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Bioaccumulation and trophic transfer of mercury in striped bass (*Morone saxatilis*) and tautog (*Tautoga onitis*) from the Narragansett Bay (Rhode Island, USA)

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2 (*Tautoga onitis*) from the Narragansett Bay (Rhode Island, USA)

3

4 Running head: Mercury in striped bass and tautog

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7 tautog, *Tautoga onitis*, trophic transfer

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18 ABSTRACT

19

20 We examined the bioaccumulation and trophic transfer of mercury in two marine finfish species,
21 striped bass (*Morone saxatilis*) and tautog (*Tautoga onitis*), collected from the Narragansett Bay
22 (Rhode Island, USA). For each of these target fish, white muscle tissue was analyzed for total
23 mercury (Hg) and results were evaluated relative to fish age, body size, and Hg content of
24 preferred prey. Dietary and stable isotope analysis was also used to elucidate the effect of
25 trophic processes on Hg concentrations in fish. The Hg content of muscle tissue was positively
26 correlated with fish age and length for both species, although striped bass accumulated Hg faster
27 than tautog. Accelerated Hg bioaccumulation in striped bass is consistent with its high trophic
28 level (trophic level = 4.07) and Hg-enriched prey (forage fish and macrocrustaceans; mean Hg
29 content = 0.03 mg Hg · kg wet wt⁻¹). In contrast, tautog maintain a lower trophic status (trophic
30 level = 3.51) and consume prey with lower Hg levels (mussels and crabs; mean Hg content =
31 0.02 mg Hg · kg wet wt⁻¹). Despite differences in Hg bioaccumulation between target fish, the
32 mean Hg concentration of tautog exceeded levels in striped bass (0.24 and 0.16 mg Hg · kg wet
33 wt⁻¹, respectively) due to a disparity in age-at-catch between sampled groups (mean age of tautog
34 and bass = 11.3 and 4.3 yr, respectively). Taking into account legal minimum catch lengths
35 further revealed that 75.0% of legal-size striped bass (>70.2 cm TL; *n* = 4) and 44.8% of tautog
36 (>40.6 cm TL; *n* = 29) had Hg levels beyond the U.S. EPA regulatory threshold of 0.3 mg Hg ·
37 kg wet wt⁻¹. Moreover, Hg-length relationships suggest that each target fish meets this threshold
38 near their minimum legal catch length. Our findings reiterate the value of species ecology to
39 improve predictions of fish Hg and permit better management of human contamination by this
40 important dietary source.

41 1. Introduction

42

43 Methylmercury (MeHg) is widely recognized as one of the most widespread and toxic
44 environmental contaminants affecting human health. For example, MeHg exposure has been
45 linked to neurological and cardiovascular disorders, immune deficiencies, and reproductive
46 deficits in humans (Moszcynski et al., 1995; Salonen et al., 1995; Grandjean et al., 1997;
47 Sorensen et al., 1999). Dietary uptake of contaminated fish and shellfish is the most important
48 mechanism by which humans are exposed to MeHg (Fitzgerald and Clarkson, 1991; U.S. EPA,
49 1997; Hightower and Moore, 2003), and MeHg constitutes the majority of total mercury (Hg) in
50 fish muscle tissue (>95%; Grieb et al., 1990; Bloom, 1992).

51 The uptake and accumulation of MeHg in aquatic food webs is affected by several
52 biological and environmental variables (Weiner et al., 2003). The main biotic factors
53 contributing to the MeHg burden in fish are age, body size, dietary preference, and trophic
54 position, such that MeHg bioaccumulation and magnification increases in larger/older fish and
55 those feeding at higher trophic levels (Weiner et al., 2003). To this end, understanding the
56 human risk to MeHg exposure requires insight into: (1) the trophic transfer of contaminants
57 through biotic receptors, including fish, and (2) the variability in fish MeHg concentrations as a
58 function of life history (e.g., ontogenetic shifts in diet and habitat use, somatic growth, and
59 longevity).

60 Visual estimates of a predator's stomach contents have traditionally been used to
61 elucidate trophic relationships in aquatic communities. While providing valuable information on
62 diet composition, stomach content analysis is limited because it only reflects immediate feeding
63 activity. Conversely, stable isotope analysis is routinely used to quantify the relative trophic

64 position of a species as a function of its time-integrated diet history (Michener and Schell, 1994).
65 For example, nitrogen isotopic signatures ($^{15}\text{N}/^{14}\text{N}$) are effective at quantifying the trophic
66 position of an organism because enrichment of the heavier isotope (^{15}N) occurs incrementally
67 across trophic levels at a constant rate (approx. 3-4‰; Michener and Schell, 1994). Conversely,
68 carbon isotopic signatures ($^{13}\text{C}/^{12}\text{C}$) are consistent across trophic levels (<1‰ change between
69 primary producer and consumer; Fry and Sherr, 1984), but are valuable biomarkers for
70 identifying different sources of primary production (e.g., salt marsh grasses, macroalgae, benthic
71 microalgae, and phytoplankton) (Peterson and Howarth, 1987), and therefore are effective at
72 distinguishing between benthic and pelagic trophic linkages (France, 1995). Moreover, recent
73 studies have utilized stable isotope techniques to determine patterns of trophic transfer of
74 contaminants in food webs, yet the majority of this research has focused on freshwater systems
75 (Jarman et al., 1996; Bowles et al., 2001; Power et al., 2002; Bank et al., 2007; Cai et al., 2007).

76 The purpose of this study was to examine the bioaccumulation and trophic transfer of
77 total mercury (Hg) in striped bass (*Morone saxatilis*) and tautog (*Tautoga onitis*): two species of
78 marine fish that support lucrative recreational and, to a lesser extent, commercial fisheries along
79 the northeastern United States. Striped bass and tautog were collected from the Narragansett
80 Bay (Rhode Island, USA), and therefore this study represents a comprehensive analysis of Hg
81 contamination at relatively small spatial scales (<400 km²). Furthermore, observed patterns of
82 Hg concentration in striped bass and tautog were analyzed relative to the individual's age and
83 body size. Conventional dietary analyses (i.e., visual observation of stomach contents) were also
84 coupled with nitrogen and carbon stable isotope analyses to define key trophic pathways in the
85 estuarine system and quantify the transfer of Hg contaminants in the food web.

86

87 2. Materials and methods

88

89 2.1. Target species

90

91 Striped bass are an estuarine-dependent species with a geographic distribution ranging
92 from the Gulf of St. Lawrence to Florida (Collette and Klein-MacPhee, 2002). As obligate users
93 of estuarine systems (Able, 2005), striped bass exhibit large plasticity in migration strategies that
94 range from local seasonal movements within estuaries to extensive coastal migrations (Secor and
95 Piccoli, 2007). Striped bass of various life history stages utilize multiple habitat-types, which are
96 governed by the availability of preferred food resources, e.g., small forage fish and
97 macrocrustaceans (Harding and Mann, 2003; Nelson et al., 2003, 2006). Moreover, somatic
98 growth rates of striped bass are consistent with other temperate, long-lived fishes (~ 20-30 yr;
99 Secor et al., 1995; Secor, 2000; Collette and Klein-MacPhee, 2002), but growth rates of striped
100 bass demonstrate significant latitudinal differences (Welsh et al., 2003).

101 Tautog are a temperate wrasse distributed along the northwestern Atlantic coast
102 extending from Nova Scotia to South Carolina, with peak concentrations occurring in coastal
103 regions from Cape Cod to the Chesapeake Bay (Collette and Klein-MacPhee, 2002). In contrast
104 to striped bass, tautog exhibit strong site fidelity (Olla et al., 1979; Able and Fahay, 1998) and
105 only limited seasonal migrations that are attributed to estuarine residency during spring spawning
106 events and the subsequent migration to nearshore wintering habitats (Olla et al., 1974; Briggs,
107 1977). The diet of tautog consists of epibenthic and encrusting invertebrates (e.g., brachyuran
108 crabs and bivalves; Steimle et al., 2000), and the longevity of this slow-growing fish exceeds 30
109 yr (Cooper, 1967; Steimle and Shaheen, 1999).

110

111 *2.2. Sample collection, processing, and preservation*

112

113 Striped bass, tautog, and “bioavailable” prey were collected from the Narragansett Bay in
114 2006 and 2007 using bottom trawls, seines, fish traps, and hook & line (Fig. 1). “Bioavailable”
115 prey are defined as small forage fish and invertebrates that were captured in the field and
116 represent common food items of striped bass and tautog (Steimle et al., 2000; Nelson et al.,
117 2003, 2006), i.e., river herring (*Alosa* spp.), bay anchovy (*Anchoa mitchilli*), Atlantic menhaden
118 (*Brevoortia tyrannus*), scup (*Stenotomus chrysops*), green crab (*Carcinus maenas*), black-finger
119 mud crab (*Panopeus herbstii*), sand shrimp (*Crangon septemspinosa*), and blue mussel (*Mytilus*
120 *edulis*). For a complete description of gear specifications, collection locations, and sample
121 frequency, refer to the sampling procedures identified in Lynch (2000) and Collie et al. (2008).

122 Fish and invertebrates captured in the field were immediately placed on ice for
123 transportation and frozen at -4°C after returning to the laboratory. Individuals were then
124 partially thawed and measured for wet weight (g) and total length (TL cm; fish and shrimp),
125 carapace width (CW cm; crabs), or shell height (SH cm; blue mussels) (Tables 1 and 2).
126 Bioavailable prey were subsequently processed and analyzed as whole-body samples, with the
127 exception of mussels that had their shells removed. For striped bass and tautog, ~ 2.5 g wet
128 weight of white muscle tissue (with scales and skin removed) was excised from the dorsal region
129 above the operculum using a stainless-steel scalpel ($D_0 = 1$ biopsy per left and right side of the
130 fish; Fig. 2A). To ensure that the total mercury concentration of this biopsy was indicative of the
131 whole-body file, a sub-sample of bass and tautog ($n = 18$ and 14 , respectively) had additional
132 biopsies excised from the dorsal and lateral tissue along the anterior-posterior axis (D_{1-3} and L_{1-3} ;

133 6 biopsies per left and right side of the fish; Fig. 2A). The stomachs of bass and tautog were also
134 removed, and the contents were examined. The “recovered” prey items from dissected stomachs
135 were identified to the lowest practical taxon, and where possible, measured for wet weight (g)
136 and TL (cm; fish and shrimp) or CW (cm; crabs). For final preservation, all samples were
137 freeze-dried for 48 hr (Labconco FreeZone 4.5 L Benchtop Freeze-Dry System), and
138 subsequently weighed (g dry weight), homogenized with a mortar and pestle, and stored at room
139 temperature in clear borosilicate 40-mL vials (Peterson et al., 2005).

140

141 2.3. Mercury analysis

142

143 Total mercury (Hg) was measured in the muscle biopsies and stomach contents (i.e.,
144 “recovered” prey) of striped bass and tautog, and whole-body samples of “bioavailable” prey
145 using a DMA-80 Direct Mercury Analyzer (Cizdziel et al., 2002). For all target fish and prey, a
146 sub-sample of freeze-dried/homogenized tissue (~ 40 mg) was added to the mercury analyzer.
147 The instrument has a detection limit of 0.01 ng Hg (typical working range 0.05-600 ng), and
148 employs thermal decomposition, amalgamation, and atomic absorption spectrophotometry (EPA
149 Method 7473; U.S. EPA, 1998). The mercury analyzer was calibrated using standard reference
150 materials (SRMs) of known Hg content and prepared by the National Research Council Canada,
151 Institute of Environmental Chemistry (Ottawa, Canada), i.e., TORT-1 (lobster hepatopancreas)
152 and DORM-2 (dogfish muscle). Calibration curves were highly significant (mean $R^2 = 1.00$;
153 range $R^2 = 0.99-1.00$; $p < 0.0001$), and the recovery of TORT-1, DORM-2, and PACS-2 (marine
154 sediment) SRMs ranged from 91.1% to 108.3% (mean = 97.3%). For quality control, all
155 samples were analyzed as duplicates (acceptance criteria = 10% error), and an additional 10% of

156 the samples were analyzed as blind replicates (acceptance criteria = 10% error). For further
157 quality assurance, blanks (i.e., empty quartz boat) were analyzed every 10 samples to assess
158 instrument accuracy and potential drift.

159 Toxic methylmercury (MeHg) typically accounts for the majority of total Hg in fish
160 tissue (>95%; Grieb et al., 1990; Bloom, 1992). To ensure the accuracy of this approximation, a
161 sub-sample of striped bass and tautog tissue (D_0 biopsy; $n = 11$ for each species) were analyzed
162 for MeHg (and inorganic Hg) concentration by isotope dilution gas chromatography inductively
163 coupled plasma mass spectrometry (GC-ICP-MS) at the Trace Element Analysis Laboratory,
164 Dartmouth College (Hanover, New Hampshire, USA). Fish tissue (30-50 mg dry weight),
165 previously freeze-dried and homogenized, was added to amber glass vials. Approximately 2.65
166 ng of aqueous $\text{CH}_3\text{Hg}^{201}$ was then added as the enriched isotope spike to the sample, followed by
167 10 ml of 4 mol l^{-1} HNO_3 (Hintelmann and Nguyen, 2005). The entire sample was heated over
168 night at 55 °C, after which a 50- μl sub-sample of the extract was analyzed by purge and trap,
169 thermal desorption GC-ICP-MS (Rodriguez Martin-Doimeadios et al., 2002). This process
170 includes the ethylation and trapping of volatile Hg species on Tenax traps (Brooks Rand, Seattle,
171 Washington, USA), followed by thermal desorption onto open column GC and Hg isotope
172 detection by ICP-MS (Element2, Thermo-Finnegan, Bremen, Germany). The recovery of MeHg
173 in TORT SRM was 94.8% (range = 91.5-96.2%) and sample precision for duplicate runs was
174 99.2% (range = 96.6-102.2%).

175 Total Hg levels measured by the DMA-80 Direct Mercury Analyzer were in good
176 agreement with the isotope dilution ICP-MS method (MeHg + inorganic Hg = total Hg) (Linear
177 regression: $R^2 = 0.902$; $p < 0.0001$; $y = 0.7659x + 0.0325$). Total Hg was higher (10.7%) in
178 samples analyzed by the DMA-80 Direct Mercury Analyzer (mean = 0.255 ± 0.032 mg Hg · kg

179 wet weight⁻¹) relative to the ICP-MS method (mean = 0.227 ± 0.026 mg Hg · kg wet weight⁻¹).
 180 This difference was not statistically significant (one-way ANOVA: $F = 0.16$, $df = 1,43$, $p =$
 181 0.693), however, and total Hg concentrations are hereafter reported for the DMA-80 Analyzer
 182 only.

183

184 2.4. Stable isotope analysis

185

186 Nitrogen and carbon isotope measurements of a sub-sample of freeze-dried target fish (D_0
 187 biopsy; $n = 18-20$) and bioavailable prey (whole-body; $n = 18-20$) were performed by the Boston
 188 University Stable Isotope Laboratory (Boston, Massachusetts, USA). Samples of animal (~1 mg
 189 dry weight) were analyzed using automated continuous-flow isotope ratio mass spectrometry
 190 (Preston and Owens, 1983). Samples were combusted in a EuroVector Euro EA elemental
 191 analyzer (Eurovector, Milan, Italy), after which N_2 and CO_2 gases were separated on a GC
 192 column, passed through a reference gas box, and introduced to an GV Isoprime isotope ratio
 193 mass spectrometer (GV Instruments, Manchester, UK). Ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ were
 194 expressed as the relative per mil (‰) difference between the samples and international standards
 195 (Vienna Peedee Belemnite carbonate, $^{13}C_{V-PDB}$, and atmospheric nitrogen, $^{15}N_{air}$, respectively):

196

$$197 \quad \delta X = \left(R_{sample} / R_{standard} - 1 \right) \times 1000 (\text{‰}) \quad (1)$$

198

199 where, $X = ^{13}C$ or ^{15}N and $R = ^{13}C/^{12}C$ or $^{15}N/^{14}N$. The sample isotope ratio was compared to a
 200 secondary gas standard, whose isotope ratio was calibrated to international standards ($R_{standard}$).

201 For $^{13}C_{V-PDB}$, the gas was calibrated against NBS 20 (Solenhofen limestone). For $^{15}N_{air}$, the gas

202 was calibrated against atmospheric N₂ and ammonium sulfate standards (IAEA standards N-1,
203 N-2, and N-3). All international standards were obtained from the National Bureau of Standards
204 in Gaithersburg, Maryland, USA.

205

206 2.5. Statistical analyses

207

208 Prior to parametric statistical analysis, total Hg data were converted to wet weight using a
209 wet/dry ratio measured for a sub-sample of striped bass, tautog, and bioavailable prey (Tables 1
210 and 2). Data were then log₁₀-transformed or arc-sin square-root transformed (proportional data)
211 to meet assumptions of normality and homogeneity of variance. Mean Hg concentrations among
212 muscle biopsies taken from striped bass ($n = 18$) and tautog ($n = 14$) were statistically compared
213 with independent one-way analysis of variance (ANOVA) models using biopsy location (D₀₋₃
214 and L₁₋₃ biopsies; Fig. 2A) as a fixed factor. Note that the Hg content of a single muscle biopsy
215 represents the average calculated for the left and right side of the fish. Interspecies differences in
216 muscle mercury levels (total Hg and %MeHg), stomach content Hg levels (recovered prey), and
217 isotopic signatures ($\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) were analyzed with one-way ANOVA models using species
218 (striped bass and tautog) as a fixed factor. The effects of target fish TL (cm) and age (yr) on
219 total Hg concentration were analyzed with least-squares (non-linear) exponential regressions.
220 The ages of individual striped bass and tautog were estimated from species-specific age-size
221 relationships reported in the literature (Hostetter and Munroe, 1993; Nelson et al., 2006). To
222 assess differences in Hg bioaccumulation rates between striped bass and tautog, two-way
223 ANOVA models were used to test for homogeneity of slopes (i.e., interaction effects between
224 size/age and species) of the linearized exponential regressions (semi-logarithmic transformation).

225 The total Hg concentration and isotopic signature of bioavailable prey were analyzed
226 with a one-way ANOVA models using prey species as a fixed factor. Mean differences in total
227 Hg levels and isotopic signatures across 8 and 7 levels of prey, respectively, were contrasted
228 with a Ryan–Einot–Gabriel–Welsch (Ryan’s Q) multiple comparison test. Note that direct
229 statistical comparisons of the Hg content and isotope values of target fish and bioavailable prey
230 were not made because of the different tissues analyzed between the groups (i.e., dorsal muscle
231 versus whole-body tissues, respectively) (Gray, 2002). Non-linear exponential regression
232 analysis was used, however, to test for the effect of trophic position ($\delta^{15}\text{N}$) and carbon sources
233 ($\delta^{13}\text{C}$) on the transfer total Hg through the estuarine food web.

234

235 3. Results

236

237 3.1. Evaluation of mercury analysis methods

238

239 There was no significant difference in the mean total Hg concentration among muscle
240 biopsies from an individual striped bass or tautog (one-way ANOVA; bass: $F = 0.15$, $df = 6,125$,
241 $p = 0.989$; tautog: $F = 0.12$, $df = 6,97$, $p = 0.994$) (Fig. 2). The Hg concentration of tissue located
242 above the operculum (D_0 biopsy; Fig. 2A) is therefore indicative of the contaminant present in
243 the whole-body white muscle filet, and Hg levels in target fish are hereafter reported for the D_0
244 biopsy only. Mercury speciation analysis also revealed that MeHg accounts for >98% (range =
245 96.3-99.6%) of the total Hg present in the muscle tissue of striped bass and tautog (Table 1). To
246 this end, measurements of total Hg are a suitable approximation of MeHg in the white muscle
247 tissue of target fish.

248

249 *3.2. Mercury analysis of target fish*

250

251 Total Hg levels in the dorsal muscle tissue of target fish ($n = 119$) ranged from 0.03 to
252 0.58 mg Hg · kg wet wt⁻¹ (Table 1). Of these samples, the mean total Hg concentration of tautog
253 was 33.3% greater than values measured in striped bass (Table 1). To account for differences in
254 age-at-catch, total Hg data were standardized by the estimated age of each fish. Accordingly,
255 age-normalized Hg levels of striped bass were 47.4% higher than concentrations measured in
256 tautog.

257 There was a significant positive correlation between total Hg concentration and TL for
258 both target fish (Exponential regression; bass: $F = 50.35$, $df = 1,65$, $p < 0.0001$; tautog: $F =$
259 86.28 , $df = 1,52$, $p < 0.0001$) (Fig. 3A). However, the slope of the linearized exponential
260 regression model for tautog ($\beta = 0.022$) was greater than striped bass ($\beta = 0.013$) (two-way
261 ANOVA; species × length: $F = 7.98$, $df = 3,118$, $p < 0.01$), indicating that tautog have higher Hg
262 concentrations at a given body length. Total Hg concentration also increased significantly with
263 fish age, irrespective of species (Exponential regression; bass: $F = 56.15$, $df = 1,65$, $p < 0.0001$;
264 tautog: $F = 82.13$, $df = 1,52$, $p < 0.0001$) (Fig. 3B). In contrast to the mercury-length
265 relationship, however, Hg bioaccumulation rates as a function of age were significantly faster in
266 striped bass than tautog ($\beta = 0.133$ and 0.065 , respectively) (two-way ANOVA; species × age: F
267 $= 13.17$, $df = 3,118$, $p < 0.0005$).

268 Of the target fish analyzed in this study, 12.1% of striped bass and 30.2% of tautog
269 exceeded the U.S. Environmental Protection Agency advisory level of 0.3 mg MeHg · kg wet
270 wt⁻¹ (U.S. EPA, 2006). Data were also analyzed with respect to legal-size limits for each

271 species, i.e., minimum catch size for striped bass and tautog in Rhode Island equal 70.2 and 40.6
272 cm, respectively (RIDEM, 2008). The mean total Hg concentration of legal-size striped bass
273 was 0.342 ± 0.040 mg Hg · kg wet wt⁻¹ ($n = 4$), of which 75.0% exceeded the U.S. EPA advisory
274 level. For legal-size tautog, the mean total Hg concentration was 0.319 ± 0.027 mg Hg · kg wet
275 wt⁻¹ ($n = 29$), and 44.8% of these fish had Hg levels above 0.3 mg MeHg · kg wet wt⁻¹. The
276 mercury-length exponential regression model also predicted that striped bass and tautog attain
277 Hg concentrations equal to the U.S. EPA advisory level near their minimum legal catch size
278 (75.7 and 48.6 cm TL, respectively; Fig. 3A).

279

280 *3.3. Stomach content analysis*

281

282 The stomach contents of striped bass and tautog revealed interspecies differences in diet
283 (Table 3). The results suggest that striped bass are opportunistic foragers, as bass consumed 10
284 different recovered prey species. Teleost fish and decapod crustaceans (sand shrimp and green
285 crab) comprised the largest fraction of the striped bass diet. Collectively, these prey items were
286 identified in 29.4% of the stomachs analyzed. Only 5 novel prey taxa were positively identified
287 in tautog stomachs (Table 3); hence, relative to bass, tautog demonstrate a selective foraging
288 strategy. The blue mussel and decapod crabs (green, mud, and unidentified crabs) were the
289 preferred prey of tautog, occurring in 43.0% of the stomachs.

290

291 *3.4. Mercury analysis of prey*

292

293 The principal prey of striped bass and tautog, as determined by dietary analysis, were
294 collected from the Narragansett Bay and subsequently analyzed for whole-body total Hg. Mean
295 total Hg levels of these bioavailable prey varied significantly as a function of prey-type (one-way
296 ANOVA; $F = 29.70$, $df = 7,835$, $p < 0.0001$) (Table 2). With the exception of the Atlantic
297 menhaden, prey that were exclusive to striped bass (anchovy, herring, scup, and sand shrimp)
298 had significantly higher Hg concentrations than the prey of tautog (blue mussel and mud crab)
299 (Ryan's Q multiple comparison test) (Fig. 4). On average, the total Hg concentration of tautog
300 prey was 32.0% lower than the diet items of striped bass. The mean total Hg concentration of
301 prey removed from tautog stomachs was also 13.2% lower than the recovered prey of striped
302 bass, but this difference was not significant at $p < 0.05$ (Table 1).

303

304 *3.5. Stable isotope analysis*

305

306 Stable nitrogen ($\delta^{15}\text{N}$) isotope signatures were used to delineate the trophic positioning of
307 target fish and bioavailable prey. Mean $\delta^{15}\text{N}$ values varied considerably among taxonomic
308 groups (Tables 1 and 2; Fig. 5). Striped bass had a significantly higher $\delta^{15}\text{N}$ value relative to
309 tautog, and both target fish had higher $\delta^{15}\text{N}$ values than their preferred prey. Among prey, $\delta^{15}\text{N}$
310 values varied significantly across species (one-way ANOVA; $F = 57.99$, $df = 6,136$, $p < 0.0001$).
311 Specifically, significant ^{15}N enrichment was observed in scup and bay anchovy, whereas the
312 most depleted $\delta^{15}\text{N}$ values were calculated for Atlantic menhaden and blue mussel (Table 2; Fig.
313 5) (Ryan's Q multiple comparison test).

314 The $\delta^{15}\text{N}$ value of the blue mussel was used to assign distinct trophic levels for each
315 consumer species analyzed in this study (modified from Hobson et al., 2002).

316

$$317 \quad \text{Trophic level} = 2 + \frac{(\delta^{15}\text{N}_{\text{consumer}} - \delta^{15}\text{N}_{\text{mussel}})}{3.4} \quad (2)$$

318

319 where, “2” is the assumed trophic level of the blue mussel, a phytoplanktivore (Newell, 1989),
 320 $\delta^{15}\text{N}_{\text{mussel}}$ and $\delta^{15}\text{N}_{\text{consumer}}$ are the respective nitrogen isotope signatures of blue mussel (10.62‰;
 321 this study) and the consumer species of interest, and “3.4” is the constant nitrogen isotope
 322 enrichment (‰) per trophic level (Post, 2002). Accordingly, striped bass and tautog were
 323 designated a trophic level of 4.07 ± 0.08 and 3.51 ± 0.03 , respectively, whereas prey species
 324 (excluding mussels) occupied trophic levels between 2.43 and 3.26 (Tables 1 and 2).

325 Stable carbon ($\delta^{13}\text{C}$) isotope signatures were used to determine the varying sources of
 326 primary production to the estuarine food web (e.g., benthic algae versus phytoplankton), and
 327 thus, distinguish between benthic and pelagic trophic linkages (Peterson and Howarth, 1987;
 328 France, 1995). Measured $\delta^{13}\text{C}$ values ranged from $-20.16 \pm 0.17\text{‰}$ to $-15.13 \pm 0.25\text{‰}$ and
 329 varied significantly between target fish (Table 1) and among prey (one-way ANOVA; $F = 40.66$,
 330 $df = 6, 136$, $p < 0.0001$) (Table 2). Moreover, two distinct isotopic groups were demarcated by a
 331 $\delta^{13}\text{C}$ value of approximately -18‰ (Fig. 5). Relative to this demarcation point, more depleted
 332 $\delta^{13}\text{C}$ values indicate a phytoplankton-based (pelagic) food web, and in this study were
 333 represented by the striped bass, planktivorous forage fish, and blue mussels. Conversely, $\delta^{13}\text{C}$
 334 signatures greater than -18‰ (i.e., more enriched) suggest benthic sources of primary production
 335 and were characteristic of tautog, scup, and decapod crustaceans.

336 Stable isotope analysis was coupled with total Hg data to provide insight into the effects
 337 of trophic structure on species contamination. There was a significant positive correlation
 338 between mean total Hg concentration and $\delta^{15}\text{N}$ values measured for target fish and bioavailable

339 prey (Exponential regression; $F = 38.79$, $df = 1,8$, $p < 0.0005$) (Fig. 6); hence verifying an
340 increase in Hg contamination at higher trophic levels in the estuarine food web. Conversely, no
341 significant relationship was observed between mean total Hg concentration and $\delta^{13}\text{C}$ values
342 measured across all species (Exponential regression; $F = 0.20$, $df = 1,7$, $p = 0.670$).

343

344 **4. Discussion**

345

346 *4.1. Mercury analysis of target fish*

347

348 This study provides information on Hg levels in the muscle tissue of striped bass and
349 tautog collected from the Narragansett Bay, and also examines the effect of several biotic factors
350 on interspecies Hg bioaccumulation patterns. A significant positive correlation between Hg
351 concentration and target fish age (and size) was observed for striped bass and tautog, and similar
352 patterns have been previously documented for each species (Hammerschmidt and Fitzgerald,
353 2006a; Mason et al., 2006). The Hg-age relationship confirms that striped bass and tautog
354 effectively bioaccumulate Hg, which is further explained by a low rate of Hg depuration relative
355 to the rapid accumulation of Hg in fish muscle tissue (Clarkson, 1992; Trudel and Rasmussen,
356 1997). It is well established that dietary uptake is the dominant source of Hg in fish (Hall et al.,
357 1997); however, striped bass bioaccumulate Hg at an accelerated rate relative to tautog. For
358 example, the slope of the linearized exponential (Hg-age) regression provides an estimate of the
359 Hg bioaccumulation rate for a given species. The comparison of these slope values between the
360 target fish predicts that striped bass ($\beta = 0.133$) accumulate Hg in muscle tissue twice as fast as
361 tautog ($\beta = 0.065$). As discussed in the subsequent section, differences in diet and trophic

362 positioning in the estuarine food web likely account for the observed patterns of Hg
363 bioaccumulation in the target fish (Weiner et al., 2003; Bank et al., 2007).

364 Although striped bass accumulate Hg more rapidly than tautog, results from this study
365 indicate that the mean Hg concentration of tautog exceeded levels in bass. This apparent
366 discrepancy is attributed to the greater age-at-catch of tautog (Cooper, 1967), and thus,
367 protracted period in which this species is exposed to Hg. Specifically, the average age of tautog
368 in this study was 2.6 times greater than striped bass; hence, at a given body length, tautog had a
369 higher Hg tissue concentration than bass. A similar explanation was provided by
370 Hammerschmidt and Fitzgerald (2006a) to reconcile the difference in Hg concentrations
371 observed in tautog and bluefish (*Pomatomus saltatrix*), an apex piscivore, from the Long Island
372 Sound. To this end, the authors recommended that fish longevity be considered when assessing
373 their potential risk to human consumers (Hammerschmidt and Fitzgerald, 2006a).

374 In this investigation, Hg concentrations of tautog were comparable to values observed in
375 conspecifics from other coastal ecosystems. Hammerschmidt and Fitzgerald (2006a), using
376 cold-vapor atomic fluorescence spectrometry (CVAFS), analyzed the mercury content of tautog
377 collected from the Long Island Sound (mean TL = 41.4 cm; $n = 32$), and reported an average
378 MeHg concentration of $0.19 \text{ mg MeHg} \cdot \text{kg wet wt}^{-1}$ for axial muscle tissue. Moreover, for
379 tautog collected from the New York Bight Apex (mean TL = 31.0 cm; $n = 14$), Deshpande et al.
380 (2000) estimated a mean total Hg concentration of $0.08 \text{ mg Hg} \cdot \text{kg wet wt}^{-1}$ for white muscle
381 tissue. Using the exponential regression presented in this study, tautog of comparable sizes (41.4
382 and 31.0 cm) from the Narragansett Bay had projected Hg values of 0.21 and $0.12 \text{ mg Hg} \cdot \text{kg}$
383 wet wt^{-1} , respectively.

384 In contrast to tautog, geographic variability in Hg contamination was apparent in striped
385 bass. In the Chesapeake Bay, for example, the dorsal muscle tissue of striped bass (mean TL ~
386 66 cm; $n = 70$) had a mean MeHg concentration of $0.12 \text{ mg MeHg} \cdot \text{kg wet wt}^{-1}$ (analyzed using
387 CVAFS; Mason et al., 2006). This level of contamination is considerably lower than the
388 estimated MeHg content of striped bass from the Narragansett Bay that are of the same TL (0.22
389 $\text{mg MeHg} \cdot \text{kg wet wt}^{-1}$; using Hg-size relationship and %MeHg data). It is also noteworthy that
390 the mean proportional contribution of MeHg to total Hg in striped bass from the Chesapeake Bay
391 (65%; Mason et al., 2006) was lower than the value reported in this study (98.7%).

392 Spatial variations in the Hg burden of marine and estuarine fish are poorly understood,
393 but are presumably a function of geographic differences in the level of Hg input to the ecosystem
394 and biogeochemical conditions that affect MeHg production and mobilization (Rolfhus and
395 Fitzgerald, 1995; Benoit et al., 2003; Kraepiel et al., 2003; Hammerschmidt and Fitzgerald,
396 2006b). Moreover, spatially-explicit physicochemical variables and predator-prey interactions
397 influence the initial incorporation of Hg into the food web and its subsequent transfer through
398 trophic assemblages (Lindqvist et al., 1991; Watras and Bloom, 1992; Mason et al., 1996; Bloom
399 et al., 1999; Sveinsdottir and Mason, 2005). The assessment of spatial differences in fish Hg
400 levels, however, are complicated for those species that exhibit large-scale seasonal migrations
401 and ontogenetic shifts in habitat use and diet, as reported for striped bass (Harding and Mann,
402 2003; Nelson et al., 2003, 2006; Secor and Piccoli, 2007).

403

404 *4.2. Diet and trophic effects on Hg bioaccumulation*

405

406 Visual analysis of the stomach contents of tautog and striped bass revealed differences in
407 their feeding strategy and diet composition. Tautog exhibited a strict durophagous foraging
408 strategy, and therefore fed exclusively on hard-bodied epibenthic and encrusting invertebrates.
409 Macrocrustaceans were also numerically dominant prey for striped bass, although dietary overlap
410 with tautog was minimal. Further, striped bass were piscivorous, with teleosts accounting for a
411 large proportion of the identified diet. These results are consistent with previous analyses of the
412 food habits of tautog and striped bass collected from other coastal Atlantic regions, including the
413 Chesapeake Bay (Hildebrand and Schroeder, 1928; Hartman and Brandt, 1995; Harding and
414 Mann, 2003; Walter and Austin, 2003), Delaware Bay (Steimle and Shaheen, 1999), New York-
415 New Jersey estuarine waters (Olla et al., 1974; Festa, 1979; Steimle and Ogren, 1982), and
416 Massachusetts coastal waters (Nelson et al., 2003, 2006).

417 Measurements of interspecies $\delta^{13}\text{C}$ signatures corroborated the findings of the
418 conventional dietary analysis of target fish. Specifically, tautog had a $\delta^{13}\text{C}$ signature consistent
419 with a benthic carbon source and presumably derived from the consumption of epibenthic
420 crustaceans. It was evident, however, that tautog maintained a lower $\delta^{13}\text{C}$ value than its
421 principal crustacean prey, the green crab. This discrepancy is attributed to the substantial
422 contribution of the blue mussel, a phytoplanktivore (Newell, 1989), to the diet of tautog. In
423 contrast to tautog, striped bass had a $\delta^{13}\text{C}$ signature characteristic of a pelagic carbon source,
424 which in turn resulted from bass feeding on forage fish. The slightly more enriched $\delta^{13}\text{C}$
425 signature of striped bass relative to planktivorous forage fish, however, may reflect the additional
426 contribution of decapod crustaceans to the diet of bass.

427 The diet and trophic ecology of striped bass and tautog are the main factors impacting
428 their respective Hg bioaccumulation rates. In this study, species-specific $\delta^{15}\text{N}$ signatures

429 indicate that striped bass occupy a higher trophic position than tautog (trophic level ~ 4.1 and
430 3.5, respectively). The variation in trophic status between target fish is adequately explained by
431 the trophic positioning of their prey. Striped bass, for example, feed on relatively high trophic
432 level prey (forage fish and decapod crustaceans; mean trophic level = 2.86), whereas tautog
433 consume prey that occupy lower trophic levels (mussel and green crab; mean trophic level =
434 2.33). The analysis of Hg levels in bioavailable prey further revealed that striped bass feed on
435 Hg-enriched prey relative to the dietary items of tautog (mean Hg content of prey = 0.03 and
436 0.02 mg Hg · kg wet wt⁻¹, respectively). The Atlantic menhaden, an important food resource of
437 striped bass (Walter and Austin, 2003; Nelson et al., 2006; this study), was an exception to this
438 observed pattern. The low Hg content of menhaden was attributed to this species occupying a
439 low trophic position in the estuary (~ 2.4). This is further supported by a depleted $\delta^{13}\text{C}$ signature
440 in menhaden, which implies that this species consumes phytoplankton (e.g., pelagic diatoms;
441 Collette and Klein-MacPhee, 2002).

442 The positive correlation between Hg levels and $\delta^{15}\text{N}$ signatures of sampled biota
443 indicates that Hg is trophically transferred through the estuarine food web, as reported in other
444 aquatic systems (Jarman et al., 1996; Bowles et al., 2001; Power et al., 2002; Bank et al., 2007;
445 Cai et al., 2007). Precaution must be exercised in this study, however, when evaluating the rate
446 of Hg increase across trophic levels. This is particularly warranted for direct comparisons
447 between target fish and bioavailable prey because different tissues were analyzed (dorsal muscle
448 and whole-body tissues, respectively). Previous studies have demonstrated that certain body
449 tissues (e.g., muscle, liver) disproportionately concentrate Hg, and thus, have higher Hg levels
450 than whole-body samples (Gray, 2002; Peterson et al., 2005). If applicable to this investigation,
451 then the muscle tissue of target fish is expected to have modestly inflated Hg levels relative to

452 the entire body. Notwithstanding this limitation, the cumulative data presented herein offers
453 compelling evidence that time-integrated diet history and trophic relationships are the dominant
454 factors impacting Hg bioaccumulation in the Narragansett Bay estuary.

455

456 *4.3. Human health perspective*

457

458 Cursory examination of this study's full data set indicates that Hg concentrations in target
459 fish are relatively low, i.e., only 12.1% of striped bass and 30.2% of tautog exceeded the U.S.
460 EPA criterion of 0.3 mg MeHg · kg wet wt⁻¹ (U.S. EPA, 2006). To accurately assess the possible
461 human health risks associated with eating fish, however, contaminant data must be analyzed
462 relative to state-imposed legal-size limits for target species. In this study, reevaluating the Hg
463 data for only legal-size fish revealed that 75.0% of striped bass and 44.8% of tautog accumulated
464 Hg levels beyond the U.S. EPA regulatory threshold. Moreover, the mercury-length exponential
465 model presented in this study suggests that striped bass and tautog obtain Hg levels of 0.3 mg Hg
466 · kg wet wt⁻¹ near their minimum legal catch size (75.7 and 48.6 cm TL, respectively). It is
467 important to note, however, that the low sample size of legal-size target fish, particularly for
468 striped bass ($n = 4$), requires that additional studies be conducted on the Hg contamination of
469 these edible species. Nevertheless, the results presented in this study indicate that frequent
470 consumption of striped bass and tautog could pose a human health risk, and thus, justify their
471 inclusion in state-specific consumption advisories. Moreover, this exercise underscores the
472 importance of coupling species-specific Hg data with state-imposed minimum catch
473 requirements; hence, focusing on fishery resources that represent Hg exposure pathways to
474 human consumers.

475

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477

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699 **Figure captions**

700

701 **Fig. 1.** Map of the Narragansett Bay (Rhode Island, USA) with points denoting collection sites
702 of striped bass (*Morone saxatilis*), tautog (*Tautoga onitis*), and bioavailable prey (forage fish and
703 invertebrates).

704

705 **Fig. 2.** (A) Sub-sampling locations in the dorsolateral muscle tissue of striped bass (*Morone*
706 *saxatilis*) and tautog (*Tautoga onitis*) (top and bottom fish image, respectively). (B) Relationship
707 between the total mercury concentration (Hg; mg Hg · kg wet weight⁻¹) of a multiple biopsies
708 removed from the muscle tissue of striped bass ($n = 18$) and tautog ($n = 14$). Each muscle biopsy
709 was excised from the dorsal and lateral tissue along the anterior-posterior axis and represents the
710 mean (\pm standard error) Hg concentration of the biopsy removed from the left and right side of
711 each fish.

712

713 **Fig. 3.** Total mercury concentration (Hg; mg Hg · kg wet weight⁻¹) of the dorsal muscle tissue of
714 striped bass ($n = 66$) and tautog ($n = 53$) as a function of fish total length, TL (A) and age, a (B).
715 Exponential models were fit to the data and the equations are presented.

716

717 **Fig. 4.** Mean total mercury concentration (Hg; mg Hg · kg wet weight⁻¹) (+ standard error) of
718 prey collected from the Narragansett Bay, i.e., “bioavailable prey”. Prey include bay anchovy
719 (*Anchoa mitchilli*; $n = 39$), scup (*Stenotomus chrysops*; $n = 56$), green crab (*Carcinus maenas*; n
720 = 110), river herring (*Alosa* spp.; $n = 183$), sand shrimp (*Crangon septemspinosa*; $n = 241$),

721 back-finger mud crab (*Panopeus herbstii*; $n = 15$), Atlantic menhaden (*Brevoortia tyrannus*; $n =$
722 32), and blue mussel (*Mytilus edulis*; $n = 160$).

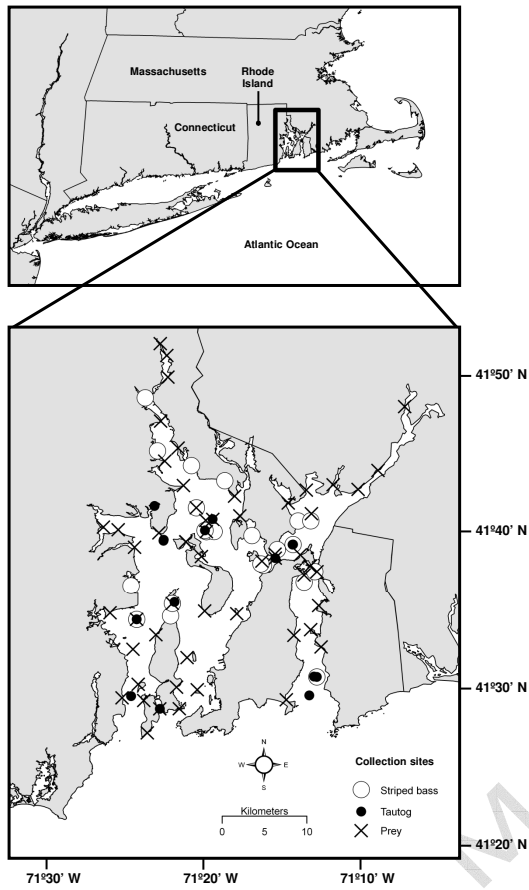
723

724 **Fig. 5.** Stable nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$) isotope signatures (mean \pm standard error) of
725 striped bass (*Morone saxatilis*), tautog (*Tautoga onitis*), and their prey ($n = 18-20$ per species).
726 Prey species include river herring (*Alosa* spp.), scup (*Stenotomus chrysops*), bay anchovy
727 (*Anchoa mitchilli*), Atlantic menhaden (*Brevoortia tyrannus*), green crab (*Carcinus maenas*),
728 sand shrimp (*Crangon septemspinosa*), and blue mussel (*Mytilus edulis*). Ovals represent
729 organisms that derive their carbon from pelagic or benthic sources, as determined by interspecies
730 $\delta^{13}\text{C}$ signatures.

731

732 **Fig. 6.** Relationship between total mercury concentration (Hg; $\text{mg Hg} \cdot \text{kg wet weight}^{-1}$) and
733 stable nitrogen ($\delta^{15}\text{N}$) isotope signatures (mean \pm standard error) of striped bass (*Morone*
734 *saxatilis*), tautog (*Tautoga onitis*), and their prey ($n = 18-20$). Prey species include river herring
735 (*Alosa* spp.), scup (*Stenotomus chrysops*), bay anchovy (*Anchoa mitchilli*), Atlantic menhaden
736 (*Brevoortia tyrannus*), green crab (*Carcinus maenas*), sand shrimp (*Crangon septemspinosa*),
737 and blue mussel (*Mytilus edulis*).

738



739

Figure 1

740 **Table 1**
 741 Comparison of total length, whole-body wet weight, muscle tissue water content, age, mercury levels [total mercury (Hg) and percent methylmercury (%MeHg)],
 742 stable nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$) isotope signatures, and trophic level status of striped bass (*Morone saxatilis*) and tautog (*Tautoga onitis*) collected from
 743 the Narragansett Bay. Statistical summaries are from one-way analysis of variance models using species (striped bass and tautog) as a fixed factor. Sample sizes
 744 (n), mean values [\pm standard error (SE)], and ranges are also presented.
 745

Parameter	Striped bass			Tautog			F	df	p
	n	Mean \pm SE	Range	n	Mean \pm SE	Range			
Total length (cm) ^a	66	49.2 \pm 1.8	26.2–102.0	53	39.3 \pm 1.6	10.7–56.4	16.84	118	< 0.0001
Wet wt (kg) ^a	66	1.40 \pm 0.14	0.18–6.82	53	1.61 \pm 0.16	0.10–3.88	0.01	118	0.918
Water content (%) ^b	42	77.2 \pm 0.7	50.4–79.3	45	78.6 \pm 0.5	63.6–87.7	3.44	86	0.067
Age (yr) ^{a,c}	66	4.3 \pm 0.2	1.7–9.6	53	11.3 \pm 0.6	3.6–18.6	168.18	118	< 0.0001
Hg (mg \cdot kg wet wt ⁻¹) ^a	66	0.16 \pm 0.01	0.03–0.45	53	0.24 \pm 0.02	0.03–0.58	6.79	118	< 0.05
Age-normalized Hg ^{a,d}	66	0.038 \pm 0.003	0.012–0.159	53	0.020 \pm 0.001	0.005–0.046	39.47	118	< 0.0001
%MeHg ^{b,e}	11	98.7 \pm 0.3	96.3–99.6	11	98.0 \pm 0.2	96.8–98.9	5.57	21	< 0.05
Recovered prey Hg ^{a,f}	54	0.060 \pm 0.005	0.016–0.190	50	0.053 \pm 0.005	0.010–0.176	1.91	103	0.170
$\delta^{15}\text{N}$ (‰)	20	17.66 \pm 0.27	15.67–19.62	18	15.76 \pm 0.12	14.94–16.80	38.92	37	< 0.0001
$\delta^{13}\text{C}$ (‰)	20	-18.27 \pm 0.42	-24.08– -15.99	18	-16.63 \pm 0.16	-18.36– -15.67	12.21	37	< 0.005
Trophic level ^g	20	4.07 \pm 0.08	3.49– 4.65	18	3.51 \pm 0.03	3.27– 3.82	39.07	37	< 0.0001

746
 747 ^a Data were log₁₀-transformed prior to statistical analysis, but raw data values are presented in the table.
 748 ^b Data were arc-sin square-root transformed prior to statistical analysis, but raw data values are presented in the table.
 749 ^c Ages for individual fish were predicted from published age-size relationships (Hostetter and Munroe, 1993; Nelson et al., 2006).
 750 ^d Age-normalized Hg = Hg (mg Hg \cdot kg tissue wet wt⁻¹) / age (yr).
 751 ^e %MeHg = [MeHg (mg MeHg \cdot kg tissue wet wt⁻¹) / total Hg (mg Hg \cdot kg tissue wet wt⁻¹)] \times 100.
 752 ^f Recovered prey Hg = Hg (mg Hg \cdot kg wet wt⁻¹) of food items removed from fish stomachs.
 753 ^g Trophic levels of individual target fish were calculated using Equation 2.

754 **Table 2**
 755 Comparison of length, whole-body wet weight, whole-body water content, stable nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$) isotope signatures, and total mercury (Hg) in
 756 prey species collected from the Narragansett Bay. Sample sizes (n), mean values (\pm standard error), and ranges (in parentheses) are presented.
 757

Species	Length (cm) ^a	Wet weight (g)	Water content (%)	$\delta^{15}\text{N}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^b	Trophic level ^c	Hg (mg · kg wet wt ⁻¹)
Division Teleostei							
Atlantic menhaden ($n = 32$)	4.2 ± 0.2 (3.0–7.5)	0.72 ± 0.13 (0.14–3.77)	79.1 ± 1.4 (71.6–83.7)	12.08 ± 0.13 (11.03–13.71)	-18.77 ± 0.11 (-20.03– -17.96)	2.43 ± 0.04 (2.12–2.91)	0.016 ± 0.002 (0.006–0.047)
Bay Anchovy ($n = 39$)	7.3 ± 0.1 (5.3–8.2)	2.72 ± 0.12 (0.98–4.01)	77.2 ± 0.5 (74.2–79.1)	14.39 ± 0.13 (13.72–15.74)	-18.34 ± 0.11 (-19.23– -16.99)	3.11 ± 0.04 (2.91–3.51)	0.035 ± 0.001 (0.029–0.055)
River herring ($n = 183$)	6.2 ± 0.2 (2.9–11.2)	2.53 ± 0.16 (0.08–11.15)	78.1 ± 0.3 (71.0–83.7)	13.42 ± 0.19 (12.31–15.47)	-19.73 ± 0.47 (-25.67– -17.04)	2.82 ± 0.06 (2.50–3.43)	0.027 ± 0.001 (0.008–0.188)
Scup ($n = 56$)	10.3 ± 0.5 (2.8–15.3)	23.75 ± 2.24 (0.32–71.21)	75.6 ± 0.3 (72.6–81.8)	14.91 ± 0.22 (12.88–16.33)	-17.09 ± 0.22 (-18.12– -13.61)	3.26 ± 0.07 (2.66–3.68)	0.033 ± 0.002 (0.015–0.066)
Class Bivalvia							
Blue mussel ($n = 160$) ^d	3.9 ± 0.1 (1.8–8.2)	7.20 ± 0.46 (1.07–38.66)	83.0 ± 0.3 (72.1–38.66)	10.62 ± 0.20 (9.15–92.7)	-20.16 ± 0.17 (-22.12– -19.27)	2.00 ± 0.06 (1.57–2.68)	0.015 ± 0.006 (0.005–0.040)
Class Crustacea							
Green crab ($n = 110$)	4.2 ± 0.2 (1.2–7.8)	24.21 ± 2.62 (0.32–104.28)	73.4 ± 1.0 (61.3–89.8)	12.90 ± 0.20 (11.10–14.48)	-15.13 ± 0.25 (-17.15– -13.25)	2.67 ± 0.06 (11.10–14.48)	0.032 ± 0.003 (0.006–0.156)
Mud crab ($n = 15$)	1.7 ± 0.2 (0.9–2.6)	2.58 ± 0.61 (0.20–7.37)	65.1 ± 3.3 (54.5–82.8)	–	–	–	0.016 ± 0.001 (0.006–0.025)
Sand shrimp ($n = 241$)	3.8 ± 0.1 (0.5–6.2)	0.49 ± 0.02 (0.08–1.94)	78.5 ± 0.4 (65.4–85.9)	13.52 ± 0.23 (11.51–15.13)	-15.67 ± 0.55 (-21.09– -12.47)	2.85 ± 0.07 (2.26–3.33)	0.020 ± 0.001 (0.006–0.123)

758
 759 ^a Length measured as total length for fish and shrimp, carapace width for crabs, and shell height for mussels.

760 ^b Sample size for stable nitrogen and carbon isotope analysis was 18-20 for all species.

761 ^c Trophic levels of individual prey species were calculated using Equation 2.

762 ^d Mussel wet weight, water content, $\delta^{15}\text{N}$, $\delta^{13}\text{C}$, and Hg were measured for soft tissue only (shell removed).

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763 **Table 3**
 764 Stomach contents of striped bass (*Morone saxatilis*) and tautog (*Tautoga onitis*) collected from the Narragansett Bay. Values represent the percent of striped
 765 bass or tautog stomachs that contained a given prey item.
 766

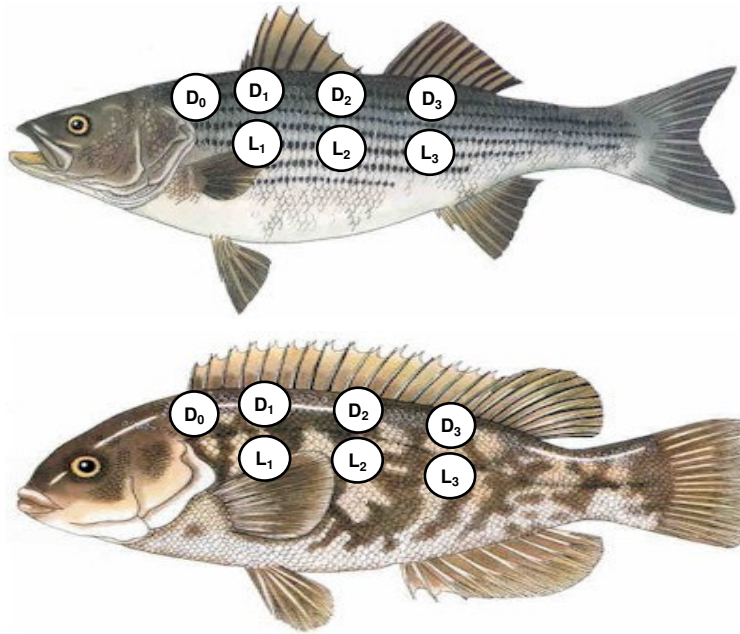
Species	Recovered prey		Target fish	
	Common name	Striped bass	Tautog	
Division Teleostei				
<i>Alosa</i> spp.	Herring	2.5	0	
<i>Anchoa mitchilli</i>	Bay anchovy	2.5	0	
<i>Brevoortia tyrannus</i>	Atlantic menhaden	1.3	0	
<i>Gobiosoma bosc</i>	Naked goby	2.5	0	
<i>Peprilus triacanthus</i>	Butterfish	1.3	0	
<i>Stenotomus chrysops</i>	Scup	1.3	0	
<i>Syngnathus fuscus</i>	Northern pipefish	1.3	0	
Class Bivalvia				
<i>Mytilus edulis</i>	Blue mussel	0	19.1	
Class Crustacea				
<i>Carcinus maenas</i>	Green crab	5.1	1.6	
<i>Crangon septemspinosa</i>	Sand shrimp	9.0	0	
<i>Panopeus herbstii</i>	Black-finger mud crab	0	4.8	
-	Unidentified crab	2.6	17.5	
Class Echinoidea				

<i>Strongylocentrotus droebachiensis</i>	Green sea urchin	0	1.6
Class Gastropoda			
<i>Crepidula fornicata</i>	Atlantic slipper snail	0	3.2
-	Unidentified gastropod	0	1.3
Class Ulvophyceae			
<i>Ulva lactuca</i>	Sea lettuce	1.3	0
Unidentified contents		50.6	49.2
Empty stomachs		17.7	3.2

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B

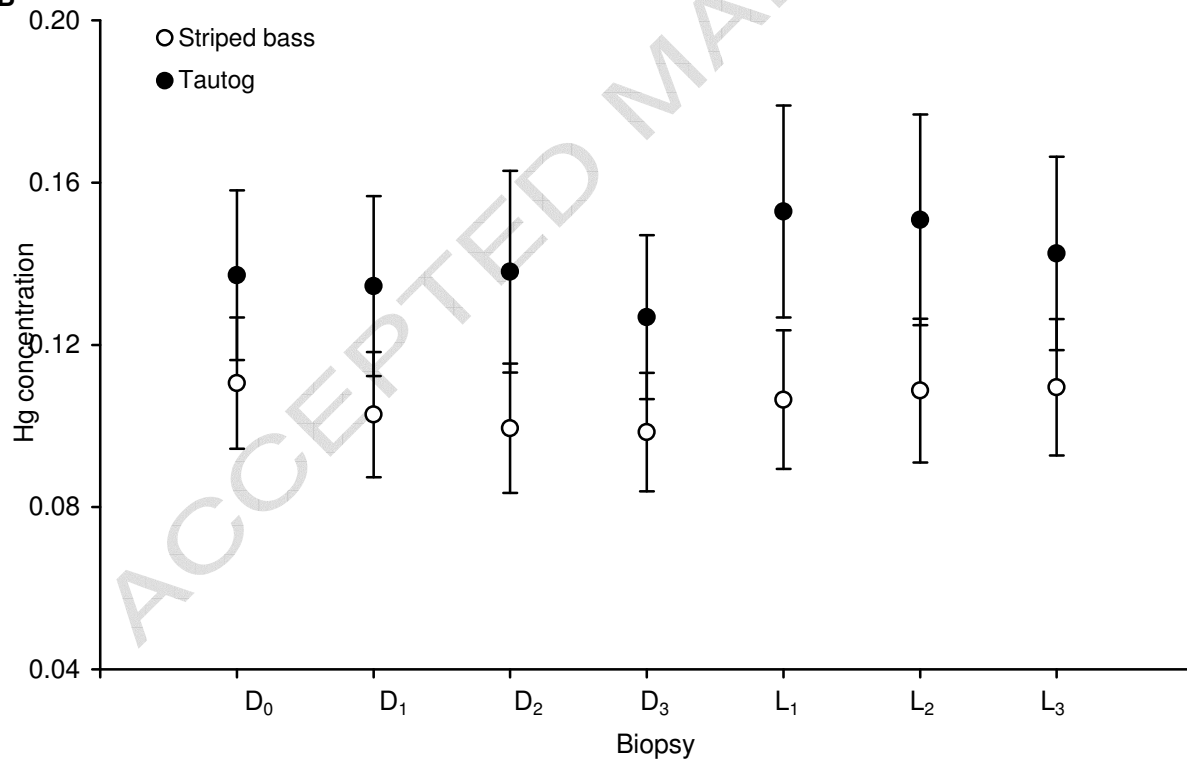


Figure 2

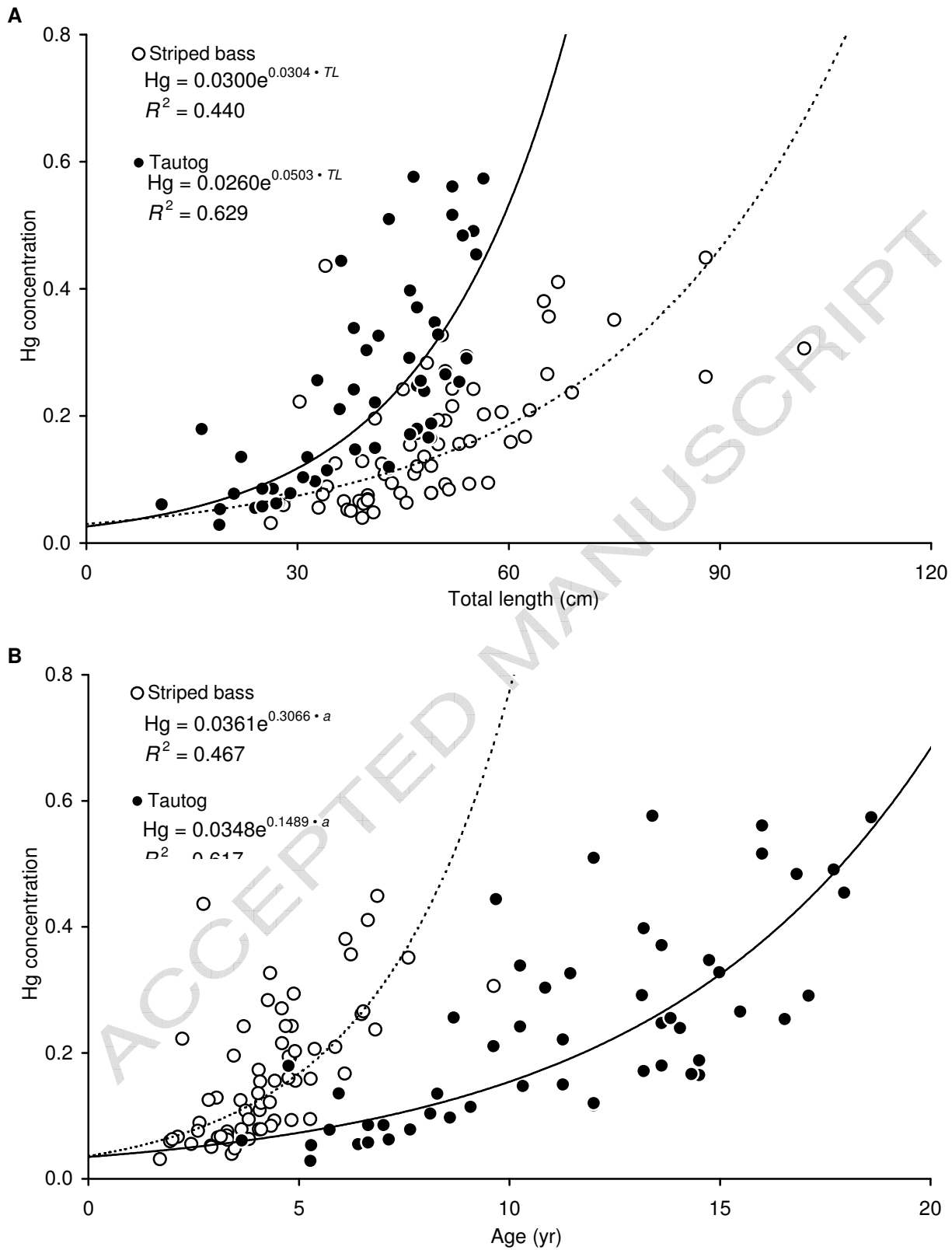


Figure 3

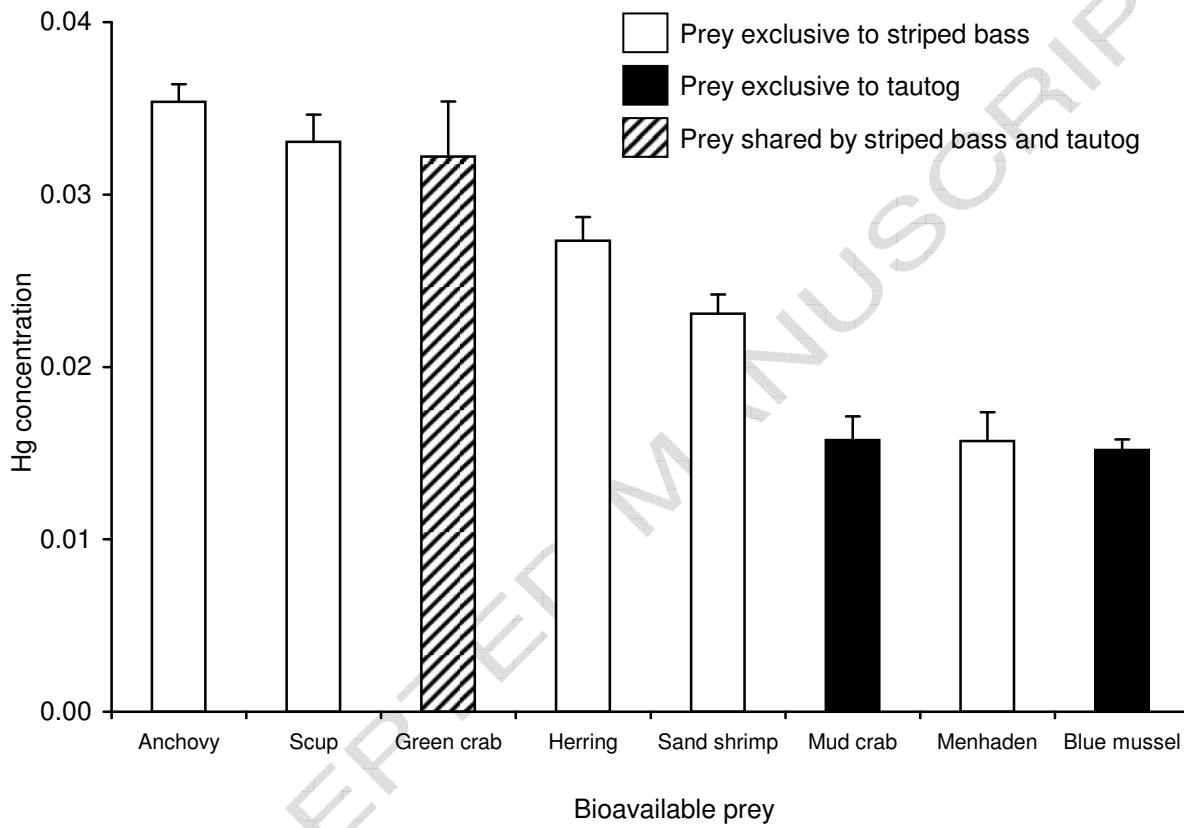


Figure 4

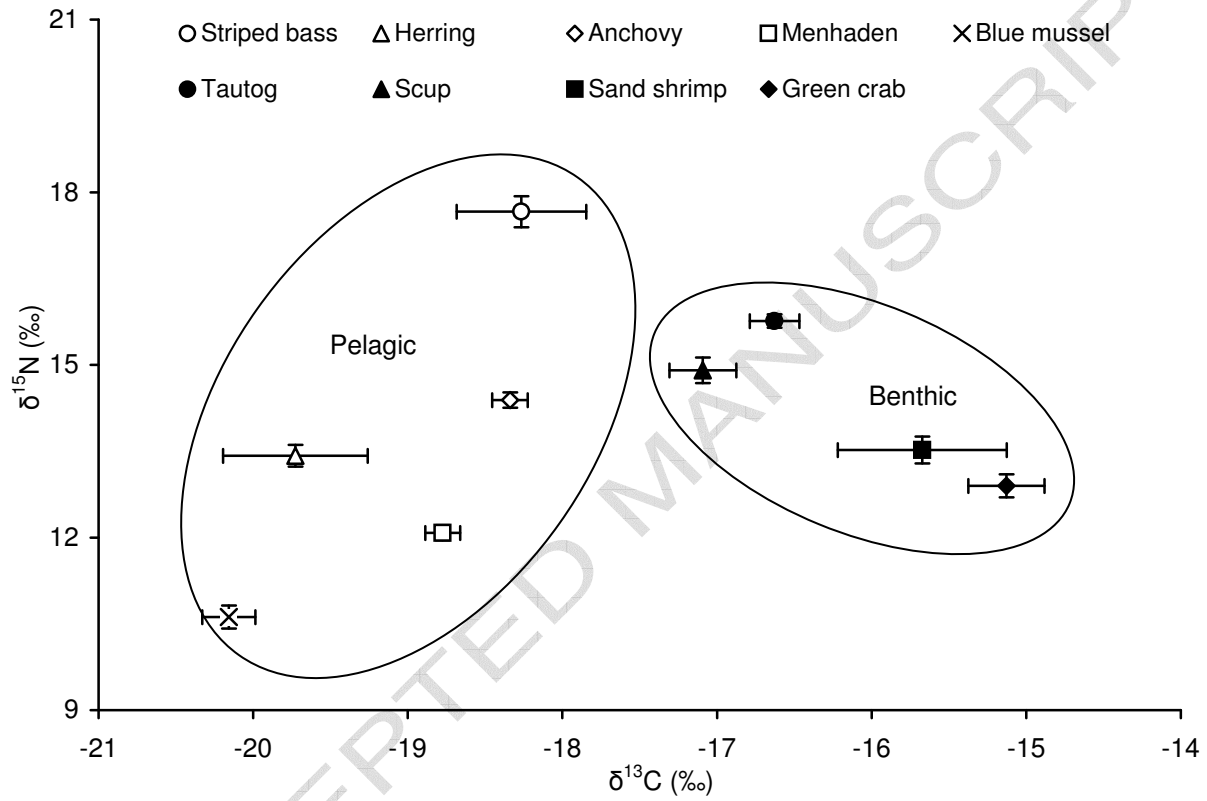


Figure 5

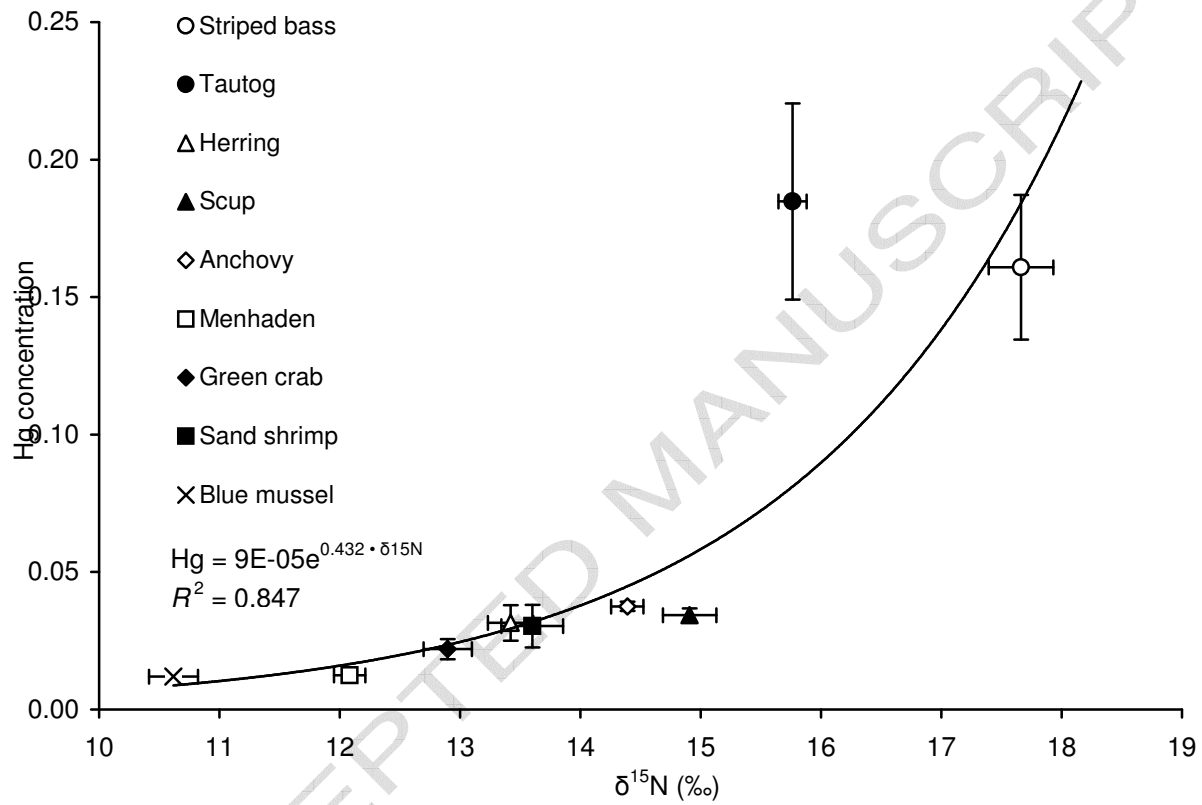


Figure 6