



Mercury Levels in Mink (*Mustela vison*) and River Otter (*Lontra canadensis*) from Northeastern North America

DAVID E. YATES,^{1,6} DAVID T. MAYACK,² KENNETH MUNNEY,³ DAVID C. EVERS,¹ ANDREW MAJOR,³ TARANJIT KAUR⁴ AND ROBERT J. TAYLOR⁵

¹*BioDiversity Research Institute, 19 Flagg Meadow Road, Gorham ME 04038, USA*

²*New York State Department of Environmental Conservation, Hale Creek Field Station, 182 Steele Ave. Ext., Gloversville, New York 12078, USA*

³*U.S. Fish and Wildlife Service, Concord, NH 03301, USA*

⁴*Virginia Polytechnic Institute and State University, Blacksburg, VA 24060, USA*

⁵*Trace Element Research Lab, Texas A&M University, College Station, TX 77843, USA*

⁶*Antioch New England Graduate School, 40 Avon Street, Keene, NH 03431, USA*

Accepted 4 December 2004

Abstract. Aquatic ecosystems have received mercury released from anthropogenic sources. The northeast region of North America is at especially high risk because of local and regional emission sources, prevailing wind patterns, and certain hydrological and biogeochemical features. Here we examine regional variation in total mercury (Hg) in brain, liver, and fur from otter and mink collected across New York, New England, and Nova Scotia. Gender and age are examined as factors potentially affecting Hg tissue levels. In addition, temporal relationships are analyzed for New York as well as correlative relationships for tissues from Maine. Animals were collected from 1982 to 2003, mostly from licensed trappers. Liver was the only tissue from otter that exhibited significant regional variation (New York versus Maine) in Hg concentration. Mercury concentration was significantly related to age but not to gender for otter. All tissues in mink exhibited significant, but inconsistent, regional variation in total Hg concentration, with the highest mean Hg concentration in liver samples from Massachusetts/Connecticut. Female mink had significantly greater Hg concentrations in liver than males. Total Hg concentration in the liver of both otter and mink from New York decreased significantly with time. Correlations among tissues for Hg concentration were stronger for male and female mink and male otter than female otter from Maine.

Keywords: mink; otter; mercury; methylmercury; gender; age

Introduction

Mercury (Hg), is a persistent, bioaccumulative toxin, and is prevalent in freshwater and marine environments (Maine DEP, 1998, NESCAUM,

1998) throughout northeastern North America. The mink (*Mustela vison*) and the river otter (*Lontra canadensis*) are mustelids that are widely distributed in northeast North America. Although mink are known prey generalists, both mink and otter have diets that include fish and crayfish, which are known methylmercury (MeHg) vectors. Their relatively high metabolic rates and the

*To whom correspondence should be addressed:

Tel.: +207-839-7600;

E-mail: dave.yates@briloon.org

significant percentage of fish in their diets result in the potential for these species to bioaccumulate MeHg in their tissues to levels of toxicological concern (USEPA, 1997).

Mercury availability is strongly influenced by hydrology and biogeochemical factors (Watras and Huckabee, 1994; Evers and Reaman, 1998; Lucotte et al., 1999). Consequently, Hg availability to fish and wildlife varies greatly intra- as well as inter-regionally (Evers et al., 1998; 2004). Mercury levels in river otter vary regionally across Ontario (Wren et al., 1980; Wren, 1985; Wren et al., 1986, Wren and Stokes, 1988, Mierle et al., 2000). Likewise, Hg levels in mink vary across southern New England (Major and Carr, 1991) and Quebec (Desai-Greenway and Price, 1976, Langis et al., 1999).

Here we examine regional variation in total Hg in brain, liver, and fur from otter and mink collected across New York, New England, and Nova Scotia. Gender and age are considered as factors potentially affecting Hg levels. In addition, for otter and mink collected from New York, we examine collection period (1982–1984 versus 1998–2000) as a factor affecting Hg levels and, for mustelids collected from Maine, determine the correlation of Hg concentration among tissues. This large regional study suggests that much of the variability in Hg concentration in brain, liver and fur from mink and otter, although large, is fairly consistent across New York, New England and Nova Scotia. However, comparisons suggest that regional differences in Hg concentration may exist between New York and Maine for otter and between Massachusetts/Connecticut and other regions for mink.

Collections and methods

A dataset for total Hg concentration in mink and river otter tissues was compiled from data obtained from non-governmental researchers, and state, federal and provincial agencies in Massachusetts/Connecticut, Maine, New Hampshire, New York, Nova Scotia, Rhode Island, and Vermont. The compiled dataset includes data from a number of regional projects with various goals and funding sources. These data represent a significant proportion of the available data for total Hg in

tissues of otter and mink collected across New York, New England and Nova Scotia from 1982 to 2003.

Collections

Massachusetts/Connecticut

Trappers collected nineteen mink from Massachusetts and Connecticut during 1989. Similarly, trappers collected 75 mink from Connecticut in during 1987 and 1988. Collections were made from nine drainages across Massachusetts: the Hudson, Housatonic, Millers, Westfield, Farmington, Merrimack, Taunton, Boston Harbor and Buzzards Bay and from three major river basins in Connecticut: the Housatonic, Connecticut, and Thames. The Massachusetts Department of Fisheries and Wildlife and the Connecticut Department of Environmental Protection prepared the liver samples. Samples were analyzed by the Environmental Trace Substances Research Center, in Columbia, MO.

Maine

Ninety mink and 61 otter were collected by the Biodiversity Research Institute and licensed trappers during 2000–2003. Animals were collected from eight areas: the St. John's River in the north, the central Millinocket region, Flagstaff Lake, the south central areas of North Anson and Orrington, the southwestern Nezinscot River area, and two coastal sites in Boothbay Harbor and Mt. Desert Island. Biodiversity Research Institute prepared the tissues samples. Brain, liver and fur samples were analyzed by the Texas A&M Trace Element Research Lab, in College Station, TX and the Maine Environmental Lab, in Yarmouth, ME.

New Hampshire

Twenty-five mink were collected from Merrimack County during the winter of 2000. New Hampshire Fish and Game Department and the US Fish and Wildlife Service prepared the tissue samples. Liver, fur and brain samples were analyzed by the Trace Element Research Lab at Texas A&M University, College Station, TX.

New York

Otter and mink were collected from New York during two distinct periods. The first collection

period included 66 otter (65 and 1 collected from 1982–1984 and 1985, respectively) and 125 mink (105, 19, and 1 collected from 1982–1984, 1988–1989 and 1991, respectively). Results from the analysis of 45 otter and 66 mink collected during 1982–1984 were used by Foley et al. (1988) to evaluate Hg contamination in these mustelids throughout New York. A second collection including 89 otter and 142 mink occurred from 1998–2002. The first collection was geographically broad. Otter were collected from western and northeastern Adirondack Mountains, and from counties bordering Lake Ontario and the Hudson River. Mink were collected from eight study areas, including the east and west Appalachian Plateau, the central Lake Ontario region and the lake plains bordering the east end, the west and northeast Adirondack Mountains, and the north and south Hudson River. Otter and mink collected only from the Hudson River drainage comprised the second collection. The New York State Department of Environmental Conservation (NYS DEC) or the Department of Natural Resources, at Cornell University prepared the liver samples. Samples from the first and second collections were analyzed respectively by the (NYS DEC) Coxsackie Analytical Laboratory, West Coxsackie, NY and Frontier Geosciences Inc., in Seattle, WA.

Nova Scotia

Sixteen mink and 28 otter were collected during 2000–2001 and 1995–1996, respectively. Collections were made from southwestern Nova Scotia, specifically Digby and Yarmouth Counties. Approximately half the animals were collected from coastal salt marshes and the remainder from inland watersheds. Tissue samples were prepared by the Nova Scotia Department of Natural Resources, Canadian Wildlife Service and the University of Prince Edward Island. Brain, fur and liver samples from mink and brain samples from otter were analyzed respectively by the Trace Element Research Lab at Texas A&M University, in College Station, TX and the Canadian Wildlife Service Research Centre, Carleton University, in Ottawa, Ontario.

Rhode Island

Thirty mink from coastal and inland locations across the state were collected during the winter of 1999–2000. Liver samples were prepared by the US

EPA National Exposure Research Laboratory, Narragansett, RI and were analyzed by Leeman Labs, in Lowell MA.

Vermont

Twenty-one otter from the southern portion of the state were collected during the 2001 trapping season. Fur samples were prepared by the Biodiversity Research Institute and were analyzed by the Texas A&M Trace Element Research Lab, in College Station, TX and the Maine Environmental Lab, in Yarmouth, ME.

Analytical analysis

Tissue samples were obtained from carcass remains donated by licensed trappers with the exception of samples from a small number of animals trapped by biologists or road killed. Species and tissue types analyzed varied with each collection; therefore, not all regions have data for each species or tissue. Liver tissue was the predominant tissue analyzed; fur and brain were less commonly analyzed. Only analytical results for total Hg determined on a wet-weight basis (WW) by cold vapor atomic absorption spectrometry (CVAAS) conducted since 1980 were included in these assessments. Detailed methods of tissue handling, processing, and analysis are available within cited documents or entities conducting preparatory or analytical procedures. Age was determined by cementum analysis at Matson's Laboratory, LLC, Milltown, MT.

For animals with age data, animals zero to one year in age were categorized as juveniles and those one or more years in age were categorized as adults for statistical analysis.

Statistical analysis

Total Hg $\mu\text{g/g}$ ww in brain, liver, and fur were multiplied by a scaling factor of 1000 and the product transformed to a base₁₀ logarithm, which improved normality of data distribution and stabilized variances for analysis. Demographic factors (region, age classification, and gender) were compared using Analysis of Variance (ANOVA). Total mercury levels in each of the three tissue types collected from otter were assessed using one-way ANOVA for "region", with gender and age as covariates. Mercury concentrations without

accompanying gender or age classification (7, 11, and 2 for brain, liver and fur samples, respectively) were not used in the analysis. One-way ANOVA was used to assess total mercury levels in each of three tissue types in mink by geographic region. Because several regions (Nova Scotia, New Hampshire) lacked gender or age data, gender and age classification were not included as covariates in the assessment of mink tissue data. For mink brain and fur, ANOVAs did not include data from New York due to limited sample size (two and one observations for brain and fur samples, respectively). For each tissue from mink, a two-way ANOVA was conducted with gender and age classification as factors for Hg concentration. Analysis was restricted to Hg concentrations with accompanying gender and age information. Sample sizes were, for brain, 3, 2 and 64 from Nova Scotia, New York, and Maine, respectively; for liver, 235, 64 and 32 from New York, Maine and Rhode Island, respectively; and, for fur, 1 and 64 from New York and Maine, respectively.

Collection period was analyzed as a factor affecting total Hg concentration in liver of otter and mink from New York. For otter, a one-way ANOVA was conducted with collection period (1982–1984 versus 1998–2000) as a factor and age classification as a covariate. For mink, a similar a one-way ANOVA was conducted with collection period as a factor and gender instead of age classification as a covariate. Only Hg data with age information for otter or gender for mink were included in respective analyses.

All ANOVAs and summary statistics were performed with the GLM and MEANS procedures, respectively, within the Statistical Analysis System (SAS Institute, 1985). Factors were considered significant if the probability of a greater *F*-value was < 0.05 . The Bonferroni *t* test, as part of the GLM procedure, was performed a posteriori test ($\alpha = 0.05$) to compare mean Hg concentrations among regions. Summary statistics were back-transformed for presentation.

Strength of association of total Hg concentrations in tissues from otter and mink from Maine were examined using Spearman rank correlations specific to gender and species (Analytical Software, 2003). Correlations with *p*-values < 0.05 were considered significant. Correlations were performed on untransformed data.

Results

Demographic factors

Liver was the only tissue from otter that exhibited significant regional differences in total Hg concentration (Table 1). Respective mean Hg concentrations in livers of adult and juvenile otter from New York were 17% and 95 % greater than concentrations in adult and juvenile otter from Maine (Table 2). Age affected Hg concentrations significantly in all tissues (Table 1). Overall, mean concentration was 67%, 34% and 58% greater in otter classified as adults as compared to juveniles for brain, liver, and fur, respectively (Table 2). However, comparison of age relationships among regions suggests that, for brain and fur, concentrations were not consistently greater in adults. Mean Hg concentrations in brain tissue of otters from Nova Scotia and fur from otters in Vermont were greater in specimens classified as juveniles than in adults. In contrast to age classification, gender was not a significant factor for Hg concentration on tissues from otter (Table 1).

All tissues in mink exhibited significant regional differences in total Hg concentration (Table 3). However, regional relationships for Hg concentrations were not consistent among tissues (Table 4). For brain, mean concentration in mink from Nova Scotia was greater than mean concentrations in mink from Maine and New Hampshire. In contrast, mean concentration in fur of mink from Nova Scotia was the lowest mean among the three regions. Also, the regional relationship for liver contrasts to those for brain and fur in that no significant variation was observed in means for liver among mink from Nova Scotia, Maine and New Hampshire. Mean concentration in liver of mink from Massachusetts/Connecticut was significantly greater than means from Maine, New York and Rhode Island. If Massachusetts/Connecticut mink are removed from regional comparison, the five remaining regions are not significantly different in mean concentration. For those five regions (Nova Scotia, New Hampshire, Maine, New York, Rhode Island) means ranged from 1.01 to 1.76 $\mu\text{g/g}$ ww, as compared to a much greater mean of 3.01 $\mu\text{g/g}$ ww, for mink from Massachusetts/Connecticut. Gender and age classification were not significant factors for Hg

Table 1. Results for one-way ANOVAs for region with gender and age as covariates for concentrations (µg/g, wet weight basis) of total mercury in tissues of river otter

Factor	F-value	Pr > F ^a	DF ^b
Brain			
Region (ME, NY, NS) ^c	0.73	0.484	2,82
Sex	0.39	0.532	1,82
Age	11.32	0.001	1,82
Sex × Age	2.94	0.090	1,82
Liver			
Region (ME, NY)	8.28	0.004	1,200
Sex	1.41	0.237	1,200
Age	19.88	<0.001	1,200
Sex × Age	0.03	0.860	1,200
Fur			
Region (ME, VT)	3.65	0.060	1,75
Sex	1.52	0.222	1,75
Age	7.56	0.008	1,75
Sex × Age	0.81	0.372	1,75

^aProbability of a greater F-value.

^bDegrees of freedom for effect and model, respectively, for ANOVAs conducted on data log₁₀ transformed before analysis. Otter of unknown gender or age were not included (7, 11 and 2, for brain, liver and fur samples, respectively)..

^cSpecific regions included in ANOVAs are in parentheses: NS, Nova Scotia; ME, Maine; NY, New York State; VT, Vermont..

Table 2. Summary statistics for log₁₀-transformed concentrations (µg/g, wet weight basis) of total mercury in tissues of river otter specific for region and age

Region ^a	Age	N ^b	Geo mean ^c	Mean–SD	Mean + SD	Min.	Max.
Brain							
NY	Adult	2	1.00	0.70	1.43	0.78	1.29
NY	Juvenile	4	0.57	0.32	1.01	0.27	1.04
ME	Adult	41	0.51	0.29	0.93	0.18	3.25
ME	Juvenile	19	0.34	0.16	0.73	0.06	2.01
NS	Adult	9	0.12	0.24	5.17	0.14	10.2
NS	Juvenile	14	0.33	0.11	1.05	0.07	1.88
All	Adult	52	0.60	0.26	1.43	0.14	10.2
All	Juvenile	37	0.36	0.14	0.88	0.06	2.01
Liver							
NY	Adult	62	2.10	1.17	3.77	0.55	6.94
NY	Juvenile	84	1.66	0.95	2.91	0.52	6.82
ME	Adult	41	1.79	1.05	3.02	0.50	8.66
ME	Juvenile	19	0.85	0.44	1.65	0.26	3.47
All	Adult	103	1.97	1.12	3.47	0.50	8.66
All	Juvenile	103	1.47	0.78	2.77	0.26	6.82
Fur							
ME	Adult	41	20.7	12.6	34.2	2.80	73.7
ME	Juvenile	19	10.2	3.84	27.1	1.14	27.6
VT	Adult	10	10.2	6.30	16.4	4.91	24.8
VT	Juvenile	10	13.9	8.42	22.9	7.74	46.5
All	Adult	51	18.0	10.2	31.8	2.80	73.7
All	Juvenile	29	11.4	4.87	26.4	1.14	46.5

^aSpecific regions for which data were available: ME, Maine; NS, Nova Scotia; NY, New York State; VT, Vermont.

^bSample size; otter of unknown age were not included (6, 10 and 1, for brain, liver and fur samples, respectively).

^cGeometric means, bounds including the standard deviation (SD), minimum (Min.), and maximum (Max.) concentrations were back-transformed.

Table 3. Results for two-way ANOVAs with gender and age as factors and one-way ANOVAs with region as a factor for concentrations ($\mu\text{g/g}$, wet weight basis) of total mercury in tissues of mink

Factor	<i>F</i> -value	Pr > <i>F</i> ^a	DF ^b
Brain			
One-way ANOVA			
Region (ME, NS, NH) ^c	4.35	0.015	2, 133
Two-way ANOVA, including ME, NS, NY			
Sex	0.11	0.736	1, 65
Age	0.08	0.780	1, 65
Sex \times Age	3.84	0.055	1, 65
Liver			
One-way ANOVA			
Region (MA/CT, ME, NS, NH, NY, RI)	23.28	< 0.001	5, 496
Two-way ANOVA, including ME, NY, RI			
Sex	26.78	< 0.001	1, 327
Age	1.66	0.199	1, 327
Sex \times Age	0.19	0.666	1, 327
Fur			
One-way ANOVA			
Region (ME, NH, NS)	4.01	0.021	2, 122
Two-way ANOVA, including ME, NY			
Sex	1.85	0.179	1, 61
Age	0.08	0.782	1, 61
Sex \times Age	0.18	0.674	1, 61

^aProbability of a greater *F*-value.

^bDegrees of freedom for effect and model, respectively, for ANOVAs conducted on data \log_{10} transformed before analysis. Mink of unknown sex or age were not included two-way ANOVAs; NY data for brain and fur (two and one samples, respectively) were not included in one-way ANOVAs.

^cSpecific regions included in ANOVAs are in parentheses: MA/CT, Massachusetts/Connecticut; ME, Maine; NH, New Hampshire; NS, Nova Scotia; NY, New York State; RI, Rhode Island.

concentrations in the three tissues of mink with the exception of gender for liver (Table 3). Overall mean concentration in liver from females was 35% greater than males (Table 5). Means for females were consistently greater than males within regions; increases ranged from 50% to 117% among the five regions (Massachusetts/Connecticut New Hampshire, Maine, and New York, Rhode Island) for which gender data were available.

Collection period

Total Hg concentration in the liver of both otter and mink from New York are significantly different between the two collection periods (Table 6). Mean Hg concentrations in adult and juvenile otters collected in 1998–2000 were, respectively, 25% and 28% (a decrease of 0.64 and 0.56 $\mu\text{g/g}$ ww, respectively) less than in adult and juvenile otters collected in 1982–1984 (Table 7). Similarly, female and male

mink collected in 1998–2000 had respective mean Hg concentrations 36% and 38% (a decrease of 0.60 and 0.52 $\mu\text{g/g}$ ww, respectively) less than females and males collected in the 1982–1984 period.

Tissue relationships

Gender-specific correlations of total Hg concentrations among tissues for otter and mink from Maine indicated a similar strength of association between Hg concentrations in brain and fur in males and females of each species (Table 8). Brain–fur correlations were slightly stronger in otter than mink. In contrast, correlations between Hg concentration in liver and concentrations in brain or fur were more variable than brain–fur correlations. Of particular note are the relatively low correlations between Hg concentration in liver with concentrations in brain or fur in otter females as compared to those for otter males and mink males and females.

Table 4. Summary statistics for log₁₀-transformed concentrations (µg/g, wet weight basis) of total mercury in tissues of mink for specific regions

Region ^a	N ^b	Geo mean ^c	Mean–SD	Mean + SD	Min.	Max.
Brain						
NS	16	0.64 (A)	0.20	2.08	0.09	4.68
ME	90	0.44 (AB)	0.24	0.82	0.11	2.55
NH	10	0.28(B)	0.17	0.44	0.12	0.48
NY	2	0.25			0.13	0.48
Liver						
MA/CT	94	3.01(A)	1.15	7.84	0.40	31.0
NS	10	1.76(AB)	0.72	4.25	0.36	5.06
NH	10	1.48(AB)	0.71	3.08	0.46	3.58
ME	89	1.23(B)	0.57	2.65	0.16	8.03
NY	267	1.08(B)	0.50	2.35	0.14	8.80
RI	32	1.01(B)	0.42	2.41	0.16	5.16
Fur						
ME	90	17.5(A)	9.14	33.5	1.78	68.5
NH	25	13.7(AB)	9.65	19.5	6.27	28.6
NS	10	10.6(B)	4.89	22.9	3.92	45.4
NY	1	2.34			2.34	2.34

^aSpecific regions: MA/CT, Massachusetts/Connecticut; ME, Maine; NH, New Hampshire; NS, Nova Scotia; NY, New York State; RI, Rhode Island.

^bSample size.

^cGeometric means, bounds including the standard deviation (SD), minimum (Min.), and maximum (Max.) concentrations were back-transformed. Means with the same letter are not significantly different ($\alpha=0.05$), Bonferroni *t* test.

Table 5. Summary statistics for log₁₀-transformed concentrations (µg/g, wet weight basis) of total mercury in liver tissue of mink for specific regions and gender

Region ^a	Sex	N ^b	Geo mean ^c	Mean–SD	Mean + SD	Min.	Max.
MA/CT	Female	14	4.49	2.69	7.52	1.50	10.4
MA/CT	Male	80	2.81	1.03	7.64	0.40	31.0
NH	Female	5	1.82	0.99	3.35	0.68	3.58
NH	Male	5	1.20	0.51	2.83	0.46	3.48
ME	Female	30	1.76	0.77	4.03	0.33	8.03
ME	Male	59	1.03	0.53	2.00	0.16	5.03
NY	Female	95	1.44	0.75	2.77	0.26	7.66
NY	Male	153	0.96	0.43	2.11	0.14	8.80
RI	Female	8	1.80	1.00	3.27	0.70	5.16
RI	Male	24	0.83	0.35	1.98	0.16	2.83
All	Female	152	1.70	0.81	3.57	0.26	10.4
All	Male	321	1.26	0.48	3.26	0.14	31.0

^aSpecific regions: MA/CT, Massachusetts/Connecticut; ME, Maine; NH, New Hampshire; ME, Maine; NH, New Hampshire; NS, Nova Scotia; NY, New York State; RI, Rhode Island.

^bSample size: mink of unknown gender were not included; no gender data were available for NS.

^cGeometric means, bounds including the standard deviation (SD), minimum (Min.), and maximum (Max.) concentrations were back-transformed.

Discussion

For regions within New York, New England and Nova Scotia, variability in total Hg concentration in tissues of otter seems largely intra- rather than inter-regional. This conclusion is suggested by the

lack of significant regional variation in brain and fur and a significant variation in concentrations in liver that may be largely explained by temporal difference in collections. Regional comparison included animals collected from New York in 1982–1984 as well as those collected in 1998–2002,

Table 6. Results for one-way ANOVAs for period of collection (1982–1984 versus 1998–2002) with age and sex as a covariates for otter and mink, respectively, for concentrations ($\mu\text{g/g}$, wet weight basis) of total mercury in livers of animals from New York State

Factor	F-value ^a	Pr > F	DF ^b
Otter			
Period	10.88	0.001	1, 143
Age	7.39	0.007	1, 143
Mink			
Period	22.85	<0.001	1, 245
Sex	5.78	0.017	1, 245

^aProbability of a greater *F*-value.

^bDegrees of freedom for effect and model, respectively, for ANOVAs conducted on data \log_{10} transformed before analysis.

inclusive of the period in which otter were collected from Maine. Mercury concentrations in liver of adult and juvenile otter collected from New York in 1982–1984 were 34% and 39% greater (elevated by 0.64 and 0.56 $\mu\text{g/g}$ ww, respectively) than otter of comparable age collected in 1998–2002. Consequently, the inclusion of otter collected in 1982–1984 may have resulted in a significantly greater Hg level in liver of otter collected from New York than Maine. Recently collected adults from New York were only 6% greater in concentration in liver than adults from Maine (1.89 versus 1.79 $\mu\text{g/g}$ ww, respectively). Juveniles from New York, which are 69% greater in concentration in liver than those from Maine

(1.44 versus 0.85 $\mu\text{g/g}$ ww, respectively), remain somewhat elevated. Consequently, for otter, evidence of significant inter-regional variation in recent collections is apparently limited to a moderate difference in Hg concentration in liver of juvenile otter from New York and Maine.

A lack of strong inter-regional variation was also evident for total Hg concentration in tissues of mink. Although regional variation for Hg concentration in brain and fur was significant for Maine, New Hampshire and Nova Scotia, the regional variation was different for each tissue; moreover, mean concentration for Hg in liver was not significantly different among these regions. Only Hg in liver of mink from Massachusetts/Connecticut had markedly elevated concentrations (mean of 3.01 $\mu\text{g/g}$ ww) in a more extensive regional comparison, including Massachusetts/Connecticut, Nova Scotia, New York, Maine, New Hampshire and Rhode Island (means ranging from 1.01 to 1.76 $\mu\text{g/g}$ ww). A temporal difference may partially account for the elevated concentration in Massachusetts/Connecticut mink that were collected in 1987–1989, considerably earlier than mink from other regions (1998–2002). For mink from New York, mean mercury concentrations in female and male mink collected in 1982–1984 were 55% and 63% greater (elevated by 0.60 and 0.52 $\mu\text{g/g}$ ww, respectively) than mink of comparable gender collected in 1998–2002. This relationship for mink from New York suggests that Massachusetts/Connecticut mink may have

Table 7. Summary statistics for \log_{10} -transformed concentrations ($\mu\text{g/g}$, wet weight basis) of total mercury in liver of otter and mink from New York State specific for collection period and specific age and gender for otter and mink, respectively

Period ^a	Age/sex	N ^b	Geo mean ^c	Mean–SD	Mean + SD	Min.	Max.
Otter							
1998–2002	Adult	43	1.89	1.05	3.39	0.55	5.79
1998–2002	Juvenile	43	1.44	0.91	2.27	0.53	4.61
1982–1984	Adult	18	2.53	1.56	4.11	1.16	5.60
1982–1984	Juvenile	42	2.00	1.05	3.81	0.52	6.94
Mink							
1998–2002	Female	33	1.08	0.63	1.86	0.28	3.01
1998–2002	Male	109	0.83	0.39	1.76	0.14	8.80
1982–1984	Female	62	1.68	0.87	3.25	0.26	7.66
1982–1984	Male	44	1.35	0.61	2.99	0.28	7.44

^aPeriods of collection included trapping seasons from 1982 to 1984 (1982–1984) and from 1998 to 2002 (1998–2002).

^bSample size; animals of unknown sex or age were included for otter and mink, respectively.

^cGeometric means, bounds including the standard deviation (SD), minimum (Min.), and maximum (Max.) concentrations were back-transformed.

Table 8. Spearman rank correlation coefficients for concentrations ($\mu\text{g/g}$, wet weight basis) of total mercury in tissues of otter (35 males and 26 females) and mink (59 males and 30 females) from Maine

Tissue	Otter		Mink	
	Fur	Liver	Fur	Liver
Male				
Liver	0.73		0.50	
<i>p</i> -Value	<0.001		<0.001	
Brain	0.64	0.55	0.50	0.51
<i>p</i> -Value	<0.001	<0.001	<0.001	<0.001
Female				
Liver	0.37		0.66	
<i>p</i> -Value	0.061		<0.001	
Brain	0.64	0.15	0.55	0.77
<i>p</i> -Value	0.001	0.473	0.002	<0.001

elevated mercury concentrations in part due to an earlier period of collection. However, if means of female and male mink from Massachusetts/Connecticut (4.49 and 2.81 $\mu\text{g/g}$ ww, respectively) are reduced by the temporal difference in concentration observed for mink from New York, calculated levels (3.89 and 2.29 $\mu\text{g/g}$ ww, for females and males, respectively) still remain elevated well above mean levels for other regions (range of 1.44–1.82 and 0.83–1.26 $\mu\text{g/g}$ ww, for regional means of females and males, respectively). This conclusion is also true if mean concentrations of Massachusetts/Connecticut mink are reduced using temporal relationships on a percentage basis (36% and 38% for females and males, respectively) resulting in calculated levels of 2.87 and 1.74 $\mu\text{g/g}$, ww, for females and males, respectively. Consequently, comparison of regional Hg concentrations for mink suggest that significant regional elevation in total Hg concentration is restricted to liver of mink from one of six regions.

Although, for otter, overall mean concentrations for total Hg increased from juvenile to adult 67%, 34% and 58% in brain (0.36–0.60 $\mu\text{g/g}$ ww), liver (1.47–1.97 $\mu\text{g/g}$ ww) and fur (11.4–18.0 $\mu\text{g/g}$ ww), respectively, relationships within regions did not consistently demonstrate an increase in mean concentration from juvenile to adult for either brain or fur, suggesting Hg–age relationships may be different inter-regionally. The unexpected lack of an Hg–age relationship for mink may be due to the use of too few age categories in classifying mink for statistical analysis. Within each age cat-

egory, mink exhibit a considerable variation in age due to long trapping seasons (up to 6 months) that result in highly variable death dates and, consequently, ages. Also, relatively few mink equal to or older than two years are in the adult category. The lack of older mink limits the representation of mink with the greatest potential to accumulate mercury in the adult category. These limitations may have reduced the likelihood of detecting a statistical increase in Hg concentration with age. For tissues of mink and otter, a significant relationship between Hg concentration and gender was observed only in liver of mink; overall mean concentration was 35% greater in females than males (1.70 versus 1.26 $\mu\text{g/g}$ ww, respectively). Mean concentration of Hg was consistently greater for female than for male mink within regions, with increases ranging regionally from 50% to 117%, suggesting Hg–gender relationships in liver of mink are consistent among regions. Mercury–age or Hg–gender relationships may be specific to species, tissue or region and need to be considered in regional or other comparisons.

The decline in Hg concentration was approximately 10% greater in mink than otter from New York over a 16-year period. For otter, mean mercury concentration in liver was less by 25% and 28% for adults (2.53–1.89 $\mu\text{g/g}$ ww) and juveniles (2.00–1.44 $\mu\text{g/g}$ ww), respectively. For mink, mean mercury concentration in liver was less by 36% and 38% for females (1.68–1.08 $\mu\text{g/g}$ ww) and males (1.35–0.83 $\mu\text{g/g}$ ww), respectively. However, the absolute decrease in mean levels was fairly consistent among these categories: 0.64, 0.56, 0.60, and 0.52 $\mu\text{g/g}$ ww for adults and juveniles of otter and females and males of mink, respectively. This uniform decline suggests that factors reducing Hg concentration in liver of mustelids, at least within New York, act fairly uniformly across species and demographic factors.

The development of a predictive relationship for Hg concentration in brain based on concentrations in liver or fur is desirable given that samples of brain are more difficult to obtain than other tissues. The degree of correlation for brain and fur is very similar for mink and otter and nearly identical between genders within species ($r = 0.64, 0.64, 0.50$ and 0.55 for male and female otter and male and female mink, respectively) suggesting a consistent strength of association

independent of species and gender. In contrast, the variable correlations between liver and brain or liver and fur and the low correlations for liver and brain and liver and fur for female otter ($r = 0.37$ and 0.15 , respectively) suggest that strength of association for liver and other tissues is specific to species and gender. Although the moderate level of correlation among tissues suggests that considerable unexplained variation would be present for any potential predictive relationship for Hg concentration for either species, predictive relationships for Hg concentration in brain based on concentration in fur would likely have less unexplained variation than those based on liver.

Dose-response studies indicate that acute mortality occurs at total Hg concentrations ranging from 20 to 25 and from 15 to 19 $\mu\text{g/g}$ ww in liver of mink and brain of otter, respectively (Wobeser and Swift, 1976, O'Connor and Neilson, 1980). Mercury concentrations of 58.2, 13.4 and 34.9 $\mu\text{g/g}$ ww, for brain, liver and fur, respectively, in mink and, likewise, 30, 96, and 47 $\mu\text{g/g}$ ww in otter have been found anecdotally in animals whose death was attributed Hg toxicity from environmental exposure (Wobeser and Swift, 1976, Wren, 1985). For otter from New York, New England and Nova Scotia, maximum concentrations for Hg in brain and liver (10.2 and 8.66 $\mu\text{g/g}$ ww, respectively) are below comparable levels associated with acute mortality. However, maximum concentrations in fur (73.7 and 46.5 $\mu\text{g/g}$ ww, for adults and juveniles, respectively) for otter from Maine and Vermont nearly equal or exceed a concentration associated with death. For mink, maximum concentrations for Hg in brain (4.68 $\mu\text{g/g}$ ww) and in liver (8.80 $\mu\text{g/g}$ ww) for regions other than Massachusetts/Connecticut are below critical levels. However, the maximum concentration for Hg in liver of mink from Massachusetts/Connecticut (31.0 $\mu\text{g/g}$ ww) and the maximum levels of Hg fur of mink from Maine and Nova Scotia (68.5 and 45.4 $\mu\text{g/g}$ ww, respectively) exceed concentrations associated with acute mortality. Apparently, the accumulation of Hg to critical toxicological levels in these species is limited to a few regions within New York, New England and Nova Scotia. This conclusion does not preclude that adverse sub-lethal effects may be associated with lower Hg concentrations (Halbrook et al., 1994, Mierle et al.,

2000) and, consequently, are more widespread than potential acute effects.

Ranges in Hg concentrations in liver of Eurasian otter (*Lutra lutra*) were 0.2–4.3, 0.3–12.4 and 0.15–17 $\mu\text{g/g}$ ww for otter from Britain, Denmark, and Ireland, respectively (Mason, 1988, Mason and Madsen, 1992, Mason and Sullivan, 1993) and were 1.3–21.7 and 0.2–17.4 $\mu\text{g/g}$ ww for liver of river otter from Manitoba and Ontario, respectively (Kucera, 1983, Wren et al., 1986, Wren and Stokes, 1988). With the exception of otter from England, Hg concentrations in liver of otter from New York, New England and Nova Scotia are generally lower (0.26–8.66 $\mu\text{g/g}$ ww). Ranges in Hg concentration in brain were 0.04–9.5 and 0.2–7.2 $\mu\text{g/g}$ ww, for otter from Manitoba and Ontario, respectively (Kucera, 1983, Wren et al., 1986). The Hg concentrations comprising these regional ranges for brain are generally similar to those comprising the range for this study (0.06–10.2 $\mu\text{g/g}$, ww). Apparently, levels of Hg contamination in otter from New York, New England and Nova Scotia are similar to or less than levels in otter from other regions.

Ranges in Hg concentration in liver were 0.01–7.5 and 2.2–20.0 $\mu\text{g/g}$ ww for mink from Ontario and Quebec, respectively (Wren et al., 1986, Langis et al., 1999). Similar or lower ranges of Hg concentrations were evident for regions within this study (0.14–8.80 $\mu\text{g/g}$ ww) with the exception of the Massachusetts/Connecticut region (0.40–31 $\mu\text{g/g}$ ww). For brain, the range in Hg concentration was 0.3–0.7 $\mu\text{g/g}$ ww for mink from Ontario (Wren et al., 1986). The range of Hg concentration in brain for mink from Nova Scotia, New Hampshire and Maine has a considerably greater maximum level (0.09–4.68 $\mu\text{g/g}$, ww) than reported for mink from Ontario. Although most regions within New York, New England and Nova Scotia seem to be at or below levels from Ontario and Quebec, the degree of Hg contamination of mink from more contaminated regions within this study seem to exceed levels in mink from these adjacent regions.

Although this study takes advantage of a large portion of the available data for New York, New England and Nova Scotia to develop an inter-regional analysis of Hg contamination in mink and otter, inferences that can be drawn from these data are limited. Dissimilar data arrays comprising the

dataset due to different goals of individual projects resulted in a weak analytical design. Lack of analysis of similar tissues and age data among regions, inter-laboratory variation in Hg analysis that may confound comparisons, and collections biased by individual project goals within regions limit the utility of these data for inter-regional comparison. This study is perhaps more illustrative than conclusive and provides a limited example of the type of information that could be generated given a higher degree of coordination in study design and data collection.

Acknowledgements

The New York State portion (1998–2002) of this study was funded by the Hudson River Estuary Management Program and by Federal Aid for the Restoration of Wildlife to New York State, Project WE-173-G. We thank J. Loukmas, K. Hellijas, and K. Geesler for technical assistance and S. Fonda and L. Capodagli for data management. We thank trappers for voluntary donation of carcasses. Maine Department of Environmental Protection funded the Maine portion of this study. We thank Barry Mower, Wally Jakubas, Gary Lee and Lucas Savoy as well as all the trappers that donated carcasses. We also thank Ken Carr and Michale Glennon for the comments and suggestions as reviewers. We also thank Jonathan Atwood and Antioch New England graduate school for their support. Eric Orff of New Hampshire Fish and Game for providing NH carcasses. Mike O'Brien from Nova Scotia DNR for mink and otter collections and data. James Lake, EPA AED (Atlantic Ecology Division) for RI data. Kim Royar for the Vermont samples. Financial support was also provided by the National Science Foundation, NSF Award Number 0238069.

References

- Analytical Software (2003). *User's Manual Statistix 8. Analytical Software*. Tallahassee, Florida, USA 396.
- Desai-Greenway, P. and Price, I.M. (1976). Mercury in Canadian fish and wildlife used in diets of native peoples. Canadian Wildlife Service Report, Toxic Chem. Division, No. 35.
- Evers, D.C. and Reaman, P.S. (1998). *A Comparison of Mercury Exposure Between Artificial Impoundments and Natural Lakes Measured in Common Loon and Their Prey*. Central Maine Power Co, Augusta 40.
- Evers, D.C., Kaplan, J.D., Meyer, M.W., Reaman, P.S., Braselton, W.E., Major, A., Burgess, N. and Scheuhammer, A.M. (1998a). A geographic trend in mercury measured in common loon feather and blood. *Environ. Toxicol. Chem.* **17**, 173–3.
- Evers, D.C., Lane, O.P., Savoy, L. and Goodale, W. (2004). Assessing the impacts of methylmercury on piscivorous wildlife using a wildlife criterion value based on the Common Loon, 1998–2003. Report BRI 200405 submitted to the Maine Department of Environmental Protection. BioDiversity Research Institute, Gorham, Maine.
- Foley, R.E., Jackling, S.J., Sloan, R.J. and Brown, M.K. (1988). Organochlorine and mercury residues in wild mink and otter: comparison with fish. *Environ. Toxicol. and Chem.* **7**, 363–74.
- Halbrook, R.S., Jenkins, J.H., Bush, P.B. and Seabolt, N.D. (1994). Sublethal concentrations of mercury in river otters: monitoring environmental contamination. *Arch. Environ. Contam. Toxicol.* **27**, 306–10.
- Kucera, E. (1983). Mink and otter as indicators of mercury in Manitoba waters. *Can. J. Zool.* **61**, 2250–6.
- Langis, R., Langlois, C. and Morneau, F. (1999). Mercury in birds and mammals. In M. Lucotte, R. Schetagne, N. Therien, C. Langlois and A. Tremblay (eds). *Mercury in the Biogeochemical Cycle*. pp. 131–144. Springer, Germany.
- Lucotte, M., Schetagne, R., Therien, N., Langlois, C. and Tremblay, A. (1999). *Mercury in the Biogeochemical Cycle* Springer, New York.
- Maine DEP. (1998). Initial evaluation and recommendation on mercury in Maine. Submitted to the Land & Water Resources Council, 1997 Annual Rept., Augusta, Maine.
- Major, A.R. and Carr, K.C. (1991). Contaminant concentrations in Connecticut and Massachusetts mink. U.S Fish and Wildlife Service New England Field Offices, Report # RY91-NEFO-5-EC.
- Mason, C.F. (1988). Concentrations of organochlorine residues and metals in tissues of otters *Lutra lutra* from the British Isles, 1985–1986. *Lutra* **31**, 62–7.
- Mason, C.F. and Madsen, A.B. (1992). Mercury in Danish otters (*Lutra lutra*). *Chemosphere* **25**, 865–7.
- Mason, C.F. and Sullivan, W.M. (1993). Heavy metals in the livers of otters, *Lutra lutra*, from Ireland. *J. Zool.* **231**, 675–8.
- Mierle, G., Addison, E.M., MacDonald, K.S. and Joachim, D.G. (2000). Mercury levels in tissues of otters from Ontario, Canada: variation with age, sex, and location. *Environ. Toxicol. and Chem.* **19**, 3044–51.
- NESCAUM. (1998). Northeast States and Eastern Canadian Provinces mercury study. NESCAUM/NEWMOA/NEW-PCC/EMAN.
- O'Connor, D.J. and Nielsen, S.W. (1980). Environmental survey of methylmercury levels in wild mink (*Mustela vison*) and otter (*Lutra canadensis*) from the northeastern United States and experimental pathology of methylmercurialism in the otter. Proceedings, World Furbearer conference. Frostburg, Maryland, USA, August 3–11, pp. 1728–45.

- SAS INSTITUTE (1985). *SAS/STAT Guide for Personal Computers Version 6 edn.* SAS Institute, Cary North Carolina 1028.
- USEPA. (1997). Mercury study report to Congress (Vol. VII): characterization of human health and wildlife risks from mercury exposure in the United States. EPA-452/R-978-009.
- Watras, C.J. and Huckabee, J.W. (1994). *Mercury Pollution: Integration and Synthesis.* Lewis Press, Boca Raton, FL.
- Wobeser, G. and Swift, M. (1976). Mercury poisoning in wild mink. *J. Wildl. Dis* **12**, 335–40.
- Wren, C.D. (1985). Probable case of mercury poisoning in wild otter, *Lutra canadensis*, in northwestern Ontario. *Can. Field-Nat.* **99**, 112–4.
- Wren, C.D. and Stokes, P.M. (1988). Depressed mercury levels in biota from acid and metal stressed lakes near Sudbury, Ontario. *Ambio* **17**(1), 28–30.
- Wren, C.D., Stokes, P.M. and Fischer, K.L. (1986). Mercury levels in Ontario mink and otter relative to food levels and environmental acidification. *Can. J. Zool.* **64**, 2854–59.
- Wren, C.D., MacCrimmon, H.R., Frank, R. and Suda, P. (1980). Total and methylmercury levels in wild mammals from the Precambrian Shield area of south central Ontario. *Bull. Environ. Contam. Toxicol.* **25**, 100–5.