AGE, GROWTH, AND DIET OF LIONFISH (*PTEROIS* SPP.) FROM LITTLE CAYMAN ISLAND, B.W.I.

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To my Dad, Mom, Joni, and Drew
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The introduction of lionfish (*Pterois* spp.) to the Western Atlantic Ocean and Caribbean Sea causes concern among natural resource managers. Impacts may include competition with native species for prey and habitat, direct predation on native species, and altered native fish community structure. Managing these impacts requires improved information on trophic biology and life history parameters used in models predicting removal rates that will reduce lionfish densities and impacts successfully. This study validated annuli and daily rings in sagittal otoliths, documented ages, estimated Brody growth coefficients (K) and asymptotic maximum lengths ($L_\infty$), and described diets for lionfish from Little Cayman Island. Annual increment formation was confirmed with marginal increment analysis, and daily ring deposition in juveniles was confirmed using an oxytetracycline hydrochloride marker. Sagittal otoliths (N = 499) from lionfish collected weekly between January and December 2011 indicated that males were 0-5 years old and females were 0-3 years old. von Bertalanffy equations estimated K as 0.42 for the population, 0.38 for males, and 0.57 for females. Estimates of $L_\infty$ were 349 mm for the population, 382 mm for males and 286 mm for females.
Lionfish consumed over 50 species, and frequencies of occurrence and dry weights indicated that shrimp were an important component in diets of juveniles and adults became more piscivorous. Overall, this study showed that lionfish exert predation pressure on a broad range of species, and their relatively rapid growth will pose challenges for removal programs.
CHAPTER 1
GENERAL INTRODUCTION

Impacts caused by invasive species can be widespread and in certain cases devastating. Impacts can be ecological, economic, or social. Ecological impacts include: competition with native species and predation on native species (Gordon 1998). Examples of economic impacts include damage to structures, reduced abundances of economically important native species, and decreased tourism (Bax et al. 2003). Social impacts also are possible, e.g., loss of jobs and detrimental effects on human health (Bax et al. 2003). In many cases, introduced species compound the effects of other anthropogenic alterations to the natural environment. Habitats become less suitable for native species when altered, and added stress arises from new competitors. For example, the invasion of the Southeastern United States by fire ants and subsequent negative impacts on native taxa may have been facilitated by previous anthropogenic alteration of habitats (Todd et al. 2008).

Approximately 50,000 introduced species generate $137 billion dollars per year in economic and ecological damages in the United States alone (Pimentel et al. 2000). At least 241 species have become established in marine systems, with some having significant impacts (Semmens et al. 2004). The North Pacific seastar (Asterias amurensis) now dominates biomass in Port Phillip Bay, Australia. An invasive ctenophore in the Black Sea and an Asian clam in San Francisco have been implicated in the collapse of fisheries (Bax et al. 2003). Currently, the introduction and establishment of lionfish (Pterois spp.) in the Western Atlantic Ocean, Caribbean Sea and Gulf of Mexico generates prominent concerns for natural resource managers in these regions.
Two species of lionfish (*Pterois volitans* and *Pterois miles*) were introduced to Florida waters in the 1980s (Morris & Whitfield 2009). They rapidly spread up the east coast of the United States, and by 2000, lionfish were found as far north as Cape Hatteras, North Carolina (Schofield 2010). Lionfish are now found throughout the Caribbean Sea and Gulf of Mexico (Aguilar-Perera & Tuz-Sulub 2010). The major factor limiting their current distribution is believed to be lower temperatures at the higher latitudes (Kimball et al. 2004). Thus, climate change and future increase in oceanic water temperatures may result in further range expansion (Schofield 2010).

Lionfish inhabit a wide variety of habitats including coral reefs, seagrasses, and mangroves (Barbour et al. 2011, Darling et al. 2011). In addition to the use of multiple habitats, their broad environmental tolerance, generalist diet, rapid growth, early sexual maturation, frequent spawning, and high fecundity make them ideal invaders as evidenced by their rapid and widespread establishment and tendency to occur in high densities (Morris & Whitfield 2009). In the Bahamas, for example, densities of lionfish have been reported to approach 400 fish per hectare (Green & Côte 2009). Lionfish reached densities of close to 600 fish per hectare four years after they were first reported off Little Cayman Island in 2008 (Frazer et al. 2012). Such densities have the potential to significantly reduce the biomass of native prey species. Albins and Hixon (2008), for example, found that lionfish on experimental patch reefs in the Bahamas reduced recruitment of native reef fish by ~79%. Management of impacts from lionfish will benefit from diet studies that determine which species are subject to the highest risk of predation and if those risks shift during ontogeny.
Current management consists of localized efforts to control lionfish numbers at discrete locations (Albins & Hixon 2011). For example, Bermuda instituted a culling program in 2008 that provided training to those interested in aiding with lionfish removal (Morris et al. 2009). However, the effectiveness of removal efforts is currently in dispute due, in part, to the lack of accurate estimates for parameters characterizing growth in different regions of the invasion. Estimates of growth have been produced thus far only for North Carolina, the northernmost region in which lionfish are able to overwinter in the invaded range. As yet, there are no growth estimates for lionfish in the Caribbean Sea (Barbour et al. 2011).

The objectives for this study were to fill gaps in information on age structure, growth and diets of lionfish in the Caribbean by (1) validating the periodicity of annual and daily otolith increments, (2) providing estimates of growth for lionfish from Little Cayman, (3) determining whether growth varied between males and females, and (4) characterizing food habits and determining the presence or absence of ontogenetic shifts in diet.
CHAPTER 2
AGE STRUCTURE AND GROWTH OF LIONFISH OFF LITTLE CAYMAN ISLAND

Introduction

Models can be useful tools to assess the potential effectiveness of lionfish removal efforts. A stage-based population model (using larvae, juvenile, and adult stages) predicted that approximately 27% of the lionfish population would need to be removed on a monthly basis in order to curb increasing abundances (Morris et al. 2010). However, this estimate was surrounded by a broad range of uncertainty due to a lack of precise estimates for key life history parameters, i.e., growth and natural mortality (Morris et al. 2010). Barbour et al. (2011) produced an age-structured model for lionfish off the coast of North Carolina and estimated that 35-65% of the population would need to be removed annually in order to induce recruitment overfishing. As part of their evaluation, Barbour et al. (2011) suggested that growth parameters for lionfish in warmer climates may differ from those estimated for lionfish from North Carolina, and that age and growth information should be collected for lionfish at lower latitudes.

Key demographic information for lionfish from different regions of the invaded range (temperate, subtropical, and tropical) is necessary to inform management decisions about removal strategies. In addition to reducing the level of uncertainty pertaining to growth, age-based studies provide a first step toward estimating natural mortality, due to its relationship with growth (Pauly 1980). Improved estimates of growth also lead to more accurate measures of yield per recruit (Lai & Gunderson 1987) and better estimates of whether the number of lionfish being removed is adequate to induce recruitment overfishing (Barbour et al. 2011).
Ages of fish often are estimated from annuli or rings that form in their sagittal otoliths. Growth can be modeled by fitting a von Bertalanffy growth equation to size at age data. In temperate and sub-tropical areas, assigning ages to sagittal otoliths can be relatively straightforward because annuli typically are readily apparent. In tropical regions assigning ages can be more difficult as opaque and hyaline bands in otoliths are less evident as a consequence of reduced seasonal variation in temperature and/or photoperiod (Green et al. 2009). For example, a change in water temperature of 3°C was enough to promote the formation of distinguishable rings in pomacentrids from the Western Atlantic but, otoliths from the same taxa collected near the equator were more difficult to read (Caldow and Wellington 2003).

In spite of the potential challenges of using otoliths to age fish in the tropics, this study relies on ages read from sagittal otoliths, total lengths and von Bertalanffy growth equations to estimate parameters characterizing growth that will improve models predicting the percentage of Caribbean lionfish populations that would need to be removed in order to decrease local abundances. Thus, the objectives of this study were to (1) validate the annual periodicity of otolith increment formation and the rate of daily ring deposition, (2) provide estimates of growth for lionfish from Little Cayman Island, and (3) determine if growth varied significantly between males and females.

**Study Site**

Little Cayman Island is located at 19° 41’ 24.47” N and 80° 02’ 10.67” W (Figure 2-1). The island is home to approximately 150 permanent residents. Human impacts on the surrounding waters are minimal. In addition to low levels of anthropogenic stress, 20% of the reefs surrounding Little Cayman are protected in no-take marine reserves (Coelho & Manfrino 2007).
Methods

Fish Collection and Processing

The majority (93%) of lionfish collected for this study were removed from reef walls in Bloody Bay Marine Park during community culling events. Divers donated the fish for research purposes. Culls occurred on a weekly basis from January to December 2011 at approximately 16:30, until day length increased, at which point collection time shifted to 17:00. Lionfish feeding activity increases during crepuscular periods, which makes dusk a suitable period for collecting (Green et al. 2011). Collectors used Hawaiian-sling-style spears and SCUBA, with fish placed into a sealed bucket for transport back to the boat. Collections generally occurred between 15 and 30 m. The efficacy of spears decreased when fish were less than ~75 mm TL; therefore, smaller size classes typically were collected separately using nets. Upon return to the dock, fish were placed on ice and transported to the Little Cayman Research Centre, where processing occurred the next day.

Processing yielded sizes and sexes of lionfish, along with otoliths for use in estimating ages. Total length to the nearest 1 mm and weight to the nearest 0.1 g were recorded for each fish. Sexes were determined macroscopically, and sagittal otoliths were removed. Otoliths were rinsed in fresh water, dried, and stored in numbered plastic vials that uniquely identified each fish.

Otolith Processing and Counts of Annuli

Whole sagittae were submersed in freshwater on a black background, and read under reflected light using a dissecting microscope at 40-60x magnification. Both the right and left sagittae were viewed in a search for the most distinct and readable annuli. An age in years was assigned according to the number of opaque zones present.
ascertain within-reader agreement, one reader analyzed all otoliths twice, with the two readings separated by several months. A second experienced reader examined the otoliths for which the two independent readings agreed. From these two sets of reads, a percentage of agreement between readers was estimated. The opinion of a third experienced reader settled disagreements between the other two readers.

To test for possible improvement in estimates of age, 250 otoliths were sectioned to compare with readings from whole otoliths. Sections proved to be more difficult to read than whole otoliths; therefore, these data were not used in subsequent analyses.

**Marginal Increment Analysis**

Marginal-increment analysis was employed to validate production of one annulus per year for lionfish off Little Cayman Island, and to also determine the timing of increment formation. These analyses were based on an index of completion (Equation 2-1):

\[
C = \frac{W_n}{W_{n-1}}
\]  

(2-1)

where \(C\) is the index of completion, \(W_n\) represents the width of the marginal increment, and \(W_{n-1}\) represents the width of the preceding complete annulus (Murie and Parkyn 2005). Measurements of \(W_n\) and \(W_{n-1}\) were made from photographs of whole otoliths using ImageJ software (Rasband 2012). All age classes were combined for this analysis, and mean indices of completion were plotted against months of collection; the presence of a single minimum, was interpreted as evidence of annuli (Murie and Parkyn 2005).

**Counts and Validation of Daily Rings**

To improve modeling of growth by assigning ages based on partial years and to determine an approximate time of spawning, otoliths of age-0 fish were prepared for
analysis of daily rings. Histamount was used to fix the otoliths to glass slides. The otoliths were then wet-ground and polished until the nucleus plane was reached and daily rings became visible. I did not attempt to count daily rings for fish older than ~110 days due to decreasing accuracy (Sweatman & Kohler 1991).

Otoliths were viewed through a compound microscope at 100-200x magnification. Two counts of daily increments separated by four weeks were performed by a single reader. The date of spawning was calculated by subtracting the daily ring count from the date when the fish was collected, and an age as a fraction of a year, was assigned to the fish by dividing the number of daily rings by 365. Average daily growth rates were calculated by dividing the standard length by the daily ring count in order to estimate mm of growth d⁻¹.

Five, age-0 lionfish were used to validate daily increment formation by immersing them in 500 mg l⁻¹ oxytetracycline hydrochloride (OTC) for 24 h. Ten days after exposure, otoliths were prepared as described for reading of daily rings. The fluorescent band produced by OTC exposure and the number of daily rings produced subsequently were identified at 400x magnification using a compound microscope equipped with a blue filter.

**Modeling Fish Growth**

Growth was modeled with the von Bertalanffy growth equation (Equation 2-2):

\[ L_t = L_\infty \left[1 - e^{-K(t-t_0)}\right] \]  

(2-2)

where \( L_t \) = length at age (t), \( L_\infty \) = asymptotic maximum length, \( K \) = the Brody growth coefficient (which describes the rate of growth toward \( L_\infty \) (Newman et al. 1996)), and \( t_0 \) = the theoretical time at which the fish would be 0 mm in length (von Bertalanffy 1957). A
maximum likelihood framework was used to estimate von Bertalanffy parameters, $L_\infty$, $K$, and $t_0$ for the population.

Growth parameters also were calculated for males and females separately, with one half of the juvenile, unsexed lionfish randomly allocated to each sex. In both cases, $t_0$ was assumed to be the same as that for the complete sample population. Akaike information criteria (AIC) were used to determine the most appropriate model for the data. I compared four different hypotheses: (1) separate parameter estimates for males and females should be used to model the lionfish population in Little Cayman, allowing all parameters ($L_\infty$, $K$, and sigma, the variance around mean size at age) to vary; (2) one set of parameter estimates for the population should be used in models, assigning the same values to all parameters for males and females, (3) the same estimate of $K$ should be used in both models, allowing the other parameters to vary independently, and (4) the same estimate of $L_\infty$ should be used in both models, allowing the other parameters to vary independently. Since $t_0$ is constrained in order to produce the separate estimates for males and females, it was not included in the AIC analysis. Models with AIC values that differed by < 2 from the model with independent estimates for all three parameters were considered potentially appropriate replacements, differences of 4-7 indicated less support for the alternative model, and differences >10 indicated no support for the alternative model (Burnham & Anderson 2004).

**Results**

**Lionfish Size Structure and Length-Weight Relationship**

From January to December 2011, 1979 lionfish were collected from the waters surrounding Little Cayman Island. Fish ranged from 27 to 391 mm in total length (Figure
(2-2) and total length accounted for approximately 97% of the variation in total weight (Figure 2-3).

**Marginal Increment Analysis**

Marginal increment analysis confirmed annual increment formation. Increment width increased from November until April and then gradually decreased throughout the rest of the year (Figure 2-4). On average, annulus formation was least complete in October, at which point formation was considered to begin. The gradual change between maximum and minimum indices of completion likely reflects the effects of relatively constant photoperiod and water temperatures in the tropics, as contrasted with more disjunct data from other fishes in temperate areas (e.g., Murie and Parkyn 2005).

**Analysis of Daily Rings**

Otoliths treated with OTC exhibited a fluorescent mark under a blue light. Beyond the OTC band, an additional 10-11 d of growth was noted, confirming the formation of daily increments (Figure 2-5).

Daily rings were counted for 29 fish ranging from 27 to 199 mm total length, which translated to ages of 23 to 110 days. Growth rates calculated using standard lengths ranged from 0.73 to 1.70 mm per day with an average of 1.03 mm per day. Back-calculated dates for hatching provided evidence that lionfish recruit to Little Cayman Island year round (Figure 2-6).

**Estimates of Growth Rates**

Of the 1979 fish collected, 1188 pairs of otoliths were read, and of those, 499 were successfully aged by counting the number of opaque rings. Otolith clarity varied significantly from fish to fish and only 42% of otoliths produced discernible rings (Figure 2-7a and b). Of the fish yielding readable otoliths, 238 could be sexed, with 110 being
males and 128 being females. This approximate 1:1 ratio was consistent with that observed for all sexed lionfish collected off Little Cayman Island in 2011 (i.e., 533 females and 563 males).

To discern the condition of lionfish that produced interpretable rings and those that did not, condition factors \( (K_n) \) were calculated as follows (Equation 2-3):

\[
K_n = \frac{W_o}{aL^b}
\]

where \( W_o \) is the observed weight, \( L \) is the total length, and \( a \) and \( b \) are constants based on the length-weight relationship \( y = aL^b \). The average condition factors for the aged fish and those that were not able to be aged were 1.15 and 1.17 respectively (Figure 2-8).

Growth curves were fit to data for all fish and data for males and females (Figure 2-9a, b and c). Comparison of AIC values supported the use of a model where all parameters varied independently (Table 2-1). Females grew 1.5\( \times \) faster than males and reached a maximum length that was only 0.75\( \times \) that of males (Table 2-2). In all cases, rapid initial growth decreased when fish reached two years old (Figure 2-9a, b and c). For both males and females, there was a large overlap in size for fish that were two years old and older, which suggested growth had begun to asymptote (Figure 2-9b and c). In combination with the fact that two year old fish represented the largest age class in this population, this result also indicated the presence of a strong year class in 2009 (Figure 2-10).

**Discussion**

This study provides the first insights into the age structure of the invasive lionfish population established off Little Cayman Island, the first successful validation of daily ring deposition for lionfish, and the first estimates of key metrics needed to model
growth of lionfish in the Caribbean. Such information can be used to improve management of this invasion and reduce impacts on Caribbean coral reefs.

No effort was made to differentiate between *P. miles* and *P. volitans* in this study. The morphologies of the two species are so similar that genetic analyses are needed to differentiate them. In addition, available data indicate that relatively low numbers of *P. miles* are found throughout the invaded range (Hamner et al. 2007), and that *P. miles* and *P. volitans* are physiologically similar (Hare & Whitfield 2003). Annuli in sagittal otoliths indicated that the population of lionfish off Little Cayman Island comprised 0-5 year old males and 0-3 year old females. In general, these results match the reported timeline of the invasion; because lionfish were first reported from Little Cayman in 2008 (Schofield 2009). The single 5 year old male provided evidence that lionfish arrived before 2008, but remained undetected. Introduced species often remain undetected until their densities increase. For example, pythons in the Everglades probably escaped detection initially as a consequence of low densities, but after densities increased and the population became established, their presence became known (Wilson et al. 2011).

Although annuli in otoliths from tropical fish can be difficult to interpret due, in large part, to the narrow range of temperature experienced and less pronounced seasonality (Caldow & Wellington 2003, Green et al. 2009, Marriott & Mapstone 2006), whole otoliths provided useful estimates of age for lionfish from Little Cayman Island, and marginal increment analysis validated an annual deposition rate for rings. I found that the visibility of annual rings in otoliths varied from fish to fish, but approximately 50% of the otoliths examined supported age determination with sufficiently distinct opaque and
hyaline bands. As found by Vilizzi and Walker (1999) for common carp, sectioning did not increase interpretability.

The inability to age approximately half of the lionfish otoliths collected in this study may be a consequence of differential growth. Hoyer et al. (1985) discuss the issues associated with using whole reads to age fish that grow slower than average. Hoyer and colleagues suggest that slower growing fish are more difficult to read due to crowding of annuli. It may be the case that the lionfish otoliths producing discernible rings came from fish experiencing faster growth. Should this be true, the resulting estimates of growth may be biased towards the faster growing individuals of the population. Condition factors calculated for the two groups of fish in this study, i.e., fish that could be aged and those that could not be aged, provide no evidence for differential growth.

Daily ageing validated by incorporation of oxytetracycline hydrochloride improved estimates of growth. Results also provided evidence of year-round spawning consistent with the findings reported by Morris & Whitfield (2009). Combining ages in days with sizes yielded an average daily growth rate of 1.03 mm d\(^{-1}\). This estimate exceeds the average daily growth rate of 0.46 mm d\(^{-1}\) reported by Jud and Layman (2012) for lionfish from the lower Loxahatchee River estuary, Florida. Standard length was used in this portion of the analysis in order to make comparisons between this study and Jud and Layman (2012). The size ranges of fish used to generate the two independent estimates overlapped (21-156 mm standard length here and 45-185 mm for Jud & Layman 2012), although Jud and Layman (2012) used a mark-recapture technique to measure growth. It is likely, however, that other factors, e.g., temperature, salinity and/or dissolved oxygen concentration, played a more important role in generating the growth differences.
between juvenile lionfish from the two study locations. Additional factors, such as diet also may have played a role (Baltz et al. 1998, Moyle & Light 1996).

Models based on combinations of ages and sizes yielded estimates of asymptotic maximum lengths ($L_{\infty}$) and Brody growth coefficients (K) for the population and separately for males and females. The $L_{\infty}$ values for all lionfish, 349 mm, males, 382 mm, and females, 286 mm, were smaller than the 455 mm calculated by Potts et al. (2010) and 425 mm calculated by Barbour et al. (2011) for lionfish from North Carolina. The K values for the population, 0.42, males, 0.38, and females, 0.57, were nearly as high or higher than the values of 0.32 and 0.47 calculated for lionfish from North Carolina (Barbour et al. 2011, Potts et al. 2010). Thus, lionfish from Little Cayman Island appear to grow as fast or faster than those from North Carolina, but they may not reach the same maximum size. Similarly, female lionfish from Little Cayman Island grew faster than males, but they did not reach the same maximum size. Faster growth for a tropical population is not unexpected given the warmer water temperatures, with Beamesderfer and North (1995), for example, reporting faster growth rates for largemouth bass in southern waters as compared to northern populations. Both populations of lionfish appear to grow faster than other native, medium-bodied predators in the Caribbean. For example, growth coefficients estimated for yellowtail snapper and graysby grouper are approximately 0.10 and 0.35, respectively (Froese & Pauly 2012). Eventually, the relatively rapid growth exhibited by lionfish may be moderated by other biotic and abiotic factors, such as food availability and density dependence (Rogers & Ruggerone 1993, Rose 2000).
Estimates of L_\infty and K may have been affected by the fact that the relatively recently established population of lionfish off Little Cayman Island lacks older and larger fish, which results in a truncated growth curve. Potts et al. (2010) found that the maximum size of lionfish taken from a 10 year old population of lionfish off North Carolina was 464 mm TL and the maximum age was 8 years old, with these fish representing larger and older fish than the 391 mm TL and 5 year old fish from Little Cayman Island. Nevertheless, growth appears to begin to asymptote at age 5 in the North Carolina population (Barbour et al. 2011), which is the oldest age class found off Little Cayman Island. For this reason, I believe that the most critical portion of the curve is represented in the data from Little Cayman Island. To explore issues associated with modeling an immature population, I truncated the size at age data from the North Carolina study and examined the resulting effects on L_\infty and K. Differences in the estimates produced by models that incorporated a consistent t_0 (using the value of -1.01 calculated for the Little Cayman Island population) were minor, with the 0-8 age range yielding an L_\infty of 483 mm TL and a K of 0.30 and the 0-5 age range yielding an L_\infty of 495 mm TL and a K of 0.29. From this information, I can infer that key parameters describing growth should not change considerably as the population matures.

Based on the reduced frequency of fish in the 60 to 120 mm TL size class, it is not unreasonable to assume that strong size dependent vulnerability exists when using spears to capture lionfish. An underrepresentation of smaller size classes can result in negative bias for estimates of t_0 and K. Gwinn et al. (2010) evaluated methods to reduce bias in growth parameters due to size selective sampling. They indicated that understanding the sampling vulnerability schedule of the species for a particular gear
type is necessary in order to determine the best method to use to correct gear bias. However, a vulnerability schedule for lionfish and spearing was not evaluated in this study. Thus, corrective measures to resolve issues associated with gear bias remain unknown.

Attempting to solve for von Bertalanffy parameters separately for males and females produced unreasonable estimates when $t_0$ was allowed to vary based on the data for each sex. Therefore, $t_0$ was constrained to the value calculated for the whole population when estimating $K$ and $L_\infty$ for the separate sexes. Vilizzi and Walker (1999) also employed this method to produce sex specific growth and maximum length parameters for similar reasons. However, fixing $t_0$ inevitably affects estimates of $L_\infty$ and $K$.

This study of Caribbean lionfish provided important information not included in Potts et al. (2010) and Barbour et al. (2011) studies. The lionfish population off Little Cayman Island exhibited sexually dimorphic growth, with males attaining larger sizes than females. Females, however, achieved their asymptotic length at a faster rate than males. Sexually dimorphic growth is a relatively common phenomenon in fish populations and has been reported for a number of taxa including snappers and white grunt (Murie & Parkyn 2005, Newman et al. 1996). In addition, Mesa et al. (2005) documented sexually dimorphic growth for *Scorpaena maderensis*, a Mediterranean scorpaenid, with males attaining a larger size and having slightly slower growth than females. The growth coefficients and values of $L_\infty$ for males and females of this species equaled 0.23 and 0.44 and 96 mm and 148 mm, respectively. With growth coefficients of 0.38 for males and 0.57 for females, lionfish off Little Cayman Island grow at a faster
rate than the Mediterranean scorpaenid. Data from larger numbers of 0-1 year old fish from Little Cayman Island may increase the accuracy of growth parameters estimated for males and females.

The relatively fast and sexually dimorphic growth of lionfish combined with evidence of year-round spawning generate several implications for managers attempting to reduce the impacts of this invasive species. For example, frequent spawning will likely complicate efforts to control lionfish at broad spatial scales due to a relatively constant supply of recruits. In fact, the most sustainable fisheries are based on fish populations that exhibit fast growth, high natural mortality, and high fecundity (Schindler et al. 2002), with restrictions placed on harvests of fish exhibiting slower growth in order to keep those fisheries from collapsing (Bennet et al. 1991). Unfortunately, for those working to reduce densities of lionfish, their relatively fast growth translates into more effort being necessary to achieve that goal. Management implications with regards to sexually dimorphic growth typically concern spawning stock biomass (Marshall et al. 2005), which depends on the number of females present in the population and their fecundity. For some fish populations that exhibit sexually dimorphic growth, fishing pressure may skew sex ratios by removing the larger individuals. If the larger individuals are females, the spawning stock biomass could decrease drastically leading to a collapse of the fishery. For lionfish, the pattern of sexually dimorphic growth could lead to removal of more males because spearfishers have been shown to remove larger lionfish first (Frazer et al. 2012). If spearing does not remove a sufficient number of females, then removal efforts may be compromised. In this study, the sex ratio
produced by spearfishers was approximately 1:1, but managers should remain vigilant to ensure the ratio does not change.
Table 2-1. Akaike Information Criteria (AIC) for model comparisons: (h) = a separate parameter for males and females; (●) = parameter shared by both sexes; ΔAIC = change in Akaike Information Criterion

<table>
<thead>
<tr>
<th>Models</th>
<th>Parameters</th>
<th>Total LL</th>
<th>AIC</th>
<th>ΔAIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_\infty(h)K(h)\sigma(h) )</td>
<td>6</td>
<td>-1560.86035</td>
<td>3133.7207</td>
<td>0</td>
</tr>
<tr>
<td>( L_\infty(h)K(\bullet)\sigma(h) )</td>
<td>5</td>
<td>-1566.60077</td>
<td>3143.2015</td>
<td>9.4808468</td>
</tr>
<tr>
<td>( L_\infty(\bullet)K(h)\sigma(h) )</td>
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<td>-1572.98708</td>
<td>3155.9742</td>
<td>22.25346</td>
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<tr>
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<td>3</td>
<td>-1586.93981</td>
<td>3179.8796</td>
<td>46.15892</td>
</tr>
</tbody>
</table>

Table 2-2. von Bertalanffy growth parameters estimated for all lionfish in the sampled population, males, and females.

<table>
<thead>
<tr>
<th>Group</th>
<th>( L_\infty ) (mm)</th>
<th>K</th>
<th>( t_0 )</th>
<th>N</th>
<th>Range of ages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
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<td>0.42</td>
<td>-1.01</td>
<td>499</td>
<td>0-5</td>
</tr>
<tr>
<td>Males</td>
<td>382</td>
<td>0.38</td>
<td>-1.01</td>
<td>110</td>
<td>0-5</td>
</tr>
<tr>
<td>Females</td>
<td>286</td>
<td>0.57</td>
<td>-1.01</td>
<td>128</td>
<td>0-3</td>
</tr>
</tbody>
</table>

Figure 2-1. Little Cayman Island and the dive sites (●) where lionfish were collected. Photograph courtesy of the Cayman Islands Department of Tourism (2012).
Figure 2-2. Length frequency distribution of lionfish from Little Cayman Island in 2011.

Figure 2-3. Length-weight data for lionfish collected in 2011 from Little Cayman Island. 
\( y = \text{total weight (g)} ; \ x = \text{total length (mm)} \).
Figure 2-4. Mean index of completion (± 1 SE) for 1-5 year old lionfish from Little Cayman Island.

Figure 2-5. Otolith showing a light colored band resulting from treatment with oxytetracycline hydrochloride (OTC) 10-11 days before the otolith was processed and photographed. The hatch marks indicate the number of rings produced after treatment.
Figure 2-6. Number of fish hatched per month. Hatch dates were calculated using daily ring counts from age-0 otoliths.

Figure 2-7. Sagittal otoliths of similarly sized lionfish (245 mm TL and 254 mm TL respectively). (a) shows two clearly visible opaque rings and (b) displays no visible rings.
Figure 2-8. Condition factors for aged fish and unaged fish.
Figure 2-9. von Bertalanffy growth curves fit to raw size at age data. (a) von Bertalanffy curve for all lionfish, (b) for females and (c) for males.
Figure 2-10. Age frequency distribution for lionfish from Little Cayman Island in 2011.
CHAPTER 3
DIET OF LIONFISH OFF LITTLE CAYMAN ISLAND

Introduction

Introduced aquatic species have the potential to alter the way in which ecosystems function (Pimentel et al. 2000). From an ecological viewpoint, the most destructive of the problematic invaders disrupt community structure and change food webs (Molnar et al. 2008). Certain high profile cases, such as the addition of Nile perch (Lates niloticus) to Lake Victoria, exemplify such disruptions. Nile perch were implicated in the extinction of ~65% of the endemic haplochromine cichlids in Lake Victoria. This reduction in planktivores may have promoted algal blooms occurring in that system (Goldschmidt et al. 1993).

Other examples include the carp (Cyprinus carpio) in Australia and the peacock hind grouper (Cephalopholis argus) in Hawaii; both became the dominant fish biomass in some areas (Dierking et al. 2009, Koehn 2004). Carp remove aquatic vegetation and in the process, increase turbidity. This leads to a reduction in light availability with consequences for photosynthesis and native fish that feed visually (Koehn 2004). The peacock hind feeds on a broad range of prey species and not just those that are locally abundant (Dierking et al. 2009). In general, understanding the threats associated with introduced species is paramount to sustaining our native biota (Cucherousset & Olden 2011). The introduction of Indo-Pacific lionfish to the Western Atlantic, Caribbean and Gulf of Mexico provides such a challenge.

Lionfish are considered to be voracious, generalist predators with the capacity to reduce recruitment of other reef fish on experimental patch reefs by 79% (Albins & Hixon 2008). Novel predation strategies, such as blowing directed jets of water at their
prey, make them extremely efficient predators on naïve prey (Albins & Lyons 2012). For example, Côté and Maljković (2010) determined an average predation rate of 1.44 kills h\(^{-1}\) for lionfish. Predation at this rate may further reduce densities of Caribbean reef fish, which are already declining due to overexploitation and habitat degradation (Paddack et al. 2009). In fact, lionfish densities have reached potentially unsustainable levels in certain areas of the invaded range. Green and Côté (2009) state that lionfish populations on the majority of 12 Bahamian coral reefs could not be sustained given the density of available prey. In addition, consumption of economically important species such as grouper and yellowtail snapper has been observed; however, these species have not comprised a significant portion of lionfish diets (Morris & Akins 2009). Species that do comprise a significant portion of lionfish diets, such as small-bodied and juvenile reef fish, render ecological services necessary for the health of coral reef ecosystems.

Lionfish may reduce populations of native herbivores needed to control algal overgrowth of coral (Morris & Whitfield 2009, Morris 2009). Evidence of such a phase shift was noted on mesophotic reefs in the Bahamas, with the abundance of herbivores decreasing after the introduction of lionfish and a subsequent shift to increased algal cover (Lesser & Slattery 2011). As these changes could not be explained by other factors, e.g., disease, overfishing, or damage from hurricanes, lionfish were implicated as the primary cause (Lesser & Slattery 2011).

Overall, impacts from the lionfish invasion will vary depending on local fish communities, the density of lionfish, and the system being invaded (Morris et al. 2008). Diets of lionfish have been characterized in the Bahamas (Green et al. 2011, Morris & Akins 2009), but such work has yet to be done in the Caribbean. Information regarding
predation on native species should be collected in various regions of the invaded range to better inform bioenergetic and trophic models that predict consumption rates for lionfish (Cerino 2010). With the information currently available for environmental conditions and observed growth, Cerino (2010) predicted daily consumption rates of 2.186 kg prey d\(^{-1}\) for an area with densities of 393 lionfish ha\(^{-1}\). In an effort to improve understanding of impacts from the invasion off Little Cayman Island, the objectives for this study were to (1) examine stomach contents of lionfish to identify the diversity of prey, (2) determine the apparent importance of prey items, (3) determine whether differences existed in average weight between male and female diet items, and (4) determine whether lionfish display an ontogenetic shift in prey consumption.

**Methods**

**Collection and Processing**

The majority (93%) of lionfish collected for this study were removed from reef wall habitat in Bloody Bay Marine Park during community culling events. Culls occurred on a weekly basis from January to December 2011 at approximately 16:30, until day length increased, at which point culls began at 17:00. Lionfish feeding activity increases at dawn and dusk, making the early evening hours suitable for finding stomachs containing identifiable prey (Green et al. 2011). Collections were performed by SCUBA divers using Hawaiian-sling-style spears, and captured fish were placed into sealed buckets for transport. Depths of collections ranged from approximately 15 to 30 m, and dive times ranged from 30 to 45 min. After docking, fish were placed on ice and transported to the Little Cayman Research Centre, where processing occurred the next day.

I recorded the total length, total weight, gape, and sex of each fish before removing stomachs. Stomachs were placed in plastic bags with 95% ethanol to stop
digestion and degradation of prey. They were later dissected, and any contents were classified to the lowest possible taxonomic level using a dissecting microscope at 40-60x magnification and Humann and DeLoach (2002) as an identification guide. Stomach contents were then placed into separate pre-weighed tins and dried in an oven at 24°C for three days prior to recording their dry weight.

**Calculation of Alimentary Indices**

To determine the importance of various prey items, I calculated alimentary indices. These indices were based on data from stomachs containing a single type of prey. The index of choice (Equation 3-1) was previously used by Valentim et al. (2008):

\[
IA_i = \left[ \frac{%FO_i \times %W_i}{\sum (%FO_j \times %W_j)} \right] \times 100
\]  

(3-1)

where \(IA_i\) = the relative importance of food item \(i\) expressed on a scale of 1 to 100, \(%FO_i\) = the relative commonness of item \(i\) expressed as a percentage occurrence in the total number of stomachs examined, and \(W_i\%\) = the relative biomass contributed by item \(i\) expressed as 100 times the sum of the dry weights for the item divided by the total dry weights of all items. For example, creole wrasse occurred in 68 lionfish stomachs. To determine \(%FO\), divide 68 by the sum of all diet item occurrences and multiply by 100. Similarly, the sum of the creole wrasse diet items equaled 33 g dry weight. To determine the \(%W\), divide 33 by the sum of all diet item dry weights and multiply by 100. Finally, to determine %IA\(i\), take the value of \(%FO_{creole\ wrasse} \times %W_{creole\ wrasse}\) and divide that by the sum of the \(%FO \times %W\) for all diet items and multiply by 100.

Combining frequency of occurrence and gravimetric data provided the opportunity to make unbiased inferences about the importance of different prey species. Indices based solely on weight can overestimate the importance of single, heavy prey items.
Frequency of occurrence was employed to avoid misrepresentation associated with attempts to discern the number of individual prey items in highly digested stomach contents (Hyslop 1980). To avoid overestimating the importance of numerous, smaller prey items, such as shrimp, dry weight was factored into the estimates of importance to capture potential caloric contributions.

A cumulative prey curve was used to assess how fully the diet of lionfish was characterized (PRIMER 6; Anderson et al. 2008). The Chao 1 index was applied to counts of prey items in order to capture the influence of rare species. A thousand permutations of samples yielded estimates of the expected number of prey items in a fully characterized diet.

**Results**

**General Observations**

In total, 1599 stomachs were analyzed, and of those, 475 stomachs were empty (~30%). Of the stomachs containing prey, 50% held fish tissue, 25% held shrimp tissue, and 25% comprised unidentifiable items, crabs, bivalves or plant matter. The average dry weight of male diets (0.21 g) was twice that of female diets (0.10 g). This difference was due to males eating both more prey (a mean of 1.3 items for males versus a mean of 0.7 items for females) and larger prey (a mean total length of 28.1 mm for prey of males versus a mean total length of 10.1 mm for prey of females). Over 50 species of fish and crustaceans were observed in the diets of lionfish suggesting a generalist, carnivorous diet. The cumulative prey curve suggested an additional 25 species eventually may be found in lionfish diets. The cumulative prey curve began to asymptote around sample number 400 at 75 unique prey items (Figure 3-1). Thus, 1599
samples characterized approximately two-thirds of the diet for lionfish from Little Cayman Island.

**Alimentary Index**

Although the complete diet of lionfish from Little Cayman included over 50 species, several species dominated according to alimentary indices (Table 3-1). In total, ~33 g (dry weight) of creole wrasse (*Clepticus parrae*) were found in 68 stomachs, ~7 g (dry weight) of fairy basslets (*Gramma loreto*) were found in 86 stomachs, and ~8 g (dry weight) of red night shrimp (*Cinetoehynchus manningi*) were found in 138 stomachs. Although red night shrimp had the highest frequency of occurrence, creole wrasse ranked highest in overall importance of identified items after weights were considered (Table 3-1). These data suggested that creole wrasse contribute the most calories to lionfish diets off Little Cayman Island.

Age data linked to stomach contents via a unique identifier for each was used to identify ontogenetic shifts in diets. As lionfish aged, the proportion of shrimp found in their diets decreased steadily; thus, older lionfish became more piscivorous (Figures 3-2; 3-3a and b). In fact, the alimentary index for red night shrimp, creole wrasse, and fairy basslets changed depending on the age of the fish. For example, red night shrimp had an alimentary index of 7.97 for age-0 lionfish, 1.4635 for lionfish 1-2 years old, and 0.4308 for lionfish 3-4 years old. Thus, the importance of red night shrimp in lionfish diets decreased as they aged. In contrast, creole wrasse had an alimentary index of 0.0000 for age-0 lionfish, 4.4775 for lionfish 1-2 years old, and 34.0980 for lionfish 3-4 years old. Therefore, the importance of creole wrasse in lionfish diets increased as lionfish aged. Lastly, alimentary index for fairy basslets was highest for lionfish that were 1-2 years old (Table 3-2).
Lionfish gape size increases as body size increases, allowing lionfish to eat a wider variety of prey of different sizes. Increased lionfish size does not, however, preclude them from continuing to eat smaller prey (Figure 3-4). In fact, all prey body depths fell below the gape measurement of the lionfish that ate them, and prey depth ranged from 5 to 77% of the gape size (Figure 3-4). The relationship between diet weight and lionfish weight showed that lionfish ate up to 9% of their body weights (Figure 3-5).

**Discussion**

Managing and mitigating impacts of invasive lionfish will benefit from knowledge of their effects on local prey fish assemblages. For example, an understanding of prey selection can help managers develop metrics of success for removal programs.

Arrington et al. (2002) found that the percentage of empty stomachs can be associated with trophic status and, to some degree, geographic location. Piscivores that consume whole prey, such as lionfish, and fish that provide parental care had the highest overall percentage of empty stomachs. When geographic location was taken into account, Arrington et al. (2002) found that the proportion of empty stomachs in Central and South America was just under 30%. Results from Little Cayman Island corroborate these findings. The large percentage of highly digested material may be due to the timing of feeding, with fish for this study collected in the early evening so any prey items consumed in the morning would have been at least partially digested (Morris & Akins 2009).

Male diets weighed twice that of females on average. This difference is most likely due to males attaining larger body sizes than females. The largest male lionfish was 391 mm TL, and the largest female was 333 mm TL. In his study of bioenergetics and
trophic impacts of lionfish, Cerino (2010) found that males gained twice as much mass and consumed 21% more prey than females. He suggested that reduced somatic growth for females may be due to a reallocation of energy stores to gamete production. Cerino (2010) also stated that lionfish consumed the most prey at 30°C; therefore, consumption probably will vary in temperate regions and remain higher and more constant in the tropics.

Lionfish from Little Cayman Island consumed similar proportions of fish and crustaceans as lionfish from the Bahamian archipelago (Morris and Akins 2009). Lionfish from both locations exhibited an ontogenetic shift from shrimp to fish. In this study, the shift was linked to age classes. As lionfish control efforts progress, the older and larger individuals in the population will likely be fished down first, truncating the size distribution (Berkeley et al. 2004, Frazer et al. 2012). A population comprised of smaller individuals may exert less pressure on native fish populations due to their propensity to consume smaller taxa comprised of shrimp (Frazer et al. 2012).

A similar ontogenetic shift is exhibited by native groupers, such as the Nassau grouper, which raises concerns about competition with lionfish. In a study done by Eggleston et al. (1988), Nassau grouper were shown to eat primarily crabs and other crustaceans in the juvenile stage and primarily fish in the adult stage. Crabs were not a significant part of juvenile or adult lionfish diets; however, competition may exist between adult lionfish and early adult grouper that feed on fish of similar sizes.

Muñoz et al. (2011) found lionfish from hard-bottom reefs in the southeastern U.S. generally were piscivorous, and prey items were consumed in proportion to their local abundance. Although we did not survey prey populations, we can infer that lionfish in
the Caribbean consume prey in the same manner. Results from surveys conducted by others (S. Barry unpublished data) ranked creole wrasse and fairy basslets (two common prey items for lionfish) as the second and fourth most common species out of 50 species, which confirms the premise that lionfish prey on locally abundant species from Little Cayman Island. In addition, qualitative abundance estimates for species consumed by lionfish in the Caribbean (Humann & DeLoach 2002) indicate that red night shrimp, creole wrasse, and fairly basslets are abundant. Species occurring less frequently in lionfish stomachs generally were described as common to occasional. While these qualitative estimates are not based solely on assemblages off Little Cayman Island, they do describe what is available in the Caribbean. Morris and Akins (2009) further corroborate this pattern, with results showing that lionfish in their study fed readily on abundant teleost fishes and crevice dwelling species. Red night shrimp and fairy basslets both inhabit reef crevices, and creole wrasse often are found on outer reefs and drop offs (Humann and DeLoach 2002) along with lionfish. The abundances of these species and the habitat overlap make them especially vulnerable to predation by lionfish.

Increases in lionfish gape as they grow in length allow them to eat a wider variety and wider size range of prey. Sharf et al. (2000) noted that larger predator gape does not necessarily mean that the predator will consume only larger prey items. Asymptotic predator size-prey size distributions exist due to larger predators continuing to eat small prey in conjunction with larger prey. St John (1999) found such a relationship between predator gape and prey depth for the grouper, *Plectropomus leopardus.*
Lionfish diets weighed up to 9% of their dry body weights. Estimates of consumption by lionfish based on observations of foraging at dusk and an assumed 2 h of foraging at that rate per day yielded a mean consumption ± standard error of approximately 9 ± 5% for lionfish in the Bahamas (Green et al. 2011). Lionfish captured near dusk off Little Cayman Island did not achieve this level of consumption in 95% of 1599 cases, which may indicate they had not foraged for 2 h. Nevertheless, all available data indicate that lionfish can consume considerable amounts of food.

Competition for food continues to be one of the perceived impacts frequently associated with the lionfish invasion (Barbour et al. 2011, Morris & Whitfield 2009). Albins (2012) attempted to provide a causal link between the presence of lionfish on experimental patch reefs, decreased abundance of native prey, decreased species richness for prey, and decreased fitness for a similar sized native piscivore, the coney grouper. By tracking prey assemblages and measuring growth of the two predators added to the experimental reefs in combination and separately, he determined that lionfish growth surpassed that of the coney grouper in all cases. Although the presence of lionfish did not appear to inhibit growth of coney grouper over an 8-week period, Albins (2012) stated that perhaps coney grouper sharing reefs with lionfish were forced to consume subpar prey, which may negatively impact growth in long run. In addition, the more rapid growth of lionfish may lead to direct effects through predation on coney grouper and other native piscivores that recruited in the same cohort.

This study provides insight into the feeding habits of lionfish in the Caribbean. Seasonal bias should not be present in our diet analysis since fish were collected every week for a year. Feeding habits and important prey species most likely will change with
the availability of prey, and diet studies should be expanded throughout the invaded area. It also is important to monitor changes in diet over time because such changes may indicate changes in the availability of prey in the invaded range. In addition, prey composition may change in areas with targeted culling. Surveys of potential prey would complement diet studies and provide a more direct assessment of availability.
Table 3-1. Taxa found in stomachs of lionfish from Little Cayman Island, with associated frequencies of occurrence, alimentary indices, and estimates of abundance. Abundance = qualitative abundance in the Caribbean according to Humann and DeLoach (2002); Rank = rank of mean abundances from surveys of three sites with few lionfish off Little Cayman Island (S. Barry, unpublished data).

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Frequency</th>
<th>%IA&lt;sub&gt;i&lt;/sub&gt;</th>
<th>Abundance</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown fish</td>
<td>595</td>
<td>85.4834</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Clepticus parrae</td>
<td>68</td>
<td>7.66047</td>
<td>Abundant</td>
<td>2</td>
</tr>
<tr>
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<td>382</td>
<td>4.08280</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cinetorhynchus manningi</td>
<td>138</td>
<td>1.42562</td>
<td>Abundant</td>
<td>—</td>
</tr>
<tr>
<td>Gramma loreto</td>
<td>86</td>
<td>0.54014</td>
<td>Abundant</td>
<td>4</td>
</tr>
<tr>
<td>Chromis multilineata</td>
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<td>0.23862</td>
<td>Abundant</td>
<td>31</td>
</tr>
<tr>
<td>Holocentridae</td>
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<td>0.13167</td>
<td>Common</td>
<td>—</td>
</tr>
<tr>
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<td>Rank</td>
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<td>Amblycirrhitus pinos</td>
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Table 3-2. Comparison of the alimentary index of three different prey items for all lionfish and three different age classes, age-0, age 1-2 and age 3-4 lionfish.

<table>
<thead>
<tr>
<th>Species</th>
<th>Overall</th>
<th>Age 0</th>
<th>Age 1-2</th>
<th>Age 3-4</th>
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<td>Cinetorhynchus manningi</td>
<td>1.4256</td>
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<td>0.9471</td>
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Figure 3-1. Cumulative species curve for lionfish prey from Little Cayman Island.

Figure 3-2. Proportion of lionfish diets containing fish or shrimp according to age. Age 0 fish = 64-282 mm; age 1 fish = 138-288 mm; age 2 fish = 169-370 mm; age 3 fish = 205-372 mm; age 4 fish = 356-392 mm.
Figure 3-3. Typical stomach contents from younger lionfish and a mature lionfish. (a) shows stomach contents of a younger lionfish entirely comprised of small shrimp and (b) shows stomach contents of an adult lionfish comprising a parrotfish, two slender filefish, a trumpet fish, and a harlequin bass.

Figure 3-4. Body depth of prey, vertical gape and horizontal gape for lionfish of differing total lengths.
Figure 3-5. Dry weights of diets versus dry weights of lionfish.
Although the growth and reproduction of lionfish complicate management of this invasive species, culling efforts in localized areas have been shown to be effective in reducing densities of lionfish, and they remain the best available option for control (Frazer et al. 2012). Jud and Layman (2012) also make a case for localized control by demonstrating that lionfish exhibit high site fidelity, which suggests replacement will be through recruitment and not immigration. Another factor influencing removal strategies involves the kind of effort and gear required to capture lionfish. Although there have been reports of hook-and-line fishermen occasionally catching lionfish, traditional hook-and-line methods will not target only lionfish, and in fact, are not very effective, (Barbour et al. 2011, Morris and Whitfield 2009). Lionfish also have been caught in lobster traps (Morris and Whitfield 2009), but trapping may yield bycatch and damage to coral reefs. To date, the least damaging and most efficient and effective means of catching lionfish are spearing or netting while on SCUBA. Limitations associated with this method include the restrictions on bottom time and depth limits. Therefore, efforts typically focus on the shallower portion of the depth range inhabited by lionfish, which may leave a source population that supplies recruits. Nevertheless, if managers can identify areas of special concern and focus removal efforts there, they may be able to reduce impacts of lionfish in the shallow water coral communities that harbor the highest diversity and density of fish or threatened and endangered species (Albins & Hixon 2008, Brokovitch et al. 2008, Frazer et al. 2012).

While a great deal of work has been done to improve our understanding of lionfish ecology and biology, questions still remain. Further research on lionfish could include a
reanalysis of the proportion of *P. miles* and *P. volitans* present in different regions of the invaded range, which would clarify the composition of the invasive populations. Reassessing growth once the Little Cayman Island population has matured may increase the accuracy of estimated growth parameters. Furthermore, steps should be taken to determine natural mortality. Natural mortality remains one of the most elusive parameters to obtain, and accurate estimates typically require a population that has been established for some time. Managers would also benefit from knowledge regarding the degree of compensatory growth and reproduction in fished populations. Once this information becomes available, it will increase the accuracy of models that predict population dynamics of lionfish and the amount of fishing pressure needed to maintain reduced densities of this invasive species.
LIST OF REFERENCES

Aguilar-Perera A, Tuz-Sulub A (2010) Non-native, invasive red lionfish (*Pterois volitans* [Linnaeus, 1758]: Scorpaenidae), is first recorded in the southern Gulf of Mexico, off the northern Yucatan Peninsula, Mexico. Aquat Invasions 5:S9


BIOGRAPHICAL SKETCH

Morgan Edwards was born and raised in Gainesville, Florida. After graduating from high school in 2002, she attended the University of Florida to study wildlife ecology and conservation. In 2008 she began work as a technician in the Department of Fisheries and Aquatic Sciences at the University of Florida. Once fully immersed in the world of field work; traveling all over Florida to help study riverine and near-shore ecosystems, and even spending a three week stint at the bottom of the Grand Canyon on a research project, she decided to pursue a graduate degree with the Frazer lab in the Fisheries department. Her graduate work focused on the invasive lionfish population of Little Cayman, and while there, she completed a teaching internship with the Little Cayman Research Centre where she resided for six months. Her experience in graduate school provided her with unique challenges that she hopes have helped her to become a better scientist. Morgan plans to continue working with the Frazer lab after graduation, working in the place where she first fell in love with the ocean, the Florida coast.