Stable Isotope Ecology of the Invasive Lionfish (*Pterois volitans* and *P. miles*) in Bermuda

La Ecología de Isótopos Estables del Invasivo Pez León (*Pterois volitans* y *P. miles*) en las Bermudas

Stable Isotope Écologie de Poissons Lions Envahissant (*Pterois volitans* et *P. miles*) aux Bermudes

COREY EDDY[1] *, JOANNA PITT[2], JENNIFER LARKUM[3], MARK ALTABET[3], and DIEGO BERNAL[1]
[1] University of Massachusetts Dartmouth, Biology Department, 285 Old Westport Road,
Dartmouth, Massachusetts 02747 USA. *coreyeddy1@gmail.com
[2] Department of Environment and Natural Resources, Government of Bermuda,
P.O. Box CR52, Crawl CRBX Bermuda.
[3] University of Massachusetts, School of Marine Science and Technology,
706 South Rodney French Boulevard, New Bedford, Massachusetts 02744 USA.

ABSTRACT

Lionfish (*Pterois volitans* and *P. miles*) from the Indo-Pacific invaded the northwest Atlantic Ocean nearly 30 years ago and have since spread into the Gulf of Mexico and Caribbean Sea. As generalist predators with a broad diet, they pose a major threat to economically and ecologically important fish species and, therefore, the overall health of coral reef ecosystems. At this time, the invasion appears to be developing slowly in Bermuda, relative to other locations throughout the Atlantic, providing an opportunity to study their ecological impact at an early stage. Using stable isotope analysis, this study investigated the feeding ecology of lionfish and, to provide a more complete assessment, lionfish prey and competitors were included in the analysis to investigate community structure and trophic interactions. Results suggest that lionfish in Bermuda primarily derive resources from the planktonic food web with only a small contribution from that of macroalgae. Further, it appears that lionfish resource use overlaps substantially with other similarly-sized mesopredators found in the same habitats, in particular the coney grouper (*Cephalopholis fulva*). Finally, this study is the first to experimentally derive stable isotope discrimination factors for lionfish and the first to visualize Bermuda's demersal ecosystem in two-dimensional isotope space. This information will help track the ecological impact of lionfish over time, predict potential changes in community structure, and inform a developing control strategy.

KEYWORDS: Lionfish, stable isotopes, ecology, competition, impact

INTRODUCTION

Since lionfish were first recorded in the Atlantic Ocean off Florida's coast in 1985 (Schofield et al. 2010), evidence has been building that suggests they could have a substantial ecological impact through their invaded range (Albins and Hixon 2008). The generalist and opportunistic feeding habits of lionfish are well-documented (Morris and Akins 2009, Eddy et al. 2016) and it seems clear that their broad diet, comprising a wide variety of teleost and crustacean species, could lead to environmental impacts via predation. The effect that lionfish may have upon community structure through resource competition has been explored to a lesser degree. Coinciding with the arrival and dispersal of lionfish through the Atlantic, stable isotope analysis (SIA) has become a common tool amongst ecologists, providing valuable insights into diet and trophic relationships within populations, communities, or entire ecosystems (Boecklen et al. 2011). SIA has proven to be an effective complement to stomach contents analysis (SCA), which has traditionally been used to obtain diet information and inform trophic relationships. Utilizing $\delta^{15}N$ and $\delta^{13}C$ values for lionfish, consumers (including both potential lionfish competitors and known prey species), and primary producers, this study explored the trophic structure of the invasive lionfish population and the community of coral reef fishes along Bermuda's south shore.

METHODS

Lionfish were collected from multiple locations and multiple depths around the Bermuda platform in 2012 - 2015. Prior to dissection, total length, standard length, and mass were recorded. Muscle samples were dehydrated at 60°F for at least 48 hours, then homogenized using a mortar and pestle. Each sample (~0.85 mg) was processed by continuous-flow isotope-ratio mass spectrometry (CF-IRMS) using a GV IsoPrime, to determine $^{15}N/^{14}N$ and $^{13}C/^{12}C$ ratios. These ratios (R) were transformed to $\delta^{15}N$ and $\delta^{13}C$ values as follows:

$$\delta X = [(R_{sample}/R_{standard})-1] \times 1000‰$$

where X is the heavy isotope of nitrogen or carbon, R_{sample} is the isotopic ratio of the sample. $R_{standard}$ is the ratio of an accepted reference material; Pee Dee Belemnite (PDB) for carbon and atmospheric N_2 gas for nitrogen. The isotopic space of the lionfish food web was visualized by plotting $\delta^{15}N$ and $\delta^{13}C$ on the y-axis and x-axis, respectively, using mean isotope values. To compare the size and position of isotopic niche space among lionfish based upon size and depth of capture, standard ellipses (i.e., two-dimensional equivalents of isotope value standard deviations) were quantified using the R statistical package SIBER (Jackson et al. 2011). These ellipses were then plotted in δ-space, as representations of isotopic niche to investigate niche overlap.

RESULTS

The δ^{15}N values for lionfish ranged from 8.4‰ to 11.1‰, with an overall range of 2.7‰ (Mean ± SE: 9.7 ± 0.04). The δ^{13}C values ranged from -18.2‰ to -14.3‰, with an overall range of 3.9‰ (Mean ± SE: -17.0 ± 0.04). The isotopic niche size for lionfish was 1.62. Most of the higher δ^{13}C values (i.e., > -14‰) were confirmed as belonging to lionfish captured in shallow, inshore areas, where δ^{13}C values are expected to be higher.

The position and size of isotopic niches for lionfish captured at different depths varied in δ-space (Figure 1). In general, as depth increased, niches moved toward lower δ^{15}N and δ^{13}C values, but there was substantial overlap between them at all depths (Figure 1). The position of lionfish captured at 60m was significantly different from all other lionfish (Hotelling T^2-test; $p < 0.05$) and the values for lionfish captured at 45 m was significantly different from those at 10m (Hotelling T^2-test; $p < 0.05$). In general, both δ^{15}N and δ^{13}C decreased with increasing depth, but linear regressions between depth and either value of stable isotope were not significant ($r^2 = 0.39$ and 0.31, respectively, ANOVA: F(1,215)= 3.88, $p > 0.05$).

Larger lionfish generally had higher δ^{15}N and δ^{13}C values, but isotopic niche position did not change much across size classes (Figure 2). The position of 250-300mm lionfish was significantly different from the largest size classes (350-400mm and >400mm; Hotelling T^2-test; $p < 0.05$), marginally different from the middle size class (300-350mm; Hotelling T^2-test; $p = 0.06$), but not significantly different from the smallest (< 250 mm; Hotelling T^2-test; $p = 0.822$). However, although isotopic niche position was relatively stable, the niche size tended to increase with increasing fish size (Figure 2).

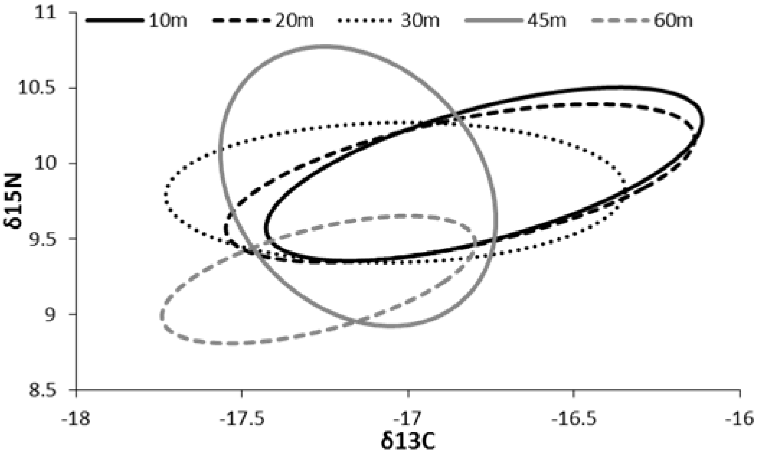

Figure 1. Isotopic niche (SEAc) for lionfish captured at all survey depths (10 m, 20 m, 30 m, 45 m, and 60 m), showing a change in niche with depth.

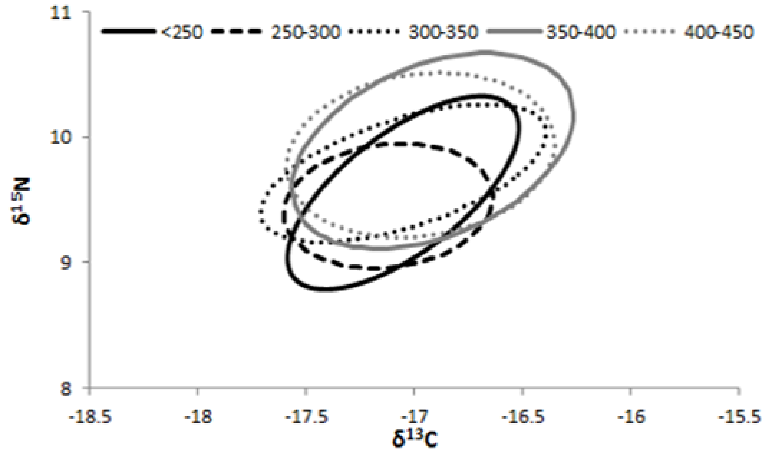

Figure 2. Isotopic niche for lionfish in different size classes. Size classes (< 250 mm, 250 - 300 mm, 300 - 350 mm, 350 - 400mm, > 400 mm).

DISCUSSION

While the isotopic composition of Bermuda's lionfish may not change in a statistically significant manner with size, increasing niche size likely reflects an increasingly broader diet (Eddy et al. 2016). However, we have found that the isotopic niche of lionfish appears to change with depth. Our results suggest that both $\delta^{15}N$ and $\delta^{13}C$ generally decrease with increasing depth, but again the linear relationship is not statistically significant. However, the isotope values of lionfish captured at 45 m were significantly different from those caught at 10 m and lionfish caught at 60m had isotope values that were significantly different from all shallower depths. Considering that many marine species, crustaceans and teleosts alike, have known depth ranges and preferences, this too seems logical. Although these 60 m areas are found within a short distance from shore in Bermuda (< 1.5 km) and even closer to areas as shallow as 10 m (< 0.5 km), the distance is great enough that shallow carbon sources are segregated from deep sources. Further, the distance is sufficient to prevent mobile species with small ranges, as lionfish are thought to be (Jud and Layman 2012), from migrating between zones, at least on the temporal scales by which isotope signals may be integrated by predators.

Recognizing the concern regarding invasive lionfish and their potential ecological impact, our results provide a foundation for resource managers to estimate the impact of lionfish upon prey species and competitors, model ecosystem-wide effects of the invasion, and design or alter fisheries management plans to account for that. Furthermore, our results provide baseline isotopic data for lionfish in Bermuda against which future changes in trophic ecology and trophodynamics can be measured.

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