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Further Evidence for the Invasion and Establishment of *Pterois volitans* (Teleostei: Scorpaenidae) Along the Atlantic Coast of the United States

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Abstract - We document the continued population expansion of red lionfish, *Pterois volitans*, the first documented successful introduction of an invasive marine fish species from the western Pacific to Atlantic coastal waters of the United States. Red lionfish are indigenous to the Indo-Pacific and have apparently established one or more breeding populations on reefs off the southeastern United States. Fifty-nine specimens, most presumably adult red lionfish, were documented or collected on live-bottom reefs off North Carolina, South Carolina, and Florida, and on a manmade structure off Georgia. Observation/collection depths and bottom water temperatures for these fish ranged from 40–99 m and 13.8–24.4 ºC, respectively. Eleven juvenile lionfish, believed to be expatriated from southeastern waters, were collected in estuaries along the coast of Long Island, NY, at depths of 0–5 m and water temperatures ranging from 13.8–16.5 ºC. Twelve of the total 70 specimens collected or observed were positively identified as red lionfish. Based on histological assessment of gonad tissue, two reproductively-active males and one immature female were collected. The life history of red lionfish, especially their reproductive biology and food habits, should be investigated along the east coast of the US to determine the potential impacts of this species on ecosystems they have invaded.

Introduction

The native range of the red lionfish, *Pterois volitans* (Linnaeus, 1758), extends throughout the tropical and subtropical Indo-Pacific from southern Japan southward to Australia and eastward to the islands of the South Pacific (Fig. 1) (Lieske and Myers 1996, Poss 1999, Schultz 1986). In their native range, red lionfish inhabit lagoon and seaward reefs to depths over 50 m (Lieske and Myers 1996, Myers 1989, Yatou 1985) and occupy one of the top levels of the food chain (Fishelson 1975). They were first observed in the Atlantic Ocean at the edge of Biscayne Bay, FL, in 1992 (Courtenay 1995). These six individuals apparently escaped from an aquarium during Hurricane Andrew. The first confirmed sighting of this species on live-bottom reefs in the western North Atlantic occurred off the coast of North Carolina in August 2000 (Whitfield et al. 2002). Live-bottom habitat, consisting of

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diverse communities of sessile invertebrates (Struhsaker 1969), covers the rocky ridges, outcrops, and ledges (Miller and Richards 1980, Parker et al. 1983) on the continental shelf of the southeastern US. Our observations of mostly adult-sized lionfish on live-bottom reefs off North Carolina, South Carolina, Georgia, and Florida, and the collection of juveniles off New York, provide documentation of the persistence of this invasive species and its expansion to new habitats (Fig. 1). If the reported escape of red lionfish off south Florida in 1992 was indeed the source of the introduction to the western North Atlantic, it is the first time that an aquarium release has been identified as the likely source of a successfully established non-native marine fish (Semmens 2004). With the occurrence of biological invasions of non-indigenous marine species on the rise worldwide (Ruiz et al. 1997), it is increasingly important to document these events and determine their impacts on native biota within the ecosystems they have invaded.

Methods

The majority of lionfish (*Pterois* sp.) sightings occurred incidentally while exploring live-bottom reefs off the southeastern coast of the US from

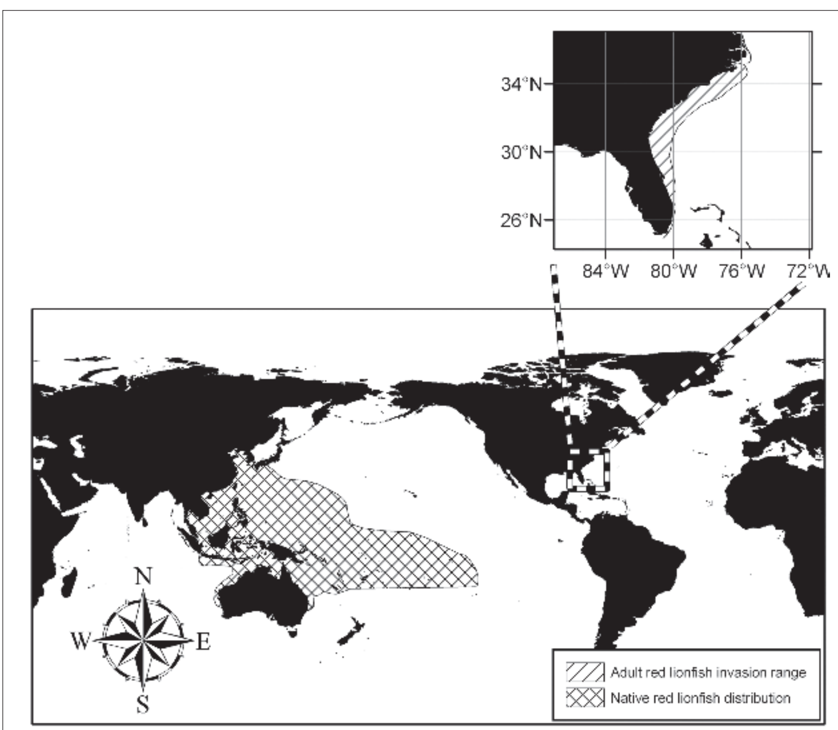

Figure 1. Native range of red lionfish, *Pterois volitans*, and western Atlantic invasive range where adult-sized individuals have been documented. See Courtenay (1995), Schultz (1986), and Whitfield et al. (2002).

St. Augustine, FL, to Cape Lookout, NC. Observations were made from the manned submersible Johnson-Sea-Link II (JSL II) during June–August 2002, 2003, and 2004 (Fig. 2). Live-bottom target sites for submersible dives were chosen from the SEAMAP-SA (2001) and MARMAP (Marine Resources Monitoring Assessment and Prediction, NOAA Fisheries and South Carolina Department of Natural Resources) program databases. Mean depths of target sites ranged from 47–192 m. Each dive had approximately 2.5 h of bottom time and consisted of 4-minute video transects and sample collections to document bottom morphology and the associated invertebrates and fishes. Transects were conducted in the direction of the current, which was generally parallel to the prominent reef feature. Stationary point counts were also made at reefs off North Carolina. Video was recorded in Mini-DV format using a 3-chip CCD color camera and a 6–48 mm lens. Two lasers mounted 25 cm apart on the video camera were used for scaling purposes. Videos were annotated for geologic features, invertebrates, and fishes. One specimen was collected using the JSL-II suction device after application of a rotenone solution and deposited at North Carolina Museum of Natural Sciences (NCSM 36685, 181 mm total length [TL]).

In addition to submersible observations, other sightings (32 individuals) off the southeastern US and those off New York were substantiated with photographs, video from a Remotely Operated Vehicle (ROV), or by specimen collection with a handnet or seine on the surface, with hook and line, or while using SCUBA. Fourteen of these specimens were collected, two of

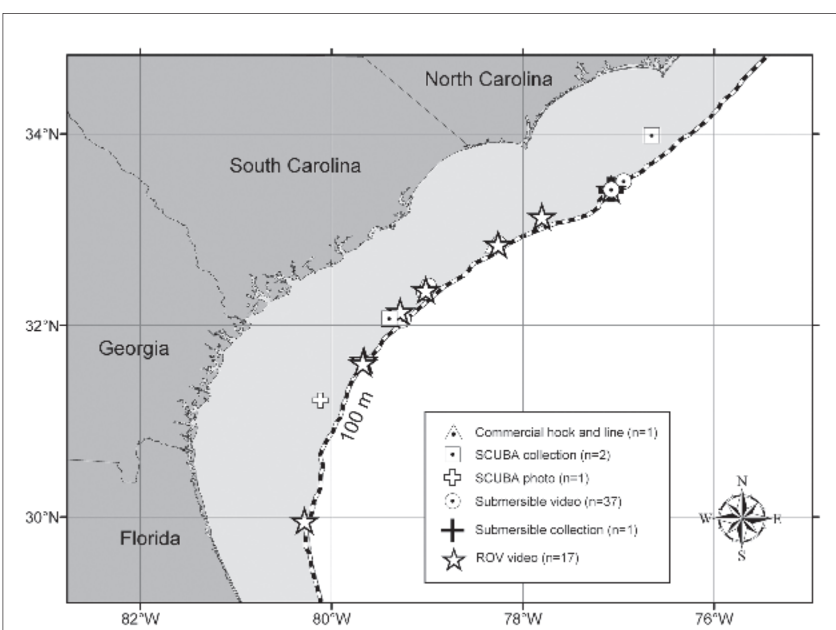

Figure 2. Locations of observations and/or collections of 59 lionfish (*Pterois* sp.) on the continental shelf off North Carolina through Florida.

which were deposited in the collection of Grice Marine Biological Laboratory (GMBL 2730, 352 mm TL; GMBL 2731, 389 mm TL).

Identification of specimens to species was based on the following characters: number of dorsal-fin rays, pectoral-fin length, and size of spots on vertical fins. All other individuals not identified to species were assumed to be red lionfish, as this is the only known member of the genus collected to date from Atlantic waters. Although similar to red lionfish, the black lionfish, *P. miles* (Bennett, 1828), which is native to the Indian Ocean, Red Sea, and Arabian Sea, has not been reported from Atlantic waters. Counts of fin elements and measurements follow Eschmeyer (1969) and Schultz (1986). The last two elements of the dorsal and anal fins originate from a common base and were counted as one ray. Anal-fin rays could not be counted in video recordings and photographs because specimens were usually resting on the bottom. In video and photographs, measurements were made only if the axis of measurement on the specimen was parallel to the focal plane. Pectoral-fin length was measured in a straight line from the base of the uppermost ray to the end of the longest ray (usually the third); if the ray was curved, measurement was made to the outermost point without straightening the tip. The most proximate spot on the last element of the dorsal fin or anal fin was measured.

To assess sex and reproductive state of three specimens, posterior portions of the gonads were fixed in 11% formalin for at least two weeks and then transferred to 50% isopropanol for two weeks in preparation for histological processing. Reproductive tissues were vacuum infiltrated and blocked in paraffin, and then sectioned (7 μm thickness) on a rotary microtome. Three sections from each sample were mounted on a glass slide, stained with double-strength Gill's hematoxylin, and counterstained with eosin Y.

Sagittal otoliths were removed from two specimens and stored dry. The left otolith from each specimen was embedded in epoxy resin and a transverse section (0.3 mm thickness) was made through the core. Two readers simultaneously counted growth increments (one opaque zone and one translucent zone) using a dissecting microscope with transmitted light. Periodicity of increment formation has yet to be validated.

Results

Seventy lionfish were documented by video, photograph, and/or specimen collection (Table 1). Thirty-eight of 70 sightings occurred during submersible dives off the southeastern US, 28 of which were sightings of solitary individuals. Additionally, one group comprising four individuals and three separate groups of two individuals each were also observed. Thirty-five submersible dives were made in depths ranging from 47–129 m (32 dives) and 177–192 m (3 dives), resulting in 86.20 h of total bottom time at the 31 sites that were explored from St. Augustine to Cape Lookout. Adult-sized lionfish (>18 cm TL) were observed at nine shelf-edge sites off

North Carolina and South Carolina at depths of 51–99 m (Table 1, Fig. 2). Sightings occurred during daylight hours on live-bottom reefs at water temperatures of 13.8–24.4 ºC (Table 1).

In addition to observations of lionfish from the submersible, video and/or photographs of 17 lionfish at depths of 50–84 m were taken using a ROV off North Carolina and South Carolina (Table 1, Fig. 3), and one red lionfish, likely an adult, was photographed off Georgia by a SCUBA diver. Bottom water temperatures ranged from 17.6–20.6 ºC. The Georgia specimen was photographed during daylight hours at a depth of 27 m on a manmade platform with a depth of 40 m at its base (Fig. 2).

Four red lionfish were collected off the southeastern US (Fig. 2). The first specimen (NCSM 36685; Specimen F in Table 2) was collected off North Carolina using the JSL-II rotenone-dispensing and suction device. This female specimen (181 mm TL) was collected at a depth of 71 m on 26 August 2003 (Dive JSL-3435). Bottom temperature was 21.6 ºC. Macroscopic examination revealed that both ovaries were small and apparently not reproductively active, constituting only 0.50% of the eviserated body weight. Its stomach was approximately 30% full and contained two whole fishes: one unidentifiable specimen about 14 mm TL and one anthiine serranid about 40 mm TL.

The second specimen (GMBL 2730; Specimen I in Table 2), a male measuring 352 mm TL, was collected with a hook and line off South Carolina by a commercial fisherman at a depth of 49 m on 14 December

Figure 3. Color plate. A red lionfish, *Pterois volitans*, at a depth of 83–84 m off the coast of North Carolina on 17 April 2004. Photograph was taken from a Remotely Operated Vehicle (Dive no. ROV-2004-003) over live-bottom habitat. Photograph © by National Undersea Research Center, University of North Carolina at Wilmington.

Table 1. Observations of 70 lionfish (*Pterois* sp.) on the continental shelf off Georgia, Florida, New York, North Carolina, and South Carolina. JSL = Johnson-Sea-Link II submersible, ROV = Remotely Operated Vehicle, UNCW = University of North Carolina at Wilmington, * = collection of specimen.

Date	Submersible/ROV dive no. or observer	Location	Latitude	Longitude	Number of lionfish	Depth (m)	Temp. (ºC)
08/14/02	JSL-3310	E/SE of Wilmington, NC	33º24.9'N	77º04.7'W	9	69–80	20.3
09/23/01	T. Gardner	S shore of Long Island, NY	40º38.4'N	73º20.2'W	1*	1	-
07/06/02	K.K. Young	E of Brunswick, GA	31º13.0'N	80º07.0'W	1	40	-
08/01/02	JSL-3294	SE of Charleston, SC	32º20.9'N	79º02.1'W	2	61	21.0
08/02/02	JSL-3296	SE of Charleston, SC	32º24.7'N	78º59.3'W	2	53	21.0
08/04/02	JSL-3300	E of Charleston, SC	32º51.2'N	78º15.2'W	1	51	21.0
08/13/02	JSL-3309	E/SE of Wilmington, NC	33º30.2'N	76º56.8'W	5	72	21.1–24.4
08/07/03	JSL-3410	SE of Charleston, SC	32º03.6'N	79º15.2'W	1	75	13.8
08/14/03	T. Gardner	S shore of Long Island, NY	40º50.4'N	72º30.1'W	2*	1.5	-
08/16/03	L. Zahradka	S shore of Long Island, NY	40º45.1'N	72º45.0'W	1	0.5	-
08/19/03	T. Gardner	S shore of Long Island, NY	40º50.4'N	72º30.1'W	1*	2	-
08/19/03	JSL-3422	E/SE of Wilmington, NC	33º25.0'N	77º04.7'W	6	73–78	18.5
08/20/03	JSL-3423	E/SE of Wilmington, NC	33º30.2'N	76º56.8'W	1	80–81	18.8
08/20/03	JSL-3424	E/SE of Wilmington, NC	33º30.2'N	76º56.8'W	1	75	19.1
08/25/03	JSL-3433	E/SE of Wilmington, NC	33º25.0'N	77º04.6'W	5	80–99	20.7–21.5
08/26/03	JSL-3435	E/SE of Wilmington, NC	33º25.0'N	77º04.7'W	2+1*	72–79	21.0–21.6
09/02/03	T. Gardner	S shore of Long Island, NY	40º38.4'N	73º20.2'W	1*	5	-
09/24/03	T. Gardner	S shore of Long Island, NY	40º38.4'N	73º20.2'W	1*	4.5	-
09/26/03	T. Gardner	S shore of Long Island, NY	40º50.4'N	72º30.1'W	1*	2	-
10/08/03	C. Paparo	S shore of Long Island, NY	40º50.4'N	72º30.1'W	1*	0	16.5
10/16/03	M. DiDominico	S shore of Long Island, NY	40º50.4'N	72º30.1'W	1*	0.5	-
10/19/03	T. Gardner	S shore of Long Island, NY	40º52.9'N	72º28.6'W	1*	1	13.8
12/14/03	F/V *Tracy Lynn*	E of Charleston, SC	32º50.0'N	78º19.0'W	1*	49	-
02/04/04	UNCW	E/SE of Wilmington, NC	33º59.1'N	76º39.2'W	1*	41.5	17.2
04/17/04	ROV-2004-003	SE of Wilmington, NC	33º25.0'N	77º04.7'W	1	83–84	-
04/21/04	ROV-2004-011	E/SE of Georgetown, SC	32º50.8'N	78º15.6'W	2	50	18.9
04/22/04	ROV-2004-013	E of Georgetown, SC	33º08.1'N	77º48.1'W	1	50	18.9

Table 1, continued.

Date	Submersible/ROV dive no. or observer	Location	Latitude	Longitude	Number of lionfish	Depth (m)	Temp. (ºC)
04/25/04	ROV-2004-016	E/SE of Charleston, SC	32 º22.2'N	79 º00.9'W	2	59	18.7
04/28/04	ROV-2004-019	E/SE of Savannah, GA	31 º38.2'N	79 º39.8'W	2	68	20.5
04/29/04	ROV-2004-020	E/SE of Savannah, GA	31 º36.4'N	79 º40.4'W	2	73	20.6
05/05/04	ROV-2004-029	E of St. Augustine, FL	29 º57.6'N	80 º17.0'W	5	58	17.6
05/21/04	ROV-2004-007D	SE of Charleston, SC	32 º08.8'N	79 º17.0'W	2	50	-
06/14/04	JSL-4690	SE of Wilmington, NC	33 º25.0'N	77 º04.5'W	2	87–89	18.4
08/19/04	L. Orr	SE of Charleston, SC	32 º04.1'N	79 º23.9'W	1*	55	-

Table 2. Meristic and morphological characters of twelve red lionfish, *Pterois volitans,* collected (*) or observed (video/photo) on the continental shelf off of North Carolina, South Carolina, Georgia, and New York. The most proximate spot on the last element of the dorsal fin or anal fin was measured. P_1 = pectoral fin, SL = standard length, TL = total length, ^{A} = anal fin, ^{D} = dorsal fin.

Specimen	Dive no. or observer	Location	Latitude	Longitude	Depth (m)	TL (mm)	SL (mm)	Dorsal spines	Dorsal rays	Anal rays	P_1 length (mm)	Vertical fin spot (mm)
A*	T. Gardner	NY	40º38.4'N	73º20.2'W	1	196	139	XIII	11	7	152	2.1^A
B*	UNCW	NC	33º59.1'N	76º39.2'W	42	120	-	XIII	11	7	-	2.0^A
C	JSL-3309	NC	33º30.2'N	76º56.8'W	74	366	258	XII	12	-	164	-
D	JSL-3309	NC	33º30.2'N	76º56.8'W	72	-	-	XIII	11	-	-	-
E	JSL-3310	NC	33º25.0'N	77º04.7'W	70	287	215	XIII	11	-	-	4.2^D
F*	JSL-3435	NC	33º25.0'N	77º04.7'W	71	181	133	XII	11	-	133	3.7^A
G	JSL-3300	SC	32º51.3'N	78º15.2'W	49	230	172	XIII	-	-	166	3.0^D
H	ROV-2004-011	SC	32º50.8'N	78º15.6'W	50	-	-	XII	11	7	-	-
I*	F/V *Tracy Lynn*	SC	32º50.0'N	78º19.0'W	49	352	256	XIII	11	7	142	-
J	JSL-3294	SC	32º21.9'N	79º02.1'W	56	203	147	XII	-	-	116	3.5^D
K*	L. Orr	SC	32º04.1'N	79º23.9'W	55	389	285	XIII	11	7	164	3.8^D
L	K.K. Young	GA	31º13.0'N	80º07.0'W	40	-	-	XIII	11	-	-	-

2003. Examination of the sectioned otolith revealed five increments, with a translucent zone on the edge, which was assumed to equate to an age of 5 years. Testes of this specimen had evidence of spermatogenesis, as spermatocytes and spermatozoa were present in histological sections. An exact reproductive state could not be determined due to post-mortem decay. Stomach contents were not identifiable.

The third specimen (Specimen B in Table 2) was hand-netted off North Carolina at a depth of 41.5 m using SCUBA and transferred to an aquarium. This specimen (120 mm TL) was collected on coarse sand at the base of a mooring anchor on 4 February 2004. Bottom temperature was 17.2 ºC.

The fourth specimen (GMBL 2731; Specimen K in Table 2), measuring 389 mm TL, was collected with a spear gun off South Carolina at a depth of 55 m on 19 August 2004. Examination of the sectioned otolith revealed six increments, with a translucent zone on the edge of the section, which was assumed to equate to an age of 6 years. This specimen was a ripe male, as spermatocytes and spermatozoa were present in histological sections. The stomach of this specimen was empty.

In addition to sightings and collections off the southeastern US, 11 juvenile (25–62 mm TL) lionfish were captured alive off Long Island, NY, from September 2001 through October 2003 at depths of 0–5 m (Table 1) and kept alive in aquaria. Underwater collections (n = 8) were made by SCUBA using a handnet. Four of these specimens were captured near concrete bridge pilings, two near wooden dock pilings, and two on rock rubble of an inlet jetty. Additionally, two specimens were handnetted at the surface from shore or pier, and one specimen was captured in surface waters while using a seine over sandy bottom with patches of eelgrass (*Zostera* spp.). Temperatures ranged from 13.8–16.5 ºC. Specimen A (Table 2) was captured at a length of approximately 40 mm TL and died at a length of 196 mm TL after 17 months in captivity. Based on a histological assessment of gonad tissue, this female specimen was reproductively inactive and probably immature, as the ovary contained small (< 80 μm in diameter) primary growth oocytes.

Five specimens from submersible video, five collected specimens, and two specimens in photographs were positively identified as red lionfish, *P. volitans* (Table 2). Lengths of these specimens ranged from 120–389 mm TL (n = 9). Pectoral-fin rays were unbranched, a generic character. Specimens A, B, C, E, F, G, I, J, and K were identified to species based on at least two of the following characters: 1) number of dorsal-fin rays, 2) pectoral-fin length, and 3) size of spots on vertical fins. The number of anal-fin rays (7) and/or the count of elements in the dorsal fin (XII or XIII, 11) were the only meristic characters that could be used to identify specimens D, H, and L as red lionfish.

Discussion

The sightings of 70 specimens of *Pterois* sp. documented here, in addition to those reported by Whitfield et al. (2002) and Hare and Whitfield (2003), provide substantial evidence that at least one breeding population of

red lionfish is established in western North Atlantic waters. We positively identified twelve specimens as red lionfish, *P. volitans*. Of species in the genus *Pterois,* only red lionfish and black lionfish (*P. miles*) are similar enough in appearance to be mistaken for one another. The two species can be separated with meristic and morphometric characters (Schultz 1986) and on the basis of mtDNA sequencing (Kochzius et al. 2003), although Kochzius et al. (2003) concludes that red lionfish and black lionfish may be two populations of a single species. Given the similarities between these species, periodic collection and identification of specimens should be conducted to ensure that only a single species occurs in the western North Atlantic. Black lionfish are available through the aquarium trade, as shipments of "red lionfish" purchased for laboratory experiments in North Carolina contained both species (Kimball et al. 2004).

Red lionfish inhabit deeper (40–99 m) continental-shelf depths off the southeastern US than the 38–43 m and 24–76 m reported by Whitfield et al. (2002) and Hare and Whitfield (2003), respectively. The occurrence of red lionfish at greater depths off the southeastern US than in their native range follows a pattern observed for other subtropical members of this reef fish community. Fishes commonly observed in shallow (< 10 m) waters of the Caribbean, Bahamas, and south Florida are established on reefs to depths of at least 100 m between Cape Hatteras and Cape Canaveral (Parker and Ross 1986). Due to factors such as distance from shore, strong currents, limited visibility, and rough bottom, hardground areas on the continental shelf of the southeastern US are difficult to sample (Quattrini et al. 2004). However, increased sampling efforts in these areas, using direct observation techniques, have resulted in numerous range extensions for a variety of tropical and subtropical reef fishes (Quattrini et al. 2004).

Potentially related to the occurrence of red lionfish at greater depths in the present study is the larger size (120–389 mm TL vs. 100–184 mm TL) of the specimens compared to those observed or collected by Whitfield et al. (2002). Other reef fish species in the region—e.g., *Balistes capriscus* Gmelin, 1789; *Epinephelus niveatus* Valenciennnes, 1828; *Mycteroperca microlepis* (Goode and Bean 1879); and *Pagrus pagrus* (Linnaeus, 1758)—exhibit a positive trend between fish size and water depth (McGovern et al. 1998, 2005; Wyanski et al. 2000). The smaller size of red lionfish reported by Whitfield et al. (2002) likely reflects the restricted depth range of their observations owing to the use of SCUBA.

Red lionfish appear to be widespread in reef habitats throughout the southeast, suggesting that their potential impact on resident populations of reef-associated species could be significant. Most red lionfish that we observed off the southeastern US were found at shelf-edge depths (45–110 m; Struhsaker 1969) on live-bottom reefs (Fig. 2). These areas of the shelf-edge, coinciding with high densities of reef habitat, have higher levels of species diversity than in shallower or deeper areas (Jennings 2001, Parker and Ross 1986), and they support most reef-associated species targeted by

fisheries (McGovern et al. 1998, Miller and Richards 1980, Parker and Ross 1986). Given the extensive amount of reef habitat in the region (Parker et al. 1983, SEAMAP-SA 2001), reefs off the southeastern US have the potential to support a large population of red lionfish. Although a very small portion of this habitat was explored in the present study, we nevertheless documented red lionfish at 9 of 29 sites in depths ≤ 129 m. Our data represent the first detailed documentation of red lionfish on reefs off South Carolina. Few red lionfish have been reported at depths < 35–40 m off North Carolina through Georgia; however, this may reflect the lack of observations at depths < 40 m by the scientific community and lack of documentation for observations made by recreational SCUBA divers.

The lowest temperature (13.8 ºC) at which we observed or collected red lionfish is greater than the lower thermal tolerance limit that was determined through experimental studies on juveniles by Kimball et al. (2005). Whitfield et al. (2002) initially proposed the 16 ºC surface isotherm as an inshore limit during winter, assuming that temperature on the continental shelf off North Carolina is vertically homogeneous during that season. However, Kimball et al. (2005) found the mean critical thermal minimum (temperature at which death occurred) for juvenile lionfish (*Pterois volitans*/*miles* complex) to be 10.0 ºC and concluded that lionfish could overwinter on the continental shelf of the southeastern US. They proposed that lionfish will have a northern limit of Cape Hatteras and an inshore limit coincident with the mean 12.0 ºC surface isotherm in February, which equates to a 10.0 ºC minimum bottom temperature. The 200-m isobath was proposed as the offshore limit (Kimball et al. 2005). Wintertime in situ observations are necessary to confirm the seasonal distribution of lionfish along the east coast of the US (Hare and Whitfield 2003, Whitfield et al. 2002). In addition, thermal tolerance studies should be conducted on adult lionfish.

It is unknown if lionfish make cross-shelf migrations to avoid lethal winter water temperatures. North of Cape Hatteras, expatriated young-of-the-year of native tropical and subtropical reef fish species (e.g., *Chaetodon* spp.) die from hypothermal conditions at the onset of winter (McBride and Able 1998). Data from bottom trawl surveys conducted by the Northeast Fisheries Science Center (Woods Hole, MA) indicate that lionfish north of Cape Hatteras do not survive the winter, as suggested by Whitfield et al. (2002). To date, no lionfish species have been collected during the autumn, winter, and spring surveys (P. Chase, National Oceanic and Atmospheric Administration Fisheries Northeast Fisheries Science Center, Woods Hole, MA, 2004, pers. comm.). These surveys sample fishes on smooth and rocky bottoms at depths of 9–366 m from Cape Hatteras to the Canadian border and beyond. No trawling survey that covers the entire continental shelf exists off the southeastern US.

Impacts of red lionfish on food web dynamics of reefs off the southeastern US are unknown. Species attempting to invade open marine ecosystems must overcome potentially adverse abiotic (e.g., temperature or salinity)

and/or biotic (e.g., predator/prey interaction, competition, or disease) factors to successfully establish a population (Baltz 1991). Temperature and salinity fluctuations at the shelf-edge will likely not adversely affect the success of the red lionfish population off the southeastern US. When compared to shallower coastal water (< 20 m) and deeper offshore water (> 80 m), the temperature and salinity at the shelf edge remains relatively stable year-round due to the influence of the Gulf Stream (Mathews and Pashuk 1986, Miller and Richards 1980, Struhsaker 1969). Competition for prey should not adversely affect red lionfish. In their native ranges, species of *Pterois* occupy one of the top trophic levels on coral reefs, demonstrating their ability to adapt quickly in terms of hunting techniques and avoidance of predation (Fishelson 1975). They are opportunistic predators that use a variety of foraging techniques including hunting as dusk approaches, thereby making prey species that are diurnally active especially vulnerable. In some cases, red lionfish gather in small groups to hunt collectively (Kendall 1990). Red lionfish also feed actively on invertebrates by vibrating their pectoral fin rays over the reef surface to flush out prey items such as shrimp and amphipods (Fishelson 1975). Though density information in their native range is limited, 80 adult-sized (300–400 g body weight) red lionfish have been documented along a portion of a 1-km reef in the Red Sea off Eilat, Israel (Fishelson 1997). Based upon food consumption experiments, these 80 red lionfish could consume over 50,000 small-bodied (3–5 g body weight) fish per year (Fishelson 1997). The only known species to prey upon lionfish in their native range is the bluespotted cornetfish, *Fistularia commersonii* Rüppell, 1838(Bernadsky and Goulet 1991). Potential predation on red lionfish in Atlantic reef systems remains unknown.

In Indo-Pacific populations, red lionfish become sexually mature around 180–190 mm TL and 140–160 g body weight (Fishelson 1997). Although individuals in this size range and larger have been observed off the southeastern US, we lack the specimens to determine size at sexual maturity. Evidence for spawning remains indirect as reproductively active females have yet to be collected. However, we did collect two adult males that were reproductively active. If individuals in Atlantic localities mature at sizes similar to those for red lionfish in the Indo-Pacific, then most individuals that we observed off North Carolina through Georgia are presumed to be adults. Our observations of multiple size groups (juveniles off New York and a wide range of adult-sized specimens off the southeastern US) strongly support the suggestion by Whitfield et al. (2002) and Hare and Whitfield (2003) that reproduction is occurring. Juveniles off New York are smaller in size (< 65 mm TL) than is typically available in the aquarium trade, which indicates that they originated from spawning off the southeastern US (Hare and Whitfield 2003).

The environmental stability of the shelf-edge habitat coupled with the diverse and abundant food supply may be factors that have enabled red lionfish to persist in these biologically productive areas off the southeastern

US. With few known predators and apparently successful reproduction, populations of red lionfish in the western North Atlantic could increase rapidly. Efforts should be made to capture juvenile and adult red lionfish for a detailed study of life history, especially investigations examining reproductive state and food habits, so that reproductive potential and impacts on trophic structure of reef communities can be more fully assessed. In addition, DNA samples should be collected to determine the Indo-Pacific source of red lionfish introduced to the western North Atlantic and dispersal patterns in their invasive range. We agree with Hare and Whitfield (2003) that addressing these questions will facilitate our ability to assess the impacts of red lionfish on the ecosystems that they have invaded.

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