

MERCURY IN NORTHERN GREEN FROGS AND SNAPPING TURTLES FROM ONONDAGA LAKE, NEW YORK



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Restoration Trustee Council**



ABSTRACT

This study was conducted to develop an initial understanding of the exposure of amphibians and reptiles at Onondaga Lake to mercury (Hg). Mercury in Onondaga Lake northern green frogs is within the range of Hg concentrations shown to affect metamorphosis and survival of southern leopard frog tadpoles and metamorphs, but less than concentrations associated with effects in wood frogs and American toads. Mercury in the toenails and blood of snapping turtles from Onondaga Lake was significantly higher than Hg in the toenails and blood of Hamlin Wildlife Management Area (reference area) snapping turtles. Onondaga Lake snapping turtles have more Hg in their keratinous tissue (toenails) than other snapping turtles sampled across New York State, but less Hg than found in keratinous tissues of snapping turtles from a Hg-contaminated area in Virginia. Snapping turtles appear fairly resistant to Hg, but the Hg concentrations found in Onondaga Lake snapping turtles are within the range of concentrations associated with altered thyroid function and immune suppression in other turtle species.

Although the diversity of amphibians and reptiles has increased at Onondaga Lake over the past two decades, the herpetofaunal diversity and population densities remain lower than in surrounding areas. This study shows that Hg may be a factor inhibiting the reproduction and health of some amphibians and reptiles at Onondaga Lake. However, other factors, such as limited wetland habitat abundance and diversity, poor turtle breeding substrate, habitat fragmentation, invasive species, and lack of ephemeral breeding sites, are also likely contributors to reduced herpetofaunal abundance and diversity.

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INTRODUCTION

Amphibians and reptiles may be susceptible to mercury (Hg) accumulation and toxicity due to their frequent association with aquatic environments where the more toxic and bioaccumulative form of Hg, methyl mercury (MeHg), is likely to be formed. Mercury accumulates in amphibians, such as leopard frogs and salamanders, as well as a variety of turtle species, and affects reproduction, survival, endocrine function, immune function, behavior, and metamorphosis in reptiles and amphibians (Unrine et al. 2004; Bergeron et al. 2007; Day et al. 2007; Grillitsch and Schiesari 2010; Burke et al. 2010; Bergeron et al. 2011; Turnquist et al. 2011; Hopkins et al. 2013a).

The objective of conducting Hg analysis in selected amphibians and reptiles at Onondaga Lake was to develop an initial understanding of the exposure of these organisms to Hg and MeHg. We identified the eastern snapping turtle (*Chelydra serpentina*) as a representative species for evaluating Hg exposure to reptiles because snapping turtles are abundant, long-lived, and associated with aquatic ecosystems. For turtles, we determined that both blood and toenail tissue would be collected and analyzed for Hg and MeHg. Other studies have used turtle blood and/or keratinous tissue (carapace or toenail) to evaluate turtle exposure to Hg. Keratinous tissue generally contains higher concentrations of Hg than blood, and is considered a better metric than for understanding long-term exposure (Presti et al. 1999; Day et al. 2005; Wang 2006; Hopkins et al. 2013b). We selected the northern green frog (*Lithobates clamitans melanota*) as a representative amphibian species for this study because it is an abundant aquatic amphibian in the vicinity of the Onondaga Lake Study Area.

Our goal was to conduct Hg analysis on ten adult northern green frogs and ten northern green frog tadpoles, as well as blood and toenail samples from ten snapping turtles at both the Onondaga Lake Site and a reference site.

METHODS

The collection and analysis discussed below is described in detail in TES (2013 a & b). The general sample collection area is shown in Figure 1. Snapping turtles sampled for Hg were collected as part of a herpetological inventory project¹ along the Onondaga Lake shoreline and from Pond 2, a ponded area in the northwest corner of the lake that is hydrologically connected to Onondaga Lake (TES 2013 a & b). Green frogs collected for Hg analysis were from a field sampling effort separate from the herpetological inventory project. At Onondaga Lake, adult

¹ Herpetological investigations were conducted at Onondaga Lake in 2011 and 2012 by Dr. Peter Ducey (State University of New York at Cortland) and Terrestrial Environmental Specialists, Inc. The primary goal of these efforts was to document the herpetofauna that currently exist in and around Onondaga Lake. These baseline data have a variety of uses, including informing habitat restoration efforts around the lake.

green frogs and a single green frog tadpole were collected mainly from Pond 2 (Figure 1). The reference area for all tissue collections was the Stanley J. Hamlin Marsh Wildlife Management Area (Hamlin Marsh), also known as Clay Marsh (Figure 1). We considered Hamlin Marsh an appropriate reference area because it supports various wetland and water habitat types that are similar to those habitat types within the Onondaga Lake Study Area, and it is not known to be contaminated with Hg or other hazardous substances (TES 2013a).

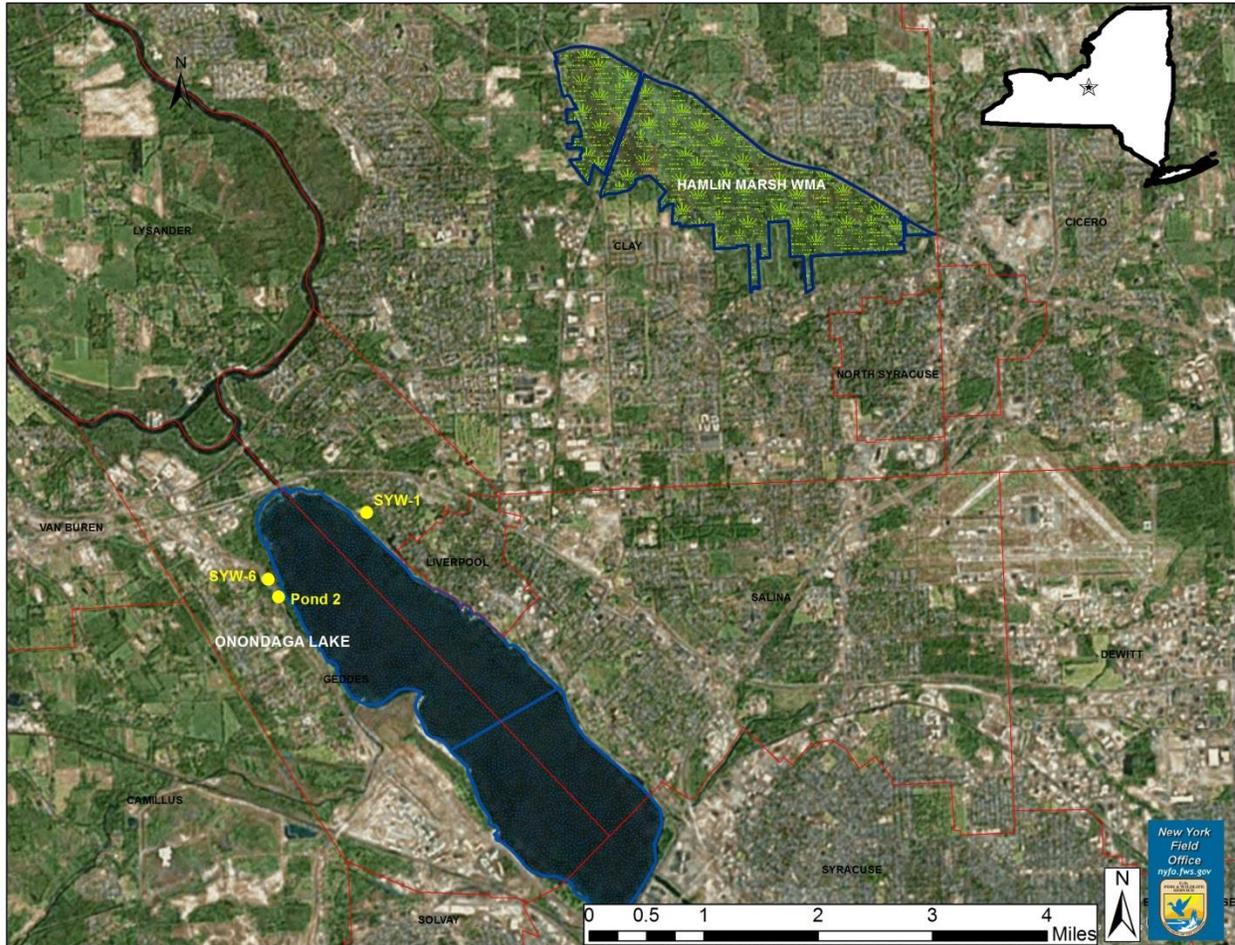
Green frog adults and green frog tadpoles were captured by hand, dip-nets, and minnow traps (funnel traps). To collect tissue, we conducted two rounds of amphibian trapping at Onondaga Lake and one round of amphibian trapping at Hamlin Marsh. In the Onondaga Lake Study Area, collection occurred from July 11-15, 2011 (24 funnel traps) and August 1-5, 2011 (27 funnel traps). At Hamlin Marsh, collection occurred from June 27 – July 1, 2011 (8 funnel traps). We captured ten green frog tadpoles and ten green frog metamorphs at Hamlin Marsh and ten adult northern green frog adults and one green frog tadpole at Onondaga Lake. All frogs and tadpoles were euthanized in the field by applying 20% benzocaine to their abdomens in accordance with guidance from the Herpetological Animal Care and Use Committee of the American Society of Ichthyologists and Herpetologists (2004).

We collected blood and toenail samples from Onondaga Lake Study Area snapping turtles from July 11-15, 2011, and from Hamlin Marsh snapping turtles during June 27 – July 1 and August 1-2, 2011. Toenails were collected from each leg using pet nail clippers. Approximately 20-50 milligrams (mg) of blood were extracted from the caudal vein of the snapping turtle tail using a hypodermic needle with storage capillary tubes. After the samples were collected, all turtles were returned to their point of capture and released.

All samples were stored on ice in the field, transferred to a freezer at Terrestrial Environmental Specialists, Inc.,² and then transported on ice to the Driscoll Lab at Syracuse University for Hg and MeHg analysis. Chain of custody procedures were followed.

² Terrestrial Environmental Specialists, Inc. collected the samples.

FIGURE 1 SAMPLE COLLECTION AREAS: ONONDAGA LAKE AND HAMLIN MARSH WILDLIFE MANAGEMENT AREA



All statistical tests were performed using Statistical Analysis System (SAS).³ Prior to data analyses, we determined whether data met the assumptions for parametric statistical tests. Where assumptions could not be met via data transformation, we used non-parametric tests. Therefore, we applied the following tests:

- Non-parametric Wilcoxon Rank Sum test to determine whether the green frog metamorphs and tadpoles from Hamlin Marsh differed in mass or average Hg concentration.
- Parametric two-tailed t-test with unequal variance to determine whether blood Hg and toenail Hg concentrations differed between Onondaga Lake and Hamlin Marsh snapping turtles.

³ Statistical Analysis System (SAS) is a software suite developed by SAS Institute for advanced analytics, multivariate analyses, data management, and predictive analytics.

- Two-tailed t-test with equal variance to evaluate whether carapace lengths differed between Onondaga Lake and Hamlin Marsh snapping turtles.
- Pearson Correlation Coefficient to evaluate the relationship between carapace length and Hg concentration in snapping turtle toenails.

We estimated wet weight mercury concentrations in snapping turtle toenails by assuming a moisture percentage of 10% in snapping turtle toenails. We were unable to find information on percent moisture in turtle toenails or shell, but Calvery (1933) found 8.6 % moisture in eggshell keratin and Encyclopedia Britannica (2015) reports that complete hydration of keratin results in 16% water. Therefore, we applied 10% moisture as an estimate of the percentage of water in snapping turtle toenail keratin.

Methyl mercury was analyzed in three green frog adults from Onondaga Lake, three green frog metamorphs from Hamlin Marsh, one green frog tadpole from Onondaga Lake, and blood and toenails from three Onondaga Lake snapping turtles.

RESULTS

Mercury and MeHg data are summarized in Table 1 and Figures 2-4. Northern green frog adults from Onondaga Lake had a mean Hg concentration of 188.4 nanograms per gram (ng/g) dry weight (dw) and the single Onondaga Lake tadpole had a Hg concentration of 84.1 ng/g dw. Hamlin Marsh green frogs originally categorized as adults had a mean wet weight (ww) mass of 3.6 grams compared with the mean ww mass of Hamlin Marsh tadpoles of 3.8 grams. Using a non-parametric Wilcoxon Rank Sum Test, the weights of the presumed adults and the tadpoles from Hamlin Marsh are not statistically different ($p=0.87$). Consequently, we reclassified Hamlin Marsh “adult” frogs as metamorphs (recently metamorphosed tadpoles). Hamlin Marsh metamorphs and tadpoles had mean Hg of 66.7 ng/g dw and 58.3 ng/g dw, respectively ($p=0.48$). The similar body mass and Hg concentrations between Hamlin Marsh tadpoles and metamorphs supports that they are likely similar in age (Figure 2). Mean MeHg concentrations in Onondaga Lake adult frogs and Hamlin Marsh metamorphs were 63% and 59% of total Hg, respectively. Lastly, 11% of the Hg detected in the green frog tadpole from Onondaga Lake was MeHg (Table 1).

Blood from Onondaga Lake snapping turtles (mean Hg = 513 ng/g ww) contained an order of magnitude greater Hg concentration than blood from Hamlin Marsh snapping turtles (mean Hg = 22 ng/g ww). The difference between mean blood Hg in Onondaga versus Hamlin Marsh snapping turtles is statistically significant ($p=0.0002$) (Figure 3). The MeHg in Onondaga Lake snapping turtle blood samples ranged from 14.8 to 22.7% of total Hg. Toenails from Onondaga Lake snapping turtles (mean Hg = 11,684 ng/g dw) had significantly greater Hg concentrations than toenails from Hamlin Marsh snapping turtles (mean Hg = 732 ng/g dw) ($p=0.01$) (Figure 4).

Methyl mercury was a small percentage (0.2 – 0.6%) of total Hg in the toenails of Onondaga Lake snapping turtles and was not measured in Hamlin Marsh snapping turtle toenails (Table 1).

TABLE 1 MERCURY AND METHYL MERCURY CONCENTRATIONS (NG/G) IN FROG AND TURTLE TISSUES FROM ONONDAGA LAKE AND HAMLIN MARSH WILDLIFE MANAGEMENT AREA, NY - 2011

LOCATION	TISSUE	MEAN Hg (N)	RANGE Hg	MEAN MEHG (N)	RANGE MEHG
NORTHERN GREEN FROG					
Onondaga Lake	Adults (dw)	188.4 (10)	78 – 276.4	145 (3)	117.7 – 168.7
	Tadpole (dw)	84.1 (1)	NA	10.7 (1)	NA
Hamlin Marsh	Metamorphs (dw)	66.7 (10)	42.6 – 100.2	39.8 (3)	21.9 – 66.3
	Tadpoles (dw)	58.3 (10)	40.8 – 81.7	NA	NA
SNAPPING TURTLE					
Onondaga Lake	Blood (ww)	513 (7)	261.9 – 768.4	81.4 (3)	61.2 – 99.2
	Toenails (dw)	11,684 (7)	2,594 – 23,815	34.2 (3)	19.6 – 50.1
Hamlin Marsh	Blood (ww)	22 (7)	8.5 – 45	NA	NA
	Toenails (dw)	732 (7)	560 – 981	NA	NA
<i>Notes:</i> N = Number of samples dw = dry weight ww = wet weight NA = Not applicable					

FIGURE 2 TOTAL MERCURY IN GREEN FROGS FROM ONONDAGA LAKE AND HAMLIN MARSH - 2011

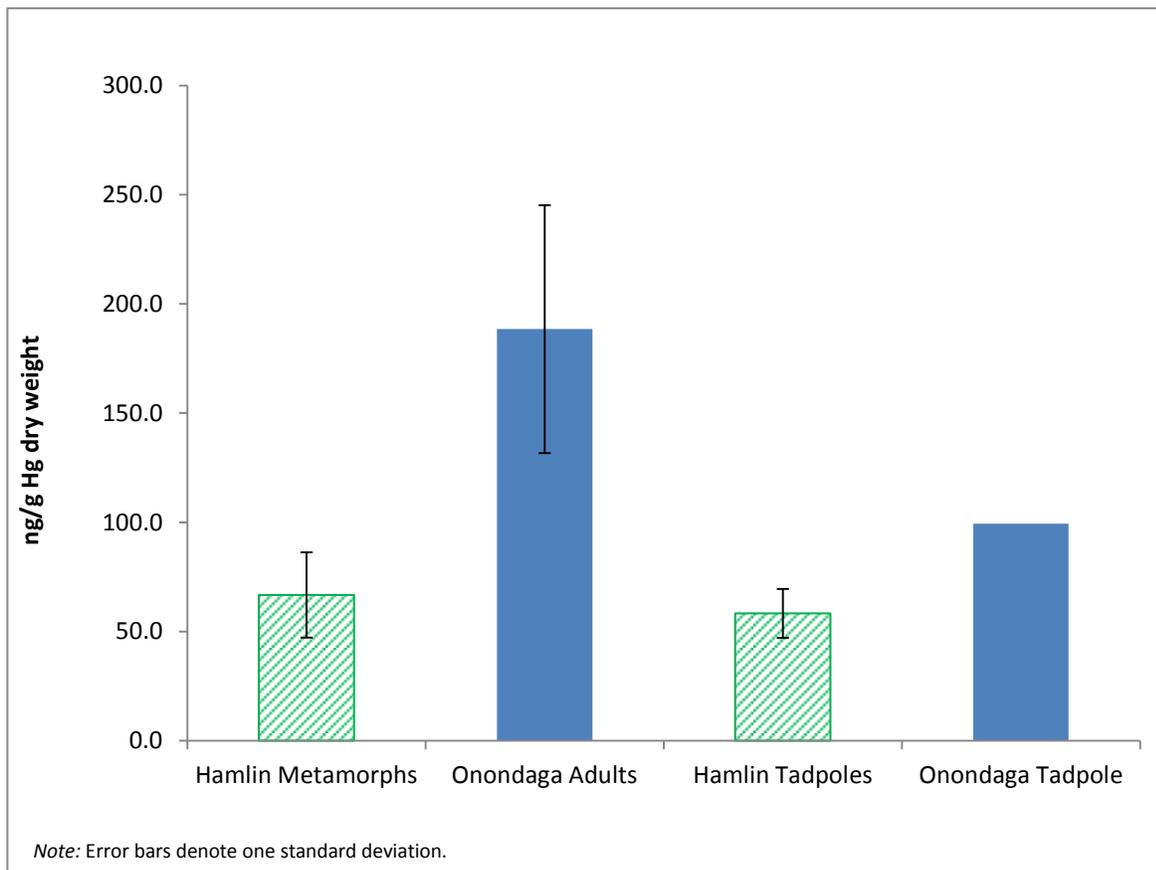


FIGURE 3 TOTAL MERCURY IN SNAPPING TURTLE BLOOD FROM ONONDAGA LAKE AND HAMLIN MARSH – 2011
(*** P=0.0002)

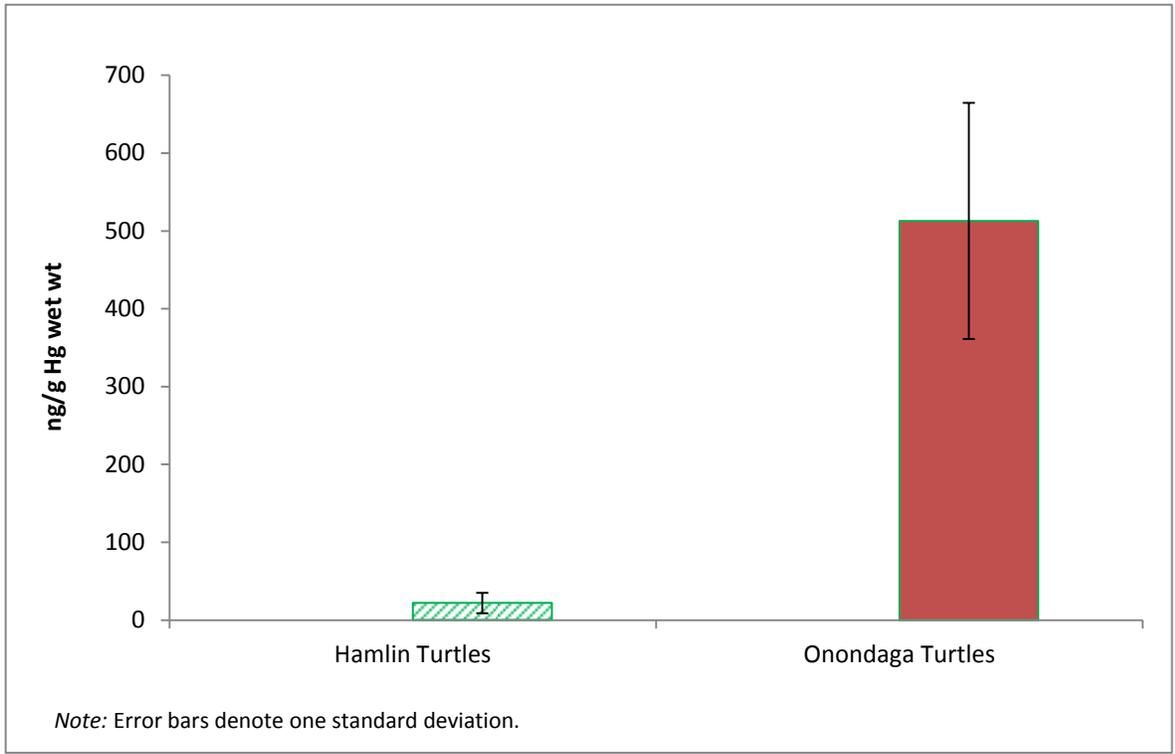
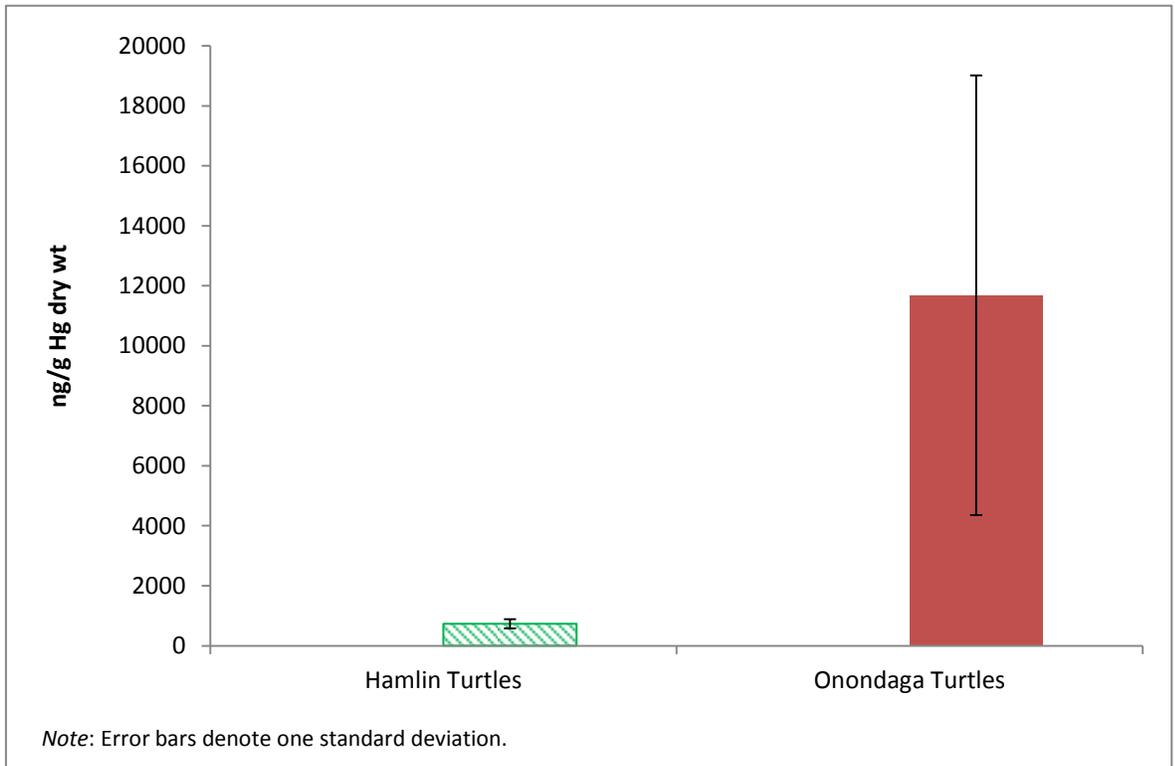
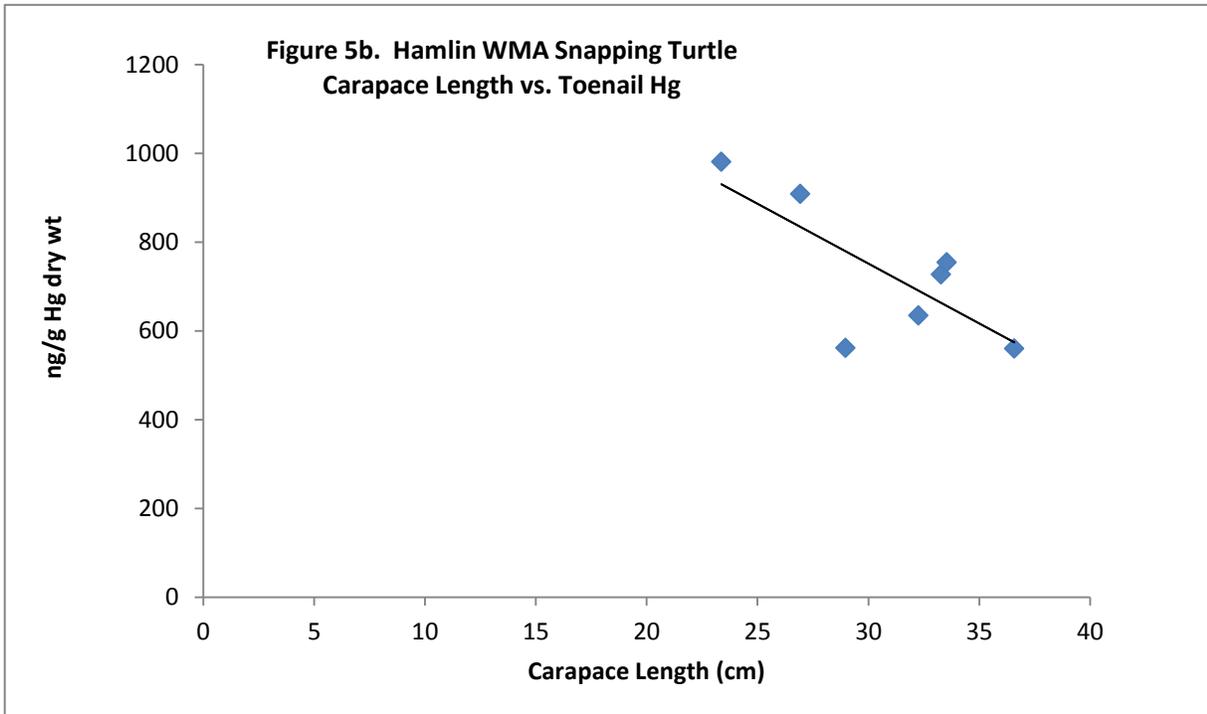
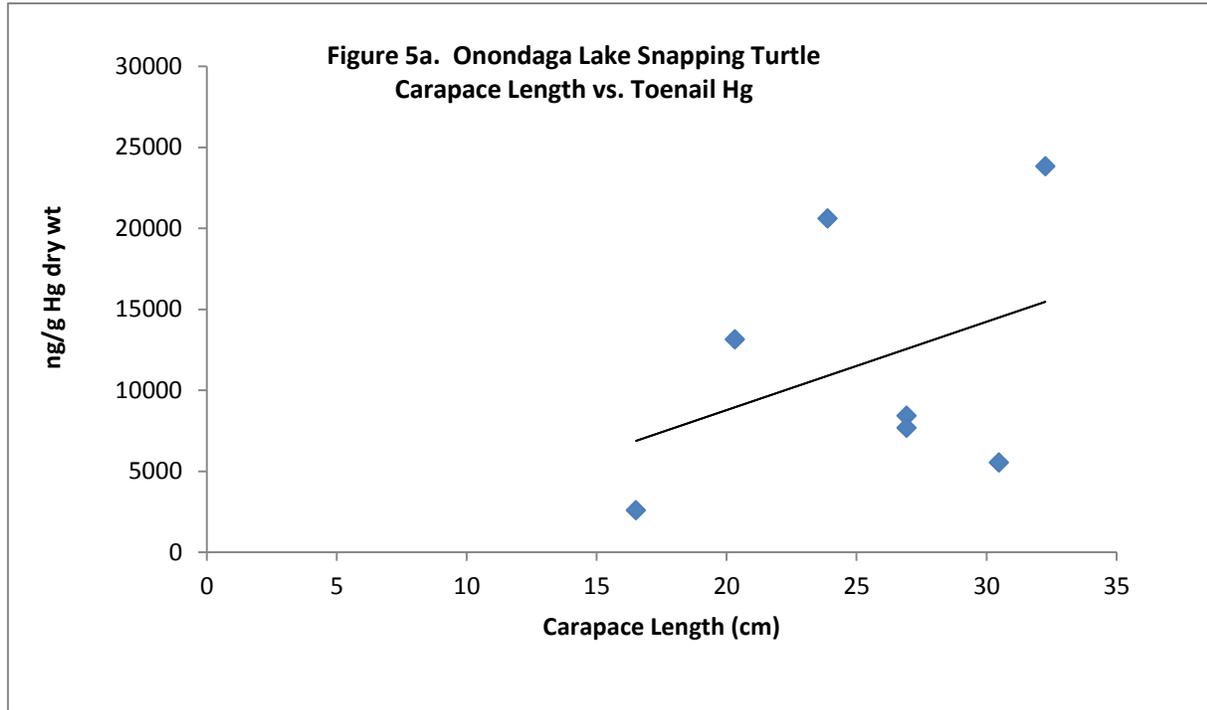


FIGURE 4 TOTAL MERCURY IN SNAPPING TURTLE TOENAILS FROM ONONDAGA LAKE AND HAMLIN MARSH - 2011 (P=0.01)**



We tested the relationship between Hg in toenails and carapace length (as a surrogate for turtle age) to evaluate whether age/size could be influencing Hg concentration differences between the two sites. Onondaga Lake snapping turtles had a mean carapace length of 25.3 cm, compared to 30.7 cm for Hamlin Marsh turtles (Appendix A). The mean carapace lengths of Onondaga Lake and Hamlin Marsh snapping turtles were marginally different ($p=0.07$). There was no relationship between carapace length and toenail Hg in Onondaga turtles ($r = 0.39$, $p=0.386$), but we identified an inverse significant relationship between carapace length and toenail Hg in Hamlin Marsh turtles ($r = - 0.74$, $p=0.06$) (Figure 5). We conclude that carapace length did not appear to be correlated with Hg in snapping turtle toenails at Onondaga Lake, but was inversely related to toenail Hg at Hamlin Marsh.

FIGURE 5 CARAPACE LENGTH (CM) VS. TOENAIL MERCURY (NG/G DW) IN SNAPPING TURTLES FROM ONONDAGA LAKE AND HAMLIN MARSH



DISCUSSION

Northern Green Frogs

Table 2 compares Hg concentrations reported in amphibians from this and other studies. Bank et al. (2007) reported a mean total Hg concentration of 25.1 ng/g ww in green frog tadpoles collected from various pond sites in Acadia National Park (NP), a site that has experienced some Hg contamination as a result of atmospheric deposition, but is not known to have any point sources of Hg. Converting our dw Hg data to ww Hg concentrations ⁴, Hamlin Marsh tadpoles contained a mean concentration of 8 ng/g Hg ww, which is less than what was reported in Bank et al. (2007; Table 2). The single green frog tadpole collected at Onondaga Lake (Pond 2) had a calculated ww Hg concentration of 15.3 ng/g Hg, also less than the mean concentration of Hg detected in Acadia NP green frog tadpoles. Tadpoles of other frog species collected at sites generally considered to have low ambient Hg (Terhivuo et al. 1984; Rock and Mayer 2011; Loftin et al. 2012) had somewhat higher Hg concentrations than what we detected at Hamlin Marsh or in the single tadpole collected from Pond 2 at Onondaga Lake (Table 2). We note that the only green frog tadpole from Onondaga Lake was collected from Pond 2. Terrestrial Environmental Specialists, Inc. was not able to collect additional tadpoles at Onondaga Lake to sample for Hg (TES 2013 a & b).

Methyl Hg comprised an average of 59% of total Hg in Hamlin Marsh tadpoles and 11% of total Hg in the single Onondaga Lake green frog tadpole. This compares to 7.6% to 40% MeHg in green frog and bullfrog tadpoles at Acadia NP (Bank et al. 2007). In southern leopard frog tadpoles and metamorphs fed Hg-enriched diets, MeHg comprised between 6.9% and 42.7% of total Hg in their tissue (Unrine & Jagoe 2004). The mean MeHg concentration in Onondaga Lake adult frogs was 63% of total Hg. Our MeHg dataset is inadequate to make comparisons between sites or against other studies, except to state that the percent MeHg in Onondaga Lake and Hamlin Marsh tadpoles is within the range of percent MeHg reported in these other studies. Methyl Hg is the more toxic form of Hg (Boening 2000).

Adult green frog adults collected at Onondaga Lake contained greater concentrations of Hg than green frog tadpoles and metamorphs from Hamlin Marsh. No statistical comparisons can be made between adult green frogs from the two areas or between green frog tadpoles from the two areas due to sampling limitations (i.e., no adult green frogs at Hamlin Marsh and only one green frog tadpole at Onondaga Lake). Adult green frogs at Onondaga Lake had greater Hg concentrations than green frog tadpoles from Acadia NP (Bank et al. 2007) or bullfrog (*Lithobates catesbeianus*) tadpoles from the St. Lawrence River (Rock and Mayer 2011). Both the Acadia NP and St. Lawrence River studies were conducted at sites with Hg enrichment from atmospheric deposition, but no known point sources of Hg. We were unable to find other Hg data on adult frogs. The Onondaga Lake green frog adults contained substantially less Hg than

⁴ wet weight Hg concentration = (dry weight Hg concentration * % solids in sample, divided by 100)

American toads (*Anaxyrus americanus*) and two-lined salamanders (*Eurycea bislineata*) from South River, VA, a known mercury-contaminated site (Burke et al. 2010; Bergeron et al. 2011) (Table 2). Adult green frogs from Onondaga Lake contained a concentration of Hg (188.4 ng/g dw) similar to that of southern leopard frog tadpoles and metamorphs fed a diet of 1,409 ng/g Hg, with resulting whole body tissue concentrations of 236 ng/g Hg dw (Unrine and Jagoe 2004; Table 2).

TABLE 2 COMPARISON OF TOTAL MERCURY IN AMPHIBIAN TISSUES FROM THIS STUDY AND OTHER STUDIES

STUDY	LOCATION – Hg SOURCE	SPECIES	TISSUE	MEAN Hg NG/G WW	MEAN Hg NG/G DW
This Study	Onondaga Lake, NY - Hg Site	Green frog tadpole	Whole Body	15.3	84.1 (n=1)
This Study	Onondaga Lake, NY – Hg Site	Green frog adult	Whole Body	37.8	188.4
This Study	Hamlin Marsh, NY – reference site	Green frog tadpole	Whole Body	8.0	58
This Study	Hamlin Marsh, NY – reference site	Green frog metamorph	Whole Body	11.8	67
Bank et al. 2007	Acadia NP – atmospheric Hg	Green frog tadpole	Whole Body	25.1	--
Connell 2006	Dos Palmas Preserve, CA – no known Hg point source	Bullfrog adult	Hind Limb	18 ng/g (unclear if ww or dw)	--
Rock and Mayer 2011	St. Lawrence River wetlands – atmospheric Hg	Bullfrog tadpole	Whole Body	38 - 65	--
Terhivuo et al. 1984	Southern Finland – no known Hg point source	Common toad (<i>Bufo bufo</i>) adult	Muscle	40	--
Byrne et al. 1975, as cited in Terhivuo et al. 1984	Yugoslavia – Hg contaminated area	Common toad (<i>Bufo bufo</i>)	Muscle	2,330	--
Loftin et al. 2012	Acadia NP – atmospheric Hg	Wood frog tadpole	Whole Body	28.2 – 54.2	--
Haruka et al. 2011	Lab feeding study: diet of 10 ng/g Hg dw	Wood frog tadpoles	Whole Body	--	30
	Lab feeding study: diet of 10,000 ng/g Hg dw	Wood frog tadpoles	Whole Body	--	3,540
Bergeron et al. 2011	South River, VA – Hg contaminated site: free ranging at South River	American toad metamorphs	Whole Body	--	2,100
	Lab feeding study: diet of 2,500 ng/g Hg	American toad metamorphs	Whole Body	--	800
	Lab feeding study: diet of 10,000 ng/g Hg	American toad metamorphs	Whole Body	--	1,700
Unrine & Jagoe 2004; Unrine et al. 2004	Lab feeding study: diet of 423 ng/g Hg dw	Leopard frog tadpoles & metamorphs	Whole Body	--	95
	Lab feeding study: diet of 1,409 ng/g Hg dw	Leopard frog tadpoles & metamorphs	Whole Body	--	236
	Lab feeding study: diet of	Leopard frog tadpoles	Whole Body	--	412

STUDY	LOCATION – Hg SOURCE	SPECIES	TISSUE	MEAN Hg NG/G WW	MEAN Hg NG/G DW
	3,298 ng/g Hg dw	& metamorphs			
Ugarte et al. 2005	Florida Everglades – Hg contaminated area	Pig frog (<i>Rana grylio</i>)	Leg	329	--
Burke et al. 2010	South River, VA – reference site	Northern two-lined salamander	Whole Body	--	256
	South River, VA – Hg contaminated site	Northern two-lined salamander	Whole Body	--	4,519

Effects of Mercury on Amphibians

A limited number of studies have evaluated the effects of Hg on amphibians. Burke et al. (2010) reported that northern two-lined salamanders with an average Hg concentration of 4,519 ng/g dw experienced reduced speed and responsiveness compared with two-lined salamanders with an average Hg concentration of 256 ng/g dw.

Bergeron et al. (2011) found that both maternally-transferred and dietary Hg impacted growth, development, and survival of American toad larvae. They reported concentrations in low diet (2,500 ng/g Hg dw) and high diet (10,100 ng/g Hg dw) whole body metamorphs at the completion of metamorphosis of approximately 800 ng/g dw and 1,700 ng/g dw, respectively. Effects on growth, metamorphosis, and survival were observed in both low and high diet toad larvae. Free ranging American toad larvae from the South River, VA (Hg-contaminated site) had a whole body total Hg concentration of approximately 2,100 ng/g dw. All of the concentrations reported in American toad larvae from the Bergeron et al. (2011) field and laboratory feeding studies (800 – 2,100 ng/g Hg dw) exceed the mean concentration of Hg detected in Onondaga Lake green frog adults (188.4 ng/g Hg dw) and the single Onondaga Lake tadpole (84.1 ng/g Hg dw).

Haruka et al. (2011) examined the effects of dietary Hg on wood frog (*Lithobates sylvatica*) development, growth, performance, survival, and thyroid hormone concentrations. They found no effects on any of these parameters at dietary concentrations as high as 10,000 ng/g Hg dw. The concentration of tissue Hg in wood frog tadpoles fed the highest dietary dose was 3,540 ng/g dw, also in excess of the Hg concentration in adult green frogs from Onondaga Lake (188.4 ng/g Hg dw).

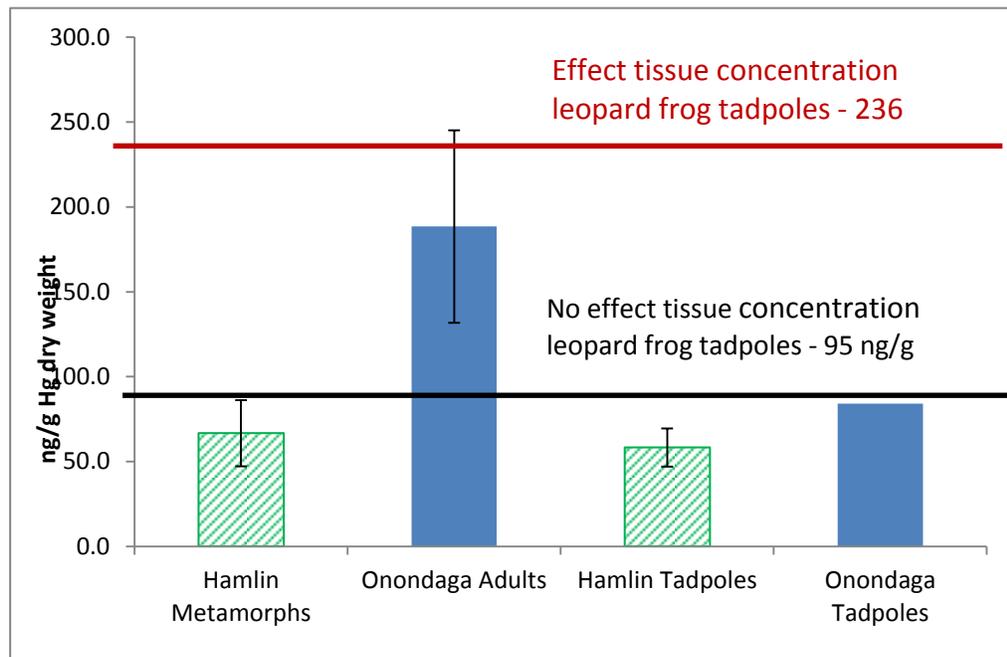
Unrine and Jagoe (2004) and Unrine et al. (2004) conducted a feeding study of southern leopard frogs (*Lithobates sphenoccephala*) using more environmentally realistic dietary Hg concentrations than those used by Bergeron et al. (2011). Tadpoles were fed diets of 423, 1,409, and 3,298 ng/g Hg fresh weight (fw), resulting in corresponding mean Hg concentrations in tadpoles and metamorphs of 95, 236, and 412 ng/g dw. The medium and high diets (1,409 and 3,298 ng/g Hg fw) reduced the survival rate and metamorphic success rate of tadpoles and metamorphs and increased the malformation rate compared to tadpoles and metamorphs fed the control and low diets, but had no effect on growth. This study concluded that dietary exposure of leopard frogs

at sites with relatively low Hg concentrations may be sufficient to cause the adverse effects described above.

The Hg concentrations reported by Unrine et al. (2004) and Unrine and Jagoe (2004) in the tissues of their low and medium diet leopard frog tadpoles (95 and 236 ng/g dw) are similar to Hg concentrations detected in Onondaga Lake green frog adults (mean=188.4 ng/g Hg dw) and the single green frog tadpole from Onondaga Lake (84.1 ng/g dw). More specifically, Onondaga Lake adult green frog adults have concentrations of Hg that are between the no effect (95 ng/g dw) and effect tissue concentration (236 ng/g dw) reported for leopard frogs in the Unrine studies (Figure 6).

Mercury concentrations in Onondaga Lake green frogs may be high enough to adversely impact sensitive species of amphibians, such as southern leopard frogs, although Onondaga Lake green frog Hg concentrations are less than effect concentrations in species such as the wood frog and American toad (Figure 6). We note that northern leopard frogs have been reported in two wetlands at Onondaga Lake: SYW-1 and SYW-6, an indication that at least adults of that species occur there (Ducey 2013).

FIGURE 6 ONONDAGA LAKE AND HAMLIN MARSH GREEN FROG BLOOD MERCURY COMPARED TO MERCURY EFFECTS LEVELS FOR SOUTHERN LEOPARD FROGS



Notes:

1. No effect and effects concentrations for leopard frogs from Unrine et al. (2004) and Unrine and Jagoe (2004).
2. Effect concentration for American toads is 800 ng/g Hg dw (Bergeron et al. 2011); no effect concentration for wood frogs is 3,540 ng/g Hg dw (Haruka et al. 2011).
3. Error bars denote one standard deviation.

Snapping Turtles

Tables 3 and 4 and Figure 7 compare Hg concentrations reported in turtles from this and other studies. With the exception of snapping turtles collected from the mercury-contaminated sections of the Holston and South Rivers in Virginia (Bergeron et al. 2007; Hopkins et al. 2013a & b), Onondaga Lake snapping turtles have higher Hg concentrations in blood and keratinous tissues (toenails) than other turtles from other locations. For example, Turnquist et al. (2011) analyzed muscle and shell samples from 48 snapping turtles collected across New York State. The shell Hg concentrations ranged from 470 – 7,430 ng/g ww. Even the highest shell Hg concentration from the Turnquist study (7,430 ng/g) is less than the estimated ww mean Hg concentration in Onondaga Lake snapping turtle keratinous tissue of 10,515 ng/g. Scutes from diamondback terrapins (*Malaclemys terrapin*) collected at a Hg point source along Purvis Creek, Georgia had a mean Hg concentration of 3,810 ng/g ww (Blanvillain et al. 2007). This is less than the Hg concentration in Onondaga Lake snapping turtle toenails (10,515 ng/g ww).

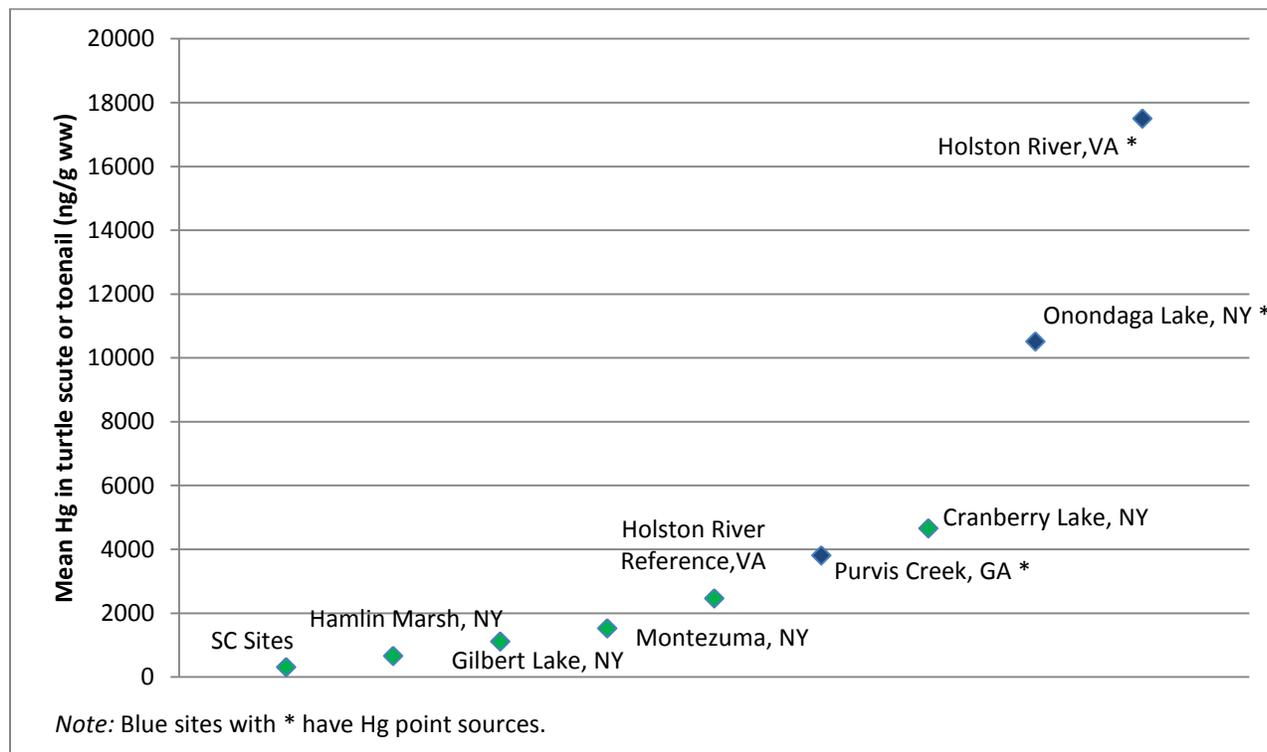
TABLE 3 COMPARISON OF MERCURY IN TURTLE BLOOD FROM THIS STUDY AND OTHER STUDIES

STUDY	LOCATION	SPECIES	MEAN (RANGE) HG NG/G WW	MEAN (RANGE) HG NG/G DW
This Study	Onondaga Lake *	Snapping Turtle	513 (262 – 768)	--
This Study	Hamlin Marsh	Snapping Turtle	22 (8 – 45)	--
Bergeron et al. 2007	South River, VA *	Snapping Turtle	~950 (from Fig 2)	--
Hopkins et al. 2013a	South River, VA* and Middle River, VA	Snapping Turtle	(100 – 4,990)	--
Golet & Haines 2001	Connecticut	Snapping Turtle	50 – 350 ^A	--
Bergeron et al. 2007	South River, VA *	Painted Turtle (<i>Chrysemas picta</i>)	~480 (from Fig 2)	--
Meyer et al. 2014	California gold mining area	Western Pond Turtle (<i>Emys marmorata</i>)	--	81 (18 – 322)
Zapata et al. 2014	Columbia, 2 locations	Colombian Slider Turtles (<i>Trachemys callirostris</i>)	30 & 60	--
Day et al. 2007	Southeastern U.S.	Loggerhead Turtle (<i>Caretta caretta</i>)	290	--
Innis et al. 2008	Cape Cod, MA	Kemps Ridley Turtles (juvenile) (<i>Lepidochelys kempii</i>)	24	--
Blanvillain et al. 2007	Purvis Creek, GA *	Diamondback Terrapin	746	--
<i>Notes:</i>				
A. Estimated from Figure 5.				
* site with known Hg point source.				
ww = wet weight, dw = dry weight.				
-- no data available.				

TABLE 4 COMPARISON OF MERCURY IN TURTLE KERATINOUS TISSUE FROM THIS STUDY AND OTHER STUDIES.

STUDY	LOCATION	SPECIES	MEAN (RANGE) HG NG/G WW	MEAN (RANGE) HG NG/G DW
This Study	Onondaga Lake *	Snapping Turtle toenail	10,515 (2,334 -21,433) ^A	11,684 (2,594-23,875)
This Study	Hamlin Marsh	Snapping Turtle toenail	659 (505-882) ^A	732 (560-981)
Turnquist et al. 2011	New York State from 10 locations	Snapping Turtle shell	470-7,430	--
Hopkins et al. 2013a	South and Middle River, VA *	Snapping Turtle toenail	150-161,110 (fw)	--
Hopkins et al. 2013b	Holston River, VA *	Snapping Turtle toenail	~2,500-18,000 (fw, multiple sites)	--
Golet & Haines 2001	Connecticut	Snapping Turtle scute	--	(500-3,300)
Zapata et al. 2014	Columbia, 2 locations	Colombian Slider Turtle (<i>Trachemys callirostris</i>) carapace	80 & 90	--
Presti et al. 1999	Mexico	Black Sea Turtle (<i>Chelonia mydas</i> <i>agassizii</i>) keratin	50.9 ^B	--
Blanvillain et al. 2007	Purvis Creek, GA *	Diamondback Terrapin scute	3,810	--
Innis et al. 2008	Cape Cod, MA	Kemps Ridley Turtle (juv) (<i>Lepidochelys</i> <i>kempii</i>) keratin	389	--
<p><i>Notes:</i> A. Wet weight Hg concentration calculated based on estimated 10% moisture in toenails (concentration ww = concentration dw * 90/100). B. Article does not specify if Hg concentrations are wet weight or dry weight. * site with known Hg point source. ww = wet weight, dw = dry weight, fw = fresh weight. -- no data available.</p>				

FIGURE 7 MEAN MERCURY IN SCUTES OR TOENAILS OF SNAPPING TURTLES OR DIAMONDBACK TERRAPINS (PURVIS CREEK & SC SITES) FROM VARIOUS U.S. SITES



Studies by Hopkins et al. (2013a) and Bergeron et al. (2007) in the South River, Virginia (known point source of Hg) provide information on Hg in snapping turtle blood. Bergeron et al. (2007) report blood Hg in four turtle species sampled at the South River, VA, with a mean Hg concentration of approximately 950 ng/g in snapping turtles and approximately 480 ng/g in painted turtles. Hopkins et al. (2013a) reported even greater Hg concentrations in blood from South River snapping turtles – maximum blood Hg concentration of 4,990 ng/g (compared to maximum blood Hg in Onondaga Lake snapping turtles of 768 ng/g). These blood Hg concentrations in snapping turtles from a site with known point sources of Hg exceed the blood Hg concentrations in Onondaga Lake snapping turtles.

Snapping turtle carapace length was not correlated with Hg in snapping turtle toenails at Onondaga Lake, but was inversely related to toenail Hg at Hamlin Marsh. Turnquist et al. (2011), in their evaluation of snapping turtle shell Hg from samples taken across New York State, did not find an overall correlation between Hg concentrations and carapace length or turtle mass, although within sample sites, the larger individuals had higher shell Hg concentrations. Our data support that snapping turtles do not necessarily accumulate greater concentrations of Hg in their toenails with increasing age, although a more robust data set would be needed to validate this observation.

Effects of Mercury on Turtles

Hopkins et al. (2013a) reported that Hg concentrations in snapping turtle eggs from the South River and Middle, VA were strongly and positively correlated with Hg levels in the blood, muscle, and nail tissues of females, whereas mercury in eggs was negatively correlated with hatching success. The authors did not report the nail and blood Hg concentrations associated with various levels of hatching success. However, they reported blood Hg in snapping turtles ranging from 10 – 4,990 ng/g ww at their three study sites (two reference sites and one Hg contaminated site), which corresponded to 10 – 6,610 ng/g Hg dw in snapping turtle eggs. Turtles with egg Hg concentrations toward the upper end of their reported egg Hg distribution (greater than approximately 5,000 ng/g dw) were predicted to have a 27% reduction in hatching success. The maximum Hg concentrations reported in snapping turtle blood from the Hopkins study were 6 – 7 times the maximum Hg concentration we report in this study (768 ng/g Hg ww in Onondaga Lake snapping turtle blood).

Snapping turtle toenail Hg concentrations from the Hopkins (2013a) study ranged from 150 to 161,000 ng/g fresh weight, compared with 2,334 to 21,433 ng/g Hg ww in Onondaga Lake snapping turtle toenails. It is unlikely that concentrations of Hg in Onondaga Lake snapping turtles are high enough to significantly impact reproduction of this species, when compared against effects concentrations of Hg in the blood and toenails of snapping turtles studied by Hopkins et al. (2013a) along the South River, VA.

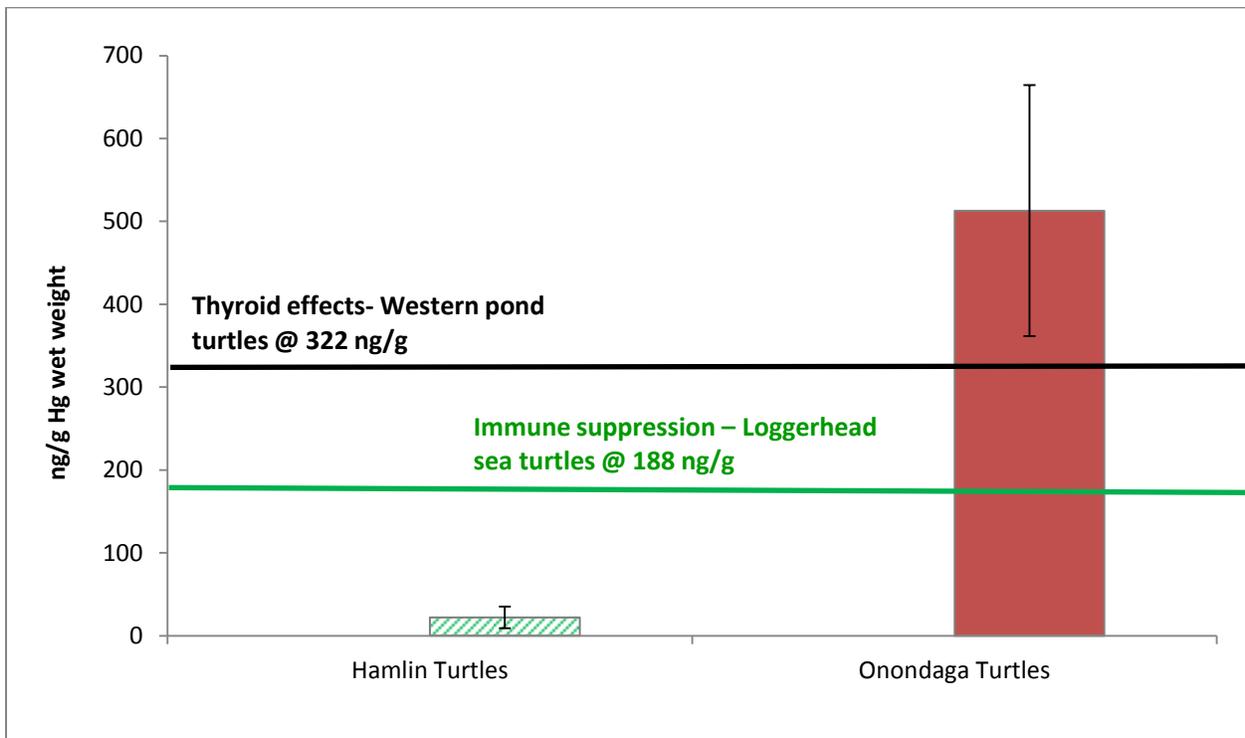
Meyer et al. (2014) measured total Hg concentrations in red blood cells (RBCs) and the thyroid hormones, T3 and T4, in plasma of Western pond turtles (*Emys marmorata*) from historic gold mining areas in California. Total Hg in RBCs ranged from 180 – 3,200 ng/g dw (geometric mean of 805 ng/g Hg dw). Using reasonable assumptions,⁵ these Hg concentrations correspond to approximately 18 to 322 ng/g Hg ww in whole blood of Western pond turtles, with an estimated mean whole blood Hg concentration of 81 ng/g ww. Meyer et al. (2014) concluded that RBC Hg was negatively correlated with T3 and positively correlated with T4, suggesting that Hg may affect thyroid function in western pond turtles. We use the estimated maximum concentration of 322 ng/g Hg in whole blood as a threshold for potential thyroid hormone-altering effects in Western pond turtles (Figure 8).

We hypothesize that Onondaga Lake snapping turtles have blood Hg concentrations (261.9-768.4 ng/g Hg ww) within the range of blood Hg in Western pond turtles that altered thyroid function (322 ng/g Hg ww). Thyroid hormones can influence growth, development, and reproduction in vertebrates and metamorphosis in amphibians (Dickoff and Darling 1983).

⁵ Turtle blood is approximately 76% plasma and 24% RBC by volume (Dessauer 1970). Turtle blood is calculated to be approximately 74% plasma and 26% RBC by weight (based on density of human plasma at 1.02 g/ml, density of human whole blood at 1.05 mg/l and density of human RBC calculated at 1.15 mg/l; Trudnowski & Rico 1974). Human RBCs are approximately 65% water and 35% solids (Beilin et al. 1966). Hg concentration whole blood ww = (concentration Hg in RBC dw * 0.35 g dry wt RBC/1 g ww RBC * 0.262 g wet weight RBC/1 g ww whole blood) / 0.91 (% Hg in whole blood that is in RBCs) (Blanvillain et al. 2007).

Day et al. (2007) evaluated the relationship between blood Hg and a number of health parameters in Loggerhead sea turtles. They concluded that in vitro immune suppression occurred at MeHg concentrations that correspond to those measured in approximately five percent of individual Loggerhead sea turtles captured in the wild. Their mean total Hg concentration in Loggerhead sea turtle blood was 29 ng/g ww, with a range of 5 to 188 ng/g total Hg. The implication from their research is that concentrations of total Hg in blood of Loggerhead sea turtles at the higher end of their reported range (5 – 188 ng/g) may be contributing to some level of immune suppression in this species. The mean blood Hg of Onondaga Lake snapping turtles (513 ng/g Hg) exceeded the maximum concentration (188 ng/g Hg) from that study, suggesting that sensitive turtle species at Onondaga Lake may experience immune suppression as a result of exposure to Hg. However, there is no information on the sensitivity to Hg of Loggerhead sea turtles compared to turtle species that may be found at Onondaga Lake.

FIGURE 8 TOTAL MERCURY IN SNAPPING TURTLE BLOOD FROM ONONDAGA LAKE AND HAMLIN MARSH (2011) COMPARED TO EFFECTS LEVELS IN WESTERN POND TURTLES AND LOGGERHEAD SEA TURTLES



Notes:

1. Western pond turtle effect level estimated from Meyer et al. (2014).
2. Loggerhead sea turtle effect level estimated from Day et al. (2007).
3. Snapping turtle effect concentration in blood approximately 4,000 - 5,000 ng/g ww (Hopkins 2013a).
4. Error bars denote one standard deviation.

CONCLUSIONS

Available information suggests that sensitive species of amphibians may be adversely affected by Hg at Onondaga Lake, with some caveats. Our data set is small and limited to northern green frogs collected at primarily one Onondaga Lake location (Pond 2) that may not be representative of the lake as a whole. The toxicological studies cited in the Results section were performed with tadpoles or metamorphs of species other than green frogs. We have no information on the sensitivity of northern green frogs to Hg and only a single data point for Hg in green frog tadpoles from Onondaga Lake. There appears to be significant differential sensitivity of various amphibian species to Hg. Studies conducted thus far indicate that southern leopard frogs may be more sensitive to Hg than species such as American toad, wood frog, and northern two-lined salamanders.

Terrestrial Environmental Specialists, Inc. was able to collect only one green frog tadpole from Onondaga Lake for tissue Hg analysis (TES 2013a). They trapped 12 other green frog tadpoles at Onondaga Lake as part of the herpetological inventory project conducted during June 20-24, 2011, July 11-15, 2011 and August 1-5, 2011. However, green frog tadpoles were collected in wetlands that surround the lake and not in Onondaga Lake itself (TES 2013a). While the difficulty of trapping green frog tadpoles in Onondaga Lake suggests that minimal reproduction of green frogs at Onondaga Lake and contiguous wetlands occurs, there may be factors in addition to Hg contamination (e.g., limited physical habitat) partially responsible for low green frog reproduction. Ducey (2013) reported evidence of some amphibian breeding activity (green frogs, spring peepers) in the vicinity of Pond 2 and wetland SYW-1 and also reported observing adult leopard frogs in SYW-1 and SYW-6 (Figure 1). Outside of these observations, the success of any amphibian breeding efforts is largely unknown.

We also demonstrated that Hg in the toenails and blood of snapping turtles from Onondaga Lake was significantly greater than Hg in the toenails and blood of Hamlin Marsh snapping turtles. Onondaga Lake snapping turtles have more Hg in their keratinous tissue (toenails) than other snapping turtles sampled across New York State. Onondaga Lake snapping turtles have more Hg than diamondback terrapins from a Hg-contaminated site at Purvis Creek, GA, but less Hg than snapping turtles from Hg-contaminated areas in Virginia. Snapping turtles appear fairly resistant to Hg, but the Hg concentrations found in Onondaga Lake snapping turtles are within the range of concentrations associated with altered thyroid function and immune suppression in other turtle species.

Ducey (2013) reported painted turtles, musk turtles, and snapping turtles in wetlands surrounding Onondaga Lake. Snapping turtles successfully breed there. Breeding success by the other two species is poorly understood (Ducey 2013).

Information from Ducey (2013) indicates that the diversity of amphibians and reptiles has increased at Onondaga Lake over the past two decades. However, the herpetofaunal diversity

and population densities remain lower than is found in surrounding areas. This study indicates that Hg may be a factor inhibiting reproduction and health of some amphibians and reptiles at Onondaga Lake. However, other factors, such as limited wetland habitat abundance and diversity, poor turtle breeding substrate, habitat fragmentation, invasive species, and lack of ephemeral breeding sites are also likely contributors to reduced herpetofaunal abundance and diversity (Ducey 2013).

LITERATURE CITED

- Bank, MS, J Crocker, B Connery and A Amirbahman. 2007. Mercury bioaccumulation in green frog (*Rana clamitans*) and bullfrog (*Rana catesbeiana*) tadpoles from Acadia National Park, Maine, USA. *Environ Toxicol Chem* 26(1): 118 – 125.
- Beilin, LJ, GJ Knight, AD Munro-Faure and J Anderson. 1966. The sodium, potassium, and water contents of red blood cells of healthy human adults. *J Clinical Investigation* 45(11): 1817 – 1825.
- Bergeron, CM, JF Husak, JM Unrine, CS Romanek and WA Hopkins. 2007. Influence of feeding ecology on blood mercury concentrations in four species of turtles. *Environ Toxicol Chem* 26(8): 1733 – 1741.
- Bergeron, CM, WA Hopkins, BD Todd, MJ Hepner and JM Unrine. 2011. Interactive effects of maternal and dietary mercury exposure have latent and lethal consequences for amphibian larvae. *Environ Sci Technol* 45:3781 – 3787.
- Blanvillain, G, JA Schwenter, RD Day, D Point, SJ Christopher, WA Roumillat and DW Owens. 2007. Diamondback terrapins, *Malaclemys terrapin*, as a sentinel species for monitoring mercury pollution of estuarine systems in South Carolina and Georgia, USA. *Environ Toxicol Chem* 26(7):1441 – 450.
- Boening, DW. 2000. Ecological effects, transport, and fate of mercury: a general review. *Chemosphere* 40: 1335-1351.
- Burke, JN, CM Bergeron, BD Todd and WA Hopkins. 2010. Effects of mercury on behavior and performance of northern two-lined salamanders (*Eurycea bislineata*). *Environ Poll* 158: 3546 – 3551.
- Byrne, AR, L Kosta and P Stegnar. 1975. The occurrence of mercury in amphibians. *Environ Lett* 8: 147 – 155.
- Calvery, HO. 1933. Some analyses of egg-shell keratin. *J Biol Chem* 100:183-186.

- Connell, J. 2006. Mercury concentrations in the muscles of the North American bullfrogs (*Rana catesbeiana*). UNLV Thesis, University of Las Vegas, Nevada.
- Day, RD, SJ Christopher, PR Becker and DW Whitaker. 2005. Monitoring mercury in the loggerhead sea turtle, *Caretta caretta*. *Environ Sci Technol* 39(2):437 – 446.
- Day, RD, AL Segars, MD Arendt, AM Lee and MM Peden-Adams. 2007. Relationship of blood mercury levels to health parameters in the loggerhead sea turtle (*Caretta caretta*). *Environ Health Perspectives* 115 (10): 1421 – 1428.
- Dessauer, HC. 1970. Blood chemistry of reptiles: physiological and evolutionary aspects. Chapter 1 of *Biology of the Reptilia*, edited by Carl Ganz, State University of New York at Buffalo. Academic Press, London and New York.
- Dickoff, WW and DS Darling. 1983. Evolution of thyroid function and its control in lower vertebrates. *Am Zool* 23:697-707.
- Ducey, PK. 2013. Analysis of amphibians and reptiles of the Onondaga Lake ecosystem, 1994-2012. State University of New York at Cortland, Cortland, NY 13045.
- Golet, WJ and TA Haines. 2001. Snapping turtles (*Chelydra serpentina*) as monitors for mercury contamination of aquatic environments. *Environ Monitor Assess* 71:211 – 220.
- Grillitsch, B and L Schiesari. 2010. The ecotoxicology of metals in reptiles, In, *Ecotoxicology of Amphibians and Reptiles*, Second Edition, DW Sparling, G Linder, CA Bishop, SK Krest Eds., CRC Press.
- Haruka, W, CM Bergeron, FMA McNabb, BD Todd, WA Hopkins et al. 2011. Dietary mercury has no observable effects on thyroid-mediated processes and fitness-related traits in wood frogs. *Environ Sci Technol* 45.18:7915 – 7922.
- Herpetological Animal Care and Use Committee (HACC) of the American Society of Ichthyologists and Herpetologists. 2004. Guidelines for use of live amphibians and reptiles in field and laboratory research. pp 1-43.
- Hopkins, BC, JD Willson and WA Hopkins. 2013a. Mercury exposure is associated with negative effects on turtle reproduction. *Environ Sci Technol* 47: 2416 – 2422.
- Hopkins, WA, C Bodinof, S Budischak and C Perkins. 2013b. Nondestructive indices of mercury exposure in three species of turtles occupying different trophic niches downstream from a former chloralkali facility. *Ecotoxicology* 22:22 – 32.
- Innis, C, M Tlusty, C Perkins, S Holladay, C Merigo and ES Weber III. 2008. Trace metal and organochlorine pesticide concentrations in cold-stunned juvenile Kemp's Ridley turtles

- (*Lepidochelys kempii*) from Cape Cod, Massachusetts. *Chelonian Conservation and Biology*. DOI: 10.2744/CCB-0707.1.
- Loftin, CS, AJK Calhoun, SJ Nelson, AA Elskus and K Simon. 2012. Mercury bioaccumulation in wood frogs developing in seasonal pools. *Northeastern Naturalist* 19(4): 579 – 600.
- Meyer, E, CA Eagles-Smith, D Sparling and S Blumenshine. 2014. Mercury exposure associated with altered plasma thyroid hormones in declining western pond turtle (*Emys marmorata*) from California mountain streams. *Environ Sci Technol* 48:2989 – 2996.
- Presti, SM, ARS Hidalgo, AE Sollod and JA Seminoff. 1999. Mercury concentration in the scutes of black sea turtles (*Chelonia mydas agassizii*) in the Gulf of California. Linnaeus Fund Research Report. *Chelonian Conservation and Biology, International Journal of Turtle and Tortoise Research* 3(3):531 – 533.
- Rock, K and M Mayer. 2011. Mercury levels in bullfrog tadpoles (*Rana catesbeiana*) in three wetlands in St. Lawrence County. Poster, Biology Dept., St. Lawrence University, Canton, NY. See also Mayer, M et al. 2011, Assessment of mercury levels in wetland wildlife in the St. Lawrence River and the St. Lawrence River Valley, Report to the St. Lawrence Research and Education Fund, New York Power Authority.
- Terrestrial Environmental Specialists, Inc. (TES). 2013a. Onondaga Lake Herpetological Investigations, Results of 2011 Studies at Onondaga Lake and Reference Areas. Prepared for Onondaga Lake Natural Resource Damage Assessment and Restoration Trustee Council.
- Terrestrial Environmental Specialists, Inc. (TES). 2013b. Onondaga Lake Herpetological Investigations, Spring 2012 Supplement. Prepared for Onondaga Lake Natural Resource Damage Assessment and Restoration Trustee Council.
- Terhivuo, J, M Lodenius, P Nuorteva and E Tulisalo. 1984. Mercury content of common frogs (*Rana temporaria* L.) and common toads (*Bufo bufo* L.) collected in southern Finland. *Ann Zool Fennici* 21:41 – 44.
- Trudnowski, RJ and RC Rico. 1974. Specific gravity of blood and plasma at 4 and 37 degrees C. *Clin Chem* 20(5): 615 – 616.
- Turnquist, MA, CT Driscoll, KL Schulz and MA Schlaepfer. 2011. Mercury concentrations in snapping turtles (*Chelydra serpentina*) correlate with environmental and landscape characteristics. *Ecotoxicology* 20:1599 – 1608.
- Ugarte, CA, KG Rice and MA Donnelly. 2005. Variation of total mercury in pig frogs (*Rana grylio*) across the Florida Everglades, USA. *Science of the Total Environment* 345:51 – 59.

- Unrine, JM and CH Jagoe. 2004. Dietary mercury exposure and bioaccumulation in southern leopard frog (*Rana sphenocephala*) larvae. *Environ Toxicol Chem* 23(12): 2956 – 2963.
- Unrine, JM, CH Jagoe, WA Hopkins and HA Brant. 2004. Adverse effects of ecologically relevant dietary mercury exposure in southern leopard frog (*Rana sphenocephala*) larvae. *Environ Toxicol Chem* 23 (12): 2964 – 2970.
- Wang, Hui-Chen (2006). Trace metal uptake and accumulation pathways in Kemp's Ridley sea turtles (*Lepidochelys kempii*). Doctoral dissertation, Texas A&M University. Texas A&M University. Available electronically from <http://hdl.handle.net/1969.1/2413>.
- Zapata, LM, BC Bock and JA Palacio. 2014. Mercury concentrations in tissues of Colombian slider turtles, *Trachemys callirostris*, from northern Colombia. *Bull Environ Contam Toxicol* 92(5):562 – 566.

APPENDIX A

TABLE A-1 SUMMARY DATA ON ONONDAGA LAKE SNAPPING TURTLES

SAMPLE ID	BLOOD Hg (NG/G WW)	TOENAIL Hg (NG/G DW)	COLLECTION LOCATION	CARAPACE LENGTH (CM)
OL-ST-1	393	5,525	NW corner	30.48
OL-ST-2	437	8,416	Outlet	26.92
OL-ST-3	567	20,612	NW corner	23.88
OL-ST-4	588	23,815	Harbor Brook	32.26
OL-ST-5	768	7,681	Harbor Brook	26.92
OL-ST-6	576	13,143	NE corner	20.32
OL-ST-7	262	2,594	NW corner	16.51

TABLE A-2 SUMMARY DATA ON HAMLIN MARSH SNAPPING TURTLES

SAMPLE ID	BLOOD Hg (NG/G WW)	TOENAIL Hg (NG/G) DW	COLLECTION LOCATION	CARAPACE LENGTH (CM)
CM-ST-1B	11	562	Study Area B	28.96
CM-ST-2B	8	560	Study Area B	36.58
CM-ST-3B	21	754	Study Area B	33.53
CM-ST-4B	9	727	Study Area B	33.27
CM-ST-5B	36	909	Study Area B	26.92
CM-ST-6B	22	981	Study Area B	23.37
CM-ST-7B	45	634	Study Area B	32.26