

**LENGTH–WEIGHT AND LENGTH–LENGTH RELATIONS,
AND RELATIVE CONDITION FACTOR OF RED LIONFISH,
PTEROIS VOLITANS (ACTINOPTERYGII: SCORPAENIFORMES: SCORPAENIDAE),
FROM TWO NATURAL PROTECTED AREAS IN THE MEXICAN CARIBBEAN**

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Background. Biological invasions are often listed among the main threats to the ecosystem and are considered drivers of biodiversity loss. The Indo-Pacific lionfish, *Pterois volitans* (Linnaeus, 1758) (hereafter lionfish), invaded the Atlantic Ocean where it threatens the stability of the marine ecosystem. It would be crucial to know its biological characteristics to understand how environmental parameters could affect its growth. It is also important to continue the earlier efforts of management and control. In this study, we described the L – W and L – L relations and the relative condition factor of lionfish in two natural protected areas in the southern coast of Quintana Roo, Mexico.

Materials and methods. Lionfish were captured during 2012 and 2013 from the Reserva de la Biosfera Banco Chinchorro (RBBC) and the Parque Nacional Arrecifes de Xcalak (PNAX). The length–weight relation was calculated based on the equation $W = aTL^b$. The relative condition factor was calculated through the relative weight.

Results. A total of 817 lionfish were caught in the frames of this study. In this number, there were 449 individuals from the RBBC (282.1 ± 62.1 mm TL) and 368 from the PNAX (249.2 ± 77.6 mm TL). The L – W relation for lionfish from the RBBC was $W = 0.0041 TL^{3.258}$ and that for the PNAX was $W = 0.0049 TL^{3.191}$. There was a significant difference between these relations (ANCOVA, $F = 3.91$; $P = 0.0481$). The growth type was positive allometric. The L – L relation was significant. The relative condition factor differed between areas only in 2013, but a high value was determined in 2012.

Conclusions. The L – W relations were different between locations (RBBC and PNAX) but no between years. The relative condition factor showed high values (>100) for both locations which may imply that lionfish is in good shape, in the studied location, due to environmental factors providing good food supply and because of the lack of predators. These results may be useful as a baseline to document the population dynamics of lionfish in the region.

Keywords: L – W relation, relative condition factor, Yucatan Peninsula, Banco Chinchorro, Xcalak

INTRODUCTION

The Indo-Pacific red lionfish, *Pterois volitans* (Linnaeus, 1758) (thereafter lionfish), invaded the eastern coast of the Atlantic Ocean, the Caribbean Sea, the Gulf of Mexico (Schofield 2010), and also the Brazilian coast (Ferreira et al. 2015). Lionfish represents a threat to the biodiversity and stability of the marine ecosystems due to its high voracity (Morris and Akins 2009) causing reduction in the abundance of native fish and invertebrates (Albins and Hixon 2008, Côté et al. 2013, Ballew et al. 2016). In Mexico, lionfish was detected in the late 2009, both in the Mexican Caribbean and southern Gulf of

Mexico (Aguilar-Perera and Tuz-Sulub 2010, Sabido-Itzá et al. 2012), where now it is considered as established (López-Gómez et al. 2014, Sabido-Itzá et al. 2016). Thus, it is imperative to know further its biology to understand the ecological effects due to its invasion in the marine ecosystem of the region.

The length–weight relation (L – W) is an important tool (Le Cren 1951, Giacalone et al. 2010) to estimate attributes of the population, such as:

- The fish weight based on length;
- Fish weight based on growth;
- Biomass; and

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- The condition factor (Petrakis and Stergiou 1995, Gonçalves et al. 1997, Kimmerer et al. 2005, Froese 2006, Froese et al. 2011).

Length-length ($L-L$) relations are used for conversion between lengths (Klassen et al. 2014). The $L-W$ relation may differ between individuals of the same species in regions, seasons and sex (Okgerman 2005, Froese 2006). While it is important to know this relation for either native species or species under population threat (Vega-Cendejas et al. 2012, Hossain et al. 2014), when an invasive species is established it is crucial to document this relation in order to detect temporal and spatial fluctuations of the population in the invaded ecosystem.

This work aimed to calculate the $L-W$ and $L-L$ relations, and the relative condition factor, of lionfish in two natural protected areas off the southern coast of Quintana Roo, Mexico.

MATERIALS AND METHODS

Study area. The Reserva de la Biosfera Banco Chinchorro (RBBC) ($18^{\circ}47'-18^{\circ}23'N$, $87^{\circ}14'-87^{\circ}27'W$) is a coral reef complex (144 360 ha) located at 30.8 km off the coast of Quintana Roo (Carricart-Ganivet and Beltrán-Torres 1998). The Parque Nacional Arrecifes de Xcalak (PNAX) ($18^{\circ}30'-18^{\circ}11'N$, $87^{\circ}43'-87^{\circ}50'W$) (17 949 ha) is located along the southern coast of Quintana Roo, close to Belize (Anonymous 2004) (Fig. 1).

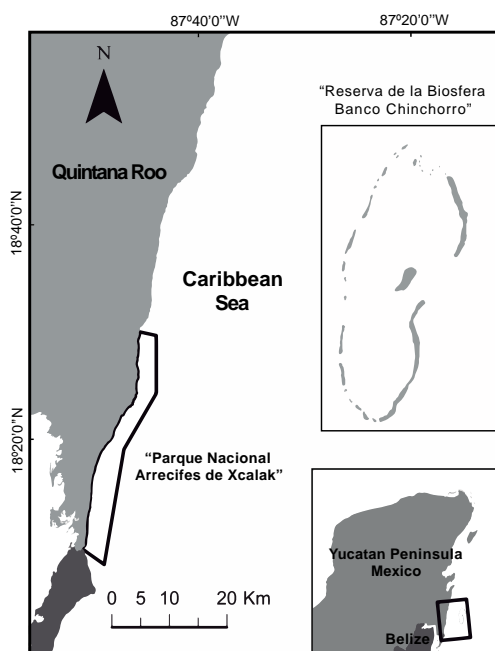


Fig 1. Location of the Natural Protected Areas, Parque Nacional Arrecifes de Xcalak and Reserva de la Biosfera Banco Chinchorro, on the southern Quintana Roo, México

Fieldwork. Lionfish were collected by local fishermen and divers with spear guns from February through November 2012 and from January through May 2013. At laboratory, each fish was taxonomically identified to species, according to Schultz (1986), measured in total length (TL) and

standard length (SL) in mm, and weighed in g to total and eviscerated weight using an electronic scale.

Data analysis. Size-frequency distributions were built based on intervals of 20 mm TL to compare the size distribution between localities using D_{\max} from Kolmogorov–Smirnov (K–S):

$$D_{\max} = \max(|F_1(x) - F_2(x)|)$$

where D_{\max} is the maximum cumulative difference from samples, F_1 is the proportion of values lesser or equal to x in the first distribution, and F_2 is the proportion of values less or equal to x in the second distribution.

The $L-W$ relation was calculated based on the equation

$$W = aTL^b$$

where W is the total weight of fish, L is the total length in mm, a is the intercept, and b is the regression coefficient (slope) (Le Cren 1951, Froese 2006). The coefficients a and b were estimated by a lineal regression on logarithms:

$$\ln(W) = \ln(a) + b \ln(L)$$

The 95% confident intervals of a and b , and the coefficient of determination (r^2) were also calculated. Outliers were addressed based on Froese (2006). The b value of each relation was evaluated with a Student's t -test to determine the difference to isometry ($b = 3$). The relation TL–SL was also estimated through a lineal regression. The slopes of the $L-W$ relation were compared between years and area through analysis of covariance (ANCOVA). In order to estimate the relative condition factor between space and time, the relative weight (W_r) was used according to Froese (2006) as:

$$W_r = 100 \frac{W}{a_m L^{b_m}}$$

where W_r is the relative weight, W and L are the weight and length of each fish, a_m and b_m are the mean values of a and b from the $L-W$ relation of each location. The Student's t -test was used to compare W_r between locations each year.

RESULTS

A total of 817 lionfish was captured, of which 449 were from the RBBC and 368 from the PNAX. For the RBBC, the fish length ranged between 100 and 395 mm TL (282.1 ± 62.1) and weight—between 9 and 845.7 g (363.9 ± 217.2), while for the PNAX the corresponding values were between 60 and 380 mm TL (249.2 ± 77.6) and 3 and 804 g (277.3 ± 198.1), respectively. The size distribution of the fish from RBBC showed a main modal group between 260 and 3340 mm TL, while that from the PNAX showed two peaks where the main was 240 and 280 mm and a second one reached 80 to 120 mm TL. There were significant differences between size distributions from

the RBBC showing larger sizes compared to those from the PNAX (K–S; $D_{max} = 0.18, P < 0.01$) (Fig. 2).

L – W relations per area and year were both significant ($P < 0.01$) with r^2 ranging between 0.95 and 0.98 (Table 1). The coefficient b was 3.25 in 2012 and 3.16 in 2013 for the PNAX and 3.27 and 3.30 for the RBBC, respectively (Table 1). The coefficient b in all relations was significantly different to isometry (t -test, $P < 0.01$); thus, the growth of lionfish represents positive allometry. There were significant differences of the L – W relation between RBBC and

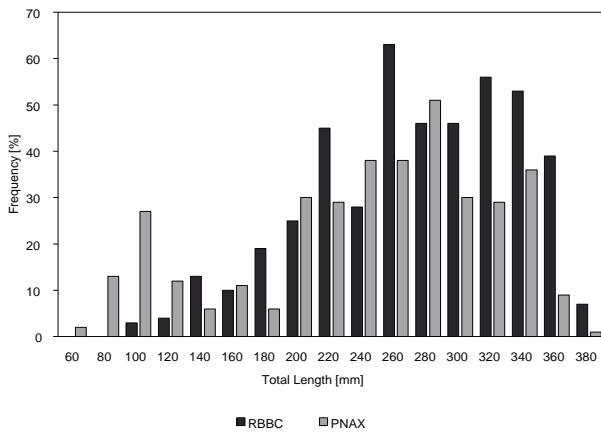


Fig. 2. Length frequency of lionfish, *Pterois volitans*, in the Reserva de la Biosfera Banco Chinchorro (RBBC, $N = 449$) and the Parque Nacional Arrecifes de Xcalak (PNAX, $N = 368$) from the Mexican Caribbean

PNAX (ANCOVA: $F = 3.91, P < 0.05$) (Fig. 3), but there were no differences between years (2012–2013) per location (RBBC: $F = 0.18, P > 0.05$; PNAX: $F = 3.53, P > 0.05$). The L – L relation was significant ($F = 29440.08, P < 0.01$) with $r^2 = 0.99$ but showed no difference between areas (ANCOVA: $F = 3.83, P > 0.05$) (Table 2).

The relative condition factor for lionfish in the RBBC ranged between 149.1 ± 19.4 in 2012 and 136.9 ± 16.9 in 2013 (t -test = 6.9, $P < 0.01$), while in the PNAX ranged

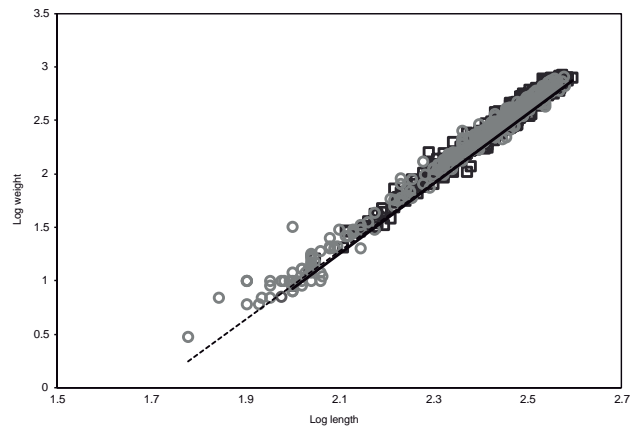


Fig. 3. Relation between Log length and log weight of lionfish, *Pterois volitans*, in two Natural Protected Areas: Reserva de la Biosfera Banco Chinchorro (RBBC) (square grey) and Parque Nacional Arrecifes de Xcalak (PNAX) (circle grey); RBBC: solid line; PNAX: dashed line

Table 1

Lineal relations ($y = a + bx$) between total length and weight of lionfish, *Pterois volitans*, in two natural protected areas in the Mexican Caribbean

Location	Year	n	TL [mm]		Weight [g]		a	b	CL 95% (a)	CL 95% (b)	r^2	W_r
			Mean	Range	Mean	Range						
RBBC	2012	324	278.6	10–386	366.7	9–845.7	0.0040	3.27	0.004–0.005	3.22–3.32	0.98	149.12
	2013	125	291.2	157–395	356.8	33–800.6	0.0036	3.30	0.003–0.005	3.17–3.42	0.95	136.99
PNAX	2012	149	269.0	60–380	319.8	3–740	0.0041	3.25	0.003–0.005	3.17–3.33	0.97	147.14
	2013	219	235.8	70–378	248.5	6–804	0.0052	3.16	0.005–0.006	3.11–3.21	0.98	145.50
RBBC	2012 + 2013	449	282.1	100–395	363.9	9–845.7	0.0041	3.25	0.004–0.005	3.20–3.30	0.97	145.74
PNAX	2012 + 2013	368	249.2	60–380	277.4	3–804	0.0049	3.19	0.004–0.005	3.14–3.23	0.98	146.18

RBBC = Reserva de la Biosfera Banco Chinchorro, PNAX = Parque Nacional Arrecifes de Xcalak, n = number of fish, TL = total length, a = intercept, b = slope, CL = confidence limit, r^2 = coefficient of determination, W_r = relative condition factor.

Table 2

Lineal relations ($y = a + bx$) between total and standard lengths of lionfish, *Pterois volitans*, in two natural protected areas in the Mexican Caribbean

Relation	Location	a	b	CL 95% (a)	CL 95% (b)	r^2
TL–SL	RBBC	–5.27	0.78	–7.74–2.80	0.77–0.78	0.98
	PNAX	–3.02	0.77	–4.69–1.35	0.76–0.77	0.99
SL–TL	RBBC	10.53	1.26	7.48–13.58	1.25–1.27	0.98
	PNAX	5.58	1.29	3.45–7.70	1.28–1.30	0.99

RBBC = Reserva de la Biosfera Banco Chinchorro, PNAX = Parque Nacional Arrecifes de Xcalak, TL = total length, SL = standard length, a = intercept, b = slope, CL = confidence limit, r^2 = coefficient of determination.

between 147.1 ± 21.9 and 145.5 ± 17.23 , respectively (t -test = 0.13, $P > 0.05$) (Table 1). W_r showed a significant difference between areas in 2013 (t -test = -4.4 , $P < 0.01$), but no difference in 2012 (t -test = 1.4, $P > 0.05$).

DISCUSSION

Size distributions of lionfish for both locations (RBBC and PNAX) mainly corresponded to reproductive capable adults (>189 mm TL) (Gardner et al. 2015). However, in the PNAX there was a modal group showing sizes representing juveniles (60–120 mm TL). Thus, it is probable that PNAX is a very important place for lionfish recruitment (Vásquez-Yeomans et al. 2011). In the PNAX, there was a change in modal groups into larger size classes from 80–160 mm TL in 2009–2011 (Sabido-Itzá et al. 2016) to 240–280 mm TL in 2012–2013. This may imply that lionfish population is experiencing a growth trend (Côté and Maljković 2010, Pusack et al. 2016).

The size of the largest lionfish collected in the Mexican Caribbean, specifically in the RBBC (395 mm TL), was relatively similar to that collected in the southern Gulf of Mexico (389 mm TL, Aguilar et al. 2013) and to that in the Cayman Islands (391 mm TL, Edwards et al. 2014). However, the largest lionfish size captured in the western Atlantic was 477 mm TL for Islamorada, Florida.

The L – W relations of lionfish from the Mexican Caribbean are described herewith for the first time. These relations explain an allometric growth type for lionfish with some slight differences. These differences may be due to environmental factors in a given geographic location, reef health, and habitat type (Díaz-Pérez et al. 2016), but also to biotic factors such as differences in the native community and availability of potential prey (Gonzalez-Salas et al. 2003, García-Salgado et al. 2006). In general, the vast majority of b coefficients calculated for lionfish in different geographic areas show values greater than 3

(positive allometry), and only in two cases the coefficient b was lower than 3 (Table 3).

The relative condition factor for lionfish from the Mexican Caribbean differed between areas only in 2013, but a high value was determined in 2012. Values of relative condition factor lower than 100 indicate that fish is under low availability of food resources and high abundance of predators, while higher values indicate high abundance of prey and low predation (Froese 2006, Rypel and Richter 2008). In this case, lionfish from Mexican Caribbean with values higher than 100 imply a well-being of fish in both areas. This latter indicates that lionfish show a high rate of prey consumption in combination with a lack of predation for native fishes (groupers and snappers) for its possible biological control (Côté and Maljković 2010, Green et al. 2011, Hackerott et al. 2013).

On its native reef, lionfish is relatively smaller compared to that on invaded reefs (Darling et al. 2011). Consequently, the invaded environment, in the Mexican Caribbean, is favourable for its growth. Our results suggest that the PNAX and the RBBC could offer a suitable habitat for the establishment of lionfish despite some of their population attributes (e.g., size distribution, condition factor and length–weight relation) may differ at close geographic proximity. This study provides suitable information useful as a baseline to delineate population dynamic models to assess the progression of the invasion of lionfish in the Mexican Caribbean. This latter is of particular importance for management practices, based on culling, to face the invasion. In fact, so far the RBBC and the PNAX are under culling program for lionfish with the collaboration of voluntary fishermen. Such programs are expected to foster conservation efforts of these natural protected areas (Sabido-Itzá et al. 2016). In addition to continuing the culling program, it is recommended to conduct surveys to estimate lionfish density. Also studies

Table 3

Mean total length and coefficients of the L – W relations estimated for lionfish, *Pterois volitans*, in Western Atlantic, Caribbean Sea, and Gulf of Mexico

Locality	TL [cm]		a	b	r^2	Source
	Mean \pm SD	Range				
North Carolina, USA	—	—	0.0000289	2.89	Na	Barbour et al. 2011
New Providence, Bahamas	23	17–29	0.00497	3.29	Na	Darling et al. 2011
Northern Gulf of Mexico	—	12.6–38.5	0.0028	3.43	0.99	Fogg et al. 2013
Puerto Rico	16.3 ± 6.1	5.7–34.9	0.08	3.11	0.95	Toledo-Hernández et al. 2014
Northern Gulf of Mexico	24.29	6.7–37.7	0.00000207	3.34	0.98	Dahl and Patterson 2014
Little Cayman	—	2.7–39.1	0.000003	3.24	0.97	Edwards et al. 2014
Costa Rica	18.7 ± 5.7	—	0.0235	2.81	Na	Sandel et al. 2015
Alacranes reef, Mexico	—	9–35	0.104	3.30	0.98	Perera-Chan and Aguilar-Perera 2014
Alacranes reef, Mexico	—	9–38.9	0.011	3.33	0.97	Rodríguez-Cortés et al. 2015
Cuba	~25	—	0.012	3.01	Na	Cobián-Rojas et al. 2016
Xcalak, Mexico	16.4 ± 7.2	2.5–37.5	0.0079	3.18	0.99	Sabido-Itzá et al. 2016
Banco Chinchorro, Mexico	28.2	10–39.5	0.0041	3.25	0.97	This study
Xcalak, Mexico	24.9	6.0–38.0	0.0049	3.19	0.98	This study

TL = total length, TL values are mean \pm standard deviation (where available) and range, a = intercept, b = slope, r^2 = coefficient of determination.

on stomach content analysis are desirable in order to determine the possible impact of the lionfish invasion on the native fauna of the region.

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