# Mercury levels in four species of sharks from the Atlantic coast of Florida

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Florida's commercial and recreational shark landings represent a significant portion of the total U.S. Atlantic shark landings (NMFS, 1993). Shark landings have increased significantly during the past decade because human consumption of shark meat has become increasingly acceptable and because, in Asian markets, the demand for shark fins is very high—as are the prices paid for them (NMFS, 1993; Brown, in press). The east-central coast of Florida is an important area for commercial and recreational shark fishing, and a wide array of shark species, including those examined in this study, are landed in this region (Trent et al., 1997; FDEP[1]).

Mercury, a toxic metallic element, has been shown to bioaccumulate in fish tissue, and therefore, fish can represent a major dietary source of mercury to humans (Phillips and Buhler, 1978; Turner et al., 1980; Lyle, 1986). Methylmercury is the most toxic form of mercury for humans to consume (Meaburn, 1978; NMFS, 1993) and essentially all mercury found in fish muscle tissue (>95%) is in the monomethyl form ($CH_3Hg$)(Grieb et al., 1990; Bloom, 1992). Therefore, the measurement of total mercury provides an approximation of methylmercury and has been recommended as the standard for regulatory monitoring (Bloom, 1992). Elevated mercury concentrations in fish have been a growing concern among resource management agencies. Apex predators, particularly long-lived species such as billfishes (Förstner and Wittman, 1981; Barber and Whaling, 1983; Kai et al., 1987), tunas (Miller et al., 1972), mackerels (Meaburn, 1978), and sharks (Forrester et al., 1972; Walker, 1976; Lyle, 1986; Vas, 1991; Hueter et al., 1995, and others) have been reported to accumulate relatively high levels of mercury.

In May 1991, the Florida Department of Health and Rehabilitative Services (FHRS) released a health advisory urging limited consumption of all shark species from Florida waters.[2] Owing to mercury concentrations in excess of U.S. Food and Drug Administration and State of Florida standards, FHRS recommended "adults should eat shark no more than once a week; children and women of childbearing age should eat shark no more than once a month." State of Florida guidelines recommended that fish containing less than 0.5 ppm of total mercury should represent no dietary risk, fish containing 0.5 to 1.5 ppm of total mercury should be consumed in limited amounts, and fish containing greater than 1.5 ppm of total mercury should not be consumed. The 1991 health advisory regarding sharks in Florida waters was derived from a limited number of samples taken from retail sources and from studies that lacked important information regarding species, capture location, sex, and size of sharks examined. Increased landings of sharks in Florida for human consumption (Brown, in press; FDEP[1]) has prompted the need for more detailed information regarding mercury levels in Florida shark species.

Consequently, we report here analyses of total mercury levels in the muscle tissue of three carcharhinids (bull shark, *Carcharhinus leucas*; blacktip shark, *C. limbatus*; and Atlantic sharpnose shark, *Rhizoprionodon terraenovae*) and one sphyrnid (bonnethead shark, *Sphyrna tiburo*) from the east-central coast of Florida.

## Materials and methods

### Sample collection and mercury analysis

Sharks were collected during the Florida Department of Environmental Protection, Florida Marine Research Institute's Fisheries-Independent Monitoring Program in the Indian River Lagoon system and adjacent coastal waters or from commercial gillnet or longline fisheries operating in the nearshore

[1] FDEP (Florida Department of Environmental Protection) Marine Fisheries Information System, Fisheries Assessment Section, 100 Eighth Ave. SE, St. Petersburg, FL 33701.

[2] FHRS (Florida Department of Health and Rehabilitative Services). 1991. Health Advisory for Marine Fish. 1317 Winewood Blvd., Tallahassee, FL 32399, 3 p.

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and offshore waters of east-central Florida. All bull sharks were collected from estuarine nursery habitats within the Indian River Lagoon system from Oak Hill, Florida (approximately 28°52'N), south to the Ft. Pierce Inlet area (approximately 27°28'N). All blacktip, sharpnose, and bonnethead sharks were collected in nearshore and offshore waters from northern Cape Canaveral, Florida (approximately 28°55'N), south to the Sebastian Inlet/Wabasso, Florida, area (approximately 27°45'N). Samples were collected from 1992 to 1995.

Sharks were placed directly on ice and returned to the laboratory, where species, precaudal length (PCL), and sex were recorded. Stage of maturity was determined by examination of internal and external reproductive organs, as well as by comparison of shark size with estimates of size at birth or maturity from previous studies (Parsons, 1983, 1993; Branstetter and Stiles, 1987; Castro, 1996). Individuals were classified as neonates on the basis of unhealed or healing umbilical scars (Castro, 1993). To allow for comparisons with other studies, total length (TL), fork length (FL), and other morphometrics were also recorded according to Compagno (1984). With the exception of embryos, all sharks sampled were considered to be within the size range landed in Florida recreational or commercial fisheries. Axial muscle tissue samples were removed from the left dorsal area anterior to the origin of the first dorsal fin. White muscle tissue taken from this region is representative of the portion of shark used for human consumption. Tissue samples were immediately placed in sterile polypropylene vials, sealed, and frozen at –20°C until analyzed. Before analysis, tissue samples were digested by using standard procedures (EPA, 1991; Frick[3]) to convert all mercury in the sample to $Hg^{+2}$. The mercury in each digested sample was reduced to atomic mercury by reaction with excess stannous chloride. This atomic mercury was purged from solution in a gas-liquid separator and swept into an atomic absorption spectrometer for detection and quantification following standardized procedures (EPA, 1991; Booeshahgi et al.[4]) at the Florida Department of Environmental Protection's Division of Technical Services by using cold vapor atomic absorption spectrometry. Quality control measures included analysis of laboratory blanks, duplicate or triplicate tissue samples, and standard fish tissue reference material (DORM-1, obtained from the National Research Council of Canada) for each group of ten shark samples analyzed (EPA, 1991; Frick[3]; Booeshahgi et al.[4]). All mercury levels are reported as parts per million (ppm) wet weight.

### Data analyses

Data regarding size and total mercury for each species were tested for normality by using the Kolmogorov-Smirnov test with Lilliefors' correction (Fox et al., 1994) and for homoscedasticity by using the $F_{max}$-test (Sokal and Rohlf, 1981) or by computing the Spearman rank correlation between the absolute values of the residuals and the observed value of the dependent variable (Fox et al., 1994). Linear regressions were used to describe relationships between shark size and total mercury concentration. Mercury data were log transformed to meet homoscedascity requirements. We used a *t*-test or Mann-Whitney rank sum test, as appropriate, to test for significant differences in total mercury levels and sizes between males and females for each species.

## Results

### Bull shark, *Carcharhinus leucas*

Eighty-three percent of 53 neonate and juvenile bull sharks (552–1075 mm PCL) tested from the Indian River Lagoon region had total mercury levels that were greater than or equal to the 0.5-ppm threshold level ($\bar{x}$=0.77 ppm; median=0.74 ppm; range 0.24–1.7 ppm) (Table 1). There was no significant difference between lengths of males ($\bar{x}$=735 mm PCL) and females ($\bar{x}$=754.6 mm PCL; *t*-test, $P>0.5$) nor was there a significant difference between mean total mercury levels between males and females ($\bar{x}$=0.76 ppm for both sexes; Mann-Whitney rank sum test, $P>0.05$). Ranges of total mercury for both sexes were also similar.

There was a significant positive correlation between total mercury level and bull shark length (both sexes combined) ($P<0.001$; Fig. 1). Total mercury levels in juvenile bull sharks increased as individuals grew larger, although some small sharks contained levels as high as those in larger sharks.

### Blacktip shark, *Carcharhinus limbatus*

Total mercury levels for 21 juvenile and adult blacktip sharks examined ranged from 0.16 to 2.3 ppm

[3] Frick, T. 1996. Digestion of fish tissue samples for total mercury analysis. Florida Department of Environmental Protection, Division of Technical Services, 2600 Blair Stone Road, Tallahassee, FL 32399. Report MT-015-1.

[4] Booeshahgi, F., M. Witt, and K. Cano. 1995. Analysis of total mercury in tissue by cold vapor atomic absorption. Florida Department of Environmental Protection, Division of Technical Services, 2600 Blair Stone Road, Tallahassee, FL 32399. Report MT-010-1.

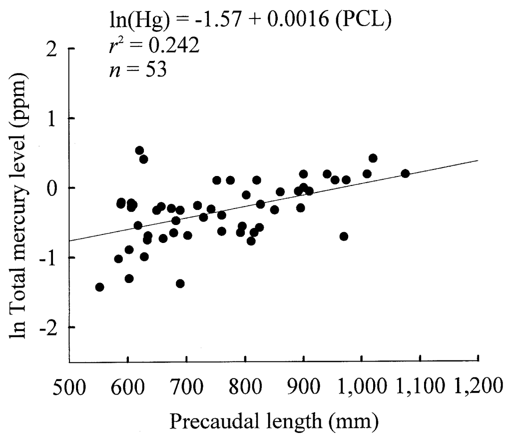


**Figure 1**

Relation between ln total mercury level (ppm) and precaudal length (mm) for juvenile bull sharks, *Carcharhinus leucas*, from the Atlantic coast of Florida.

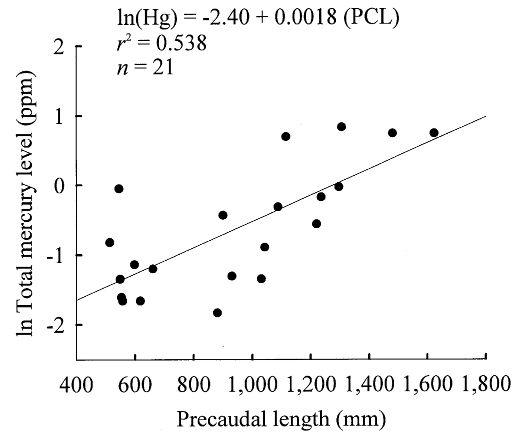


**Figure 2**

Relation between ln total mercury level (ppm) and precaudal length (mm) for juvenile and adult blacktip sharks, *Carcharhinus limbatus*, from the Atlantic coast of Florida.

**Table 1**

Total mercury levels in sharks from the Atlantic coast of Florida. $n$ = number of sharks analyzed.

| | | | | Total mercury (ppm wet weight) | | | Precaudal length (mm) | |
|---|---|---|---|---|---|---|---|---|
| Species | Common name | $n$ | Life history stage | Range | Mean | Standard deviation | Range | Mean |
| *Carcharhinus leucas* | bull shark | 53 | neonate/juvenile | 0.24–1.7 | 0.77 | 0.32 | 552–1075 | 755.6 |
| *Carcharhinus limbatus* | blacktip shark | 21 | juvenile/adult | 0.16–2.3 | 0.77 | 0.71 | 513–1,623 | 939.6 |
| | | 4 | embryo | 0.63–0.78 | 0.69 | 0.07 | 225–232 | 228.7 |
| *Rhizoprionodon terraenovae* | Atlantic sharpnose shark | 81 | juvenile/adult | 0.11–2.3 | 1.06 | 0.63 | 220–857 | 591.6 |
| | | 6 | embryo | 0.17–0.29 | 0.22 | 0.02 | 74–85 | 80.3 |
| *Sphyrna tiburo* | bonnethead shark | 95 | juvenile/adult | 0.13–1.5 | 0.50 | 0.36 | 297–1081 | 590.3 |
| | | 41 | embryo | 0.08–0.35 | 0.16 | 0.07 | 206–255 | 232.1 |

($\bar{x}$=0.77 ppm; median=0.44 ppm) (Table 1). Mean total mercury levels for females ($\bar{x}$=0.87 ppm) were higher than those for males ($\bar{x}$=0.58 ppm); however, these differences were not analyzed for statistical significance because sample sizes were small ($n$=14 females; $n$=7 males). The female blacktip sharks collected in this study were larger ($\bar{x}$=994.3 mm PCL) than the males ($\bar{x}$=830.1 mm PCL). Almost half (47.6%) of the blacktip sharks examined had mercury levels that were greater than or equal to the 0.5-ppm threshold level. The four blacktip shark embryos ($\bar{x}$=235 mm PCL), collected from a single 1050-mm-PCL female whose total mercury level was 2.3 ppm, had total mercury levels ranging from 0.63 to 0.78 ppm ($\bar{x}$=0.69 ppm; median=0.68 ppm) (Table 2). Mercury levels in these embryos equaled 27.4–33.9% of levels observed in their mother.

There was a significant positive correlation between total mercury level and blacktip shark length (both sexes combined)($P$<0.0001; Fig. 2). Total mercury levels in blacktip sharks increased as individuals grew larger, although some small sharks contained levels as high as those in larger sharks.

### Atlantic sharpnose shark, *Rhizoprionodon terraenovae*

Total mercury levels for 81 juvenile and adult Atlantic sharpnose sharks ranged from 0.11 to 2.3 ppm ($\bar{x}$=1.06 ppm; median=0.95 ppm) (Table 1). Although

**Table 2**

Total mercury levels of pregnant female sharks and associated embryos from the Atlantic coast of Florida.

| Species | Pregnant female: Precaudal length (mm) | Pregnant female: Total mercury (ppm) | Embryos: Precaudal length (mm) | Embryos: Sex | Embryos: Total mercury (ppm) |
|---|---|---|---|---|---|
| *Carcharhinus limbatus* | 1050 | 2.3 | 230 | M | 0.78 |
| | | | 227 | M | 0.73 |
| | | | 235 | M | 0.63 |
| | | | 223 | F | 0.63 |
| *Rhizoprionodon terraenovae* | 766 | 1.9 | 84 | F | 0.29 |
| | | | 83 | M | 0.29 |
| | 782 | 1.6 | 76 | M | 0.17 |
| | | | 74 | M | 0.18 |
| | 784 | 2.3 | 85 | F | 0.19 |
| | | | 80 | F | 0.20 |
| *Sphyrna tiburo* | 990 | 1.1 | 229 | M | 0.12 |
| | | | 233 | F | 0.12 |
| | | | 236 | F | 0.14 |
| | 855 | 1 | 225 | M | 0.13 |
| | | | 237 | F | 0.19 |
| | | | 227 | F | 0.12 |
| | 1081 | 1.5 | 238 | F | 0.35 |
| | | | 230 | M | 0.14 |
| *Sphyrna tiburo* | 768 | 0.53 | 239 | F | 0.32 |
| | | | 229 | F | 0.30 |
| | | | 241 | M | 0.26 |
| | | | 224 | F | 0.28 |
| | | | 240 | M | 0.26 |
| | 877 | 1.1 | 238 | F | 0.11 |
| | | | 215 | M | 0.11 |
| | | | 228 | M | 0.13 |
| | | | 239 | F | 0.21 |
| | | | 230 | M | 0.10 |

females ($\bar{x}$=624 mm PCL) were significantly larger than males ($\bar{x}$=541.9 mm PCL) ($t$-test, $P<0.05$), total mercury levels of males ($\bar{x}$=0.92 ppm) and females ($\bar{x}$=1.15 ppm) were not significantly different (Mann-Whitney rank sum test, $P>0.1$). A total of 72.8% of all juvenile and adult Atlantic sharpnose sharks tested had mercury levels that were greater than or equal to the 0.5-ppm threshold level.

Total mercury levels for the six embryos (74–85 mm PCL) examined ranged from 0.17 to 0.29 ppm ($\bar{x}$=0.22 ppm; median=0.19 ppm). Mercury levels for embryos within each litter were very similar (Table 2) and equaled 8.3–15.3% of levels observed in their respective mothers. Overall mercury levels among litters were also similar (±0.02 SD). All confirmed pregnant females had levels greater than 1.0 ppm.

There was a significant positive correlation between total mercury level and Atlantic sharpnose shark length (both sexes combined)($P<0.0001$; Fig. 3). Total mercury level in this species increased as individuals grew larger. Total mercury levels for larger At-

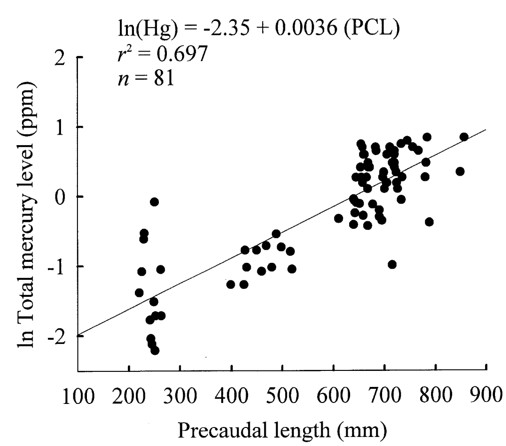


**Figure 3**

Relation between ln total mercury level (ppm) and precaudal length (mm) for juvenile and adult Atlantic sharpnose sharks, *Rhizoprionodon terraenovae*, from the Atlantic coast of Florida.

lantic sharpnose sharks (>500 mm PCL) were always greater than 0.5 ppm.

### Bonnethead shark, *Sphyrna tiburo*

Total mercury levels for the 95 juvenile and adult bonnethead sharks sampled (297–1081 mm PCL) ranged from 0.13 to 1.5 ppm ($\bar{x}$=0.50 ppm; median=0.29 ppm) (Table 1). Forty percent of all juveniles and adults tested had mercury levels that were greater than or equal to the 0.5-ppm threshold level. Mean lengths of males ($\bar{x}$=564.6 mm PCL) and females ($\bar{x}$=619 mm PCL) were not significantly different (Mann-Whitney rank sum test, $P$>0.1) and there were no significant differences in mercury levels between males ($\bar{x}$=0.49 ppm) and females ($\bar{x}$= 0.50 ppm) (Mann-Whitney rank sum test, $P$>0.5). There was a significant positive correlation between total mercury level and bonnethead shark length (both sexes combined) ($P$<0.0001; Fig. 4).

Total mercury levels for the 41 embryos examined (206–255 mm PCL) ranged from 0.08 to 0.35 ppm ($\bar{x}$=0.16 ppm; median=0.13 ppm). Mean length for male and female embryos were both 232-mm PCL. Total mercury levels of male ($\bar{x}$=0.15 ppm) and female ($\bar{x}$=0.18 ppm) embryos were similar (Table 2). Mercury levels for embryos within each litter were similar (± 0.03 SD)(Table 2), as were overall mercury levels among litters (mean mercury level/litter = 0.1–0.28 ppm). Total mercury levels in embryos of this species equaled 9.1–60.4% of levels observed in their respective mothers.

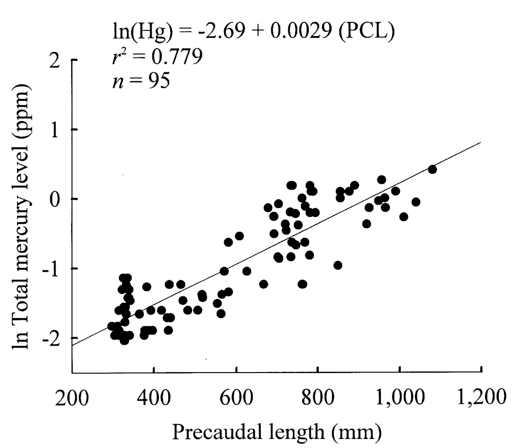


**Figure 4**

Relation between ln total mercury level (ppm) and precaudal length (mm) for juvenile and adult bonnethead sharks, *Sphyrna tiburo*, from the Atlantic coast of Florida.

## Discussion

Results of this study indicated that most individuals in the four species of sharks tested had accumulated levels of total mercury that were as high as or higher than the regulatory threshold levels. Approximately 60% of the juvenile and adult sharks tested in this study had total mercury levels that were greater than or equal to the 0.5-ppm threshold level, and 12% had levels greater than 1.5 ppm. Information regarding mercury in sharks from other areas is limited; however, elevated levels of mercury in various shark species have been documented in several regions, including waters off Florida and the southeastern United States (Gardner et al., 1975; Hueter et al., 1995; FHRS[2]), Canada (Forrester et al., 1972), Great Britain (Vas, 1991), and Australia (Lyle, 1984, 1986). Although the life-history patterns of different shark species are diverse, most sharks grow slowly and have long lifespans. These general life-history characteristics, together with the high trophic status of many shark species, may contribute significantly to the accumulation of high concentrations of mercury (Lyle, 1984).

Mercury levels were directly related to shark size in all species tested. Length differences accounted for 78% of the total variation in mercury levels observed in bonnethead sharks, nearly 70% in Atlantic sharpnose sharks, and approximately 54% in blacktip sharks. The relation between mercury levels and length of juvenile bull sharks was less clear; length differences accounted for only 24% of the variation in mercury levels. The comparatively weak relation between mercury level and size in this species may stem from the fact that only neonates and small juveniles were sampled. Growth rates of bull sharks at the juvenile stage are thought to be quite variable (Dodrill, 1977; Thorson and Lacey, 1982; Branstetter and Stiles, 1987), which may explain some of the observed variability of mercury levels in juveniles of this species. For species we examined, the relations between total mercury and shark size demonstrated that larger, presumably older, individuals accumulated higher levels of mercury. The accumulation of mercury with increasing size and age is likely to be a result of the slow and inefficient elimination of mercury from fish tissue in relation to the rate of accumulation (Rodgers and Beamish, 1982; Bryan, 1984).

Because mercury levels increase as individuals grow larger, levels in juveniles can potentially be viewed as minima for the overall population. Although all bull sharks tested were either neonates or juveniles and the majority of blacktip sharks were juveniles or young adults, both species typically had high mercury concentrations. High mean methylmercury levels (>1.0 ppm wet weight) were also detected in 29 larger size-class bull sharks (approx. 1300–2800 mm TL) and six blacktip sharks (> approx. 1500–1800 mm TL) collected off Florida (Hueter et al., 1995). Two of these bull sharks were collected off east-central Florida; however, specific size or sex data were not reported for these individuals. The observed relation of length to total mercury in juvenile bull sharks, together with results reported for larger size-class bull sharks and other closely related species (Lyle, 1984, 1986; Hueter et al., 1995), indicates that large adult bull sharks could contain excessive mercury levels. Blacktip sharks collected off northern Australia, which were of similar mean length and size range to those examined in our study, also had relatively high total mercury levels (Lyle, 1984, 1986). These data suggest that through bioaccumulation, larger, older adults of these common species potentially contain excessive mercury burdens. Total mercury levels for larger size-class Atlantic sharpnose sharks (>500 mm PCL) that we examined were consistently greater than 0.5 ppm. Muscle tissue from the related Australian sharpnose shark, *Rhizoprionodon taylori*, and the milk shark, *R. acutus*, tested from northern Australian waters (Lyle, 1986) contained mercury levels that were comparable to levels we detected in Atlantic sharpnose sharks. Milk sharks of comparable size examined by Lyle (1986) had total mercury concentrations (range=0.16–2.00 ppm wet weight; $\bar{x}$=1.01 ppm) that were very similar to those in Atlantic sharpnose sharks in the current study.

Bonnethead sharks had the lowest mean mercury content of the four species tested. The relatively low levels found in bonnethead sharks may be related to the comparatively fast growth rate and short life span of this species; however, diet is also an important factor. Bonnethead sharks off Cape Canaveral, Florida (senior author, unpubl. data), as well as off southwest Florida (Cortes et al., 1996), feed principally on crustaceans, whereas the other three species consume a larger proportion of fish (Compagno, 1984; Snelson et al., 1984; Castro, 1996; senior author, unpubl. data). Although available data are limited, crustaceans may contain mercury levels that are lower than those found in many fish species (Gardner et al., 1975; Stickney et al., 1975; Jop et al., 1997).

Mercury levels observed in embryos and neonates, as well as comparisons between pregnant females and associated embryos, indicated that transmission of mercury from maternal sources may be an important factor contributing to total mercury concentrations in shark muscle tissue. Total mercury levels in embryos of all species examined ranged from 8.3 to 60.4% of levels observed in their mothers, whose mercury levels were greater than the 0.5-ppm threshold (Table 2). Mercury levels of embryos within all litters were found to be similar. Mercury concentrations in embryos were variable among species. Atlantic sharpnose and bonnethead shark embryos all contained total mercury levels below the 0.5-ppm threshold; in contrast, all four embryos collected from a 1050-mm-PCL female blacktip shark had mercury levels greater than the threshold level. Variations in mercury concentrations found in embryos of different species could stem from differences in gestation periods or related physiological differences. Blacktip sharks have a two-year reproductive cycle with a 12-month gestation period (Castro, 1996), whereas Atlantic sharpnose sharks have a one-year reproductive cycle with a 10–11 month gestation period (Parsons, 1983). Bonnethead sharks have a gestation period of only 4–5 months (Parsons, 1993)—the shortest known gestation period of any placental viviparous shark species (Parsons[5]). This short gestation period, combined with other physiological factors and maternal diet may explain why bonnethead shark embryos contained the lowest mean mercury levels in this study. Walker (1976) suggested that transfer of mercury to developing ova and embryos may reduce mercury levels in mature females; however, little is currently known about maternal transmission of mercury in fishes. Mercury levels were relatively high in large females despite transfer of mercury to developing ova and embryos.

Results of this study indicate that the majority of sharks examined accumulated levels of total mercury that were greater than or equal to the threshold level of 0.5 ppm determined by the state of Florida. Mercury concentrations in adults and larger juveniles were typically elevated for all species; however, relatively high concentrations were also frequently observed in smaller juvenile bull and blacktip sharks. These data support the current health advisory in Florida urging limited consumption of sharks because of elevated mercury concentrations. Our data, in conjunction with the results of other studies conducted in the region (Gardner et al., 1975; Hueter et al., 1995; FHRS[2]), illustrate that mercury concentrations in several commonly landed shark species from the southeastern United States often exceed state and federal regulatory levels.

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[5] Parsons, G. R. 1997. Department of Biology, University of Mississippi, University, MS 38677. Personal commun.

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