



Bioaccumulation of Contaminants in Fish and Larval Dragonflies in Six National Park Units of the Western Great Lakes Region, 2008-2009

Natural Resource Data Series NPS/GLKN/NRDS—2013/427



ON THE COVER

Newly emerged dragonfly at Sargent Lake, Isle Royale National Park (Michigan). Weighing a largemouth bass at Round Lake, Sleeping Bear Dunes National Lakeshore (Michigan).
NPS photos/Ted Gostomski.



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January 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Wiener, J. G., R. J. Haro, K. R. Rolfhus, M. B. Sandheinrich, S. W. Bailey, R. M. Northwick, and T. J. Gostomski. 2013. Bioaccumulation of persistent contaminants in fish and larval dragonflies in six national park units of the western Great Lakes region, 2008-2009. Natural Resource Data Series NPS/GLKN/NRDS—2013/427. National Park Service, Fort Collins, Colorado.

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Executive Summary

We report results of an initial assessment completed during 2008 and 2009 of selected bioaccumulative contaminants in aquatic organisms in six national park units within the Great Lakes Inventory and Monitoring Network. The park units included in our study were Grand Portage National Monument (GRPO), Indiana Dunes National Lakeshore (INDU), Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), Sleeping Bear Dunes National Lakeshore (SLBE), and Voyageurs National Park (VOYA). The principal objectives of this project were (1) to assess spatial patterns in contamination of aquatic biota in the six park units, (2) to identify park units and surface waters where concentrations of bioaccumulative contaminants may pose a risk to organisms atop aquatic food webs, and (3) to evaluate temporal trends in contamination of aquatic food webs in parks of the Great Lakes Network. The contaminants analyzed were total mercury, methylmercury, total lead, the insecticide DDT and its metabolites (DDE and DDD), polychlorinated biphenyls (PCBs, 72 congeners), perfluorochemicals (PFCs, 9 analytes), and polybrominated diphenyl ethers (PBDEs, 9 congeners). Study sites included five streams in or near GRPO, Long Lake and Great Marsh at INDU, four lakes at ISRO, five lakes at PIRO, four lakes at SLBE, and four lakes at VOYA.

Three groups of biosentinel organisms (adult predatory fish, prey fish, and larval dragonflies) were sampled and analyzed to assess contamination of aquatic resources. Axial muscle tissue (skinless fillets) of adult predatory fish and whole prey fish were analyzed for total mercury. Axial muscle of adult predatory fish was also analyzed for total lead and selected bioaccumulative organic contaminants (DDT, PCBs, PBDEs, PFCs). Dragonflies (Insecta: Odonata), which are predatory benthic macroinvertebrates as aquatic larvae, were analyzed whole for total mercury and methylmercury.

The accumulation of mercury in biosentinel organisms varied substantially among water bodies, both within and among the six park units. Moreover, fish in some park units have bioaccumulated mercury (as methylmercury) to toxicologically relevant levels.

Concentrations of mercury in axial muscle of adult predatory fish from several water bodies substantially exceeded 300 ng/g (parts per billion) wet weight, the U.S. Environmental Protection Agency (EPA) tissue residue criterion for methylmercury, which was established to protect the health of humans who eat noncommercial fish. Concentrations of mercury in axial muscle tissue of some *individual* predatory fish from four park units—including fish from four lakes at VOYA, four lakes at PIRO, four lakes at ISRO, and three lakes at SLBE—exceeded the EPA tissue residue criterion. *Mean* concentrations of mercury in axial fillets of predatory fish exceeded the EPA criterion in four lakes at VOYA, three lakes at PIRO, two lakes at ISRO, and three lakes at SLBE.

In some predatory fish, concentrations of mercury were high enough to adversely affect fish health and reproduction. Concentrations in axial muscle tissue of one or more individual predatory fish from a total of 14 water bodies in four park units (ISRO, PIRO, SLBE, and VOYA) exceeded an estimated threshold (500 ng/g wet weight) associated with altered biochemical processes, damage to cells and tissues, and impaired reproduction in fish. Mean concentrations exceeded this threshold in predatory fish from a total of seven water bodies from

four park units, including three lakes at VOYA, two lakes at PIRO, one lake at ISRO, and one lake at SLBE. Concentrations of mercury in whole prey fish from some water bodies were considered high enough to adversely affect reproduction of piscivorous fish or fish-eating aquatic birds, such as common loons.

Although no long-lived, predatory fish were obtained from streams at GRPO, analyses of prey fish and larval dragonflies showed that methylmercury is accumulating to high concentrations in the lower food web in streams in that park unit. Moreover, concentrations of total mercury in whole prey fish from three streams exceeded an estimated dietary threshold (40 ng/g wet weight in prey fish) associated with reproductive effects of methylmercury on piscivorous fish.

At INDU, levels of total mercury in whole prey fish and of methylmercury in larval dragonflies from the Great Marsh and Long Lake were relatively low. We caught only one piscivorous fish—a small grass pickerel—at INDU. Low concentrations of dissolved oxygen in the Great Marsh and Long Lake may render those systems unsuitable as habitat for long-lived piscivorous fish.

Whole larval dragonflies were judged to be useful biosentinels of methylmercury in aquatic food webs in the western Great Lakes region. Mean concentrations of methylmercury (combined data for all odonate species and water bodies within each park unit) were highest at GRPO and VOYA. Most of the mercury present in larvae was methylmercury. Mean percent methylmercury (as a fraction of total mercury) was also highest in larvae from GRPO (95%) and VOYA (84%), ranging from 71% to 77% at the other four park units. High levels of methylmercury, with means exceeding 100 ng/g dry weight, were found in larvae from Grand Portage, Snow, and Poplar creeks at GRPO; Lake Harvey at ISRO; Legion Lake at PIRO; and Sand Point and Ryan lakes at VOYA; concentrations of mercury were also high in coexisting fish from these water bodies.

Our findings for mercury support results of prior studies showing that the northern Great Lakes region is a mercury-sensitive area. In this region, atmospheric deposition is the dominant pathway for entry of mercury into ecosystems, and geologic (natural) sources of mercury are small. The high mercury levels in biota inhabiting several water bodies indicate that inorganic mercury from wet and dry atmospheric deposition—the primary influxes of mercury to the parks—is readily methylated, bioaccumulated as methylmercury, and biomagnified to high, potentially harmful concentrations in aquatic food webs.

In marked contrast to the results for mercury, the concentrations of legacy contaminants (DDT and metabolites, PCBs, total lead) and emerging contaminants (PBDEs and PFCs) in the axial muscle of fish from five park units (GRPO, ISRO, PIRO, SLBE, VOYA) were low or below limits of detection in 60 samples, which included 41 composite samples and 19 individual fish. DDT and its metabolites (DDE and DDD) were below the limit of detection in all 60 samples. PCBs were detected in 5 samples, PBDEs detected in 4, and PFCs in 39 of the 60 samples. Levels of total lead in axial muscle tissue were also low, ranging from 2 to 31 ng/g wet weight. The measured concentrations of legacy and emerging organic contaminants in axial fillets of fish from the five park units during 2008 and 2009 were well below levels considered harmful to the health of fish-eating humans. The lack of predatory fish in our samples from INDU precluded analysis of organic contaminants and total lead for that park unit.

Results from this 2-year study have provided an initial foundation for examining spatiotemporal patterns and assessing potential toxicological risks of bioaccumulative contaminants in aquatic systems in the six park units. Additional data on mercury and organic contaminants in predatory fish and mercury in prey fish, larval dragonflies, and components of the lower food web from continuation of monitoring during 2010-2012 will be applied to the further evaluation of bioaccumulation and ecological risk of these contaminants in national park units of the western Great Lakes region.

Acknowledgments

This investigation was funded by the National Park Service, Great Lakes Inventory and Monitoring Network under Task Agreement J2105080012 of the Great Lakes-Northern Forest Cooperative Ecosystem Studies Unit under Cooperative Agreement H6000082000 between the National Park Service and the University of Minnesota. We are grateful to the following National Park Service personnel for assisting with planning, logistical preparations, or sampling of biota: Bill Route, David Cooper, Joan Elias, Paul Brown, Randy Knutson, Jaime LeDuc, Lora Loope, Ryan Maki, Joy Marburger, Chris Otto, Mark Romanski, Brandon Seitz, Steve Windels, and Steve Yancho. We thank Katie Challis, Nicole Forseth, Ryan Lepak, Jordan Ludwigson, Anthony Schmidt, and Yang Liu—all undergraduate students at the University of Wisconsin-La Crosse—for providing technical assistance in the field and laboratory. Bruce Monson and Harold Wiegner (Minnesota Pollution Control Agency) assisted with sampling at Voyageurs National Park, and Seth Moore and co-workers with the Grand Portage Band of Chippewa sampled fish from Hollow Rock Creek and Reservation River. The lead author (JGW) was supported by the University of Wisconsin System Distinguished Professors Program and the University of Wisconsin-La Crosse Foundation during the preparation of this report. We thank Jay Glase, Brenda Moraska Lafrancois, and Bill Route for providing helpful reviews of an earlier draft of this report.

List of Terms and Acronyms

National Park Service units

APIS	Apostle Islands National Lakeshore
GLKN	Great Lakes Inventory and Monitoring Network
GRPO	Grand Portage National Monument
INDU	Indiana Dunes National Lakeshore
ISRO	Isle Royale National Park
MISS	Mississippi National River and Recreation Area
NPS	National Park Service
PIRO	Pictured Rocks National Lakeshore
SACN	St. Croix National Scenic Riverway
SLBE	Sleeping Bear Dunes National Lakeshore
VOYA	Voyageurs National Park

Other abbreviations

CV	coefficient of variation
CVAFS	cold-vapor atomic fluorescence spectrophotometry
DDD	dichloro-diphenyl-dichloroethane
DDE	dichloro-diphenyl-dichloroethylene
DDT	dichloro-diphenyl-trichloroethane
DOC	dissolved organic carbon
EPA	Environmental Protection Agency
Hg	mercury

Max	maximum
MeHg	methylmercury
Min	minimum
ng/g	nanogram per gram, equivalent to part per billion
NIST	National Institute of Standards and Technology
NRCC	National Research Council Canada
Pb	lead
PCB	polychlorinated biphenyl
PBDE	polybrominated diphenyl ethers
PFC	perfluorochemical
PFOS	perfluorooctanesulfonate
PFOA	perfluorooctanoic acid
ppb	part per billion (concentration)
ppm	part per million (concentration)
RSD	relative standard deviation
SRM	standard reference material
Std dev	standard deviation
Std error	standard error
THg	total mercury
USEPA	United States Environmental Protection Agency
WPI	wing pad index (larval dragonflies)

Introduction

Concentrations of certain bioaccumulative contaminants in fish are elevated across parts of the Laurentian Great Lakes region, exceeding federal and state criteria established to protect the health of humans who eat wild fish (Great Lakes Fish Advisory Workgroup 2007, Evers et al. 2011b). The National Park Service manages nine park units across the western Great Lakes region, and the Great Lakes Inventory and Monitoring Network (GLKN) evaluates conditions within these national park units. *Trophic Bioaccumulation* has been identified as one of the Vital Signs to be examined in parks within the Great Lakes Network (Route and Elias 2007), with emphasis on assessing contaminants that biomagnify in food webs, are highly toxic, and constitute a threat to organisms (humans or wildlife) in upper trophic levels (Route et al. 2011).

National park units within the Great Lakes Network include Apostle Islands National Lakeshore (APIS), Grand Portage National Monument (GRPO), Indiana Dunes National Lakeshore (INDU), Isle Royale National Park (ISRO), Mississippi National River and Recreation Area (MISS), Pictured Rocks National Lakeshore (PIRO), Sleeping Bear Dunes National Lakeshore (SLBE), St. Croix National Scenic Riverway (SACN), and Voyageurs National Park (VOYA) (Figure 1). These park units contain abundant and diverse aquatic resources, including intermittent streams, vernal pools, about 1300 km of perennial streams, large river systems, more than 130 inland lakes, more than 300 square kilometers of wetlands, and near-shore areas in Lakes Michigan and Superior (Lafrancois and Glase 2005).

This contaminant assessment focused on six of the nine park units in the Great Lakes Network: Grand Portage National Monument, Indiana Dunes National Lakeshore, Isle Royale National Park, Pictured Rocks National Lakeshore, Sleeping Bear Dunes National Lakeshore, and Voyageurs National Park. Bioaccumulative contaminants at the other three park units (APIS, MISS, and SACN) are being monitored by sampling of blood and feathers of nestling bald eagles, *Haliaeetus leucocephalus* (Route et al. 2011). Together, the two studies provide an assessment of contaminants in biota across all nine of the park units in the Great Lakes Network.

We present results from a 2-year pilot study (2008-2009) that has provided a foundation for examining spatiotemporal patterns and assessing potential toxicological risks of selected bioaccumulative contaminants in aquatic systems within the six park units (Table 1). The sampling and analysis of biosentinel organisms in this project, which was subsequently intensified with funding from the Great Lakes Restoration Initiative, will address three principal objectives: (1) to assess spatial patterns in contamination of aquatic biota in the six park units, (2) to identify park units and surface waters where concentrations of bioaccumulative contaminants may pose a risk to organisms atop aquatic food webs, and (3) to evaluate temporal trends in contamination of aquatic food webs in parks of the Great Lakes Network.

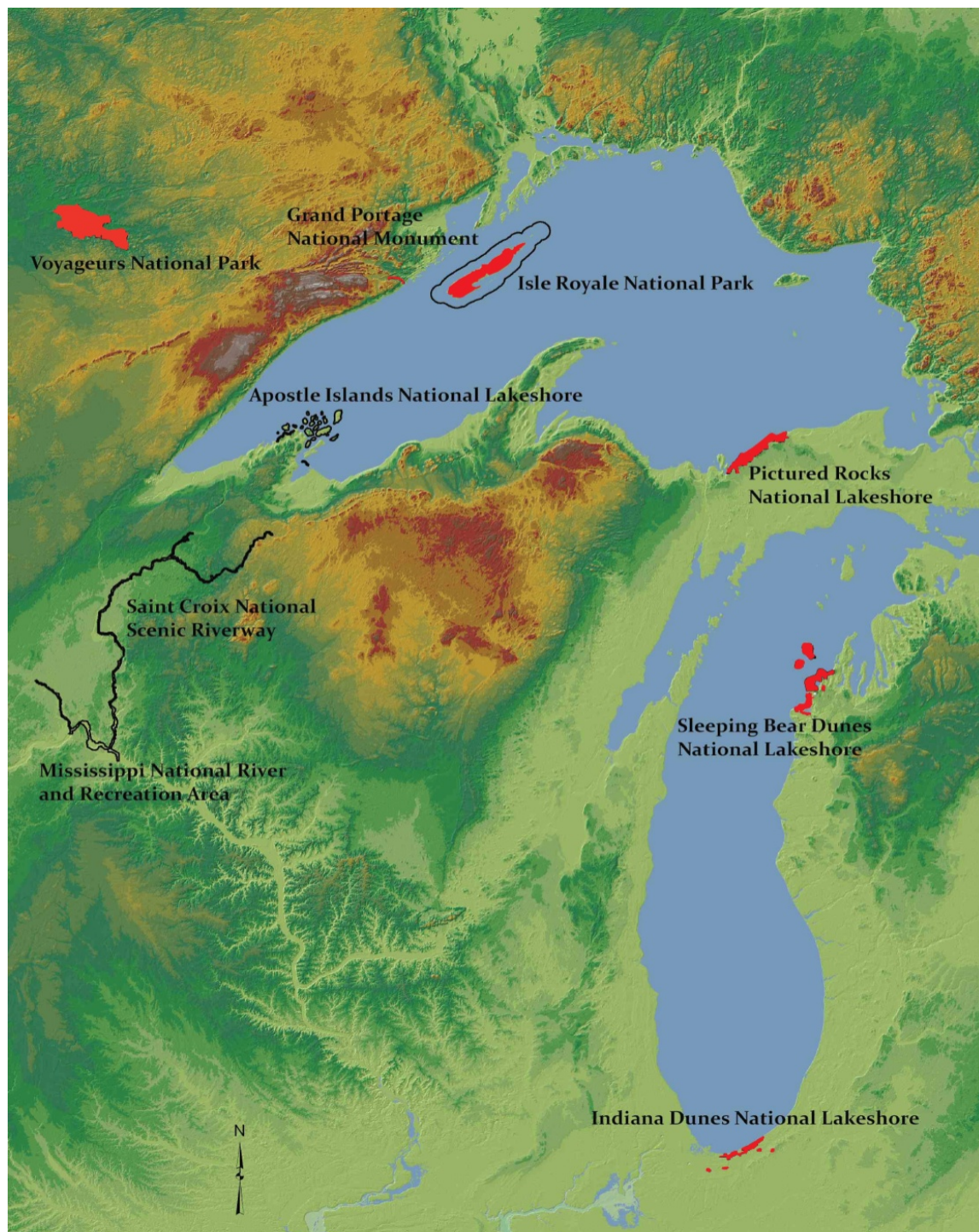


Figure 1. Map of the western Great Lakes region, showing the nine national park units in the Great Lakes Inventory and Monitoring Network. The six park units included in this study are denoted in red. The map was modified from an earlier version created by the Great Lakes Inventory and Monitoring Network.

Table 1. Physical characteristics of 22 water bodies within six park units where biosentinel organisms were sampled during 2008-2009.

NPS park unit and Water body	Lakes and Wetlands		Streams	
	Maximum depth (m)	Surface area (ha)	Drainage area (km ²)	Stream order
Grand Portage National Monument				
Grand Portage Creek			17.14	3
Poplar Creek			16.25	2
Snow Creek			5.15	2
Indiana Dunes National Lakeshore				
Long Lake	1.5	33		
Great Marsh	<1	1,500		
Isle Royale National Park				
Angleworm Lake	8.4	50		
Lake Harvey	4.3	55		
Lake Richie	10.5	216		
Sargent Lake	12.7	143		
Pictured Rocks National Lakeshore				
Beaver lake	9.2	310		
Chapel Lake	45.0	28		
Grand Sable Lake	19.2	255		
Legion Lake	11.9	14		
Miners Lake	3.3	5		
Sleeping Bear Dunes National Lakeshore				
Bass Lake (Leelanau Co.)	7.0	38		
Bass Lake (Benzie Co.)	8	12		
Lake Manitou	10.7	104		
Round Lake	6.9	6		
Voyageurs National Park				
Brown Lake	8.0	31		
Peary Lake	5.0	45		
Ryan Lake	4.0	14		
Sand Point Lake	56.0	3,580		

Contaminants Analyzed in this Study

It would be prohibitively expensive to monitor the many hundreds of contaminants that are present within water and park units of the Great Lakes region. Route et al. (2009), therefore, applied the following four criteria to identify and select specific pollutants for investigation in the nine park units within the Great Lakes Network:

- (1) contaminants that persist in the environment and bioaccumulate in fish and wildlife;
- (2) contaminants that have caused a park water body to be listed as polluted under section 303(d) of the U.S. Clean Water Act (e.g., contaminants that have prompted a fish-consumption advisory);

- (3) contaminants that are listed as a Level I Substance in the Great Lakes Binational Toxics Strategy, Appendix I; Level I Substances are defined as substances that have been associated with or have the potential to cause deleterious environmental impacts in the Great Lakes Basin (http://binational.net/bns/strategy_en.pdf); and
- (4) contaminants identified by state and federal authorities as new and emerging chemicals of concern.

Based on these criteria, the following contaminants were selected for analysis in this study:

Mercury (Hg), including total Hg (THg) and methylmercury (MeHg)
Lead (Pb)
DDT (dichloro-diphenyl-trichloroethane), including its metabolites,
DDE (dichloro-diphenyl-dichloroethylene) and
DDD (dichloro-diphenyl-dichloroethane)
PCBs (polychlorinated biphenyls; total concentration and 72 congeners)
PFCs (perfluorochemicals; total concentration and 9 analytes)
PBDE (polybrominated diphenyl ethers; total and 9 congeners)

Mercury

Atmospheric deposition is the primary source of the mercury accumulating in most inland watersheds and surface waters in the Great Lakes region (Wiener et al. 2006, Evers et al. 2011b, Drevnick et al. 2012), and analyses of sediment cores from inland lakes have shown that most (circa 70%) of this atmospheric mercury is from anthropogenic sources (Swain et al. 1992, Wiener et al. 2006, Drevnick et al. 2012). In addition, a growing body of evidence indicates that atmospheric deposition is the primary source of mercury accumulating as methylmercury in aquatic food webs and fish in lakes (Wiener et al. 2006, Orihel et al. 2007, Munthe et al. 2007, Harris et al. 2007, Evers et al. 2011b). Spatial patterns in wet deposition of mercury during 2002-2008 and of dry deposition (litterfall) during 2007-2009 across the Great Lakes region were influenced by regional emissions (Risch et al. 2012a, 2012b). Mean annual inputs of mercury in wet and dry deposition were greatest in areas with substantial anthropogenic emissions (Indiana, Ohio, Illinois, eastern and northwestern Pennsylvania, southern Michigan, and southeastern Wisconsin) and lowest in areas with few anthropogenic sources (northern Wisconsin, Minnesota, northern Michigan, and Ontario). In 2005, coal-fired power plants accounted for an estimated 57% of total anthropogenic emissions of mercury to the atmosphere in the Great Lakes region (Evers et al. 2011b).

Toxicological concerns about mercury pollution of aquatic systems focus appropriately on methylmercury, which can biomagnify to high, sometimes harmful, concentrations in organisms in upper trophic levels (Wiener et al. 2003, Scheuhammer et al. 2007, Sandheinrich and Wiener 2011). Although most of the mercury in atmospheric deposition exists as inorganic forms, nearly all of the mercury accumulated by fish is methylmercury (Grieb et al. 1990, Bloom 1992, Hammerschmidt et al. 1999, Van Wallegghem et al. 2007), an organic compound produced by methylating bacteria present in wetlands, sediment, and anoxic bottom waters (Benoit et al. 2003). Methylmercury readily crosses external and internal biological membranes (Pickhardt et al. 2006), is eliminated slowly relative to its rate of uptake (Trudel and Rasmussen 1997, Van Wallegghem et al. 2007), and accumulates to concentrations in aquatic organisms that vastly exceed those in surface water (Wiener et al. 2003). In fish, for example, concentrations of methylmercury commonly exceed those in the water in which they reside by a factor of 10^6 to 10^7 or more.

Aquatic food webs are the primary pathway for exposure of humans and wildlife to methylmercury (National Research Council 2000, Mergler et al. 2007, Scheuhammer et al. 2007). Methylmercury is highly neurotoxic, adversely affecting both the adult and developing brain (Clarkson and Magos 2006). In birds and mammals, methylmercury from reproducing females readily passes to the developing egg or embryo, life stages that are much more sensitive than the adult to methylmercury exposure (Wiener et al. 2003, Heinz et al. 2009). Methylmercury is an endocrine disrupter and impairs reproduction partly by disruption of the hypothalamic-pituitary-gonadal axis (Colborn et al. 1993, Tan et al. 2009). Recent experiments and field studies have also shown that exposure of fish to environmentally realistic concentrations of methylmercury can adversely affect gene expression, metabolism, reproduction, and health (reviewed by Sandheinrich and Wiener 2011).

Concentrations of mercury in predatory fish from many water bodies in the United States and Canada, including the Great Lakes region, exceed state, provincial, and federal criteria for the protection of human health (Evers et al. 2011a, 2011b). In the United States, mercury was responsible for 81% of the fish-consumption advisories posted in 2010, when all 50 states, 1 territory, and 3 tribes had advisories attributed to mercury (USEPA 2011); moreover, more than 66,000 km² of lake area and 1,800,000 km of river were under advisory for mercury (USEPA 2011). Four of the eight states in the Great Lakes region (Illinois, Indiana, Ohio, and Wisconsin) have issued statewide advisories for mercury in fish from all inland waters, two (Michigan and Minnesota) have issued statewide advisories for mercury in fish from all inland lakes, and two (New York and Pennsylvania) have issued advisories for specific water bodies (USEPA 2011). In the Canadian province of Ontario, more than 86% of the fish-consumption advisories issued for sport fish in inland waters are attributed to methylmercury (Ontario Ministry of the Environment 2011). Thus, much of the Great Lakes region can be considered a mercury-sensitive landscape (Wiener et al. 2003, Evers et al. 2011b) in which atmospheric deposition of mercury has led to high concentrations of methylmercury in predatory fish.

Lead

Starting in the early 1920s, alkyl-lead was blended with gasoline to boost octane levels (Nriagu 1990). In 1973, the U.S. Environmental Protection Agency (USEPA) implemented regulations to reduce the amount of lead in gasoline. The standards issued in 1973 required a gradual reduction from about 0.5-8 g Pb/L to 0.026 g Pb/L of gasoline by 1986. By 1995, leaded fuel accounted for only 0.6% of total gasoline sales in the United States. The sale of leaded fuel for on-road use in automobiles was banned entirely effective January 1, 1996. Concentrations of lead have decreased significantly in nearly all environmental media examined—including air, water, sediment, soils, fish, piscivorous wildlife, and humans—since the phase out of leaded gasoline in the United States and elsewhere (Schmitt et al. 1999, Renberg et al. 2000, Lind et al. 2006, Mahler et al. 2006, Stromberg et al. 2008, Chadwick et al. 2011). Vehicular emissions from combustion of leaded gasoline probably contributed much or most of the anthropogenic lead deposited in parks of the Great Lakes network since the 1920s (e.g., Pattee and Pain 2003, Dunlap et al. 2008).

Birds can be exposed to toxic levels of lead by ingestion of spent lead shot from hunting or of lead weights or jigs used in recreational fishing (Scheuhammer and Norris 1996). The ingestion of lead shot, weights, or jigs is the primary cause of elevated lead exposure and poisoning in many species of waterbirds, including common loons (*Gavia immer*), bald eagles, and several species of ducks and geese (reviewed by Sanderson and Bellrose 1986, Scheuhammer and Norris 1996). A

nationwide ban on the use of lead shot for waterfowl hunting was implemented in the United States in 1991, and ingestion of toxic pellets by waterfowl and the mortality of waterfowl caused by lead poisoning have since declined substantially (e.g., Anderson et al. 2000). However, spent lead shot deposited onto soils and sediments can persist for several decades.

DDT

DDT is an organochlorine compound that was discovered in 1939 to have insecticidal properties. DDT was used to control disease vectors and agricultural pests during and after World War II, and its usage in the United States peaked in 1959 (Blus 2003). During subsequent years and decades a steadily increasing body of evidence revealed the devastating adverse effects of DDT and its metabolite DDE on non-target organisms, which caused the decline and extirpation of many bird populations and led to the banning of most uses of DDT in the United States in 1972 (Blus 2003). The sub-lethal effects of DDE on reproduction of birds—including the thinning of eggshells—have been documented in both descriptive and experimental studies (Wiemeyer et al. 1984, Bowerman et al. 1995, Blus 2003, Henny et al. 2009). DDT and its metabolites or breakdown products, DDE and DDD, are persistent in the environment, bioaccumulate in exposed organisms, and biomagnify to high concentrations in organisms in upper trophic levels of food webs (Kidd et al. 2001, Blus 2003, Henny et al. 2009).

PCBs

Polychlorinated biphenyls (PCBs) are a group of synthetic organic chemicals consisting of 209 potential compounds or congeners (Rice et al. 2003). Commercial distribution of PCBs, which were used in hydraulic fluids, electrical transformers, and capacitors, began in the late 1920s. Environmental contamination by PCBs was detected in the mid 1930s and peaked in the early 1970s (Hansen 1987, Rice et al. 2003). Much of the concern about environmental contamination by PCBs stems from potential effects of exposure on human health (Kimbrough 1987, Rice et al. 2003), and two states in the Great Lakes region have issued statewide fish consumption advisories for PCBs: Indiana for rivers and Minnesota for lakes (USEPA 2005). PCBs cause a number of adverse health effects in animals, and are classified by the USEPA as probable human carcinogens. Other health effects, documented with test animals, include effects on the immune, reproductive, nervous, and endocrine systems (Hansen 1987, Kimbrough 1987, Rice et al. 2003). PCBs are transported in aquatic systems and in the atmosphere, resist degradation in the environment, bioaccumulate in exposed organisms, and biomagnify in aquatic food webs (Rice et al. 2003). Mink (*Mustela vison*), a carnivorous mammal that is distributed throughout the Great Lakes region and across much of North America, are highly sensitive to PCB exposure (Leonards et al. 1995, Basu et al. 2007). On the Upper Mississippi River, for example, populations of mink declined precipitously during 1959-1965 and have since gradually recovered as PCB contamination of the aquatic food web has decreased (Wiener and Sandheinrich 2010). Among bioaccumulative contaminants, PCBs rank a distant second nationally (to mercury) in the number of fish-consumption advisories posted for rivers and lakes (USEPA 2011).

PFCs

Perfluorochemicals (PFCs) are a family of stable, fluorinated organic compounds manufactured since the 1950s for use in a variety of industrial processes and commercial products, including polyurethane production, water and stain repellants, fire-fighting foams, and surfactants (Prevedouros et al. 2006, Lindstrom et al. 2011). The toxicity of PFCs is not well characterized, but these compounds have been shown to cause alterations in mammalian development and thyroid

hormone production, liver damage, immunosuppression, and carcinogenesis (Lau et al. 2007). Perfluoroalkyl compounds, such as perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), are persistent in the environment and bioaccumulate in exposed organisms (Conder et al. 2008, Houde et al. 2006), including fish (Holzer et al. 2011). Atmospheric transport has distributed these compounds globally, and their presence has been documented in tissues of humans, fish, and wildlife (Giesy and Kannan 2001, Smithwick et al. 2006, Tao et al. 2006, Calafat et al. 2007, Dreyer et al. 2009, Houde et al. 2011, Lindstrom et al. 2011). Perfluorooctane sulfonate (PFOS) was the predominant perfluorinated compound found in fish from the Ohio, Missouri, and Upper Mississippi rivers (Ye et al. 2008).

PBDEs

Polybrominated diphenyl ethers (PBDEs) are a class of halogenated flame retardants used in plastics, polyurethane foams, and textiles that are released to the environment during product use and disposal (Vonderheide et al. 2008). PBDEs are now ubiquitous in the environment and enter aquatic systems in atmospheric deposition (Breivik et al. 2006, Streets et al. 2006), sewage effluent (Hale et al. 2006, Song et al. 2006), and runoff from nonpoint sources, transported in association with eroded soil particles (Zou et al. 2007). PBDEs are lipophilic, and some congeners readily biomagnify (Law et al. 2006, Wu et al. 2009). Concentrations of PBDEs in the environment have increased substantially since the 1980s (Rayne et al. 2003, Batterman et al. 2007, Gauthier et al. 2008).

Methods

Biosentinel Organisms

To assess contamination of aquatic food webs in the six park units, we sampled and analyzed three groups of biosentinel organisms (small prey fish, adult predatory fish, and larval dragonflies) that are widely distributed across the Great Lakes region. These biosentinels are considered relevant and sufficiently diagnostic to detect spatiotemporal variations in the concentrations of mercury and other bioaccumulative contaminants (Wiener et al. 2007, Wiener et al. in press). All three groups of biosentinel organisms were analyzed for mercury, whereas only adult predatory fish were analyzed for organic contaminants and total lead.

Prey fish

Prey fish (often termed “forage fish”) are here defined as small finfish that are consumed whole by predatory fish and aquatic wildlife. The advantages and rationale for the use of small prey fish as biosentinels in aquatic monitoring and assessment programs for mercury and other bioaccumulative contaminants have been discussed in detail (Yearley 2000, Lazorchak et al. 2003, Choy et al. 2008, Wiener et al. 2007, Wiener et al. in press). Prey fish are important in the transfer of methylmercury to predatory fish and many fish-eating birds, and the mean concentration of total mercury in prey fish is a useful indicator of methylmercury contamination in food webs supporting the production of sport fish and wildlife. Small yellow perch (*Perca flavescens*) were the preferred target prey fish in this study, because of their widespread distribution, abundance, and importance in the diets of many piscivores (Colby et al. 1979, Barr 1996, Soupier et al. 2000, Liao et al. 2002, Merrill et al. 2005, Wiener et al. 2012a). Alternative prey-fish species were sampled in water bodies that did not contain or yield yellow perch during sampling. Alternative prey fishes included green sunfish *Lepomis cyanellus*, bluegill *Lepomis macrochirus*, blacknose dace *Rhinichthys atratulus*, longnose dace *Rhinichthys cataractae*, central mudminnow *Umbra limi*, mottled sculpin *Cottus bairdii*, slimy sculpin *Cottus cognatus*, johnny darter *Etheostoma nigrum*, and Iowa darter *Etheostoma exile*.

Concentrations of mercury in whole yellow perch were tabulated for two total-length groups: fish less than 100 mm and fish 100 mm or greater. Mercury concentrations in fish typically increase with age and body size, and the mercury data for yellow perch in the smaller length group (<100 mm) are more applicable for comparison to other prey fishes analyzed in this study. Yellow perch in both length groups are important prey, given that some piscivores, such as adult common loons and large piscivorous fishes, can consume fish larger than 100 mm (Barr 1996, Merrill et al. 2005).

Adult predatory fish

Most species of fish in this group of biosentinel organisms are in upper trophic levels of aquatic food webs, and many are largely piscivorous as adults. This group also contains sport fishes that are commonly sought by anglers. Therefore, the analysis of axial muscle (tissue from skinless fillets) from predatory fishes provides information on concentrations of contaminants in fish tissue that may be eaten by humans. The analyses of total mercury, organic contaminants, and lead in edible fillets of predatory fish will, therefore, provide information useful for health-risk assessment.

Northern pike (*Esox lucius*), which are largely piscivorous as adults, were the preferred predatory-fish biosentinel in this study. Northern pike are widely distributed and often abundant in inland lakes, rivers, and streams in parks within the northern Great Lakes region (Kallemeyn 2000, Kallemeyn et al. 2003). Northern pike are also a popular sport fish in the region, and fish caught by anglers are often eaten.

Alternative predatory fish species were sampled in water bodies that did not contain or yield northern pike during sampling. Alternative predatory fishes included grass pickerel *Esox americanus*, smallmouth bass *Micropterus dolomieu*, largemouth bass *Micropterus salmoides*, large yellow perch, walleye *Sander vitreus*, rainbow trout *Oncorhynchus mykiss*, and creek chub *Semotilus atromaculatus*.

Some study lakes did not yield northern pike, smallmouth bass, or largemouth bass during sampling. For these lakes, we used yellow perch exceeding 130 mm in total length—if present in our catch—as a representative predatory fish sample. The diet and trophic position of yellow perch change substantially during their growth and development, and have been well described. During their first year after hatching, yellow perch feed on zooplankton and small zoobenthos (Graeb et al. 2006). Yellow perch begin feeding on small fish when they reach a total length of about 65-80 mm (Fullhart et al. 2002, Graeb et al. 2006). At a total length of 130 mm, yellow perch regularly consume fish prey (Tonn and Paszkowski 1986, Fullhart et al. 2002), and perch larger than 190-200 mm in length are effective piscivores, feeding primarily on fish (Paskowski and Tonn 1994, Fullhart et al. 2002).

Larval dragonflies

Dragonflies (Insecta: Anisoptera: Odonata) are a well-known and conspicuous group of insects. Larval dragonflies are present in a wide variety of freshwater ecosystems. Compilation of county records from the North American Odonate Database (Abbott 2007) indicate that several species of the families Libellulidae, Gomphidae, Corduliidae, and Aeshnidae should inhabit parks of the Great Lakes Network (Wiener et al. in press).

The ecology of larval dragonflies is well documented at the genus level (Tennesen 2007). All larval dragonflies are obligate, generalist predators; however, the type of prey encountered and their diet is a function of habitat preference and mode of habit (i.e., burrowing, climbing, or sprawling). Species in the families Gomphidae and Cordulegastridae, for example, are primarily burrowers that feed on benthic invertebrates. Species in the family Aeshnidae are climbers that cling to vertical portions of aquatic vegetation and feed on invertebrates, including zooplankton, that inhabit the water column. Such differences are probably important in defining pathways for dietary methylmercury uptake (Tremblay et al. 1996).

Larval dragonflies have been used as sentinel organisms (Johnson et al. 1993) to detect and monitor heavy metal pollution in a number of freshwater ecosystems. Factors and characteristics that contribute to their utility as biosentinels for mercury include the following:

- (1) All species are obligate predators and as such, bioaccumulate methylmercury.
- (2) They persist and reproduce in low to moderately contaminated ecosystems.
- (3) Larvae are restricted to the ecosystems in which they were hatched.

- (4) Individuals of most species are large enough to provide adequate biomass for whole body analysis of methylmercury and total mercury.
- (5) Many species are ubiquitous across ecosystems at the regional level.
- (6) Most species in northern parts of the western Great Lakes region are long-lived, spending 3 to 4 years as aquatic larvae.
- (7) Larvae can be readily obtained with simple, inexpensive, and portable sampling gear, and little training is needed to collect samples.
- (8) Larvae are robust enough to survive handling in the laboratory and field.
- (9) Most mature larvae can be taxonomically identified to species level.

Mercury: Sampling, Sample Preparation, Analysis, and Risk Assessment

We attempted to sample all three groups of aquatic biota at each study site. The species of prey fish, predatory fish, and larval dragonflies sampled and analyzed for contaminants are summarized in Table 2.

Table 2. Water bodies studied at each park unit, sampling dates, and biosentinel organisms collected during 2008-2009.

Park unit	Water body	Sampling date	Biosentinel organisms sampled and analyzed		
			Prey fish	Predatory fish	Dragonflies ¹
GRPO	Grand Portage Creek	1 June 2009	longnose dace slimy sculpin	rainbow trout	A, C
	Hollow Rock Creek	29 July 2009	--	rainbow trout	--
	Poplar Creek	1 June 2009	blacknose dace longnose dace	creek chub	A, C
	Reservation River	9 July 2009	--	rainbow trout	--
	Snow Creek	2 June 2009	central mudminnow	--	A, C, L
INDU	Great Marsh	21 May 2008	central mudminnow green sunfish	grass pickerel	L
	Long Lake	20 May 2008	green sunfish	--	L
ISRO	Angleworm Lake	28 May 2009	--	northern pike	G, L, M
	Lake Harvey	23-24 May 2009	yellow perch	yellow perch	A, C, G, M
	Lake Richie	25-26 May 2009	yellow perch	northern pike	A, G, L
	Sargent Lake	27 May 2009	yellow perch	northern pike	A, G, M
PIRO	Beaver Lake	31 May 2008	iowa darter johnny darter mottled sculpin yellow perch	northern pike walleye	A, G, M
	Chapel Lake	2 June 2008	iowa darter johnny darter yellow perch	yellow perch	A, G, M
	Grand Sable Lake	1 June 2008	iowa darter johnny darter mottled sculpin	northern pike smallmouth bass	A, G
	Legion Lake	3 June 2008	central mudminnow	--	A, G
	Miners Lake	30 May 2008	mottled sculpin	northern pike	A

Table 2 (continued). Water bodies studied at each park unit, sampling dates, and biosentinel organisms collected during 2008-2009.

SLBE	Bass Lake (Benzie)	28 May 2008	bluegill iowa darter johnny darter	largemouth bass northern pike	A, G, L
	Bass Lake (Leelanau)	27 May 2008	yellow perch	largemouth bass northern pike	G, L
	Lake Manitou	24-25 May 2008	iowa darter	smallmouth bass	A, G, M
	Round Lake	23 May 2008	bluegill yellow perch	largemouth bass	A, G, L
VOYA	Brown Lake	19 May 2009	yellow perch	northern pike	A, G, L, M
	Peary Lake	18 May 2009	yellow perch	northern pike	A, G, L, M
	Ryan Lake	17 May 2009	yellow perch	northern pike	A, G, L, M
	Sand Point Lake	20 May 2009	yellow perch	northern pike	G, M

¹Dragonfly larvae sampled and analyzed are indicated by family, abbreviated as follows: A = Aeshnidae, C = Corduliidae, G = Gomphidae, L = Libellulidae, M = Macromiidae.

Prey fish

Prey fish were sampled in littoral habitats during the spring (generally a few weeks after ice melt) with DC-pulse back-pack electrofisher, small-mesh bag seine, or dip nets. In the field, prey fish were temporarily held in labeled, zip-seal freezer bags. In the laboratory, each fish was thawed, identified to species, measured (total length to the nearest millimeter), and weighed (to 0.001 g). Each fish was placed into a labeled, zip-seal plastic bag, and stored in a domestic chest freezer until lyophilization to a nearly constant mass. After lyophilization, double-bagged samples were stored in a dessicator until each whole fish was homogenized in a stainless steel blender, which was washed with Citranox® acid cleaner and detergent (Alconox Co., White Plains, NY) between batches of samples from different species or water bodies.

Two methods and mercury detectors were used to quantify total mercury in whole prey fish sampled in 2008. Of the prey fish obtained in 2008, 308 fish were acid digested and analyzed with a Teledyne Leeman Labs Hydra AF Gold Plus automated analyzer by CVAFS, as follows. The total mercury content of whole prey fish was determined with methods adapted from U.S. EPA Method 1631 (USEPA 2001) and from Hammerschmidt et al. (1999). Lyophilized and homogenized samples were weighed into plastic tubes, and then digested in a strong acid solution to free mercury from its organic matrix. Additional chemical digestion with a free radical source was used to aid in organic matrix oxidation. Digested samples were then placed into an autosampler and analyzed by adding a reducing agent that converts inorganic mercury to gas phase Hg⁰, which is analyzed by CVAFS.

The remaining 188 whole prey fish sampled in 2008 and all prey fish sampled in 2009 were analyzed without digestion by direct mercury analysis, following U.S. EPA Method 7473 (USEPA 2007). A 40- to 50-mg sample of dried, homogenized whole fish was weighed into quartz boats and analyzed directly by thermal decomposition and atomic absorption with an automated Milestone DMA-80 Direct Mercury Analyzer. Concentrations of total mercury in all whole prey fish exceeded our calculated method detection limits, which were 12.4 ng/g dry weight for samples analyzed by direct mercury analysis with the DMA-80 and 17.5 ng/g dry

weight for samples analyzed by acid digestion and CVAFS with the Leeman Labs Hydra AF Gold Plus analyzer.

The analysis of whole prey fish provides ecologically relevant data on whole-body concentration and burden. Mercury *burden*, defined as the total mass of mercury accumulated in a whole fish, can be calculated as the product of body weight and whole-body concentration. The burden also represents the mass of mercury that a predator would ingest when eating the prey fish.

Predatory fish

Adult predatory fish were collected with multiple sampling gears, including hook and line, variable-mesh gill nets, and DC-pulse backpack electrofisher. While sampling was in progress, predatory fish were held in clean mesh bags suspended in the water column. Before departing the study site, each fish was euthanized, given a metal jaw tag for identification, and placed into two labeled, food-grade plastic bags for transport in coolers with wet ice. At day's end, predatory fish were double-bagged and stored in a domestic freezer until transport to the University of Wisconsin-La Crosse.

In the laboratory, each fish was slowly thawed, weighed, and measured (total length). A sample of axial muscle tissue (skinless fillet) was dissected, placed into a zip-seal plastic bag, and stored frozen until lyophilization. After lyophilization to a nearly constant dry weight, each axial sample was homogenized in a stainless steel blender, which was washed with Citranox® acid cleaner and detergent between batches of samples from different species or water bodies.

Total mercury in axial muscle from all but 11 fish was determined with procedures modified from EPA Method 1631. A 100-mg sample of dried, homogenized fillet tissue was weighed into a polypropylene digestion vial and acid-digested in 10 mL of a 3:7 (v:v) solution of 16 M HNO₃ and 18 M H₂SO₄ for 3 hours at 90°C. An additional 40 mL of BrCl was added, followed by digestion for 8 hours at 40°C in a laboratory oven. After cooling, 2 mL (w/v) of NH₂OH·HCl was added to each digestate.

Two mercury detectors were used to quantify total mercury in *digestates* of axial muscle. All predatory fish sampled in 2008 and 20 of the fish sampled in 2009 were analyzed with a Teledyne Leeman Labs Hydra AF Gold Plus automated analyzer by CVAFS. The remaining 106 predatory fish sampled in 2009 were analyzed with a Tekran CVAFS Mercury Detector 2500. Concentrations of total mercury in all samples exceeded our calculated method detection limit (3.4 ng/g dry weight) for axial muscle.

Axial muscle from 11 fish was analyzed without digestion by direct mercury analysis, following U.S. EPA Method 7473. The samples analyzed with a Milestone DMA-80 Direct Mercury Analyzer included 10 yellow perch collected from Chapel Lake (PIRO) in 2008 and a single northern pike collected from Anglemore Lake (ISRO) in 2009. Concentrations of total mercury in all axial muscle samples quantified by direct mercury analysis exceeded our calculated method detection limit of 4.2 ng/g dry weight.

Larval dragonflies

Larvae were collected from benthic, vegetated, and woody substrates with hand-held dip nets, a few weeks before the older larvae were expected to emerge as adults. Most dragonflies in the

western Great Lakes region have long life cycles, in which the larval stage can continue for up to 4 years (Hilsenhoff 1995), and our sampling focused on larger larvae (late instars) that were within a few weeks of emergence. In the field, dragonfly larvae were held in zip-seal bags with water from the sampled water body. After each day of sampling, larvae were held overnight in aerated water at room temperature to allow egestion of gut contents, and on the next morning were placed into plastic vials and frozen in domestic freezers until further processing.

In the laboratory, thawed larvae were identified to species (Hilsenhoff 1995, Needham et al. 2000), sexed (Needham et al. 2000), photographed, lyophilized to a constant dry weight, and homogenized in an acid-washed ceramic or glass mortar and pestle. Dried samples were stored in a desiccator until acid digestion. The total length (from apex of head to the terminus of the abdomen), head capsule width, forewing length, fore femora length, and wing pad index of each larval dragonfly were obtained from images taken with a Nikon DXM 1200 digital camera. The wing pad index (WPI) is the abdominal segment overlain by the distal tip of the hind wingpad (the metathoracic wing sheath). This index was used to discriminate among the final intermolt periods of larval dragonflies. The maximum reach of the hind wingpad over the abdomen varies among odonate species, but for a given species the WPI provides a relative index of how near a larvae is to its terminal stadium, the one prior to emergence as an adult (Corbet 1999).

Whole dragonfly larvae were digested and analyzed individually for total mercury and methylmercury. For methylmercury, 40 to 60 mg of dried, homogenized tissue was weighed into a 22-mL acid-washed Teflon vial, to which 7 mL of 4.5 M HNO_3 was added. The samples were capped and digested at 60°C for 12 hours, and samples were typically analyzed within 1 week. A 0.10-mL aliquot was added to a 40-mL borosilicate glass autosampler vial containing about 35 mL of deionized water, with 0.10 mL of 4.5 M KOH, 0.40 mL of 2 M acetate buffer, and 0.050 mL of a 1% (w/v) sodium tetraethylborate solution. Reagent-grade water was added to fill vials completely, the vials were capped, and samples were analyzed by gas chromatography separation and CVAFS on an automated Brooks Rand MERX-M analyzer.

Total mercury content of larval dragonflies was determined from the same digestate as that used in methylmercury analyses. Each digestion vial received 1.0 mL of 0.18 M bromine monochloride (BrCl) to oxidize organic matter, followed by digestion at 40°C for an additional 12 hours. After cooling, 0.20 mL of 20% (w/v) hydroxylamine hydrochloride ($\text{NH}_2\text{OH}\cdot\text{HCl}$) was added. Each 40-mL glass autosampler vial received about 25 mL of reagent-grade water, 1.0 mL of digested sample, and 0.10 mL of 20% (w/v) stannous chloride (SnCl_2). Samples were analyzed by CVAFS with an automated Brooks Rand MERX-T analyzer. Measured concentrations of mercury in all larvae analyzed exceeded our calculated method detection limits, which were 8.9 ng/g dry weight for total mercury and 8.1 ng/g dry weight for methylmercury.

Quality assurance for mercury determinations

Precision and accuracy of total mercury and methylmercury determinations for biological samples were quantified by the analyses of (1) analytical and procedural blanks, (2) replicate samples, (3) certified reference materials from the National Institute of Standards and Technology (NIST) and the National Research Council of Canada (NRCC), and (4) spiked samples. Quality assurance measures for fish analyzed by acid digestion + CVAFS were similar

to those for fish analyzed by direct mercury analysis. For analyses of fish preceded by acid digestion of samples, 57 of 72 (79%) certified reference materials were within the certified ranges; all values outside the certified range were from analyses of NIST Mussel 2976, which had a very narrow certified range. For samples of fish analyzed by direct mercury analyses, 59 of 60 (98%) certified reference materials were within the certified ranges. The relative standard deviation (RSD) of fish samples analyzed in triplicate averaged 5.2% for acid-digested samples and 7.4% for direct-measured samples. Mean recoveries of mercury from spiked samples of fish were 96% for acid-digested samples and 105% for direct-measured samples. Results of quality-assurance measures are summarized in Table 3 for determination of total mercury in fish and in Table 4 for determination of total mercury and methylmercury in larval dragonflies.

Table 3. Summary of quality-assurance measures during determination of total mercury in fish sampled from six national park units during 2008-2009.

Method	Quality assurance metric	Material analyzed	Quality assurance results		
			<i>n</i>	<i>Our mean</i> $\pm$ 95% <i>CI</i> ¹	<i>Target result</i>
<i>EPA Method 1631 (acid digestion, CVAFS)</i>					
	Precision (CV, %) ¹	Triplicate samples	57	5.2 $\pm$ 0.7%	$\leq$ 10%
	Recovery (%)	Spiked samples	170	95.6 $\pm$ 1.3%	90% - 110%
	Accuracy (conc, ng/g) ²	NIST SRM 2976 (mussel tissue)	36	62.0 $\pm$ 1.8	57.4 - 64.6 ng/g (certified range)
	Accuracy (conc, ng/g) ²	NRCC TORT-2 (lobster hepatopancreas)	36	286.6 $\pm$ 6.5	210 - 330 ng/g (certified range)
<i>EPA Method 7473 (direct mercury analysis)</i>					
	Precision (CV, %) ¹	Triplicate samples	51	7.2 $\pm$ 1.2%	$\leq$ 10%
	Recovery (%)	Spiked samples	147	104.9 $\pm$ 1.3%	90% - 110%
	Accuracy (conc, ng/g) ²	NIST SRM 2976 (mussel tissue)	21	61.5 $\pm$ 0.8	57.4 - 64.6 ng/g (certified range)
	Accuracy (conc, ng/g) ²	NRCC DORM-3 (fish protein)	33	383.0 $\pm$ 7.2	322 - 442 ng/g (certified range)
	Accuracy (conc, ng/g) ²	NRCC DOLT-4 (dogfish liver)	18	2669 $\pm$ 36	2360 - 2800 ng/g (certified range)

¹CI is confidence interval; CV is coefficient of variation (CV = 100 $\times$ RSD).

²Concentration in nanogram per gram (ng/g), equivalent to part-per-billion, on a dry-weight basis.

Table 4. Summary of quality-assurance measures during determination of total mercury (THg) and methylmercury (MeHg) in larval dragonflies sampled from six national park units in 2008-2009.

Analyte	Quality assurance metric	Material analyzed	Quality assurance results		
			<i>n</i>	<i>Our mean</i> <i>± 95% CI</i> ¹	<i>Target result or</i> <i>certified range</i>
THg	Precision (CV, %) ¹	Triplicate samples	51	6.1 ± 1.5%	≤15%
	Recovery (%)	Spiked samples	80	102.7 ± 3.4%	75% - 125%
	Accuracy (conc, ng/g) ²	NIST SRM 2976 (mussel tissue)	85	59.0 ± 1.6 ng/g	57.4 - 64.6 ng/g (certified range)
	Accuracy (conc, ng/g) ²	NRCC TORT-2 (lobster hepatopancreas)	80	279.2 ± 5.7 ng/g	210 - 330 ng/g (certified range)
MeHg	Precision (CV, %) ¹	Triplicate samples	49	6.4 ± 1.6%	≤15%
	Recovery (%)	Spiked samples	93	104.6 ± 3.7%	75% - 125%
	Accuracy (conc, ng/g) ²	NIST SRM 2976 (mussel tissue)	105	26.7 ± 0.5 ng/g	27.8 - 28.4 ng/g (certified range)
	Accuracy (conc, ng/g) ²	NRCC TORT-2 (lobster hepatopancreas)	99	150.4 ± 3.7 ng/g	139 - 165 ng/g (certified range)

¹CI is confidence interval; CV is coefficient of variation (CV = 100 × RSD).

²Concentration in nanogram per gram (ng/g), equivalent to part-per-billion, on a dry-weight basis.

Indicators of risk

Concentrations of mercury in axial muscle of predatory fish from each park unit and water body were compared to the USEPA Tissue Residue Criterion for methylmercury (300 ng/g wet weight), a criterion established to protect the health of humans who eat noncommercial fish (Borum et al. 2001). The total-mercury concentration in the axial fillet of fish provides a valid estimate of methylmercury concentration, given that nearly all (generally ≥ 98%) of the mercury in axial muscle tissue of fish is present as methylmercury (Grieb et al. 1990, Bloom 1992).

The concentration of mercury in the axial muscle of adult fish is strongly correlated with that in blood (Schmitt and Brumbaugh 2007). Thus, the concentration of total mercury in axial muscle also provides a toxicologically relevant indicator of methylmercury exposure that can be used to assess ecological risk. To assess the potential for adverse effects of methylmercury exposure on predatory fish, we compared concentrations measured in axial muscle tissue to an estimated threshold concentration of mercury associated with sub-lethal and reproductive effects in fishes.

For adult fish, we used a threshold value of 500 ng/g wet weight in axial muscle, which was estimated in a critical review of mercury concentrations associated with altered biochemical processes, damage to cells and tissues, and impaired reproduction in fish (Sandheinrich and Wiener 2011). This estimated threshold is in agreement with the findings of Dillon et al. (2010), who used data from laboratory experiments to develop a dose-response curve for adult fish based on biological endpoints that are directly related to mortality or are biologically equivalent to mortality (e.g., reproductive failure). Dillon et al. (2010) estimated that a whole-body concentration of 300 ng/g wet weight (a value equivalent to a wet-weight concentration of 500 ng/g in axial muscle) would, on average, injure 8% of the fish.

To assess the toxicological risk of mercury in whole prey fish to piscivorous fish, we applied an estimated dietary threshold concentration for reproductive effects on fish. Reproduction of fish is affected at much lower dietary concentrations of methylmercury than other biological endpoints, such as growth, behavior, and mortality (Depew et al. 2012). Concentrations of total mercury in whole prey fish were compared to the estimated dietary threshold (40 ng/g wet weight in prey fish) associated with reproductive effects of methylmercury on piscivorous fish (Depew et al. 2012). Our analyses for total mercury yield valid estimates of the methylmercury concentration in whole prey fish, given that most (generally $\geq 95\%$) of the mercury in whole prey fish is present as methylmercury (Hammerschmidt et al. 1999, Drysdale et al. 2005, Van Wallegghem et al. 2007, Greenfield and Jahn 2010). For each park unit, water body, and species of prey fish sampled, we tabulated the number and percentages of fish having mercury concentrations exceeding the dietary threshold value.

Lead and Organic Contaminants: Sample Preparation and Analyses

Total lead (Pb) and selected bioaccumulative organic contaminants were quantified in samples of (mostly predatory) fish obtained in 2008 and 2009 from five park units (GRPO, ISRO, PIRO, SLBE and VOYA). Organic contaminants included DDT and its metabolites (DDE and DDD), PCBs (total concentration and 75 congeners), PFCs (total concentration and 9 analytes), and PBDEs (total concentration and 9 congeners).

Sixty (60) frozen fish samples (axial muscle without skin) were prepared and provided to the Wisconsin State Laboratory of Hygiene in Madison for analysis. Each frozen sample was packaged in multiple layers of baked foil and identified by a unique sample identification code. Forty-one (41) of these samples were composite samples with nearly equal mass of axial muscle from multiple fish of a single species and similar total length (Appendix A). When allocating fish to a composite sample we followed the *75 percent rule*, which states that the length of the smallest fish should be at least 75% of the length of the largest fish in the composite sample. The ratio of minimum to maximum total length of fish ranged from 0.739 to 0.995 in our 41 composite samples, with a median ratio of 0.932 (data not shown). For composite samples, we allocated nearly equal mass of axial muscle from each fish in the sample to obtain an estimate of the mean concentration of each contaminant in the fish composing the sample. The remaining 19 samples contained axial muscle from a single fish. An inventory of these samples, including species of fish, number and size of fish in each sample, and total wet mass of axial muscle in each sample, is given in Appendix A. We attempted to include at least 10 g of (wet) axial muscle tissue in each sample; however, 4 samples composed of small stream fish contained less than 10 g of axial muscle.

Sample splitting

At the State Laboratory of Hygiene, semi-thawed axial muscle samples were ground with dry ice in a stainless steel blender, transferred to a tared glass beaker, and held overnight at -20°C to allow the CO₂ to sublime, before each sample was split into subsamples for determinations of PFCs, total lead, organochlorine compounds (PCBs, DDT and derivatives) and organobromine compounds (PBDEs). From each sample, a 1.0-g subsample for determination of PFCs was weighed into a polypropylene tube. For total lead, a 4-g subsample from each of 12 samples was transferred into a glass jar. For the remaining samples, a 0.5-g subsample for analysis for total lead was weighed into plastic Petri dishes, which were then wrapped with Teflon tape. This shift in subsample mass was due to a change in the method chosen for lead determination. All subsamples were stored in a freezer until analysis, and samples were ground and split in batches of 10. Method blanks including dry ice were prepared for each batch of 10 subsamples.

Determination of DDT, PCBs, and PBDEs

For several samples with limited mass, the entire mass of sample remaining after removal of subsamples for PFCs and lead was extracted for chlorinated and brominated compounds. Sample mass ranged from 3.9 to 6.9 g, but was 5.0 g for most samples. Extractions were performed within a few days after grinding. Samples were blended with anhydrous sodium sulfate, poured into a 2-cm (i.d.) glass column, and extracted with methylene chloride by gravity elution. Extracts were concentrated and solvent-exchanged to hexane. Clean up and fractionation was attained with Florisil and silica-gel. The extracts were concentrated to 5.0 mL, and internal standards were added. The extract was then treated with concentrated sulfuric acid, mixed, and allowed to sit for several hours before an aliquot was transferred to a GC vial. The concentrated samples were injected onto a gas chromatograph equipped with an electron-capture detector. PCBs and PBDEs were analyzed in the first fraction off the Silica Gel, on a 60-m DB-5 capillary column, with confirmation on a 60-m DB-1 column.

The quantitation standard for PCB congeners was the Mullin Mix of Aroclors 1232, 1248, and 1262. Pesticides were analyzed in both Silica Gel fractions, with the DB-1 column used as the primary column and the DB-5 column used for confirmation. Quality assurance procedures included matrix spikes of ocean perch with each batch of 10 samples, spiked before extraction. The spike solution for PCB congeners consisted of a mixture of Aroclors 1232, 1248 and 1262. A method blank was analyzed with each batch. A few samples were run in duplicate if sample quantity was sufficient. Surrogate standards were added to all samples to monitor analytical recoveries. The surrogate spike solution consisted of PCB congeners #14, #65, and #166, and 1.0 mL of this solution was added to each sample before extraction.

Determination of PFCs

Samples were analyzed by WSLH Method 1480 (Analysis of Perfluorosulfonates and Perfluoro Acids in Fish Tissue by HPLC-MS/MS). To summarize, perfluorinated compounds in fish tissue samples were extracted by an ion-pairing liquid/liquid extraction with MTBE, evaporated to dryness under nitrogen gas, reconstituted in 50:50 2 mM ammonium acetate:MeOH and then analyzed by HPLCMS/MS. Separation of the analytes was achieved with gradient-elution chromatography. After elution from the HPLC column, the analytes were analyzed with a turbo-ion-spray, triple-quadrupole mass spectrometer in the negative ionization mode.

Quality assurance

Quality control (QC) requirements listed in WSLH Method 1480 were initial demonstration of laboratory capability, analysis of laboratory reagent blanks, laboratory spiked samples, laboratory method blanks, and check standard samples. Standard curve points were extracted with samples. There were not enough QC sample data points (20-30) to determine in-house statistical limits before this study; therefore, the acceptance limits of 70% to 130%, which were specified in the EPA Solid Waste methods manual, were used as guidance. Analytes that did not perform well due to poor chromatography or consistently unacceptable QC sample recovery were not reported by the Wisconsin State Laboratory of Hygiene.

Results and Discussion

In this section, we present and discuss results for each of the six national park units, and follow with a regional assessment encompassing all six park units. Descriptive statistical summaries of data from samples analyzed for mercury are provided for each park unit, water body, and species analyzed in Appendix C for prey fish, Appendix D for adult predatory fish, and Appendices E and F for larval dragonflies. Analytical results for total lead and organic contaminants in axial muscle of fish from five park units are summarized in Appendix G.

Grand Portage National Monument (GRPO)

Small prey fish were sampled from Grand Portage Creek, Poplar Creek, and the lower reach of Snow Creek. Backpack electrofishing yielded no fish at the beaver pond adjacent to the boardwalk in Snow Creek. Mean concentrations of mercury in prey fish were highest in blacknose dace and longnose dace from Poplar Creek (Table 5).

Table 5. Fish length and mercury (Hg) concentration in whole prey fish sampled in 2009 from streams in Grand Portage National Monument.

Stream	Species	n	Total length (mm)		Hg (ng/g) ¹	
			mean	range	mean	range
Grand Portage Creek	Longnose dace	30	78	56-105	58	29-175
	Slimy sculpin	23	58	43-83	28	10-48
Poplar Creek	Blacknose dace	15	73	54-89	87	51-143
	Longnose dace	7	75	65-97	75	50-100
Snow Creek	Central mudminnow	26	58	38-108	58	34-82

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

Mean concentrations in dace from Poplar Creek and Grand Portage Creek and in central mudminnow from Snow Creek exceeded the estimated dietary threshold (40 ng/g wet weight in prey fish) associated with reproductive effects of mercury on piscivorous fish (Depew et al. 2012). The mean concentration of mercury was lower in slimy sculpin from Grand Portage Creek (Table 5). The maximum concentrations in individual prey fish were 175 ng/g in longnose dace and 143 ng/g in blacknose dace. These maximal values exceed dietary levels (160 ng/g) associated with effects of mercury on reproduction of some fish-eating birds (Evers et al. 2011b).

The concentrations of mercury in axial muscle of rainbow trout from Grand Portage Creek, Hollow Rock Creek, and Reservation River were low (Table 6), probably because the diet of small rainbow trout consists largely of aquatic insects and other invertebrates (Becker 1983). Concentrations in axial muscle of creek chub from Poplar Creek were higher than those in rainbow trout from streams at or near GRPO (Table 6). The diet of creek chub often includes small prey fish, such as shiners (Becker 1983), and creek chubs probably occupy a higher trophic position than the small rainbow trout inhabiting these streams. Concentrations of total mercury in

axial muscle from all rainbow trout and creek chub analyzed were below the USEPA tissue residue criterion for methylmercury (300 ng/g) and the estimated threshold level (500 ng/g) for adverse effects on fish health and reproduction.

Table 6. Fish length and mercury (Hg) concentration in axial muscle (skinless fillets) of fish sampled in 2009 from streams in or near Grand Portage National Monument.

Stream	Species	n	Total length (mm)		Hg (ng/g) ¹	
			mean	range	mean	range
Grand Portage Creek	Rainbow trout	8	116	97-157	35	29-41
Hollow Rock Creek ²	Rainbow trout	6	122	113-129	19	15-22
Reservation River ²	Rainbow trout	6	136	118-148	42	28-72
Poplar Creek	Creek chub	4	145	128-168	110	60-168

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

²Fish from Hollow Rock Creek and Reservation River were sampled by the Grand Portage Band of Lake Superior Chippewa.

Grand mean concentrations of methylmercury (145 ng/g dry weight) and total mercury (151 ng/g dry weight) in 59 larval dragonflies from the three streams at GRPO (Appendices E and F) substantially exceeded those in larvae from the five other park units (Table 7). The fraction of total mercury present as methylmercury (95%) in larval dragonflies from GRPO also exceeded that in larvae from the other five park units (Table 7). Site- and species-specific mean concentrations of methylmercury ranged from 115 to 173 ng/g dry weight for the nine species of odonates sampled at GRPO (Appendix F). Mean concentrations of methylmercury were highest in species sampled from Grand Portage Creek (158 ng/g), Poplar Creek (143-163 ng/g), and lower Snow Creek (157-173 ng/g). Mean concentrations of methylmercury in four species sampled from the beaver pond in upper Snow Creek ranged from 115 to 139 ng/g (Appendix F).

A total of nine composite samples of fish from four streams were analyzed for organic contaminants and total lead (Appendix A). Each composite sample contained an equivalent mass of axial muscle tissue from four to seven fish of similar total length of a given species. Composite samples included creek chub from Poplar Creek and rainbow trout from Grand Portage Creek, Hollow Rock Creek, and Reservation River. Concentrations of PBDEs and PCBs were low (Appendix G-1). PBDEs were detected (concentration range, 1.0-1.9 ng/g wet weight) only in composite samples of rainbow trout from Hollow Rock Creek. PCB congeners were detected (range, 0.84-3.6 ng/g wet weight) in rainbow trout from Grand Portage Creek, Hollow Rock Creek, and Reservation River. Concentrations of DDT, DDE, and DDD were below limits of detection (Σ DDT: 10 ng/g) in all samples. Low concentrations of PFCs were detected (range, 0.50-2.5 ng/g wet weight) in creek chubs from Poplar Creek and in rainbow trout from Grand Portage Creek, Hollow Rock Creek, and Reservation River. Concentrations of lead were low and averaged 8 ng/g wet weight (range, 8-9 ng/g) in creek chub and 13 ng/g wet weight (range, 4-23 ng/g) in rainbow trout.

Table 7. Grand means and 95% confidence intervals for methylmercury (MeHg), total mercury (THg), and percent MeHg in larval dragonflies sampled from six park units during 2008-2009. Means were calculated from combined data for all species and water bodies from each park unit. Sample size (n) indicates the number of larvae analyzed individually for both methylmercury and total mercury.

Park unit	Number of families	Number of species	n	MeHg (ng/g) ¹	THg (ng/g) ¹	% MeHg (range)
GRPO	3	9	59	145 (132-158)	151 (139-163)	95 (93-97)
INDU	1	1	12	52 (34-70)	75 (53-96)	71 (51-91)
ISRO	5	10	139	57 (50-64)	73 (67-80)	74 (71-76)
PIRO	3	11	99	64 (56-71)	93 (83-103)	71 (67-76)
SLBE	4	11	119	51 (38-63)	64 (50-77)	77 (73-81)
VOYA	4	12	116	98 (90-104)	119 (110-128)	84 (81-86)

¹Concentrations are given in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Indiana Dunes National Lakeshore (INDU)

Small prey fish were sampled from Long Lake and from three sites in the Great Marsh, an interdunal wetland on the Lake Michigan shoreline that is undergoing ecological restoration to increase diversity of native plants and animals and to provide habitat for migratory birds. Whole-body concentrations of mercury in small green sunfish were low at both sites, averaging 26 ng/g wet weight in Long Lake and 34 ng/g in the Great Marsh (Table 8). The central mudminnow, a species that is able to survive prolonged conditions of low dissolved oxygen (Becker 1983), was by far the most abundant species of fish encountered during sampling at all three sites in the Great Marsh. Mean concentrations of mercury in whole central mudminnows ranged from 24 to 39 ng/g at the three sites in the Great Marsh (Table 8).

A single grass pickerel was obtained by electrofishing at site GRMA-2 in the Great Marsh. The concentration of total mercury in axial muscle tissue of this grass pickerel (total length, 173 mm) was 192 ng/g wet weight. Attempts to obtain additional predatory fish with gill nets and by angling in the Great Marsh were unsuccessful. None of the fish sampled from INDU during 2008, which consisted almost entirely of small prey fish, were analyzed for total lead or organic contaminants.

Concentrations of mercury in eight larval dragonflies (family Libellulidae, *Pachydiplax longipennis*) from the Great Marsh averaged 65 ng/g dry weight for methylmercury, 86 ng/g for total mercury, and 82% for percent methylmercury. Concentrations were lower in four larval dragonflies of the same species from Long Lake, averaging 25 ng/g dry weight for methylmercury and 51 ng/g for total mercury and 50% for percent methylmercury.

Table 8. Fish length and mercury (Hg) concentration in whole prey fish sampled in 2008 from Indiana Dunes National Lakeshore.

Water body	Species	n	Total length (mm)		Hg (ng/g) ¹	
			mean	range	mean	range
Long Lake	Green sunfish	31	39	33-54	26	13-44
Great Marsh ²						
GRMA-1	Green sunfish	2	47	43-51	34	26-42
GRMA-1	Central mudminnow	21	69	24-98	34	7-79
GRMA-2	Central mudminnow	32	78	20-123	39	11-84
GRMA-3	Central mudminnow	24	68	21-96	24	11-58

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

²Sites in the Great Marsh are delineated as follows: GRMA-1 included open water and near-shore areas located south of Beverly Drive and east of Broadway; GRMA-2 included channel habitat located south of Beverly Drive and west of Broadway; GRMA-3 included open water areas (with emergent woody vegetation) located north of Beverly Drive and east of East State Park Road.

Isle Royale National Park (ISRO)

Yellow perch—a regionally widespread and abundant prey fish—were sampled from Harvey, Richie, and Sargent lakes and analyzed whole for total mercury. Concentrations in all yellow perch analyzed from Lake Harvey substantially exceeded those in perch from Richie and Sargent lakes (Table 9).

Table 9. Fish length and mercury (Hg) concentration in whole prey fish (yellow perch) sampled in 2009 from three lakes in Isle Royale National Park.

Lake	Total-length group	n	Total length (mm)		Hg (ng/g) ¹	
			mean	range	mean	range
Harvey	<100 mm	4	91	79-97	151	122-201
	≥100 mm	11	141	100-213	190	84-432
	all fish	15	127	79-213	180	84-432
Richie	<100 mm	15	83	68-96	42	31-57
	≥100 mm	12	115	103-155	39	24-82
	all fish	27	97	68-155	41	24-82
Sargent	<100 mm	30	70	58-85	41	27-72

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

The whole fish analyzed from all three lakes at ISRO are within the length range of yellow perch eaten by adult common loons (Barr 1996, Wiener et al. 2012a). In Lake Harvey, the mean concentration of mercury in whole yellow perch exceeded 160 ng/g wet weight, a prey-fish concentration causing a 40% reduction in production of fledged loons relative to production in reference areas with low mercury levels (Evers et al. 2004, 2008). Concentrations in some

yellow perch from Lake Harvey exceeded 210 ng/g, a prey-fish concentration associated with a 50% decrease from maximum production of loon chicks (Burgess and Meyer 2008). The highest concentrations of mercury in whole yellow perch from Lake Harvey exceeded 410 ng/g, a value associated with complete reproductive failure of common loons (Burgess and Meyer 2008).

A total of 38 northern pike were obtained from Angleworm, Richie, and Sargent lakes and 9 large yellow perch (ranging 208-321 mm in total length and presumably piscivorous) were obtained from Lake Harvey, which does not contain northern pike. Concentrations of mercury in axial muscle tissue in individual northern pike ranged from 101 to 702 ng/g wet weight, exceeding the USEPA fish tissue criterion for methylmercury in 14 (37%) of 38 fish (Table 10). Concentrations in 3 (8%) of the 38 northern pike exceeded 500 ng/g, the estimated threshold level associated with adverse effects on the health and reproduction of fish. Concentrations in axial muscle of yellow perch from Lake Harvey were notably higher than those in northern pike from the other three lakes. Mercury levels in axial muscle of yellow perch ranged from 502 to 1261 ng/g, exceeding the USEPA fish tissue criterion for methylmercury and the estimated fish-health threshold in all 9 fish.

Table 10. Fish length and mercury (Hg) concentration in axial muscle (skinless fillets) of predatory fish sampled in 2009 from four lakes in Isle Royale National Park.

Lake	Species	n	Total length (mm)		Hg (ng/g) ¹		% (number) of fish exceeding	
			mean	range	Mean	range	USEPA criterion	Fish-health threshold
Angleworm	Northern pike	13	576	359-684	257	101-702	23 (3)	8 (1)
Richie	Northern pike	15	492	304-575	222	103-602	20 (3)	7 (1)
Sargent	Northern pike	10	616	568-718	378	258-567	80 (8)	10 (1)
Harvey	Yellow perch	9	280	208-321	889	502-1,261	100 (9)	100 (9)

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

²Fish with mercury concentrations exceeding the USEPA tissue residue criterion for methylmercury in fish (300 ng/g) and the estimated threshold level for adverse effects on the health and reproduction of fish (500 ng/g).

A total of 139 larval dragonflies were sampled from the four lakes at ISRO and analyzed for mercury. Grand means for all species and all ISRO lakes combined were 57 ng/g (dry weight) for methylmercury, 73 ng/g for total mercury, and 74% for percent methylmercury (Table 7). Concentrations were highest in dragonflies from Lake Harvey, averaging 120 ng/g dry weight for methylmercury and 131 ng/g for total mercury (Appendix E). Concentrations of methylmercury in larvae from the three other lakes were substantially less, averaging 38 ng/g in both Angleworm and Sargent lakes and 54 ng/g in Lake Richie. In larvae from Lake Harvey, the fraction of total mercury present as methylmercury averaged 89%, exceeding that in larvae from the other three lakes (means ranging 65% to 76%) (Appendix E).

Eight composite samples of northern pike from Richie, Sargent, and Anglemworm lakes—each sample containing an equivalent mass of axial muscle from 4 fish of similar total length—were analyzed for organic contaminants and total lead (Appendix A). Two composite samples of large yellow perch from Lake Harvey—each containing axial muscle from 3 or 4 fish of similar total length—were also analyzed for organic contaminants and lead. Concentrations of PCBs, PBDEs, DDT, DDE, and DDD in all samples from ISRO were below limits of detection, which were 0.5-16 ng/g for PCBs, 1.0-2.0 ng/g for PBDEs, and 10 ng/g wet weight for total DDT (Appendix G-2). The concentrations of PFCs were low (range, 0.6-2.1 ng/g wet weight) in fish from Sargent, Anglemworm, and Harvey lakes and were below reporting levels (0.5-2.0 ng/g wet weight) in northern pike from Lake Richie. Lead concentrations were also low, averaging 5 ng/g wet weight (range, 3-7 ng/g) in yellow perch and 8 ng/g (range, 2-25 ng/g) in northern pike.

Pictured Rocks National Lakeshore (PIRO)

Total mercury was quantified in whole prey fish from five lakes at PIRO (Table 11), and concentrations were highest in prey fish from Chapel and Legion lakes. In Chapel Lake, mean concentrations in three species of prey fish ranged from 65 to 175 ng/g wet weight, and concentrations in all 37 prey fish analyzed equaled or exceeded 40 ng/g, the estimated dietary threshold for reproductive effects of methylmercury on piscivorous fishes (Depew et al. 2012). The central mudminnow is the only fish species present in Legion Lake—a clear-water,

Table 11. Fish length and mercury (Hg) concentration in whole prey fish sampled in 2008 from five lakes in Pictured Rocks National Lakeshore.

Lake	Species	n	Total length (mm)		Hg (ng/g) ¹	
			mean	range	mean	range
Beaver	Iowa darter	23	47	35-53	67	25-111
	Johnny darter	16	48	38-63	24	11-45
	Mottled sculpin	31	51	43-60	25	13-42
	Yellow perch (<100 mm)	31	54	49-63	29	20-38
Chapel	Iowa darter	10	50	31-62	81	40-157
	Johnny darter	4	57	33-70	65	52-77
	Yellow perch <100 mm	1	69	—	62	—
	≥100 mm	22	140	101-285	180	64-508
	all fish	23	137	69-285	175	62-508
Grand Sable	Iowa darter	26	47	39-55	52	4-83
	Johnny darter	34	43	35-57	44	7-72
	Mottled sculpin	17	51	45-64	21	12-49
Legion	Central mudminnow	31	78	52-115	122	56-289
Miners	Mottled sculpin	6	57	54-60	19	15-24

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

acidic lake—and is the presumed prey of common loons that forage on the lake. Concentrations in 31 central mudminnows averaged 122 ng/g wet weight, ranged from 56 to 289 ng/g, and were positively correlated with fish length. The concentration of mercury in 6 (19%) of the 31 central mudminnows exceeded 160 ng/g wet weight, a prey-fish concentration associated with a 40% reduction in production of fledged loons relative to production of chicks in reference areas with low mercury levels (Evers et al. 2004, 2008). Concentrations in 3 central mudminnows from Legion Lake equaled or exceeded 210 ng/g, a prey-fish concentration associated with a 50% decrease from maximum production of loon chicks (Burgess and Meyer 2008).

Mercury levels were lower in prey fish from Beaver, Grand Sable, and Miners lakes; yet mean concentrations in darters from Beaver and Grand Sable lakes exceeded the estimated dietary threshold (40 ng/g) for reproductive effects on piscivorous fish. Concentrations were low in mottled sculpin, with means for sculpin from three lakes ranging from 19 to 25 ng/g (Table 11).

Concentrations of total mercury in axial muscle from 15 northern pike, 1 smallmouth bass, and 1 walleye from three lakes (Beaver, Grand Sable, and Miners) ranged from 126 to 1212 ng/g wet weight, exceeding the USEPA tissue residue criterion for methylmercury in 10 (59%) of 17 fish (Table 12). Concentrations in 8 of these 17 predatory fish exceeded the estimated threshold for sublethal and reproductive effects on fish. Mercury levels were highest in predatory fish from

Table 12. Fish length and total-mercury concentration in axial muscle (skinless fillets) of predatory fish sampled in 2008 from four lakes in Pictured Rocks National Lakeshore.

Lake	Species	n	Total length (mm)		Hg (ng/g) ¹		% (number) of fish exceeding criteria ²	
			mean	range	mean	Range	USEPA criterion	Fish-health threshold
Beaver	Northern pike	2	548	345-751	293	155-432	50 (1)	0 (0)
	Walleye	1	557	--	631	--	100 (1)	100 (1)
Chapel	Yellow perch	10	168	132-285	332	178-690	40 (4)	20 (2)
Grand Sable	Northern pike	6	626	401-784	821	379-1,212	100 (6)	83 (5)
	Smallmouth bass	1	398	--	615	--	100 (1)	100 (1)
Miners	Northern pike	7	549	392-805	274	126-737	14 (1)	14 (1)

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

²Fish with mercury concentrations exceeding the USEPA tissue residue criterion for methylmercury in fish (300 ng/g) and the estimated threshold level for adverse effects on health and reproduction of fish (500 ng/g).

Grand Sable Lake, averaging 821 ng/g in 6 northern pike and 615 ng/g in a single smallmouth bass. Mercury concentrations were much lower in predatory fish from Miners Lake, averaging 274 ng/g in 7 northern pike. Concentrations in axial muscle of 10 yellow perch from Chapel

Lake averaged 332 ng/g, exceeding the USEPA tissue residue criterion in 4 fish and the estimated threshold for sub-lethal and reproductive effects in 2 fish (Table 12).

A total of 99 larval dragonflies were sampled from the five lakes at PIRO and analyzed for mercury. Grand means for all odonate species and PIRO lakes combined were 64 ng/g (dry weight) for methylmercury, 93 ng/g for total mercury, and 71% for percent methylmercury (Table 7). Mean concentrations of methylmercury were highest in dragonflies from Legion (121 ng/g), Miners (95 ng/g), and Chapel (81 ng/g) lakes, although the sample from Miners Lake contained only two larvae (Appendix E). Concentrations of methylmercury in larvae from Beaver and Grand Sable lakes were substantially less, averaging 49 ng/g in Beaver Lake and 57 ng/g in Grand Sable. The fraction of total mercury present as methylmercury averaged from 65% to 81% in the five lakes (Appendix E).

Fifteen samples of predatory fish (axial muscle)—including 10 individual northern pike, 3 composite (multiple fish) samples of northern pike, 1 individual walleye, and 1 individual smallmouth bass—were analyzed for organic contaminants and total lead. Concentrations of DDT, DDE, DDD, and PBDEs in all samples from PIRO were below limits of detection, which were 10 ng/g wet weight for total DDT and 1.0-2.0 ng/g for PBDEs (Appendix G-3). Concentrations of PCB congeners were also very low and were detected only in the single smallmouth bass from Grand Sable Lake (range, 0.8-1.3 ng/g wet weight). Concentrations of PFCs were below the reporting limits of 0.50 to 2.0 ng/g for 8 of 9 analytes; concentrations of perfluoro-1-octanesulfonate (PFOS) were low and ranged from 0.77 to 1.6 ng/g. Concentrations of lead in all samples were low, averaging 8 ng/g (range, 4-28 ng/g) in the 13 individual and composite samples of northern pike from PIRO lakes. Lead concentrations were 7 ng/g in the smallmouth bass and 10 ng/g in the walleye.

Sleeping Bear Dunes National Lakeshore (SLBE)

A total of 134 prey fish were sampled from four lakes at SLBE and analyzed for total mercury (Table 13). Concentrations were highest in prey fish from Bass Lake-Benzie, averaging 97 ng/g wet weight in small bluegills and 112 ng/g in Iowa darters; these levels exceed the estimated dietary threshold (40 ng/g wet weight in prey fish; Depew et al. 2012) associated with reproductive effects of mercury on piscivorous fish. Mean concentrations were substantially less in the other three lakes, ranging from 17 to 35 ng/g in whole prey fish from Bass Lake-Leelanau, Lake Manitou, and Round Lake (Table 13).

Concentrations of mercury in axial muscle from predatory fish (14 largemouth bass, 11 smallmouth bass, and 5 northern pike) from four lakes at SLBE ranged from 117 to 713 ng/g wet weight (Table 14), exceeding the USEPA tissue residue criterion in 8 (27%) of the 30 fish. Mercury levels in 2 (7%) of the 30 fish exceeded 500 ng/g wet weight, an estimated threshold value for sub-lethal and reproductive effects in fish (Table 14).

A total of 119 larval dragonflies were sampled from the four lakes at SLBE and analyzed for mercury. Grand means for all SLBE lakes and odonate species combined were 51 ng/g (dry weight) for methylmercury, 64 ng/g for total mercury, and 77% for percent methylmercury (Table 7). Mean concentrations of methylmercury were highest in dragonflies from Bass Lake-Benzie (98 ng/g), intermediate in Round Lake (68 ng/g), and lowest in Bass Lake-Leelanau

(39 ng/g) and Manitou Lake (46 ng/g) (Appendix E). The fraction of total mercury present as methylmercury averaged from 64% to 82% in the four lakes (Appendix E).

Table 13. Fish length and mercury (Hg) concentration in whole prey fish sampled in 2008 from four lakes in Sleeping Bear Dunes National Lakeshore.

Lake	Species	n	Total length (mm)		Hg (ng/g) ¹	
			mean	range	mean	range
Bass (Benzie)	Bluegill	31	36	29-54	97	28-157
	Iowa darter	9	44	35-50	112	61-284
	Johnny darter	2	55	48-61	30	21-39
Bass (Leelanau)	Yellow perch (<100 mm)	31	67	48-84	22	15-35
Manitou	Iowa darter	26	53	45-63	29	16-46
Round	Bluegill	31	36	27-62	35	15-74
	Yellow perch (<100 mm)	4	78	74-82	17	10-27

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

Table 14. Fish length and mercury (Hg) concentration in axial muscle (skinless fillets) of predatory fish sampled in 2008 from four lakes in Sleeping Bear Dunes National Lakeshore.

Lake	Species	n	Total length (mm)		Hg (ng/g) ¹		% (number) of fish exceeding ²	
			mean	range	mean	range	USEPA criterion	Fish-health threshold
Bass (Benzie)	Largemouth bass	1	383	--	659	--	100 (1)	100 (1)
	Northern pike	2	442	431-453	404	357-451	100 (2)	0 (0)
Bass (Leelanau)	Largemouth bass	2	427	408-445	456	453-459	100 (2)	0 (0)
	Northern pike	3	571	557-586	249	202-287	0 (0)	0 (0)
Manitou	Smallmouth bass	11	383	338-440	326	221-713	27 (3)	9 (1)
Round	Largemouth bass	11	295	228-346	194	117-268	0 (0)	0 (0)

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

²Fish with mercury concentrations exceeding the USEPA tissue residue criterion for methylmercury in fish (300 ng/g) and the estimated threshold level for adverse effects on health and reproduction of fish (500 ng/g).

Sixteen samples of axial muscle from the four lakes at SLBE were analyzed for organic contaminants and total lead (Appendix A). These samples included northern pike (3 samples of individual fish and 1 composite sample), largemouth bass (1 individual fish and 5 composite samples) and smallmouth bass (3 individual fish and 3 composite samples). Concentrations of PBDEs and PCBs were low (Appendix G-4). PBDEs were detected (concentration range, 1.0-1.4 ng/g wet weight) in only two smallmouth bass from Lake Manitou, and PCB congeners were

detected (range, 0.74-1.3 ng/g wet weight) in only one smallmouth bass from Lake Manitou. Concentrations of DDT, DDE, and DDD were below limits of detection (Σ DDT: 10 ng/g) in all samples. Low concentrations of PFCs were detected (range, 0.52-2.1 ng/g wet weight) in smallmouth bass from Lake Manitou and in largemouth bass from Round Lake and Bass Lake (Leelanau). Lead concentrations were also low, averaging 5 ng/g wet weight (range, 3-8 ng/g) in northern pike, 6 ng/g (range, 2-10 ng/g) in largemouth bass, and 6 ng/g (range, 3-11 ng/g) in smallmouth bass.

Voyageurs National Park (VOYA)

Small yellow perch were sampled from the four study lakes at VOYA and analyzed whole for total mercury. Mean concentrations of mercury in yellow perch, which ranged from 30 to 124 ng/g wet weight, were highest in Ryan and Sand Point lakes and lowest in Peary Lake (Table 15).

Table 15. Fish length and mercury (Hg) concentration in whole yellow perch (prey fish) sampled in 2009 from four lakes in Voyageurs National Park.

Lake	Total-length group	n	Total length (mm)		Hg (ng/g) ¹	
			mean	range	mean	range
Brown	<100 mm	26	48	43-57	93	59-116
Peary	<100 mm	30	42	37-50	30	22-40
Ryan	<100 mm	21	74	45-97	113	67-198
	≥100 mm	1	104	—	112	—
	all fish	22	75	45-104	113	68-198
Sand Point	<100 mm	31	56	47-68	124	80-170

¹Concentrations are given in nanograms per gram (ng/g) wet weight, which are equivalent to parts per billion.

The mercury levels in yellow perch in three of the lakes at VOYA may be toxicologically significant to piscivorous fish. Yellow perch are important in the diet of northern pike in lakes at VOYA (Soupir et al. 2000), and mean concentrations in small yellow perch from Brown, Ryan, and Sand Point lakes greatly exceeded the estimated dietary threshold (40 ng/g wet weight in prey fish) associated with reproductive effects of methylmercury on piscivorous fish (Depew et al. 2012).

A total of 56 northern pike from the four lakes at VOYA were analyzed for total mercury. Concentrations in axial muscle tissue from 52 (93%) of the 56 northern pike exceeded 300 ng/g wet weight, the USEPA tissue residue criterion for methylmercury in fish (Table 16). Mercury concentrations in 36 (64%) of these fish exceeded 500 ng/g, an estimated threshold level associated with adverse effects on the health and reproduction of freshwater fish (Table 16). Mercury levels were highest in Ryan and Sand Point lakes, lowest in Peary Lake, and intermediate in Brown Lake. Prior analyses of dated sediment cores and forest soils have shown

that atmospheric deposition is the dominant source of mercury in the park, and that most of the mercury accumulating in lakes at VOYA was from anthropogenic sources (Wiener et al. 2006).

Table 16. Fish length and mercury (Hg) concentrations in axial muscle (skinless fillets) of predatory fish sampled in 2009 from four lakes in Voyageurs National Park.

Lake	Species	n	Total length (mm)		Hg (ng/g) ¹		% (number) of fish exceeding ²	
			mean	range	mean	range	USEPA criterion	Fish-health threshold
Brown	Northern pike	13	477	355-571	686	430-1,149	100 (13)	85 (11)
Peary	Northern pike	16	531	398-634	379	180-564	75 (12)	12 (2)
Ryan	Northern pike	15	502	358-589	1055	354-2192	100 (15)	80 (12)
Sand Point	Northern pike	12	541	493-613	930	483-1,472	100 (12)	92 (11)

¹Concentrations are in nanograms per gram (ng/g) wet weight, equivalent to parts per billion.

²Fish with concentrations exceeding the USEPA tissue residue criterion for methylmercury in fish (300 ng/g) and the estimated threshold level for adverse effects on health and reproduction of fish (500 ng/g).

A total of 116 larval dragonflies were sampled from the four lakes at VOYA and analyzed for mercury. Grand means for all VOYA lakes and odonate species combined were 98 ng/g (dry weight) for methylmercury, 119 ng/g for total mercury, and 84% for percent methylmercury, values exceeded only for larval dragonflies sampled from streams at GRPO (Table 7). Mean concentrations of methylmercury were highest in dragonflies from Sand Point (115 ng/g) and Ryan lakes (105 ng/g), lowest in Peary Lake (75 ng/g), and intermediate in Brown Lake (87 ng/g) (Appendix E). The fraction of total mercury present as methylmercury averaged from 78% to 91% in the four lakes (Appendix E).

Ten composite samples of northern pike from the four lakes at VOYA—each composite containing an equivalent mass of axial muscle from 4 or 5 fish of similar length from a single lake—were analyzed for bioaccumulative organic contaminants and total lead (Appendix A). Concentrations of PCBs, PBDEs, DDT, DDE, and DDD in all samples from VOYA were below limits of detection, which were 0.5-16 ng/g for PCBs, 1.0-2.0 ng/g for PBDEs, and 10 ng/g wet weight for total DDT (Appendix G-5). Concentrations of PFCs were low (range, 0.50-0.69 ng/g wet weight) in northern pike from Brown and Sand Point lakes and were below reporting levels (0.5-2.0 ng/g wet weight) in northern pike from Peary and Ryan lakes. Lead concentrations were also low, averaging 8 ng/g wet weight (range, 2-31 ng/g) in northern pike from the four lakes (Appendix G-5).

Regional Assessment

Our results revealed substantial spatial variation among water bodies in the accumulation of mercury in biosentinel organisms, both within and among the six park units. It is also evident that prey fish and predatory fish in some park units have bioaccumulated methylmercury to toxicologically relevant concentrations.

Concentrations of mercury in axial muscle tissue of predatory fish from four park units—including individual fish from 4 lakes at VOYA, 4 lakes at PIRO, 4 lakes at ISRO, and 3 lakes at SLBE—exceeded the USEPA tissue residue criterion of 300 ng/g wet weight for methylmercury, a criterion established to protect the health of humans who eat noncommercial, wild fish. Mean concentrations in axial fillets of predatory fish exceeded the USEPA tissue residue criterion in 4 lakes at VOYA, 3 lakes at PIRO, 2 lakes at ISRO, and 3 lakes at SLBE.

In some predatory fish, concentrations of mercury were high enough to adversely affect fish health and reproduction. Concentrations in axial muscle tissue of one or more individual predatory fish from a total of 14 water bodies in four park units (ISRO, PIRO, SLBE, and VOYA) exceeded an estimated threshold level (500 ng/g wet weight) associated with altered biochemical processes, damage to cells and tissues, and impaired reproduction in fish. Mean concentrations exceeded this threshold in predatory fish from 3 lakes at VOYA, 2 lakes at PIRO, 1 lake at ISRO, and 1 lake at SLBE. These findings are consistent with published reports showing widespread, elevated mercury levels in piscivorous fish inhabiting inland lakes in northern parts of the Laurentian Great Lakes region (Grieb et al. 1990, Rasmussen et al. 2007, Evers et al. 2011b, Monson et al. 2011, Sandheinrich et al. 2011).

No long-lived, piscivorous fish were obtained during our sampling in streams at GRPO. However, our analyses of prey fishes and larval dragonflies (Figure 2) indicate that methylmercury is bioaccumulating to high concentrations in biotic components of the lower food web in the lotic systems at that park unit. Concentrations of total mercury in whole prey fish from each of the three streams at GRPO exceeded an estimated dietary threshold (40 ng/g wet weight in prey fish) associated with reproductive effects of methylmercury on piscivorous fish. Moreover, concentrations of total mercury and methylmercury in stream water sampled from GRPO during 2010 and 2011 (Kristofer Rolfhus, University of Wisconsin-La Crosse, personal communication) substantially exceed the range of aqueous concentrations typically measured in surface waters in the western Great Lakes region (Brigham et al. 2009, Rolfhus et al. 2011, Tsui and Finlay 2011).

We caught only one piscivorous fish—a small grass pickerel—while sampling in the Great Marsh and Long Lake at INDU, and periods of oxygen depletion and low concentrations of dissolved oxygen may render these aquatic systems unsuitable as habitat for long-lived piscivorous fish (Garza et al. 2002). Concentrations of total mercury in whole prey fishes and of methylmercury in larval dragonflies from these two water bodies were generally low.

In the Laurentian Great Lakes region, atmospheric deposition is the dominant source of mercury and geologic (natural) sources of mercury are small (Wiener et al. 2006, Woodruff and Cannon 2010, Evers et al. 2011a, Drevnick et al. 2012, Risch et al. 2012a, 2012b). It can be reasonably inferred from these recent regional investigations that (1) nearly all of the mercury present in national park units in the western Great Lakes region is from wet and dry atmospheric deposition, (2) that most of this atmospherically deposited mercury is from anthropogenic emissions, and (3) that most of the mercury bioaccumulating as methylmercury in aquatic food webs and biosentinel organisms sampled in this study is from anthropogenic sources.

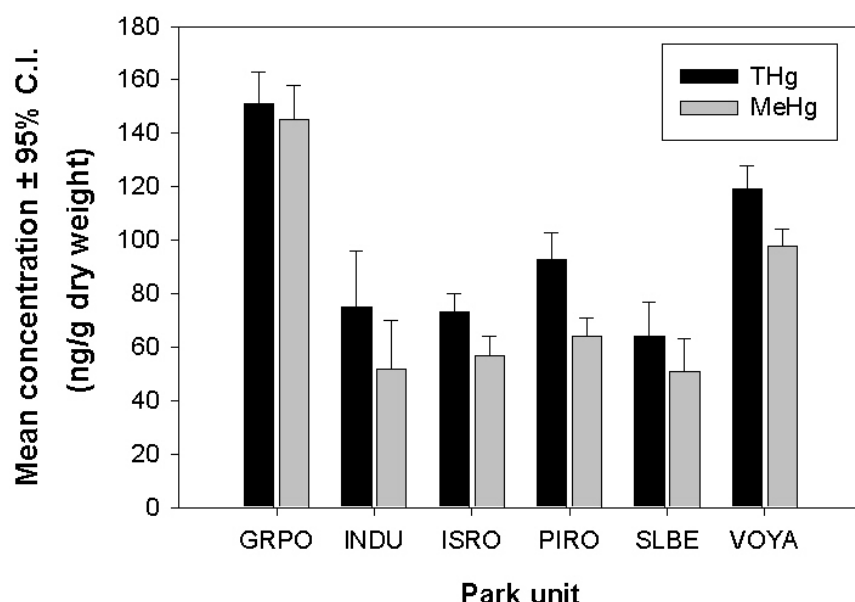


Figure 2. Total mercury (THg) and methylmercury (MeHg) in larval dragonflies from six park units in the Great Lakes network. Means and confidence intervals (C.I.) were calculated from combined data for all species and water bodies in each park unit.

Our results support the findings of a recent synthesis showing that the northern Great Lakes region is a mercury-sensitive area in which inorganic mercury from atmospheric deposition is readily methylated, bioaccumulated as methylmercury, and biomagnified in aquatic food webs to high, potentially harmful concentrations in predatory fish (Evers et al. 2011a, 2011b, Monson et al. 2011, Sandheinrich et al. 2011, Wiener et al. 2012b). A number of environmental factors contribute to the high sensitivity of the northern Great Lakes region to mercury. The region contains abundant wetlands, which are important sites of mercury methylation and export of methylmercury to hydrologically connected surface waters (Hurley et al. 1995, Sellers et al. 2001, Branfireun et al. 2005, Brigham et al. 2009), and water and biota in wetland-influenced lakes and streams often contain high concentrations of methylmercury (Wiener et al. 2006, Brigham et al. 2009, Chasar et al. 2009, Route et al. 2011). Concentrations of methylmercury are also typically elevated in aquatic organisms inhabiting low-pH or low-alkalinity waters (Wiener et al. 2003, Burgess and Meyer 2008), which are abundant and widespread in northern parts of the Great Lakes region (Eilers et al. 1988).

Variation in the mercury sensitivity of landscapes as receptors of mercury from atmospheric deposition is illustrated by a comparison of concentrations of the metal in central mudminnows sampled from three national park units in 2008 (INDU, PIRO) and 2009 (GRPO) (Figure 3). Contemporary rates of wet and dry deposition of mercury, reported by Risch et al. (2012a, 2012b), were greater at INDU, which is near industrialized and urban atmospheric sources of mercury along the southern shore of Lake Michigan (Gratz et al. 2012), than at PIRO in the upper peninsula of Michigan and GRPO in northeastern Minnesota. Yet concentrations of mercury in central mudminnows were greater in fish from PIRO and GRPO than in fish from INDU. Concentrations in central mudminnows were highest at Legion Lake, a clear-water, acidic

lake at PIRO, intermediate at Snow Creek in GRPO, and lowest at the Great Marsh in INDU (Figure 3). Low pH and low biotic productivity are two factors that probably contribute to the high mercury concentrations in central mudminnows inhabiting Legion Lake.

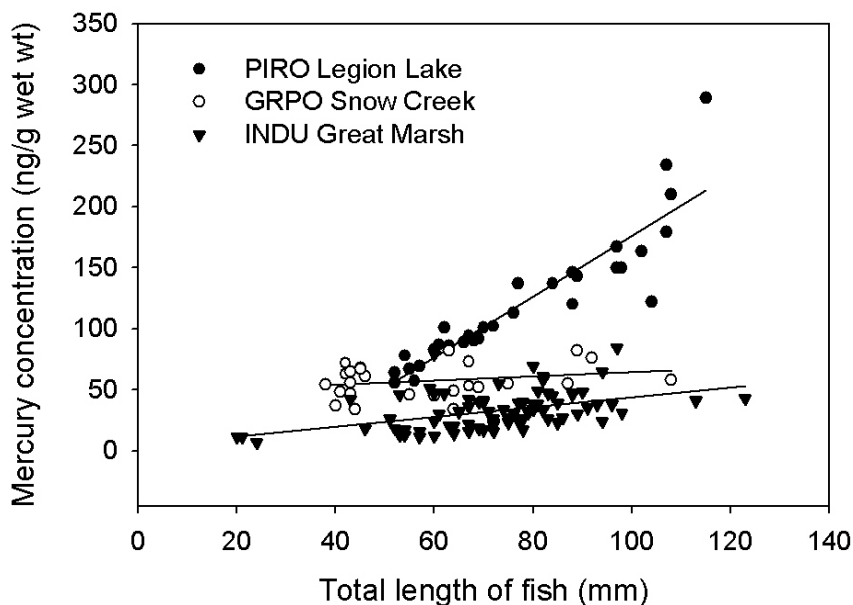


Figure 3. Concentrations of mercury as a function of total length in whole central mudminnows from water bodies at three national park units in the western Great Lakes region.

The northern Great Lakes region also contains many oligotrophic surface waters with low primary productivity. Concentrations of methylmercury at the base of the aquatic food web are higher in oligotrophic waters than in more productive waters because there is less biodilution of methylmercury by algal biomass in waters with low primary productivity (Pickhardt et al. 2002). The higher concentrations of methylmercury at the base of the food web in oligotrophic waters lead to higher concentrations in zooplankton, fish, and other biota of higher trophic levels (Chen and Folt 2005, Chen et al. 2012).

The warm water in small lakes during ice-free periods also contributes to the high concentrations of mercury in fish in small inland lakes, because the microbial production of methylmercury and its concentration in fish are strongly correlated with epilimnetic water temperature (Ramlal et al. 1993, Bodaly et al. 1993). In remote lakes in northwestern Ontario, for example, mean concentrations of mercury in axial muscle of adult piscivorous fish (walleye and northern pike) and in small prey fish (yearling yellow perch) were much higher in small lakes (89-706 ha) than in nearby larger, colder lakes (2,219-34,690 ha) (Bodaly et al. 1993).

Whole larval dragonflies appear to be useful biosentinels of methylmercury in aquatic food webs in the western Great Lakes region. Larvae of the family Gomphidae, for example, were obtained from 15 lakes and four park units in the present study. Most of the mercury in larval gomphids was methylmercury (Figure 4), which averaged 78% of total mercury in gomphids across the 15

lakes. Concentrations of methylmercury were greatest in gomphid larvae from Voyageurs National Park.

In marked contrast to the situation for mercury, the concentrations of legacy contaminants (DDT and metabolites, PCBs, total lead) and emerging contaminants (PBDEs and PFCs) in the axial muscle of fish from five park units were low and below analytical limits of detection in most samples. Concentrations of DDT, DDE, and DDD were below the limit of detection (10 ng/g for total DDT) in all 60 samples, which included 41 composite samples and 19 samples of individual fish. Concentrations of PCBs, detected in 5 of 60 samples, were also low. Concentrations of total lead were low in the axial muscle tissue of fish from the five park units, ranging from 2 to 31 ng/g wet weight in the 60 samples. PBDEs were below the limits of detection in 56 of the 60 samples, and the maximum concentration of total PBDE in the 4 samples with detectable levels was 3.1 ng/g.

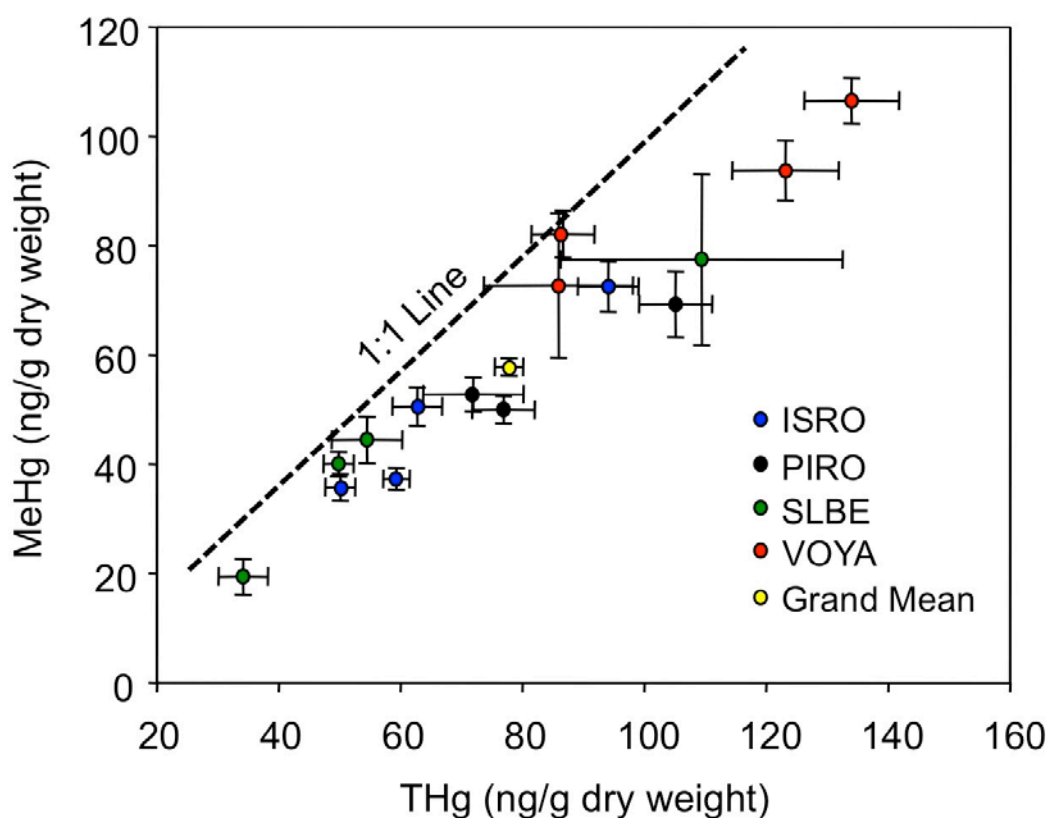


Figure 4. Mean concentrations ($\pm$ SE) of methylmercury (MeHg) vs. total mercury (THg) in larval gomphid dragonflies from 15 lakes in four park units in the Great Lakes Network. Means for each lake are for combined data for all gomphid species. The dashed 1:1 line indicates methylmercury as 100% of total mercury.

Concentrations of the legacy and emerging organic contaminants in fillets of fish sampled from five park units in 2008 and 2009 were well below levels considered harmful to the health of fish-eating humans. The Minnesota Department of Health, for example, does not recommend

restricting consumption (meal frequency) of fish with total PCBs less than 50 ng/g wet weight, whereas consumption of fish with PCBs in the range of 51-220 ng/g should be limited to 1 meal per week (<http://www.health.state.mn.us/divs/eh/fish/eating/mealadvicetables.pdf>). In the present study, the maximum concentration of total PCBs, estimated as the sum of detectable congeners, in the 5 fish samples with detectable levels was 9.3 ng/g, well below Minnesota's recommended consumption guideline of 51 ng/g for total PCBs. For PFOS, a perfluorochemical, the Minnesota Department of Health does not recommend restricted consumption of fish with concentrations less than 40 ng/g wet weight, whereas it advises that consumption of fish with PFOS in the range of 41-200 ng/g be limited to 1 meal per week. In the present study, PFCs were detected in 39 of 60 fish samples, and the maximum concentration of PFOS was 2.1 ng/g wet weight, well below Minnesota's recommended consumption guideline of 40 ng/g.

Annual sampling and monitoring of mercury in predatory fish, prey fish, and larval dragonflies—along with other components of the lower food web—has continued in these six park units during 2010-2012. The additional information from the analyses of samples obtained during 2010-2012 will strengthen the evaluation of spatiotemporal patterns in bioaccumulation and ecological risk, and should support the identification of factors influencing concentrations of methylmercury in aquatic organisms. Determinations of bioaccumulative organic contaminants and total lead during 2010-2012 will focus on whole predatory fish, supporting a more comprehensive evaluation of potential risks posed by legacy and emerging contaminants in the six park units.

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Appendix A: Inventory of fish samples from five park units in the western Great Lakes region that were analyzed (axial muscle) for total lead and bioaccumulative organic contaminants.

Park unit	Water body	Species	Description of fish in sample ¹			Sample identification code ²	Axial muscle sample mass (g, wet wt.)
			<i>n</i>	<i>Total length (mm)</i>	<i>Wet weight (g)</i>		
GRPO	Grand Portage Creek	rainbow trout	4	116-157	16.7-45.6	2009-GRPO-GRAN-RT-Comp1	5.759
		rainbow trout	4	97-105	10.9-12.9	2009-GRPO-GRAN-RT-Comp2	5.234
GRPO	Hollow Rock Creek	rainbow trout	6	113-129	16.2-23.3	2009-GRPO-HOLL-RT-Comp1	11.129
		rainbow trout	6	100-112	11.8-14.2	2009-GRPO-HOLL-RT-Comp2	12.298
GRPO	Poplar Creek	creek chub	4	128-168	22.4-48.5	2009-GRPO-POPL-CC-Comp1	10.472
		creek chub	4	93-122	8.3-19.2	2009-GRPO-POPL-CC-Comp2	9.301
GRPO	Reservation River	rainbow trout	6	118-148	19.2-34.0	2009-GRPO-RESE-RT-Comp1 (R1)	10.935
		rainbow trout	6	118-148	19.2-34.0	2009-GRPO-RESE-RT-Comp3 (R2)	9.157
		rainbow trout	7	94-111	8.9-14.7	2009-GRPO-RESE-RT-Comp2	12.653
ISRO	Angleworm Lake	northern pike	4	505-561	790-1170	2009-ISRO-ANGL-NP-Comp1	12.312
		northern pike	4	578-611	1240-1460	2009-ISRO-ANGL-NP-Comp2	12.28
		northern pike	4	613-684	1410-1930	2009-ISRO-ANGL-NP-Comp3	12.116
ISRO	Lake Harvey	yellow perch	3	285-292	177-270	2009-ISRO-HARV-YP-Comp1	11.961
		yellow perch	4	301-321	296-385	2009-ISRO-HARV-YP-Comp2	12.099
ISRO	Lake Richie	northern pike	4	444-497	470-770	2009-ISRO-RICH-NP-Comp1	12.134
		northern pike	4	529-546	800-970	2009-ISRO-RICH-NP-Comp2	12.304
		northern pike	4	547-575	830-1310	2009-ISRO-RICH-NP-Comp3	12.441
ISRO	Sargent Lake	northern pike	4	583-608	1200-1510	2009-ISRO-SARG-NP-Comp1	11.891
		northern pike	4	624-718	1430-3030	2009-ISRO-SARG-NP-Comp2	12.04
PIRO	Beaver Lake	northern pike	1	751	2240	2008-PIRO-BEAV-NP-Ind1 (R1)	11.793
		northern pike	1	751	2240	2008-PIRO-BEAV-NP-Ind12 (R2)	11.95
PIRO	Beaver Lake	northern pike	1	345	233	2008-PIRO-BEAV-NP-Ind2	11.586
		walleye	1	557	1500	2008-PIRO-BEAV-WE-Ind1	13.313
PIRO	Grand Sable Lake	northern pike	3	605-643	1460-1600	2008-PIRO-GRSA-NP-Comp1	13.503
		smallmouth bass	1	398	1050	2008-PIRO-GRSA-SB-Ind1	13.333

Appendix A (continued): Inventory of fish samples from five park units in the western Great Lakes region that were analyzed (axial muscle) for total lead and bioaccumulative organic contaminants.

Park unit	Water body	Species	Description of fish in sample ¹			Sample identification code ²	Axial muscle sample mass (g, wet wt.)
			<i>n</i>	<i>Total length (mm)</i>	<i>Wet weight (g)</i>		
PIRO	Grand Sable Lake (continued)	northern pike	1	401	450	2008-PIRO-GRSA-NP-Ind6	13.089
		northern pike	1	700	2340	2008-PIRO-GRSA-NP-Ind2	13.136
		northern pike	1	784	2930	2008-PIRO-GRSA-NP-Ind1 (R1)	12.08
		northern pike	1	784	2930	2008-PIRO-GRSA-NP-Ind12 (R2)	12.953
PIRO	Miners Lake	northern pike	2	392-394	385-390	2008-PIRO-MINE-NP-Comp1	13.064
		northern pike	2	547-592	1250-1425	2008-PIRO-MINE-NP-Comp2	12.695
		northern pike	1	805	3570	2008-PIRO-MINE-NP-Ind1	12.325
		northern pike	1	651	1800	2008-PIRO-MINE-NP-Ind4	13.01
		northern pike	1	463	590	2008-PIRO-MINE-NP-Ind7	11.929
SLBE	Bass Lake (Benzie)	largemouth bass	1	383	760	2008-SLBE-BABE-LB-Ind1	11.137
		northern pike	1	453	550	2008-SLBE-BABE-NP-Ind1 (R1)	10.077
		northern pike	1	453	550	2008-SLBE-BABE-NP-Ind12 (R2)	10.988
		northern pike	1	431	425	2008-SLBE-BABE-NP-Ind2	12.192
SLBE	Bass Lake (Leelanau)	largemouth bass	2	408-445	960-1340	2008-SLBE-BALE-LB-Comp1	13.207
		northern pike	3	557-586	1150-1290	2008-SLBE-BALE-NP-Comp1	13.37
SLBE	Lake Manitou	smallmouth bass	3	367-374	770-860	2008-SLBE-MANI-SB-Comp1	12.273
		smallmouth bass	3	377-389	710-840	2008-SLBE-MANI-SB-Comp2	12.536
		smallmouth bass	3	390-393	850-930	2008-SLBE-MANI-SB-Comp3	12.533
		smallmouth bass	1	338	690	2008-SLBE-MANI-SB-Ind9 (R1)	13.418
		smallmouth bass	1	338	690	2008-SLBE-MANI-SB-Ind92 (R2)	12.403
		smallmouth bass	1	440	1200	2008-SLBE-MANI-SB-Ind1	12.459
SLBE	Round Lake	largemouth bass	3	228-259	140-205	2008-SLBE-ROUN-LB-Comp1	11.945
		largemouth bass	3	302-307	315-370	2008-SLBE-ROUN-LB-Comp2	12.167
		largemouth bass	3	308-312	380-380	2008-SLBE-ROUN-LB-Comp3	12.462
		largemouth bass	2	328-346	470-490	2008-SLBE-ROUN-LB-Comp4	12.339
VOYA	Brown Lake	northern pike	5	437-469	470-610	2009-VOYA-BROW-NP-Comp1	13.784
		northern pike	5	512-571	600-940	2009-VOYA-BROW-NP-Comp2	13.414

Appendix A (continued): Inventory of fish samples from five park units in the western Great Lakes region that were analyzed (axial muscle) for total lead and bioaccumulative organic contaminants.

Park unit	Water body	Species	Description of fish in sample ¹			Sample identification code ²	Axial muscle sample mass (g, wet wt.)
			<i>n</i>	<i>Total length (mm)</i>	<i>Wet weight (g)</i>		
VOYA	Peary Lake	northern pike	4	497-511	710-790	2009-VOYA-PEAR-NP-Comp1	10.734
		northern pike	5	530-553	830-970	2009-VOYA-PEAR-NP-Comp2	13.144
		northern pike	5	564-634	1020-1490	2009-VOYA-PEAR-NP-Comp3	13.51
VOYA	Ryan Lake	northern pike	5	487-523	550-770	2009-VOYA-RYAN-NP-Comp1	13.326
		northern pike	5	556-589	790-990	2009-VOYA-RYAN-NP-Comp2	13.594
VOYA	Sand Lake	northern pike	4	493-517	650-730	2009-VOYA-SAND-NP-Comp1	11.134
		northern pike	4	529-538	740-930	2009-VOYA-SAND-NP-Comp2	10.881
		northern pike	4	549-613	850-1370	2009-VOYA-SAND-NP-Comp3	11.115

¹ For composite samples containing multiple fish, the minimum and maximum total length and wet weight of fish in the sample are provided.

² (R1) and (R2) in adjacent rows indicate replicate samples from the same individual fish or the same composite sample.

Appendix B: Common and scientific names of fishes analyzed in this study, following standardized nomenclature by the American Fisheries Society (Nelson et al. 2004).

Family	Species common name	Species scientific name
Esocidae	northern pike	<i>Esox lucius</i>
	grass pickerel	<i>Esox americanus</i>
Salmonidae	rainbow trout	<i>Oncorhynchus mykiss</i>
Cyprinidae	creek chub	<i>Semotilus atromaculatus</i>
	blacknose dace	<i>Rhinichthys atratulus</i>
	longnose dace	<i>Rhinichthys cataractae</i>
Umbridae	central mudminnow	<i>Umbra limi</i>
Centrarchidae	green sunfish	<i>Lepomis cyanellus</i>
	bluegill	<i>Lepomis macrochirus</i>
	smallmouth bass	<i>Micropterus dolomieu</i>
	largemouth bass	<i>Micropterus salmoides</i>
Percidae	Iowa darter	<i>Etheostoma exile</i>
	johnny darter	<i>Etheostoma nigrum</i>
	yellow perch	<i>Perca flavescens</i>
	walleye	<i>Sander vitreus</i>
Cottidae	mottled sculpin	<i>Cottus bairdii</i>
	slimy sculpin	<i>Cottus cognatus</i>

Appendix C: Summary statistics for total length (TL), wet weight, mercury concentration (Hg conc), and mercury burden in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008-2009 (n = number of fish, std dev = standard deviation, min = minimum value, max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Min	Max	Kurtosis	Skewness
GRPO	Grand Portage Creek	longnose dace	30	TL (mm)	77.6	8.8	1.6	56	105	3.12	0.79
				Weight (g)	4.3	2.1	0.4	1.3	13.2	10.11	2.76
				Hg conc (ng/g)	57.5	31.2	5.7	29.3	174.6	6.62	2.38
				Hg burden (ng)	247.1	188.5	34.4	70.4	831.4	4.31	2.14
		slimy sculpin	23	TL (mm)	57.7	10.3	2.1	43	83	-0.14	0.49
				Weight (g)	2.2	1.1	0.2	0.8	5.3	0.7	0.92
				Hg conc (ng/g)	28.1	10.7	2.2	10.3	48.1	-0.8	0.16
				Hg burden (ng)	65.8	49.6	10.3	8.6	201.5	1.32	1.29
GRPO	Poplar Creek	blacknose dace	15	TL (mm)	73	12.1	3.1	54	89	-1.36	-0.17
				Weight (g)	4.9	2.5	0.6	1.5	8.5	-1.44	0.13
				Hg conc (ng/g)	87.3	26.4	6.8	50.5	142.7	-0.02	0.66
				Hg burden (ng)	464.4	321.7	83.1	77	1091.8	-0.67	0.64
		longnose dace	7	TL (mm)	75.1	12.2	4.6	65	97	0.28	1.22
				Weight (g)	4.2	2.2	0.8	2.3	8.2	1.16	1.27
				Hg conc (ng/g)	75.1	20.7	7.8	50.1	100.1	-1.95	0.16
				Hg burden (ng)	338.8	233.6	88.3	121.5	706.3	-1.46	0.64
GRPO	Snow Creek	central mudminnow	26	TL (mm)	58.4	19.1	3.8	38	108	0.33	1.04
				Weight (g)	2.7	2.5	0.5	0.6	7.9	0.68	1.38
				Hg conc (ng/g)	57.5	13.3	2.6	33.8	81.8	-0.48	0.08
				Hg burden (ng)	163	174.7	34.3	30.5	648.5	2.2	1.75
INDU	Great Marsh 1	central mudminnow	21	TL (mm)	69	16.1	3.5	24	98	1.84	-0.84
				Weight (g)	4.7	2.5	0.6	0.1	9.3	-0.88	0.24
				Hg (ng/g)	33.8	19.3	4.2	6.9	79.4	0.19	0.92
				Hg burden (ng)	160.9	116.8	25.5	1	464	1.15	1.03
		green sunfish	2	TL (mm)	47	5.7	4	43	51	.	.
				Weight (g)	2.6	1.3	0.9	1.7	3.6	.	.
				Hg (ng/g)	33.7	11.5	8.1	25.6	41.9	.	.
				Hg burden (ng)	81	14.1	10	71	91	.	.
INDU	Great Marsh 2	central mudminnow	32	TL (mm)	78.2	18.1	3.2	20	123	3.16	-0.44
				Weight (g)	6.5	4.6	0.8	0.1	24.4	7.65	2.44

Appendix C (continued): Summary statistics for total length (TL), wet weight, mercury concentration (Hg conc), and mercury burden in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008-2009 (n = number of fish, std dev = standard deviation, min = minimum value, max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Min	Max	Kurtosis	Skewness
INDU	Great Marsh 2 (continued)	central mudminnow		Hg (ng/g)	38.6	13.6	2.4	10.9	83.7	3.12	0.97
				Hg burden (ng)	273.2	230.4	40.7	1	1056	3.63	1.84
INDU	Great Marsh 3	central mudminnow	24	TL (mm)	68.4	15.9	3.2	21	96	2.38	-0.96
				Weight (g)	4.9	2.8	0.6	0.1	12.3	1.42	0.91
				Hg (ng/g)	23.9	11.9	2.4	10.7	57.5	1.99	1.43
				Hg burden (ng)	135.5	122.3	25	1	462	1.26	1.36
INDU	Long Lake	green sunfish	31	TL (mm)	39.4	4.7	0.8	33	54	3.02	1.82
				Weight (g)	1.1	0.5	0.1	0.7	2.7	3.54	2.07
				Hg (ng/g)	26.1	7.8	1.4	13.3	43.5	-0.18	0.39
				Hg burden (ng)	29.1	14.1	2.5	12	72	2.26	1.52
ISRO	Lake Harvey	yellow perch	15	TL (mm)	127.3	42.7	11	79	213	-0.44	1.01
				Weight (g)	26.1	28.7	7.4	3.4	95.8	1.42	1.59
				Hg conc (ng/g)	179.8	89.6	23.1	83.5	432.3	3.69	1.79
				Hg burden (ng)	6906.6	11347	2930	474	41424	6.04	2.42
ISRO	Lake Richie	yellow perch	27	TL (mm)	97.3	20.3	3.9	68	155	1.2	0.64
				Weight (g)	11.8	9.3	1.8	2.7	49.4	10.19	2.73
				Hg conc (ng/g)	40.7	10.8	2.1	23.6	82	7.78	2.14
				Hg burden (ng)	477.3	447.3	86.1	123.2	2091.8	8.41	2.86
ISRO	Sargent Lake	yellow perch	30	TL (mm)	69.5	8.7	1.6	58	85	-1.46	0.47
				Weight (g)	3.3	1.1	0.2	2	5.9	-0.34	0.87
				Hg conc (ng/g)	41.2	10.4	1.9	27.1	72.4	1.16	0.89
				Hg burden (ng)	138.7	69.9	12.8	59.2	282.9	-1.16	0.7
PIRO	Beaver Lake	iowa darter	23	TL (mm)	46.6	5.4	1.1	35	53	-0.42	-0.85
				Weight (g)	0.8	0.3	0.1	0.3	1.2	-1.12	-0.41
				Hg (ng/g)	66.5	24.1	5	24.9	110.6	-0.56	0.05
				Hg burden (ng)	54.3	30.1	6.3	13	118	-0.81	0.24
		johnny darter	16	TL (mm)	48.4	5.8	1.5	38	63	1.68	0.77
				Weight (g)	0.9	0.4	0.1	0.4	1.9	3.25	1.31
				Hg (ng/g)	24	9	2.3	11	45.4	0.62	0.88
				Hg burden (ng)	22	12	3	6	48	-0.08	0.81
		mottled sculpin	31	TL (mm)	50.7	4.3	0.8	43	60	0.24	0.21
				Weight (g)	1.5	0.4	0.1	0.8	2.5	0.42	0.59
				Hg (ng/g)	24.7	7.9	1.4	13.2	42.2	-0.12	0.6
				Hg burden (ng)	35.6	9.3	1.7	22	62	0.85	0.67
PIRO	Beaver Lake	yellow perch	31	TL (mm)	53.9	3.3	0.6	49	63	2.43	1.59

Appendix C (continued): Summary statistics for total length (TL), wet weight, mercury concentration (Hg conc), and mercury burden in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008-2009 (n = number of fish, std dev = standard deviation, min = minimum value, max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake (continued)	yellow perch		Weight (g)	1.4	0.3	0	1	2.1	2.49	1.5
				Hg (ng/g)	29	4.7	0.8	19.7	37.6	-0.46	-0.01
				Hg burden (ng)	39.7	10.7	1.9	22	74	2.13	1.17
PIRO	Chapel Lake	Iowa darter	10	TL (mm)	50	11.4	3.6	31	62	-0.67	-0.92
				Weight (g)	1	0.6	0.2	0.2	1.8	-1.14	-0.37
				Hg (ng/g)	80.8	39.4	12.5	39.7	156.9	0.01	1.02
				Hg burden (ng)	88.7	65.1	20.6	9	190	-1.4	0.2
		Johnny darter	4	TL (mm)	56.8	16.3	8.1	33	70	3.08	-1.66
				Weight (g)	1.6	1	0.5	0.2	2.4	2.17	-1.52
				Hg (ng/g)	64.8	12.8	6.4	51.5	77	-5.2	-0.08
				Hg burden (ng)	102	64.2	32.1	17	170	1	-0.73
		yellow perch	23	TL (mm)	137.3	41.1	8.6	69	285	7.28	2.11
				Weight (g)	30.3	45.3	9.4	3	229.6	19.05	4.22
				Hg (ng/g)	174.8	100.4	20.9	61.8	508.1	4.3	1.67
				Hg burden (ng)	8265	23758	4954	186	116652	22.42	4.71
PIRO	Grand Sable Lake	Iowa darter	26	TL (mm)	46.7	5.1	1	39	55	-1.37	0.26
				Weight (g)	0.8	0.3	0.1	0.4	1.4	-0.1	0.85
				Hg (ng/g)	52	19	3.7	4	83.4	1.62	-1.06
				Hg burden (ng)	46.1	23.8	4.9	17	94	-0.83	0.76
		Johnny darter	34	TL (mm)	42.6	5.1	0.9	35	57	1.53	1.15
				Weight (g)	0.6	0.3	0.1	0.3	1.6	2.07	1.56
				Hg (ng/g)	43.6	13.6	2.3	6.6	72	0.88	-0.17
				Hg burden (ng)	27.2	18.5	3.2	4	88	3.79	1.96
		mottled sculpin	17	TL (mm)	51.2	5.3	1.3	45	64	0.42	0.96
				Weight (g)	1.8	0.7	0.2	1	3.5	-0.06	0.88
				Hg (ng/g)	20.8	9.2	2.2	12.2	49.4	5.33	2.18
				Hg burden (ng)	39.4	32.3	7.8	19	157	12.47	3.35
PIRO	Legion Lake	central mudminnow	31	TL (mm)	78.1	19.8	3.5	52	115	-1.29	0.35
				Weight (g)	5.7	4.1	0.7	1.4	14.2	-0.68	0.79
				Hg (ng/g)	121.8	53.9	9.7	55.9	289.3	2	1.32
				Hg burden (ng)	885.2	998.1	179.3	92	4011	2.75	1.73
PIRO	Miners Lake	mottled sculpin	6	TL (mm)	56.7	2.4	1	54	60	-1.79	0.46
				Weight (g)	2.5	0.3	0.1	2.2	2.8	-2.88	0.07

Appendix C (continued): Summary statistics for total length (TL), wet weight, mercury concentration (Hg conc), and mercury burden in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008-2009 (n = number of fish, std dev = standard deviation, min = minimum value, max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Min	Max	Kurtosis	Skewness
PIRO	Miners Lake (continued)	mottled sculpin		Hg (ng/g)	18.8	3.6	1.5	15	23.5	-1.76	0.37
				Hg burden (ng)	46.7	7.9	3.2	33	52	0.57	-1.37
SLBE	Bass Lake (Benzie)	bluegill	31	TL (mm)	36.5	6.1	1.1	29	54	2.13	1.56
				Weight (g)	0.7	0.4	0.1	0.3	2.1	5.38	2.37
				Hg (ng/g)	97.3	29	5.2	27.6	157.4	0.13	0.17
				Hg burden (ng)	63.7	41.7	7.5	11	203	3.32	1.81
		iowa darter	9	TL (mm)	43.6	5	1.7	35	50	-0.67	-0.32
				Weight (g)	0.6	0.2	0.1	0.3	0.9	-0.12	0.34
				Hg (ng/g)	111.7	66.6	22.2	60.8	283.7	7.49	2.64
				Hg burden (ng)	65.6	51.9	17.3	26	193	5.39	2.21
		johnny darter	2	TL (mm)	54.5	9.2	6.5	48	61	.	.
				Weight (g)	1.4	0.6	0.4	1	1.9	.	.
				Hg (ng/g)	29.8	12.7	9	20.8	38.8	.	.
				Hg burden (ng)	38.5	0.7	0.5	38	39	.	.
SLBE	Bass Lake (Leelanau)	yellow perch	31	TL (mm)	67.5	10.4	1.9	48	84	-1.42	0.04
				Weight (g)	3.3	1.5	0.3	1.1	5.8	-1.45	0.32
				Hg (ng/g)	21.9	5.6	1	15.5	34.6	-0.17	0.83
				Hg burden (ng)	76.6	48.9	8.8	25	196	-0.47	0.73
SLBE	Lake Manitou	iowa darter	26	TL (mm)	53	4.7	0.9	45	63	-0.43	0.39
				Weight (g)	1	0.3	0.1	0.6	1.8	0.79	0.95
				Hg (ng/g)	28.7	8.6	1.7	15.9	46.3	-0.71	0.48
				Hg burden (ng)	30	14.8	2.9	11	64	0.21	1.11
SLBE	Round Lake	bluegill	31	TL (mm)	35.9	8.4	1.5	27	62	4.28	2.07
				Weight (g)	0.7	0.7	0.1	0.2	3.5	8.84	2.98
				Hg (ng/g)	35.5	13.2	2.4	15.2	74.2	1.07	0.91
				Hg burden (ng)	20.6	15.6	2.8	7	78	10.22	3.21
		yellow perch	4	TL (mm)	78	3.7	1.8	74	82	-3.3	0
				Weight (g)	4.4	0.6	0.3	3.7	4.9	-3.27	-0.31
				Hg (ng/g)	17.3	7.3	3.6	10.1	27.3	1.32	1
				Hg burden (ng)	76.3	37.1	18.6	50	130	2.48	1.62
		yellow perch	26	TL (mm)	48	3.6	0.7	43	57	1.23	1.18
				Weight (g)	1	0.3	0.1	0.7	1.9	2.12	1.62
				Hg conc (ng/g)	93.4	17.3	3.4	58.5	115.7	-1.21	-0.26
				Hg burden (ng)	96	27	5.3	58.2	165	0.91	1.13

Appendix C (continued): Summary statistics for total length (TL), wet weight, mercury concentration (Hg conc), and mercury burden in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008-2009 (n = number of fish, std dev = standard deviation, min = minimum value, max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Min	Max	Kurtosis	Skewness
VOYA	Peary Lake	yellow perch	30	TL (mm)	42.3	3.3	0.6	37	50	-0.19	0.65
				Weight (g)	0.7	0.2	0	0.4	1.4	3.07	1.52
				Hg conc (ng/g)	29.9	4.4	0.8	22.4	40	-0.21	0.27
				Hg burden (ng)	21.4	6.7	1.2	14.3	41.6	2.64	1.69
VOYA	Ryan Lake	yellow perch	22	TL (mm)	75.3	20.4	4.4	45	104	-1.58	-0.43
				Weight (g)	5	3.2	0.7	0.8	11.9	-0.87	0.11
				Hg conc (ng/g)	113.4	33.9	7.2	67.5	198.4	0.35	0.87
				Hg burden (ng)	621.2	448.7	95.7	76	1339.3	-1.61	0.03
VOYA	Sand Point Lake	yellow perch	31	TL (mm)	56.3	4.4	0.8	47	68	0.89	0.57
				Weight (g)	1.8	0.4	0.1	1.1	2.9	1.13	0.95
				Hg conc (ng/g)	123.9	23.5	4.2	80.2	170	-0.44	0.3
				Hg burden (ng)	226.2	90.3	16.2	113	476.4	1.02	1.18

Appendix D: Summary statistics for total length (TL), wet weight, and mercury concentration (Hg) in axial muscle tissue (skinless fillets) of adult predatory fish sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (n = number of fish, std dev = standard deviation, min = minimum value, max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Min	Max	Kurtosis	Skewness
GRPO	Grand Portage Creek	rainbow trout	8	TL (mm)	116.4	19.5	6.9	97	157	2.18	1.47
				Weight (g)	19	11.4	4	10.9	45.6	5.42	2.25
				Hg (ng/g)	34.7	4.3	1.5	29.3	40.6	-1.63	0.12
GRPO	Hollow Rock Creek	rainbow trout	6	TL (mm)	121.8	6.5	2.7	113	129	-1.72	-0.54
				Weight (g)	20.5	3	1.2	16.2	23.3	-1.86	-0.41
				Hg (ng/g)	18.9	2.4	1	14.8	21.6	1.45	-0.94
GRPO	Poplar Creek	creek chub	4	TL (mm)	145.3	18.7	9.4	128	168	-2.88	0.49
				Weight (g)	33.2	12.3	6.2	22.4	48.5	-2.49	0.6
				Hg (ng/g)	110.4	54.2	27.1	60.2	167.6	-5.1	0.12
GRPO	Reservation River	rainbow trout	6	TL (mm)	136.2	10.1	4.1	118	148	2.32	-1.18
				Weight (g)	28.3	5.5	2.3	19.2	34	-0.02	-0.9
				Hg (ng/g)	41.5	16.1	6.6	27.9	72.5	3.76	1.85
INDU	Great Marsh	grass pickerel	1	TL (mm)	173	.	.	173	173	.	.
				Weight (g)	49	.	.	49	49	.	.
				Hg (ng/g)	192	.	.	192	192	.	.
ISRO	Angleworm Lake	northern pike	13	TL (mm)	575.7	83.3	23.1	359	684	3.17	-1.41
				Weight (g)	1261.5	428.5	118.8	300	1930	1.06	-0.65
				Hg (ng/g)	257.4	163.9	45.5	101	702	4.14	2.02
ISRO	Lake Harvey	yellow perch	9	TL (mm)	279.8	40.4	13.5	208	321	0.37	-1.33
				Weight (g)	243.1	98.5	32.8	96.6	384.8	-0.92	-0.39
				Hg (ng/g)	888.8	240.1	80	502	1261	-0.36	0.04
ISRO	Lake Richie	northern pike	15	TL (mm)	491.7	76.2	19.7	304	575	1	-1.13
				Weight (g)	799.3	249.3	64.4	450	1310	-0.32	0.26
				Hg (ng/g)	222.4	123.3	31.8	103	602	6.39	2.27
ISRO	Sargent Lake	northern pike	10	TL (mm)	616.2	45.8	14.5	568	718	1.61	1.28
				Weight (g)	1546	546.2	172.7	1110	3030	7.71	2.64
				Hg (ng/g)	378	98.9	31.3	258	567	-0.32	0.78
PIRO	Beaver Lake	northern pike	2	TL (mm)	548	287.1	203	345	751	.	.

Appendix D (continued): Summary statistics for total length (TL), wet weight, and mercury concentration (Hg) in axial muscle tissue (skinless fillets) of adult predatory fish sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (n = number of fish, std dev = standard deviation, min = minimum value, max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake (continued)	northern pike		Weight (g)	1236.5	1419.2	1003.5	233	2240	.	.
				Hg (ng/g)	293.5	195.9	138.5	155	432	.	.
PIRO	Beaver Lake	walleye	1	TL (mm)	557	.	.	557	557	.	.
				Weight (g)	1500	.	.	1500	1500	.	.
				Hg (ng/g)	631	.	.	631	631	.	.
PIRO	Chapel Lake	yellow perch	10	TL (mm)	167.9	43.9	13.9	132	285	6.82	2.5
				Weight (g)	52.3	63.4	20.1	17.6	229.6	9.06	2.97
				Hg (ng/g)	332.2	174.6	55.2	178	690	0.26	1.1
PIRO	Grand Sable Lake	northern pike	6	TL (mm)	625.8	127.9	52.2	401	784	2.15	-1
				Weight (g)	1725	844.5	344.8	450	2930	0.49	-0.06
				Hg (ng/g)	820.8	303.1	123.8	379	1212	-0.76	-0.23
PIRO	Grand Sable Lake	smallmouth bass	1	TL (mm)	398	.	.	398	398	.	.
				Weight (g)	1050	.	.	1050	1050	.	.
				Hg (ng/g)	615	.	.	615	615	.	.
PIRO	Miners Lake	northern pike	7	TL (mm)	549.1	149.4	56.5	392	805	-0.11	0.67
				Weight (g)	1344.3	1123.7	424.7	385	3570	2.38	1.47
				Hg (ng/g)	274.1	210.3	79.5	126	737	5.76	2.32
SLBE	Bass Lake (Benzie)	largemouth bass	1	TL (mm)	383	.	.	383	383	.	.
				Weight (g)	760	.	.	760	760	.	.
				Hg (ng/g)	659	.	.	659	659	.	.
SLBE	Bass Lake (Benzie)	northern pike	2	TL (mm)	442	15.6	11	431	453	.	.
				Weight (g)	487.5	88.4	62.5	425	550	.	.
				Hg (ng/g)	404	66.5	47	357	451	.	.
SLBE	Bass Lake (Leelanau)	largemouth bass	2	TL (mm)	426.5	26.2	18.5	408	445	.	.
				Weight (g)	1150	268.7	190	960	1340	.	.
				Hg (ng/g)	456	4.2	3	453	459	.	.
SLBE	Bass Lake (Leelanau)	northern pike	3	TL (mm)	571	14.5	8.4	557	586	.	0.31
				Weight (g)	1213.3	70.9	41	1150	1290	.	0.82
				Hg (ng/g)	248.7	43.1	24.9	202	287	.	-0.84
SLBE	Lake Manitou	smallmouth bass	11	TL (mm)	382.9	24.7	7.5	338	440	3.11	0.73
				Weight (g)	858.2	136.1	41.1	690	1200	3.86	1.54
				Hg (ng/g)	325.8	143.2	43.2	221	713	5.88	2.39
SLBE	Round Lake	largemouth bass	11	TL (mm)	294.8	37.6	11.3	228	346	-0.25	-0.85
				Weight (g)	332.3	116.8	35.2	140	490	-0.71	-0.56
				Hg (ng/g)	193.6	55.6	16.7	117	268	-1.54	-0.31

Appendix D (continued): Summary statistics for total length (TL), wet weight, and mercury concentration (Hg) in axial muscle tissue (skinless fillets) of adult predatory fish sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (n = number of fish, std dev = standard deviation, min = minimum value, max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Min	Max	Kurtosis	Skewness
VOYA	Brown Lake	northern pike	13	TL (mm)	477.2	56.7	15.7	355	571	0.45	-0.44
				Weight (g)	622.3	194.3	53.9	250	940	-0.08	0.02
				Hg (ng/g)	686.3	221.9	61.6	430	1149	0.62	1.1
VOYA	Peary Lake	northern pike	16	TL (mm)	531.3	63.6	15.9	398	634	0.57	-0.69
				Weight (g)	904.4	286.8	71.7	430	1490	0.25	0.43
				Hg (ng/g)	378.6	108.4	27.1	180	564	-0.76	0.09
VOYA	Ryan Lake	northern pike	15	TL (mm)	501.7	70.1	18.1	358	589	-0.02	-0.83
				Weight (g)	663.3	223.8	57.8	280	990	-0.65	-0.4
				Hg (ng/g)	1054.7	590.3	152.4	354	2192	-0.81	0.55
VOYA	Sand Point Lake	northern pike	12	TL (mm)	540.8	35.7	10.3	493	613	0.31	0.95
				Weight (g)	861.7	217.8	62.9	650	1370	1.6	1.45
				Hg (ng/g)	929.7	278.5	80.4	483	1472	-0.14	0.29

Appendix E: Summary statistics for total body length, dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated from combined data for all species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
GRPO	Grand Portage Creek	3	Length (mm)	22.6	7.7	4.5	18.6	17.6	31.5	.	1.7
			Dry weight (g)	0.1	0.1	0	0.1	0.1	0.2	.	1.69
			MeHg (ng/g)	158.3	68.2	39.4	158.4	90.1	226.5	.	0
			THg (ng/g)	165.3	61.1	35.3	163.5	105.2	227.3	.	0.14
			%MeHg	94.1	7.4	4.3	96.9	85.6	99.6	.	-1.46
GRPO	Poplar Creek	13	Length (mm)	22.1	6.6	1.8	19.8	17.6	37	2.96	2.08
			Dry weight (g)	0.1	0	0	0.1	0.1	0.2	4.15	2.1
			MeHg (ng/g)	160.1	58.7	16.3	140.8	89.2	311	2.82	1.5
			THg (ng/g)	166.3	51.5	14.3	148.3	105.7	284.5	0.94	1.12
			%MeHg	95.2	7.2	2	93.9	84.3	109.3	0.06	0.61
GRPO	Snow Creek (lower reach)	17	Length (mm)	22.2	2.2	0.5	22.1	19.8	29.4	8.11	2.43
			Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-0.48	0.74
			MeHg (ng/g)	162.4	22.5	5.5	157.3	116.6	211.1	0.91	0.32
			THg (ng/g)	169.5	17.9	4.3	169	130.6	201	0.14	-0.14
			%MeHg	95.7	6.9	1.7	96.2	78.1	105	1.88	-1.18
GRPO	Snow Creek (upper reach)	26	Length (mm)	17.5	2	0.4	16.8	14.6	22.1	0.16	1.09
			Dry weight (g)	0	0	0	0	0	0.1	0.13	1.29
			MeHg (ng/g)	125.3	53.3	10.4	117.7	53.1	237.9	0	0.75
			THg (ng/g)	129.8	48.6	9.5	123.1	61.9	229.7	-0.57	0.45
			%MeHg	95.3	9.2	1.8	98.4	78.1	115.5	-0.59	0.03

Appendix E (continued): Summary statistics for total body length, dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated from combined data for all species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
INDU	Great Marsh	8	Length (mm)	17.2	1.2	0.4	17.3	16	19.5	0.5	0.83
			Dry weight (g)	0	0	0	0	0	0	-0.67	0.62
			MeHg (ng/g)	65.1	25.2	8.9	65.4	13.7	98.2	2.28	-1.05
			THg (ng/g)	86.4	34.4	12.2	77.5	49.9	155.7	1.56	1.34
			%MeHg	81.6	34.1	12.1	87.3	15.7	128.1	1.3	-0.85
INDU	Long Lake	4	Length (mm)	12.5	0.7	0.4	12.2	12	13.5	3.63	1.89
			Dry weight (g)	0	0	0	0	0	0	-0.29	0.86
			MeHg (ng/g)	24.7	4.4	2.2	26	18.3	28.3	2.71	-1.56
			THg (ng/g)	50.6	14.8	7.4	45.6	39.7	71.6	1.64	1.44
			%MeHg	50.3	10.9	5.4	48.2	39.5	65.2	1.44	1.03
ISRO	Angleworm Lake	37	Length (mm)	27	3.1	0.5	26	22.3	33.6	-0.86	0.56
			Dry weight (g)	0.1	0	0	0.1	0.1	0.3	9.75	2.79
			MeHg (ng/g)	37.6	13.5	2.2	34.6	20.7	81.5	2.32	1.39
			THg (ng/g)	51	13	2.1	47.9	33.6	101.8	5.4	1.82
			%MeHg	73.1	14.4	2.4	69.3	51.2	107.7	-0.85	0.36
ISRO	Lake Harvey	29	Length (mm)	26.8	4.5	0.8	26.2	19.3	34.5	-0.97	-0.12
			Dry weight (g)	0.1	0.1	0	0.1	0	0.3	-1.01	0.34
			MeHg (ng/g)	119.8	48.3	9	129.1	40.1	204.8	-1.38	-0.07
			THg (ng/g)	130.6	40.4	7.5	119.8	55.6	212	-0.54	0.12
			%MeHg	89	14.3	2.7	89.9	56.8	110.5	-0.66	-0.26
ISRO	Lake Richie	15	Length (mm)	31	3	0.8	32	23.7	34.1	2.59	-1.78
			Dry weight (g)	0.1	0	0	0.1	0	0.1	3.02	-1.6
			MeHg (ng/g)	53.8	18.6	4.8	50.6	26.3	98.2	0.91	0.98
			THg (ng/g)	72.4	23.1	6	70.5	37.4	134	2.71	1.17
			%MeHg	76	19.1	4.9	76.4	45.9	121.4	1.23	0.43
ISRO	Sargent Lake	58	Length (mm)	28.5	1.9	0.3	28.7	24.5	32.6	-0.63	0.09
			Dry weight (g)	0.2	0.1	0	0.1	0.1	0.3	-1.37	0.55
			MeHg (ng/g)	37.9	11.4	1.5	35	19.2	77.4	2.86	1.52
			THg (ng/g)	58.9	14.5	1.9	55.5	41.2	117.4	4.06	1.77
			%MeHg	65.3	14.9	2	65	35.2	99.8	-0.08	0.04

Appendix E (continued): Summary statistics for total body length, dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated from combined data for all species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake	44	Length (mm)	29	4.1	0.6	27.1	24.1	37	-1.4	0.43
			Dry weight (g)	0.1	0.1	0	0.1	0.1	0.5	4.27	1.94
			MeHg (ng/g)	48.8	15.9	2.4	48.2	15.3	86.9	0.01	0.35
			THg (ng/g)	81.3	35	5.3	71.9	36.1	224.3	6.21	2.08
			%MeHg	65	20.9	3.1	69.4	17.1	102.9	-0.52	-0.41
PIRO	Chapel Lake	17	Length (mm)	26.7	4	1	25.5	15.2	32.3	3.32	-1.27
			Dry weight (g)	0.1	0	0	0.1	0	0.2	1.13	1.03
			MeHg (ng/g)	81	42.5	10.3	66.2	32.8	210.7	4.82	2.07
			THg (ng/g)	115.8	35.2	8.5	108.1	73.4	202.7	1.35	1.19
			%MeHg	69.3	22.2	5.4	71.2	32.9	125.3	1.7	0.83
PIRO	Grand Sable Lake	28	Length (mm)	27.2	3.2	0.6	25.9	22.3	34.1	-0.07	1.04
			Dry weight (g)	0.1	0	0	0.1	0.1	0.2	0.62	1.23
			MeHg (ng/g)	57	23.9	4.5	51	35.6	158.2	12.2	3.15
			THg (ng/g)	75.9	43.2	8.2	64.1	37.6	258.8	12.01	3.21
			%MeHg	80.6	19.8	3.7	80.7	36.6	118.8	0.08	-0.3
PIRO	Legion Lake	8	Length (mm)	33.8	7.2	2.6	36.3	25.4	40.7	-2.34	-0.31
			Dry weight (g)	0.1	0	0	0.1	0.1	0.2	7.28	2.66
			MeHg (ng/g)	121.3	90.1	31.8	105.4	27	221	-2.53	0.12
			THg (ng/g)	162	91.7	32.4	195.9	48.3	271.5	-2	-0.37
			%MeHg	74.7	28.9	10.2	82.2	15.6	105.5	1.82	-1.29
PIRO	Miners Lake	2	Length (mm)	30	2.2	1.5	30	28.5	31.6	.	.
			Dry weight (g)	0.1	0.1	0	0.1	0	0.1	.	.
			MeHg (ng/g)	94.5	6.1	4.3	94.5	90.2	98.8	.	.
			THg (ng/g)	121.7	0	0	121.7	121.6	121.7	.	.
			%MeHg	77.7	5	3.6	77.7	74.1	81.3	.	.

Appendix E (continued): Summary statistics for total body length, dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated from combined data for all species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Benzie)	8	Length (mm)	25.4	7.4	2.6	26.6	15.2	36.4	-1.13	0.04
			Dry weight (g)	0.1	0.1	0	0.1	0	0.4	2.14	1.59
			MeHg (ng/g)	98.2	50.9	18	92	21.3	175.1	-0.55	-0.05
			THg (ng/g)	128.6	60.7	21.5	153.9	36.3	207.9	-0.98	-0.58
			%MeHg	77.8	25.4	9	71.4	56.7	129.7	1.63	1.3
SLBE	Bass Lake (Leelanau)	47	Length (mm)	27.4	4.8	0.7	28	17	35.3	-0.78	-0.17
			Dry weight (g)	0.1	0.1	0	0.1	0	0.5	1	1.55
			MeHg (ng/g)	39	14.1	2.1	38.3	11.6	71	-0.54	0.16
			THg (ng/g)	49.9	15.8	2.3	49.2	21.7	90	-0.1	0.32
			%MeHg	78.1	16	2.3	77	51	127	1.72	0.97
SLBE	Lake Manitou	43	Length (mm)	30.9	1.8	0.3	30.8	24.2	35.1	3.79	-0.63
			Dry weight (g)	0.1	0	0	0.1	0	0.2	3.21	0.54
			MeHg (ng/g)	45.6	26.8	4.1	44.8	8.6	161.4	7.14	1.87
			THg (ng/g)	56	35.8	5.5	52.3	16.9	228.8	12.99	3.05
			%MeHg	82.1	18.4	2.8	83.2	22.1	128.5	2.14	-0.51
SLBE	Round Lake	21	Length (mm)	25.8	3.2	0.7	25	20.1	31.7	-0.67	0.25
			Dry weight (g)	0.1	0	0	0.1	0	0.3	8.9	2.6
			MeHg (ng/g)	68.1	149.3	32.6	19	0	607.4	9.55	3.14
			THg (ng/g)	85.4	159.2	34.7	37.4	11.1	667.2	9.86	3.16
			%MeHg	63.9	30.6	6.7	76.7	0	116.5	-0.39	-0.62
VOYA	Brown Lake	12	Length (mm)	27.3	5	1.4	26.2	21.7	36.4	-0.48	0.85
			Dry weight (g)	0.1	0.1	0	0.1	0.1	0.2	-1.98	0.42
			MeHg (ng/g)	87.3	45.2	13.1	79.3	22.1	159.7	-0.85	0.35
			THg (ng/g)	105.3	44.1	12.7	101.4	39.1	190.1	-0.09	0.31
			%MeHg	79.3	12.6	3.6	78.8	56.7	104.2	0.52	0.29
VOYA	Peary Lake	35	Length (mm)	28.5	3.6	0.6	27.3	20.8	33.8	-1.16	-0.13
			Dry weight (g)	0.1	0.1	0	0.1	0	0.3	1.91	1.51
			MeHg (ng/g)	74.8	19.5	3.3	75.9	26.6	130.2	2.36	0.63
			THg (ng/g)	83.1	18.7	3.2	82.4	53.5	131	0.37	0.69
			%MeHg	90.9	15.7	2.7	92	29.7	122.1	5.95	-1.49

Appendix E (continued): Summary statistics for total body length, dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated from combined data for all species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
VOYA	Ryan Lake	30	Length (mm)	25.6	4.8	0.9	25	15.1	36.4	0.54	0.56
			Dry weight (g)	0.1	0.1	0	0.1	0	0.2	-0.76	0.82
			MeHg (ng/g)	105.2	30.1	5.5	100	50.3	178.9	0.61	0.52
			THg (ng/g)	125.6	28.4	5.2	124.8	66	191.2	0.3	0
			%MeHg	83.8	13.7	2.5	83.6	51.3	104.3	-0.07	-0.46
VOYA	Sand Lake	39	Length (mm)	28.9	3	0.5	28.7	21.5	34.9	0.19	-0.17
			Dry weight (g)	0.1	0	0	0.1	0.1	0.2	0.98	0.93
			MeHg (ng/g)	114.9	43.7	7	110.2	62.1	254.5	2.95	1.69
			THg (ng/g)	150.5	60.9	9.8	141.7	79.5	436.6	12.56	3.01
			%MeHg	78.3	14.8	2.4	79.4	18	109	6.62	-1.59

Appendix F: Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
GRPO	Grand Portage Creek (lower reach)	<i>Boyeria vinosa</i>	1	Length (mm)	31.5	.	.	31.5	31.5	31.5	.	.
				WPI	4	.	.	4	4	4	.	.
				Dry weight (g)	0.2	.	.	0.2	0.2	0.2	.	.
				MeHg (ng/g)	158.4	.	.	158.4	158.4	158.4	.	.
				THg (ng/g)	163.5	.	.	163.5	163.5	163.5	.	.
				%MeHg	96.9	.	.	96.9	96.9	96.9	.	.
		<i>Somatochlora minor</i>	2	Length (mm)	18.1	0.7	0.5	18.1	17.6	18.6	.	.
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	.	.
				MeHg (ng/g)	158.3	96.4	68.2	158.3	90.1	226.5	.	.
				THg (ng/g)	166.3	86.3	61	166.3	105.2	227.3	.	.
GRPO	Poplar Creek (south branch)	<i>Aeshna umbrosa</i>	2	%MeHg	92.6	9.9	7	92.6	85.6	99.6	.	.
				Length (mm)	36.7	0.3	0.2	36.7	36.5	37	.	.
				WPI	4.5	0.7	0.5	4.5	4	5	.	.
				Dry weight (g)	0.2	0	0	0.2	0.2	0.2	.	.
				MeHg (ng/g)	143.2	7.1	5	143.2	138.2	148.2	.	.
		<i>Somatochlora minor</i>	11	THg (ng/g)	148.9	7.6	5.4	148.9	143.5	154.3	.	.
				%MeHg	96.2	0.1	0.1	96.2	96.1	96.3	.	.
				Length (mm)	19.5	1.1	0.3	19.4	17.6	21.3	-0.21	0.02
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-1.2	0.26
				MeHg (ng/g)	163.1	63.8	19.2	140.8	89.2	311	1.89	1.28
				THg (ng/g)	169.5	55.7	16.8	148.3	105.7	284.5	0.21	0.9
				%MeHg	95	7.8	2.4	93.8	84.3	109.3	-0.37	0.66
		<i>Aeshna umbrosa</i>	1	Length (mm)	29.4	.	.	29.4	29.4	29.4	.	.
				WPI	2	.	.	2	2	2	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	156.6	.	.	156.6	156.6	156.6	.	.
				THg (ng/g)	188.3	.	.	188.3	188.3	188.3	.	.
	Snow Creek (lower reach)	<i>Epitheca canis</i>	10	%MeHg	83.2	.	.	83.2	83.2	83.2	.	.
				Length (mm)	21.4	1.2	0.4	21.2	19.8	23.4	-0.76	0.55
				WPI	5.6	0.5	0.2	6	5	6	-2.28	-0.48
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-0.06	0.85

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
GRPO	Snow Creek (lower reach)	<i>Epitheca canis</i> (continued)		MeHg (ng/g)	156.7	20.2	6.4	159.8	116.6	187.2	0.73	-0.71
				THg (ng/g)	165.3	16.8	5.3	166.8	130.6	194.6	1.82	-0.54
				%MeHg	94.8	7	2.2	96	78.1	102.8	3.73	-1.55
		<i>Somatochlora williamsoni</i>	6	Length (mm)	22.4	0.5	0.2	22.5	21.5	23	-0.02	-0.83
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	0.69	1.14
				MeHg (ng/g)	172.8	26.2	10.7	163.8	146.5	211.1	-1.43	0.72
				THg (ng/g)	173.5	19.8	8.1	169	152.3	201	-1.88	0.41
				%MeHg	99.3	4.2	1.7	97.6	95.4	105	-1.8	0.73
GRPO	Snow Creek (upper reach)	<i>Leucorrhinia frigida</i>	10	Length (mm)	16	0.6	0.2	16.1	14.6	16.9	2.27	-1.04
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0	0	0	0	0	0	-1.19	0.63
				MeHg (ng/g)	117.7	45.7	14.4	118.3	57.6	193	-1.05	0.24
				THg (ng/g)	125.4	47.4	15	120.2	64.4	188	-1.57	0.07
				%MeHg	93.8	6	1.9	90.9	87.8	104	-1.33	0.64
		<i>Leucorrhinia intacta</i>	10	Length (mm)	17	0.6	0.2	17.2	15.9	17.6	-0.29	-0.87
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0	0	0	0	0	0	1.17	0.6
				MeHg (ng/g)	138.6	56.7	17.9	121.2	79	237.9	-0.05	1.06
				THg (ng/g)	135.8	45.1	14.3	121.5	83.1	218.7	-0.01	1.02
				%MeHg	100.3	10.6	3.3	102.7	78.1	115.5	1.52	-1.11
		<i>Libellula quadrimaculata</i>	5	Length (mm)	20.6	0.9	0.4	20.3	19.7	22.1	0.66	1.06
				WPI	5.8	0.4	0.2	6	5	6	5	-2.24
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	3.32	-1.56
				MeHg (ng/g)	115.1	71.2	31.8	116.6	53.1	227.2	1.08	1.08
				THg (ng/g)	128.8	70.3	31.4	133.3	61.9	229.7	-0.68	0.55
				%MeHg	87.5	7	3.1	86.5	80	98.9	2.5	1.27
		<i>Somatochlora tenebrosa</i>	1	Length (mm)	21.8	.	.	21.8	21.8	21.8	.	.
				WPI	6	.	.	6	6	6	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	118.8	.	.	118.8	118.8	118.8	.	.
				THg (ng/g)	119	.	.	119	119	119	.	.
				%MeHg	99.8	.	.	99.8	99.8	99.8	.	.
INDU	Great Marsh	<i>Pachydiplax longipennis</i>	8	Length (mm)	17.2	1.2	0.4	17.3	16	19.5	0.5	0.83
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0	0	0	0	0	0	-0.67	0.62
				MeHg (ng/g)	65.1	25.2	8.9	65.4	13.7	98.2	2.28	-1.05
				THg (ng/g)	86.4	34.4	12.2	77.5	49.9	155.7	1.56	1.34
				%MeHg	81.6	34.1	12.1	87.3	15.7	128.1	1.3	-0.85
INDU	Long Lake	<i>Pachydiplax longipennis</i>	4	Length (mm)	12.5	0.7	0.4	12.2	12	13.5	3.63	1.89
				WPI	3	0	0	3	3	3	.	.
				Dry weight (g)	0	0	0	0	0	0	-0.29	0.86
				MeHg (ng/g)	24.7	4.4	2.2	26	18.3	28.3	2.71	-1.56

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
INDU	Long Lake	<i>Pachydiplax longipennis</i> (continued)		THg (ng/g)	50.6	14.8	7.4	45.6	39.7	71.6	1.64	1.44
				%MeHg	50.3	10.9	5.4	48.2	39.5	65.2	1.44	1.03
ISRO	Angleworm Lake	<i>Didymops transversa</i>	2	Length (mm)	27	1	0.7	27	26.3	27.7	.	.
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.3	0.1	0	0.3	0.2	0.3	.	.
				MeHg (ng/g)	35.2	6.5	4.6	35.2	30.6	39.8	.	.
				THg (ng/g)	47.8	0.7	0.5	47.8	47.3	48.3	.	.
				%MeHg	73.5	12.5	8.8	73.5	64.7	82.3	.	.
		<i>Gomphus (Phanogomphus) lividus</i>	19	Length (mm)	25.4	1.7	0.4	25.4	22.7	31.4	8.06	2.23
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	1.32	-0.92
				MeHg (ng/g)	41.7	14.9	3.4	37.7	23.4	81.5	2.09	1.51
				THg (ng/g)	53	16	3.7	48.4	33.6	101.8	3.89	1.71
				%MeHg	78.6	13.7	3.1	80.9	55.1	107.7	-0.39	0.18
		<i>Gomphus (Phanogomphus) spicatus</i>	12	Length (mm)	30.6	1.6	0.5	30.5	28.4	33.6	-0.64	0.29
				WPI	4.1	0.3	0.1	4	4	5	12	3.46
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-1.36	-0.33
				MeHg (ng/g)	27.4	5.3	1.5	26.3	20.7	37.7	-0.4	0.7
				THg (ng/g)	45.5	7.4	2.1	42.9	35.2	58.9	-0.38	0.76
				%MeHg	60.5	8.6	2.5	59.5	51.2	84.9	6.72	2.29
		<i>Ladona julia</i>	4	Length (mm)	23.4	0.9	0.4	23.5	22.3	24.4	0.57	-0.5
				WPI	5.8	0.5	0.3	6	5	6	4	-2
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-3.22	0.41
				MeHg (ng/g)	50.5	2.2	1.1	50.5	47.8	53.2	0.58	-0.02
				THg (ng/g)	60	4.6	2.3	60.2	55.1	64.7	-4.47	-0.07
				%MeHg	84.5	7.8	3.9	85.8	73.9	92.5	1.22	-0.91
ISRO	Lake Harvey	<i>Aeshna umbrosa</i>	2	Length (mm)	28.4	5.1	3.6	28.4	24.8	32	.	.
				WPI	2.5	0.7	0.5	2.5	2	3	.	.
				Dry weight (g)	0	0	0	0	0	0	.	.
				MeHg (ng/g)	176.4	1.3	0.9	176.4	175.6	177.3	.	.
				THg (ng/g)	195.3	12.3	8.7	195.3	186.6	204	.	.
				%MeHg	90.5	5.1	3.6	90.5	86.9	94.1	.	.
		<i>Basiaeschna janata</i>	1	Length (mm)	34.5	.	.	34.5	34.5	34.5	.	.
				WPI	4	.	.	4	4	4	.	.
				Dry weight (g)	0.2	.	.	0.2	0.2	0.2	.	.
				MeHg (ng/g)	154	.	.	154	154	154	.	.
				THg (ng/g)	171.3	.	.	171.3	171.3	171.3	.	.
				%MeHg	89.9	.	.	89.9	89.9	89.9	.	.
		<i>Didymops transversa</i>	12	Length (mm)	24	3	0.9	25.3	19.3	27.4	-1.41	-0.72
				WPI	5.4	0.9	0.3	6	4	6	-0.91	-1.05
				Dry weight (g)	0.2	0.1	0	0.2	0.1	0.3	-1.22	-0.45

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
ISRO	Lake Harvey	<i>Didymops transversa</i> (continued)		MeHg (ng/g)	159.9	21.1	6.1	160.1	129.1	204.8	0.78	0.41
				THg (ng/g)	156.6	22.8	6.6	156	118.7	212	2.96	0.98
				%MeHg	102.5	6.5	1.9	101.2	90.7	110.5	-1.07	-0.21
		<i>Epitheca (Tetragoneuria)</i> <i>spinigera</i>	1	Length (mm)	23.7	.	.	23.7	23.7	23.7	.	.
				WPI	6	.	.	6	6	6	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	98.6	.	.	98.6	98.6	98.6	.	.
				THg (ng/g)	110.3	.	.	110.3	110.3	110.3	.	.
				%MeHg	89.4	.	.	89.4	89.4	89.4	.	.
		<i>Gomphus exilis</i>	1	Length (mm)	24.4	.	.	24.4	24.4	24.4	.	.
				WPI	4	.	.	4	4	4	.	.
				Dry weight (g)	0	.	.	0	0	0	.	.
				MeHg (ng/g)	102.5	.	.	102.5	102.5	102.5	.	.
				THg (ng/g)	119.8	.	.	119.8	119.8	119.8	.	.
				%MeHg	85.6	.	.	85.6	85.6	85.6	.	.
		<i>Gomphus (Phanogomphus)</i> <i>spicatus</i>	11	Length (mm)	29.1	4.3	1.3	30.7	19.6	32.8	1.17	-1.43
				WPI	3.5	0.9	0.3	4	2	4	-0.76	-1.19
				Dry weight (g)	0.1	0	0	0.1	0	0.1	-0.24	-0.9
				MeHg (ng/g)	68.9	18.3	5.5	68.2	40.1	92.1	-1.06	-0.17
				THg (ng/g)	92.7	20.5	6.2	99.1	55.6	115.6	0.17	-1.08
				%MeHg	74.1	8	2.4	72.6	56.8	87.5	1.58	-0.63
		<i>Hagenius brevistylus</i>	1	Length (mm)	30.2	.	.	30.2	30.2	30.2	.	.
				WPI	3	.	.	3	3	3	.	.
				Dry weight (g)	0.2	.	.	0.2	0.2	0.2	.	.
				MeHg (ng/g)	87.9	.	.	87.9	87.9	87.9	.	.
				THg (ng/g)	96.5	.	.	96.5	96.5	96.5	.	.
				%MeHg	91.1	.	.	91.1	91.1	91.1	.	.
ISRO	Lake Richie	<i>Aeshna umbrosa</i>	1	Length (mm)	30.4	.	.	30.4	30.4	30.4	.	.
				WPI	3	.	.	3	3	3	.	.
				Dry weight (g)	0	.	.	0	0	0	.	.
				MeHg (ng/g)	98.2	.	.	98.2	98.2	98.2	.	.
				THg (ng/g)	134	.	.	134	134	134	.	.
				%MeHg	73.2	.	.	73.2	73.2	73.2	.	.
		<i>Gomphus (Phanogomphus)</i> <i>spicatus</i>	12	Length (mm)	32.2	1.1	0.3	32.4	30.2	34.1	-0.48	-0.18
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	0.79	1.14
				MeHg (ng/g)	52	13.7	3.9	49.5	37.4	76.8	-0.54	0.91
				THg (ng/g)	70.3	14.7	4.2	71.9	50.6	91.4	-1.69	-0.05
				%MeHg	76.1	21.4	6.2	80.1	45.9	121.4	0.56	0.39

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
ISRO	Lake Richie (continued)	<i>Ladona julia</i>	2	Length (mm)	24.1	0.5	0.4	24.1	23.7	24.4	.	.
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	.	.
				MeHg (ng/g)	42.6	23.1	16.4	42.6	26.3	59	.	.
				THg (ng/g)	54	23.4	16.6	54	37.4	70.5	.	.
				%MeHg	77	9.4	6.7	77	70.3	83.6	.	.
ISRO	Sargent Lake	<i>Aeshna umbrosa</i>	1	Length (mm)	24.5	.	.	24.5	24.5	24.5	.	.
				WPI	1	.	.	1	1	1	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	54	.	.	54	54	54	.	.
				THg (ng/g)	75.2	.	.	75.2	75.2	75.2	.	.
				%MeHg	71.8	.	.	71.8	71.8	71.8	.	.
		<i>Didymops transversa</i>	20	Length (mm)	26.8	0.8	0.2	27	25.1	27.9	-0.88	-0.32
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.2	0	0	0.2	0.2	0.3	-0.72	-0.14
				MeHg (ng/g)	37.3	6.8	1.5	37.2	19.2	50.6	1.69	-0.56
				THg (ng/g)	56	15.8	3.5	53.4	41.2	117.4	13.08	3.32
				%MeHg	69	14.9	3.3	70.2	35.2	99.8	1.52	-0.63
		<i>Dromogomphus spinosus</i>	1	Length (mm)	32.6	.	.	32.6	32.6	32.6	.	.
				WPI	4	.	.	4	4	4	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	31.9	.	.	31.9	31.9	31.9	.	.
				THg (ng/g)	80.2	.	.	80.2	80.2	80.2	.	.
				%MeHg	39.8	.	.	39.8	39.8	39.8	.	.
		<i>Gomphus (Phanogomphus) lividus</i>	2	Length (mm)	26.8	0.8	0.5	26.8	26.2	27.3	.	.
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	.	.
				MeHg (ng/g)	29.3	6	4.3	29.3	25	33.6	.	.
				THg (ng/g)	47	0.5	0.4	47	46.7	47.4	.	.
				%MeHg	62.4	13.6	9.6	62.4	52.8	72	.	.
		<i>Gomphus (Phanogomphus) spicatus</i>	34	Length (mm)	29.6	1.3	0.2	29.6	25.8	32.6	1.5	-0.35
				WPI	4.1	0.2	0	4	4	5	14.24	3.93
				Dry weight (g)	0.1	0	0	0.1	0.1	0.2	-0.03	0.68
				MeHg (ng/g)	38.5	13.5	2.3	33.6	23.3	77.4	1.81	1.53
				THg (ng/g)	60.2	13.5	2.3	57.9	41.9	95.6	0.68	1.05
				%MeHg	63.8	14.8	2.5	64.2	36.4	96.5	-0.06	0.43
				Length (mm)	34.3	1.6	1.1	34.3	33.2	35.5	.	.
				WPI	4.5	0.7	0.5	4.5	4	5	.	.
PIRO	Beaver Lake	<i>Basiaeschna janata</i>	2	Dry weight (g)	0.2	0	0	0.2	0.1	0.2	.	.
				MeHg (ng/g)	69.4	24.8	17.5	69.4	51.9	86.9	.	.

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake	<i>Basiaeschna janata</i>		THg (ng/g)	93.6	28.3	20	93.6	73.6	113.6	.	.
		(continued)		%MeHg	73.6	4.2	3	73.6	70.6	76.6	.	.
		<i>Didymops transversa</i>	5	Length (mm)	24.9	0.8	0.4	24.6	24.1	26.2	-0.03	0.99
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.2	0	0	0.2	0.1	0.2	1.51	1.36
				MeHg (ng/g)	36.7	3.7	1.7	36.8	31.5	41.6	0.51	-0.19
				THg (ng/g)	115	65.1	29.1	92.2	63.3	224.3	2.64	1.63
				%MeHg	39.1	17.8	8	39.9	17.1	57.3	-2.39	-0.2
		<i>Dromogomphus spinosus</i>	14	Length (mm)	33	0.8	0.2	33	31.8	34.5	-0.34	0.42
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-0.05	0.32
				MeHg (ng/g)	44.6	10.9	2.9	45.8	27.1	62.2	-0.95	-0.17
				THg (ng/g)	75.2	21.9	5.8	70.9	44.1	126.4	1.89	1.31
				%MeHg	62.3	17.6	4.7	66.8	34.8	81.9	-1.26	-0.59
		<i>Gomphus adelphus</i>	1	Length (mm)	24.4	.	.	24.4	24.4	24.4	.	.
				WPI	4	.	.	4	4	4	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	37.8	.	.	37.8	37.8	37.8	.	.
				THg (ng/g)	36.8	.	.	36.8	36.8	36.8	.	.
				%MeHg	102.9	.	.	102.9	102.9	102.9	.	.
		<i>Gomphus exilis</i>	14	Length (mm)	25.6	0.6	0.2	25.7	24.5	26.4	-0.86	-0.65
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-1.27	0.18
				MeHg (ng/g)	54.1	14.2	3.8	53.3	35.8	80.5	-0.8	0.34
				THg (ng/g)	73.1	21.5	5.8	67.9	36.1	109.2	-0.86	0.19
				%MeHg	77.1	16.9	4.5	78.6	32.8	99.4	2.74	-1.23
		<i>Hagenius brevistylus</i>	2	Length (mm)	36.8	0.3	0.2	36.8	36.6	37	.	.
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.5	0	0	0.5	0.5	0.5	.	.
				MeHg (ng/g)	64	23.1	16.3	64	47.7	80.3	.	.
				THg (ng/g)	134.6	60.8	43	134.6	91.6	177.6	.	.
				%MeHg	48.7	4.9	3.4	48.7	45.2	52.1	.	.
		<i>Macromia illinoiensis</i>	6	Length (mm)	27.4	0.8	0.3	27.5	26.2	28.3	-0.72	-0.6
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.3	0	0	0.3	0.2	0.3	0.32	-0.14
				MeHg (ng/g)	46.3	22.9	9.4	55.5	15.3	71.1	-1.64	-0.69
				THg (ng/g)	72.4	26.3	10.7	67.9	46.1	112.1	-0.93	0.6
				%MeHg	61.3	19.7	8	63.8	33.2	83.2	-1.25	-0.41
PIRO	Chapel Lake	<i>Basiaeschna janata</i>	1	Length (mm)	15.2	.	.	15.2	15.2	15.2	.	.
				WPI	1	.	.	1	1	1	.	.
				Dry weight (g)	0	.	.	0	0	0	.	.
				MeHg (ng/g)	131.2	.	.	131.2	131.2	131.2	.	.

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
PIRO	Chapel Lake	<i>Basiaeschna janata</i> (continued)		THg (ng/g)	179.8	.	.	179.8	179.8	179.8	.	.
				%MeHg	73	.	.	73	73	73	.	.
		<i>Didymops transversa</i>	2	Length (mm)	24.9	0.1	0.1	24.9	24.8	24.9	.	.
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.2	0	0	0.2	0.1	0.2	.	.
				MeHg (ng/g)	149.9	86	60.8	149.9	89.1	210.7	.	.
				THg (ng/g)	158.5	62.5	44.2	158.5	114.3	202.7	.	.
				%MeHg	91	18.4	13	91	78	104	.	.
		<i>Gomphus (Phanogomphus) spicatus</i>	14	Length (mm)	27.8	2.8	0.7	27.5	24.4	32.3	-1.71	0.22
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0	0.1	-1.49	-0.04
				MeHg (ng/g)	67.6	23.2	6.2	64.9	32.8	133.4	4.99	1.84
				THg (ng/g)	105.1	22.4	6	103.3	73.4	150.1	-0.42	0.29
				%MeHg	65.9	22.2	5.9	63.7	32.9	125.3	3.37	1.24
	Grand Sable Lake	<i>Basiaeschna janata</i>	1	Length (mm)	32.4	.	.	32.4	32.4	32.4	.	.
				WPI	5	.	.	5	5	5	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	61.4	.	.	61.4	61.4	61.4	.	.
				THg (ng/g)	89.7	.	.	89.7	89.7	89.7	.	.
				%MeHg	68.5	.	.	68.5	68.5	68.5	.	.
		<i>Dromogomphus spinosus</i>	6	Length (mm)	31.1	3.6	1.5	32.4	24.4	34.1	2.22	-1.57
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.2	4.21	1.97
				MeHg (ng/g)	50.9	7.7	3.2	51.4	38.4	62.2	1.69	-0.32
				THg (ng/g)	62.2	9.9	4	63.4	47.9	77.5	1	0.11
				%MeHg	83.6	19	7.8	81.7	60.7	111	-1.19	0.33
		<i>Gomphus exilis</i>	12	Length (mm)	25.3	1.2	0.4	25.7	22.3	26.7	2.19	-1.51
				WPI	3.9	0.3	0.1	4	3	4	12	-3.46
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-0.41	0.19
				MeHg (ng/g)	50.9	11.5	3.3	48.1	35.6	70	-1.18	0.3
				THg (ng/g)	63.9	20.8	6	60.2	37.6	121.4	5.6	2.05
				%MeHg	83.9	21.2	6.1	85.9	39.2	118.8	0.66	-0.48
		<i>Gomphus (Hylogomphus) viridifrons</i>	8	Length (mm)	26	0.7	0.3	25.9	25	27.3	0.34	0.63
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-1.15	0.29
				MeHg (ng/g)	57.5	19.6	6.9	51.2	40	99.2	2.67	1.65
				THg (ng/g)	79.5	35	12.4	63.1	54.5	149.4	1.25	1.51
				%MeHg	77.4	20.7	7.3	81.3	36.6	104.2	1.49	-1.08
		<i>Gomphus (Phanogomphus) spicatus</i>	1	Length (mm)	31.4	.	.	31.4	31.4	31.4	.	.
				WPI	4	.	.	4	4	4	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
PIRO	Grand Sable Lake	<i>Gomphus (Phanogomphus) spicatus</i> (continued)		MeHg (ng/g)	158.2	.	.	158.2	158.2	158.2	.	.
				THg (ng/g)	258.8	.	.	258.8	258.8	258.8	.	.
				%MeHg	61.1	.	.	61.1	61.1	61.1	.	.
PIRO	Legion Lake	<i>Aeshna umbrosa</i>	4	Length (mm)	38.2	3.6	1.8	39.8	32.9	40.4	3.88	-1.96
				WPI	3.3	1	0.5	3.5	2	4	-1.29	-0.85
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-0.43	0.83
				MeHg (ng/g)	203.6	27.9	13.9	215.6	162.3	221	3.51	-1.87
				THg (ng/g)	214.5	23.8	11.9	211.1	191.3	244.7	-1.44	0.62
				%MeHg	94.9	9.4	4.7	94.7	84.8	105.5	-3.06	0.09
		<i>Arigomphus cornutus</i>	4	Length (mm)	29.4	7.5	3.8	25.7	25.4	40.7	3.98	1.99
				WPI	2.5	1	0.5	2	2	4	4	2
				Dry weight (g)	0.1	0.1	0	0.1	0.1	0.2	3.95	1.98
				MeHg (ng/g)	39	9.1	4.5	40.3	27	48.4	0.88	-0.77
				THg (ng/g)	109.5	108.1	54.1	59.1	48.3	271.5	3.95	1.99
				%MeHg	54.4	27.6	13.8	61.1	15.6	79.5	1.9	-1.28
		<i>Aeshna umbrosa</i>	2	Length (mm)	30	2.2	1.5	30	28.5	31.6	.	.
				WPI	2.5	0.7	0.5	2.5	2	3	.	.
				Dry weight (g)	0.1	0.1	0	0.1	0	0.1	.	.
				MeHg (ng/g)	94.5	6.1	4.3	94.5	90.2	98.8	.	.
				THg (ng/g)	121.7	0	0	121.7	121.6	121.7	.	.
				%MeHg	77.7	5	3.6	77.7	74.1	81.3	.	.
SLBE	Bass Lake (Benzie)	<i>Basiaeschna janata</i>	1	Length (mm)	28	.	.	28	28	28	.	.
				WPI	5	.	.	5	5	5	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	146.1	.	.	146.1	146.1	146.1	.	.
				THg (ng/g)	164.2	.	.	164.2	164.2	164.2	.	.
				%MeHg	88.9	.	.	88.9	88.9	88.9	.	.
		<i>Celithemis elisa</i>	1	Length (mm)	15.2	.	.	15.2	15.2	15.2	.	.
				WPI	6	.	.	6	6	6	.	.
				Dry weight (g)	0	.	.	0	0	0	.	.
				MeHg (ng/g)	175.1	.	.	175.1	175.1	175.1	.	.
				THg (ng/g)	207.9	.	.	207.9	207.9	207.9	.	.
				%MeHg	84.2	.	.	84.2	84.2	84.2	.	.
		<i>Dromogomphus spinosus</i>	1	Length (mm)	33	.	.	33	33	33	.	.
				WPI	4	.	.	4	4	4	.	.
				Dry weight (g)	0.2	.	.	0.2	0.2	0.2	.	.
				MeHg (ng/g)	21.3	.	.	21.3	21.3	21.3	.	.
				THg (ng/g)	36.3	.	.	36.3	36.3	36.3	.	.
				%MeHg	58.5	.	.	58.5	58.5	58.5	.	.
		<i>Gomphus graslinellus</i>	2	Length (mm)	22.6	3.8	2.7	22.6	19.9	25.3	.	.
				WPI	3	1.4	1	3	2	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0	0.1	.	.

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Benzie)	<i>Gomphus graslinellus</i> (continued)		MeHg (ng/g)	85.1	59.1	41.8	85.1	43.3	126.9	.	.
				THg (ng/g)	73.8	34	24	73.8	49.7	97.8	.	.
				%MeHg	108.4	30.1	21.3	108.4	87.1	129.7	.	.
		<i>Hagenius brevistylus</i>	3	Length (mm)	27.3	9.4	5.4	27.9	17.7	36.4	.	-0.27
				WPI	3	2	1.2	3	1	5	.	0
				Dry weight (g)	0.2	0.2	0.1	0.2	0.1	0.4	.	0
				MeHg (ng/g)	91.1	2.1	1.2	90.5	89.2	93.4	.	1.03
				THg (ng/g)	157.5	6.3	3.7	154.8	153	164.7	.	1.56
				%MeHg	57.8	1	0.6	58.3	56.7	58.5	.	-1.7
				SLBE	Bass Lake (Leelanau)	<i>Gomphus graslinellus</i>	5	Length (mm)	21.4	3.2	1.4	22.9
WPI	3	1.4	0.6					4	1	4	-1.75	-0.88
Dry weight (g)	0	0	0					0.1	0	0.1	-2.61	-0.57
MeHg (ng/g)	47.2	15.8	7.1					49.3	20.7	60.3	2.7	-1.57
THg (ng/g)	52.4	10.4	4.6					56.9	37.4	61.9	-1.16	-0.84
%MeHg	89.1	26.1	11.7					83.1	55.4	127	1.08	0.38
		<i>Gomphus (Phanogomphus) spicatus</i>	9					Length (mm)	30	0.6	0.2	29.9
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	1.48	1.02
				MeHg (ng/g)	38.7	16.2	5.4	36.2	17.3	63.3	-0.59	0.39
				THg (ng/g)	53.3	22.6	7.5	57.8	21.7	90	-0.55	0.05
				%MeHg	73.7	8	2.7	71.7	61.2	88.8	0.73	0.55
				14	Length (mm)	29.6	6.5	1.7	33.3	20.7	35.3	-1.79
			WPI		4.1	1.6	0.4	5	2	6	-1.72	-0.5
			Dry weight (g)		0.3	0.1	0	0.3	0.1	0.5	-1.48	-0.41
			MeHg (ng/g)		45.7	11.8	3.2	44.2	28.4	71	0.36	0.42
			THg (ng/g)		57.2	12.3	3.3	53.1	36.8	78	-0.73	0.25
			%MeHg		80.8	16.3	4.4	79.4	54.3	111.2	-0.13	0.13
			4		Length (mm)	22.2	0.5	0.2	22	21.8	22.8	1.96
				WPI	6	0	0	6	6	6	.	.
Dry weight (g)	0.1	0		0	0.1	0.1	0.1	-1.07	-0.79			
MeHg (ng/g)	19.9	8.6		4.3	18.8	11.6	30.2	-3.02	0.41			
THg (ng/g)	28.9	7.8		3.9	27.5	21.8	38.8	-2.04	0.64			
%MeHg	66.4	11.8		5.9	67.2	53.2	77.8	-4.32	-0.2			
15	Length (mm)	27.4		1.7	0.5	27.5	21.8	29.4	7.99	-2.47		
	WPI	3.9	0.3	0.1	4	3	4	15	-3.87			
	Dry weight (g)	0.1	0	0	0.1	0.1	0.1	4.35	-1.71			
	MeHg (ng/g)	35.3	9.9	2.5	35	20.1	55	0.04	0.54			
	THg (ng/g)	45.8	11.6	3	42.5	28.7	76.6	2.65	1.39			
	%MeHg	77.7	15.1	3.9	74.9	51	120.4	4.55	1.42			
	SLBE	Manitou	<i>Basiaeschna janata</i>	2	Length (mm)	32.1	2.4	1.7	32.1	30.4	33.8	.
WPI					4.5	0.7	0.5	4.5	4	5	.	.
Dry weight (g)					0.1	0	0	0.1	0.1	0.1	.	.
MeHg (ng/g)					71.8	16.7	11.8	71.8	59.9	83.6	.	.

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
SLBE	Manitou	<i>Basiaeschna janata</i>	31	THg (ng/g)	84	19.2	13.6	84	70.4	97.6	.	.
		(continued)		%MeHg	85.4	0.4	0.3	85.4	85.1	85.7	.	.
		<i>Dromogomphus spinosus</i>		Length (mm)	30.9	1.5	0.3	30.8	28.5	35.1	1.52	1.07
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0	0.1	2.35	-0.64
				MeHg (ng/g)	50.4	26.5	4.8	48.9	18.8	161.4	9.79	2.46
				THg (ng/g)	61.2	37.9	6.8	53.9	25.8	228.8	13.29	3.34
				%MeHg	85.4	19.1	3.4	85.5	22.1	128.5	3.23	-0.79
		<i>Gomphus (Phanogomphus) spicatus</i>		Length (mm)	31.3	1.4	0.5	31.9	29.5	33.7	-1.11	0.24
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-0.89	-0.35
				MeHg (ng/g)	24.1	17.9	6	17.7	8.6	63.3	2.09	1.52
				THg (ng/g)	31.3	17.4	5.8	25	16.9	70	2.34	1.59
				%MeHg	71.3	15	5	71.6	47.6	90.4	-0.64	-0.58
		<i>Macromia illinoiensis</i>		Length (mm)	24.2	.	.	24.2	24.2	24.2	.	.
				WPI	6	.	.	6	6	6	.	.
				Dry weight (g)	0.2	.	.	0.2	0.2	0.2	.	.
				MeHg (ng/g)	40.8	.	.	40.8	40.8	40.8	.	.
				THg (ng/g)	58.9	.	.	58.9	58.9	58.9	.	.
				%MeHg	69.2	.	.	69.2	69.2	69.2	.	.
		<i>Aeshna umbrosa</i>		Length (mm)	31.3	0.6	0.4	31.3	30.9	31.7	.	.
				WPI	2	0	0	2	2	2	.	.
				Dry weight (g)	0.1	0.1	0	0.1	0	0.1	.	.
				MeHg (ng/g)	500.9	150.6	106.5	500.9	394.4	607.4	.	.
				THg (ng/g)	542.6	176.3	124.7	542.6	417.9	667.2	.	.
				%MeHg	92.7	2.4	1.7	92.7	91	94.4	.	.
		<i>Gomphus exilis</i>		Length (mm)	24.1	0.7	0.2	23.8	23.5	25	-1.86	0.61
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0	0.1	0.91	0.74
				MeHg (ng/g)	22.8	11.6	4.1	21.3	5.4	36.9	-1.39	-0.06
				THg (ng/g)	32.3	12.6	4.5	32	19	45.4	-2.61	0.01
				%MeHg	70.4	27.3	9.7	76	28.2	116.5	0.4	-0.03
		<i>Gomphus (Phanogomphus) spicatus</i>		Length (mm)	29.1	1	0.5	28.9	28.2	30.2	-4.39	0.27
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-5.91	0
				MeHg (ng/g)	3.5	2.6	1.3	3.8	0	6.3	1.76	-0.71
				THg (ng/g)	38	29.2	14.6	29.6	14.4	78.4	0.66	1.21
				%MeHg	17.5	15.6	7.8	18.1	0	33.8	-3.54	-0.13
		<i>Hagenius brevistylus</i>		Length (mm)	27.1	.	.	27.1	27.1	27.1	.	.
				WPI	3	.	.	3	3	3	.	.
				Dry weight (g)	0.3	.	.	0.3	0.3	0.3	.	.
				MeHg (ng/g)	18.4	.	.	18.4	18.4	18.4	.	.

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
SLBE	Round Lake	<i>Hagenius brevistylus</i> (continued)		THg (ng/g)	22.8	.	.	22.8	22.8	22.8	.	.
				%MeHg	80.8	.	.	80.8	80.8	80.8	.	.
		<i>Ladona julia</i>	3	Length (mm)	21.2	1.1	0.6	21.1	20.1	22.4	.	0.55
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	.	0.85
				MeHg (ng/g)	39.3	52.3	30.2	13.3	5	99.5	.	1.68
				THg (ng/g)	53.6	66.1	38.2	19.9	11.1	129.8	.	1.7
				%MeHg	62.9	16.2	9.3	66.9	45.1	76.7	.	-1.05
		<i>Progomphus obscurus</i>	3	Length (mm)	26.3	0.7	0.4	26.6	25.6	26.9	.	-1.37
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	.	1.34
				MeHg (ng/g)	32	1.7	1	32.3	30.1	33.5	.	-0.79
				THg (ng/g)	37.8	2.4	1.4	37.4	35.7	40.4	.	0.75
				%MeHg	84.6	5.2	3	83	80.4	90.4	.	1.25
VOYA	Brown Lake	<i>Aeshna umbrosa</i>	1	Length (mm)	30.2	.	.	30.2	30.2	30.2	.	.
				WPI	2	.	.	2	2	2	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	122.3	.	.	122.3	122.3	122.3	.	.
				THg (ng/g)	129.2	.	.	129.2	129.2	129.2	.	.
				%MeHg	94.7	.	.	94.7	94.7	94.7	.	.
		<i>Basiaeschna janata</i>	2	Length (mm)	36	0.6	0.4	36	35.5	36.4	.	.
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.2	0	0	0.2	0.2	0.2	.	.
				MeHg (ng/g)	141.5	21.4	15.1	141.5	126.4	156.6	.	.
				THg (ng/g)	168.1	31.1	22	168.1	146.2	190.1	.	.
				%MeHg	84.4	2.9	2	84.4	82.4	86.5	.	.
		<i>Didymops transversa</i>	3	Length (mm)	26.3	0.2	0.1	26.3	26.1	26.5	.	-0.93
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.2	0	0	0.2	0.2	0.2	.	0.95
				MeHg (ng/g)	99.6	54.5	31.4	85.6	53.5	159.7	.	1.08
				THg (ng/g)	109	41.5	23.9	102.3	71.2	153.4	.	0.7
				%MeHg	87.7	14.9	8.6	83.7	75.1	104.2	.	1.12
		<i>Gomphus (Phanogomphus) spicatus</i>	1	Length (mm)	31.2	.	.	31.2	31.2	31.2	.	.
				WPI	4	.	.	4	4	4	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	84.1	.	.	84.1	84.1	84.1	.	.
				THg (ng/g)	102	.	.	102	102	102	.	.
				%MeHg	82.5	.	.	82.5	82.5	82.5	.	.
		<i>Ladona julia</i>	5	Length (mm)	23	0.9	0.4	22.9	21.7	24.3	2.03	0.26
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-2.65	0.7
				MeHg (ng/g)	51.9	23.8	10.6	64.4	22.1	74.5	-2.76	-0.57

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
VOYA	Brown Lake	<i>Ladona Julia</i> (continued)		THg (ng/g)	73.7	29.4	13.2	91.3	39.1	100.8	-3.1	-0.56
				%MeHg	68.5	7.1	3.2	69.3	56.7	74.3	2.44	-1.5
VOYA	Peary Lake	<i>Aeshna umbrosa</i>	2	Length (mm)	28.7	3.8	2.7	28.7	26	31.4	.	.
				WPI	1.5	0.7	0.5	1.5	1	2	.	.
				Dry weight (g)	0.1	0	0	0.1	0	0.1	.	.
				MeHg (ng/g)	63.5	8.5	6	63.5	57.5	69.5	.	.
				THg (ng/g)	81.4	3.7	2.6	81.4	78.7	84	.	.
				%MeHg	77.9	6.9	4.9	77.9	73	82.8	.	.
		<i>Gomphus exilis</i>	11	Length (mm)	25.9	1.9	0.6	26.3	20.8	27.7	5.88	-2.21
				WPI	3.8	0.6	0.2	4	2	4	11	-3.32
				Dry weight (g)	0.1	0	0	0.1	0	0.1	-0.84	-0.58
				MeHg (ng/g)	79.4	26.6	8	76.3	49.2	130.2	0.48	1.1
				THg (ng/g)	83.2	25.5	7.7	82.4	53.5	131	-0.09	0.83
				%MeHg	95.6	12.1	3.7	93.4	72.2	117.6	0.72	-0.09
		<i>Gomphus (Phanogomphus) spicatus</i>	14	Length (mm)	32.3	0.8	0.2	32.2	30.9	33.8	-0.01	0.31
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	-1	0.37
				MeHg (ng/g)	80.9	9.3	2.5	80.8	67	95.1	-1.26	0.01
				THg (ng/g)	85.5	16.6	4.4	81.4	58.8	118.8	-0.36	0.47
				%MeHg	96.3	11.1	3	97.4	76.2	122.1	1.46	0.52
		<i>Ladona julia</i>	4	Length (mm)	23.7	1.1	0.6	23.7	22.3	24.8	-2.76	-0.25
				WPI	5.8	0.5	0.3	6	5	6	4	-2
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	3.18	1.79
				MeHg (ng/g)	51.3	17.8	8.9	54.9	26.6	68.8	2.19	-1.14
				THg (ng/g)	76.2	14.1	7	77.1	61.1	89.6	-4.85	-0.13
				%MeHg	70.1	27.5	13.7	79.6	29.7	91.3	3.33	-1.75
		<i>Macromia illnoensis</i>	4	Length (mm)	26.7	0.5	0.2	26.6	26.3	27.4	1.06	1.19
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.2	0	0	0.3	0.2	0.3	-1.27	-0.83
				MeHg (ng/g)	70.2	11.5	5.8	75.5	52.9	76.8	3.92	-1.98
				THg (ng/g)	81.9	17.1	8.5	83.6	59.9	100.4	0.4	-0.54
				%MeHg	86.5	8.9	4.4	86.7	75.6	97	0.87	-0.14
VOYA	Ryan Lake	<i>Basiaeschna janata</i>	2	Length (mm)	36.3	0.2	0.2	36.3	36.1	36.4	.	.
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.2	0	0	0.2	0.2	0.2	.	.
				MeHg (ng/g)	130.5	4.7	3.3	130.5	127.2	133.8	.	.
				THg (ng/g)	137.5	20.7	14.6	137.5	122.9	152.1	.	.
				%MeHg	95.8	11	7.8	95.8	88	103.5	.	.
		<i>Celithemis elisa</i>	1	Length (mm)	15.1	.	.	15.1	15.1	15.1	.	.
				WPI	6	.	.	6	6	6	.	.
				Dry weight (g)	0	.	.	0	0	0	.	.
				MeHg (ng/g)	116.5	.	.	116.5	116.5	116.5	.	.

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
VOYA	Ryan Lake	<i>Celithemis elisa</i>	13	THg (ng/g)	141.9	.	.	141.9	141.9	141.9	.	.
		(continued)		%MeHg	82.1	.	.	82.1	82.1	82.1	.	.
		<i>Gomphus (Phanogomphus) lividus</i>		Length (mm)	24.5	3	0.8	26	21	28.9	-1.93	-0.02
				WPI	3.1	1	0.3	4	2	4	-2.36	-0.18
				Dry weight (g)	0.1	0	0	0	0	0.1	-0.74	0.62
				MeHg (ng/g)	105.8	20	5.6	100.7	71.9	143	-0.56	0.29
				THg (ng/g)	127.2	19.8	5.5	133.1	97.5	156.4	-1.14	-0.12
				%MeHg	83.4	10.7	3	81.9	67.8	104.3	-0.45	0.36
		<i>Gomphus (Phanogomphus) spicatus</i>		Length (mm)	32.5	0.8	0.5	32.5	31.6	33.2	.	-0.27
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	.	0
				MeHg (ng/g)	63	5	2.9	62.4	58.3	68.3	.	0.53
				THg (ng/g)	101.2	33.7	19.5	104.5	66	133.2	.	-0.43
				%MeHg	66.4	19.4	11.2	59.7	51.3	88.3	.	1.37
		<i>Ladona julia</i>		Length (mm)	23	1	0.5	22.9	21.9	24.4	1.66	0.56
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	3.2	1.7
				MeHg (ng/g)	91.1	27.9	13.9	100.5	50.3	113	3.12	-1.7
				THg (ng/g)	107.4	29.4	14.7	113.9	66.4	135.4	1.94	-1.2
				%MeHg	84.5	13	6.5	79.4	75.8	103.3	2.66	1.67
		<i>Macromia illinoiensis</i>		Length (mm)	24.6	1.9	0.7	24.9	20.7	26.2	4.57	-1.97
				WPI	5.7	0.8	0.3	6	4	6	7	-2.65
				Dry weight (g)	0.2	0	0	0.2	0.1	0.2	1.21	-1.17
				MeHg (ng/g)	121.6	40	15.1	99.3	78.2	178.9	-1.27	0.76
				THg (ng/g)	137.6	38	14.4	126.8	93.6	191.2	-1.83	0.28
				%MeHg	88.6	14.9	5.6	90.9	59	103.9	2.59	-1.45
VOYA	Sand Point Lake	<i>Didymops transversa</i>	4	Length (mm)	26.2	1.1	0.5	26.5	24.6	27.1	3.01	-1.6
				WPI	6	0	0	6	6	6	.	.
				Dry weight (g)	0.2	0	0	0.2	0.2	0.2	3.4	1.84
				MeHg (ng/g)	221.4	29.8	14.9	223.3	184.4	254.5	-0.38	-0.33
				THg (ng/g)	222.4	41.7	20.9	224.7	169.1	271	1.53	-0.33
			17	%MeHg	100.4	6.9	3.5	99.4	93.9	109	-2.27	0.56
		<i>Dromogomphus spinosus</i>		Length (mm)	28.9	1.1	0.3	28.7	27.3	30.7	-1.24	0.08
				WPI	4.5	0.5	0.1	4	4	5	-2.27	0.13
				Dry weight (g)	0.1	0	0	0.1	0.1	0.2	0.49	-0.02
				MeHg (ng/g)	91.4	19	4.6	90.3	62.1	131.7	-0.16	0.32
				THg (ng/g)	121.9	22	5.3	120.4	88.5	159.3	-0.72	0.29
				%MeHg	75.3	10.2	2.5	74.7	51.5	93.4	0.91	-0.4
		<i>Gomphus adelphus</i>	10	Length (mm)	32.3	2	0.6	32.7	28.7	34.9	-0.18	-0.63
				WPI	3.9	0.3	0.1	4	3	4	10	-3.16
				Dry weight (g)	0.2	0	0	0.2	0.1	0.2	-0.98	0.18
				MeHg (ng/g)	113.7	16.2	5.1	114.9	78.4	134	1.8	-1.03

Appendix F (continued): Summary statistics for total body length, wing pad index (WPI), dry weight, methylmercury (MeHg), total mercury (THg), and percent methylmercury (%MeHg) in whole larval dragonflies sampled from six park units in the Great Lakes Inventory and Monitoring Network in 2008-2009 (std dev = standard deviation, min = minimum value, max = maximum value). Statistics for each water body were calculated for each species, and sample size (n) indicates the number of dragonflies (analyzed individually). Mercury concentrations are in nanograms per gram (ng/g) dry weight, which are equivalent to parts per billion.

Park unit	Water body	Species	n	Variable	Mean	Std dev	Std error	Median	Min	Max	Kurtosis	Skewness
VOYA	Sand Point Lake	<i>Gomphus adelphus</i> (continued)		THg (ng/g)	184.3	89.3	28.2	159.4	141.2	436.6	9.59	3.07
				%MeHg	69.6	18.9	6	73.9	18	83.6	7.86	-2.69
		<i>Gomphus exilis</i>	4	Length (mm)	24.4	0.8	0.4	24.6	23.2	25.1	1.87	-1.37
				WPI	4	0	0	4	4	4	.	.
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	1.34	-0.7
				MeHg (ng/g)	96.6	27.3	13.7	92.2	68.8	133.3	1.06	0.88
				THg (ng/g)	116.4	32.6	16.3	113.7	79.5	158.5	1.28	0.47
				%MeHg	83.1	3.3	1.7	83.7	78.6	86.5	1.73	-0.97
		<i>Gomphus (Phanogomphus)</i> <i>spicatus</i>	3	Length (mm)	29.2	0.8	0.4	29	28.6	30.1	.	1.33
				WPI	4.3	0.6	0.3	4	4	5	.	1.73
				Dry weight (g)	0.1	0	0	0.1	0.1	0.1	.	-1.73
				MeHg (ng/g)	115.7	14.8	8.5	111.4	103.6	132.2	.	1.21
				THg (ng/g)	137.7	16.7	9.6	141.7	119.4	152	.	-1.02
				%MeHg	84.1	4.8	2.8	86.8	78.6	87	.	-1.73
		<i>Hagenius brevistylus</i>	1	Length (mm)	21.5	.	.	21.5	21.5	21.5	.	.
				WPI	2	.	.	2	2	2	.	.
				Dry weight (g)	0.1	.	.	0.1	0.1	0.1	.	.
				MeHg (ng/g)	171.3	.	.	171.3	171.3	171.3	.	.
				THg (ng/g)	186.3	.	.	186.3	186.3	186.3	.	.
				%MeHg	91.9	.	.	91.9	91.9	91.9	.	.

Appendix G: Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of organic contaminants and lead in composite samples of axial muscle from fish collected in 2008-2009 from five national park units in the Great Lakes Inventory and Monitoring Network.

Appendix G-1. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of organic contaminants and lead in 9 composite samples of axial muscle from fish collected in 2009 from 4 stream sites at Grand Portage National Monument.

Analyte(s)	Detection of analyte(s)		LOD (ng/g)	Maximum concentration		
	Number of samples	Number of sites		Concentration (ng/g wet wt)	Location	Species
<i>p,p'</i> -DDT ¹	0	0	10	ND	NA	NA
<i>p,p'</i> -DDD ²	0	0	10	ND	NA	NA
<i>p,p'</i> -DDE ³	0	0	10	ND	NA	NA
Perfluoro-1-hexanesulfonate	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-1-octanesulfonate	9	4	NA	2.0	Reservation River	Rainbow trout
Perfluoro-n-butanoic acid	2	1	NA	2.5	Hollow Rock Creek	Rainbow trout
Perfluoro-n-decanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-dodecanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-hexanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-nonanoic acid	3	1	NA	0.84	Reservation River	Rainbow trout
Perfluoro-n-octanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-undodecanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Total PBDEs ⁴	2	1	1.0-2.0	3.1	Hollow Rock Creek	Rainbow trout
Total PCBs ⁵	3	2	0.5-16	9.3	Hollow Rock Creek	Rainbow trout
Total Lead	9	4	9.04	22.6	Hollow Rock Creek	Rainbow trout

ND, not detected

NA, not applicable

¹2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

²2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

³2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

⁴Sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

⁵Sum of polychlorinated biphenyl (PCB) numbers 3, 4/10, 5/8, 6, 7/9, 15/17, 16/32, 18, 19, 22, 24/27, 25, 26, 28/31, 33, 37/42, 40, 41/64/71, 45, 46, 47/48, 49, 51, 52, 53, 56/60, 63, 66, 70/76, 74, 77/110, 82, 83, 84/92, 85, 87, 89, 91, 95, 97, 99, 101, 105/132/153, 118, 123/149, 128, 136, 137/176, 138/163, 141, 146, 151, 167, 170/190, 171/202, 172, 174, 177, 178, 180, 182/187, 183, 185, 193, 194, 195/208, 196/203, 198, 199, 201, 206, 207

⁶Less than the report limit

Appendix G-2. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of organic contaminants and lead in 10 composite samples of axial muscle from fish collected in 2009 from 4 lakes at Isle Royale National Park.

Analyte(s)	Detection of analyte(s)			Maximum concentration		
	Number of samples	Number of sites	LOD (ng/g)	Concentration (ng/g wet wt)	Location	Species
<i>p,p'</i> -DDT ¹	0	0	10	ND	NA	NA
<i>p,p'</i> -DDD ²	0	0	10	ND	NA	NA
<i>p,p'</i> -DDE ³	0	0	10	ND	NA	NA
Perfluoro-1-hexanesulfonate	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-1-octanesulfonate	6	3	NA	2.1	Lake Harvey	Yellow perch
Perfluoro-n-butanoic acid	0	0	NA	<2.0 ⁶	NA	NA
Perfluoro-n-decanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-dodecanoic acid	0	0	NA	0.80	Lake Harvey	Yellow perch
Perfluoro-n-hexanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-nonanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-octanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-undecanoic acid	2	1	NA	1.0	Lake Harvey	Yellow perch
Total PBDEs ⁴	0	0	1.0-2.0	ND	NA	NA
Total PCBs ⁵	0	0	0.5-16	ND	NA	NA
Total Lead	10	4	2.50	24.6	Angleworm Lake	Northern pike

ND, not detected

NA, not applicable

¹2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

²2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

³2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

⁴Sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

⁵Sum of polychlorinated biphenyl (PCB) numbers 3, 4/10, 5/8, 6, 7/9, 15/17, 16/32, 18, 19, 22, 24/27, 25, 26, 28/31, 33, 37/42, 40, 41/64/71, 45, 46, 47/48, 49, 51, 52, 53, 56/60, 63, 66, 70/76, 74, 77/110, 82, 83, 84/92, 85, 87, 89, 91, 95, 97, 99, 101, 105/132/153, 118, 123/149, 128, 136, 137/176, 138/163, 141, 146, 151, 167, 170/190, 171/202, 172, 174, 177, 178, 180, 182/187, 183, 185, 193, 194, 195/208, 196/203, 198, 199, 201, 206, 207

⁶Less than the report limit

Appendix G-3. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of organic contaminants and lead in 15 individual and composite samples of axial muscle from fish collected in 2008 from 3 lakes at Pictured Rocks National Lakeshore.

Analyte(s)	Detection of analyte(s)		LOD (ng/g)	Maximum concentration		
	Number of samples	Number of sites		Concentration (ng/g wet wt)	Location	Species
<i>p,p'</i> -DDT ¹	0	0	10	ND	NA	NA
<i>p,p'</i> -DDD ²	0	0	10	ND	NA	NA
<i>p,p'</i> -DDE ³	0	0	10	ND	NA	NA
Perfluoro-1-hexanesulfonate	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-1-octanesulfonate	8	2	NA	1.6	Miners Lake	Northern pike
Perfluoro-n-butanoic acid	0	0	NA	<2.0 ⁶	NA	NA
Perfluoro-n-decanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-dodecanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-hexanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-nonanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-octanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-undodecanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Total PBDES ⁴	0	0	1.0-2.0	ND	NA	NA
Total PCBs ⁵	1	1	0.5-16	3.4	Grand Sable Lake	Smallmouth bass
Total Lead	15	3	3.45	27.6	Beaver Lake	Northern pike

ND, not detected

NA, not applicable

¹2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

²2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

³2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

⁴Sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

⁵Sum of polychlorinated biphenyl (PCB) numbers 3, 4/10, 5/8, 6, 7/9, 15/17, 16/32, 18, 19, 22, 24/27, 25, 26, 28/31, 33, 37/42, 40, 41/64/71, 45, 46, 47/48, 49, 51, 52, 53, 56/60, 63, 66, 70/76, 74, 77/110, 82, 83, 84/92, 85, 87, 89, 91, 95, 97, 99, 101, 105/132/153, 118, 123/149, 128, 136, 137/176, 138/163, 141, 146, 151, 167, 170/190, 171/202, 172, 174, 177, 178, 180, 182/187, 183, 185, 193, 194, 195/208, 196/203, 198, 199, 201, 206, 207

⁶Less than the report limit

Appendix G-4. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of organic contaminants and lead in 16 individual and composite samples of axial muscle from fish collected in 2008 from 4 lakes at Sleeping Bear Dunes National Lakeshore.

Analyte(s)	Detection of analyte(s)		LOD (ng/g)	Maximum concentration		
	Number of samples	Number of sites		Concentration (ng/g wet wt)	Location	Species
<i>p,p'</i> -DDT ¹	0	0	10	ND	NA	NA
<i>p,p'</i> -DDD ²	0	0	10	ND	NA	NA
<i>p,p'</i> -DDE ³	0	0	10	ND	NA	NA
Perfluoro-1-hexanesulfonate	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-1-octanesulfonate	11	3	NA	2.1	Lake Manitou	Smallmouth bass
Perfluoro-n-butanoic acid	0	0	NA	<2.0 ⁶	NA	NA
Perfluoro-n-decanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-dodecanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-hexanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-nonanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-octanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-undodecanoic acid	5	1	NA	1.1	Lake Manitou	Smallmouth bass
Total PBDEs ⁴	2	1	1.0-2.0	1.4	Lake Manitou	Smallmouth bass
Total PCBs ⁵	1	1	0.5-16	5.95	Lake Manitou	Smallmouth bass
Total Lead	16	4	3.2-6.9	10.7	Lake Manitou	Smallmouth bass

ND, not detected

NA, not applicable

¹2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

²2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

³2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

⁴Sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

⁵Sum of polychlorinated biphenyl (PCB) numbers 3, 4/10, 5/8, 6, 7/9, 15/17, 16/32, 18, 19, 22, 24/27, 25, 26, 28/31, 33, 37/42, 40, 41/64/71, 45, 46, 47/48, 49, 51, 52, 53, 56/60, 63, 66, 70/76, 74, 77/110, 82, 83, 84/92, 85, 87, 89, 91, 95, 97, 99, 101, 105/132/153, 118, 123/149, 128, 136, 137/176, 138/163, 141, 146, 151, 167, 170/190, 171/202, 172, 174, 177, 178, 180, 182/187, 183, 185, 193, 194, 195/208, 196/203, 198, 199, 201, 206, 207

⁶Less than the report limit

Appendix G-5. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of organic contaminants and lead in 10 individual and composite samples of axial muscle from fish collected in 2009 from 4 lakes at Voyageurs National Park.

Analyte(s)	Detection of analyte(s)		LOD (ng/g)	Maximum concentration		
	Number of samples	Number of sites		Concentration (ng/g wet wt)	Location	Species
<i>p,p'</i> -DDT ¹	0	0	10	ND	NA	NA
<i>p,p'</i> -DDD ²	0	0	10	ND	NA	NA
<i>p,p'</i> -DDE ³	0	0	10	ND	NA	NA
Perfluoro-1-hexanesulfonate	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-1-octanesulfonate	5	2	NA	0.69	Sand Point Lake	Northern pike
Perfluoro-n-butanoic acid	0	0	NA	<2.0 ⁶	NA	NA
Perfluoro-n-decanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-dodecanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-hexanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-nonanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-octanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Perfluoro-n-undecanoic acid	0	0	NA	<0.50 ⁶	NA	NA
Total PBDEs ⁴	0	0	1.0-2.0	ND	NA	NA
Total PCBs ⁵	0	0	0.5-16	ND	NA	NA
Total Lead	10	4	6.8	30.6	Peary Lake	Northern pike

ND, not detected

NA, not applicable

¹2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

²2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

³2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

⁴Sum of PBDE numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

⁴Sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

⁵Sum of polychlorinated biphenyl (PCB) numbers 3, 4/10, 5/8, 6, 7/9, 15/17, 16/32, 18, 19, 22, 24/27, 25, 26, 28/31, 33, 37/42, 40, 41/64/71, 45, 46, 47/48, 49, 51, 52, 53, 56/60, 63, 66, 70/76, 74, 77/110, 82, 83, 84/92, 85, 87, 89, 91, 95, 97, 99, 101, 105/132/153, 118, 123/149, 128, 136, 137/176, 138/163, 141, 146, 151, 167, 170/190, 171/202, 172, 174, 177, 178, 180, 182/187, 183, 185, 193, 194, 195/208, 196/203, 198, 199, 201, 206, 207

⁶Less than the report limit

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NPS 920/119607, January 2013

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