



Density, size, biomass, and diet of lionfish in Guanahacabibes National Park, western Cuba

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ABSTRACT: The Indo-Pacific lionfish *Pterois volitans* is an invasive species that was first recorded in the Guanahacabibes National Park (GNP), a marine protected area in western Cuba, in 2009. In order to determine the invasion progression of this species, we studied lionfish abundance, size, and diet at 6 sites in the GNP between 2010 and 2014. The species' density, biomass, and length increased over this period, probably due to the abundance of food and shelter in the GNP. Analysis of stomach contents indicated that lionfish fed primarily on fish and crustaceans; main prey were teleosts, predominantly Gobiidae, Pomacentridae, Mullidae, Labridae, Scaridae, and Grammatidae. This example of a rapid increase in an unmanaged population at the onset of invasion provides information that can be used to design a management program targeting lionfish.

KEY WORDS: Invasive species · Marine protected area · Reef habitat · Fish · Scorpaenidae · *Pterois volitans*

INTRODUCTION

Invasive alien species are those introduced species that become established in natural or semi-natural ecosystems and constitute an agent of change and threat to the native species and biological diversity of the region (Mendoza & Koleff 2014). They are typically introduced in a voluntary or accidental manner, mediated by human action (Gutiérrez 2006). In recent decades, the prevalence of invasive species has increased in both terrestrial and marine environments, reaching unprecedented levels (Meyerson &

Mooney 2007). The main environmental impacts caused by these species are degradation of habitats, ecosystem imbalances, displacement and extinction of native flora and fauna, disruption of trophic structure, facilitation of subsequent invasions, and disease transmission (Gutiérrez 2006, Pyšek & Richardson 2010). Populations of invasive species may actually increase faster and achieve higher densities in the invaded area than in their original habitat (Cox 2004). The reasons for the success of these biological invasions are not simple; they depend on the traits of the ecosystems themselves (e.g. habitat complexity;

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Alexander et al. 2015), as well as on the inherent characteristics of the invading species (Mendoza & Koleff 2014). Studies of biological invasions have a long tradition; however, literature on the subject has only increased significantly since the 1990s (Pyšek & Richardson 2010). From this perspective, invasion biology is still a very young discipline (Pyšek & Hulme 2009).

The establishment of Indo-Pacific lionfish *Pterois volitans* populations in the western Atlantic is the utmost example of a marine fish invasion (Ruiz-Carus et al. 2006). Schofield (2010) described the timing of the invasion. In Cuba, lionfish were first recorded in 2007 off the north coast east of Havana and in the southeast near Santiago (Chevalier et al. 2008). Since that time, lionfish have thoroughly and swiftly invaded the area, taking only 1.5 yr to reach the westernmost tip of Cuba. The first sightings of lionfish occurred in Guanahacabibes National Park (GNP), western Cuba, in 2009. This invader can now be found in mangroves, seagrass prairies, and coral (Cobián et al. 2013). As observed elsewhere in the region, this invasion success is attributable to its dispersal mode, fecundity, and feeding habits, as well as a lack of natural predators (Layman & Allgeier 2012). Darling et al. (2011) and Morris (2009) suggest that the biological and ecological characteristics of lionfish have allowed their populations to achieve higher densities in invaded regions than in their native habitats; e.g. in the Bahamas, the species has reached densities >0.039 ind. m^{-2} (Green & Côté 2009), much higher than e.g. in their native Palau (0.000022 ind. m^{-2} ; Grubich et al. 2009).

Ours is the first study related to lionfish autoecology in western Cuba. This research is relevant not only because of its novelty for the area, but also because there are few (if any) cases where this type of research has been conducted in strictly non-fished areas. In the GNP, the ecosystem is healthy and well-conserved; richness is high for corals, fishes, and other groups (Cobián & Chevalier 2009). Similarly, coral reefs in GNP lack any human impact since no commercial or recreational fishing is practiced in the area, and there is no pollution. The complete absence of management against lionfish in GNP (until 2015) makes these data an important reference for comparisons throughout the region.

The aim of this article was to determine the progression of density, biomass, and individual size of lionfish in GNP between 2010 and 2014. Compared to the invasion patterns of lionfish in other countries (Morris & Akins 2009, Schofield 2010, Green et al. 2012), we believe that the favorable conditions of this

area have allowed a significant increase in the lionfish population.

MATERIALS AND METHODS

Study site

GNP was established as a marine protected area in 2001 and encompasses 39 830 ha (including land) in the westernmost region of Cuba, from Cabo Corrientes (21° 45' N, 84° 30' W) to the site known as Verraco (21° 91' N, 84° 61' W). The fringing coral reefs in GNP form a single terrace, with isolated coral heads but no well-defined crest. The sandy terrace ends at 12 to 20 m at a deep drop-off, which is composed of a varied and often quite complex architecture. *Orbicella*, *Agaricia*, *Porites*, and *Siderastrea* dominate the coral community (González-Ferrer et al. 2007).

Underwater visual censuses and lionfish sampling

Underwater visual censuses were conducted at 6 sites (Fig. 1) during Dec 2010, Sep 2011, Apr 2012, Jun 2013, and Feb 2014 in the front reef, from the edge of the drop-off to 25 m along the wall. Sampling habitats were classified as drop-off (Cuevas de Pedro, Encanto, Yemaya and Uvero Quemado) or spur-and-groove (Veral and Verraco). All surveys were conducted between 15 and 25 m depth. At every site, 6 linear transects (50 m long, 2 m wide) were surveyed, according to Brock (1954). Individual lionfish were carefully sought in cracks, caves, and hollows. The size of every lionfish sighted was visually estimated to the nearest cm, and the total weight of individuals was calculated employing length–weight equations obtained for Cuban waters (P. Chevalier unpubl. data), equation parameters $a = 0.012$ and $b = 3.017$. We calculated the density (ind. m^{-2}) and biomass (gm^{-2}) of lionfish for every transect and averaged these variables for every site.

Lionfish were collected at 8 sites in June 2013 and June 2014 (Fig. 1), following sampling and processing protocols outlined by Chevalier et al. (2014). Specimens were collected with hand nets or spears. Dissections were performed on 411 freshly caught specimens. Individual prey items in lionfish stomachs were identified to the lowest taxon possible; fish identification was based on Guitart (1985) and Humann & DeLoach (2002); crustaceans were identified based on Martínez-Iglesias & Gómez (1986) and Ortiz et al. (2010).

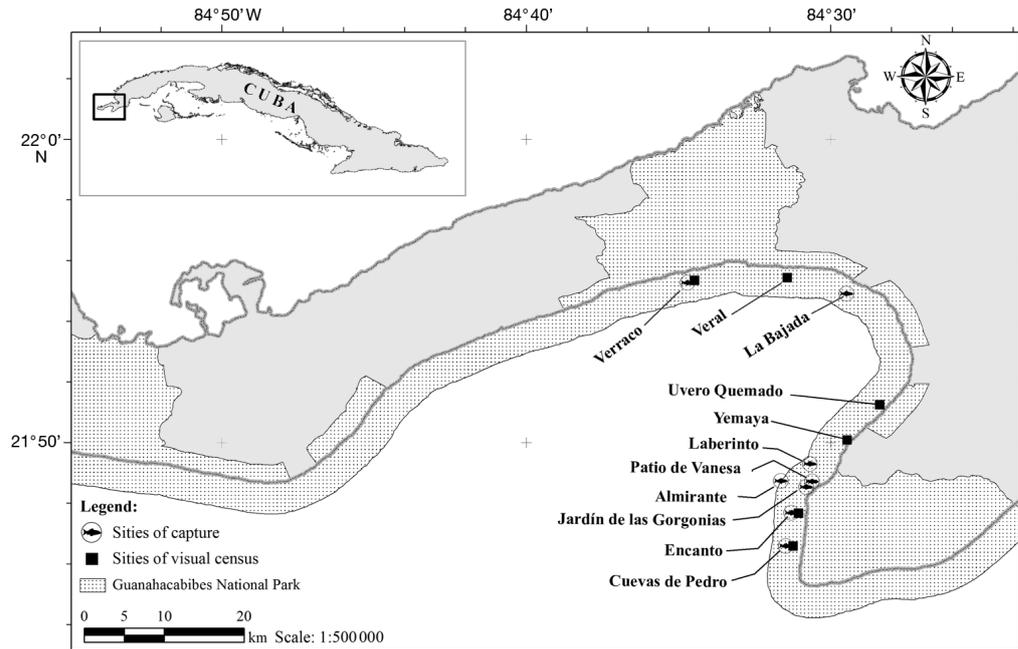


Fig. 1. Survey and collection sites for lionfish within Guanahacabibes National Park, Cuba

Data analyses

Data were tested for normality (Shapiro-Wilk test) and homoscedasticity (Levene's test) and were found to have a normal distribution and homogeneity of variance, so no transformation was necessary. Repeated-measures ANOVA was conducted on the density, biomass and size of lionfish by site; to determine the trend over time, an average of these variables was calculated with the values of the 6 sites for each sampling date. Significance was assessed at $\alpha = 0.05$; a Student-Newman-Keuls test was performed when differences were significant. Statistical analyses were conducted using Statistica v. 8.0 (StatSoft).

Diet analysis combined calculations of relative abundance (number of prey items, %N), frequency of stomachs in which prey items were present (%F), and relative volume (%V) into an index of relative importance (IRI; Pinkas et al. 1971), where $IRI = (\%N + \%V) \times \%F$. This was also rescaled as a percent: $\%IRI = 100 \times IRI_i / \sum^n IRI_i$ (Morato et al. 2003), where n is the number of prey items and i is the i th item. To explore the relationship between lionfish size versus consumption of fish and crustaceans, Spearman's non-parametric rank analysis was performed separately for %F, %N, and %V.

RESULTS

Lionfish densities during the first survey in December 2010 were low (<0.01 ind. m^{-2}), but by Septem-

ber 2011 mean densities for all GNP sites reached ≥ 0.05 ind. m^{-2} . Density continued to increase at all sites during the first 2 to 3 yr after the initial invasion in 2009, leveling off around 2013. Density was highest in the drop-off habitats, at Veral and Verraco (Fig. 2). Total length of individuals also increased steadily until at least 2012 (Fig. 3) subsequently leveling off; biomass also increased, in some sites until 2013, leveling off or, in some sites, decreasing afterwards (Fig. 4). On average, density, biomass, and size increased significantly during the first years of the invasion; afterwards density decreased and the other variables leveled off (Fig. 5).

Of the 411 lionfish stomachs examined, 67 (16.3%) were empty. A total of 54 prey items were identified, 35 of which could be identified to species level. Approximately 55% of the fish stomach contents could not be identified due to advanced stages of digestion (Fig. 6, Table S1 in the Supplement at www.int-res.com/articles/suppl/b024p219_supp.pdf). Lionfish consumed prey belonging to 19 fish families, the most important being Gobiidae, Pomacentridae, Mullidae, Labridae, Scaridae, and Grammatidae (Fig. 7). Crustaceans included Decapoda, Stomatopoda, and Mysida. Mollusks consisted only of Cephalopoda.

For crustaceans, abundance, biomass, and frequency were negatively correlated with lionfish size (%N: $r_s = -0.137$, $p = 0.005$; %F: $r_s = -0.138$, $p = 0.004$; %V: $r_s = -0.091$, $p = 0.050$), whereas there was no significant correlation between lionfish size and fish consumption (%N: $r_s = -0.008$, $p = 0.867$; %F: $r_s = -0.052$, $p = 0.290$; %V: $r_s = -0.008$, $p = 0.867$) (Fig. 8).

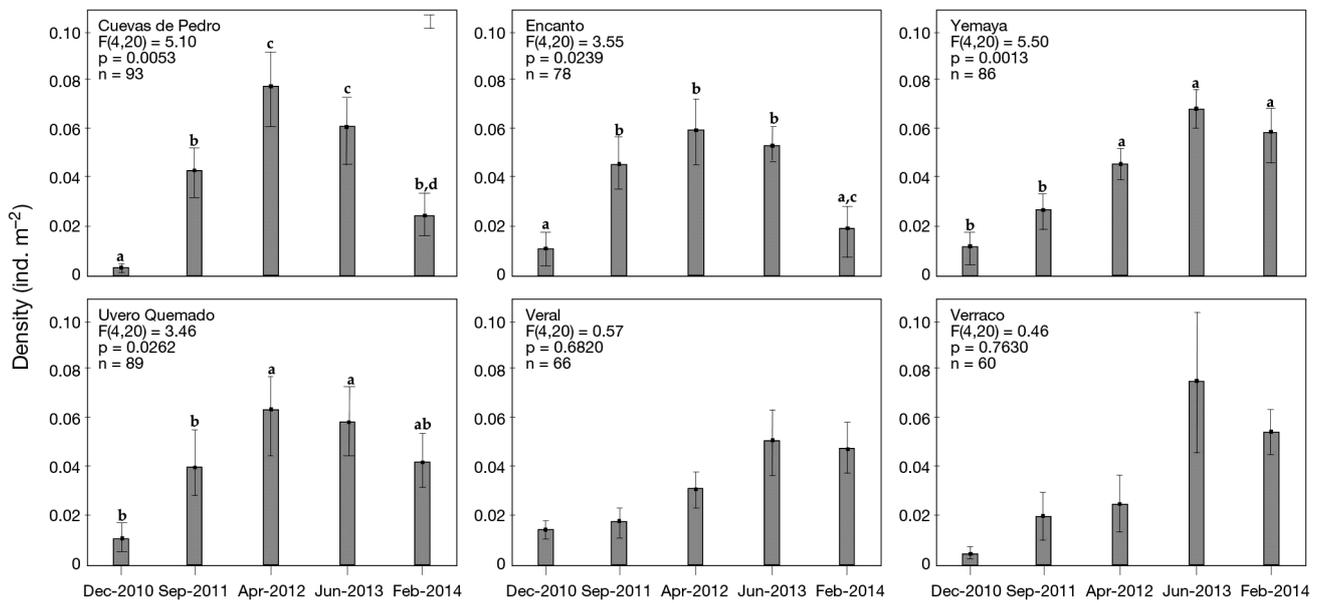


Fig. 2. Mean (\pm SD) lionfish density at 6 sites in Guanahacabibes National Park, Cuba, determined through surveys carried out between 2010 and 2014. Lowercase letters above the bars indicate homogeneous groups found by the SNK test

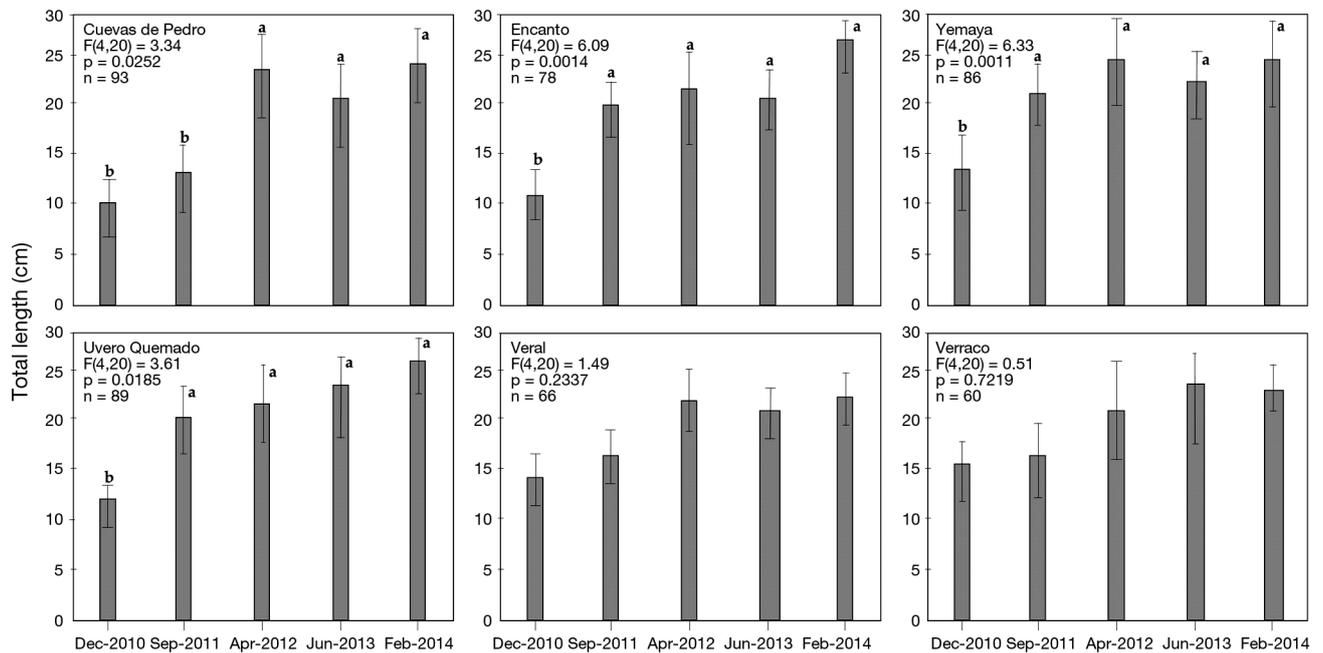


Fig. 3. Mean (\pm SD) total length of lionfish at 6 sites in Guanahacabibes National Park, Cuba, determined through surveys carried out between 2010 and 2014. Lowercase letters above the bars indicate homogeneous groups found by the SNK test

DISCUSSION

Initial lionfish density in the GNP in February 2010 was very low compared to regions on the northern coast of Cuba at that time, such as Santa Lucía (0.005 to 0.017 ind. m^{-2}), Sabana-Camagüey (0.032 to 0.042 ind. m^{-2}), and Bahía de Puerto Padre (0.021 to 0.088 ind. m^{-2}) (Chevalier et al. 2013). However by 2013,

overall density in GNP (0.031 ind. m^{-2}) was higher than that of the other locations (Chevalier et al. 2013), probably due to the isolation of the GNP from most human impacts and the absence of active management against lionfish. Additional factors that likely contributed to the success of the lionfish invasion in this region include the structural complexity of local reefs (which provide abundant shelter and prey) and

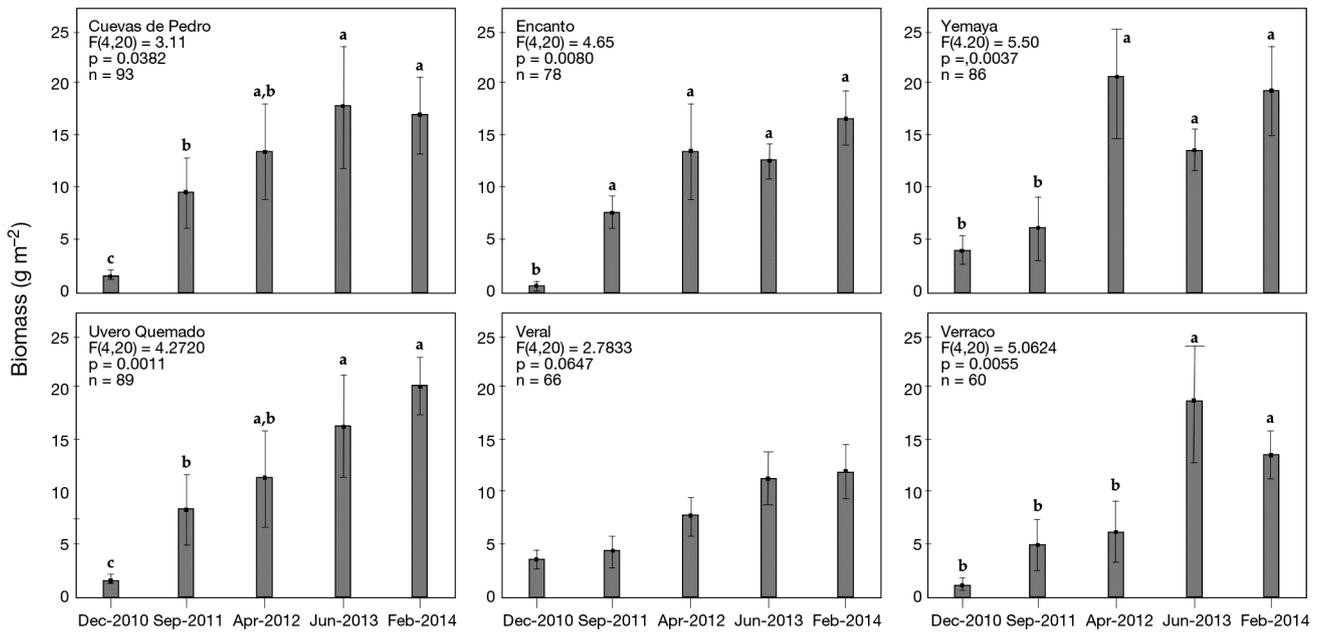


Fig. 4. Mean (\pm SD) biomass of lionfish at 2 sites in Guanahacabibes National Park, Cuba, during surveys carried out between 2010 and 2014. Lowercase letters above the bars indicate homogeneous groups found by the SNK test

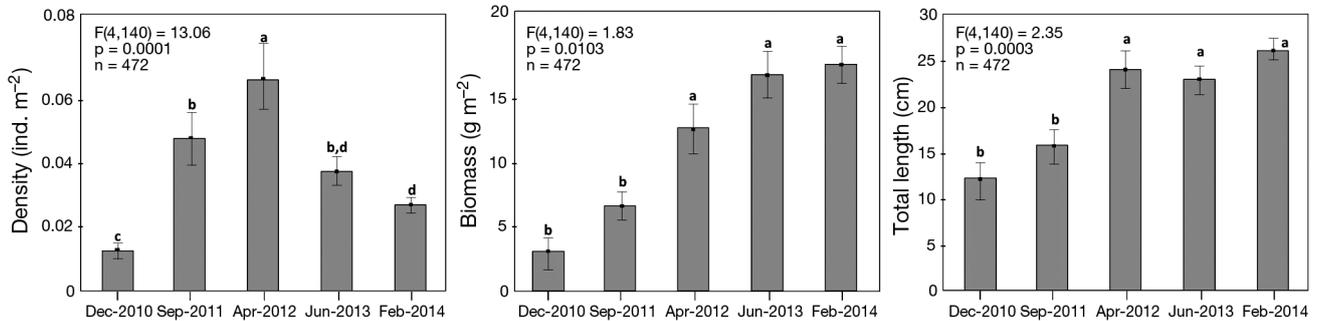


Fig. 5. Mean (\pm SD) density, biomass, and total length of lionfish at 6 sites sampled at Guanahacabibes National Park, Cuba. Lowercase letters above the bars indicate homogeneous groups found by the SNK test

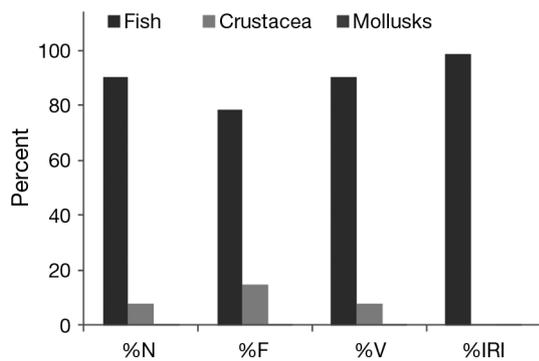


Fig. 6. Main prey groups of lionfish diet in Guanahacabibes National Park, Cuba. %N: relative abundance by number of prey individuals; %F: frequency of stomachs in which prey was present; %V: relative volume or biomass; %IRI: index of relative importance rescaled to percentage

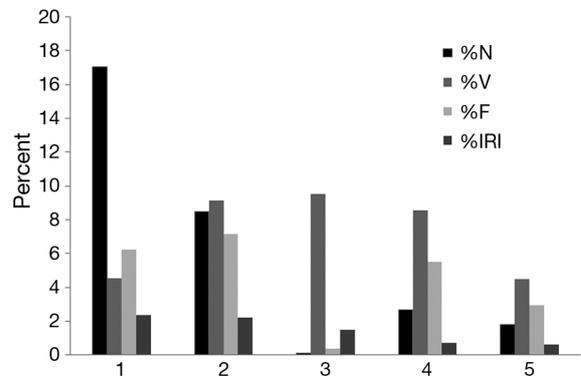


Fig. 7. Trophic spectrum of lionfish, showing fish families dominant in its diet at Guanahacabibes National Park, Cuba. %N: relative abundance by number of prey individuals; %F: frequency of stomachs in which prey was present; %V: relative volume or biomass; %IRI: index of relative importance rescaled to percentage. 1: Gobiidae, 2: Pomacentridae, 3: Mullidae, 4: Labridae and 5: Scaridae

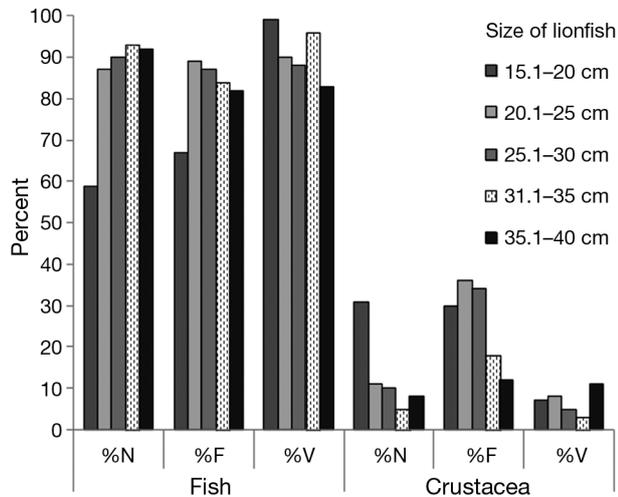


Fig. 8. Fish and crustacean consumption by lionfish size class at Guanahacabibes National Park, Cuba. %N: relative abundance by number of prey individuals; %F: frequency of stomachs in which prey was present; %V: relative volume or biomass

the strict regulations of the GNP that prohibit any fishing activity (except scientific collecting). The management of Jardines de la Reina National Park in central southern Cuba is as strict as in GNP; however, it includes regular campaigns targeted at catching lionfish. Other regions in Cuba are much more accessible to artisanal fishing.

Núñez-Lara & Arias González (1998) suggested that topographical complexity was the single most important factor affecting the reef fish community in the southern Mexican Caribbean. Cobián et al. (2011) evaluated the complexity of the substrate at the same sites surveyed in the present study; their results showed that the drop-off habitat had a high cover of live coral and greater structural complexity consisting of cavities, caves, crevices, shelves, and tunnels, providing fishes with a wide panoply of shelter. In line with this, in our study we found higher density and biomass of lionfish in this habitat. The drop-off habitat allows lionfish to remain aggregated in the same structure and refuge during the day. Adult lionfish exhibit high site fidelity (Morris 2009). This behavior could influence the high densities observed (Fishelson 1997), at least in the drop-off habitat; in the spur-and-groove habitat where structural complexity is lower, density was lower as well, and no aggregation of individuals was observed. These results are consistent with Fishelson (1997), who suggested that the density of lionfish could be influenced by local factors such as the availability of shelters and the structural complexity of the habitat. Another aspect to consider is the chronology of the invasion. The

earliest sightings of lionfish in GNP occurred in late 2009 in the southeast of the Guanahacabibes peninsula. In this area, the dominant habitat is drop-off, which provides favorable conditions for lionfish populations to establish and rapidly increase during the first 3 yr of the invasion. The population then expanded westward, following the trend of the general lionfish dispersal in Cuba (Chevalier et al. 2013).

There was no evidence of predation on lionfish in the GNP reefs, in spite of a high density and biomass of large carnivorous fishes (Cobián et al. 2011). According to Hackerott et al. (2013), the presence of predators does not appear to be a limiting factor for lionfish populations in the Caribbean. Hackerott et al. (2013) found high densities of lionfish on reefs that also supported large populations of potential predators, such as in the Jardines de la Reina National Park in Cuba, which has the highest biomass of fishes in the Caribbean but also high densities of lionfish, similar to those found in the Mesoamerican reef where predators are less common.

With regard to the size of lionfish, most of the population in GNP is composed of large adults, with a higher proportion than in other areas of Cuba and the Caribbean (Sabido Itzá et al. 2011, Chevalier et al. 2013, de León et al. 2013). Our study design did not include surveys of shallower areas, which might explain why we did not observe juveniles. Claydon et al. (2012) suggest that lionfish generally prefer to settle in shallow habitats before moving to deeper reefs as they grow. A related factor may be the absence of mangrove and seagrass ecosystems in our study area; in GNP the coast consists of sandy beaches, rocky coastline, and cliffs. Mumby et al. (2004, 2007) and Barbour et al. (2010) suggest that lionfish use mangrove systems as breeding sites. In GNP, mangroves are located north of the park, where juvenile lionfish may be more likely to occur.

The density of lionfish in GNP in 2013 was 0.031 ind. m⁻², similar to published records for the Bahamas (0.039 ind. m⁻²; Green & Côté 2009) and North Carolina (0.040 ind. m⁻²; Morris 2009). These densities are much higher than in their natural range, such as New Caledonia (0.000026 ind. m⁻²; Kulbicki et al. 2012), and may be related to the availability of food and shelter in these newly occupied areas. Morris (2013) stated that the success of the lionfish invasion can be attributed largely to its broad diet and extensive habitat preferences. Its rapid expansion in the Atlantic and the Caribbean could also be due to a more traditional reason for the success of invasive species: the absence of natural enemies that co-evolved with them in their original range as predators, parasites, or pathogens

(Liu & Stiling 2006) that normally control the population growth of these species.

Layman & Allgeier (2012) considered lionfish to be an opportunistic generalist. However, we found that in GNP, they occupy a rather narrow trophic niche—more as a specialist piscivore (especially in larger size classes), similar to that described by Green et al. (2012) for lionfish in the Bahamas. The fish families best represented in its diet are also those most abundant in these reefs (Cobián & Chevalier 2009, Cobián et al. 2011). Gobies, damselfishes, and wrasses are closely associated with the bottom, making them an ideal prey. Among gobies, *Coryphopterus* spp. were the most abundant prey in the GNP. These gobies tend to concentrate at specific points in the reef, facilitating hunting with a lower energy cost. Layman & Allgeier (2012) suggest that lionfish may select their fine-scale habitat based on prey density.

Juveniles of commercially important species such as *Mycteroperca* spp., *Epinephelus* spp., and *Lutjanus* spp. were not among the most relevant prey items, probably because their nursery sites (mangrove and seagrass prairies) are not present in GNP. In contrast, Morris & Akins (2009), found juveniles of *Epinephelus striatus* in several Bahamian biotopes. Future studies on lionfish in the GNP should include mangrove and seagrass habitats, in order to obtain a more complete picture of the impact of lionfish in this area.

Our results confirm information obtained so far in the Caribbean for this species, and suggest that the impact of lionfish on its prey increases as the lionfish grow in size and population. It is feared that this invader may adversely affect the diversity of small-sized fishes in GNP, as found by Green et al. (2012) in Bahamian reefs. The situation at GNP represents perhaps one of the clearest pictures of unmanipulated local invasion dynamics of lionfish, given the lack of management actions to date. A permanent extraction program to mitigate the invasion undertaken by GNP managers in collaboration with local communities, tourism workers, and environmental specialists, can be monitored using the information presented here as a reference.

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