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Research Article

Feeding and growth of the lionfish *Pterois volitans* (Linnaeus, 1758) in the southern zone of the Veracruz Reef System

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ABSTRACT. This contribution reports information about the feeding and growth of the lionfish *Pterois volitans* in the southern area of the Veracruz Reef System National Park (PNSAV, by its Spanish acronym); 230 specimens were collected by free diving and harpoons between 2019 and 2023 with standard length interval of 65 to 335 mm and 6 to 1,100 g in weight; this fish species follows a positive allometric growth through the weight-length ratio (b = 3.25), three condition factor models were estimated that showed that the organisms occupying this area are in good body condition, in addition, individual condition (*kc*) was correlated with weight increases (r = 0.46, P < 0.05); in this sample, only organisms in early stages of gonadic maturity were found. The lionfish diet in the study consisted of fish and crustaceans. Among the fish prey, 7 families and 14 species were identified. *Haemulon aurolineatum*, *Azurina multilineata*, and *Diplectrum bivittatum* contributed the most to the diet of *P. volitans*. *Starksia hassi* was also recorded, marking a first record for the PNSAV. The consumption of crustaceans was represented by *Xiphopenaeus kroyeri*, and other crustaceans belong to the families Sycionidae and Diogenidae. These results indicate that lionfish is a generalist predator that consumes fish and crustaceans in this area, with a good individual body condition that is reflected in the type of growth of the organisms. The absence of organisms in reproductive stages opens the possibility that *P. volitans* move to other sites on the reef to reproduce.

Keywords: *Pterois volitans*; lionfish; invasive species; Veracruz Reef System; Gulf of Mexico

INTRODUCTION

The lionfish *Pterois volitans* (Linnaeus, 1758) is a species native to the Indian and western Pacific oceans; its natural habitat corresponds to tropical marine waters in areas with water temperatures between 14 to 28°C and at depths of 10 to 175 m. Their original distribution ranges from South Korea, southern Japan, to Micronesia, Philippines, Malaysia, French Polynesia, Australia, and New Zealand (Green et al. 2011).

The most accepted explanation for the arrival of lionfish in the American Atlantic is that they were introduced to aquariums in 1980, where their release occurred; the first record on the coasts of Florida oc-

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curred in 1985, and from there, it dispersed to the north coast of the USA, then it reached Bermuda in 2000, distributing southwards through the Caribbean Sea and westwards in the Gulf of Mexico through ocean currents (Kitchens et al. 2017), its dispersion has expanded to the southern hemisphere, since 2014 it has been reported in Brazil (Luiz et al. 2021).

In Mexico, lionfish are classified as an invasive exotic species, as defined by CONABIO (2017), which means these species are outside their natural range. They are capable of surviving, reproducing, and establishing themselves in other habitats and natural ecosystems, threatening native biological diversity, the economy, or public health. This species can have a drastic impact on food webs because it preys on native species of fish, crustaceans, and mollusks (Reynaldo de la Cruz et al. 2019).

Santander-Monsalvo et al. (2012) provided the first photographic record of lionfish in the Veracruz Reef System National Park (PNSAV, by its Spanish acronym) at the Anegada de Adentro Reef in December 2011. By the beginning of 2012, the first specimen was captured using a hand net. Aguilar-Medrano & Vega-Cendejas (2020) provided the only available information on lionfish feeding, with fish collected from reefs of the Lobos-Tuxpan Reef located in the north of the state of Veracruz. They reported that the density of the lionfish in that study area was low, and the diet consisted of fish, crustaceans, and mollusks.

This contribution presents information on the feeding, growth, and gonadic maturity of the lionfish collected from reefs in the south of PNSAV, which can be useful as a basis for managing and controlling this invasive species.

MATERIALS AND METHODS

The PNSAV is part of a group of coral reefs that are among the most complex and important in the Gulf of Mexico (Salas-Pérez & Granados-Barba 2008). It is located on the western shelf of the Gulf of Mexico in the central portion of the Veracruz coast off the coasts of the municipalities of Veracruz, Boca del Río, and Alvarado (Granados-Barba et al. 2007), between geographic coordinates 19°02'16''-19°15'32''N and 95°46'55''-96°11'45''W. The PNSAV is made up of 23 platform-type reefs naturally divided into the north and south groups by the discharges of the Jamapa River (Fig. 1).

The PNSAV has been designated as a Natural Protected Area since 1992 (DOF 1992). For its natural values, it has received two international recognitions: it has been a Ramsar site since 2004 and, as a Biosphere Reserve, it has been included in the World Network of Biosphere Reserves of the Man and the Biosphere Program (MAB) of UNESCO since 2006. This coral reef stands out for its high biodiversity, estimated at 1,300 marine species, of which 472 are fish (Robertson et al. 2019).

The identification of the specimens was done using the description of Schultz (1986). Biological samples were obtained in two phases: the first in 2019, before the pandemic confinement, and the second between March 2022 and April 2023. In this period, a total of 230 specimens of *P. volitans* were collected on the reefs of the southern area of the PNSAV, particularly in the La Blanca and Enmedio reefs (19°06'21''N, 95°56'18''W) (Fig. 1).

The catch was made by local fishermen using free diving techniques and harpoons. We attempted to obtain fish from other reefs in the area, but different fishermen's cooperatives argued that catching lionfish is more difficult and risky. The caught fish were placed in sealable bags and stored in a cooler to maintain a temperature below 3°C, to be processed within the following 24 h. In some cases, the fish were frozen at -10°C for processing later, with periods not exceeding 96 h.

Specimens were measured in standard length (L) up to 0.01 cm and weighed with a digital scale with an accuracy of 0.01 g (W) Acculab VI-1. The dissections were performed according to the method described by Green et al. (2012), and the organisms were sexed macroscopically using the criteria outlined by Brown-Peterson et al. (2011).

To estimate the type of growth, the length-weight relationship was analyzed using the allometric growth function: $W = a \times L^b$ (Froese 2006), calculating *a* value as the intercept to zero and *b* the slope of the equation, where W is the total weight in grams, and L the standard length in centimeters, the coefficients (*a* and *b*) were estimated through an ordinary least squares regression.

With the value of *b*, the type of growth was determined: isometric ($b = 3$), where the individual maintains its shape as it grows; positive allometric ($b > 3$), when individuals increase their weight in greater proportion than their length; and negative allometric ($b < 3$), when individuals increase their length more than their weight (Cifuentes et al. 2012).

For *P. volitans*, three models of condition factor were estimated in the PNSAV. First, the Fulton condition factor was estimated as $kc = 100 \times (W / L^3)$

Figure 1. Location of the Veracruz Reef System National Park (PNSAV, by its Spanish acronym), Veracruz, Mexico. The area delimited by the oval corresponds to the collection area of *P. volitans* in PNSAV. Modified from Google Earth Image© Maxar Technologies Data SIO, NOAA, US Navy, NGA, GEBCO Image© 2023, Airbus Image© 2023 Terrametrics.

(Fulton 1911). The Fulton factor is used as an approximate value, even under the theoretical consideration that allometric growth is more appropriate for the model.

The allometric condition factor was calculated as $ka = 100 \times (W / L^b)$, where W is the total weight of the fish, L is its standard length, and b is the constant of the standard length-to-weight ratio (Bagenal & Tesch 1978). This factor is less used, although it is more relevant because it uses the constant b calculated from the parameters of the analyzed sample.

The values of *kc* and *ka* are interpreted directly. At higher values of *kc* or *ka*, the condition of the fish is better. The relative condition factor was estimated as $kn = Wo / Wc$, where Wo is the total observed weight of the fish, and Wc is the total calculated weight of the respective fish using the equation $Wc = a \times L^b$ (Le Cren 1951). In this study, *kn* was used to infer the habitat conditions of the species, so when *kn* is greater than or equal to 1, the fish is in good condition, but when *kn* is less than 1, the fish is in poor condition. Statistical tests were performed with the PAST program (Hammer et al. 2001).

The composition of the diet of *P. volitans* was described by analyzing the stomach contents of specimens. The digestive tract of each specimen was dissected, and the contents were analyzed with a stereoscopic microscope Nikon SMZ-645. To identify the prey at the lowest level species, but according to the degree of digestion some items were only identified: 1) at the family or genus level, 2) when a reliable identification was not possible due to the level of degradation, the foods were labeled in large groups as crustacean remains (CrusRe), fish remains (FishRe), and 3) when this was also not possible, the content was classified as unidentified animal organic matter (UOM).

For the identification of prey fish species, the keys of Carpenter (2002) were used, and the validity of the scientific names of each species was updated with information from FishBase (Froese & Pauly 2024). For crustaceans, the keys of Williams (1984) and Carpenter (2002) were used.

Individually identified prey were counted and weighed on a digital scale, depending on their weight size up to a level of 0.01 to 0.001 g. Initially, the contribution of each prey taxon to the diet of *P. volitans* was quantified using three measures based on percentage frequency (%F), percentage composition per mass (%W), and percentage composition per number (%N) (Hyslop 1980).

The prey-specific index of relative importance (% PSIRI) (Brown et al. 2011) was used to evaluate, in an integrated manner, the importance of each prey item in the diet of the predator, which utilizes the values of %N and %W adjusted to the specific abundance of the food entities.

This index was calculated in the following manner:

$$\%\text{PSIRI} = \frac{\%\text{FO}_i * (\%\text{PN}_i + \%\text{PW}_i)}{2}$$

where $\%FO_i$ is the frequency of occurrence, and $\%PN_i$ and $\%PW_i$ are the indices of prey specific abundance ($\%PA = \sum \%A_{ij} / n_i$), where $\%A_{ij}$ is the abundance (expressed in number or weight) of the prey *i* category in the j^{th} stomach, n_i is the number of stomachs containing prey *i*, and *n* is the total number of stomachs.

Comparison of food composition between sizes

Size class intervals were generated using L data with the Battacharya (1967) method to analyze the variation in food item combinations according to size and gender (male, female, and undifferentiated). A permutational multivariate analysis of variance (two-way PERMANOVA) test was applied. The resemblance matrix for the density of species was achieved using Euclidian dissimilarity (Clarke & Gorley 2015). The analysis was computed with 9,999 permutations of residuals in a reduced model.

RESULTS

A total of 230 ind of *P. volitans* were collected in a standard-length range of 65 to 335 mm, with a mean (± standard deviation, SD) of 192.4 ± 53.4 mm. The weight was recorded from 6 to 1,100 g, with a mean value (± SD) of 298.6 ± 239.8 g. Of the 144 ind with visible gonads, 35 were found to be undifferentiated. In reproductive maturity stage II, 14 females and 68 males were found, and in maturity stage III, 25 females and 2 males were found. In the total sample, no specimens in more advanced reproductive stages were found.

The parameters of the growth model of *P. volitans* in this area of the PNSAV are shown in Figure 2. It was estimated that the lionfish exhibits positive allometric growth, with $b = 3.253$ ($r = 0.977$, $R^2 = 0.956$, $P < 0.001$). Table 1 shows the average values ± SD, as well as the minimum and maximum intervals of the condition factors *kc*, *ka*, and *kn*.

The three condition factor models show that most individuals approach or exceed the mean level of well-being estimated by these indicators (Figs. 3a-c), only low percentages of the sample (*kc:* 17 ind, 7.4%; *ka:* 12 ind, 5.2%; *kn:* 14 ind, 6.8%) were found below the lower limit, this group of fish corresponds to small fish of less than 150 mm in standard length; in contrast, more fish were close to the upper limit of the models (*kc* 33 ind, 14.34%; *ka* 23 ind, 10%; *kn* 24 ind, 10.43%). The three indices show that more than 90% of *P. volitans* individuals tend to present a good body condition.

Only the *kc* condition factor showed low positive correlations with weight ($r = 0.46$) and standard length ($r = 0.308$), both with $P < 0.05$. For the other two models (*ka* and *kn*), there was no correlation.

Considering the total sample, 120 stomachs were empty (52.3%). Table 2 shows the feeding composition of lionfish in PNSAV. Fish remains (FishRe) were the food type with the highest percentages in the variables mass, frequency, and number, at 43.15, 77.36, and 52.51%, respectively, followed by UOM at 15.17, 43.95, and 19.83%. Crustacean remains (CrusRe) were recorded in lower percentages: 2.63%M, 44.65%F, and 18.83%N.

Among the fish food contents identified, the families Atherinopsidae, Pomacentridae, and Chaenopsidae contributed the highest percentages of number, mass, and frequency compared to other families such as Pempheridae, Eleotridae, Achiridae, and Cyclopsettidae.

Fourteen species of fish were identified, with the greatest contribution to the lionfish diet being made by *Haemulon aurolineatum*, *Azurina multilineata*, and *Diplectrum bivittatum*. *Starksia hassi* Klausewitz, 1958, is a new record for the PNSAV. Another item found were remains of crustaceans belonging to the families Sycionidae and Diogenidae, specifically the genus *Squilla* sp., and four shrimp species, of which *Xiphopenaeus kroyeri* contributed the highest percentage to the crustacean group. A fragment of an alga from the family Gigartinaceae was found in one specimen, considered an incidental consumption. With the variables measured for each food item, the PSIRI importance values were calculated: for FishRe, 80.49; UOM, 17.0; and CrusRe, 2.51.

With the Bhattacharya method, seven size intervals were defined: size I 13.1-15.8 cm, size II 15.9-18.8 cm, size III 18.9-20.8 cm, size IV 20.9-23.4 cm, size V 23.25.4 cm, size VI 25.5-26.9 cm and size VII 27.0-33.6 cm. According to the PERMANOVA, the food items changed as a function of size and gender ($P < 0.05$). The pairwise revealed that gender differences were found among undifferentiated males and females in stage III; the size I concerning the sizes III to VII and the sizes VI to VII concerning the sizes II, III, and IV ($P < 0.05$) (Table 3).

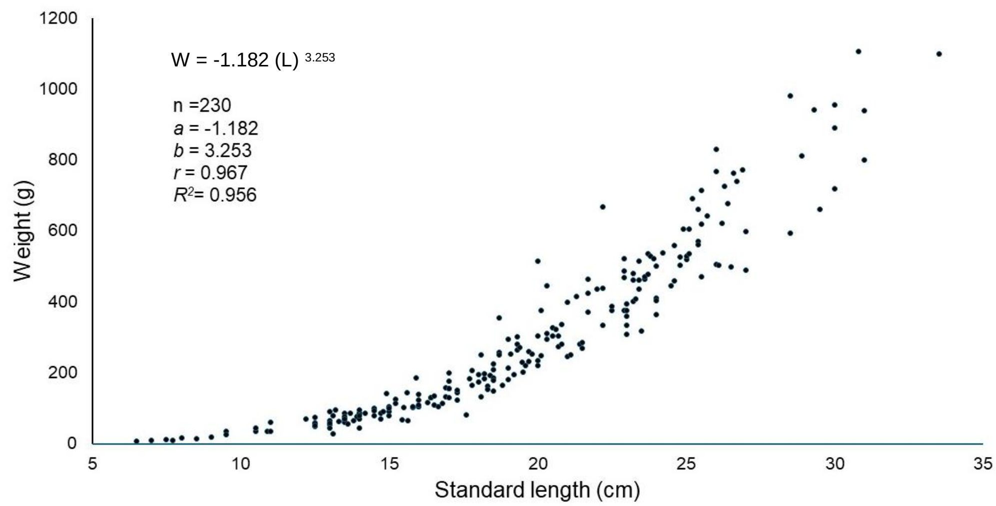

Figure 2. Growth model of *P. volitans* in southern reefs of the Veracruz Reef System National Park. W: weight (g), L: standard length (cm).

Table 1. Estimated values of the condition factors for *P. volitans* in the Veracruz Reef System National Park. *kc*: condition factor, *ka*: allometric condition factor, *kn*: relative condition factor.

Model	Mean ± standard deviation	Minimum-maximum interval
kc	3.24 ± 0.72	1.24 - 6.43
ka	1.54 ± 0.32	0.64 - 3.01
kn	1.00 ± 0.043	0.74 - 1.14

DISCUSSION

Coral reefs are particularly important to local communities because they provide them with high-protein foods, areas for recreational activities and serve as protective barriers to the coastline; they are also home to almost a third of all marine fish in the world (Pimiento et al. 2013). Historically, the PNSAV has been subject to strong environmental impacts such as the extraction of coral stone for the construction of buildings in colonial times (Carricart-Ganivet 1998), sedimentation by river discharges (Krutak et al. 1997), pollution by wastewater discharges, garbage and overfishing (Ortiz-Lozano et al. 2005) and since 2010 by port expansion activities that directly affect the reefs near the port of Veracruz (APIVER 2011).

Added to this scenario of environmental degradation is the presence, since 2011, of the lionfish *P. volitans*, which, as an invasive species and voracious predator, can severely impact the ecological interactions of native prey and competitor fish species.

Based on the specimens collected, *P. volitans* was fully identified, although there is some controversy about the joint presence of this species and *P. miles* (Bennett, 1828) in the Gulf of Mexico; Valdez-Moreno et al. (2012) used a molecular barcode method for the identification of lionfish in the Caribbean and only identified *P. volitans*, another genetic study showed that the lionfish population in PNSAV corresponds to this fish species (Guzmán-Méndez et al. 2020).

In this work, we report a specimen of 335 mm in standard length and 1,100 g in weight that contrasts with Aguilar-Perera et al. (2013), who reported the specimen with the highest total length in the Gulf of Mexico, which corresponded to a female of 390 mm total length and weight of 1,090 g, we do not rule out that by the fact of having measured the standard length, our specimen exceeds this record. These authors cite that specimens with the highest total length have been reported for the Bahamas (420 mm), North Carolina (450 mm), and Florida (474 mm).

In PNSAV, the growth of *P. volitans* presented a positive allometric trend, as has been reported for other Mexican localities. Aguilar-Perera & Quijano-Puerto (2016) reported this type of growth in the Alacranes Reef. Although they found significant differences

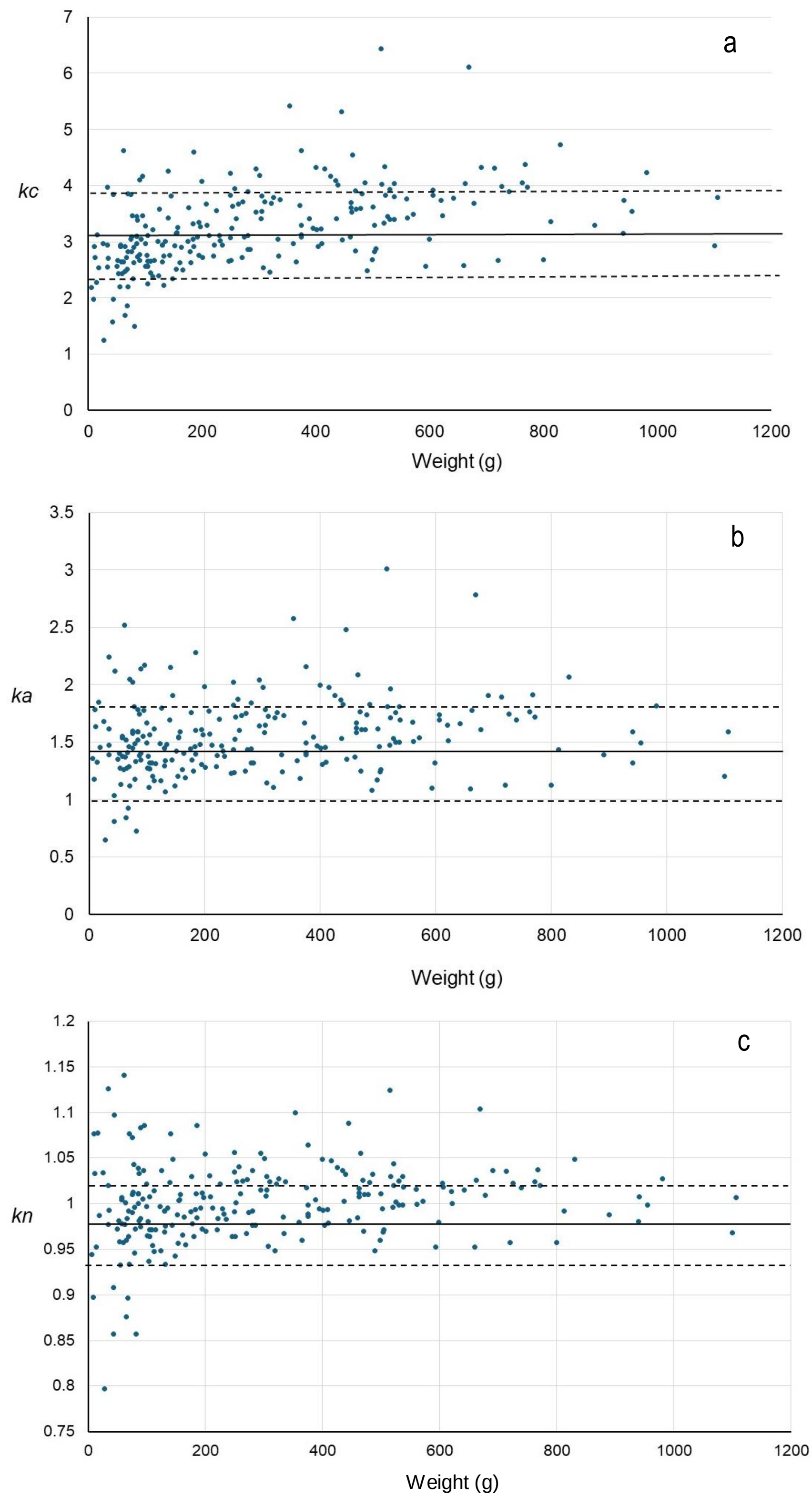

Figure 3. Relationship of the a) condition factor (*kc*), b) allometric condition factor (*ka*), and c) relative condition factor (*kn*) concerning the weight of the lionfish organisms *P. volitans* in reefs of the south of the Veracruz Reef System National Park. The solid line represents the mean value of each condition factor, and the dotted lines represent the lower and upper interval defined by the mean ± standard deviation.

Table 2. Food items consumed by lionfish *P. volitans* in southern reefs of the Veracruz Reef System National Park. Their arrangement reflected their contribution and importance to the species' diet. N: number; M: biomass consumed; F: frequency in stomachs; %PNi: percentage of contribution in number; %PWi: percentage of contribution in biomass consumed; %FOi: frequency in the total number of stomachs; PSIRI: prey-specific index of relative importance; FishRe: fish remains; UOM unidentified animal organic matter; CrusRe: crustacean remains.

Food items	N	M (g)	F	%PNi	%PWi	%FOi	%PSIRI
FishRe	188	213.27	123	52.51	43.15	77.36	80.49
UOM	71	74.98	71	19.83	15.17	44.65	17.00
CrusRe	33	13.01	31	9.22	2.63	19.5	2.51
Teleost Fish, families							
Atherinopsidae	2	5.77	2	0.56	1.17	1.26	2.12
Pomacentridae	1	6	1	0.28	1.21	0.63	0.91
Chaenopsidae	1	5.3	1	0.28	1.07	0.63	0.83
Pempheridae	1	3.37	1	0.28	0.68	0.63	0.59
Eleotridae	1	1.14	1	0.28	0.23	0.63	0.31
Achiridae	1	0.97	1	0.28	0.2	0.63	0.29
Cyclopsettidae	1	0.47	1	0.28	0.1	0.63	0.23
Teleost Fish, genus, and species							
Haemulon aurolineatum	22	18.57	6	6.15	3.76	3.77	36.27
Azurina multilineata	3	59.11	3	0.84	11.96	1.89	23.48
Diplectrum bivittatum	4	14.7	4	1.12	2.97	2.52	10.00
Haemulon sp.	3	13.3	3	0.84	2.69	1.89	6.48
Starksia hassi	3	11.54	3	0.84	2.33	1.89	5.82
Pristipomoides aquilonaris	1	13	1	0.28	2.63	0.63	1.78
Pempheris schomburgkii	1	7.9	1	0.28	1.6	0.63	1.15
Microspathodon chrysurus	1	5.82	1	0.28	1.18	0.63	0.89
Abudefduf saxatilis	2	0.37	2	0.56	0.07	1.26	0.77
Brachygenys chrysargyreus	1	4.2	1	0.28	0.85	0.63	0.69
Halichoeres cf. burekae	1	1.28	1	0.28	0.26	0.63	0.33
Polydactilus octenemus	1	0.67	1	0.28	0.14	0.63	0.26
Ophidion josephi	1	0.49	1	0.28	0.1	0.63	0.23
Ophididium brevibarbe	1	0.33	1	0.28	0.07	0.63	0.21
Parablennius marmoreus	1	0.25	1	0.28	0.05	0.63	0.20
Crustacean Families							
Sycionidae	2	1.61	2	0.56	0.33	1.26	1.09
Diogenidae	1	0.63	1	0.28	0.13	0.63	0.25
Crustacean Genus and species							
Xiphopenaeus kroyeri	2	2.35	4	0.56	0.48	2.52	2.54
Achelous spinicarpus	2	7.65	1	0.56	1.55	0.63	1.29
Achelous gibbesi	1	1.92	1	0.28	0.39	0.63	0.41
Squilla sp.	1	0.28	1	0.28	0.06	0.63	0.21
Penaeus aztecus	1	0.21	1	0.28	0.04	0.63	0.20

between males and females, the regressions by sex and with the total sample confirmed this type of growth; this trend is also similar for localities in the northern Gulf of Mexico, as reported by these authors.

In the compilation by Villaseñor-Derbez & Fitzgerald (2019), they noted that differences exist in the weight-length relationship between organisms from the Caribbean and the northwest Atlantic. In both regions, they recorded negative allometric growth models. For other localities in the Gulf of Mexico mentioned there, the explanation for these differences seems to lie in environmental conditions such as climate (Fogg et al. 2019) and those caused by the use of available energy for two populations, one in the Caribbean and the other "northern" in the Gulf of Mexico, which were genetically distinguished by Betancur-R et al. (2011).

Table 3. Permutational multivariate analysis of variance of the food items according to size and gender (M: male, F: female, and U: undifferentiated), based on an orthogonal two-factor model. Pairwise tests between sizes and gender from the standard model of the PERMANOVA. *Significant differences *P* < 0.05.

Source	df	ss	ms	F	p(perm)	Groups	t	p(perm)
Size	6	405.39	67.565	0.989	0.0136*	U-M III	31.39	0.039*
Gender	4	749.67	187.42	2.745	0.0125*	U-F III	3.559	0.005*
Interaction size-gender	24	-2623.5	-109.31	-1.6	0.2688	Size I-Size III	2.994	0.044*
Residual	80	5462.6	68.283			Size I-Size V	1.287	0.018*
Total	114	3994.2				Size I-Size VI	2.842	0.006*
						Size I-Size VII	8.124	0.025*
						Size VI-Size III	2.272	0.045*
						Size VI-Size IV	2.291	0.028*
						Size VII-Size II	4.136	0.044*
						Size VII-Size III	6.205	0.026*
						Size VII-Size IV	6.029	0.028*

An outstanding aspect related to growth is pointed out by Pussack et al. (2016), who showed that the growth rate of lionfish in the Atlantic Ocean can be up to 2.25 times faster than in native areas of the Pacific Ocean; this is an aspect that seems to favor the successful invasion of this species, which is manifested in the increase in body size (Darling et al. 2011) and the modification of predation behavior (Cure et al. 2012) that can be reflected in the favorable conditions offered by the new invaded habitats.

Based on the above, for the specimens of the PNSAV, it was found that the condition factor increased concerning the size of the organisms; statistically, a moderately high positive relationship was verified between the condition factor and the weight and with the height of the organisms; several studies have shown that there is a positive correlation between the accumulation of body fat stimulated by the availability of food; the variations in these indices indicate that seasonal declines in the condition factor of fish are inversely proportional to gonadal development (del Río et al. 2023). González et al. (2006) point out that condition factors are measures of energy reserves related to environmental conditions, maturity stages, diet, diseases or effects of parasitism. In our case, it was observed that organisms with some level of gonadic development showed low levels of body fat. In general, the three condition factors indicated that the organisms have an acceptable level of well-being, inferring that this area of the PNSAV provides them with adequate food resources for their growth.

Different publications show that, as was recorded in the PNSAV fish sample, the diet of lionfish in the Atlantic is composed of fish and crustaceans as the most preponderant groups. These results coincide with other reefs in the Caribbean and the Antilles (Morris et al. 2009), northern reef systems of the PNSAV (Aguilar-Medrano & Vega-Cendejas 2020), and depending on the reef localities, other important complementary foods such as mollusks were recorded (Cure et al. 2012, Layman & Allgeier 2012, Arredondo-Chávez et al. 2016, Reynaldo de la Cruz et al. 2019).

This feeding pattern is common in areas occupied by lionfish (Peake et al. 2018). In this combination, crustaceans are the most frequent complementary prey, followed by other groups, such as mollusks and echinoderms. In our report, the crustacean foods that complemented the diet were sycionid and penaeid shrimps.

Regarding prey fish, organisms of the families Pomacentridae and Haemulidae were the most important taxa in the lionfish diet; in contrast, Muñoz et al. (2011) argued that, although pomacentrids are the most frequent prey in lionfish from localities in Carolina, USA, as is also the case in the Bahamas (Morris et al. 2009) and Florida (Jud et al. 2011).

Peake et al. (2018) provided a regional comparison of lionfish feeding ecology, and their results demonstrated that western Atlantic lionfish are opportunistic generalist carnivores that consume at least 167 species of vertebrate and invertebrate prey, which participate at different trophic levels; from this work, it can be generalized that the diet of this species in the American Atlantic is fish-dominated as occurs in the PNSAV.

Cure et al. (2012) found an ontogenetic variation in the composition of the lionfish diet. In small-sized fish, crustaceans were their most abundant and important prey, while larger individuals consumed fish in greater quantities. Other similar findings are those of Pantoja et al. (2017), who showed that there is no difference in the diet between sizes of *P. volitans*, with a preponderance of fish over other types of food. In general terms, this is the case in the PNSAV.

However, Eddy et al. (2019) note that in Bermuda, the contribution of teleost fish to the lionfish diet increases significantly with the size of the individuals. In this context, according to the results of PERMANOVA, there are statistical differences in the proportions of the main food types. The undifferentiated organisms presented differences concerning male fish and female fish. A trend of dietary change was also found among organisms of small sizes compared to larger ones.

It is frequently mentioned that lionfish can be a serious threat to the populations of the organisms on which they feed, severely impacting the food webs of reefs due to the consumption of native species of fish and invertebrates (Valdez-Moreno et al. 2012, Morris & Green 2013).

Several ecological advantages are recognized for *P. volitans* as a successful invasive species. Albins (2013) and Benkwitt (2015) provided information indicating that lionfish can be a more skilled competitor in the competition for food, in addition to its voracity directly decreasing the abundance of small native fish populations.

Besides, *P. volitans* achieve high reproductive rates and faster growth rates in the Atlantic Ocean compared to congeners of their original habitat (Pusack et al. 2016); they are efficient competitors and predators (Arellano-Méndez et al. 2017) because they consume a wide variety of reef fish and invertebrates in their diet (Valdez-Moreno et al. 2012, Albins 2013), this represents a great threat because it can displace native fish from similar trophic levels (Pantoja et al. 2017), with potential effects on the entire reef ecosystem (Green et al. 2011, Albins 2015). Due to its impacts on coral reefs in locations in the Atlantic Ocean, this invasive species is among the primary conservation concerns worldwide (Sutherland et al. 2010).

Without intending to minimize the ecological risks of lionfish in PNSAV, other publications, such as that of Pantoja et al. (2017), report that the diet of lionfish does not overlap with the diets of other fish of the same trophic level in Cuban reefs, but this varies according to the locality, the ecological zone, the availability, and abundance of prey in the natural environment, in that report also state that the availability of food was not a limiting factor for lionfish and native fish, so no evidence of food competition was found. In PNSAV, it is necessary to initiate this type of approach because the diet of many fish species in this reef ecosystem is unknown.

In this regard, Hackerott et al. (2017) conducted a four-year study that did not produce evidence that lionfish affect the density, richness, or species composition of prey fish on Belize reefs. However, the occurrence of more evident punctual negative effects in places where lionfish densities are higher is not ruled out.

In PNSAV, several attempts have been made to control the presence of lionfish by promoting its consumption through gastronomic propaganda; it has been determined that *P. volitans* participates in the PNSAV in the life cycles of parasitic helminths as an accidental, paratenic or intermediate host (Montoya-Mendoza et al. 2017), concentrations of cadmium, lead, vanadium, and zinc were also detected in muscle tissue that did not exceed the limits established by the National Standard Mexican NOM-242-SSA1-2009 (Secretaría de Salud 2009), with this information it is assumed that the consumption of this species is not a risk to human health (Montoya-Mendoza et al. 2019).

The results presented here highlight the urgency of conducting more intense fieldwork to evaluate the lionfish impacts on the marine animal communities of the PNSAV.

Credit author contribution

R. Chávez-López: conceived and designed the study, processing of biological material; A. Morán-Silva: conceived and designed the study; K.P. Monroy-Praxedis: processing of biological material; J. Montoya-Mendoza: processing of biological material; A. Morán-Silva: conducted the data analysis; S. Cházaro-Olvera: conducted the data analysis. All authors contributed to improving the final version of this manuscript.

Conflict of interest

The authors declare having no conflict of interest.

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