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research paper

Total mercury levels in invasive lionfish, *Pterois volitans* and *Pterois miles* (Scorpaenidae), from Florida waters

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ABSTRACT.—Indo-Pacific lionfish, *Pterois* spp., are opportunistic carnivores that have established invasive populations off the southeastern United States, The Bahamas, the Caribbean, and off the northern coast of South America. Because lionfish have few natural predators in their invasive range, a proposed option for controlling populations and limiting ecological damage is to establish directed fisheries for the species and promote their consumption by humans. However, carnivorous marine fishes can contain high levels of mercury, a toxic, heavy-metal pollutant that can cause neurological and behavioral impairment in humans. We analyzed total mercury levels in dorsal muscle tissue from 260 lionfish collected along Florida's Gulf of Mexico and Atlantic coasts. Fish were collected from offshore waters corresponding to four coastal regions—the southeast Atlantic, the Florida Keys, the southwest Gulf of Mexico, and the Florida Panhandle. Fish ranged in size from 63 to 262 mm standard length (mean = 153 mm), and mercury levels ranged from 0.01 to 0.34 mg kg^{-1} (mean = 0.07 mg kg^{-1}). The mean mercury level in fish larger than 180 mm standard length, which are commonly represented in Florida's commercial fisheries, was 0.09 mg kg^{-1}. Mercury levels increased logarithmically with fish length in all regions. Mercury levels did not differ between males and females, but there were differences among regions, with the greatest concentrations seen in fish from the Florida Keys and highest bioaccumulation rates from the southwest Gulf of Mexico study region. Mercury levels in lionfish were similar to those in marine and estuarine species that fall under Florida's least restrictive consumption advisory levels for the general human population.

The red lionfish, *Pterois volitans* (Linnaeus, 1758), and devil firefish, *Pterois miles* (Bennett, 1828), are invasive scorpaenid species that have established populations in the western Atlantic Ocean, including Florida's reef and estuarine systems (Meisner et al. 2005, Ruiz-Carus et al. 2006, Jud and Layman 2012). *Pterois volitans* is native to reef habitats of the Indo-Pacific region, whereas *P. miles* is native to the Indian Ocean and Red Sea (Shultz 1986). However, in recent years, specimens have been sighted, captured, or killed in US Atlantic and Gulf of Mexico waters from New York to Florida and in the Caribbean Sea as far south as the Windward Islands and

northern coast of South America (Schofield 2010, USGS 2013). The most likely vector for introduction was the intentional or accidental release of captive specimens from aquaria (Courtenay 1995, Semmens et al. 2004, Ruiz-Carus et al. 2006). In the western Atlantic, the two species are indistinguishable by external examination (Hamner et al. 2007), and whether the two species share the same distribution in United States waters is unknown. Hereafter in this paper, the term *lionfish* refers collectively to both of these species.

The numbers of lionfish in US Atlantic, Gulf of Mexico, and Caribbean waters appear to be increasing rapidly. Between 2004 and 2008, lionfish densities off North Carolina burgeoned from 21 fish ha^{-1} to >350 fish ha^{-1} (Whitfield et al. 2007, Morris et al. 2009), and individuals have dispersed from the US mainland and established populations throughout The Bahamas and Caribbean Sea (Freshwater et al. 2009, Morris and Green 2102). This rapid population increase may be partly owing to low predation pressure as a result of the fish's venomous spines (Bernadsky and Goulet 1991), but lionfish also exhibit many of the life history traits that facilitate invasiveness in freshwater species including a protracted reproductive season, a long planktonic larval stage, fast growth, young age at maturity, a broad diet, and high physical tolerances (Morris et al. 2009, Morris and Green 2012). Recent research shows that these lionfish populations are having a negative impact on communities of indigenous reef fishes (Albins and Hixon 2008, Barbour et al. 2011, Green et al. 2012). The lionfish is an opportunistic carnivore (Morris and Akins 2009, Côté et al. 2013) and will consume juveniles of commercial and recreational fishery species such as snappers and groupers, along with those of ecologically important herbivorous reef species such as parrotfish (Albins and Hixon 2008, Morris and Akins 2009, Green et al. 2012, Côté et al. 2013). In Florida, the adult lionfish has no documented natural predators, though they have been found in the stomach of large groupers in the Caribbean (Maljkovic et al. 2008). Biological control of lionfish populations by large grouper species may be possible in areas where groupers are especially abundant (e.g., marine protected areas) and lionfish are not (Mumby et al. 2011). Hackerott et al. (2013) found no evidence of biological control by groupers in a broad spatial examination of Caribbean reefs; however, a critical evaluation of their methods and results suggested that confounding factors may challenge these conclusions (Mumby et al. 2013). Regardless, in areas where predator populations are small or lionfish are abundant, the promotion of directed eradication programs or commercial fisheries for lionfish may be the only viable means of managing their populations (Akins 2012). Recently, fishing derbies encouraging the harvest and consumption of lionfish by humans have been promoted in the United States and The Bahamas (REEF 2012), and in Florida, commercial landings increased almost 500% from 2011 to 2012 with more than 10,000 fish harvested in 2012 (National Marine Fisheries Service, Southeast Fisheries Science Center, Trip Interview Program, pers comm).

Mercury is a toxic metallic element that accumulates as methylmercury in fish tissue and can pose a health threat to humans and wildlife consuming these fish. Metal accumulation can be affected by many factors including dietary intake (i.e., ingestion rate, trophic level, metal concentrations in prey), influx from the environment, individual growth rates (Luoma and Rainbow 2005), fish sex (Gewurtz et al. 2011), and others. As carnivores, lionfish could potentially accumulate relatively high levels of mercury (Cabana and Rasmussen 1994). Fish consumption has been positively correlated with mercury levels in humans (Choy et al. 2002, Hightower and Moore

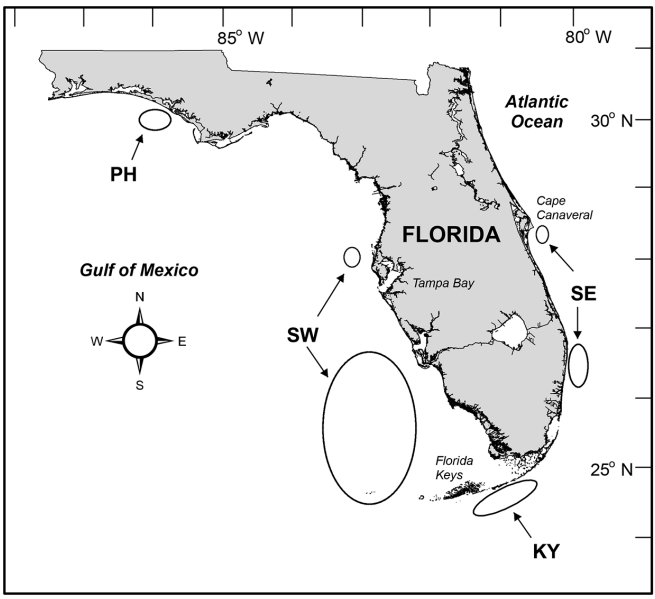

Figure 1. Coastal Florida study areas, showing the approximate collection locations for the southeast (SE), Florida Keys (KY), southwest (SW), and Florida panhandle (PH) sampling regions.

2003), and consumption of contaminated fish is the most important known source of human exposure in the United States (NRC 2000). The potential risk of consuming lionfish taken from the western Atlantic is uncertain because, until recently (Hoo Fung et al. 2013), no baseline mercury data existed. Here, we report the results of a Florida Fish and Wildlife Conservation Commission–Fish and Wildlife Research Institute (FWC-FWRI) study that examined mercury levels in fillet muscle tissue of lionfish collected in Florida waters. The study objectives were to determine mercury concentrations in lionfish relative to current consumption advisory guidelines and to explore the relationship between mercury levels and fish sex, size, and capture location.

Materials and Methods

We collected lionfish along Florida's Atlantic and Gulf of Mexico coasts from August 2011 through July 2012 during sampling by the FWC-FWRI fisheries research program and with the assistance of non-agency partners, including local organizations that conduct recreational lionfish derbies. Fish were assigned to one of four study regions according to capture location (Fig. 1). These were the southeast (SE), the Florida Keys (KY), the southwest (SW), and the Florida Panhandle (PH). Fish from the SE, KY, and PH regions were collected primarily by scientific or recreational divers within approximately 30 km of the coast (5–30 m depth), whereas fish from the SW region were collected in benthic trawls towed in waters 75–250 km offshore (16–43 m depth). After capture, fish were frozen or placed on ice and returned to the FWC-FWRI laboratory for processing. For each individual, we recorded standard length (SL), sex, and capture region. Total length (TL) was also measured, but

was not available for all individuals due to incidences of caudal fin damage during handling. Therefore, SL was used in all analyses.

We collected muscle tissue for mercury analysis from the area above the lateral line and anterior to the origin of the first dorsal fin on the left side of each fish using a clean stainless-steel knife. White muscle tissue taken from this region is representative of the portion of fish consumed by humans (Adams and McMichael 2001). Care was taken to ensure that the sample made no contact with the skin of the specimen, blood, scales, or surrounding surfaces. Tissue samples were immediately placed in sterile polyethylene vials and stored at –20 °C until analysis.

The total mercury (THg) concentration of each sample was determined at FWC-FWRI by EPA Method 7473 [determination of mercury in tissues by thermal decomposition, amalgamation, and atomic absorption spectrometry (EPA 1998)]. THg serves as a reasonable proxy for methylmercury in fish because the majority of mercury in fish muscle tissue (>95%) is in the monomethyl form (CH_3Hg) (Grieb et al. 1990, Bloom 1992). Mercury analysis was completed with a calibrated DMA-80 Direct Mercury Analyzer (Milestone Inc., Shelton, Connecticut). Quality control procedures included analysis of laboratory method blanks, duplicate or triplicate tissue samples, and certified reference material (CRM DOLT-4 or TORT-2 obtained from the National Research Council of Canada) for each group of 10 samples analyzed. In addition, we performed duplicate matrix spikes for each group of 40 samples analyzed. Mercury concentrations were measured and reported as milligrams per kilogram wet weight (mg kg^{-1}).

We summarized fish length and THg levels for all lionfish collected, and separately for the larger individuals likely to be consumed in local fisheries. To determine a minimum summary length for the fishery, we analyzed the length distribution in Florida commercial landings from 2012 and 2013 (National Marine Fisheries Service, Southeast Fisheries Science Center, Trip Interview Program, pers comm). Lionfish landed in Florida's commercial fisheries ranged from 87 to 287 mm SL (mean = 211 mm SL), but we used the midpoint of the modal length size class (180 mm SL) to represent the size at full recruitment and the minimum size that would be commonly available to consumers. Because the influence of sex on mercury accumulation has been documented in other species (Monteiro and Lopes 1990, Gewurtz et al. 2011), including related scorpaenids (Montiero et al. 1991), we tested for differences in mercury levels between male and female lionfish within sampling regions prior to completing the broad state-wide spatial analyses. We used analysis of covariance (ANCOVA)—specifically the significance level of the interaction between treatment effect (sex) and covariate (SL)—to determine potential differences in mercury bioaccumulation rates (regression slopes) between males and females in each of the SE, KY, and PH study areas. We did not include individuals whose sex was not identified or make comparisons in the SW region where no males were identified in the samples. We then used linear regression to describe for each region the relationship between fish length and THg. To compare mercury levels between sampling regions, we used an ANCOVA with sampling region, fish length, and the interaction of these two variables as model factors. The interaction term was significant ($F_{3, 252} = 3.19$, $P = 0.024$) indicating that the relationships between fish length and mercury concentration differed across regions. Therefore, we compared mean THg levels at three representative fish lengths that were observed in all regions (low = 100 mm SL, moderate = 130 mm SL, and high = 160 mm SL) to make general statements about the

Table 1. Total mercury concentrations (dorsal axial muscle tissue as mg kg^{-1} wet weight) and standard lengths (mm) for lionfish collected in four sampling regions along Florida's coast (SE = southeast, KY = Florida Keys, SW = southwest, PH = Florida Panhandle). Within each region, data are provided for all individuals (ALL), females (F), males (M), and unidentified sex (U). Overall summary statistics are also provided for fish >180 mm that represent sizes observed in Florida's commercial fishery. Lionfish from regions with different parenthetic letters have significantly different mercury levels (ANCOVA) or standard lengths (ANOVA). SD = standard deviation; Min = minimum; Max = maximum.

Sample			Total mercury (mg kg^{-1})				Standard length (mm)			
Region	Sex	*n*	Mean	SD	Min	Max	Mean	SD	Min	Max
SE	ALL	88	0.072 (A)	0.045	0.023	0.228	155 (a)	34	63	262
	F	45	0.085	0.051	0.034	0.228	156	21	115	217
	M	22	0.071	0.043	0.026	0.180	176	42	121	262
	U	21	0.049	0.021	0.023	0.100	130	33	63	224
KY	ALL	96	0.095 (B)	0.053	0.035	0.336	160 (a)	32	94	239
	F	26	0.100	0.063	0.040	0.275	151	21	111	198
	M	68	0.094	0.050	0.035	0.336	165	33	94	239
	U	2	0.066	0.014	0.056	0.076	112	21	97	126
SW	ALL	39	0.026 (C)	0.018	0.012	0.098	110 (b)	19	74	161
	F	14	0.033	0.027	0.014	0.098	112	23	80	156
	U	25	0.021	0.006	0.012	0.041	108	17	74	161
PH	ALL	37	0.040 (C)	0.016	0.021	0.081	175 (c)	24	80	232
	F	10	0.048	0.014	0.028	0.073	175	11	159	189
	M	24	0.036	0.013	0.022	0.076	183	16	160	232
	U	3	0.045	0.032	0.021	0.081	119	34	80	145
ALL	–	260	0.069	0.050	0.012	0.336	153	35	63	262
>180 mm	–	56	0.094	0.060	0.027	0.336	201	19	181	262

differences among regions (Littell et al. 2006). Means comparisons were performed on least squares means (LSM) using the least significant difference test ($\alpha = 0.05$). THg levels were log-transformed prior to the ANCOVA analysis to meet or improve the assumptions of normality and homogeneity of variance.

Results

We collected and analyzed 260 lionfish from Florida waters (Table 1). Overall, fish ranged in size from 63 to 262 mm SL (94–350 mm TL), with differences in mean fish length between regions. Samples from the SW and PH regions were skewed toward smaller and larger individuals, respectively, whereas samples from the SE and KY regions were distributed more evenly over a broad size range. Mercury levels in individual fish ranged from 0.012 to 0.336 mg kg^{-1} (mean = 0.069 mg kg^{-1}). We found the greatest mean and maximum mercury levels in the KY region, but statewide, >80% of individuals contained mercury levels <0.100 mg kg^{-1} (n = 210; 63–238 mm SL). Mercury levels in fish larger than 180 mm SL, which are commonly represented in Florida's commercial fisheries, ranged from 0.027 to 0.336 mg kg^{-1} (mean = 0.094 mg kg^{-1}). Within individual study regions, ANCOVA models revealed no differences in mercury bioaccumulation rates between male and female lionfish (Table 2). Therefore, we pooled all lionfish within regions for subsequent regression analysis.

Table 2. Covariance model statistics for the interaction term (SL × sex), comparing mercury bioaccumulation levels in male and female lionfish, for three coastal Florida sampling regions.

Region	Source	df	Mean square[a]	*F*-value[b]	r^2
Southeast	Model	3	0.529	16.83*	0.59
	SL × Sex	1	0.083	2.63ns	
	Error	63	0.031		
Florida Keys	Model	3	0.109	2.54ns	0.08
	SL × Sex	1	0.028	0.67ns	
	Error	90	0.043		
Panhandle	Model	3	0.141	16.87*	0.63
	SL × Sex	1	0.016	1.87ns	
	Error	30	0.008		

[a] Partial (type-III) mean squares are shown.

[b] * = $P < 0.001$; ns = not significant

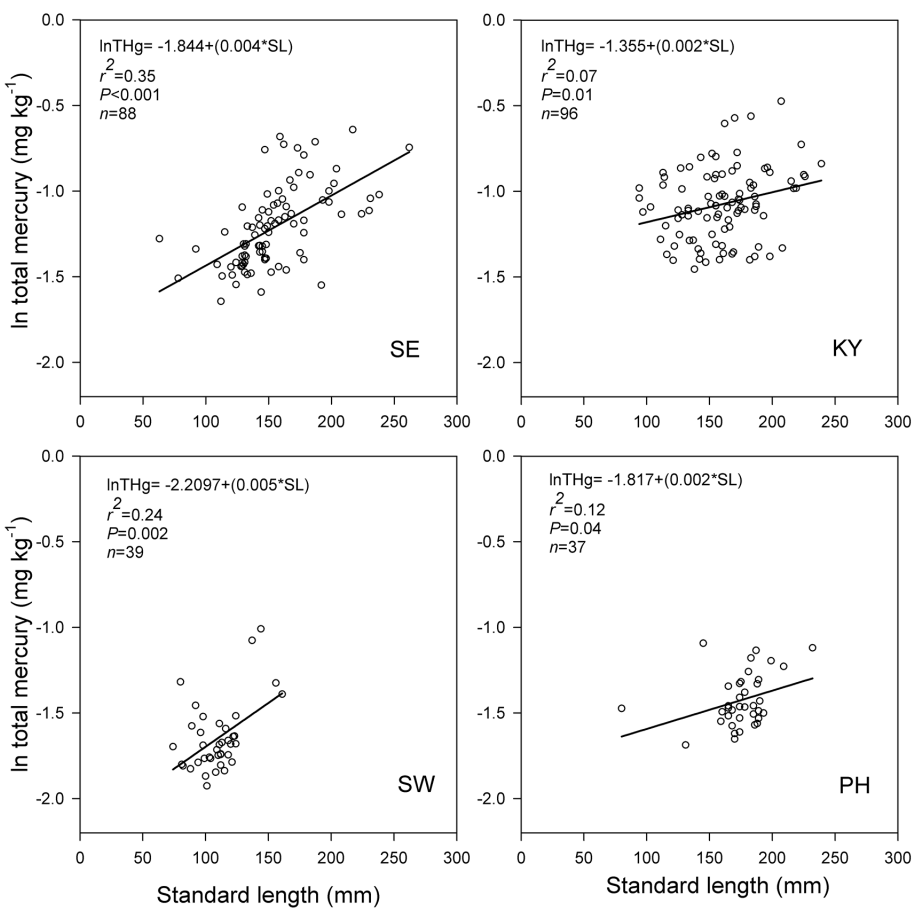

Figure 2. Linear regression relationships between fish length and mercury level for lionfish collected in the southeast (SE), Florida Keys (KY), southwest (SW), and Florida Panhandle (PH) sampling regions.

Table 3. Least square means and standard error estimates of total mercury (lnTHg) in lionfish at three representative lengths for four coastal Florida sampling regions. Lionfish from regions with different letters have significantly different mercury levels based on ANCOVA (least significant difference test: $P < 0.05$).

Region	100 mm SL	130 mm SL	160 mm SL
Southeast	−1.434 (0.04) A	−1.312 (0.02) A	−1.189 (0.02) A
Florida Keys	−1.180 (0.04) B	−1.128 (0.03) B	−1.108 (0.02) B
Southwest	−1.698 (0.03) C	−1.544 (0.04) C	−1.391 (0.09) C
Panhandle	−1.593 (0.10) A	−1.526 (0.07) C	−1.459 (0.04) C

There was a significant positive relationship between fish length and mercury level in all four coastal regions ($P < 0.05$; Fig. 2). The relationship was strongest in the SE region ($r^2 = 0.35$) and weakest in the KY region ($r^2 = 0.07$). Mercury bioaccumulation rates as a function of length (determined by the slope of the linear regression) were highest in the SW region ($b = 0.005$) and lowest in the KY and PH regions ($b = 0.002$).

The ANCOVA identified differences in LSM-adjusted mercury levels among sampling regions at each of the three representative fish lengths chosen for comparison (Table 3). At the smallest chosen length (100 mm SL), we observed differences in THg levels among all regions except the PH and SE study areas. At the larger lengths (130 and 160 mm SL), the highest mercury levels occurred in fish from the KY region, followed by fish on the Atlantic coast (SE). Fish from the gulf regions (SW and PH) had the lowest mercury levels and were statistically similar to each other (Least significant difference test: $P > 0.05$).

Quality assurance measurements during mercury analysis are summarized in Table 4. All measurements were within recommended EPA limits for the analytical method (EPA 1998). Mean mercury concentrations of certified reference materials (CRM) were accurate and within certified confidence intervals for both TORT-2 and DOLT-4. Precision, estimated as the coefficient of variation, was <5% for both CRMs and duplicate samples. The method blanks averaged 0.18 ng, and all were less than 10% of the lowest sample analyzed. The method detection limit, calculated as three times the standard deviation of the method blank, was 0.21 ng and well below the

Table 4. Summary quality assurance data in lionfish tissue mercury analysis. CRM = certified reference material, RPD = relative percent difference.

	CRM (mg kg^{-1})		Duplicates	Method	Spike
	TORT-2	DOLT-4	(RPD)	blank (ng)	recovery
Certified value	0.27 ± 0.06	2.58 ± 0.22			
Lionfish summary data					
Mean	0.26	2.51	1.4%	0.18	99.8%
Standard deviation	0.01	0.07	4.9	0.07	5.7
n	15	15	25	28	5
Coefficient of variation (%)	2.7%	3.7%			5.7%
Method detection limit (ng)				0.21	

level recorded in any sample fish tissues. Spike recoveries averaged 99.8%, indicating the fish tissue matrix did not bias analytical results.

Discussion

The present study reports mercury levels in invasive Indo-Pacific lionfish in the western Atlantic and quantifies mercury variability in relation to fish size and capture location. Mercury levels in lionfish collected from Florida waters were low, particularly in comparison with those reported for some of the most commonly consumed fish families such as Serranidae (groupers), Lutjanidae (snappers), and Scombridae (tunas and mackerels) (Table 5). Mean mercury levels were also lower than those reported for other scorpaenids from the North Atlantic, Mediterranean, and Australia waters (mean THg levels up to 0.77 mg kg^{-1}; summarized in Monteiro et al. 1991), but were almost twice the levels reported for a limited sample of 25 lionfish from Jamaica (Hoo Fung et al. 2013). Although lionfish are considered opportunistic carnivores (Morris and Green 2012, Côté et al. 2013), mercury levels from our collections were aligned more closely with those seen in lower-trophic-level fishes in Florida, such as *Mugil cephalus* (Linnaeus, 1758) and *Trachinotus carolinus* (Linnaeus, 1766) (Adams et al. 2003), which feed on vegetation, algae, or invertebrates. *Mugil cephalus* and *T. carolinus* both fall under Florida's least restrictive consumption advisory levels for the general human population (FDOH 2013), which promote up to two 6-oz meals per week.

Lionfish in the western Atlantic are larger than those found in their native range (Darling et al. 2011) and can attain a total length of 450 mm (approximately 340 mm SL) or more (Whitfield et al. 2007). In Florida, lionfish enter the commercial fishery at approximately 130 mm SL and are fully recruited by 180 mm SL, but few exceeded 275 mm SL (National Marine Fisheries Service, Southeast Fisheries Science Center, Trip Interview Program, pers comm). Based on their size, the lionfish collected in the present study were likely young individuals. Therefore, the mercury levels we report may not fully represent levels found in the largest individuals. Invasive lionfish populations have only been established in the western Atlantic for the past decade (Morris and Green 2012), and larger and older individuals (with potentially greater mercury burdens) could become more widely available as the invasive population ages.

The fish from the Florida Keys, southeast, and panhandle regions were collected in directed scientific diver surveys and in conjunction with fishing derbies that promote the removal of all lionfish encountered. In essence, these divers performed "lionfish-focused searches", which yield the highest probabilities of detection in scientific surveys, particularly for larger lionfish (Green et al. 2013). We found no evidence in the literature that large lionfish exhibit behaviors that make them more cryptic to divers than do smaller individuals, so the fish we collected may represent well the current demographic in coastal Florida populations. One exception may be in the southwest region, where our benthic trawls, which are restricted to low-relief habitats, may have been biased toward smaller individuals. For example, Biggs and Olden (2011) found that seagrass habitats in Roatan, Honduras, contained juvenile lionfish, whereas larger individuals selected the complex structure associated with aggregate reef habitats. Future mercury studies on lionfish throughout their invasive range should include efforts directed toward larger individuals that will likely be targeted in developing fisheries.

Table 5. Mercury concentrations [mean (range)] in commonly consumed fish species from Florida. Lengths [mean (range)] are reported as standard length unless otherwise noted. The Florida Department of Health (FDOH) fish consumption advisory data for the general population (without risk factors) are reported (FDOH 2013) as number of meals (6 oz).

Scientific name	Common name	*n*	THg (mg kg^{-1})	Length (mm)	Area	FDOH Advisory	Ref.***
Pterois spp.	Lionfish	260	0.07 (0.01–0.34)	153 (63–262)	Florida	na	
		25	0.04 (0.02–0.06)	(250–350)*	Jamaica	na	5
Epinephelus morio (Valenciennes, 1828)	Red grouper	559	0.17 (0.03–0.79)	429 (163–874)	Gulf	1 wk^{-1}	2
Mycteroperca bonaci (Poey, 1860)	Black grouper	13	0.91 (0.26–1.60)	840 (505–1,373)	Gulf	1 wk^{-1}	2
Mycteroperca microlepis (Goode and Bean, 1879)	Gag	351	0.27 (0.04–1.06)	490 (111–1,140)	Gulf	1 wk^{-1}	2
Mycteroperca phenax (Jordan and Swain, 1884)	Scamp	49	0.19 (0.04–0.59)	481 (282–744)	Gulf	1 wk^{-1}	2
Trachinotus carolinus	Florida pompano	51	0.10 (0.04–0.37)	273 (61–412)	Atlantic	2 wk^{-1}	1
		23	0.20 (0.06–0.49)	289 (193–395)	Gulf	2 wk^{-1}	1
Lutjanus griseus (Linnaeus, 1758)	Gray snapper	92	0.19 (0.08–0.65)	284 (104–505)	Atlantic	2 wk^{-1}	1
		69	0.18 (0.06–0.54)	176 (133–437)	Gulf	2 wk^{-1}	1
		140	0.21 (0.03–0.62)	246 (152–396)	Florida Keys	2 wk^{-1}	1
Mugil cephalus	Striped mullet	14	0.06 (0.02–0.24)	302 (237–469)	Atlantic	2 wk^{-1}	1
		54	0.06 (0.1–0.78)	296 (155–444)	Gulf	2 wk^{-1}	1
Euthynnus alletteratus (Rafinesque, 1810)	Little tunny	114	0.94 (0.11–3.4)	594 (320–803)	Atlantic	1 mo^{-1}	4
Scomberomorus cavalla (Cuvier, 1829)	King mackerel	143	0.94 (0.19–3.6)	904 (595–1,330)**	Atlantic	1 mo^{-1}	3
		136	1.51 (0.18–4.0)	1,024 (559–1,330)**	Gulf	1 mo^{-1}	3
Scomberomorus maculatus (Mitchill, 1815)	Spanish mackerel	195	0.32 (0.04–1.3)	383 (156–752)**	Atlantic	1 wk^{-1}	3
		385	0.53 (0.09–3.2)	382 (190–689)**	Gulf	1 wk^{-1}	3
Thunnus albacares (Bonnaterre, 1788)	Yellowfin tuna	56	0.25 (0.07–0.65)	847 (602–1,340)**	Atlantic	2 wk^{-1}	4
Thunnus atlanticus (Lesson, 1831)	Blackfin tuna	37	1.07 (0.16–2.0)	732 (452–860)**	Atlantic	1 mo^{-1}	4

* Length measure undefined

** Fork length

*** 1: Adams et al. (2003); 2: Tremain and Adams (2012); 3: Adams and McMichael (2007); 4: Adams (2004); 5: Hoo Fung et al. (2013)

Lionfish mercury levels increased with fish length, following a pattern that has been widely reported for many fish species in the southeastern United States (Adams et al. 2003) and in related scorpaenid species from the Azores (Monteiro et al. 1991). However, variability within our regional regression models was considerable, particularly in the Florida Keys region ($r^2 = 0.07$), which had the highest mercury levels but the lowest bioaccumulation rates. This contrasts with the relatively low variability observed for native grouper species in Florida ($r^2 \geq 0.64$, 111–1140 mm SL; Tremain and Adams 2012), which use similar habitats to lionfish (Bullock and Smith 1991). Fish length can serve as a proxy variable that encompasses the underlying factors that affect mercury levels in an individual or species during growth (i.e., differential uptake or absorption rates associated with ontogenetic shifts in prey selection, habitat, and bioenergetics). Invasive lionfish are trophic generalists (Layman and Allgeier 2012, Côté et al. 2013) that utilize many habitats and that can exhibit strong site fidelity (Jud and Layman 2012). Therefore, habitat selection by lionfish can influence mercury uptake, particularly if mercury levels in available prey species differ among habitats. For instance, mercury level differences observed in juvenile red snapper, *Lutjanus campechanus* (Poey, 1860), between trawl-disturbed and natural habitats may partially be explained by red snapper feeding at higher trophic levels over the disturbed substrates (Wells et al. 2008). Further, lionfish are adapted to withstand lengthy periods of starvation, up to 3 mo (Fishelson 1997), and their feeding behaviors can follow a "feast and famine" pattern dependent upon prey availability (Fishelson 1997, Green et al. 2011). Because lionfish growth is tied to feeding rate (Fishelson 1997), this unpredictable feeding strategy may partly explain the high variability in mercury levels among individual fish of similar length. Finally, both *P. volitans* and *P. miles* co-occur in US waters (Freshwater et al. 2009), and both species might have been collected (though not identified) in the present study. The regression variability we observed may be compounded if mercury bioaccumulation rates were found to differ between the two species. In the Azores, Monteiro et al. (1991) found substantially different mercury levels in a comparison of two related scorpaenid species, *Helicolenus dactylopterus* (Delaroche, 1809) and *Pontinus kuhlii* (Bowdich, 1825), although fish size was a confounding factor in that study. Additional data are needed to better understand the factors that contribute to the high variability observed in the present study.

We observed spatial differences in lionfish mercury levels between our Florida study regions, and in comparison to recent data from Jamaica (Hoo Fung et al. 2013). Mercury levels were typically low throughout Florida, but were highest in the Florida Keys. The Florida Keys (including Florida Bay) and the southwest Florida coast are areas in which elevated mercury concentrations have been documented for many fish families including the Centropomidae (snooks), Carangidae (jacks), and Sciaenidae (seatrout and drum) (Strom and Graves 2001, Adams et al. 2003, Adams and Onorato 2005). These elevated levels have been partly attributed to biogeochemical factors in the Florida Everglades that enhance methylation and uptake of mercury (Evans and Crumley 2005, Bergameshi et al. 2012). Most fish in the present study were collected in nearshore coastal environments, but the lionfish from the southwest region were collected 75–250 km offshore. This factor may have contributed to the low mercury levels observed in fish from the southwest region due to the reduced influence of the nearshore environmental conditions that affect mercury levels in biota. Lionfish collected in nearshore waters from Jamaica had low mercury levels similar to our

southwest region samples (Hoo Fung et al. 2013); however, direct comparisons between the two studies are problematic owing to a lack of useable size data in the Jamaica study and differing mercury analysis methods. Rates of metal bioaccumulation in species can reflect site-specific geochemical influences and species-specific physiological constants including assimilation efficiency, detoxification rates, and excretion rates (Luoma and Rainbow 2005). These physiological constants are unknown for lionfish, and future studies that generate these constants will help define mechanisms of mercury bioaccumulation in these species.

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