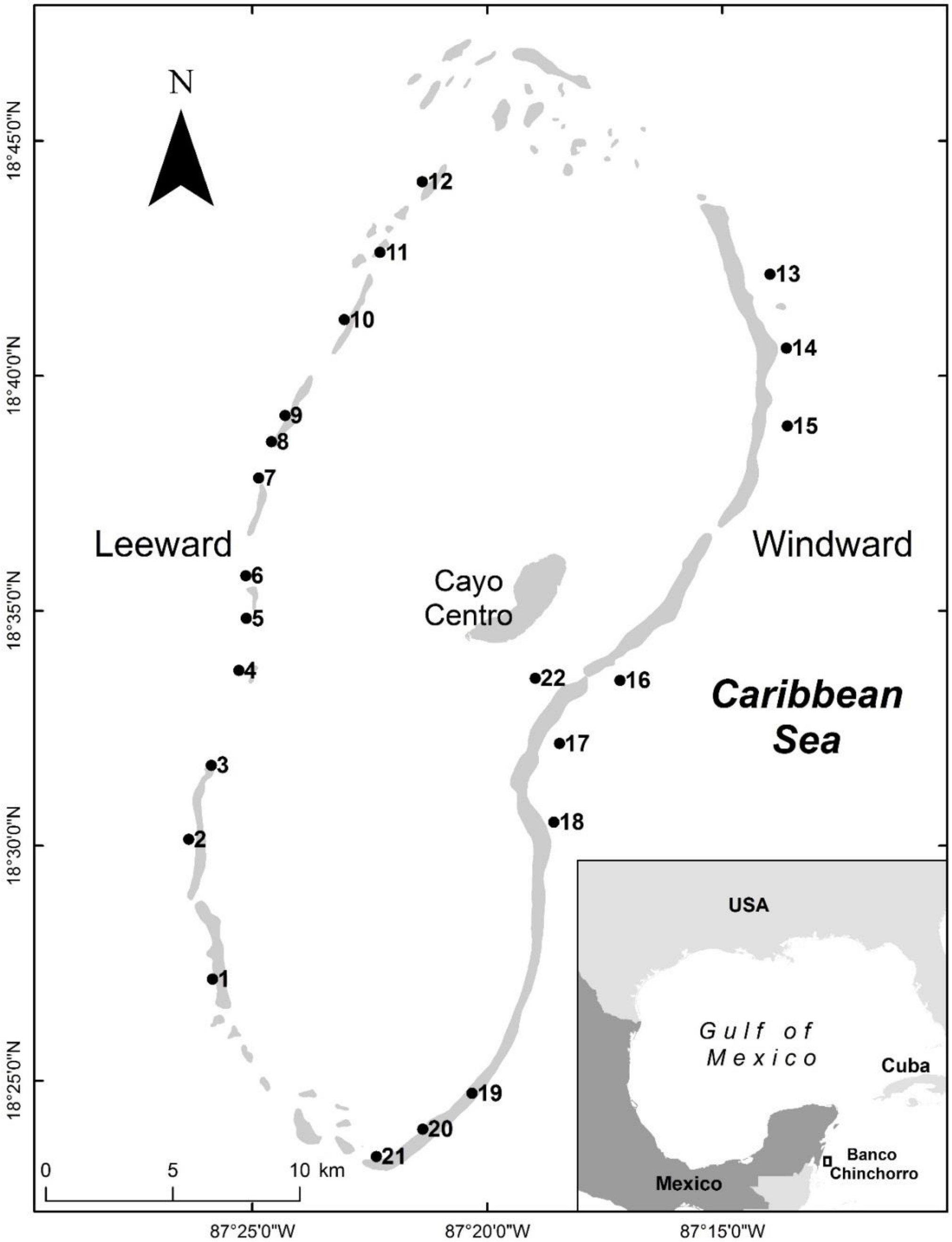

Figure 1. Monitoring sites of lionfish *Pterois* spp. in Banco Chinchorro Biosphere Reserve (BCBR), Mexico.

In order to estimate the abundance and distribution of the lionfish in the reefs of BCBR four sites were monitored (Baliza, González, Acuario and Acuario II) in 2012, and 22 sites in 2013 from March to May between 09:00 h and 12:00 h. The sites ranged in depth from 6 to 30 m. Visual censuses transect band measuring 30×4 m (120 m^2) was the sampling method. Depending on the depth and sea conditions, between four and six censuses were performed, deployed parallel to the main reef formation at each site (Table S1). To avoid bias in the detection of lionfish, two people trained in monitoring performed censuses. Each diver made a thorough search in cavities, overhangs, cracks and any potential habitat, recording the total number of lionfish in each transect, visually estimating the size of each fish to the nearest centimeter and its gregarious behavior (single, couples or more individuals together). This methodology was adapted from those proposed by Green *et al.* (2013).

We converted the recorded lengths of the lionfish to weight using the length-weight relationship $W = aL^b$, where W is weight, a: regression intercept, L: total length in cm, and b: the regression coefficient (slope). The constants $a = 0.0042$ and $b = 3.258$, obtained from Sabido-Itzá *et al.* (2016a), derived from 449 organisms captured at Banco Chinchorro during 2012 and 2013. The biomass was estimated as the sum of fish weights recorded in a transect. A Simple Variance Analysis (ANOVA) was used to determine statistical differences between densities and biomass, and sites, followed by a post-hoc LSD-Fisher test. The data were transformed to Log (x + 1), due to the large number of zeros found in transects. The normality and homogeneity of variance were tested by the Shapiro-Wilks and Levene's tests, respectively. By means of the *t*-Student test, the lengths and weights were evaluated by zone.

Lionfish groups were classified into four categories: lone individual, group of two, group of three and group ≥4 fish. The number of lionfish showing some grouping (≥2 organisms) among the total recorded fish, obtained the relative gregarious behavior. Finally, the mean cluster size (# fish) was obtained among the total groupings observed.

At 22 sites monitored in 2013A, 137 lionfish were found, covering an area of 14,040 m^2 (117 transects). *Pterois* spp. was recorded in almost all sites, except site number 16. The average density (mean ± SD) found in Banco Chinchorro was 97.58 ± 140.25 ind. ha^{-1}. Abundances ranged from 0 (Cayo Centro) to 333.3 ind. ha^{-1} at site 7 (Jardines) (Fig. 2a). The biomass was between 0 (Cayo Centro) and 50 kg ha^{-1} at site 11 with 18.20 ± 29.88 kg. ha^{-1} on the average (Fig. 2b).

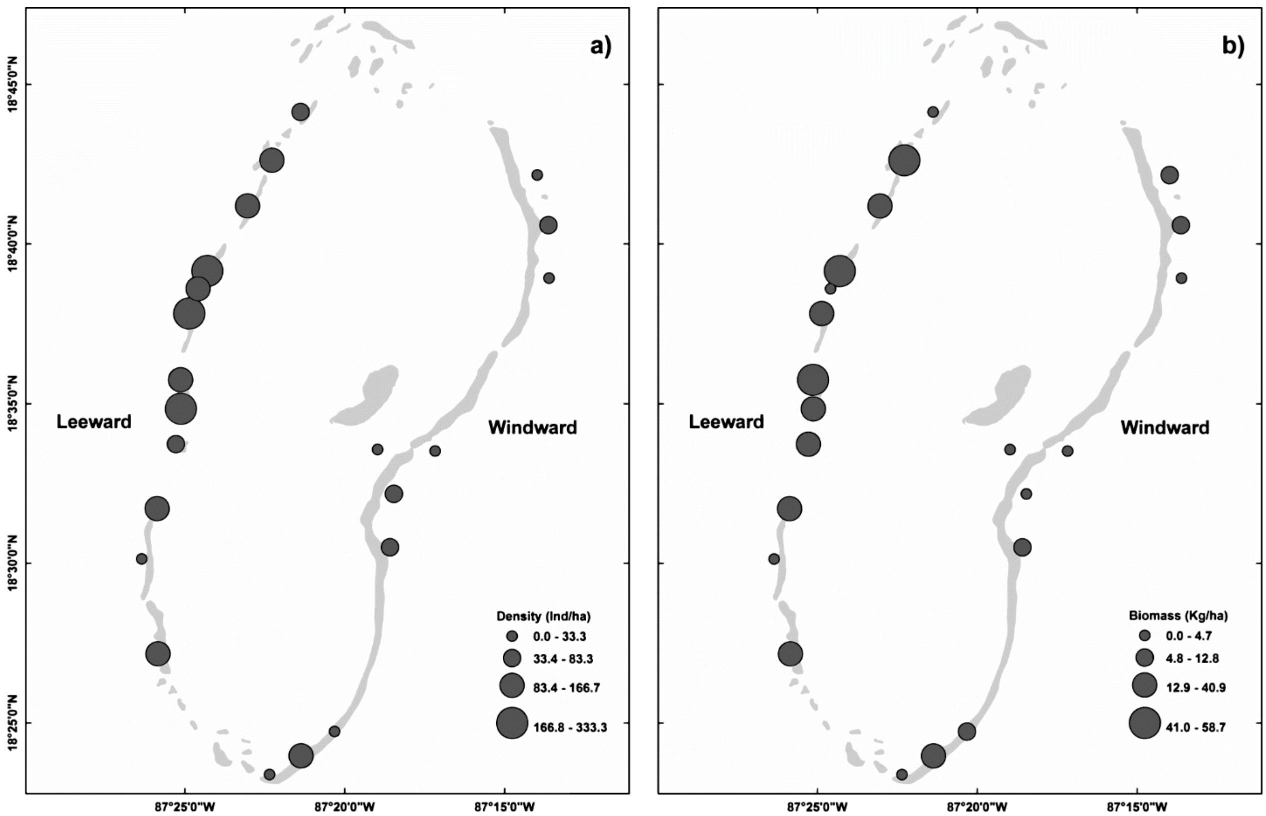

Figure 2. Lionfish *Pterois* spp. abundance spatial distribution in 22 sites in Banco Chinchorro Biosphere Reserve (BCBR), Mexico: a) density and b) biomass.

At the sites, significant differences were found between densities (ANOVA: $F_{21,95} = 2.6$, $P < 0.001$) and biomass (ANOVA: $F_{21,92} = 2.6$, $P < 0.001$). There was a marked difference in abundance and biomass at sites located in the leeward reefs (LR) with respect to those located in the windward reef (WR), so they were divided into 12 and 10 sites, respectively, for analysis. The results revealed that the abundance of *Pterois* spp., both in terms of density and biomass, differ significantly between the windward and leeward areas (ANOVA: $F_{1,115} = 30.01$, $P < 0.000$ and ANOVA: $F_{1,112} = 23.29$, $P < 0.000$ for density and biomass respectively). LR mean density was 4.6 times higher than in WR (154.67 ± 33.33 vs 163.8 ± 63.3 ind. ha^{-1})· The mean biomass was 3.9 times higher in LR (28.42 ± 7.25 vs 35 ± 1.8 kg ha^{-1}) (Figs. 3a-b).

To compare densities between 2012 and 2013, four sites were monitored on the leeward side, and we found that in 2013 the densities were 1.9 times greater than in 2012.

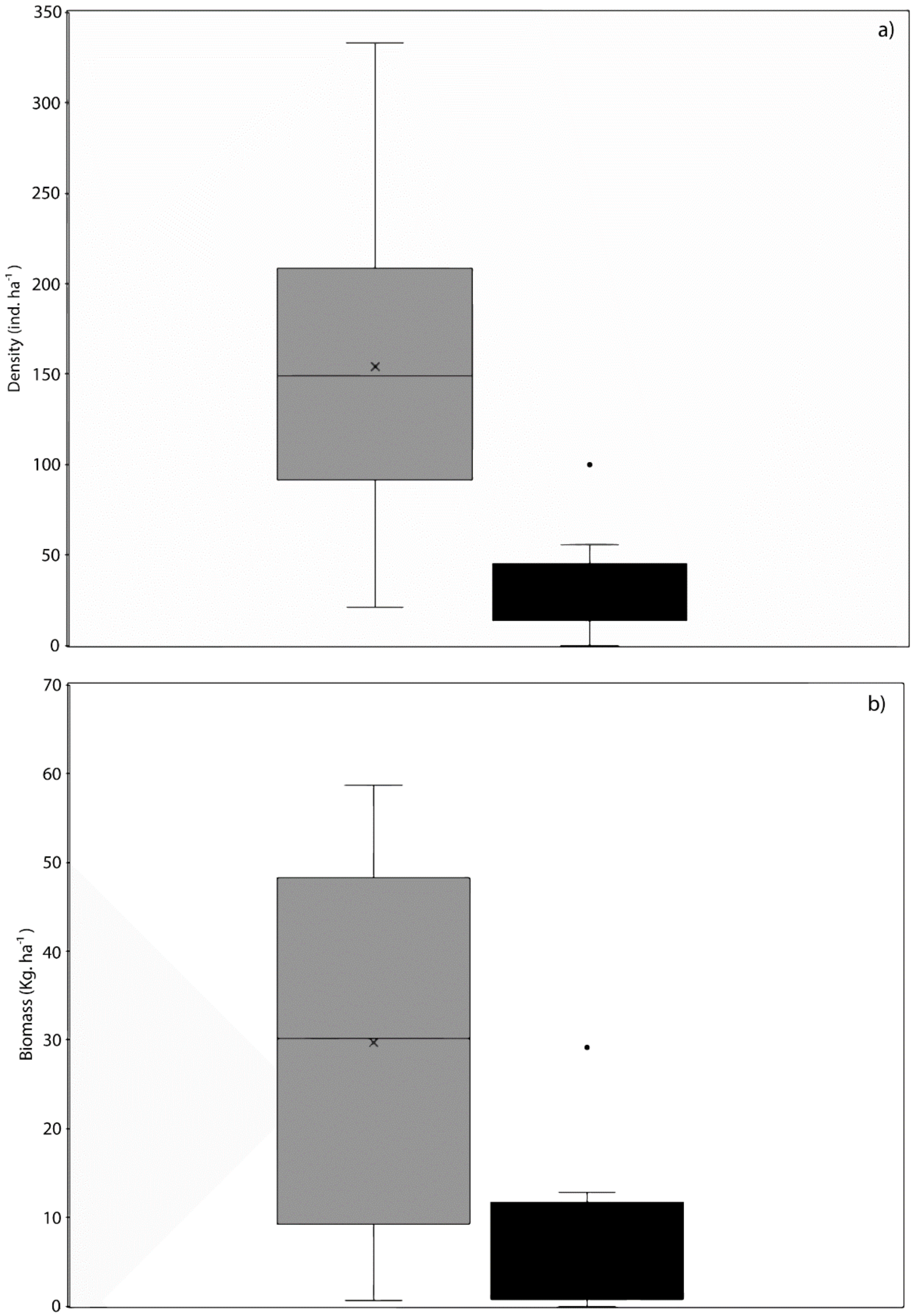

Figure 3. Comparison of the abundance of lionfish *Pterois* spp. between the leeward reef (light gray) and the windward reef (dark gray) in the Banco Chinchorro Biosphere Reserve (BCBR), Mexico: a) density and b) biomass.

At sites "8" and "10" densities increased about 2.8 times from 55.5 a 152.8 ind. ha^{-1} and 41.7 to 116.7 ind. ha^{-1}, respectively.However, no significant difference was found when all of the sites were considered in the comparison between years ($F_{1,43} = 3.04$, $P = 0.088$ ANOVA).

Total length ranged from 5 to 40 cm (23.4 ± 9 cm), while weight ranged from 0.8 to 696.4 g (188.2 ± 179.3 g). Because no difference was found between LR and WR sizes ($t = 0.25$, $P = 0.80$), were all grouped into a histogram. There are two main modal groups, the first with sizes between 11 and 15 cm (21.5%) and the second between 26-30 cm (18.5%). 66% of all organisms were considered adults. The low representation of juvenile organisms of 1-5 cm is observed with only one fish recorded (Fig. 4). From the total number of observations, 47.5% of the lionfish presented some type of aggregation, of which 26.3% were in pairs and with one group of 7 organisms observed. The mean size of the lionfish group was 2.5 ± 1.1 fish (Table 1). Finally, the number of groups of lionfish was higher in LR (24) than in WR (2).

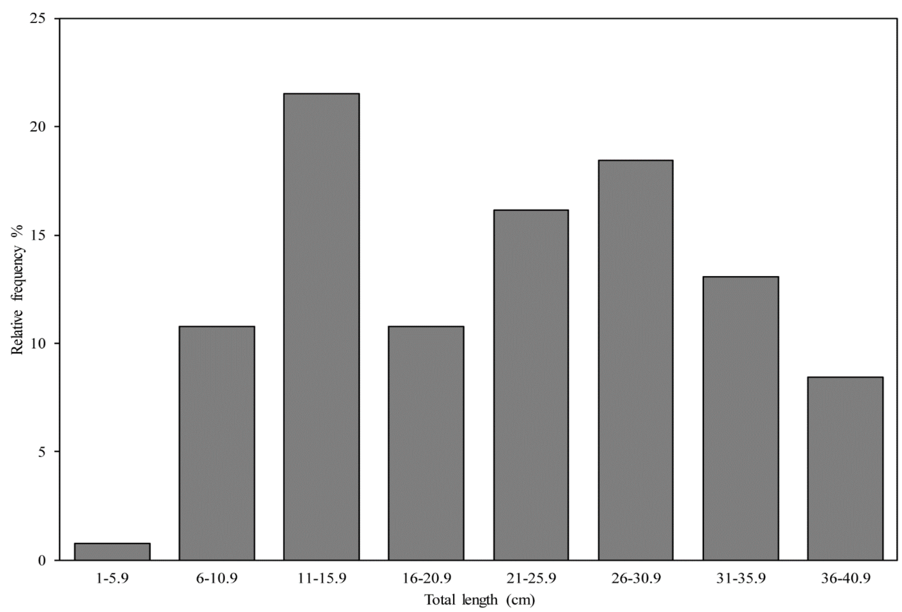

Figure 4. Distribution of the relative frequencies of the lengths of lionfish *Pterois* spp. in the Banco Chinchorro Biosphere Reserve (BRBC), Mexico.

Data collected in this study confirm the settlement and wide distribution of *Pterois* spp. on the reefs of the BCBR, Mexico. The lionfish densities are higher than in their native environment, confirming previous results of comparisons for other invaded areas (Darling *et al.*, 2011; Kulbicki *et al.*, 2012).

Table 1. Gregarious behavior of lionfish *Pterois* spp. in Banco Chinchorro Biosphere Reserve, Mexico. Data are presented as the total number of registered fish (N°. fish), number of solitary fish, total number of registered groups, group number 2, 3 and from 4 to 7 fish and the average group size (n. Fish ± SD). N: number of fishes, %: percentage of each group.

	N° fish	Solitary	N° group (total)	Groups of two fishes	Groups of three fishes	Groups of four to seven fishes	Mean group size
N	137	72	26	18	6	2	2.5 ± 1.1
%	100	52.5	47.5	26.3	13.1	8.1	

Densities reported here can be considered as intermediate, within the invaded range, because sites with densities below 50 ind ha^{-1} have been reported in Belize, Turks and Caicos Islands (Tilley *et al.*, 2016; Chapman *et al.*, 2017). In the Bahamas and Cuba, densities of 300 ind. ha^{-1} have been recorded (Green & Côté, 2009; Cobián-Rojas *et al.*, 2016) (Table 2).

Biomass in BCBR (18.2 ± 29.9 kg ha$^{-1)}$ was very similar to that found in New Providence, in the Bahamas, with 19.2 ± 29.3 kg ha^{-1}. Nevertheless, it was 6 to 12 times higher than that found in San Salvador Island and Kenya with 2.7 and 1.5 kg ha^{-1}, respectively (Darling *et al*., 2011; Anton *et al*., 2014). The wide variety of records reported here and in the Atlantic, may be related to factors characteristic of the biogeographic region (Hackerott *et al.*, 2013; Cure *et al.*, 2014), the year of the first report and subsequent monitoring (Alemu, 2016; Cobián-Rojas *et al*., 2016); habitat (Lesser & Slattery, 2011; Claydon *et al.*, 2012; Anton *et al.*, 2014; Bejarano *et al.*, 2015), or the methodology used in sampling (Green *et al*., 2013; Tilley *et al.*, 2016).

The location of sites, relative to wave exposure, had a great influence on the values of the density and biomass of *Pterois* spp., where leeward reefs had more than 4.5 times the density and about 4 times higher biomass than windward reefs. Chollett & Mumby (2012) mentioned that the winds in the region are predominantly northeasters, dominating the patterns of wave exposure, *i.e.* causing fewer waves on the leeward side than in the windward direction. Lack of wave exposure favors the presence of lionfish as the higher waves inhibit their hunting functions (Anton *et al.*, 2014). A study of lionfish behavior and habitat in the BCBR confirms that lionfish hunts in low current zones (M. Garcia-Rivas, *com. pers*.) coinciding with Anton *et al.* (2014) and Cure *et al.* (2014).

Table 2. Densities of lionfish *Pterois* spp. reported in native and invaded sites.

Region	Locality	Density	Media ± SD (ind. ha^{-1})	Source
Native	Philippines	Low	21.94±6.5	Cure *et al*. (2014)
Native	Guam	Low	3.53±0.9	Cure *et al*. (2014)
Native	Mombasa, Kenya	Low	25.1±45.7	Darling *et al*. (2011)
Native	Red Sea	Low	24.1±44.9	McTee & Grubich (2014)
Native	Pacific Ocean	Low	0.17	Kulbicki *et al*. 2012
Native	Indian Ocean	Low	3.6	Kulbicki *et al*. 2012
Invaded	Island of San Salvador, Bahamas	Low	13±18	Anton *et al*. (2014)
Invaded	Venezuelan coast	Low	25.83±66.51	Agudo & Klein-Salas (2014)
Invaded	South Caicos, Turks & Caicos Islands	Low	16.79	Tilley *et al*. (2015)
Invaded	Trinidad island, Trinidad &Tobago	Low	10.5	Alemu (2016)
Invaded	Bacalar Chico, Belize	Low	27.1±8.8	Chapman *et al*. (2016)
Invaded	New Providence, Bahamas	Medium	101.7± 103	Darling *et al*. (2011)
Invaded	Curaçao	Medium	127	de León *et al*. (2013)
Invaded	Bonaire	Medium	66	de León *et al*. (2013)
Invaded	Little Cayman, Cayman Islands	Medium	162	Bejarano *et al*. 2015
Invaded	Tobago Island, Trinidad &Tobago	Medium	136.6	Alemu (2016)
Invaded	New Providence, Bahamas	High	393.3 ±144.4	Green & Côté (2009)
Invaded	Lee Stocking Island, Bahamas	High	530 y 640	Lesser & Slattery (2011)
Invaded	Cape Eleuthera, Bahamas	High	300±600	Green *et al*. (2013)
Invaded	Cape Eleuthera, Bahamas	High	440±50	Hackerott *et al*. (2013)
Invaded	Guanahacabibes, Cuba	High	310	Cobián-Rojas *et al*. (2016)
Invaded	Banco Chinchorro leeward, Mexico	Medium	156.8±185	This study
Invaded	Banco Chinchorro winward, Mexico	Medium	83.3±84.5	This study
Invaded	Banco Chinchorro, Mexico	Medium	92.6±92.2	This study

The reduced wave exposure has enabled the Mesoamerican Reef System to become dominated by species of the stony coral genus *Orbicella*, which create a structurally complex environment, hosting many species of fish (Chollett & Mumby, 2012). This habitat is conducive to the establishment of *Pterois* spp., because it can use the structurally complex habitat for shelter and as a feeding area (Bejarano *et al.*, 2015). Ocean currents can also play an important factor. Around the BCBR, the currents are usually less rapid, allowing for the retention and settlement of larvae (Carrillo *et al.*, 2015).

Although there was no significant difference between densities at the four sites monitored, in both 2012 and 2013, abundances in the "Acuario" and "Acuario II" sites more than doubled from one year to the next. It is likely that this rapid population increase was due to: i) the remoteness, depth, and low fishing effort at these sites, ii) the absence of potential predators (Hackerott *et al.*, 2013), or iii) the wide availability of food sites as determined by the high abundance of reef fish recruits (Villegas-Sánchez *et al.*, 2015).

Sizes and weights found in the BCBR are similar to that of various regions in the Atlantic (Sabido-Itzá *et al.*, 2016b; Alemu, 2016; Chapman *et al*., 2016; Cobián-Rojas *et al.*, 2016). Rapid growth rates (Pusack *et al.*, 2016) and high prey consumption has helped to achieve greater lengths than those found in its natural range (Darling *et al.*, 2011). In our study, about 65% of the organisms were considered sexually mature, *i.e.* the population is dominated by adults (Gardner *et al.*, 2015), however, juvenile fish, indicative of reproduction and recruitment, were found in the area. The low proportion of juveniles maybe related to juveniles' preference for shallow environments such as seagrass beds, mangroves, and coral patches (Claydon *et al.*, 2012).

Finally, it has been reported that in their natural habitat (Pacific and Indian), and in the Atlantic (Agudo & Klein-Salas, 2014), the herding behavior of the lionfish is common (Cure *et al.*, 2014; McTee, Grubich, 2014). In our study, we found that 52.5% of the fish were solitary during the day, while the remaining 47.5% presented some type of gregarious behavior ranging from 2 to 7 individuals. In Venezuela, gregarious behavior was reported for 44% of the individuals, whereas in the Philippines and Guam in the Pacific was 54 and 26% respectively (Agudo & Klein-Salas, 2014; Cure *et al.*, 2014). The average number of lionfish found in groups in BCBR was less (2.5 ind.) than that found in their native communities (4.9 and 3.8 ind.) (Cure *et al.*, 2014). Respect to surveys areas, LR present major proportion of groups than WR. Ecologically, these aggregations serve to increase the success of hunting and reproduction and that in LR can be more significantly due availability of potential preys and adundance of lionfish for possible mating (Morris *et al.*, 2011; Rizzari & Lönnstedt, 2014).

Since the earliest records of lionfish in Mexico, authorities have implemented actions such as fishing tournaments (Malpica-Cruz *et al.*, 2016) and promoted its use for consumption (Carrillo-Flota & Aguilar-Perera, 2017) to try to reduce its abundance and consequent impact on local ecosystems. In Banco Chinchorro, management is based on capture during fishing tournaments and by daily catch brigades for approximately five months with local anglers and tourist service providers. However, our results show that at least as of 2013, the abundance of lionfish has not diminished. Therefore, better planning is needed. Our recommendation is to promote lionfish extraction from leeward reefs in order to benefit and aid in the conservation of the native species that inhabit this area. This work serves to understand the distribution of the lionfish in the BCBR. Now, a study that focuses on corroborating the environmental factors that determine the distribution of the lionfish in the Mexican coasts is required.

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