

Novel Predator, Novel Habitat: A Diet Analysis and Experimental Test of the Ecological Effects of Invasive Lionfish in Florida Bay

Un Depredador sin Igual Asechando Un Nuevo Hábitat: Análisis Alimenticio y Prueba Experimental de los Efectos Ecológicos del Invasor Pez León en la Bahía de Florida

Nouveau Prédateur, Nouvel Habitat: Une Analyse de la Nutrition et Un Test Expérimental sur les Effets Écologiques de L'invasion de la Baie de Floride par les Rascasse Volante

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ABSTRACT

Since its introduction to the western Atlantic and Caribbean, the Indo-Pacific lionfish (*Pterois volitans/miles*) has undergone a population explosion that threatens the ecosystems it is invading. Determining the diet of invading lionfish among the various habitats where they are found is critical for understanding the ecological effects of the invasion. Our study combined a diet analysis and transplant experiment of lionfish found among the hardbottom habitats of Florida Bay. During June and July 2013 we collected and analyzed the stomach contents of lionfish (n = 32) associated with hardbottom habitat north of Marathon, FL. Prey found in collected stomachs were composed predominantly of teleost fishes (47.9% by number), although we also found a significant number of crustaceans in the diet (38% by number). Of the identifiable teleost prey consumed, gobies were the dominant prey item followed by juvenile grunts. Palaemonid shrimp were the most common crustacean in the diet. For the transplant experiment we captured lionfish (n = 8) and released them at unoccupied solution holes. Prey communities were monitored by divers on SCUBA for six weeks and compared to solution holes where lionfish absent (n = 8). The presence of lionfish resulted in significantly fewer juvenile reef fishes (< 5 cm TL) after just 3 weeks. Our study of lionfish in Florida Bay adds to the mounting evidence on the ecological effects of this novel invasive predator.

KEY WORDS: Lionfish, invasion, diet

INTRODUCTION

The Pacific lionfish (*Pterois volitans/miles*) has been present in the western Atlantic since at least 1985 (Morris and Akins 2009), and since 2009 have been increasingly observed among the hardbottom habitats of Florida Bay (R.D.E., Unpublished data). Previous studies of lionfish in invaded habitats have shown lionfish to have significant and negative effects on the native reef fish assemblage on coral reefs (Albins and Hixon 2008) and hardbottom habitats offshore (Munoz 2011), yet it is presently unknown how lionfish may alter fish communities in bay habitats. Florida Bay is a large open embayment located at the southern end of the Florida peninsula bounded to the north by the Florida mainland, by the islands of the Florida Keys to the east and south, and by the Gulf of Mexico to the west (Figure 1). The bay serves as an important nursery for both fish and invertebrates, some of which inhabit the bay as juveniles and move out of the bay onto nearby coral reefs as adults (Fourqurean and Robblee 1999). These species may be especially vulnerable to predation by lionfish, a novel predator in this ecosystem.

Determining the diet of lionfish that settle in Florida Bay is a critical first step to understanding the full ecological effects of their invasion. In June and July of 2013 we collected lionfish from coral heads and solution holes – the two dominant hardbottom habitat features found in Florida Bay – to analyze their diet. Concurrently we investigated how the presence of lionfish at hardbottom sites might alter potential prey communities in Florida Bay. We accomplished this by evaluating the communities of fishes and motile macro-invertebrates found at hardbottom sites that were similar in all respects except for the presence or absence of lionfish. We also experimentally tested the effect of lionfish presence on potential prey communities by transplanting lionfish onto solution holes. Together, the diet analysis and transplant experiment better elucidate the detrimental effects that invasive lionfish may have on native populations of reef fish that use Florida Bay as nursery habitat.

METHODS

We surveyed hardbottom habitats in Florida Bay (Figure 1) starting in early June 2013. During our initial surveys, divers on snorkel looked for lionfish. When a lionfish was found it was captured by a diver via pole spear, immediately transferred into an individually labeled plastic bag and placed on ice for later dissection. Following the collection of a lionfish, a team of divers on SCUBA conducted a visual census of the faunal community associated with the hardbottom habitat site. The abundance and identity of all fishes and decapod crustaceans found within 2 m of the lionfish's capture location were recorded until all were counted, or for a minimum of five minutes. One diver counted fish while the other counted crustaceans in order to maximize the chances that all potential prey were included in the survey. Although all fishes and crustaceans were counted, special attention was given to those less than 5 cm total length (TL) as this was the predicted

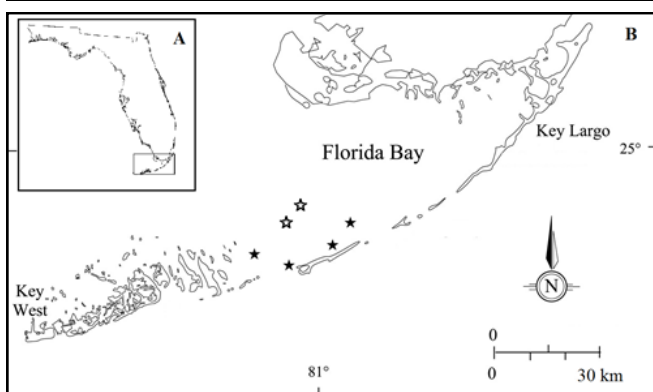


Figure 1. Approximate locations in Florida Bay of hardbottom habitat where lionfish (*Pterois volitans / miles*) were collected for this study. Transplant experiments were conducted at the two north-westernmost sites.

prey group based on the size of lionfish encountered in Florida Bay.

Dissections of collected lionfish were performed back on land where gut contents were weighed and all prey groups identified to the lowest possible taxon. Gut content data were used to calculate an Index of Relative Importance (IRI; Pinkas 1971) for each prey category based on the frequency and weight composition of prey groups. IRI values were converted to %IRI by standardizing IRI values to 100% in order to facilitate comparisons between prey groups (Cortés 1997). Selectivity by lionfish was estimated with Chesson's alpha index (1978) which relates the frequency of prey items in gut contents to their availability in the system, in this case measured as the abundance of each prey species counted during diver surveys.

Sixteen solution-hole sites in the north-western survey area (open stars, Figure 1) where we did not find lionfish were selected for the transplant experiment. These sites were first surveyed according to the protocols described above to determine the associated faunal community at the start of the experiment. Eight lionfish were collected from hardbottom habitats elsewhere in Florida Bay and moved to randomly selected sites, while the remaining eight sites were left absent of lionfish to serve as a control. The identity and abundance of the faunal communities associated with each site were surveyed on SCUBA each week for six weeks. At the end of the experiment all transplanted lionfish were collected and used in the diet analysis described above. Results compared the overall change in abundance for each prey group relative to baseline censuses conducted at the start of the study. Analyses were conducted using square-root transformed abundances to account for non-normality of count data.

RESULTS

Between 2 June and 27 July 2013, we collected a total of 32 lionfish at 26 of the 69 (37.7%) hardbottom sites we surveyed. At five sites we collected two lionfish simultane-

ously, and at one site we collected two lionfish during different surveys at the beginning and end of the study. We never observed more than two individual lionfish at a single site during the study. Lionfish ranged from 95-mm to 330-mm total length ($176 \text{ mm} \pm 8.7 \text{ mm}$ [mean \pm SEM]). Only a single individual had an empty stomach during gut content analysis. In the gut contents we were able to identify three families of teleost fishes and two families of decapod crustaceans. Teleost fishes dominated the diet by number (47.9%) and by weight (87.1%), followed by crustaceans (38.5% by number, 9.86% by weight); the remaining 13.5% of prey items were unidentifiable (Figure 2). Of the teleost fishes, gobies (Family: Gobiidae) had the largest %IRI value (11.7%) and largest Chesson's α -value (0.621) suggesting strong, positive selectivity for this group by lionfish. Juvenile grunts (4 total species; Genus: *Haemulon*) were the most abundant (14.5 ± 5.87 individuals per site surveyed) and most often encountered (present at 55.3% of sites surveyed) fish species we counted during diver surveys. However, grunts occurred less in lionfish diets (%IRI = 2.91, Chesson's α = 0.011; Table 1) than expected from their abundance in the habitat. The only other teleost fish found in any lionfish stomach was a single snapper (*Lutjanus spp.*). This was also the largest single prey item found (104 mm TL) and was found in the largest lionfish we collected (33.0 cm TL).

Small crustaceans were abundant in both the diet analysis and potential prey surveys. Of the decapod crustacean groups found in lionfish stomachs, the palaemonid shrimp (Family: Palaemonidae) were the most abundant crustacean by frequency of occurrence (19.8% by number) and the most important crustacean in the diet (% IRI = 3.21), but had a low Chesson's α -value (0.0612)

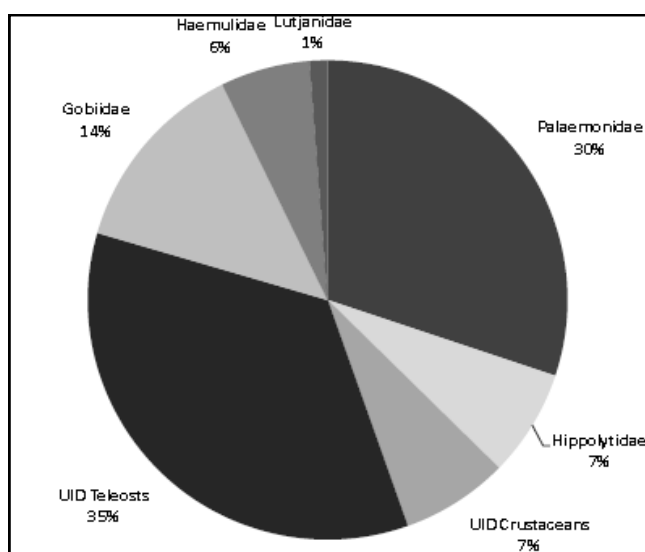


Figure 2. Percentage by number of major identifiable prey groups in lionfish stomach contents ($n = 32$) collected from outer Florida Bay, June – July 2013 ("UID" indicates prey was unidentifiable past listed taxa).

Table 1. Major prey groups identified in lionfish stomach contents collected from hardbottom sites in Florida Bay. Data for prey taxa are listed by lowest identifiable taxon and includes the total number of each prey group found in all stomachs, the frequency of occurrence, Index of Relative Importance (IRI), percent IRI, and Chesson's α values which is included as a measure of selectivity.

Prey Taxa	Number	Frequency of occurrence	IRI	%IRI	Chesson's α
Crustacea	37				
Unidentified crustacean	1	3.13	2.58	0.0846	
Unidentified shrimp	5	3.13	12.9	0.423	
Hippolytidae	6	12.5	61.9	2.03	
<i>Lysmata spp.</i>	6	9.38	49.4	1.62	0.212
Palaemonidae	19	6.25	98.0	3.21	0.061
Teleosts	46				
Unidentified teleost	29	62.5	2101	68.9	
Lutjanidae	1	3.13	70.6	2.32	0.094
Haemulon	4	9.38	88.7	2.91	0.011
<i>Haemulon plumierii</i>	1	3.13			
Gobiidae	10	18.8	322	10.6	0.621
<i>Coryphopterus glaucofraenum</i>	1	3.13	6.56	0.215	
UID	13	21.9	235	7.71	
Total	96			100	

suggesting negative selectivity for these shrimp. The only other crustacean group identified in the diet analysis was cleaner shrimp of the genus *Lysmata* (Family: Hippolytidae), which were found in 12.5% of lionfish stomachs. Unidentifiable crustacean parts were found in 6.25% of lionfish stomachs.

Potential prey surveys identified 23 species of fishes representing 10 families and 16 genera. Of the potential fish prey, 12 of the 23 species were considered rare (encountered at < 5% of sites surveyed). The majority of teleost fishes found during gut content analysis were unidentifiable (29 of 46 total prey items); those that were identifiable down to genus represented just three of the 16 genera identified during diver surveys. At least six species of decapod crustaceans representing five genera from three families were identified during potential prey surveys (the *Lysmata* species complex may represent up to six unique species unidentifiable via visual survey [Rhyne and Lin 2006]). Of these the cleaner shrimp (*Ancylomenes pederstoni*, *Periclimenes yucatanicus*, *Lysmata spp.*) were the only group also found in gut content analysis. Neither of the two species of clinging crab (*Mithrax spp.*), the only other crustacean group < 5 cm in size encountered during diver surveys, were found in lionfish stomachs.

The addition of lionfish to solution-hole habitats resulted in a significantly reduced number of all juvenile reef fishes after six weeks compared to solution-holes where lionfish were absent ($T = -2.15$, $p = 0.049$; see Figure 3). However, we found no difference in the number of cleaner shrimp between the lionfish transplant sites and control sites after six weeks ($T = -1.28$, $p = 0.217$).

DISCUSSION

Similar to previous investigations of lionfish diet in invaded Caribbean and Atlantic habitats, lionfish in Florida Bay consumed mostly small teleost fishes (Morris and Akins 2009, Munoz et al. 2011). However, we also found a relatively large number of crustaceans in the diet contents.

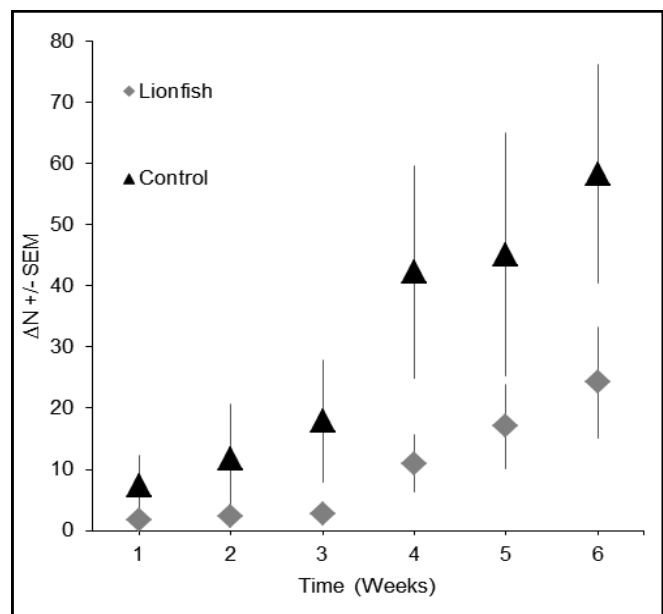


Figure 3. Change in abundance from baseline census of juvenile reef fish ≤ 5 cm (TL) in experimental solution hole communities with ($n = 8$) and without ($n = 8$) lionfish (ΔN ; mean \pm SEM).

Comparison to prey availability suggests that, with two exceptions, lionfish in Florida Bay act primarily as generalist predators, consuming prey according to their availability and without preference. The first exception to this pattern is the bridled goby, *Coryphopterus glaucofraenum*, which was found more often in the stomach contents than what would be expected from estimates of prey availability. Previous studies of lionfish diets have identified preference for bridled goby in lionfish gut contents (Côté et al. 2013), and in field experiments (Albins 2013), so our finding of similar preference in Florida Bay lionfish is not unexpected.

The other exception to the lionfish as generalist predator pattern is in the grunt species complex (*Haemulon spp.*), which is represented here by four species. Despite being the most commonly encountered and abundant prey group counted during diver surveys, grunts only appeared in 12.5% of lionfish stomachs analyzed (see Table 1). Grunts are primarily planktivorous as small juveniles (Cocheret de la Morinière et al. 2003) and in Florida Bay were most often found hovering in the water column up to 1-m above hardbottom habitat features. This behavior may reduce encounter rates between juvenile grunts and lionfish, which tend to hover directly over the bottom, and may explain the observed underrepresentation of juvenile grunts in lionfish stomachs. However, the results of our transplant experiment suggest that grunts may be consumed more often than the diet analysis suggests. The number of juvenile fishes at sites with a transplanted lionfish was less than half that at control sites after six weeks (24.3 ± 9.10 vs. 58.3 ± 12.9 ; see Figure 3). While the juvenile grunt complex represented just four of the 23 species of juvenile reef fish that we identified during diver surveys, they represented over 90% of juvenile reef fish abundance. Based on these experimental results, we should expect to find small grunts more often inside lionfish stomachs. Our diet analysis was only able to positively identify 37% of all teleost fishes found in lionfish stomachs, leaving it possible that some of these unidentifiable prey items were in fact juvenile grunts. Recent studies using DNA barcoding of prey items found in lionfish stomachs suggest that visual identification of fish prey may significantly underestimate the number of prey species consumed by lionfish (Valdez-Moreno et al. 2012, Côté et al. 2013). Such methods applied here may give a more comprehensive picture of lionfish diets in Florida Bay and alleviate the discrepancy we find between the diet analysis and experimental transplant results.

The addition of lionfish to hardbottom sites resulted in significantly fewer small juvenile reef fish compared to sites without lionfish. These findings support those from similar studies of lionfish predation on post-settlement reef fishes in the Bahamas (Albins and Hixon 2008, Albins 2013). Curiously, despite their presence in lionfish stomachs, the number of cleaner shrimp in solution-hole communities did not significantly decline following the addi-

tion of lionfish to previously unoccupied sites. We suspect that symbiotic associations of these cleaner shrimp species with the anemones *Condylactis gigantea* and *Bartholomea annulata*, both of which are commonly encountered in the study habitat, may explain this result, however our sample size was too small to test this here. Anemone hosts are known to offer protection to crustacean symbionts such as *P. yucatanicus* and *A. pedersoni* (Silbiger et al. 2008). These two shrimp species in turn provide cleaning services for at least 22 families of reef fish in the Caribbean by reducing ectoparasite load on client fish (Becker et al. 2004, Huebner et al. 2012). The potential loss of cleaning stations represents an important indirect effect of the lionfish invasion: if predation of cleaner shrimp by lionfish results in fewer cleaning stations, this may result in a decline in health of reef fish.

We observed no predation on any transplanted lionfish, despite the presence of native predators (e.g. groupers, nurse sharks) that have been cited as possible biotic control mechanisms of invasive lionfish (Mumby et al. 2012). All of our transplanted lionfish remained at the solution holes for the duration of the six-week experiment, save for a single individual that moved ~50 m to an adjacent solution hole (this individual was absent from the treatment site for less than 48 hours and was captured and returned to the initial transplant site upon discovery). The results of our study verify the negative ecological effects of invasive lionfish on native fish populations and suggest that these effects may extend lionfish invading Florida Bay.

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