Age And Growth Of The Invasive Lionfish: North Carolina, USA, vs Bonaire, Dutch Caribbean

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ABSTRACT

Lionfish are an invasive species that are now well established throughout the Atlantic. Originally from the Indo-Pacific, they have decimated local fishes' populations due to their rapid reproduction, broad environmental tolerance, voracious appetite, and lack of predators. Through the examination of otoliths paired with morphometric data, this study investigates the age and growth of lionfish (sp. P. volitans) from two locations: North Carolina, USA and Bonaire, Dutch Caribbean. Otoliths were extracted from lionfish samples, embedded in resin, and then sectioned so that age could be determined with microscopic analysis. These age estimates along with the corresponding total lengths were used to calculate growth rates via the von Bertalanffy growth equation. Results returned a K and L-infinity value of 0.32 cm and 42.5 cm for lionfish from NC and 0.39 cm and 38.7 cm for Bonaire, respectively. These findings suggest that lionfish from NC have slower growth but grow older and larger than that of lionfish from Bonaire. This likely attributes to location as well as convenience and strength of removal efforts. In Bonaire, lionfish are hunted often and are easily accessible to the public, whereas in North Carolina, lionfish are found miles off the coast and their harvesting is not as popular.

Lionfish are an invasive species deriving from the Indo-Pacific that have now come to thrive in the Atlantic and Caribbean. Invasive lionfish can be classified into two species, the fire devil fish (*P. miles*) and red lionfish, (*P. volitans*). Both species look and behave very similar; they both appear to have red and white zebra-like stripes, long pectoral fins, venomous spines, and a sedentary, fearless demeanor (Schultz 1986). However, meristic counts differ between the species. *P. miles* generally has 10 dorsal-fin rays and 6 anal-fin rays while *P. volitans* usually has 11 dorsal-fin rays and 7 anal-fin rays (Schultz 1986). Also, Species *P. volitans* has a wider geographic invasive range than *P. miles* (Schofield 2009). This study focuses on species *P. volitans*.

The earliest sighting of lionfish in the Atlantic dates to 1985 off the southeastern coast of Florida and thought to be caused by negligent aquarists. Through mitochondria DNA analysis, this was shown to be likely source of the invasive (Freshwater et al. 2009). In 2000, multiple individuals were sighted off North Carolina and the surrounding states; nine years later, in 2009, lionfish were seen in Bonaire (de León et al. 2013). Presently, lionfish have been found as far south as Brazil and as far north as New York (Morris and Whitfield 2009, Freshwater et al. 2009, Green et al. 2012, Ferreira et al.

2015). Lionfish are expected to continue invading the remainder of the Caribbean and to continue southward along the coast of South America until the water temperatures fall below their thermal tolerance limit (Morris and Whitfield 2009).

Lionfish are classified as generalist carnivores that feed on a wide variety of fishes and crustaceans (Morris and Akins 2009). Lionfish consume prey at high rates, largely during crepuscular periods (Green et al. 2012). Their hunting strategy is unique among predatory fishes within the Caribbean. Lionfish hover motionless over prey with their large pectoral fins extended and are able to approach their prey closely before making a rapid strike. They also can extrude water jets to orient the prey towards the mouth before striking (Albins and Lyons 2012). Their relentless predation wreaks havoc on communities. For example, a 79% reduction in fish recruitment on experimental patch reefs in the Bahamas was observed during a five-week observation period in the presence of a single small lionfish (Albins and Hixon 2008). Another study reported lionfish prey biomass reduced by an average of 65% over a two-year-period (Green et al. 2012). This mass predation is cause for concern as the over-consumption of herbivore fishes can shift ecosystems to algae dominated coral as shown by Lesser and Slattery (2011). These shifts that can effect both habitat and economy as seen during the mass extinction of the sea urchin, *Diadema antillarum* in the 1980's (Mumby et al. 2006).

Lionfish are extremely tolerant and adaptive. They have been reported from all major marine seafloor and substrate types within the invaded Atlantic, and they occupy a range of depths (Morris et al 2009). They have no known predators and a proven voracious appetite; this paired with their ability to reproduce every 4 days drives their success (Morris et al 2009). Through the analysis of otoliths and recorded total lengths, this study aims to (1) produce von Bertalanffy growth curves and (2) investigate the age structure and growth with regards to environmental influences for two very different locations: North Carolina, USA and Bonaire, Dutch Caribbean.

METHODS

Lionfish samples were obtained from both locations during the summer of 2015 (June – August) (Figure 1). In North Carolina, 21 lionfish were purchased from local fisherman after their returns from the Onslow Bay area. In Bonaire, 17 lionfish were speared and donated by locals. Bonaire samples all were from the west coast of the island. However, due to human or experimental error, only 13 otoliths from each location were able to be completely evaluated.

For all samples collected, the species was verified, total length (TL) recorded, and the sagittal otoliths were extracted. Otoliths are small bones that are found within fishes' craniums that help facilitate balance, orientation, and sound (Secor et al. 1991). As these bones grow, they form annual rings similar to like rings of a tree. These annuli can be counted to give age estimates and used in further calculations to produce growth curves (Secor et al. 1991). The otoliths were embedded in resin, mounted, and sectioned with an Isomet™ Low Speed Saw as following protocol from the *Manual for Otolith Removal and Preparation for Microstructural Examination* (Secor et al. 1991). Sections were then analyzed for annuli under a compound microscope to determine age. Further analysis for growth was conducted following protocol set forth by the FAO's (Food and Agriculture Organization of the United Nations) manual, *Introduction to Tropical Fish Stock Assessment* (Sparre and Venema 1998).

The age estimates from the otolith analyses along with the corresponding total lengths were used to calculate a growth rates via the von Bertalanffy growth equation (Table 1.):

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

where l(t) is length at time, t(0) is the

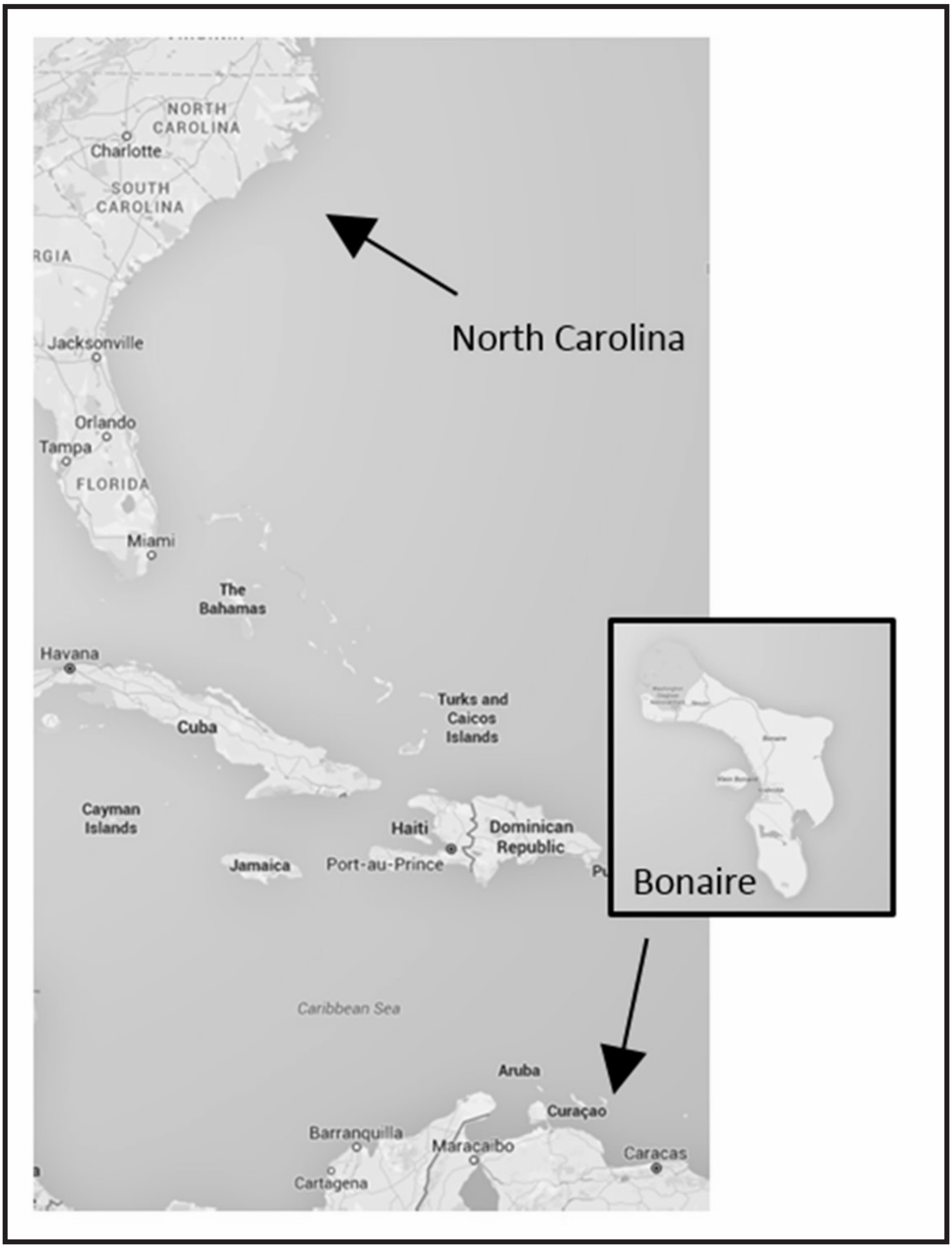

Figure 1. *Map of study area*

North Carolina		Bonaire	
Age (years)	Total Length (cm)	Age (years)	Total Length (cm)
0.6	15	0.1	10.2
0.6	14	0.2	10
0.8	17	0.3	13.4
1	28	0.5	16
1	30	0.7	16
2	34.5	0.8	20
2	35	1	26.7
2	36	1	20
3	31	1	32
3	32	2	34
4	35	3	25
4	36	3	27
6	40	5	43

Table 1. *Raw otolith and corresponding age data for samples from North Carolina and Bonaire*

Parameters	North Carolina	Bonaire
L_∞	42.5 cm	38.7 cm
K	0.32 cm per year	0.39 cm per year
$T(0)$	-0.85	0.048

Table 2. *Comparison between parameters of von Bertalanffy growth equation for North Carolina and Bonaire*

theoretical length at age 0, K is the growth rate and L_∞, termed 'L infinity' in fisheries science, is the asymptotic length at which growth is zero(von Bertalanffy 1934). This equation assumes that body length is a function of age. Parameters for this equation were calculated by the Ford-Walford plot. This plot graphs a fish's length at year (t+1) against the fish's length the previous year (t) producing the equation:

$$L_{t+1} = L_\infty \ (1 - e^{-K}) + L_t \, e^{-K}$$

From this, the following parameters can be calculated from the linear regression via:

$$L_{t+1} = a + b \, L_t$$

$$K = - \ln(b)$$

$$L_\infty = a \,/\, (1\text{-}b)$$

the parameter, t(0) was calculated by creating a Von Bertalanffy plot. This plots age (t) against:

$$-\ln\left(1 - L(t)/\,L_\infty\right)$$

from the linear regression of this plot, t(0) can be simply calculated by:

$$t_0 = -a/b$$

RESULTS AND DISCUSSION

Results return a K and L-infinity value of 0.32 cm and 42.5 cm for lionfish from NC and 0.39 cm and 38.7 cm for Bonaire, respectively (Table 2 and Figure 2). The age range of lionfish found in North Carolina was 0.6-6.0 years old with an average age of 2 years old (Figure 3). Bonaire lionfish showed a range of 0.1-5.0 years old with an average

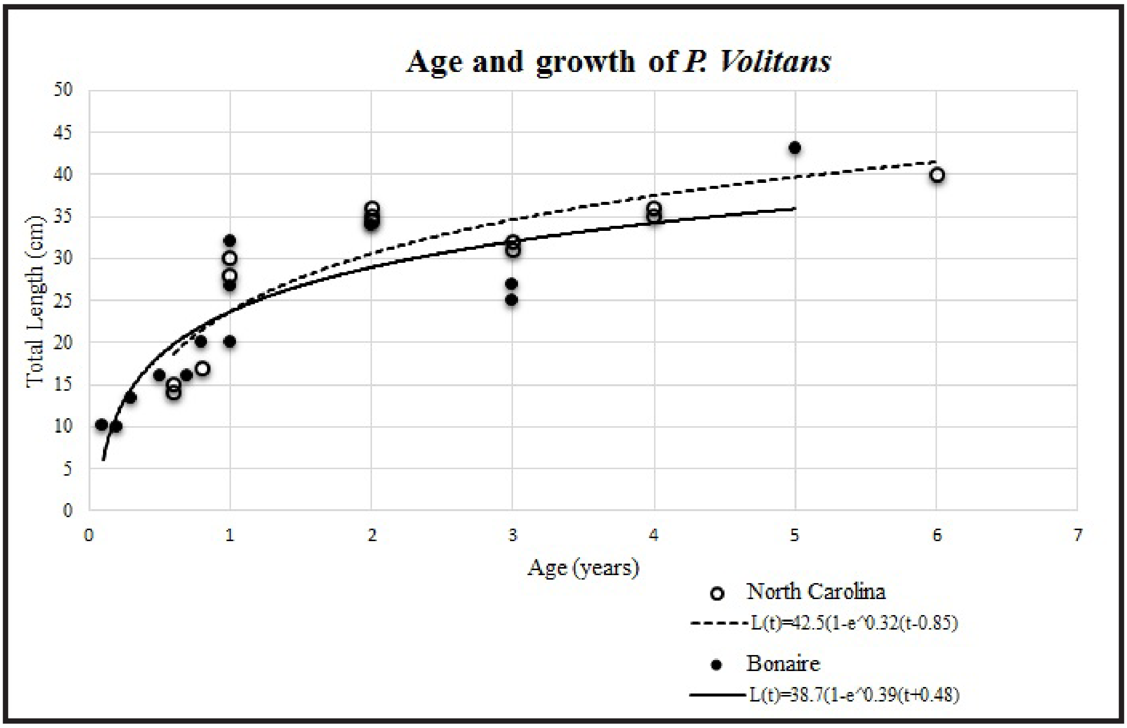

Figure 2. *Von Bertalanffy growth curves calculated from lionfish samples for both North Carolina and Bonaire*

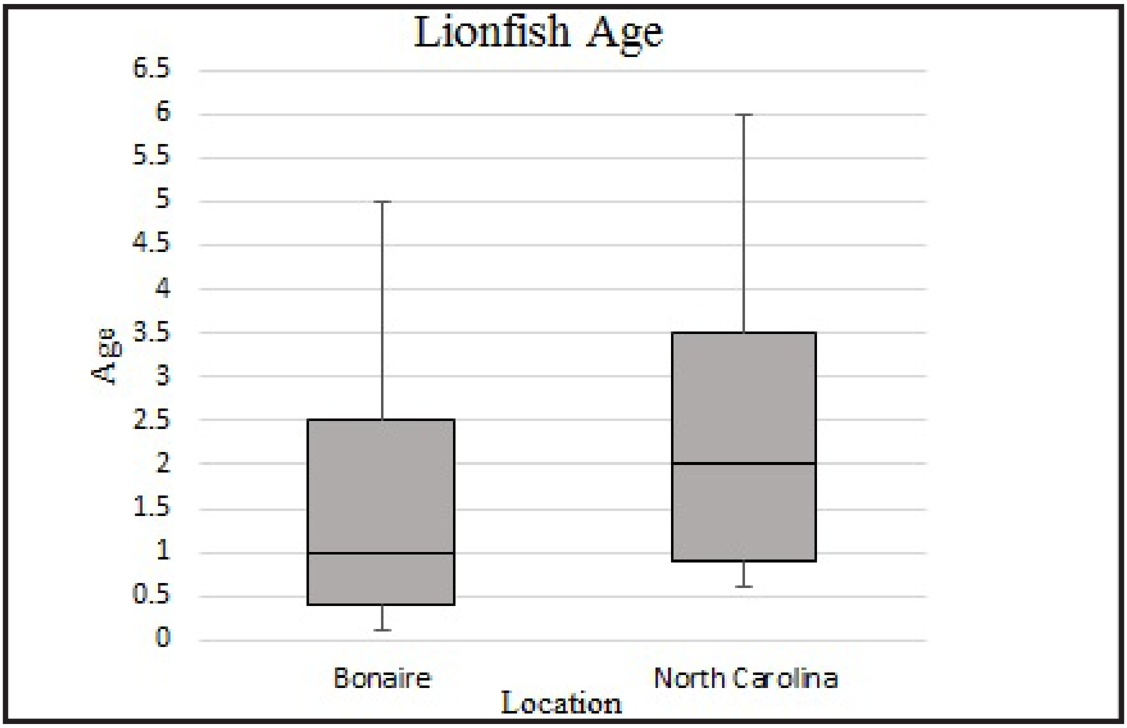

Figure 3. *Age structure of lionfish samples from Bonaire and North Carolina*

age of 1 year (Figure 3).

These results are similar to those found in past studies from the Western Atlantic and Caribbean. One study from the Cayman Islands reported lionfish with a K growth rate of 0.42 and a L_∞ value of 34.9 cm (Edwards et al. 2014) while another from Onslow Bay, NC reported lionfish with a K growth rate of 0.32 and a L_∞ value of 45.5 cm (Potts et al. 2010). While the von Bertalanffy growth function (VBGF) is widely accepted, the assumptions and limitations should be recognized (Pardo et al. 2013). The VBGF is was not adjusted for seasonality which could produce variations in the growth coefficient. Additionally, bias in K has been shown based on the variation between using the calculated value of the length at age zero parameter, t(0), versus observed values (Pardo et al. 2013).

North Carolina lionfish appeared to be older and larger than Bonaire lionfish. However, Bonaire lionfish showed a slightly faster growth rate. This could be influenced by climate and temperature. Bonaire's year-round monthly average temperature is ~ 29°C (84°F). These warmer temperatures increase metabolic efforts which in turn affects growth (Thresher et al. 2007). The age structure seen in Figure 3 is likely attributed to other environmental influences such as location and accessibility. Bonaire is a small island renowned for its convenience for pristine diving. Local efforts to eliminate lionfish and help protect and conserve Bonaire's reefs are strong. Government organizations (STINAPA), educational institutes (CIEE Research Station Bonaire), local dive shops, and visitors work closely together reporting and monitoring lionfish sightings to each other. These sightings are uploaded online to a 'lionfish database' that is open to the public. One can even go on to take a lionfish spearing course and after completion of the course receive a 'lionfish license', allowing them join the removal force. While these efforts target all lionfish, typically older, larger fish are the first to be removed affecting overall age structure. These types of collaborations and removal efforts have proven effective in reducing lionfish abundance (Ali 2015, Ali et al. 2013, Barbour et al. 2011, de León et al. 2013). The role of volunteers and group effort is described as essential as increased removal effort has both decreased lionfish and allowed researchers to collect a large sample size in a short time to collect further data (Ali 2015, Ali et al. 2013). Moreover, a study that compared fished and unfished areas of Bonaire over a two year period (2009-2011) found that lionfish biomass in fished locations on Bonaire was 2.76-fold lower than in unfished areas on the same island (de León et al. 2013).

Additionally, the culling of lionfish is not just beneficial for the environment; it has been shown to be tasty and nutritious as well. The fish is described to have a "delicate flakey white meat" and shown to have a high omega-3 content (Morris et al., 2011). Thus, it is not uncommon to see lionfish on the menu in restaurants or markets throughout the Caribbean.

As discussed, in Bonaire, lionfish are hunted often and are easily accessible to the public. However, in North Carolina, this is not the case. Lionfish are found miles off the coast and in much deeper water (~40 m). Most importantly, their removal is not as popular. There are some lionfish derbies that have proven successful in the area as well as educational outreach, but these removal efforts are not as consistent as that of Bonaire. Recent surveys from 2010 have shown that lionfish densities in Onslow Bay were as high as 200 lionfish per hectare (Whitfield et al. 2014). Thus, this number will likely increase unless a balance is found within the ecosystem or their removal and harvesting gains popularity.

This study has implications for management, tracking and monitoring, and planning of the lionfish invasion. The produced von Bertalanffy growth curves (Figure 2) allow for an estimate of age based only on the total length measurement of a fish. This can save future researchers the cumbersome task of otolith extraction and analysis. While the accessibility of lionfish cannot be changed in North Carolina, other aspects from Bonaire's successful removal effort could be adapted for North Carolina. Outreach education programs and removal efforts can be increased. Restaurants and markets alike could be encouraged to offer lionfish. Additionally, a lionfish database to which reported sightings can easily be uploaded would prove beneficial.

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