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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, southeastern Mexico

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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 recorded appearance in Mexico was in 2009. Twenty-two sites were monitored around the reef of Banco Chinchorro Biosphere Reserve (BCBR), to estimate their abundance, 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 than WR, respectively. 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 lionfishes in the BCBR, management and control actions in areas of high lionfish abundance should be prioritized.

Keywords: *Pterois volitans*; *Pterois miles*; lionfish; invasive species; Banco Chinchorro; leeward reef; gregarious behavior; Mexican Caribbean

The invasion of lionfishes (*Pterois volitans*, *P. miles*) is considered one of the greatest threats to biodiversity in the Atlantic Ocean (Hixon *et al.*, 2016). In three decades, lionfishes invaded and settled in the eastern coasts of the United States, the Caribbean Sea, the Gulf of Mexico and the southeastern coast of Brazil (Côté & Smith, 2018), reaching higher densities than in its native area (Darling *et al.*, 2011; Kubicki *et al.*, 2012). Its presence in reefs has caused ecological impacts triggering a decrease in the density and biomass of native fishes (Albins, 2015), and competing 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 Caribbean reefs (Albins & Hixon, 2013), resulting in a biodiversity crisis.

In Banco Chinchorro, Mexico, the first lionfish (14 cm total length) was captured by a fisherman nearby Cayo Centro area, at 3 m water depth on 9 July 2009. However, it is very likely that the invasion had begun years before the first sighting (Sabido-Itzá *et al.*, 2016b). The impacts of the rapid population establishment on Mexican coasts is just beginning to be understood (García-Rivas *et al.*, 2018).

The objectives of this study are to describe the abundance (density and biomass), spatial distribution, size structure, and gregarious behavior of the lionfishes in Banco Chinchorro Biosphere Reserve (BCBR). "Lionfish" and *Pterois* spp. refer to both species, due to the recent record of *P. miles* in BCBR (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 to determine the course of monitoring and control efforts.

The Chinchorro reef system is in the southeastern of the Yucatan Peninsula, Mexico (18°47'-18°23'N,

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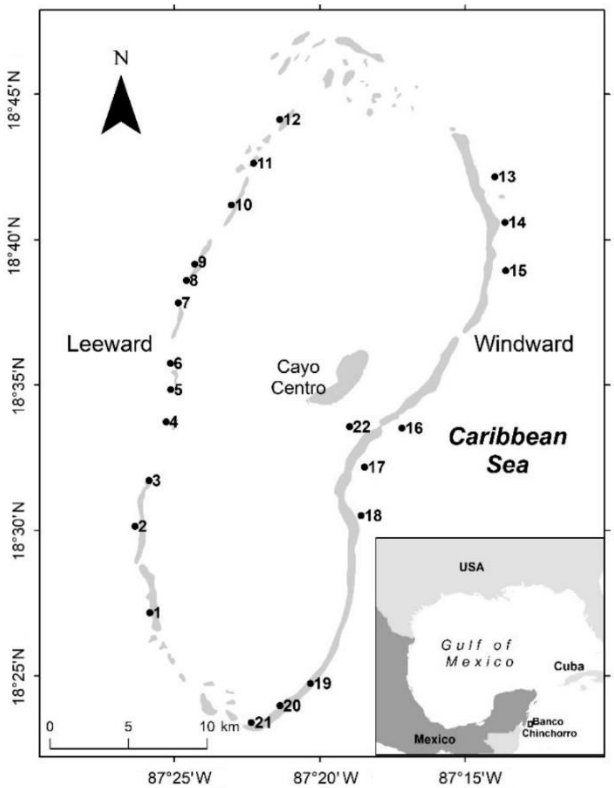

Figure 1. Monitoring sites of lionfish *Pterois* spp. in Banco Chinchorro Biosphere Reserve (BCBR), Mexico.

87°14'-87°27'W) (Carricart-Ganivet & Beltrán-Torres, 1998), 30.8 km away from the mainland and separated from the coast by a 1,000 m deep channel (Fig. 1).

In order to estimate the abundance and distribution of the lionfish in the reefs of BCBR, four sites were monitored (4, 5, 8 and 10) in 2012, and 22 sites in 2013 from March to May between 09:00 h and 12:00 h. Depending on the depth and sea conditions, between four and six visual censuses of 30 m length and 4 m width were performed, deployed parallel to the main reef formation at each site. To avoid bias in the detection of lionfish, two people trained in monitoring performed censuses. Each diver did a thorough search in cavities, overhangs, cracks and any potential habitat, recording the total number of lionfishes in each transect, visually estimating the size of all fishes to the nearest centimeter and its gregarious behavior. This methodology was adapted from that proposed by Green *et al.* (2013).

The recorded lengths of the lionfishes were converted to weight using the length-weight relationship parameters (a = 0.0042, b = 3.258), obtained from Sabido-Itzá *et al.* (2016a). The biomass was estimated as the sum of fish weights recorded in a transect. A *t*-test was used to determine differences in density and biomass between years and a Simple Variance Analysis (ANOVA) was used to determine statistical differences in density and biomass between sites and distribution zones in 2013, followed by a *post-hoc* LSD-Fisher test.

The data were transformed to log (x + 1), due to a large number of zeros found in transects. The normality and homogeneity of variance were tested by the Shapiro-Wilks and Levene's tests, respectively. The lengths and weights were evaluated by zone using the *t*-test.

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

Four sites were monitored on the leeward side to compare densities and biomass between 2012 and 2013, and we found that in 2013 the densities were 1.9 times greater than in 2012 (75.36 ± 106.70 *vs* 147.73 ± 166.53) and biomass was similar (18.86 ± 27.93 *vs* 20.42 ± 27.02). However, no significant difference was found between years (t = -0.72, P = 0.47 and t = 0.76, P = 0.45).

At the 22 sites monitored in 2013, the average density and biomass (mean ± SD) found in BCBR was 97.58 ± 140.25 ind ha^{-1} and 18.20 ± 29.88 kg ha^{-1} respectively (Table 1). 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 density and biomass of *Pterois* spp. at sites located in the leeward reefs (LR) with respect to those located in the windward reef (WR), (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 WR (154.57 ± 163.8 *vs* 33.33 ± 63.3 ind ha^{-1}). The mean biomass was 3.9 times higher in LR than WR (28.42 ± 35.0 *vs* 7.25 ± 17.8 kg ha^{-1}) (Figs. 2a-2b).

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), total lengths were all grouped into a histogram (Fig. 3). From the total number of observations, 47.5% of the lionfishes presented some sort of aggregation. Finally, the number of groups of lionfishes was higher in LR (24) than WR (2) (Table 2).

Data collected in this study confirm the settlement and wide distribution of *Pterois* spp. on the reefs of the BCBR, Mexico. The lionfish densities and biomass are

Table 1. Lionfish (*Pterois* spp.) density and biomass in monitored sites in 2013 in Banco Chinchorro Biosphere Reserve (BCBR), Mexico. SD: standard deviation.

Zone	Site	2013	
		Density ± SD (ind ha^{-1})	Biomass ± SD (kg ha^{-1})
Leeward reef	1	125 ± 87.40	32.15 ± 23.11
	2	20.83 ± 41.67	4.54 ± 9.08
	3	152.78 ± 97.42	33.46 ± 31.94
	4	83.33 ± 58.92	22.93 ± 14.28
	5	222.22 ± 291.86	28.15 ± 42.46
	6	145.83 ± 125	50.82 ± 57.46
	7	333.33 ± 68.04	40.85 ± 32.81
	8	152.78 ± 97.42	4.68 ± 4.04
	9	291.67 ± 296.98	51.77 ± 53.80
	10	116.67 ± 95.01	27.54 ± 28.65
	11	166.67 ± 117.85	58.74 ± 41.20
	12	41.67 ± 69.72	0.61 ± 1.20
Windward Reef	13	20.83 ± 41.67	9.39 ± 18.78
	14	55.56 ± 68.04	6.99 ± 13.96
	15	13.89 ± 34.02	2.09 ± 5.12
	16	0	0
	17	41.67 ± 45.64	0.92 ± 1.72
	18	41.67 ± 45.64	11.36 ± 12.45
	19	33.33 ± 74.54	12.78 ± 28.57
	20	100 ± 149.07	29.13 ± 41.07
	21	16.67 ± 37.27	4.54 ± 10.16
	22	13.89 ± 34.02	0.11 ± 0.26
	Total	97.58 ± 140.25	18.20 ± 29.88

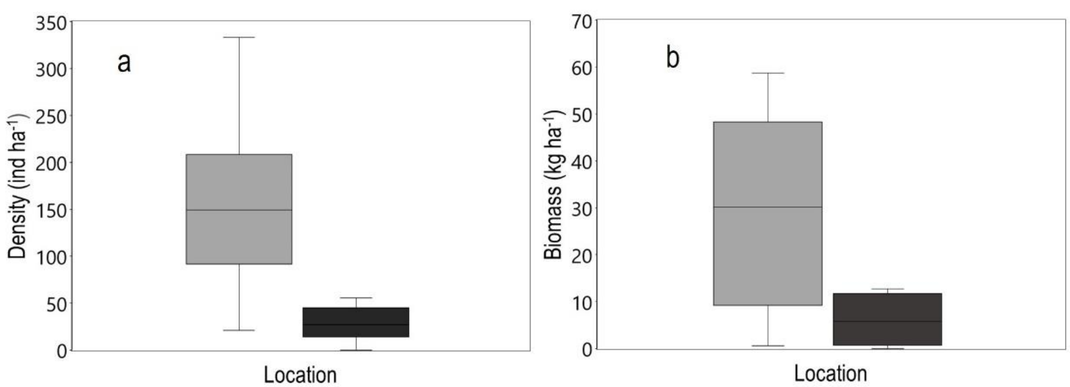

Figure 2. Comparison of the abundance of lionfish *Pterois* spp. between the leeward reef (light gray) and the windward reef (dark gray) in the Banco Chinchorro Biosphere Reserve (BCBR), Mexico. a) Density, b) Biomass.

higher than in their native environment, confirming previous results of comparisons for other invaded areas (Darling *et al.,* 2011; Kulbicki *et al.,* 2012).

Densities reported here can be considered as intermediate, within the invaded range, because sites with densities below 50 ind ha^{-1} and sites above 300 ind ha^{-1} have been recorded (Table 3). Sites with high densities (>300 ind ha^{-1}), may present significant negative changes in the native reef-fish community (Albins, 2015).

Biomass in BCBR 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 density and biomass

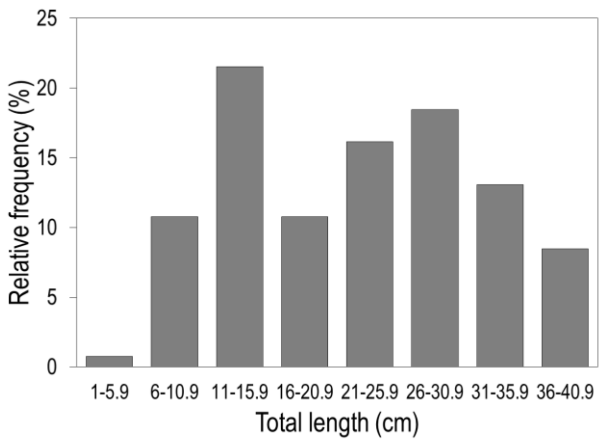

Figure 3. Distribution of the relative frequencies of the lengths of lionfish *Pterois* spp. in the Banco Chinchorro Biosphere Reserve, Mexico.

records reported here and in the Atlantic Ocean 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 (Cobián-Rojas *et al*., 2016), habitat (Lesser & Slattery, 2011; 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 in BCBR, relative to wave exposure, had a great influence on the values of the density and biomass of *Pterois* spp. Chollett & Mumby (2012) mentioned that the winds in the region are predominantly northeastern, dominating the patterns of wave exposure, *i.e.*, causing fewer waves on the leeward side than in the windward direction. Lack of wave exposure in LR favors the presence of lionfish while the higher waves inhibit their hunting functions (Anton *et al.*, 2014; García-Rivas *et al.*, 2018). Also,

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

	N° fish	Solitary	N° groups 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	

Table 3. Densities of lionfish *Pterois* spp. reported in native and invaded sites. SD: standard deviation.

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	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	Lee Stocking Island, Bahamas	High	530 y 640	Lesser & Slattery (2011)
Invaded	Cape Eleuthera, Bahamas	High	300 ± 600	Green *et al*. (2013)
Invaded	Guanahacabibes, Cuba	High	310	Cobián-Rojas *et al*. (2016)
Invaded	San Andrés, Colombia	High	379 ± 220	González-Corredor *et al.* (2016)
Invaded	Banco Chinchorro, Mexico	Medium	97.6 ± 140.2	This study

LR is likely to serve as a feeding ground for lionfishes, due to the high abundance of reef fish recruits (Villegas-Sánchez *et al.*, 2015). Ocean currents can also play an important factor. On the western flank on the BCBR, the currents usually move south (anticyclonically) slowly, allowing for the retention and settlement of larvae (Carrillo *et al.,* 2015).

Sizes and weights found in the BCBR are like that of various regions in the Atlantic Ocean (Sabido-Itzá *et al.*, 2016b; Chapman *et al*., 2016; Cobián-Rojas *et al.*, 2016). Rapid growth rates (Côté & Smith, 2018) and high prey consumption have 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).

Finally, it has been reported that in their natural habitat (Cure *et al.,* 2014; McTee & Grubich, 2014) and in the Atlantic Ocean (Agudo & Klein-Salas, 2014: García-Rivas *et al*., 2018), the herding behavior of the lionfish is common. In Venezuela, gregarious behavior was reported for 44% of the individuals, whereas in the Philippines and Guam in the Pacific Ocean was 54 and 26% respectively (Agudo & Klein-Salas, 2014; Cure *et al.,*2014). The average number of lionfishes 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). Regarding survey areas, LR presents a major proportion of groups than WR. Ecologically, these aggregations serve to increase the success of hunting and reproduction, which can be more significant in LR due to the availability of potential preys and abundance of lionfish for possible mating (García-Rivas *et al.*, 2018).

Since the earliest records of lionfish specimens 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 the 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, studies that focus on corroborating the environmental factors that determine the distribution of the lionfish, its impacts in the native reef-fish community and the efficacy of ongoing removals in the Mexican coasts are required.

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