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Total Mercury in Six Antarctic Notothenioid Fishes

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Abstract We analyzed white muscle samples from six species of Antarctic fish (suborder Notothenioidei) collected in 2011 from McMurdo Sound, Ross Sea, Antarctica, to assess levels of total mercury (THg). *Gymnodraco acuticeps* and *Trematomus bernacchii* exhibited the highest concentrations of THg followed by *Trematomus pennellii, Trematomus nicolai, Trematomus newnesi* and *Pagothenia borchgrevinki*, (71.3, 53.9 ± 32.1, 45.8 ± 27.3, 37.2 ± 18.6, 35.7 ± 23.6, and 21.9 ± 2.8 ng/g wet weight, respectively). The results from this study suggest that THg has the potential to bioaccumulate from various marine Antarctic ecosystems into biota.

Keywords Antarctic fish · Notothenioidei · Mercury · Bioaccumulation

Antarctica has typically played a vital role in the discussion of environmental pollutants. The Southern Ocean and the Ross Sea in particular have recently been identified as the most pristine marine ecosystem on the planet, with relatively few anthropogenic impacts compared to other global oceans (Halpern et al. 2008). However, its remoteness does not protect the Ross Sea from human impacts and a better understanding of pollutants in the high latitude Southern Ocean is needed. In fact, several studies have demonstrated that anthropogenic contaminants can be detected in Antarctic ecosystems and organisms (Aronson et al. 2011).

The distribution and bioaccumulation of contaminants like mercury, is complex, with most contamination coming from anthropogenic sources at lower latitudes. The high latitudes act as a chemical sink for contaminants through a process known as "cold condensation" (Bogillo and Bazylevska 2008). Contaminants emitted in the warmer latitudes make their way to the poles by way of atmospheric streams. Since the poles are much colder and have depleted stratospheric ozone levels, atmospheric contaminants can undergo chemical transformation and condense out of the atmosphere, accumulating in various environmental compartments (Moore et al. 2014).

The dominant fish fauna of the Southern Ocean are from families in the suborder notothenioidei (La Mesa et al. 2004). Multiple studies have looked at THg in various species of notothenioids from every trophic guild in the Southern Ocean. However, levels of THg reported varied considerably (Bargagli et al. 1998; Honda et al. 1987; Maggi et al. 2009). Looking at the entire trophic guild in this group of fish may provide clues to the distribution of THg in the Antarctic marine environment since each species differ in their depth preference (Eastman and McCune 2000).

The objective of this study is to measure total mercury levels in white muscle tissue from six co-occuring species of notothenioid fish *Gymnodraco acuticeps, Trematomus bernacchii, Trematomus pennellii, Trematomus nicolai, Trematomus newnesi* and *Pagothenia borchgrevinki,* in order to provide information on THg concentrations in this unique group of Antarctic fish, and to see if differences in

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contaminant levels exist between species occupying different depths.

Materials and Methods

Muscle samples were obtained from 21 specimens of six species of Antarctic notothenioid fish: *G. acuticeps* (n = 1), *T. bernacchii* (n = 4), *T. pennellii* (n = 4), *T. nicolai* (n = 4), *T. newnesi* (n = 4), and *P. borchgrevinki* (n = 4). Specimens were collected over a 30 day period from October to November 2011, via hook-and-line through holes drilled in the sea ice from two fishing sites: between Cape Evans Wall (77°38′24″ S, 166°31′04″ E) and Inaccessible Island (77°39′53″ S, 166°21′75″ E), approximately 20 km north of McMurdo Station. These sites were chosen in order to reduce the effects of anthropogenic pollution resulting from historic dumpsites near McMurdo station where heavy metals have been detected in environmental samples (Bargagli 2006). Fish were transported back to McMurdo Station in aerated coolers. Muscle tissue was removed from the dorso-lateral region, immediately wrapped in aluminum foil and frozen on liquid nitrogen. Samples were stored at −80°C until analyzed. Morphological data, including length and weight, were recorded during collection.

Muscle tissues (approximately 10 g) were homogenized using a Brinkmann polytron tissue homogenizer. All glassware was cleaned using ACS grade acids before and after each tissue sample homogenization and digestion. Total mercury analysis involved digestion of subsamples of tissue homogenates (approximately 1 g) according to the methods described by Gloss et al. (1990).

Analysis of digested tissues for total mercury was done according to United States Environmental Protection Agency (USEPA) method 1631, revision B (1999). Subsamples (approximately 1 g) of homogenized fish tissues were digested in concentrated sulfuric acid (70°C) for 30 min, followed by the addition of 30 % hydrogen peroxide to the digestion, which was run for 2 additional hours. Potassium permanganate (5 %) was added to digested samples and the total volume of each sample was brought up to 100 mL with distilled water. One mL of digested samples were added to glass bubblers containing 50 mL of distilled water, 5 mL of a 3 % solution of hydroxylamine hydrochloride solution and 2 mL of a 10 % stannous chloride solution (reducing agent). Bubblers were purged with ultrapure nitrogen (20 min), followed by collection of the elemental mercury on gold-coated sand traps. Gold traps were subsequently desorbed thermally and measured using a Tekran Cold Vapor Atomic Fluorescence Spectrophotometer (Model 2500). Peak areas of samples and standards were recorded using a Hewlett Packard 3396A Integrator. Working mercury standards were prepared from a stock mercury standard in nitric acid (Sigma-Aldrich, St. Louis, MO).

Quality assurance methods included the analysis of blanks, and duplicates (for every 10 samples). Percent recovery for fortified mercury tissue samples ranged between 87 % and 115 %. The method detection limit for mercury samples was 17 ng/g wet weight. Mercury sample concentrations are reported on a wet weight basis.

A one-way ANOVA was used to test for significant differences in contaminant levels between species. Linear regression analysis was performed to look for an association between length, mass and THg. A parametric statistic (*t* test) was used to test THg between cryopelagic and benthic species. All statistical analyses were run using SPSS statistical software (version 20.0), with a significance level of (0.05). *G. acuticeps* was excluded from ANOVA and *t* test statistical analysis due to a sample size of one individual.

Results and Discussion

Individual levels of THg in the six species of Nototheniods analyzed ranged from 10.1 to 93.6 ng/g wet weight (three individuals were below the method detection limit for those samples of 17.0 ng/g). The highest concentration of mean THg was found in *T. bernacchii* (53.9 ± 32.1 ng/g wet weight), followed by *T. pennellii* (45.8 ± 27.3 ng/g wet weight), *T. nicolai* (37.2 ± 18.6 ng/g wet weight), *T. newnesi* (35.7 ± 23.6 ng/g wet weight), and *P. borchgrevinki* (21.9 ± 2.8 ng/g wet weight) (Table 1).

The distribution of individual values varied, therefore species THg concentrations are given as mean ± standard deviation. Bargagli et al. (1998) found THg levels ranging from 170 to 1790 ng/g dry weight in *T. bernacchii* (n = 12) and 90–820 ng/g dry weight in *T. newnesi* (n = 7) collected from the inner shelf of Terra Nova Bay Antarctica. The ranges reported for these species are over tenfold higher than ranges reported for the same species in our study. However, Bargagli et al. (1998) reported THg levels as dry weight values, which are expected to be higher than wet weight values. Dry weight values can be up to sevenfold higher than wet weight values. The U.S. National survey of mercury concentrations in fish (EPA 1999) found a range of muscle tissue moisture content in a variety of fish species (74 %–85 % moisture content). Maggi et al. (2009) found THg levels in *T. bernacchii* of 92.6 ng/g dry weight, *T. pennelli* was 299 ng/g dry weight, *G. acuticeps* was 396 ng/g dry weight (n = 1 for all samples) collected from Terra Nova Bay Antarctica. Taking the dry weights into account these values are within the range of values reported from our study for the same

Table 1 Muscle tissues sampled from Notothenioid fishes collected 20 km north of McMurdo station, Antarctica in 2011

Species	Mass	Length	THg
G. acuticeps	122	25	71.3
Mean ± SD	N/A	N/A	N/A
T. bernacchii	115	19	93.6
T. bernacchii	90	18	60.6
T. bernacchii	86	19	44.6
T. bernacchii	65	17	16.6
Mean ± SD	89.0 ± 20.5	18.3 ± 1.0	53.9 ± 32.1
T. pennellii	37	14.5	46.5
T. pennellii	36	13.5	31.1
T. pennellii	36	14	83.7
T. pennellii	30	12.5	21.8
Mean ± SD	34.8 ± 3.2	13.6 ± 0.9	45.8 ± 27.3
T. nicolai	86	19	15.2
T. nicolai	79	18	26
T. nicolai	59	17	56.2
T. nicolai	50	15.5	49.4
Mean ± SD	68.5 ± 16.8	17.4 ± 1.5	37.2 ± 18.6
T. newnesi	105	19.5	12.4
T. newnesi	112	20	10.1
T. newnesi	134	21.5	66.2
T. newnesi	85	18.5	42.5
Mean ± SD	109.0 ± 20.2	19.9 ± 1.3	35.7 ± 23.6
P. borchgrevinki	79	19	23.6
P. borchgrevinki	117	22	18.4
P. borchgrevinki	129	22.5	20.9
P. borchgrevinki	159	25.5	24.6
Mean ± SD	121.0 ± 33.1	22.3 ± 2.7	21.9 ± 2.8

Mass (g), Length (cm), THg levels (ng/g wet weight), for individual fish. Mean (±SD), length, THg concentrations are shown for each species group

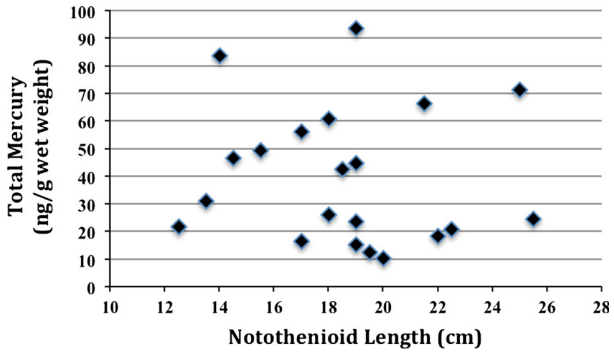

Fig. 1 *Scatter plot* diagram of total mercury (ng/g wet weight) and Notothenioid length (cm)

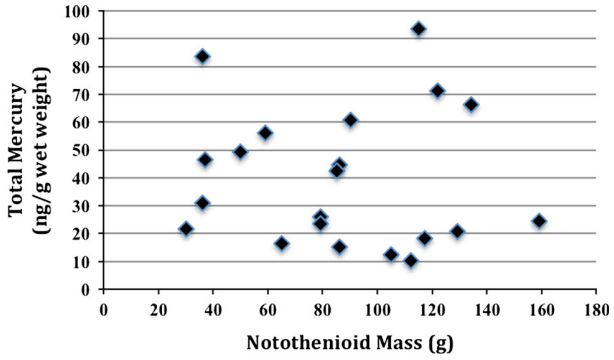

Fig. 2 *Scatter plot* diagram of total mercury (ng/g wet weight) and Notothenioid mass (g)

species. Honda et al. (1987) reported a range of muscle THg levels of 20–650 ng/g wet weight for *T. bernacchii* (n = 30) and 20–90 ng/g wet weight for *P. borchgrevinki* (n = 22) collected from Smoya Station Antarctica. The upper values of the ranges reported by Honda et al. (1987) are higher than those reported from our study (sevenfold higher for *T. bernacchii* and over threefold higher for *P. borchgrevinki*). These higher values reported by Honda et al. (1987) may be due to the greater number of samples analyzed for each species as compared to our study and the fish were collected from a different site.

There were no significant differences in THg among species (only one *G. acuticeps* was tested). Additionally, no significant correlation between length, mass and THg was detected (Figs. 1, 2) Both of these metrics provide a surrogate for age and the absence of any relationship may actually provide an indication of the capacity of these fish to achieve the steady state condition with environmental and dietary sources of Hg (Alam et al. 2002). There was no significant difference between cryopelagic and benthic species mean THg, but the *p* value ($p = 0.07$) was close to the level set for significance. It is possible that a larger sample size might have shown a significant difference between these two groups. If a difference does exist, this could be explained by the more direct exposure of benthic species to bottom sediments, which can sorb lipophilic contaminants like methyl mercury (Seelye et al. 1982). *T. newnesi* and *P. borchgrevinki* are cryopelagic, primarily living near the surface, but have been found as deep as 540 and 588 meters, respectively, feeding on species such as pteropods, copepods, gammarids, hyperiids, decapods, euphausiids and fishes (DeWitt et al. 1990). The other four species, *T. nicolai, T. bernacchii*, *T. pennellii* and *G. acuticeps* are all considered benthic species, primarily living deeper in the water column, up to 508, 604, 732 and 800 m deep, respectively, at or near the substrate (Dewitt et al. 1990; Gon 1990).

The implications of these contaminants on fish health suggest that sublethal effects are possible, resulting in a

reduced ability to survive or reproduce (Blus 2011). Adverse effects due to THg exposure are well documented throughout the world, and Antarctica is not immune despite its remoteness (Geisz et al. 2008). Anthropogenic pollutants have far-reaching abilities and are being deposited from the atmosphere and historic dumpsites, leaving the Antarctic continent and surrounding waters subjected to mercury (Bargagli et al. 1998; Focardi et al. 1992; Geisz et al. 2008).

Conclusion

The THg concentrations reported here were marginally above the method detection limits and well below the international guidelines with respect to human consumption (500 ng/g wet weight). However, that these very geographically remote and generally deep dwelling species can bioaccumulate Hg to a detectable extent emphasizes the ubiquity of Hg as a global contaminant (and most likely anthropogenic in origin) in the Antarctic. Owing to the highly pristine nature and potential ecological sensitivity of such remote Antarctic food webs, this research underscores the need for further investigation of global contaminants such as Hg.

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