National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Bioaccumulative Contaminants in Aquatic Food Webs in Six National Park Units of the Western Great Lakes Region

2008–2012

Natural Resource Report NPS/GLKN/NRR—2016/1302





ON THIS PAGE
Students from the University of Wisconsin-La Crosse retrieve a nitex net towed through the water to collect zooplankton from Lake Manitou on North Manitou Island (Sleeping Bear Dunes National Lakeshore). Photograph by Sean Bailey (University of Wisconsin-La Crosse).

ON THE COVER
Collection and processing of samples by students and faculty from the University of Wisconsin-La Crosse. *Top row (left to right)*: northern pike from Grand Sable Lake (PIRO), water sample from Bass Lake (Benzie County, SLBE), field crew en route to study site at ISRO, prey fish from Lake Richie (ISRO), processing of water samples at INDU; *middle row*: processing fish samples at UW-La Crosse, on portage at ISRO, largemouth bass from Round Lake (SLBE), freeze-dried larval dragonfly, filtration of water samples from Lake Harvey (ISRO) for suspended matter content, sampling for larval dragonflies at Great Marsh (INDU); *bottom row*: field crew en route to Chapel Lake (PIRO), sample of zooplankton from Peary Lake (VOYA), netting for larval dragonflies at Snow Creek (GRPO), backpack electrofishing at Lake Manitou (SLBE). Photographs courtesy of participating personnel with the University of Wisconsin-La Crosse and National Park Service.

Bioaccumulative Contaminants in Aquatic Food Webs in Six National Park Units of the Western Great Lakes Region

2008–2012

Natural Resource Report NPS/GLKN/NRR—2016/1302

James G. Wiener, Roger J. Haro, Kristofer R. Rolfhus, Mark B. Sandheinrich, Sean W. Bailey, Reid M. Northwick

University of Wisconsin–La Crosse
River Studies Center
1725 State Street
La Crosse, Wisconsin 54601

and

Theodore J. Gostomski

National Park Service
Great Lakes Inventory and Monitoring Network
2800 Lakeshore Drive East, Suite D
Ashland, Wisconsin 54806

September 2016

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Great Lakes Inventory and Monitoring Network website (http://science.nature.nps.gov/im/units/glkn/publications.cfm?tab=2) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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. 2016. Bioaccumulative contaminants in aquatic food webs in six national park units of the western Great Lakes region: 2008–2012. Natural Resource Report NPS/GLKN/NRR—2016/1302. National Park Service, Fort Collins, Colorado.

NPS 920/134144, September 2016

Contents

Page

Figures vii
Tables ix
Appendices xv
Executive Summary xvii
Acknowledgments xxi
List of Terms xxiii
National Park Service (NPS) units xxiii
Other abbreviations xxiii
Introduction 1
Contaminants Analyzed in this Study 3
Mercury 3
Lead 5
DDT 6
PCBs 7
PFCs 9
PBDEs 10
Study Areas 13
Methods 17
Mercury in Aquatic Food Webs and Ecosystems—Approach 17
Sampling of Lower Food Web, Soil, Sediment, and Larval Dragonflies 17
Mercury Analyses—Lower Food Web, Soil, Sediment, and Larval Dragonflies 19
Sampling and Mercury Analyses of Prey Fish 20
Sampling and Mercury Analyses of Adult Fish 22
Quality Assurance and Quality Control 23
Assessing Ecological and Health Risks of Methylmercury 29
Benchmarks for Assessing Mercury Risk to Fish 29
Benchmarks for Assessing Mercury Risk to Piscivorous Wildlife 30
Benchmarks for Assessing Mercury Risk to Fish-Eating Humans 32

Contents (continued)

Page

Lead and Organic Contaminants in Adult Fish 32
Sample Preparation, Analyses, and Quality Assurance 34
Benchmarks for Assessing Risks to Fish-Eating Humans 36
Benchmarks for Assessing Risks to Fish and Wildlife 36
Results and Discussion 39
Grand Portage National Monument (GRPO) 39
Mercury in Streams and Food Webs 40
Ecological and Health Risks of Methylmercury 43
Lead and Organic Contaminants 45
Indiana Dunes National Lakeshore (INDU) 46
Mercury in Water Bodies and Food Webs 47
Ecological and Health Risks of Methylmercury 52
Lead and Organic Contaminants 53
Isle Royale National Park (ISRO) 54
Mercury in Water Bodies and Food Webs 55
Ecological and Health Risks of Methylmercury 60
Lead and Organic Contaminants 61
Pictured Rocks National Lakeshore (PIRO) 62
Mercury in Lakes and Food Webs 63
Ecological and Health Risks of Methylmercury 70
Lead and Organic Contaminants 72
Sleeping Bear Dunes National Lakeshore (SLBE) 74
Mercury in Lakes and Food Webs 74
Ecological and Health Risks of Methylmercury 79
Lead and Organic Contaminants 82
Voyageurs National Park (VOYA) 83
Mercury in Lakes and Food Webs 84
Ecological and Health Risks of Methylmercury 89

Contents (continued)

Page

Lead and Organic Contaminants 91
Regional Assessment of Bioaccumulative Contaminants 92
Mercury 92
Lead and Organic Contaminants 104
Conclusions 107
Recommendations 111
Literature Cited 113

Figures

Page

Figure 1. Map of the western Great Lakes region, showing the nine national park units in the Great Lakes Inventory and Monitoring Network 2

Figure 2. Concentrations of total mercury in whole central mudminnows from Legion Lake in relation to total length of the fish 72

Figure 3. Relation of total mercury (Hg) in surficial soil (upper panel) and sediment (lower panel) to percent loss on ignition (a surrogate measure of organic matter content) in six national park units in the Great Lakes region 93

Figure 4. Relation of filter-passing total mercury (Hg) in water to dissolved organic carbon (DOC) in water bodies at six national park units in the Great Lakes region 94

Figure 5. Concentrations of methylmercury (MeHg) in three components of the lower aquatic food web in six national park units in the western Great Lakes region 95

Figure 6. Relation of park mean concentration of methylmercury (MeHg) in bulk zooplankton to that in 0.45-µm filtered water from lakes and Middle Lagoon 96

Figure 7. Linear regression between mean concentration of total mercury (THg) in small, whole yellow perch (<76 mm) and mean concentrations of (a) THg and (b) MeHg in coexisting larval *Gomphus* across 15 lakes in the northwestern Great Lakes region 98

Figure 8. Bioaccumulation factors for methylmercury in seston, bulk zooplankton, larval dragonflies (Odonates), and selected prey fish, relative to concentrations in unfiltered water in six national park units in the western Great Lakes region 99

Figure 9. Box and whisker plots of distribution of total mercury levels in whole prey fish < 100 mm in total length from six park units in the western Great Lakes region 101

Figure 10. Bar and whisker plots of distribution of total mercury levels in whole prey fish < 250 mm in total length from six park units in the western Great Lakes region 102

Figure 11. Concentrations of mercury as a function of total length in whole central mudminnows sampled from water bodies at three national park units in the western Great Lakes region 103

Tables

Page

Table 1. Physical characteristics of 23 water bodies studied in six national park units during 2008–2009 and 2010–2012 and their watersheds. 14

Table 2. Summary of quality assurance measures during determination of total mercury (THg) and methylmercury (MeHg) in soil sampled during 2012 and in surficial sediment and seston sampled during 2010–2012 from six national park units. 24

Table 3. Summary of quality assurance measures during determination of total mercury (THg) and methylmercury (MeHg) in unfiltered and 0.45-µm filtered water sampled from six national park units during 2010–2012. 25

Table 4. Summary of quality assurance measures during determination of total mercury (THg) and methylmercury (MeHg) in larval dragonflies sampled during 2008–2012 and in zooplankton sampled during 2010–2012 from six national park units. 26

Table 5. Summary of quality assurance measures during determination of total mercury in axial muscle tissue of fish and in whole prey fish sampled from six national park units during 2008–2012. 27

Table 6. Summary of method detection limits (MDL) during determination of total mercury (THg) and methylmercury (MeHg) in physical and biological samples collected from six national park units during the study. 28

Table 7. Concentrations of mercury in fish used as benchmarks to assess risks of methylmercury (MeHg) to fish and piscivorous wildlife. 31

Table 8. Guidelines for human consumption of sport fish containing mercury, PCBs, PFOS, PBDEs, and DDT in their fillets. 33

Table 9. Concentrations in whole fish used as benchmarks to assess risks of bioaccumulative organic contaminants to fish and piscivorous wildlife. 37

Table 10. Summary of water quality measurements (mean ± SE) in three streams at Grand Portage National Monument, derived from annual *in situ* measurements and analyses of water samples during 2010–2012 39

Table 11. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in soils near streams in Grand Portage National Monument 40

Table 12. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and loss on ignition in surficial sediments (upper 5 cm) from streams in Grand Portage National Monument during 2010–2012 41

Table 13. Total mercury and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water sampled from streams in Grand Portage National Monument 41

Table 14. Total mercury, methylmercury (MeHg), and percent MeHg in seston (suspended particles) from streams in Grand Portage National Monument 42

Tables (continued)

Page

Table 15. Total mercury, methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2009–2012 from streams in Grand Portage National Monument. 42

Table 16. Fish length and concentration of total mercury (Hg) in whole body and axial muscle tissue (skinless fillets) of fish sampled from streams in Grand Portage National Monument during 2009–2012. 43

Table 17. Concentrations of mercury (Hg) in whole fish from three streams in Grand Portage National Monument, with numbers (n) and percentages (%) of fish exceeding screening dietary benchmarks for the belted kingfisher (30 ng/g wet wt) and American mink (70 ng/g). 44

Table 18. Summary of water quality measurements (mean ± SE) in three water bodies at Indiana Dunes National Lakeshore, derived from *in situ* measurements and from analyses of water samples taken during early spring of 2010–2012. 47

Table 19. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in soils sampled near two water bodies in Indiana Dunes National Lakeshore 47

Table 20. Mean total mercury (Hg), methylmercury (MeHg), percent MeHg, and loss on ignition in surficial sediments (upper 5 cm) sampled from water bodies in Indiana Dunes National Lakeshore during 2010–2012 48

Table 21. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water sampled from three water bodies in Indiana Dunes National Lakeshore 48

Table 22. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from waters in Indiana Dunes National Lakeshore. 49

Table 23. Total mercury, methylmercury (MeHg), and percent MeHg in bulk zooplankton sampled from two water bodies in Indiana Dunes National Lakeshore during 2010–2012 49

Table 24. Total mercury, methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Indiana Dunes National Lakeshore. 50

Table 25. Fish length and concentration of total mercury (Hg) in whole prey fish sampled in 2008 and 2010–2012 from Indiana Dunes National Lakeshore. 51

Table 26. Fish length and concentration of total mercury (Hg) in axial muscle (skinless fillets) of adult fish sampled from three water bodies in Indiana Dunes National Lakeshore during 2010–2012. 52

Table 27. Summary of water quality measurements (mean ± SE) in four lakes at Isle Royale National Park, derived from annual *in situ* measurements and from analyses of water sampled during 2010–2012. 54

Tables (continued)

Page

Table 28. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in soils sampled near lakes in Isle Royale National Park 55

Table 29. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in surficial sediments (upper 5 cm) sampled from four lakes in Isle Royale National Park during 2010–2012 55

Table 30. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water from four lakes in Isle Royale National Park 56

Table 31. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from four lakes in Isle Royale National Park. 57

Table 32. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in bulk zooplankton from four lakes in Isle Royale National Park during 2010–2012 57

Table 33. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Isle Royale National Park. 58

Table 34. Fish length and concentration of total mercury (Hg) in whole yellow perch sampled during 2009–2012 from four lakes in Isle Royale National Park. 59

Table 35. Fish length and concentration of total mercury (Hg) in axial muscle of piscivorous fishes sampled in 2009–2012 from four lakes in Isle Royale National Park 59

Table 36. Percentages of whole yellow perch from four lakes in Isle Royale National Park with mercury levels exceeding screening dietary benchmarks for belted kingfisher (30 ng/g wet weight), piscivorous fish (40 ng/g), and American mink (70 ng/g) 60

Table 37. Summary of water quality measurements (mean ± SE) in five lakes at Pictured Rocks National Lakeshore, derived from annual *in situ* measurements and from analyses of water samples during 2010–2012. 63

Table 38. Total mercury, methylmercury (MeHg), percent MeHg, and percent loss on ignition in soil sampled near lakes in Pictured Rocks National Lakeshore 63

Table 39. Mean total mercury (Hg), methylmercury (MeHg), percent MeHg, and loss on ignition in surficial sediments (upper 5 cm) sampled from lakes in Pictured Rocks National Lakeshore during 2010–2012 64

Table 40. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water sampled from lakes in Pictured Rocks National Lakeshore 65

Table 41. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from five lakes in Pictured Rocks National Lakeshore. 65

Table 42. Total mercury, methylmercury (MeHg), and percent MeHg in bulk zooplankton sampled from lakes in Pictured Rocks National Lakeshore during 2010–2012 66

Tables (continued)

Page

Table 43. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Pictured Rocks National Lakeshore. 67

Table 44. Fish length and concentration of total mercury (Hg) in whole prey fish sampled during 2008 and 2010–2012 from five lakes in Pictured Rocks National Lakeshore. 68

Table 45. Total mercury (Hg) in axial muscle (skinless fillets) and length of predatory fish sampled from four lakes in Pictured Rocks National Lakeshore in 2008 and 2010–2012 69

Table 46. Percentages of whole prey fish from five lakes in Pictured Rocks National Lakeshore with mercury levels exceeding screening dietary benchmarks for belted kingfisher (30 ng/g wet weight), piscivorous fish (40 ng/g), and American mink (70 ng/g). 71

Table 47. Summary of water quality measurements (mean ± SE) in lakes at Sleeping Bear Dunes National Lakeshore, derived from annual *in situ* measurements and from analyses of water samples taken during 2010–2012. 74

Table 48. Total mercury, methylmercury (MeHg), percent MeHg, and percent loss on ignition in soil sampled near lakes in Sleeping Bear Dunes National Lakeshore 75

Table 49. Mean total mercury (Hg), methylmercury (MeHg), percent MeHg, and loss on ignition in surficial sediments (upper 5 cm) sampled from lakes in Sleeping Bear Dunes National Lakeshore during 2010–2012 75

Table 50. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and filtered water (0.45 µm) sampled from four lakes in Sleeping Bear Dunes National Lakeshore 76

Table 51. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from four lakes in Sleeping Bear Dunes National Lakeshore. 76

Table 52. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in bulk zooplankton from lakes in Sleeping Bear Dunes National Lakeshore during 2010–2012. 76

Table 53. Total mercury, methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Sleeping Bear Dunes National Lakeshore. 77

Table 54. Fish length and concentrations of total mercury (Hg) in whole prey fish sampled from four lakes in Sleeping Bear Dunes National Lakeshore during 2008 and 2010–2012 79

Table 55. Fish length and concentration of total mercury (Hg) in axial muscle of predatory fish collected during 2008 and 2010–2012 from four lakes in Sleeping Bear Dunes National Lakeshore. 80

Tables (continued)

Page

Table 56. Percentages of whole prey fish from four lakes in Sleeping Bear Dunes National Lakeshore with mercury levels exceeding screening dietary benchmarks for belted kingfisher (30 ng/g wet weight), piscivorous fish (40 ng/g), and American mink (70 ng/g). 81

Table 57. Summary of water quality measurements (mean ± SE) in four lakes at Voyageurs National Park, derived from annual *in situ* measurements and from analyses of water samples collected during 2010–2012. 84

Table 58. Total mercury, methylmercury (MeHg), percent MeHg, and percent loss on ignition in soils sampled near lakes in Voyageurs National Park 84

Table 59. Mean total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in surficial sediments (upper 5 cm) sampled from lakes in Voyageurs National Park during 2010–2012 85

Table 60. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water from lakes in Voyageurs National Park 85

Table 61. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from lakes in Voyageurs National Park. 86

Table 62. Total mercury, methylmercury (MeHg), and percent MeHg in bulk zooplankton from four lakes in Voyageurs National Park during 2010–2012. 86

Table 63. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Voyageurs National Park. 87

Table 64. Fish length and concentration of total mercury (Hg) in whole yellow perch sampled in 2009–2012 from lakes in Voyageurs National Park. 88

Table 65. Fish length and concentrations of total mercury (Hg) in axial muscle tissue of predatory fish collected during 2009–2012 from four lakes in Voyageurs National Park. 89

Table 66. Percentages of whole yellow perch from four lakes in Voyageurs National Park with mercury levels exceeding dietary benchmarks for belted kingfishers (30 ng/g wet weight), American mink (70 ng/g), and adult common loons (100 ng/g) 90

Table 67. Number of water bodies at six national park units with mercury levels in axial muscle tissue of adult fish exceeding benchmarks for risks to human health (300 ng/g wet weight) and to fish health and reproduction (500 ng/g wet weight). 100

Appendices

Page

Appendix A. Land cover of watersheds containing water bodies studied at six national park units in the Great Lakes Inventory and Monitoring Network. 137

Appendix B. Common and scientific names of fishes analyzed in this study, following standardized nomenclature by the American Fisheries Society. 139

Appendix C. Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg* conc, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in composite samples of soils collected during 2012 from six park units in the Great Lakes Inventory and Monitoring Network 141

Appendix D. Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in surficial sediment sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network 145

Appendix E. Concentrations of total mercury (*THg conc*, ng/L) and methylmercury (*MeHg conc*, ng/L), and percent of total mercury present as methylmercury (*%MeHg*) in samples of unfiltered (*U*) and 0.45-µm filtered (*F*) water collected during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network 149

Appendix F. Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in seston, listed alphabetically by park unit and water body, sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network y. 155

Appendix G. Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in bulk zooplankton, listed alphabetically by park unit and water body sampled during 2010–2012 from parks in the Great Lakes Inventory and Monitoring Network. 159

Appendix H. Summary statistics for total length (*Length*, mm), percent moisture (*Moisture*, %), concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network 163

Appendix I. Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 221

Appendices (continued)

Page

Appendix J. Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 233

Appendix K. Inventories of fish samples from park units in the western Great Lakes region that were analyzed for selected organic contaminants and total lead. 243

Appendix L. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentrations of selected organic contaminants and total lead in samples of fish collected in 2008–2012 from six national park units in the Great Lakes Inventory and Monitoring Network 255

Executive Summary

We report results of an intensive assessment of selected bioaccumulative contaminants in aquatic food webs and ecosystems 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 ecosystems and biota in the six park units, (2) to identify park units and water bodies where bioaccumulative contaminants may pose a risk to organisms—particularly piscivores atop aquatic food webs, and (3) to provide data for assessing temporal trends in contamination of fish and 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, nine analytes), and polybrominated diphenyl ethers (PBDEs, 9 to 17 congeners). A total of 23 water bodies were studied, including three streams at GRPO, three sites at INDU (Great Marsh, Long Lake and Middle Lagoon), four lakes at ISRO, five lakes at PIRO, four lakes at SLBE, and four lakes at VOYA.

This study followed a pilot study that quantified bioaccumulative contaminants in adult predatory fish, prey fish, and larval dragonflies sampled in 2008–2009 from the six park units (Wiener et al. 2013). Subsequent funding from the Great Lakes Restoration Initiative was used to expand the sampling and analyses of mercury in the six park units during 2010–2012 to include water, surficial sediment, soil, seston, and zooplankton, and to continue sampling and analyses of larval dragonflies, prey fish, and adult predatory fish. Adult predatory fish were also analyzed for selected bioaccumulative organic contaminants (DDT, PCBs, PBDEs, PFCs) and total lead; for these analytes, we analyzed axial muscle tissue from fish collected during 2008–2009 and whole-body samples from fish collected during 2010–2012.

The accumulation of mercury (as methylmercury) in aquatic food webs and fish varied greatly among the 23 water bodies studied, both within and among the six park units. Moreover, fish in some park units have bioaccumulated mercury to toxicologically significant levels. Mercury concentrations in axial muscle tissue (skinless fillets) of adult predatory fish from several water bodies substantially exceeded 300 ng/g (parts per billion) wet weight, the U.S. Environmental Protection Agency (USEPA) tissue residue criterion for methylmercury, which was established to protect the health of humans who eat noncommercial fish. Concentrations of mercury in axial fillets of one or more *individual* predatory fish from five park units—including fish from four lakes at VOYA, four lakes at PIRO, four lakes at ISRO, and four lakes at SLBE—exceeded the USEPA tissue residue criterion. None of the individual fish from streams at GRPO and only one fish from INDU exceeded the USEPA tissue residue criterion. *Mean* concentrations of mercury in axial fillets of predatory fish exceeded the USEPA criterion in four lakes at VOYA, three lakes at PIRO, two lakes at ISRO, and two lakes at SLBE.

In some predatory fish, concentrations of mercury in axial muscle tissue exceeded 500 ng/g wet weight, a benchmark concentration associated with altered biochemical processes, damage to cells and tissues, and diminished reproduction in fish. Concentrations in axial muscle tissue of one or more individual predatory fish from a total of 16 water bodies in four park units (ISRO, PIRO, SLBE, and VOYA) exceeded this benchmark. *Mean* concentrations exceeded this benchmark level in predatory fish from a total of eight water bodies from four park units, including all four lakes at VOYA, two lakes at PIRO, one lake at ISRO, and one lake at SLBE. At INDU, mercury levels in whole prey fish and in axial muscle of adult fish from three water bodies (Great Marsh, Long Lake, and Middle Lagoon) were generally lower than those in fish from the other park units.

Concentrations of mercury in whole prey fish from some water bodies were considered high enough to adversely affect piscivorous fish or fish-eating wildlife. The fraction of small whole prey fish (<100 mm in total length) exceeding the screening-level dietary benchmark of 30 ng/g wet weight for belted kingfisher, an avian piscivore that is highly sensitive to methylmercury, ranged from 39% at INDU to 93% at VOYA. The estimated dietary threshold (100 ng Hg/g wet weight) for adverse impacts on behavior of adult common loons, an iconic species that is moderately sensitive to methylmercury, was exceeded in 27% of the whole prey fish at ISRO, 31% of the prey fish at PIRO, and 43% at VOYA. No long-lived, piscivorous fish were obtained for analysis from the small stream systems at GRPO, yet small prey fish in these streams are accumulating mercury to concentrations that could adversely affect species of piscivorous wildlife, such as the belted kingfisher and mink, that are highly sensitive to methylmercury.

Concentrations of total mercury and methylmercury were measured in multiple components of the lower food web (soil, sediment, filtered and unfiltered water, seston, and zooplankton). Mercury levels in both soil and sediment were strongly correlated with organic matter content at all study sites. Mercury concentrations in soil and sediment from the GRPO streams were from three- to four-fold higher per unit of organic matter than those in other sampled water bodies and in values reported for other regional streams, leading us to hypothesize that the GRPO sites were contaminated with mercury from vermillion used in the fur trade. The GRPO streams also had the highest percent methylmercury and methylmercury concentrations in water, with concentrations at the high end of values reported for streamwater across the western Great Lakes region. We conclude that GRPO is a highly mercury-sensitive landscape with high rates of methylmercury production. In lentic waterbodies sampled in the other five park units, the percent of total mercury present as methylmercury increased from <10% in soil, sediment, and water to an average of 43% in bulk zooplankton, indicative of methylmercury biomagnification through the food web.

Methylmercury concentrations in bulk zooplankton were strongly related to concentrations in water, suggesting bottom-up control of methylmercury bioaccumulation in aquatic food webs. The trophic transfer of methylmercury through components of the lower food web varied little across the six park units, based on comparison of bioaccumulation factors for methylmercury, providing further evidence of bottom-up control. Thus, factors that increase methylmercury production and transport in water and sediment will strongly influence mercury levels in fish and piscivorous wildlife. Such factors include low pH, high dissolved sulfate, high dissolved organic carbon (DOC), low biotic

productivity, and high wetland and forest cover in the watershed. Lakes showed a general increase in methylmercury in water and zooplankton from southeast (INDU and SLBE) to northwest (VOYA), corresponding to increased wetland and forest cover in watersheds, as well as somewhat lower pH, higher DOC, and lower productivity in water bodies. Spatial patterns of methylmercury contamination across the park units did not parallel patterns of regional mercury emission or atmospheric deposition, underscoring the importance of factors that control landscape sensitivity to anthropogenic mercury and its microbial conversion to methylmercury.

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 in three regionally widespread families of dragonfly (Aeshnidae, Corduliidae, and Gomphidae) were highest at GRPO, PIRO, and VOYA, and generally reflected mercury levels in coexisting fish across the water bodies studied. Most of the mercury in dragonflies was methylmercury, with mean percent methylmercury in larvae from individual park units ranging from 69% to 93%.

Our findings for mercury support results of prior studies showing that the northern Great Lakes region is a mercury-sensitive area. Atmospheric deposition is the dominant modern pathway for entry of mercury into national park units in this region, and on-site geologic sources of mercury are generally very small. The high methylmercury levels in biota inhabiting several water bodies indicate that a toxicologically significant fraction of the inorganic mercury entering the park units in wet and dry atmospheric deposition is being microbially methylated, bioaccumulated as methylmercury, and biomagnified to potentially harmful concentrations in aquatic food webs.

In marked contrast to the results for mercury, the concentrations of legacy contaminants (DDT and metabolites, PCBs, and total lead) and emerging contaminants (PBDEs and PFCs) in the axial muscle (skinless fillets) of fish collected during 2008–2009 from five park units (GRPO, ISRO, PIRO, SLBE, VOYA) were low or below limits of detection. The concentrations of measured legacy and emerging organic contaminants in axial fillets of fish from the five park units during 2008 and 2009 were below levels considered harmful to the health of fish-eating humans. Concentrations of lead and organic contaminants in whole fish collected during 2010–2012 from GRPO, ISRO, PIRO, SLBE, and VOYA were also low or below limits of detection. Concentrations of organic contaminants in whole fish at these five park units did not exceed screening-level benchmark values associated with adverse effects on piscivorous birds and mammals and probably do not pose significant risks to the health of piscivorous wildlife.

At INDU, the concentrations of legacy contaminants and emerging contaminants in whole fish from Great Marsh and Long Lake were below limits of detection or less than reported benchmark levels associated with adverse effects on piscivorous birds and mammals.

At Middle Lagoon, however, concentrations of DDT and metabolites, PCBs, and total lead were elevated in whole fish. Maximum concentrations of DDE, total PCBs, and total lead were 570, 446, and 304 ng/g wet weight in gizzard shad from the lagoon. Concentrations of total DDT (ΣDDT, defined as the sum of concentrations of DDT, DDE, and DDD) exceeded screening-level benchmark concentrations associated with altered health and reproduction in fish, belted kingfisher, and

American mink, indicating that fish and piscivorous wildlife may be at risk from these legacy contaminants in Middle Lagoon. Fillets of fish from INDU were not analyzed for organic contaminants and lead, and an assessment of potential risk to human consumers will require further sampling of fish from the lagoon and subsequent analyses of edible fillets.

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 and by the Great Lakes Restoration Initiative, Environmental Protection Agency Project Number 222, under Task Agreement J2105100001 of the Great Lakes-Northern Forest Cooperative Ecosystem Studies Unit—both under Cooperative Agreement H6000082000 between the NPS and the University of Minnesota. 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 are grateful to the following National Park Service personnel for assisting with planning, logistical preparations, or sampling of biota: B. Route, J. Elias, P. Brown, D. Cooper, L. Kainulainen, R. Knutson, J. LeDuc, L. Loope, R. Maki, J. Marburger, C. Otto, M. Romanski, B. Seitz, S. Windels, and S. Yancho. We thank M. Blazel, S. Buechel, K. Challis, A. Devonald, C. Folster, N. Forseth, M. Hess, L. Jacobson, J. Kotnour, R. Lepak, A. Long, J. Ludwigson, R. Mooney, G. Perrine, W. Puent, A. Ritchay, R. Sadowski, L. Savidusky, A. Schmidt, P. Schulze, J. Schwartz, A. Tronnes, and Y. Liu—all students at the University of Wisconsin-La Crosse—for technical assistance in the field and laboratory. B. Monson and H. Wiegner (Minnesota Pollution Control Agency) assisted with sampling at Voyageurs National Park. We thank M. Brigham, B. Moraska Lafrancois, P. McCann, B. Route, and an anonymous review for providing constructive reviews of an earlier draft of this report.

List of Terms

National Park Service (NPS) 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
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
LOD	limit of detection (analytical)
LOI	loss on ignition (a surrogate measure of organic matter content)
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 state and federal guidelines 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).

The Great Lakes Inventory and Monitoring Network includes nine national park units: 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 more than 130 inland lakes, more than 300 km^2 of wetlands, intermittent streams, about 1,300 km of perennial streams, large river systems, vernal pools, and nearshore areas in Lakes Michigan and Superior (Lafrancois and Glase 2005).

The present assessment focused on bioaccumulative contaminants in aquatic ecosystems and food webs—including fish—in 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 assessed by sampling and analyses of feathers and blood from nestling bald eagles, *Haliaeetus leucocephalus* (Route et al. 2011, 2014a, 2014b). Collectively, these studies provide an extensive assessment of bioaccumulative contaminants in biota across the nine park units in the Great Lakes Network.

The present study followed a two-year pilot study that quantified bioaccumulative contaminants in selected aquatic biosentinel organisms, including adult predatory fish, prey fish, and larval dragonflies, which were sampled in 2008–2009 from selected water bodies in the six park units (Wiener et al. 2013). During 2010–2012, funding from the Great Lakes Restoration Initiative was used to expand the sampling and mercury analysis of aquatic systems in the six park units to include water, surficial sediment, soil, seston, and zooplankton, as well as larval dragonflies, prey fish, and adult predatory fish. We report findings from analyses of these ecosystem and food web components and assess the mercury contamination and sensitivity of studied aquatic systems, the exposure of biota to methylmercury, and the potential ecotoxicological significance of methylmercury, lead, and selected organic contaminants in the six park units.

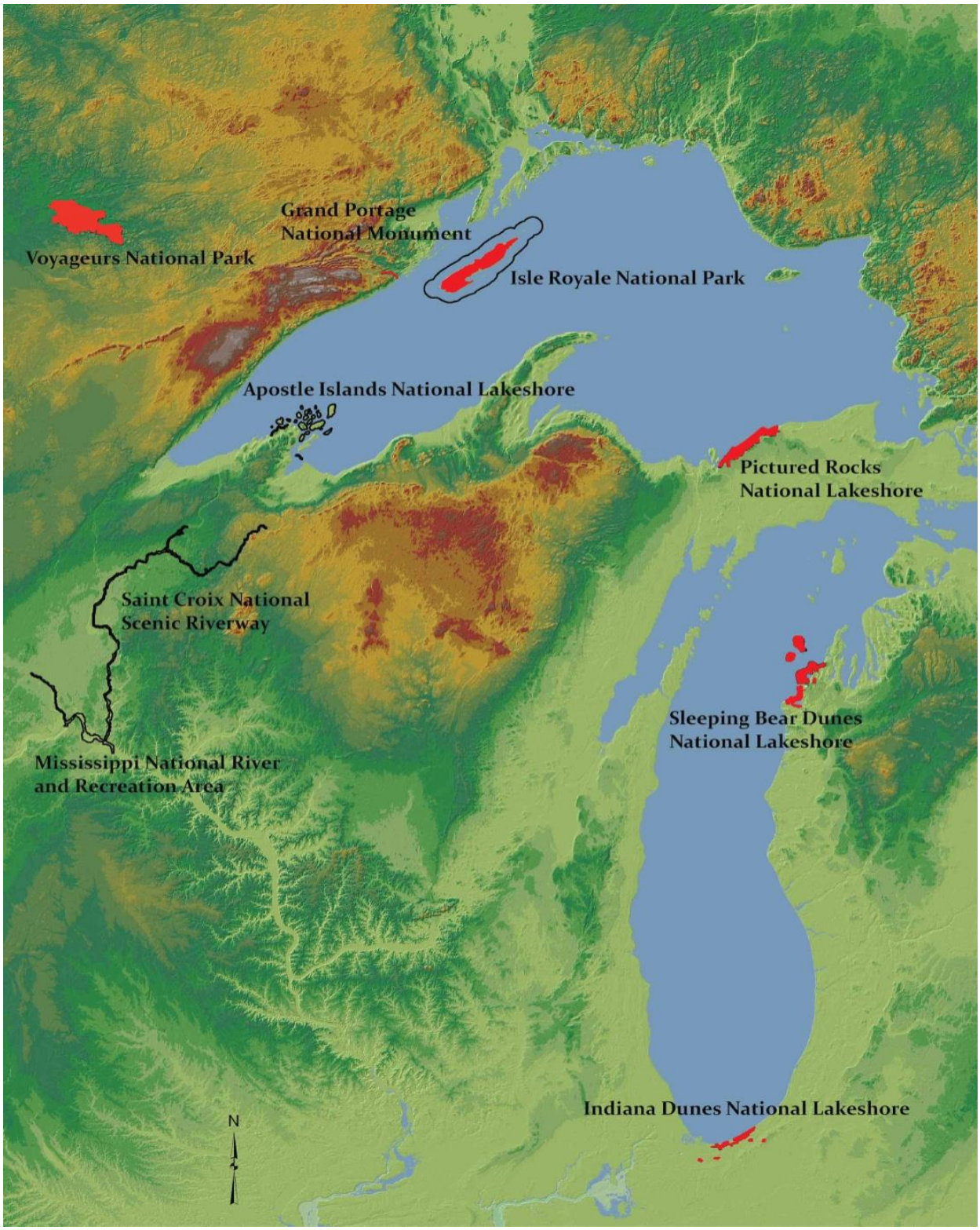


Figure 1. Map of the western Great Lakes region, showing the nine national park units in the Great Lakes Inventory and Monitoring Network. The six park units included in this study are shown in red. The map was modified from an earlier version created by the Great Lakes Inventory and Monitoring Network.

The present study addresses three principal objectives: (1) to assess spatial patterns in contamination of aquatic systems and biota in the six park units, (2) to identify park units and water bodies where bioaccumulative contaminants may pose a risk to organisms—particularly piscivores—atop aquatic food webs, and (3) to provide data for assessing temporal trends in contamination of fish and aquatic food webs in parks of the Great Lakes Network.

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. Therefore, Route et al. (2009) applied the following four criteria to identify, prioritize, 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 either caused a park water body to be listed as polluted under section 303(d) of the U.S. Clean Water Act or 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; a Level I Substance is defined as a substance that has been associated with or has the potential to cause deleterious environmental impacts in the Great Lakes Basin; 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 mercury (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 nine analytes)
PBDE (polybrominated diphenyl ethers; total concentration and 9 to 17 congeners)

Mercury

Atmospheric transport and deposition are the primary pathways for entry of mercury into most watersheds and surface waters in the western Great Lakes region (Wiener et al. 2006, Evers et al. 2011b, Drevnick et al. 2012, Lepak et al. 2015), 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 lacustrine food webs and fish (Wiener et al. 2006, Orihel et al. 2007, Munthe et al. 2007, Harris et al. 2007, Evers et al. 2011b, Lepak et al. 2015).

Spatial patterns in wet deposition of mercury across the Great Lakes region during 2002–2008 and in dry deposition (litterfall) during 2007–2009 were influenced by regional emissions from anthropogenic sources (Risch et al. 2012a, 2012b). Mean annual inputs of mercury in wet and dry deposition were greatest in areas with the greatest emissions from anthropogenic sources (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).

The microbial production of methylmercury strongly affects its concentrations in water and aquatic biota, including fish (Bodaly et al. 1993, Paterson et al. 1998). Landscape factors, including wetland density (Hurley et al. 1995, Chasar et al. 2009) and coniferous forest cover (Drenner et al. 2013, Eagles-Smith et al. 2013), also affect methylmercury levels in water and fish. Thus, both water bodies and landscapes can differ greatly in their sensitivity to mercury loadings from the atmosphere. In mercury-sensitive ecosystems, inorganic mercury is more efficiently converted to methylmercury, and seemingly small inputs of inorganic mercury can cause significant methylmercury contamination of fish and wildlife (Wiener et al. 2003).

Mercury is a highly toxic metal that has no known essential biological function. 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 and other top predators is methylmercury (Grieb et al. 1990, Bloom 1992, Hammerschmidt et al. 1999, Van Walleghem et al. 2007), an organic compound produced by anaerobic bacteria that are present in wetlands, sediment, and anoxic bottom waters (Benoit et al. 2003, Colombo et al. 2013, Gilmour et al. 2013, Parks et al. 2013). In fish, methylmercury readily crosses internal and external biological membranes (Pickhardt et al. 2006), is eliminated very slowly relative to its rate of uptake (Trudel and Rasmussen 1997; Van Walleghem et al. 2007, 2013), and accumulates to concentrations that vastly exceed those in surface water (Wiener et al. 2003). Concentrations of methylmercury in piscivorous fish commonly exceed those in the water in which they reside by a factor of 10^6 to 10^7 or more (Wiener et al. 2003).

Aquatic food webs are the principal pathways for exposure of humans and wildlife to methylmercury (Mergler et al. 2007; Scheuhammer et al. 2007, 2012; McKelvey and Oken 2012; Driscoll et al. 2013). Methylmercury is highly neurotoxic, adversely affecting both the adult and developing brain (Clarkson and Magos 2006, McKelvey and Oken 2012). 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. 2009b). 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 studies have also shown that exposure of fish to environmentally realistic concentrations of methylmercury can

adversely affect gene expression, metabolism, reproduction, and health (Crump and Trudeau 2009, Sandheinrich and Wiener 2011, Scheuhammer et al. 2012).

Concentrations of mercury in predatory fish from many water bodies in the Great Lakes region exceed state and provincial guidelines for fish consumption (Evers et al. 2011a, 2011b) as well as the U.S. Environmental Protection Agency (USEPA) Fish Tissue Residue Criterion for Methylmercury, which was established to protect human health (Borum et al. 2001). Most states in the Great Lakes region have issued statewide guidelines advising that women of childbearing age and children limit their consumption of fish, and many states have issued advisories for specific water bodies (USEPA 2011). In the Canadian province of Ontario, 88% of the fish consumption advisories issued for sport fish in inland waters are due to mercury (Ontario Ministry of Environment 2013). Thus, much of the Great Lakes region can be considered a mercury-sensitive landscape in which atmospheric deposition of mercury has led to high concentrations of methylmercury in predatory fish (Wiener et al. 2003, Evers et al. 2011b).

Lead

Lead is a highly toxic metal that has no known essential biological function. Lead affects all systems in the body, and exposure to lead causes multiple sublethal effects in fish, birds, and mammals (Pattee and Pain 2003, Franson and Pain 2011, Ma 2011). The most sensitive toxicological endpoint for lead is neurotoxicity caused by exposure during early developmental life stages.

Anthropogenic emissions and usage of lead have greatly increased its abundance in the environment (Pattee and Pain 2003). Most of the anthropogenic lead deposited from the atmosphere onto national park units of the Great Lakes Network was probably from vehicular emissions from combustion of leaded gasoline (e.g., Pattee and Pain 2003, Dunlap et al. 2008). 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 1996.

Since the phase-out of leaded gasoline in the United States and elsewhere, concentrations of lead have decreased in nearly all environmental media examined, including air, water, surficial sediment, soils, fish, piscivorous wildlife, and humans (Trefry et al. 1985, Schmitt et al. 1999, Renberg et al. 2000, Lind et al. 2006, Mahler et al. 2006, Stromberg et al. 2008, Wiener and Sandheinrich 2010, Chadwick et al. 2011). Lead in recent atmospheric deposition in the Great Lakes region appears to be derived from coal combustion and industrial processing of lead ore, based on the isotopic composition of metals in wet deposition during 2003–2007 (Sherman et al. 2015).

The uptake, elimination, and distribution of lead in fish have been critically reviewed by Spry and Wiener (1991). Unlike methylmercury, inorganic Pb(II) does not biomagnify in aquatic food webs, and the concentrations of lead within a fish population do not typically increase with increasing body size or age. Lead accumulates chiefly in the bone, scales, gills, kidney, and liver of fish, and its

depuration is slow. Lead does not accumulate appreciably in the skeletal muscle tissue of fish, and consumption of fish is generally not considered a significant pathway for human exposure to lead. As in birds and mammals, the toxicity of lead to fish is systemic, and chronic toxicity increases with increasing concentration of lead in the tissues (Hodson et al. 1982, Hodson 1986).

Wildlife can be exposed to toxic levels of lead by ingestion of spent lead ammunition from hunting or by ingestion of lead weights or jigs used in recreational fishing (Scheuhammer and Norris 1996, Franson and Pain 2011). The ingestion of lead shot, weights, or jigs is the primary cause of elevated lead exposure and poisoning in many avian species, including common loons (*Gavia immer*), bald eagles, golden eagles (*Aquila chrysaetos*), and several species of ducks and geese (reviewed by Sanderson and Bellrose 1986, Scheuhammer and Norris 1996, Franson and Pain 2011, Franson and Russell 2014, Russell and Franson 2014). The use of lead shot for waterfowl hunting was banned in the United States in 1991, and subsequent declines in both the ingestion of lead shot by waterfowl and the associated mortality of waterfowl caused by lead poisoning have been documented (e.g., Anderson et al. 2000). However, spent lead shot deposited onto surface waters remains a long-term threat to birds supported by the benthic food web, given that lead pellets can persist in surficial sediments for several decades (Perroy et al. 2014). Moreover, the ingestion of grossly contaminated sediment can expose foraging waterfowl to lethal amounts of lead (Henny 2003).

Elevated exposure to lead from ingestion of lead-based ammunition also occurs in scavenging birds, such as the bald eagle and the endangered California condor (*Gymnogyps californianus*), that feed on carcasses or discarded viscera from animals shot with lead ammunition (reviewed by Johnson et al. 2013). Moreover, recent studies indicate that many lead poisonings in bald and golden eagles are caused by the ingestion of lead shot and bullet fragments present in unretrieved carcasses or discarded viscera from animals other than waterfowl (Redig et al. 2009, Russell and Franson 2014).

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 use in the United States peaked in 1959 (Blus 2003). In 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, 2011). Fish kills were also documented in many waters shortly after spraying of DDT (Beckvar and Lotufo 2011). After the ban, the concentrations of total DDT, DDE, and DDD in freshwater fish sampled from major rivers across the United States declined significantly (Schmitt et al. 1999), and fish-eating birds, such as osprey (*Pandion haliaetus*) and bald eagles, began to recover as their dietary exposures to DDT and DDE decreased (Grier 1982, Blus 2003, Henny et al. 2009). In North America, the concentrations of DDE in eggs and carcasses of birds have continued to decline during recent decades (Mora et al. 2016). During 1992–2010, the concentrations of total DDT (the sum of DDT, DDE, and DDD) in atmospheric samples and predatory fish from three Great Lakes (Erie, Michigan, and Superior) decreased at similar rates, with halving times for total DDT ranging from 8.4 to 10 years in the atmosphere and from 6.2 to 13 years in fish (Salamova et al. 2013).

DDT and its metabolites or breakdown products, DDE and DDD, persist in the environment, bioaccumulate and are slowly eliminated in exposed organisms, and biomagnify in food webs to high concentrations in upper trophic levels (Kidd et al. 2001, Blus 2003, Houde et al. 2008, Henny et al. 2009, Beckvar and Lotufo 2011). The effects of DDE on the reproduction of birds—including the thinning of eggshells—have been extensively documented (Wiemeyer et al. 1984; Bowerman et al. 1995; Henny et al. 2009; Blus 2003, 2011; Odsjö and Sondell 2014; Mora et al. 2016).

The reproductive impacts of exposure to DDT and its metabolites were particularly severe on populations of fish-eating birds, such as the bald eagle. The population-level effects of DDT and its metabolites on bald eagles and their response to the DDT ban are illustrated by regional trends in the abundance and productivity of nesting bald eagles in the Upper Mississippi River National Wildlife and Fish Refuge (Refuge), based on monitoring of eagles by the U.S. Fish and Wildlife Service. The Refuge extends along almost 500 km of the upper Mississippi River channel and covers about 80,000 ha of the river floodplain in Minnesota, Wisconsin, Iowa, and Illinois. The number of nesting bald eagles on the Refuge declined precipitously during the mid to late 1950s, years when the use of DDT in the United States was at its peak. By 1972, the Refuge contained only one active bald eagle nest (Wiener et al. 1998). After the DDT ban, the number of active bald eagle nests on the Refuge increased from a single nest in 1972 to nine nests in 1986, 62 in 1996, and 167 in 2005. Moreover, the annual production of bald eagles on the Refuge increased 31-fold from 1986 to 2005 (U.S. Fish and Wildlife Service 2006). The numbers of other piscivorous birds, including the double-crested cormorant (*Phalacrocorax auritus*) and American white pelican (*Pelecanus erythrorhynchos*), have also increased substantially on the Refuge since the DDT ban (Wiener et al. 1998), paralleling national population trends for these species (Grier 1982, Bowerman et al. 1995).

Statistical analyses of compiled, published data for bald eagle nestlings from the south shore of Lake Superior, an area with a multi-decadal record of measurement, showed that DDE levels in blood plasma of nestlings declined significantly during 1989–2008, with an average annual decrease of 3.0% (Dykstra et al. 2010). DDE remained detectable in blood plasma from all bald eagle nestlings sampled during 2006–2009 from three areas in the Upper Midwest, including the south shore of Lake Superior (including Apostle Islands National Lakeshore), Mississippi National River and Recreation Area, and St. Croix National Scenic Riverway (Route et al. 2011).

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). The manufacture and use of PCBs were banned in the United States in 1977, after it was determined that these compounds adversely affect wildlife, domestic animals, and humans (Rice et al. 2003).

Concern about environmental contamination by PCBs stems largely from the potential adverse effects of exposure on human health (Kimbrough 1987, Rice et al. 2003, Carpenter 2006). PCBs are classified as probable human carcinogens by the USEPA. In laboratory test animals, PCBs cause a

number of adverse health effects on the reproductive, immune, nervous, and endocrine systems (Hansen 1987, Kimbrough 1987, Rice et al. 2003, Basu et al. 2007).

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, which are important pathways for dietary exposure of fish, wildlife, and humans to PCBs (Rice et al. 2003, Houde et al. 2008). In the United States, PCBs rank second nationally to mercury among bioaccumulative contaminants in the numbers of fish consumption advisories that have been posted for rivers and lakes (USEPA 2011). In the Great Lakes region, fish consumption advisories based on levels of PCBs in fish are in place for all of the Great Lakes and major rivers, and for some contaminated sites (USEPA 2007a, 2011).

Trend analyses have shown that regulatory actions taken to reduce emissions of PCBs have been effective in reducing PCB levels in environmental media, including fish (Salamova et al. 2013, Rasmussen et al. 2014) and bald eagles (Dykstra et al. 2010). Analyses of data from long-term atmospheric monitoring of PCBs in the Arctic, Europe, and North America show that concentrations of PCBs in the atmosphere are generally decreasing, with 247 (74%) of 332 time series showing decreasing trends of PCBs in the atmosphere and 24 time series (7%) showing increasing trends (Kong et al. 2014). In Lake Michigan, PCB levels in skin-on fillets of coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tshawytscha*) decreased rapidly during 1975 to the mid-1980s, and declined more slowly during the mid-1980s to 2010 (Rasmussen et al. 2014).

Atmospheric deposition is an important pathway for entry of PCBs into the Great Lakes and inland waters, and emissions from urban areas appear to be the principal sources of the deposited PCBs (Sofuoglu et al. 2013, Melymuk et al. 2014). In the Great Lakes, temporal trends in concentrations of PCBs in predatory fish closely parallel those in the atmosphere (Salamova et al. 2013). During 1992–2010, the concentrations of total PCB (estimated as the sum of measured congeners) in atmospheric samples and lake trout (*Salvelinus namaycush*) from Lakes Michigan and Superior decreased at similar rates, with halving times for total PCBs ranging from about 12 to 13 years in the atmosphere and from about 10 to 14 years in fish (Salamova et al. 2013).

The American mink (*Neovison vison*, formerly *Mustela vison*), a carnivorous mammal that is distributed throughout the Great Lakes region and across much of North America, is highly sensitive to PCB exposure (Leonards et al. 1995, Basu et al. 2007, Bursian et al. 2013). Declines in wild populations and in ranched mink have been documented—some occurring in apparent response to PCB contamination of their aquatic food resources (Basu et al. 2007). On the Upper Mississippi River National Wildlife and Fish Refuge, for example, populations of American mink declined precipitously during 1959–1965 (Wiener and Sandheinrich 2010). Wiener et al. (1998) concluded that contamination of the riverine food web with PCBs was the probable cause of the decline in mink populations. The timing of the decline of mink on the Refuge coincided with the period of most severe PCB contamination of the river, whereas the partial recovery of mink populations that began in the late 1970s coincided with a period of declining PCB levels in riverine fishes. For comparison, mink populations in the adjoining states of Iowa, Minnesota, and Wisconsin were relatively stable

during this same overall period and did not exhibit the pattern of decline and partial recovery seen in mink populations on the Refuge (Wiener et al. 1998).

PFCs

Perfluorochemicals (PFCs) are a family of stable, fluorinated organic compounds manufactured since 1949 for use in a variety of industrial applications and consumer products, including polyurethane production, water and stain repellants, fire-fighting foams, lubricants, and surfactants (Prevedouros et al. 2006, Paul et al. 2009, Lindstrom et al. 2011). Sources of PFCs to the environment include manufacturing plants, sewage treatment plants, landfills, and households (Ahrens and Bundschuh 2014).

Perfluoroalkyl compounds with long carbon chains, including 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, 2011), including fish (Holzer et al. 2011, Fujii et al. 2015). Long-chain PFCs biomagnify in aquatic food webs (Xu et al. 2014) and accumulate in the axial muscle tissue of fish (Delinsky et al. 2009, Pan et al. 2014, Fujii et al. 2015). Thus, consumption of contaminated fish can be an important pathway for exposure of piscivorous wildlife and humans to long-chain PFCs (e.g., Zhou et al. 2014, Fujii et al. 2015).

Estimated global production and emissions of perfluorooctane sulfonyl fluoride (POSF)-based fluorochemicals (including PFOS) increased substantially during 1970–2000 and subsequently declined rapidly after the voluntarily phase-out by the 3M Company, the major global producer, during 2000–2002 (Paul et al. 2009, Ahrens and Bundschuh 2014). Emissions of PFOA to the environment are also expected to decrease in response to commitments by major industrial producers to reduce production and emissions of PFOA by 99% by 2015 (Ahrens and Bundschuh 2014). However, short-chain perfluorinated compounds continue to be produced.

During the 1970s to 2000, concentrations of PFCs in biota increased rapidly in response to increasing production and releases to the environment, with doubling times ranging from 6 to 10 years (Paul et al. 2009). Since the reduction in emissions by 3M, temporal trends in PFCs in fish and wildlife have been variable, with some studies reporting decreasing concentrations, some reporting increases, and some reporting no change (e.g., Paul et al. 2009, Gewurtz et al. 2012, Roos et al. 2013, Route et al. 2014b, Ullah et al. 2014). In some of these studies, trends in concentrations have varied among analytes (Gewurtz et al. 2012, Route et al. 2014b).

PFCs have been distributed globally by long-range physical transport in fresh waters, the oceans, and the atmosphere (Paul et al. 2009, Ahrens and Bundschuh 2014). Thus, some of these compounds are now analytically detectable in water, fish, and wildlife across geographically widespread locations, including very remote sites (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, Letcher et al. 2015, Lucia et al. 2015).

PFOS is the dominant perfluorinated compound accumulated in fish and wildlife, generally accounting for 60% to 90% or more of total PFCs (sum of all congeners) in the tissues analyzed. This

pattern has been documented in the western Great Lakes region and the upper midwestern United States (Ye et al. 2008; Delinsky et al. 2009, 2010; Custer et al. 2014; Route et al. 2014b; Letcher et al. 2015), as well as other sites around the globe (Houde et al. 2011, Roos et al. 2013, Fang et al. 2014, Pan et al. 2014, Zhou et al. 2014). PFOS was the primary perfluorinated compound present in homogenates of whole fish sampled in 2005 from three large rivers in the Upper Midwest, accounting for 73% of total PFCs in fish from the Ohio and Missouri rivers and for 91% of total PFCs in fish from the upper Mississippi River (Ye et al. 2008). In Minnesota, PFOS was also the most prevalent of 10 PFCs determined in skin-on fillets of three species of panfish sampled in 2007 from 59 lakes and from eight sites on the Mississippi River (Delinsky et al. 2010). Concentrations of PFOS in Minnesota fishes were highest in samples from riverine and lacustrine sites within or downstream from the Minneapolis-St. Paul metropolitan area. In contrast, concentrations of PFOS were low—often below the limit of quantification—in fish from rural Minnesota lakes or from reaches of the Mississippi River upstream from the metropolitan area (Delinsky et al. 2010). In the Great Lakes region, the states of Minnesota, Illinois, Michigan, and Wisconsin have issued fish consumption advisories for areas of the Mississippi River and other water bodies that contain fish contaminated by PFOS. The fish consumption advice issued for PFOS by the States of Minnesota, Wisconsin, and Illinois was based on a reference dose developed by the Minnesota Department of Health (http://www.health.state.mn.us/divs/eh/risk/guidance/gw/pfos.pdf).

In bald eagles, PFOS was the most abundant of 16 PFCs determined in the blood plasma of nestling eaglets sampled during 2006–2011 from six areas in the Upper Midwest, including samples from three national park units (APIS, SACN, and MISS) (Route et al. 2014b). PFOS accounted for 67% of the total PFC present in plasma of eaglets, and perfluorodecanesulfonate (PFDS) accounted for 23%. Concentrations of PFOS, PFDS, and total PFCs were highest in eaglets from nests located in more urban and industrial areas (Route et al. 2014b).

The toxicity of PFCs to fish and wildlife is not well characterized, but these compounds can cause alterations in mammalian development and thyroid hormone production, liver damage, immunosuppression, and cancer (Lau et al. 2007). The reproductive success of tree swallows (*Tachycineta bicolor*) nesting at PFC-contaminated sites in the Minneapolis-St. Paul metropolitan area was diminished by *in ovo* exposure to PFCs (Custer et al. 2014); in that study, the percent of eggs hatching at highly contaminated sites was substantially less than that at both reference areas and the national average (Custer et al. 2014). In general, the toxicological effects of long-term exposure to PFCs in fish and wildlife have been little studied, and effects of low-level exposure are poorly understood (Ji et al. 2008, Custer et al. 2014, Letcher et al. 2015, Lucia et al. 2015).

PBDEs

Polybrominated diphenyl ethers (PBDEs) are a class of persistent, halogenated flame retardants first used in the 1970s in plastics, polyurethane foams, furniture, textiles, and automobiles (Abassi et al. 2015). PBDEs are released to the environment during product use and disposal (Vonderheide et al. 2008, Abassi et al. 2015) and can enter aquatic systems via multiple pathways, including effluents from wastewater treatment plants, runoff and stream flow from nonpoint sources, and atmospheric deposition (Breivik et al. 2006, Hale et al. 2006, Song et al. 2006, Streets et al. 2006, Zou et al. 2007,

Melymuk et al. 2014). Concentrations of PBDEs in the environment have increased substantially since their production and usage as flame retardants intensified in the 1980s (Rayne et al. 2003, Batterman et al. 2007, Gauthier et al. 2008).

PBDEs are lipophilic, and some congeners readily biomagnify in food webs (Law et al. 2006, Wu et al. 2009, Airaksinen et al. 2015, Pérez-Fuentetaja et al. 2015). Thus, fishes with high lipid content generally contain higher concentrations of total PBDEs than fishes with low lipid content (Williams and Schrank 2015). Consumption of fish can be a significant pathway for exposure of wildlife and humans to PBDEs (Route et al. 2014a, Airaksinen et al. 2015, Lyche et al. 2015). Moreover, the environmental ubiquity of PBDEs is illustrated by their presence in wildlife inhabiting remote sites, such as the high Arctic (Lucia et al. 2015). The principal PBDE congeners detected in wildlife sampled from the United States and Canada generally include BDE-47, BDE-99, BDE-100, BDE-153, BDE-154, and BDE 209 (Chen et al. 2013, Eng et al. 2014, Gilchrist et al. 2014, Route et al. 2014a, Spears and Isanhart 2014, Pérez-Fuentetaja et al. 2015, Williams and Schrank 2015). Concentrations are generally highest in wildlife sampled near known sources of PBDEs, such as wastewater treatment plants, landfills, and metropolitan areas (Chen et al. 2013, Gilchrist et al. 2014, Route et al. 2014a, Spears and Isanhart 2014).

From the early 2000s through 2013, concerns about increasing human exposure and health effects led to a series of bans and voluntary phase outs in the production and marketing of new products containing penta-, octa-, and deca-BDEs in the European Union, the United States, and Canada (reviewed by Abassi et al. 2015, Lyche et al. 2015). The bans and restrictions on PBDEs do not affect pre-existing stocks of PBDE-containing products that either remain in use or have entered the waste phase, and such products can be expected to be a continuing source of biotic exposure to these compounds (Abbasi et al. 2015). Landfills used for disposal of municipal solid waste, for example, are significant sources of PBDEs and other flame retardants that were used in consumer products. Concentrations of PBDEs in eggs of European starlings (*Sturnus vulgaris*), a terrestrial omnivorous bird, that feed and nest near landfills are orders of magnitude higher than PBDE levels in eggs from starlings nesting in urban industrial and rural environments (Chen et al. 2013). Although penta-BDE, octa-BDE, and deca-BDE have been phased out of production, the remaining large quantities of consumer products containing these compounds continue to release PBDEs into the environment. The congener composition of PBDEs in sport fishes sampled from Lake Michigan, Lake Superior, and inland waters in Wisconsin during 2002–2012 indicates that PBDEs in these fishes were derived largely from commercial mixtures used in household products (Williams and Schrank 2015).

Responses of PBDEs in the atmosphere have varied among monitoring sites since the relevant commercial penta- and octa-BDEs were banned in North America and the European Union. At two atmospheric monitoring stations in Sweden and Finland where BDE-47, BDE-99, and BDE-100 were regularly detected during 2003–2012, the concentrations of PBDEs decreased rapidly, with half-times ranging from 3.0 to 7.3 years (Kong et al. 2014). In contrast, concentrations of PBDEs in air and precipitation sampled every 12 days during 2005–2011 at five Integrated Atmospheric Deposition Network sites (U.S.) near the Great Lakes varied among monitoring locations and among congeners (Ma et al. 2013). Trend analysis of 14 PBDE congeners in wet deposition, sampled

monthly at nine sites in the Canadian Great Lakes between 2004 and 2010, showed that two congeners (BDE-154 and BDE 209) had consistent temporal trends at three or more sites (Robson et al. 2013); BDE-154 had increasing concentrations over time, whereas BDE-209 had decreasing concentrations.

The effects of low-level exposure to PBDEs on wildlife have received little study, making it difficult to evaluate effects of these compounds on wildlife (Spears and Isanhart 2014, Lucia et al. 2015). Total concentrations of PBDEs were generally low yet varied greatly (range 2.0–307 ng/g wet weight) in eggs of European starlings sampled from nest boxes at an agricultural site in British Columbia (Canada), but reproductive success and measures of condition in the mothers or other offspring from the sampled nests were unrelated to total PBDEs in eggs (Eng et al. 2014).

Williams and Schrank (2015) assessed the need for fish consumption advisories for PBDEs based on reference doses (RfDs) for four congeners (BDE-47, BDE-99, BDE-153, and BDE 209) determined in sport fishes sampled during 2002–2012 from Lake Michigan, Lake Superior, and 19 inland water bodies in Wisconsin. They found that an 8-ounce serving of fillets from most locations would not exceed the RfDs for BDE-47, except for lake trout from the Great Lakes and for common carp from Badfish Creek (Dane County), the Milwaukee River Estuary, and the Sheboygan River. For BDE-99, only siscowet lake trout from Lake Superior exceeded the RfD, whereas the RfDs for BDE-153 and BDE-209 were not exceeded for any fish at any location. Although some fish from a few locations exceeded the RfD for individual congeners, the PBDE levels in most fish were not high enough to trigger exceptions to Wisconsin statewide fish consumption advice already in place for PCBs and mercury (Williams and Schrank 2015).

Study Areas

We studied a total of 23 water bodies at the six national park units. National Park Service biologists and managers at each park unit provided substantial information and input on the selection of study sites at individual park units. To the extent feasible, we included water bodies for which water quality was being monitored by the NPS Great Lakes Inventory and Monitoring Network.

The 23 study sites included three streams at GRPO, three aquatic systems at INDU (Great Marsh, Long Lake, and Middle Lagoon), four lakes at ISRO, five lakes at PIRO, four lakes at SLBE, and four lakes at VOYA (Table 1). Each site was sampled annually during 2010–2012. All of these study sites except Middle Lagoon (INDU) had also been sampled during the two-year pilot study of 2008 and 2009. During the pilot study, the water bodies at INDU, PIRO, and SLBE were sampled during 2008, and the water bodies at GRPO, ISRO, and VOYA were sampled during 2009.

Grand Portage National Monument (GRPO) is in the North Shore Highlands Ecoregion (USEPA 2013). Present-day vegetation in this ecoregion is comprised largely of a mixture of quaking aspen and paper birch (Sanders and Kirschbaum 2015, MN DNR 2006). Land cover (Appendix A) in the drainage areas above the stream reaches sampled was dominated by evergreen forest (32.4%–38%), deciduous forest (11.2%–19.2%), and mixed forest (16.4%–26%) (Fry et al. 2011). Topographic relief among the drainage areas ranged from 186 to 534 m above mean sea level (MSL).

Indiana Dunes National Lakeshore (INDU) is in the Michigan Lake Plain Ecoregion (USEPA 2013). Vegetation in this ecoregion is primarily black oak savanna mixed with conifers (Sanders and Grochowski 2013). Land cover (Appendix A) in the drainage areas above the sampled water bodies was characterized by developed land (24.7%–46.1%), woody wetlands (0.2%–42.6%) and deciduous forest (12.4%–24.2%) (Fry et al. 2011). Topographic relief among the drainage areas ranged from 178 to 231 m above MSL.

Isle Royale National Park (ISRO) is a Laurentian archipelago in the western basin of Lake Superior and is part of the Superior Mineral Ranges Ecoregion (USEPA 2013). Vegetation on the island is a mixture of quaking-aspen, birch, white spruce, and balsam fir (USEPA 2013). Land cover (Appendix A) in the drainage areas above the primary sampling was dominated by mixed forest (27.5%–37.7%), deciduous forest (14%–36.2%), and evergreen forest (14%–19%). Topographic relief among the drainage areas ranged from 189 to 369 m above MSL.

Pictured Rocks National Lakeshore (PIRO) is in the Grand Marais Lakeshore Ecoregion (USEPA 2013). Vegetation along the lakeshore reflects pre-Euro-American cover and includes jack, red, and white pine growing on dune complexes and dry lake beds, whereas tamarack, spruce, and white cedar are common in poorly drained areas (USEPA 2013). Land cover (Appendix A) in the drainage areas above our primary sampling sites was dominated by deciduous forest (59%–76.2%). Topographic relief among the drainage areas ranged from 184 to 339 m above MSL.

Sleeping Bear Dunes National Lakeshore (SLBE) is in the Manistee-Leelanau Shore Ecoregion (USEPA 2013). A beech-sugar maple complex interspersed with other northern hardwoods

dominates the vegetative community along the sandy portions of the lakeshore (USEPA 2013). Land cover (Appendix A) in the drainage areas above the primary sampling was dominated by deciduous forest (20.6%–82%). Topographic relief among the drainage areas ranged from 177 to 316 m above MSL.

Table 1. Physical characteristics of 23 water bodies studied in six national park units during 2008–2009 and 2010–2012 and their watersheds.

	Lakes and Wetlands		Watersheds		Streams	
National park unit and water body	***Max. depth (m)***	***Surface area (ha)***	***Drainage area (km^2)***	***Elevation min-max (m)***	***Total length (km)***	***Stream order***
GRPO						
Grand Portage Creek			18.13	186–534	13.6	2
Poplar Creek			11.43	299–534	12.1	2
Snow Creek			4.05	382–451	2.2	1
INDU						
Long Lake	1.5	33	16.70	178–226		
Middle Lagoon	3.1	9.9	3.00	180–231		
Great Marsh	<1	1500	0.54	179–209		
ISRO						
Angleworm Lake	8.4	50	2.77	238–313		
Lake Harvey	4.3	55	3.00	232–368		
Lake Richie	10.5	216	21.10	189–313		
Sargent Lake	12.7	143	11.30	207–349		
PIRO						
Beaver Lake	9.2	310	32.30	184–323		
Chapel Lake	45	28	23.90	186–322		
Grand Sable Lake	19.2	255	41.30	221–334		
Legion Lake	11.9	14	0.77	278–323		
Miners Lake	3.3	5	63.5	189–301		
SLBE						
Bass Lake (Leelanau Co.)	7	38	8.54	195–288		
Bass Lake (Benzie Co.)	8	12	0.31	177–193		
Lake Manitou	10.7	104	15.00	188–315		
Round Lake	6.9	6	0.46	181–231		
VOYA						
Brown Lake	8	31	5.67	359–417		
Peary Lake	5	45	9.50	343–417		
Ryan Lake	4	14	1.10	353–393		
Sand Point Lake	56	3580	2,057,636	335–682		

Voyageurs National Park (VOYA) is in the Boundary Lakes and Hills Ecoregion (USEPA 2013). Vegetation in the forested hills of the park is dominated by jack pine, spruce, and northern hardwoods (Faber-Langendoen et al. 2007). Land cover (Appendix A) in the drainage areas above the primary sampling was dominated by deciduous forest (9.3%–42.2%) and mixed forest (23.7%–39.2%). Topographic relief among the drainage areas ranged from 335 to 682 m above MSL.

The water bodies studied at VOYA included three small drainage lakes (Brown, Peary, and Ryan lakes) with small watersheds, and one much larger lake (Sand Point Lake) with a vastly larger watershed (see Table 1). Mercury contamination of fish had been investigated in each of these water bodies for several years before the present study was begun (e.g., Sorensen et al. 2005, Wiener et al. 2006, Brigham et al. 2014).

More detailed descriptions of these park units and their aquatic resources have been provided elsewhere (Lafrancois and Glase 2005; Kallemeyn 2000; Soupir et al. 2000; Kallemeyn et al. 2003; Kraft et al. 2010; Mechenich et al. 2009; Elias and Damstra 2011, 2012; Gorman et al. 2014; Kraft et al. 2014; Rolfhus et al. 2015a).

Methods

Mercury in Aquatic Food Webs and Ecosystems—Approach

We determined total mercury and methylmercury in unfiltered and filtered water, seston, bulk pelagic zooplankton, larval dragonflies, littoral surficial sediment, and nearshore surficial soil. Total mercury was determined in prey fish and adult predatory fish.

We used information from the analyses of these ecosystem and food web components to assess patterns in mercury contamination, ecosystem sensitivity to mercury, biotic exposure to methylmercury, and the potential ecotoxicological significance of methylmercury in selected water bodies within the six park units. Concentrations of total mercury in surficial soil and sediment indicate the contamination of the studied systems (Krabbenhoft et al. 2007). Methymercury concentrations and percent methylmercury (the fraction of total mercury present as methylmercury in water, surficial sediment, and soil) are indicators of the microbial production of methylmercury (Heyes et al. 2006, Krabbenhoft et al. 2007), the organic compound that readily accumulates in biota and biomagnifies in food webs. Larval dragonflies, small prey fish, and adult fish are relevant and useful biosentinels for assessing spatiotemporal patterns in the concentration of methylmercury in aquatic biota and associated risks to wildlife and humans (Wiener et al. 2007, Haro et al. 2013).

A survey of lakes in the western Great Lakes region (Rolfhus et al. 2011) indicated that the supply of aqueous methylmercury is probably responsible for patterns in the bioaccumulation of methylmercury in pelagic food webs. The greatest trophic biomagnification of methylmercury occurs in the lowest portion of the aquatic food web (Rolfhus et al. 2011). Concentrations of methylmercury, for example, typically increase by 100,000-fold or more between water and phytoplankton (a biotic component of seston), with lesser incremental increases in concentration as methylmercury is transferred up the aquatic food web to piscivorous fish and wildlife. It is widely accepted that the bioaccumulation of methylmercury in upper trophic levels is strongly influenced by the amount of methylmercury available for entry into the base of the food web (Paterson et al. 1998, Chasar et al. 2009, Bradley et al. 2013).

Sampling of Lower Food Web, Soil, Sediment, and Larval Dragonflies

Water, Seston, and Zooplankton

We sampled unfiltered and filtered water, seston, and bulk zooplankton. Environmental concentrations of total mercury and methylmercury in these components are generally quite low, typically in the parts per trillion to parts per billion range. Therefore, clean techniques were applied in the field and laboratory to prevent contamination of samples during collection, handling, and processing.

Unfiltered and filtered water was sampled at a depth of 1–2 m from the approximate center of each lake, and 1 m from the margin of streams. Water was collected in acid-washed Teflon bottles with a peristaltic pump, Teflon tubing, and in-line 0.45-µm polyethersulfone filters (filtered samples only). Water samples were promptly acidified with trace-grade HCl to 0.5% v/v and stored in a refrigerator until analysis. Samples for measurement of dissolved sulfate ion (Dionex IC-90 instrument) and dissolved organic carbon (DOC; Shimadzu TOC-V-CSH) were collected concurrently with the water

samples taken for mercury determination. Aqueous pH, temperature, dissolved oxygen, and specific conductance were measured *in situ* with a multi-parameter probe (Thermo-Fisher Orion 5-Star).

Seston (suspended particulate matter) was collected by pumping 1 to 2 L of water onto ashed quartz-fiber filters held in an in-line Teflon filter pack. Filters were removed from the packs and stored frozen in plastic petri dishes until analysis. Bulk zooplankton was collected with a 152-µm nitex conical net, towed horizontally for 20–30 m within the mixed surface layer at a depth of about 5–10 m near the center of each lake. Net material was collected into a Teflon cup, poured through nitex to remove water, and stored frozen in Teflon vials until analysis.

Surficial Sediment and Soil

Surficial sediment was collected with an acid-washed, acrylic sleeve and Teflon plunger. The sleeve was manually pushed into sediment, capped, and the sample extruded into polypropylene cups before freezing. Sediment was collected in areas within 10 to 20 m of sampling sites for dragonfly larvae, typically in 0.1–1.0 m of water. The sampled sediments were often sandy and had very low organic matter content because of the high-energy mixing and sorting that is characteristic of nearshore areas. Surficial soil (0–5 cm depth) was collected in 2012 from lake and stream margins, at a distance of 2 to 4 m from the shoreline. Soils were collected with a 2.5-cm stainless steel soil corer equipped with acid washed plastic liner, and stored frozen in polypropylene cups. Five surface core samples were composited into a single sample at PIRO and SLBE, whereas two to four individual cores were collected at each of the other parks. Mercury and methylmercury in sediment and soil are strongly associated with organic matter; therefore, we measured loss on ignition (LOI) to examine and compare variation in concentrations of total mercury and methylmercury among sediment samples that differed in organic matter content. To determine LOI, which was used as a surrogate measure of organic matter content, the lyophilized samples were combusted at 550ºC for five hours and the resulting change in sample mass was quantified.

Larval Dragonflies

Dragonflies (Insecta: Anisoptera: Odonata) are a well-known group of insects, whose larvae inhabit a diverse variety of freshwater ecosystems. County records from the North American Odonate Database (Abbott 2007) indicate that many species of dragonflies from the families Libellulidae, Gomphidae, Corduliidae, and Aeshnidae occur in the vicinity of national park units of the Great Lakes Inventory and Monitoring Network. The advantages and rationale for the use of larval dragonflies as biosentinels in aquatic monitoring and assessment programs for mercury and other toxic metals have been described in detail (Johnson et al. 1993, Haro et al. 2013, Wiener et al. 2013).

The ecology of larval dragonflies is well documented at the genus level (Tennessen 2007). All larval dragonflies are obligate, generalist predators that bioaccumulate methylmercury. 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). For example, species in the families Gomphidae and Cordulegastridae, 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 in trophic pathways can be expected to influence dietary uptake of methylmercury (Tremblay et al. 1996).

Larval dragonflies were sampled annually during April through early June with dip nets from benthic, sedimentary, vegetated, and woody substrates in nearshore, littoral areas of lakes (INDU, ISRO, PIRO, SLBE, VOYA) and along the margins of streams (GRPO) or wetlands (Great Marsh at INDU). Most dragonflies in the western Great Lakes region have long life cycles, in which the larval stage can continue for as long as four years (Hilsenhoff 1995). Our sampling targeted larger larvae (late instars), which were expected to emerge within a few weeks as winged adults. In the field, netted larvae were handled with stainless steel forceps and held in zip-seal bags with lake water or stream water. After collection, larvae were held overnight in aerated water at room temperature to allow egestion of gut contents. During the next morning, larvae were placed into plastic vials filled with tap water and then stored in a domestic freezer until further processing.

In the laboratory, larvae were thawed, identified to species (Hilsenhoff 1995, Needham et al. 2000), sexed, photographed, and measured (body length and wet weight). The total length (distance from the apex of the head to the terminus of the abdomen) and wingpad index of each larval dragonfly were obtained from images taken with a Nikon DXM 1200 digital camera. The *wingpad index,* defined as the abdominal segment overlain by the distal tip of the front wingpad (the mesothoracic wing sheath), was used to discriminate among the final instars of larval dragonflies. The maximum reach of the front wingpad over the abdomen varies among odonate species, but for a given species the wingpad index provides a relative index of how developed a larvae is relative to its terminal stadium, the one prior to emergence as an adult (Corbet 1999). The sex of larvae was determined by examination of secondary sexual characteristics, including swellings on abdominal segments 2 and 3 in male larvae (Needham et al. 2000).

Individual larvae were lyophilized whole to a nearly constant dry weight and homogenized with an acid-washed ceramic or glass mortar and pestle. Samples for mercury determination were processed, stored, and analyzed according to standard "clean-hands" procedures detailed in EPA Method 1631 (USEPA 2001), and lyophilized homogenates were stored in a desiccator until acid digestion.

Mercury Analyses—Lower Food Web, Soil, Sediment, and Larval Dragonflies

Methodological advances in mercury analyses now allow reliable measurements at parts-per-trillion levels, with a purge-trap technique that converts mercury to gaseous forms followed by detection of the mercury vapor by atomic fluorescence or atomic absorption.

Methylmercury Determinations

Methylmercury in water, seston, sediment, and soil was analyzed by an adaptation of the standard steam distillation method (USEPA 1998, Olson et al. 1997). Approximately 90 mL of an aqueous sample, a seston-laden filter, or a 0.05- to 1.0-g mass of soil/sediment sample was added to a Teflon bottle containing 1.0 mL of 20% w/v $CuSO_4$. Seston, sediment, and soil had an additional 90 mL of deionized water added, as well as 0.5 mL 25% w/v KCl, and 0.5 mL 50% v/v H_2SO_4. Samples were distilled at 120ºC through Teflon tubing into an ice-cold receiving Teflon container, at 50 mL/minute N_2 purge rate until 60% to 90% of the original solution volume was transferred. Distillates were then analyzed by pouring a sub-sample into an amber 40-mL autosampler vial, adding 0.4 mL of 2 M acetate buffer, 0.03–0.05 mL of sodium tetraethylborate, and deionized water to exactly 40 mL.

Samples were analyzed by GC-separation cold vapor atomic fluorescence spectrometry (CVAFS) with a Brooks Rand MERX-M instrument and Model III detector.

Methylmercury in dragonfly larvae and bulk zooplankton was determined with an adaptation of Hammerschmidt and Fitzgerald (2005). A mass of dried, homogenized sample (0.02–0.07 g) was added to a 22-mL Teflon vial, as well as 7.0 mL of 4.5 M HNO_3. The solution was then digested at 60ºC for 12 h in a laboratory oven. After digestion, a 0.10-mL aliquot was added to a MERX-M autosampler vial and analyzed with the analytical procedure described above for water.

Total Mercury Determinations

Total mercury in water and seston was determined by an adaptation of EPA Method 1631 and Olson et al. (1997). Briefly, 2 mL of 0.2 M BrCl was added to each water sample bottle or vial containing a seston filter, followed by digestion at 40oC for 12 h in a laboratory oven. After digestion, samples were reduced by adding 0.20 mL of 30% w/v $NH_2OH \cdot HCl$. Approximately 20 mL of sample and 0.1 mL of 20% w/v $SnCl_2$ was added into a clean 40-mL autosampler vial. Samples were then analyzed by cold vapor atomic fluorescence spectrometry with a Brooks Rand MERX-T autosampler instrument and Model III detector. Total Hg in seston was determined by placing seston-laden filters into a Teflon vial with 20 mL deionized water and 2.0 mL of 0.2 M BrCl, followed by digestion at 40ºC for 12 h and analysis in a manner identical to the water samples.

Total mercury in dragonfly larvae and bulk zooplankton was determined from the original digested sample used for methylmercury analysis (Hammerschmidt and Fitzgerald 2005). An additional 2.0 mL of 0.2 M BrCl was added to the vial, followed by a second digestion at 40ºC for 12 h. Following digestion, samples were reduced by adding 0.20 mL of 30% w/v $NH_2OH \cdot HCl$. A 1.0-mL aliquot of sample and 0.1 mL of 20% w/v $SnCl_2$ were added into a clean 40-mL autosampler vial, along with approximately 20 mL of deionized water. Instrumental methods were identical to the determination of total Hg in water samples described above.

Total mercury in sediment and soil was determined without chemical digestion by direct mercury analysis, following EPA Method 7473 (USEPA 2007b). A 0.05- to 1.0-g dried, homogenized sample was weighed into a clean quartz boat and analyzed by thermal/catalytic decomposition and atomic absorption spectrometry with an automated Milestone DMA-80 direct mercury analyzer.

Sampling and Mercury Analyses of Prey Fish

Prey fish (often termed “forage fish”) are small finfish that are consumed whole by predatory fish and many species of piscivorous 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 (Yeardley 2000, Lazorchak et al. 2003, Choy et al. 2008, Wiener et al. 2007, Ackerman et al. 2015). Prey fish are important in the transfer of methylmercury to piscivorous fish and to 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 in the Great Lakes region (Colby et al. 1979, Barr 1996, Soupir 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; these included green sunfish (*Lepomis cyanellus*), bluegill (*Lepomis macrochirus*), rock bass (*Ambloplites rupestris*), blacknose dace (*Rhinichthys atratulus*), longnose dace (*Rhinichthys cataractae*), creek chub (*Semotilus atromaculatus*), fathead minnow (*Pimephales promelas*), central mudminnow (*Umbra limi*), johnny darter (*Etheostoma nigrum*), Iowa darter (*Etheostoma exile*), mottled sculpin (*Cottus bairdii*), slimy sculpin (*Cottus cognatus*), and brook stickleback (*Culaea inconstans*).

Prey fish were sampled annually from each water body with a DC-pulse back-pack electrofisher, small-mesh bag seine, or dip nets. In the field, prey fish were euthanized with tricaine methansulfonate (MS-222) and subsequently frozen 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 then placed into a labeled, zip-seal plastic bag, and stored in a domestic chest freezer until lyophilization to a nearly constant dry 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.

All prey fish were analyzed individually, as recommended by Wiener et al. (2007). Two methods and mercury detectors were used to quantify total mercury in whole prey fish. Most (n = 308) of the prey fish sampled in 2008 were acid-digested and analyzed with a Teledyne Leeman Labs Hydra AF Gold Plus automated analyzer by CVAFS, with methods described by Wiener et al. (2013). The remaining whole prey fish sampled in 2008 (n = 188) and all prey fish sampled during 2009–2012 were analyzed without digestion by direct mercury analysis, following EPA Method 7473 (USEPA 2007b). Individual 40- to 50-mg samples of dried, homogenized whole fish were 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 averaged 8.8 ng/g dry weight (or about 2 ng/g wet weight) for all samples analyzed. The concentration of total mercury in each whole prey fish was quantified on a dry-weight basis and converted to a wet-weight value based on the percent water content of the fish sample. Quality assurance metrics for fish analyzed by acid digestion plus CVAFS were similar to those for fish analyzed by direct mercury analysis (documented in Table 3 in Wiener et al. 2013).

For whole yellow perch, we tabulated concentrations of mercury for two total-length groups: fish <100 mm and fish ≥100 mm. 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 piscivorous fishes, can consume fish larger than 100 mm (Barr 1996, Merrill et al. 2005).

Sampling and Mercury Analyses of Adult Fish

This sampling targeted fishes in upper trophic levels of aquatic food webs, particularly sport fishes that are largely piscivorous as adults and that are commonly sought by anglers. The analyses of axial muscle (skinless fillets) from adult predatory fishes provide information on concentrations of contaminants in fish tissue that are commonly eaten by humans. Accordingly, the analyses of total mercury, organic contaminants, and lead in edible fillets of predatory fish provides information useful for human health-risk assessment.

Northern pike (*Esox lucius*), which are largely piscivorous as adults, were the preferred predatory fish in this study. Northern pike are widely distributed and often abundant in inland lakes, rivers, and streams in national parks and elsewhere within the northern Great Lakes region (Kallemeyn 2000, Kallemeyn et al. 2003, Bethke and Staples 2015). Northern pike are also a popular sport fish in the region, and fish caught by anglers are often eaten. Additional predatory fish species sampled in water bodies with or without northern pike included smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), walleye (*Sander vitreus*), grass pickerel (*Esox americanus*), large yellow perch, and large rock bass. Other adult fishes analyzed for mercury included black crappie (*Pomoxis nigromaculatus*), channel catfish (*Ictalurus punctatus*), black bullhead (*Ameiurus melas*), common carp (*Cyprinus carpio*), rainbow trout (*Oncorhynchus mykiss*), and creek chub. A complete list of fish species sampled and analyzed in this study is provided in Appendix B.

For two study lakes—Chapel Lake (PIRO) and Lake Harvey (ISRO)—we used yellow perch or rock bass as representative predatory fish because no northern pike, walleye, smallmouth bass, or largemouth bass were obtained during four (annual) sampling visits to either lake. The diet and trophic position of yellow perch change substantially during their growth and development. 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 about 130 mm, yellow perch regularly consume fish prey (Tonn and Paszkowski 1986, Fullhart et al. 2002). Yellow perch exceeding 190–200 mm in length are effective piscivores, feeding primarily on fish (Paskowski and Tonn 1994, Fullhart et al. 2002). Rock bass begin preying on small fishes at an age of about 4 years (Keast and Welsh 1968, Keast 1985). The total lengths of yellow perch analyzed for mercury (axial muscle) ranged from 132–285 mm in Chapel Lake and from 128–347 mm in Lake Harvey, whereas the rock bass (Chapel Lake) analyzed for mercury ranged from 95–231 mm in total length. We assume that the fish in these samples were largely piscivorous, based on published food-habit studies for these species.

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, captured fish were held in mesh bags suspended in the water column. Before departing the study site, each fish was euthanized with a sharp blow to the head and cervical dislocation, given a metal jaw tag for identification, and placed into two labeled, food-grade plastic bags for transport in coolers with wet

or dry 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). Structures for age estimation were taken from northern pike (cleithra), largemouth bass (scales), smallmouth bass (scales), walleye (scales), and yellow perch (scales) (DeVries and Frie 1996). 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 muscle 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.

The age of predatory fish was estimated from the cleithra or scales examined by two persons working independently of each other. If the initial two age estimates differed for an individual fish, a third person also independently estimated the age of the fish. Age estimates were retained for fish for which two estimates of age were in agreement.

Mercury Determination—Axial Muscle Tissue

All adult fish were analyzed individually. Total mercury in axial muscle from all but 11 of the predatory fish sampled during the pilot study (2008–2009) was determined with procedures modified from EPA Method 1631, with methods for digestion and analysis of samples described by Wiener et al. (2013). Axial muscle from the 11 remaining predatory fish sampled during 2008–2009 and from all predatory fish sampled during 2010–2012 was analyzed for total mercury without digestion with a Milestone DMA-80 Direct Mercury Analyzer (EPA Method 7473; USEPA 2007b). Concentrations of total mercury in all axial muscle samples exceeded our calculated method detection limits, which averaged 12.1 ng/g dry weight (or about 2.5 ng/g wet weight) for all samples analyzed. Total mercury in each sample was quantified on a dry-weight basis, and the dry-weight concentration was converted to a wet-weight value based on the percent water content of the axial muscle sample.

Quality Assurance and Quality Control

The precision and accuracy of total mercury and methylmercury determinations 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. In this section, we summarize quality-assurance metrics during determinations of total mercury and methylmercury in physical and biological samples from the six national park units.

Soil, Sediment and Seston

Quality assurance during analyses of solids (soil, sediment, and seston) was assessed for precision, spike recovery, and recovery from standard reference materials (Table 2). For total mercury, mean precision (coefficient of variation) during analyses of triplicate samples was 7.8%, mean spike recovery was 98.2%, and mean recoveries from two reference materials were within the certified ranges. For methylmercury, mean precision during analyses of triplicate sample was 13.2%, spike recovery was 102.4%, and the mean recovery from a NIST reference material was just above the certified range, but had a 95% confidence interval that overlapped the certified concentration range.

These results represent an acceptable outcome relative to our target expectations for determinations of total mercury and methylmercury in soil, seston, and surficial sediment (Table 2).

Table 2. Summary of quality assurance measures during determination of total mercury (THg) and methylmercury (MeHg) in soil sampled during 2012 and in surficial sediment and seston sampled during 2010–2012 from six national park units.

Analyte	Quality assurance metric	Material analyzed	Quality assurance results		
			n	*Our mean ± 95% CI* [1]	*Target result or certified range*
THg	Precision (CV, %) [1]	Triplicate samples	11	7.8 ± 3.0%	≤15%
	Recovery (%)	Spiked samples	8	98.2 ± 2.1%	85% – 115%
	Accuracy (conc, ng/g) [2]	NRCC MESS-3 (estuarine sediment)	8	92.0 ± 2.2 ng/g	82 – 100 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NIST SRM 2976 (mussel tissue)	3	59.8 ± 5.1 ng/g	57.4 – 64.6 ng/g (certified range)
MeHg	Precision (CV, %) [1]	Triplicate samples	10	13.2 ± 5.2%	≤25%
	Recovery (%)	Spiked samples	9	102.4 ± 7.9%	75% – 125%
	Accuracy (conc, ng/g) [2]	NIST SRM 2976 (mussel tissue)	15	29.7 ± 1.4 ng/g	27.8 – 28.4 ng/g (certified range)

[1] CI is confidence interval; CV is coefficient of variation (CV = 100 x RSD); n is the number of determinations made on the material analyzed.

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

Water

Quality assurance during analyses of water samples was assessed by recovery of standard additions and precision (Table 3). No reliable reference material for water matrices was available for use during the study. For total mercury, the mean precision (coefficient of variation) during analyses of triplicate samples was 9.9%, and spike recovery averaged 104%. For methylmercury, the mean percent difference during analyses of duplicate samples was 14.9% (acceptable given the large number of low-concentration samples analyzed), and the mean spike recovery was 105%. These results represent an overall acceptable outcome relative to our target expectations for determinations of total mercury and methylmercury in unfiltered and filtered surface water (Table 3).

Table 3. Summary of quality assurance measures during determination of total mercury (THg) and methylmercury (MeHg) in unfiltered and 0.45-µm filtered water sampled from six national park units during 2010–2012.

Analyte	Quality assurance metric	Material analyzed	Quality assurance results		
			n	*Our mean ± 95% CI* [1]	*Target result*
THg	Precision (CV) [1]	Triplicate samples	6	9.9 ± 12.0%	≤15%
	Recovery (%)	Spiked samples	6	104 ± 10%	85% – 115%
MeHg	Precision (% difference) [1]	Duplicate samples	12	14.9 ± 4.1 %	≤25%
	Recovery (%)	Spiked samples	15	105 ± 10 %	75% – 125%

[1] CI is confidence interval; CV is coefficient of variation (CV = 100 x RSD); n is the number of determinations made on the material analyzed.

Zooplankton and Larval Dragonflies

Quality assurance during analyses of aquatic invertebrates (bulk zooplankton and larval dragonflies) was assessed by precision, spike recovery, and recovery from standard reference materials (Table 4). For total mercury, mean precision during analyses of triplicate sample was 4.9% (coefficient of variation), mean spike recovery was 106%, and the mean recoveries from two reference materials were near the midpoints of the two certified ranges. For methylmercury, mean precision during analyses of triplicate samples was 7.6%, mean spike recovery was 105%, and the mean recovery from reference material NRCC TORT-2 was within the certified range. Our results during analysis of NIST standard reference material 2976 (mussel tissue) were slightly below the certified range. We note that most of the samples of aquatic invertebrates analyzed had concentrations closer to the certified range of the NRCC TORT-2 reference material (lobster hepatopancreas). These results represent an overall acceptable outcome relative to our target expectations for determinations of total mercury and methylmercury in zooplankton and larval dragonflies (Table 4).

Table 4. Summary of quality assurance measures during determination of total mercury (THg) and methylmercury (MeHg) in larval dragonflies sampled during 2008–2012 and in zooplankton sampled during 2010–2012 from six national park units.

Analyte	Quality assurance metric	Material analyzed	Quality assurance results		
			n	***Our mean ± 95% CI*** [1]	***Target result or certified range***
THg	Precision (CV, %) [1]	Triplicate samples	94	4.9 ± 1.0%	≤15%
	Recovery (%)	Spiked samples	92	106 ± 2%	85% – 115%
	Accuracy (conc, ng/g) [2]	NIST SRM 2976 (mussel tissue)	87	61.1 ± 0.8 ng/g	57.4 – 64.6 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC TORT-2 (lobster hepatopancreas)	94	281 ± 3 ng/g	210 – 330 ng/g (certified range)
MeHg	Precision (CV, %) [1]	Triplicate samples	96	7.6 ± 1.2%	≤25%
	Recovery (%)	Spiked samples	96	105 ± 3%	75% – 125%
	Accuracy (conc, ng/g) [2]	NIST SRM 2976 (mussel tissue)	91	26.9 ± 0.3 ng/g	27.8 – 28.4 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC TORT-2 (lobster hepatopancreas)	97	154 ± 2 ng/g	139 – 165 ng/g (certified range)

[1] CI is confidence interval; CV is coefficient of variation (CV = 100 x RSD); n is the number of determinations made on the material analyzed.

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

Fish

Mean concentrations of total mercury were within the certified ranges for all reference materials analyzed with axial fillets and whole prey fish sampled during 2008–2012 (Table 5). The precision (coefficient of variation) of samples analyzed in triplicate averaged 3.8% for axial fillets and 6.2% for whole prey fish. Mean recoveries of mercury from spiked samples were 102.6% for axial fillets and 100.4% for whole prey fish. In addition, we note that the quality assurance measures for samples of fish analyzed by acid digestion and CVAFS during 2008–2009 were similar to those for fish analyzed by direct mercury analysis (see Table 3 in Wiener et al. 2013). These results represent an acceptable outcome relative to our target expectations for determination of total mercury in fish (Table 5).

Table 5. Summary of quality assurance measures during determination of total mercury in axial muscle tissue of fish and in whole prey fish sampled from six national park units during 2008–2012.

Fish sample matrix	Quality assurance metric	Material analyzed	Quality assurance results		
			n	*Our mean ± 95% CI* [1]	*Target result*
Axial muscle tissue (skin-off fillets)					
	Precision (CV, %) [1]	Triplicate samples	43	3.8 ± 0.85%	≤10%
	Recovery (%)	Spiked samples	43	102.6 ± 1.4%	90% – 110%
	Accuracy (conc, ng/g) [2]	NIST SRM 2976 (mussel tissue)	6	62.1 ± 5.0	57.4 – 64.6 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC TORT-2 (lobster hepatopancreas)	5	291 ± 28	210 – 330 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC DORM-3 (dogfish muscle)	38	389 ± 5	322 – 442 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC DOLT-4 (dogfish liver)	37	2664 ± 16	2360 – 2800 ng/g (certified range)
Whole prey fish					
	Precision (CV, %) [1]	Triplicate samples	127	6.2 ± 0.4%	≤10%
	Recovery (%)	Spiked samples	127	100.4 ± 0.9%	90% – 110%
	Accuracy (conc, ng/g) [2]	NIST SRM 2976 (mussel tissue)	75	61.7 ± 0.5	57.4 – 64.6 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC TORT-2 (lobster hepatopancreas)	9	285 ± 9	210 – 330 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC TORT-3 (lobster hepatopancreas)	8	288 ± 8	270 – 314 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC DORM-3 (dogfish muscle)	118	384 ± 3	322 – 442 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC DORM-4 (dogfish muscle)	11	396 ± 4	355 – 465 ng/g (certified range)
	Accuracy (conc, ng/g) [2]	NRCC DOLT-4 (dogfish liver)	39	2641 ± 19	2360 – 2800 ng/g (certified range)

[1] CI is confidence interval; CV is coefficient of variation (CV = 100 x RSD); n is the number of determinations made on the material analyzed.

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

Method Detection Limit (MDL)

Method detection limits were used to assess the ability of our methods to measure instrumental signals relative to background variability. The MDL was determined for each type of analysis by calculating three-times the standard deviation of three to seven replicates of the procedural blank mercury mass, divided by the average sample mass or volume. Our MDL values were near or slightly below typical values generated in reputable laboratories across the globe that are conducting similar analyses. Almost 100% of our measurements were above the detection limits for total mercury, and more than 90% for methylmercury (Table 6). Samples in physical and biotic components of the lower food web typically have low concentrations of methylmercury; therefore, the fraction of samples below the calculated method detection limit was greater for components of the lower food web than that for other environmental samples, such as predatory fish, prey fish, and larval dragonflies. In samples where mercury was detected instrumentally but below our calculated MDLs, we used the estimated concentrations during statistical analysis of data. Methylmercury was not determined in fish samples, because nearly all (generally ≥95%) of the mercury in whole prey fish is present as methylmercury (Hammerschmidt et al. 1999, Drysdale et al. 2005, Van Walleghem et al. 2007, Greenfield and Jahn 2010) and virtually all of the mercury in the axial muscle tissue (skinless fillets) of fish is methylmercury (Grieb et al. 1990, Bloom 1992).

Table 6. Summary of method detection limits (MDL) during determination of total mercury (THg) and methylmercury (MeHg) in physical and biological samples collected from six national park units during the study.

		Quality assurance results	
Analyte	**Material analyzed**	***Our mean MDL*** [1]	***Percent of samples exceeding MDL***
THg	water	0.22 ng/L	99.6
	sediment and soil	0.35 ng/g	99.0
	seston	1.0 ng/g	100
	zooplankton	2.1 ng/g	100
	larval dragonflies	5.0 ng/g	99.9
	whole prey fish	8.8 ng/g	100
	fish axial muscle tissue	12.1 ng/g	100
MeHg	water	0.025 ng/L	92.5
	sediment and soil	0.020 ng/g	88.7
	seston	0.80 ng/g	96.4
	zooplankton	11 ng/g	91.0
	larval dragonflies	0.89 ng/g	99.9

[1] MDLs for all materials other than water are expressed on a dry-weight basis.

Assessing Ecological and Health Risks of Methylmercury

For methylmercury, we used two approaches to assess the potential adverse ecological effects of mercury quantified in fish from the park units. The first was the tissue residue-effects approach, which uses the concentration of mercury in whole fish or axial muscle tissue as a metric to assess the effect of methylmercury exposure on the analyzed organism. The tissue residue-effects approach, which is considered valid for ecological risk assessments for methylmercury, has been reviewed in detail (Adams et al. 2011, McElroy et al. 2011, Sappington et al. 2011). The second ecological assessment approach, applied to mercury concentrations measured in whole prey fish, used dietary threshold or benchmark concentrations above which methylmercury causes ecologically significant adverse effects in piscivorous fish and wildlife, for which consumption of prey fish is the dominant pathway for methylmercury uptake and exposure (e.g., Depew et al. 2012a, 2012b, 2013). To assess the potential for harmful methylmercury exposure in humans who eat fish from park waters, we compared mercury levels in axial fillets of adult fish to the U.S. Environmental Protection Agency's tissue residue criterion for methylmercury (300 ng/g wet weight; Borum et al. 2001).

Benchmarks for Assessing Mercury Risk to Fish

The concentration of mercury in the axial muscle of adult fish is strongly correlated with that in blood (Schmitt and Brumbaugh 2007), enhancing the toxicological relevance of the mercury concentration in axial muscle as an indicator of methylmercury exposure in ecological risk assessment.

To assess the potential for adverse effects of methylmercury exposure on adult fish, we compared concentrations measured in their axial muscle tissue to a published benchmark concentration associated with sub-lethal and reproductive effects in fishes. For adult fish, we used a benchmark value of 500 ng/g wet weight in axial muscle, based on 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 benchmark 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, such as reproductive failure, that are directly related to mortality or are biologically equivalent to mortality. Dillon et al. (2010) estimated that a whole-body concentration of 300 ng/g wet weight (equivalent to a wet-weight concentration of 500 ng/g in axial muscle) would, on average, injure 8% of the fish.

For adult piscivorous fish, we also compared concentrations measured in coexisting prey fish to a published benchmark concentration of dietary methylmercury that are associated with reproductive effects in fishes. Reproduction of fish is affected at much lower dietary concentrations of methylmercury than other biological endpoints, such as growth, behavior, and mortality (Dillon et al. 2010, Depew et al. 2012a). We compared concentrations of total mercury in whole prey fish to an estimated dietary threshold (40 ng/g wet weight in prey fish) associated with reproductive effects of methylmercury on piscivorous fish (Depew et al. 2012a, 2013). Most (generally ≥95%) of the mercury in whole prey fish is present as methylmercury (Hammerschmidt et al. 1999, Drysdale et al. 2005, Van Walleghem et al. 2007, Greenfield and Jahn 2010); therefore, our analyses for total mercury yield valid estimates of the methylmercury concentration in whole prey fish. For each park

unit, water body, and species of prey fish, we tabulated the number and percentages of prey fish with mercury concentrations exceeding the estimated dietary threshold of 40 ng/g wet weight for reproduction effects on piscivorous fishes.

Six of the water bodies in the present study did not yield long-lived, piscivorous fishes during the four years of annual sampling. These included three streams at GRPO, Long Lake and Great Marsh at INDU, and Legion Lake at PIRO. To assess risks of methylmercury exposure to whole prey fish at these sites, we used a whole-body concentration of 200 ng/g wet weight, an estimated tissue threshold associated with sublethal and reproductive effects in fish (Beckvar et al. 2005). Whole body concentrations below this threshold value are not expected to adversely affect the growth, reproduction, or survival of freshwater fish. Benchmark concentrations used to assess ecological risks of methylmercury exposure to fish are summarized in Table 7.

Benchmarks for Assessing Mercury Risk to Piscivorous Wildlife

Several piscivorous birds and mammals occur in the national park units studied here. Avian piscivores that nest in the western Great Lakes region include osprey, bald eagle, common loon, common merganser (*Mergus merganser*), hooded merganser (*Lophodytes cucullatus*), red-breasted merganser (*Mergus serrator*), common tern (*Sterna hirundo*), belted kingfisher (*Ceryle alcyon*), American bittern (*Botaurus lentiginosus*), great blue heron (*Ardea herodias*), and little blue heron (*Egretta caerulea*). Mammalian piscivores in the area include American mink and river otter (*Lontra canadensis*).

We used the belted kingfisher, common loon, and American mink as model piscivores to assess potential ecological risks of methylmercury in whole prey fish to fish-eating wildlife. Each of these species is distributed across much of the United States and Canada, and each forages in aquatic habitats, with small fish typically composing half (American mink), most (belted kingfisher), or nearly all (common loon) of their diet (Salyer and Lagler 1949, Davis 1982, Barr 1996, Merrill et al. 2005, Evers et al. 2005, Basu et al. 2007, Kelly et al. 2009). The belted kingfisher and American mink are both considered highly sensitive to methylmercury, and each has been used in assessments of ecological risks of methylmercury in aquatic food webs (Lazorchak et al. 2003, Basu et al. 2007, Scheuhammer et al. 2007, Walters et al. 2010, Eagles-Smith et al. 2013). We used Wildlife Values derived by Lazorchak et al. (2003) as screening-level, dietary benchmarks to assess potential risks of methylmercury in fish on the health and reproduction of belted kingfisher and American mink; these screening dietary benchmarks (mercury concentration in whole prey fish) were 30 ng/g wet weight for the belted kingfisher and 70 ng/g wet weight for American mink.

In birds, the embryo is the most methylmercury-sensitive life stage (Scheuhammer et al. 2007, 2012), and methylmercury in the diet of reproducing females is transferred rapidly to the developing egg (Heinz et al. 2009a). The *in ovo* sensitivity of birds to methylmercury can vary greatly among species. In egg-injection experiments by Heinz et al. (2009b), the sensitivity of embryos to methylmercury varied 20-fold among 23 avian species, with the median lethal concentration (LC_{50}) for egg-injected methylmercury ranging from 0.12 to 2.4 µg/g wet weight. In the Great Lakes region, Rutkiewicz et al. (2011) found that about 14% to 27% of adult bald eagles may be exposed to mercury levels capable of causing changes in brain chemistry.

Table 7. Concentrations of mercury in fish used as benchmarks to assess risks of methylmercury (MeHg) to fish and piscivorous wildlife.

Risk group or species	Biological indicator used	MeHg exposure indicated	Benchmark concentration (ng/g wet weight)[1]	Adverse effect	Reference
Prey fish	whole prey fish	bioaccumulation in whole body	200	health and reproduction (threshold)	Beckvar et al. 2005
Adult fish	axial muscle (adult fish)	bioaccumulation in muscle tissue	500	health and reproduction	Sandheinrich and Wiener 2011, Dillon et al. 2010
	whole prey fish	concentration in diet	40	reproductive effects (threshold)	Depew et al. 2012b
Belted kingfisher	whole prey fish	concentration in diet	30	health and reproduction (threshold)	Lazorchak et al. 2003
American mink	whole prey fish	concentration in diet	70	health and reproduction (threshold)	Lazorchak et al. 2003
Common loon	whole prey fish	concentration in diet	100	behavior (threshold)	Depew et al. 2012a
	whole prey fish	concentration in diet	180	significant reproductive effects	Depew et al. 2012a
	whole prey fish	concentration in diet	400	complete reproductive failure	Depew et al. 2012a

[1] Concentrations are in nanograms per gram (ng/g), which are equivalent to parts per billion.

Toxicological benchmarks for the common loon can be used to gage the potential risks of methylmercury in fish to fish-eating birds that are moderately sensitive to methylmercury. The ecotoxicological effects of methylmercury have been intensively studied in the common loon, which has been widely used as a bioindicator for assessing ecological risks of mercury in aquatic food webs (Depew et al. 2012b, 2013). The LC_{50} for methylmercury in eggs of common loons is 1.78 µg/g wet weight (Kenow et al. 2011)—a value near the upper end of the range of LC_{50} reported for the 23 avian species studied by Heinz et al. (2009b). Thus, the common loon is less sensitive to methylmercury than many avian species. The estimated dietary threshold for adverse behavioral impacts of methylmercury in adult loons is 100 ng/g wet weight in prey fish, whereas a mercury concentration of 180 ng/g in prey fish adversely affects reproductive success of adult loons (Depew et al. 2012b, 2013). Benchmarks used to assess ecological risks of methylmercury exposure to piscivorous wildlife are summarized in Table 7.

Benchmarks for Assessing Mercury Risk to Fish-Eating Humans

Aquatic food webs are the primary pathways for exposure of humans to methylmercury (Mergler et al. 2007, McKelvey and Oken 2012). To assess the potential for harmful methylmercury exposure in humans consuming fish from the water bodies studied here, we compared mercury levels in axial muscle of adult fish to the U.S. Environmental Protection Agency tissue residue criterion for methylmercury (300 ng/g wet weight), which was established to protect the health of humans who eat noncommercial fish, such as wild-caught sport fishes (Borum et al. 2001). Virtually all of the mercury in the fillets of fish is methylmercury (Grieb et al. 1990, Bloom 1992), and the total mercury levels measured in axial fillets are valid estimates of methylmercury concentrations. We also considered the fish consumption guidelines for mercury recommended by the Great Lakes Fish Advisory Workgroup (2007) (Table 8), a group from the eight Great Lake states with substantial expertise on bioaccumulative contaminants in fishery resources of the Great Lakes region as well as the health risks of contaminants to humans who consume fish.

Lead and Organic Contaminants in Adult Fish

The analyses of axial muscle and whole fish for total lead and organic contaminants were done at the Wisconsin State Laboratory of Hygiene (WSLH, Madison, WI), following established analytical protocols. During 2010–2012, samples of *whole* adult fish from all six park units were analyzed for total lead and organic contaminants. During the pilot study of 2008 and 2009, concentrations of total lead and selected organic contaminants were determined in samples of *axial muscle* (skinless fillets) from adult fish from five park units (GRPO, ISRO, PIRO, SLBE, and VOYA); the analytical results for axial muscle, previously reported by Wiener et al. (2013), are included here for completeness. Organic contaminants included DDT and its metabolites (DDE and DDD), PCBs (total concentration and 75 congeners), PFCs (total concentration and nine analytes), and PBDEs (total concentration and 9 to 17 congeners).

Data from the analyses of organic contaminants were used in a screening-level assessment of the selected legacy and emerging contaminants in the six park units. Analytical results for fish fillets were used to assess the potential for health risks to humans who eat fish from the studied water

bodies, whereas the analytical results for whole fish were used to assess ecological risks to fish and wildlife.

Table 8. Guidelines for human consumption of sport fish containing mercury, PCBs, PFOS, PBDEs, and DDT in their fillets.

Contaminant	Concentration range in fish (ng/g wet weight)	Consumption advice (fish-meal frequency)
Mercury [1]	≤50	unrestricted consumption
	51–110	2 meals per week
	111–220	1 meal per week
	221–950	1 meal per month
	>950	do not eat
PCBs [2]	≤50	unrestricted consumption
	51–220	1 meal per week
	221–950	1 meal per month
	951–1,890	6 meals per year
	>1,890	do not eat
PFOS [3]	≤40	unrestricted consumption
	>40 – 200	1 meal per week
	>200 – 800	1 meal per month
	>800	do not eat
PBDE [4]	≤100	3 servings per week
	>100 – 210	2 servings per week
	>210 – 630	1 serving per week
	>630	do not eat
DDT [5]	≤520	3 servings per week
	>520–1,000	2 servings per week
	>1,000–2,100	1 serving per week
	>2,100	do not eat

[1] Guidelines for the methylmercury-sensitive group (including pregnant women, women who may become pregnant, and children under 15 years of age), recommended in the protocol for mercury-based fish consumption advice (Great Lakes Fish Advisory Workgroup 2007).

[2] Guidelines recommended in the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory (Anderson et al. 1993).

[3] Guidelines recommended by the Minnesota Department of Health (http://www.health.state.mn.us/divs/eh/fish/eating/mealadvicetables.pdf).

[4] Guidelines developed by the California Office of Environmental Health Hazard Assessment (Klasing and Brodberg 2011).

[5] Guidelines developed by the California Office of Environmental Health Hazard Assessment (Klasing and Brodberg 2008).

Sample Preparation, Analyses, and Quality Assurance

The analyses of axial muscle and whole fish for total lead and organic contaminants were completed at the Wisconsin State Laboratory of Hygiene (WSLH, Madison, WI). In 2008–2009, 60 frozen fish samples (axial muscle without skin) were prepared and provided to WSLH for analysis. Each frozen sample was packaged in multiple layers of food-grade aluminum foil and identified by a unique sample identification code. Forty-one (41) of these samples were composite samples of axial muscle from multiple fish of a single species. With the exceptions of one composite sample of rainbow trout from Grand Portage Creek (Appendix K, Table K-1; Sample ID 2009-GRPO-GRAN-RT-COMP1) and one composite sample of creek chub from Poplar Creek (Appendix K, Table K-2; Sample ID 2011-GRPO-POPL-CC-Comp1), the smallest fish was no less than 75 percent of the total length of the largest fish in the composite sample, as recommended by USEPA (2000).

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 in the sample. The remaining 19 samples were not composite samples, but each instead 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 weight of axial muscle in each sample, is given in Appendix K, Table K-1. We attempted to include at least 10 g (wet weight) of axial muscle tissue in each sample; however, four samples composed of small stream fish contained less than 10 g of axial muscle.

During 2010–2012, we processed 121 whole-fish samples (with skin) and transported these to WSLH for analysis. Each frozen sample was packaged (without thawing) in multiple layers of food-grade aluminum foil and identified by a unique sample identification code. A total of 120 of these 121 samples were composite samples containing from two to five fish of a single species and similar total length; the remaining sample was a single rainbow trout from GRPO (Appendix K, Table K-2).

Sample splitting

At the Wisconsin State Laboratory of Hygiene, composite samples of whole fish were cut into large pieces and homogenized three times in a Hobart grinder. Aliquots of the homogenized whole fish were removed and frozen. Semi-thawed samples of whole fish and axial muscle 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 CO_2 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). All subsamples were stored in a freezer until analysis, and samples were ground and split into batches of 10. Method blanks including dry ice were prepared for each batch of 10 subsamples.

Determination of Total Lead

About 0.5 to 1.0 g of thawed tissue was placed into a vial with 1.0 mL of concentrated nitric acid. Vials were capped and shaken, and samples were allowed to pre-digest overnight. Vials were then placed into a hot block at 95°C for 1 hr. After cooling, 0.5 mL of hydrogen peroxide was added to each sample and the vials were re-heated to 95°C for 0.5 hr. The addition of hydrogen peroxide and heat was repeated and the cooled solutions were brought to a final volume of 25 mL with ultrapure water. Each digestion batch contained a blank, a lab-fortified blank, and a certified reference material (NIST TORT-2); 10% of samples were analyzed in duplicate and spiked.

Digested solutions were analyzed for total lead by inductively coupled plasma-mass spectroscopy according to U.S. Environmental Protection Agency Method 1638 (USEPA 1996). The instrument was calibrated with a blank and five standards prepared from an internal standard mix of gallium, indium, and bismuth. Calibration was verified initially and again after every 10th sample with a blank and a quality control sample from a source that differed from the standards.

Determination of DDT, PCBs, and PBDEs

For samples of whole fish, 10 g of tissue were extracted for chlorinated and brominated compounds. For several samples of axial muscle with limited mass, the entire mass of sample remaining after removal of subsamples for PFCs and lead was extracted; sample mass ranged from 3.9 to 6.9 g, but was about 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. Each 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. 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.

The quantitation standard for PCB congeners used for analyses of axial muscle (sampled in 2008 and 2009) was the Mullin Mix of Aroclors 1232, 1248, and 1262. The quantitation standard for PCB congeners in whole fish (sampled in 2010, 2011, and 2012) was a dilution of custom stock solutions of individual congeners obtained from ULTRA Scientific (ULTRA Custom 10477, 10478, 10479, and 10480; Kingston, RI). 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 methyl tert-butyl ether (MTBE), evaporated to dryness under nitrogen gas, reconstituted in 50:50 2 mM ammonium acetate:MeOH and then analyzed by high performance liquid chromatography (HPLC) in combination with two mass analyzers in a single mass spectrometry (MS) instrument (abbreviated as 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-quadruple mass spectrometer in the negative ionization mode.

Quality control (QC) requirements listed in WSLH Method 1480 were the initial demonstration of laboratory capability, analysis of laboratory reagent blanks, laboratory spiked samples, laboratory method blanks, and check standard samples. Procedural standards were extracted with samples and used to establish a standard curve. 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 USEPA Solid Waste methods manual, were used as guidance. Analytes that did not perform well due to poor chromatography or to consistently unacceptable QC sample recovery were not reported by the Wisconsin State Laboratory of Hygiene.

An interlaboratory comparison done during companion studies of bald eagles is pertinent to the analysis of fish from the present study for PFCs. Plasma from eaglets was analyzed for PFCs in a blind test at three laboratories: our primary laboratory (WSLH); the USEPA laboratory at Research Triangle Park, North Carolina; and the 3M Environmental Laboratory in Maplewood, Minnesota (3M is the primary commercial producer of perfluorinated compounds). This interlaboratory comparison showed that analytical results for PFCs from the three laboratories were comparable, with correlation coefficients between paired laboratories and the intraclass correlation coefficient between all three laboratories greater than 0.80. Coefficients of variation for each laboratory were less than 26% for the sum of all PFCs and for those PFC analytes that accounted for more than 90% of the total PFC burden in eagle plasma (Route et al. 2014b).

Benchmarks for Assessing Risks to Fish-Eating Humans

To assess the potential for harmful PCB exposure in humans consuming fish from the park units, we compared total PCB levels in axial muscle of adult fish to the fish consumption guidelines for PCBs recommended by the Great Lakes Fish Advisory Task Force (see Table 8). The Task Force was composed of representatives of agencies in the eight states bordering the Great Lakes, a group with substantial knowledge and expertise concerning PCBs in fishery resources of the Great Lakes region and the associated health risks to humans who consume contaminated fish. To assess the potential for harmful exposure to PFOS in humans consuming fish from the park units, we compared PFOS levels in axial muscle of adult fish to the fish consumption guidelines for PFOS recommended by the States of Minnesota, Illinois, and Wisconsin (see Table 8). For DDT and PBDEs, we used the advisory tissue levels for fish developed by the California Office of Environmental Health Hazard Assessment for total DDT (Klasing and Brodberg 2008) and total PBDEs (sum of congeners; Klasing and Brodberg 2011) (see Table 8). In this overall assessment, we used data from the pilot study (Wiener et al. 2013) on total PCBs, PFOS, total PBDEs, and total DDT in axial muscle of adult fish sampled in 2008 and 2009 from five park units (GRPO, ISRO, PIRO, SLBE, and VOYA).

The consumption of fish is generally not considered a significant pathway for human exposure to lead, because inorganic Pb(II) does not accumulate appreciably in the skeletal muscle tissue of fish (Spry and Wiener 1991). Consequently, we did not include lead in axial fillets in our assessment of potential human health risks.

Benchmarks for Assessing Risks to Fish and Wildlife

Concentrations of organic contaminants in whole fish were used to assess the potential adverse effects of organic contaminants on fish or piscivorous birds and mammals. For this assessment we

used published estimates of threshold (predicted no effect) concentrations in whole fish, levels above which adverse effects can occur in fish or in piscivorous birds and mammals.

For total DDT (ΣDDT, defined as the sum of concentrations of DDT, DDE, and DDD), we used the whole-body concentration of 600 ng/g wet weight estimated by Beckvar et al. (2005) as a threshold level for juvenile and adult fish (Table 9). Beckvar et al. (2005) advised that this estimated threshold concentration of 600 ng/g for total DDT in fish be considered provisional, given the paucity of sublethal toxicological studies of DDT in their analysis.

Table 9. Concentrations in whole fish used as benchmarks to assess risks of bioaccumulative organic contaminants to fish and piscivorous wildlife.

Contaminant	Risk group or species	Exposure indicated	Benchmark concentration[1] (ng/g wet weight)	Effects threshold	Reference
DDT and metabolites	Fish	concentration in whole body	ΣDDT: 600	health and reproduction (threshold)	Beckvar et al. 2005
DDT and metabolites	Belted kingfisher	concentration in diet	ΣDDT: 20	health and reproduction (threshold)	Lazorchak et al. 2003
DDT and metabolites	American mink	concentration in diet	ΣDDT: 360	health and reproduction (threshold)	Lazorchak et al. 2003
PCBs	Belted kingfisher	concentration in diet	ΣPCB: 440	health and reproduction (threshold)	Lazorchak et al. 2003
PCBs	American mink	concentration in diet	ΣPCB: 130	health and reproduction (threshold)	Lazorchak et al. 2003
PBDEs	Aquatic mammals	concentration in diet	ΣPBDE: 100	thyroid function (threshold)	Zhang et al. 2014
PBDEs	Aquatic birds	concentration in diet	ΣPBDE: 100	reproduction (threshold)	Zhang et al. 2014
PFOS	Birds	concentration in diet	280	reproduction (threshold)	Newsted et al. 2005

[1] Concentrations are in nanograms per gram (ng/g), which are equivalent to parts per billion.

We used Wildlife Values derived by Lazorchak et al. (2003) as screening-level, dietary benchmarks to assess potential risks of DDT and PCBs in whole fish on the health and reproduction of two model piscivores, belted kingfisher and American mink (Table 9). For total DDT, these screening dietary benchmarks were 20 ng/g wet weight for the belted kingfisher and 360 ng/g wet weight for American mink. For total PCBs (ΣPCB, defined as the sum of PCB congeners), these screening dietary benchmarks were 440 ng/g wet weight for the belted kingfisher and 130 ng/g wet weight for American mink.

Relative to legacy contaminants, such as DDT, mercury, and PCBs, comparatively few studies have examined the effects of low-level exposure of PFCs and PBDEs on fish and wildlife. In general, the

ecotoxicological effects of these and other "emerging" contaminants are poorly understood (Ji et al. 2008, Lucia et al. 2015), and there are few published benchmarks for assessing ecological risks of dietary exposure.

For total PBDEs (ΣPBDE), we used the dietary toxicity reference value of 100 ng DE-71/g wet weight for aquatic mammals and birds that was derived by Zhang et al. (2014). This estimated threshold was based on the effects of DE-71, a commercial mixture of PBDEs containing BDE-47, BDE-99, BDE-99, BDE-100, and BDE-153 (La Guardia et al. 2006) on the thyroid function of mink and on the reproduction of American kestrels (*Falco sparverius*).

PFOS is the dominant PFC accumulated in fish and wildlife in both the western Great Lakes region and the upper midwestern United States (Ye et al. 2008, Delinsky et al. 2010, Custer et al. 2014, Route et al. 2014b). Therefore, we used the dietary toxicity reference value of 280 ng PFOS/g wet weight, which was derived for top avian predators by Newsted et al. (2005). This estimated threshold was based on chronic studies of dietary PFOS on mallards (*Anas plathyrhnchos*) and northern bobwhite quail (*Colinus virgiansus*).

Results and Discussion

In this section, we first present and discuss results for each of the six national park units, then follow with a regional assessment encompassing all six of the park units. The analytical results from the pilot study of 2008–2009 have been included for completeness. For mercury, descriptive statistical summaries of data are provided for each park unit and water body in Appendix C for soil, Appendix D for surficial sediment, Appendix E for water, Appendix F for seston, Appendix G for zooplankton, Appendix H for larval dragonflies, Appendix I for whole prey fish, and Appendix J for axial muscle tissue of adult fish. The samples of adult fish analyzed for total lead and organic contaminants are described in Appendix K (Table K-1 for samples of axial muscle and Table K-2 for samples of whole fish). The analytical results for total lead and organic contaminants in adult fish from the park units are summarized in Appendix L, which contains 11 tables.

Grand Portage National Monument (GRPO)

We sampled four stream sites at GRPO: the lower reach of Grand Portage Creek, the south branch of Poplar Creek, and two sites in Snow Creek (see Table 1). The Snow Creek sites were the beaver pond in the upper reach (adjacent to the Grand Portage boardwalk) and a lower reach near the confluence with the Pigeon River. Sampling in each stream was done annually during 2009–2012 in late May or early June. Water in these streams during our sampling events had low to circumneutral pH (range 6.2–8.1), high concentrations of dissolved organic carbon (DOC) (15–26 mg/L), low to moderate dissolved sulfate (0.5–7.5 mg/L) and specific conductance (55–139 µS/cm), and low hardness (42–80 mg/L) and alkalinity (31–65 mg/L) (Table 10). Water in the beaver pond at the upper reaches of Snow Creek had much lower pH and dissolved oxygen concentration than water at the other three stream sites (Table 10).

Table 10. Summary of water quality measurements (mean ± SE) in three streams at Grand Portage National Monument, derived from annual *in situ* measurements and analyses of water samples during 2010–2012.

Stream	Temperature (°C)	DO[1] (mg/L)	Specific conductance (µS/cm)	pH[1] (s.u.)	Sulfate (mg/L)	DOC[1] (mg/L)
Snow Creek (lower reach)	19 ± 3	7.3	72 ± 8	7.5 ± 0.2	1.6 ± 0.2	26.3 ± 0.6
Snow Creek (beaver pond)	14 ± 1	1.9	55 ± 5	6.2 ± 0.1	0.5 ± 0.1	25.1 ± 0.8
Poplar Creek	16 ± 3	10.6	73 ± 13	7.8 ± 0.3	3.0 ± 0.7	21.2 ± 0.6
Grand Portage Creek	14 ± 3	11.3	139 ± 16	8.1 ± 0.1	7.5 ± 1.2	14.5 ± 1.0

[1] DO is dissolved oxygen, s.u. is standard pH units, and DOC is dissolved organic carbon.

Mercury in Streams and Food Webs

Soil and Sediment

Surficial soils sampled in 2012 from the three stream sites in Snow and Poplar creeks had mean concentrations of total mercury ranging from 62 to 164 ng/g dry weight (Table 11). Soil from the fourth site, Grand Portage Creek, had a total-mercury concentration of 1,180 ng/g, a provisional value exceeding concentrations at the other stream sites (Table 11). Mean methylmercury in soils from Snow and Poplar creeks ranged from 1.6 to 2.9 ng/g dry weight, representing 1.0% to 2.6% of total mercury. In surficial sediment sampled from the four stream sites during 2010–2012, mean concentrations of total mercury ranged from 37 to 141 ng/g dry weight (Table 12). Mean concentrations of methylmercury in sediment from the four stream sites averaged from 0.81 to 1.82 ng/g dry weight, accounting for 1.2% to 2.2% of total mercury. Total mercury in soil from Poplar and Snow creeks ($r^2 = 0.92$; data not shown) and surficial sediment from the four stream sites ($r^2 = 0.58$; data not shown) were positively correlated with percent loss on ignition (LOI), a surrogate measure of organic matter content.

Table 11. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in soils near streams in Grand Portage National Monument. Two composite samples, each composed of subsamples of surface soil (upper 5 cm) collected in 2012 from five locations along each stream site, were analyzed.

	Total Hg (ng/g dry weight)		MeHg (ng/g dry weight)		Percent MeHg (mean)	Loss on ignition (%)	
Stream	***mean***	***range***	***mean***	***range***		***mean***	***range***
Snow Creek (lower reach)	164	152–178	2.90	2.65–3.16	1.8	17.4	17.0–17.8
Snow Creek (beaver pond)	152	150–154	1.58	1.58–1.59	1.0	19.2	18.9–19.5
Poplar Creek	62	58.2–65.5	1.58	1.58–1.59	2.6	6.7	6.6–6.7
Grand Portage Creek	1,180 [1]	—	2.26	1.99–2.54	0.2 [1]	7.2	4.9–9.4

[1] The values reported for total Hg and percent MeHg at Grand Portage Creek should be considered provisional estimates, because the total Hg concentration in the sample exceeded the range of the standard curve during analyses of these soil samples.

Water

In water, mean concentrations of total mercury ranged from 8.7 to 16.9 ng/L in unfiltered samples and from 5.4 to 8.3 ng/L in filtered (0.45 μm) samples, with filter-passing mercury accounting for 62% ± 5% (SE) of the total mercury present in unfiltered samples (Table 13). Mean concentrations of methylmercury ranged from 0.57 to 2.7 ng/L in unfiltered samples and from 0.35 to 1.9 ng/L in filtered samples, with filter-passing methylmercury accounting for 63% ± 6% of the total methylmercury present in unfiltered water. Methylmercury accounted for 15% ± 6% of the total mercury in unfiltered samples and for 14% ± 6% of the total mercury in filtered samples. The beaver pond site on the upper reaches of Snow Creek had the highest concentrations of methylmercury and percent methylmercury in water.

Table 12. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and loss on ignition in surficial sediments (upper 5 cm) from streams in Grand Portage National Monument during 2010–2012. Five samples of sediment were collected annually from each stream site.

	Total Hg (ng/g dry weight)		MeHg (ng/g dry weight)		Percent MeHg (mean)	Loss on ignition (%)	
Stream	***mean***	***SE***	***mean***	***SE***		***mean***	***range***
Snow Creek (lower reach)	132	16	1.82	0.34	1.4	18	8.8–22
Snow Creek (beaver pond)	141	40	1.70	0.42	1.2	27	22–36
Poplar Creek	61	6	0.90	0.10	1.5	10	7.2–15
Grand Portage Creek	37	—[1]	0.81	0.40	2.2	5.8	4.9–6.7

[1] Total Hg is reported only for 2011 and 2012.

Table 13. Total mercury and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water sampled from streams in Grand Portage National Monument (n is the number of water samples collected and analyzed during 2010–2012).

	Total Hg (ng/L)					MeHg (ng/L)				
		Unfiltered		***Filtered***			***Unfiltered***		***Filtered***	
Stream	***n***	*mean*	*SE*	*mean*	*SE*	***n***	*mean*	*SE*	*mean*	*SE*
Snow Creek (lower reach)	6	9.81	1.85	7.39	1.80	5	1.89	—[1]	0.85	0.20
Snow Creek (beaver pond)	6	9.47	0.29	5.82	0.70	6	2.70	0.22	1.90	0.25
Poplar Creek	5	16.9	—[2]	8.25	1.76	5	0.77	0.03	0.57	—[1]
Grand Portage Creek	6	8.65	1.11	5.43	0.64	6	0.57	0.16	0.35	0.04

[1] Samples are reported for 2010 and 2012 only.

[2] Samples are reported for 2011 and 2012 only.

Seston

In seston (suspended particulates), mean concentrations of total mercury ranged from 50 to 241 ng/g dry weight and methylmercury from 1.2 to 16.2 ng/g dry weight, with methylmercury accounting for 5.3% ± 2.1% of the total mercury (Table 14). Seston from the beaver pond at Snow Creek had the highest concentration of methylmercury.

Larval Dragonflies

Larvae of the families Aeshnidae and Corduliidae were the most widely distributed dragonflies collected at GRPO, inhabiting all four stream sites and accounting for 62% of the 214 larvae analyzed (Table 15). Larvae from three other families of dragonflies—including 22 cordulegastrids, 1 gomphid, and 59 libellulids—from one or two of the four sites were also analyzed (Table 15). Mean concentrations of methylmercury in larval dragonflies from the four stream sites ranged from 118 to 190 ng/g dry weight in aeshnids and 136–185 ng/g in corduliids. Methylmercury accounted

for more than 90% of the total mercury in dragonfly larvae for most taxa and stream sites (Table 15). For example, mean percent methylmercury in larvae from the four stream sites ranged from 81% to 94% in aeshnids and from 91% to 97% in corduliids.

Table 14. Total mercury, methylmercury (MeHg), and percent MeHg in seston (suspended particles) from streams in Grand Portage National Monument. Total Hg is reported for samples collected during 2011–2012, and MeHg is for samples collected during 2010–2012.

	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg
Stream	***n***	***mean***	***range***	***n***	***mean***	***SE***	**(mean)**
Snow Creek (lower reach)	2	241	134–348	5	8.65	3.46	3.3
Snow Creek (beaver pond)	2	138	77–200	6	16.2	4.56	11.4
Poplar Creek	2	74.3	16–133	6	1.21	0.51	4.2
Grand Portage Creek	2	50.2	40–61	6	1.20	0.04	2.4

Table 15. Total mercury, methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2009–2012 from streams in Grand Portage National Monument.

		Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg	
Stream	**Family**	***n***	***mean***	***SE***	***n***	***mean***	***SE***	***mean***	***SE***
Snow Creek (lower reach)	Aeshnidae	11	233	11	11	190	20	81	7.1
	Corduliidae	16	168	4.5	16	163	5.8	97	1.6
Snow Creek (beaver pond)	Aeshnidae	7	142	14	7	129	13	92	4.5
	Corduliidae	30	140	7.4	30	136	7.9	96	2.0
	Gomphidae	1	70	—	1	54	—	77	—
	Libellulidae	58	134	6.0	58	124	6.3	92	1.9
Poplar Creek	Aeshnidae	19	129	9.6	19	118	8.9	94	5.0
	Cordulegastridae	12	126	7.0	12	118	8.1	95	6.5
	Corduliidae	31	194	14	32	185	15	96	2.1
	Libellulidae	1	177	—	1	111	—	63	—
Grand Portage Creek	Aeshnidae	10	162	13	10	143	14	87	2.7
	Cordulegastridae	10	168	7.5	10	159	6.2	95	2.2
	Corduliidae	8	149	20	9	136	15	91	4.9

Whole Prey Fish

Mean concentrations of mercury in individual prey fish species varied from 24 to 58 ng/g wet weight in Grand Portage Creek (two species), from 49 to 91 ng/g in Poplar Creek (five species), and from 50

to 63 ng/g in the lower reach of Snow Creek (four species) (Table 16). In the beaver pond at upper Snow Creek, the concentration of mercury averaged 35 ng/g in the central mudminnow, the only species obtained from that site in sufficient numbers for statistical estimation. Species means for whole fish within individual stream sites ranged from 24 ng/g in slimy sculpin to 91 ng/g in blacknose dace and longnose dace.

Adult Fish (Axial Muscle)

In axial fillets, concentrations of total mercury averaged 40 ng/g wet weight in rainbow trout from Grand Portage Creek, ranging from 23 to 69 ng/g in individual fish (Table 16). Concentrations were higher in fillets of creek chub from Poplar Creek, averaging 91 ng/g and ranging from 54 to 168 ng/g.

Table 16. Fish length and concentration of total mercury (Hg) in whole body and axial muscle tissue (skinless fillets) of fish sampled from streams in Grand Portage National Monument during 2009–2012.

Fish tissue and stream	Species	n	Total length (mm)		Hg concentration[1] (ng/g wet weight)		
			mean	*range*	*mean*	*SE*	*range*
Whole prey fish							
Grand Portage Creek	longnose dace	110	77	49–107	58	4	21–355
	slimy sculpin	68	59	41–83	24	1	8–54
Poplar Creek	creek chub	49	80	56–105	49	3	29–118
	blacknose dace	43	72	46–89	91	6	43–242
	longnose dace	16	76	64–97	91	9	50–194
	central mudminnow	14	50	32–77	67	6	37–123
	brook stickleback	7	48	44–55	73	10	47–112
Snow Creek (upper beaver pond)	central mudminnow	40	52	33–80	35	2	15–69
	fathead minnow	1	77	--	75	--	--
	brook stickleback	1	50	--	27	--	--
Snow Creek (lower reach)	central mudminnow	83	66	36–124	63	2	25–204
	fathead minnow	10	72	61–83	50	4	29–65
	brook stickleback	7	55	49–62	53	4	39–74
	creek chub	5	114	90–144	51	3	43–60
Axial muscle							
Grand Portage Creek	rainbow trout	35	117	75–308	40	2	23–69
Poplar Creek	creek chub	12	130	99–168	91	11	54–168

[1] Concentrations are in nanograms per gram (ng/g), which are equivalent to parts per billion.

Ecological and Health Risks of Methylmercury

Only four of the 454 prey fish analyzed had whole-body concentrations of mercury exceeding 200 ng/g wet weight, an estimated tissue threshold associated with sublethal and reproductive effects in fish (Beckvar et al. 2005). Mercury levels in most (99%) of the prey fish sampled and analyzed from

the three streams would, therefore, not be expected to adversely affect the health or reproduction of prey fishes. Stream-specific, mean concentrations of total mercury exceeded 40 ng/g wet weight, an estimated dietary threshold associated with diminished reproduction of piscivorous fish (Depew et al. 2012a), in most of the species of prey fish analyzed (Table 16). The slimy sculpin was the only species with an overall mean concentration (24 ng/g) less than the estimated 40 ng/g threshold value for reproductive effects on piscivorous fish. The three streams studied at GRPO do not provide habitat suitable for sustaining resident populations of long-lived piscivorous fish. Nonetheless, the mercury levels measured in prey fish could adversely affect the reproduction of piscivorous fishes if they inhabited in these streams.

The screening-level dietary benchmark for belted kingfisher (30 ng/g wet weight) was exceeded in 79% of the whole fish analyzed from the three streams (Table 17). The dietary benchmark for belted kingfisher was exceeded in 61% of the fish from Grand Portage Creek, 97% from Poplar Creek, and 84% from Snow Creek. Mean concentrations of mercury in all species except slimy sculpin exceeded the dietary benchmark for belted kingfisher (Tables 16 and 17). The screening benchmark for mercury in the diet of American mink (70 ng/g wet weight) was exceeded in 23% of the whole prey fish analyzed from the three streams, including 11% of the fish from Grand Portage Creek, 47% of the fish from Poplar Creek, and 17% of the fish from Snow Creek. In Poplar Creek, mean concentrations of mercury in three species of fish (blacknose dace, longnose dace, and brook stickleback) exceeded the estimated dietary benchmark for American mink.

Table 17. Concentrations of mercury (Hg) in whole fish from three streams in Grand Portage National Monument, with numbers (n) and percentages (%) of fish exceeding screening dietary benchmarks for the belted kingfisher (30 ng/g wet wt) and American mink (70 ng/g).

				Fish with Hg > 30 ng/g		Fish with Hg > 70 ng/g	
Stream	**Species**	**n**	**Range in Hg (ng/g wet wt.)**	***n***	***%***	***n***	***%***
Grand Portage Creek	longnose dace	110	21–355	91	83	20	18
	slimy sculpin	68	8–54	18	26	0	0
Poplar Creek	creek chub	49	29–118	45	92	6	12
	blacknose dace	43	43–242	43	100	32	74
	longnose dace	16	50–194	16	100	12	75
	central mudminnow	14	37–123	14	100	7	50
	brook stickleback	7	47–112	7	100	3	43
Snow Creek	creek chub	5	43–60	5	100	0	0
	fathead minnow	11	29–75	10	91	1	9
	central mudminnow	123	15–204	102	83	23	19
	brook stickleback	8	27–74	7	88	1	13
All streams	All species	454	--	358	79	105	23

The belted kingfisher and American mink are highly sensitive to methylmercury. Common loons, which are moderately sensitive to methylmercury, do not feed in small streams such as those studied

at GRPO. However, we note that the mean concentrations of mercury in the seven species of fish sampled at GRPO were less than the dietary benchmarks associated with behavioral effects (100 ng/g wet weight in prey fish) and diminished reproductive success (180 ng/g in prey fish) in adult common loons. This suggests that ecological risks of methylmercury would be small for moderately sensitive avian piscivores that feed on fish in streams at GRPO.

None of the fillets of rainbow trout had a mercury concentration exceeding the USEPA fish-tissue criterion of 300 ng/g wet weight for methylmercury (see Table 16). The mean concentration of mercury in fillets of small rainbow trout from Grand Portage Creek were below concentrations considered harmful to sensitive groups of humans, such as women of childbearing age and children (compare Tables 8 and 16). In general, the small streams at GRPO do not contain resident populations of long-lived piscivorous fish that would be expected to accumulate high concentrations of methylmercury in axial muscle tissue.

Lead and Organic Contaminants

The concentrations of legacy contaminants (DDT, DDE, DDD, PCBs, and Pb) and emerging contaminants (PBDEs and PFCs) in fish from the streams at GRPO were low, commonly below limits of detection.

Axial Muscle

Analytical results for organic contaminants and lead in axial muscle (skinless fillets) of fish sampled in 2009, which were reported by Wiener et al. (2013), are summarized briefly here. Four composite samples of fish from two streams at GRPO were analyzed: two with rainbow trout from Grand Portage Creek and two with creek chub from Poplar Creek. Each composite sample contained an equivalent mass of axial muscle tissue from four fish of a given species with similar total lengths (Appendix K, Table K-1).

PBDEs were not detected in any of the four composite samples of axial muscle (Appendix L, Table L-1). DDT, DDE, and DDD in all four samples were also below the limit of detection (LOD for total DDT, 10 ng/g wet weight). Concentrations of PCBs were low, but PCB congeners were detected in axial muscle of rainbow trout from Grand Portage Creek (congener #132/153/105 = 1.2 ng/g; #163/138 = 1.3 ng/g wet weight). Concentrations of PFCs were also low, but were detected in creek chub from Poplar Creek (perfluoro-1-octanesulfonate range 0.72–0.83 ng/g) and in rainbow trout from Grand Portage Creek (perfluoro-1-octanesulfonate range 1.5–1.6 ng/g). Concentrations of lead were low, averaging 8 ng/g wet weight (range 8–9 ng/g) in creek chub from Poplar Creek and 10 ng/g wet weight (range 7–14 ng/g) in rainbow trout from Grand Portage Creek.

These concentrations in axial muscle do not pose significant risks to human health. Total PCBs, PFOS, total PBDE, and total DDT in all four composite samples were substantially below levels at which limited consumption of these fishes by humans would be advised (see Table 8).

Whole fish

Individual and composite samples of whole fish collected in 2010, 2011, and 2012 were analyzed for selected contaminants. These included (1) five composite samples of creek chub from Poplar Creek,

each containing four adult fish; and (2) one individual and three composite samples (2–4 fish) of whole rainbow trout from Grand Portage Creek (Appendix K, Table K-2). Samples collected in 2010 and 2012 were analyzed for DDT and metabolites (DDE and DDD), 95 polychlorinated biphenyl congeners (PCBs), 9 to 17 polybrominated diphenyl ethers (PBDEs) and 16 perfluorinated compounds (PFCs). Because of the low concentrations of total lead and some organic contaminants measured in fish sampled in 2010, total lead (Pb) was not measured in fish collected at GRPO in 2011 and 2012. In addition, the analyses of organic contaminants in fish collected in 2011 were limited to PFCs (Appendix L, Table L-2).

Concentrations of Pb in whole creek chub were low, averaging 37 ng/g wet weight. In creek chub, concentrations of organic contaminants were below limits of detection for PCBs (<1–3.5 ng/g), for PBDEs (<1 ng/g), and for DDT and its metabolites (LOD, 10 ng/g wet weight for total DDT). In whole rainbow trout, concentrations of DDT and its metabolites were also below limits of detection, whereas concentrations of individual PCBs and PBDEs were low to below limits of detection, with maximum concentrations of total PCBs less than 7 ng/g and total PBDEs less than 1.5 ng/g. Concentrations of most PFCs were below analytical reporting limits (<0.5 ng/g) in creek chub and rainbow trout. Of those PFCs detected in the samples, concentrations of perfluorinated acids and perfluorinated sulfonates were less than 4 ng/g and 25 ng/g wet weight, respectively.

The concentrations of total DDT, total PCBs, total PBDEs, and PFOS in whole fish from GRPO streams were substantially less than reported benchmark concentrations associated with adverse effects on piscivorous birds or mammals (Table 9). These concentrations observed in whole fish from streams at GRPO do not pose significant risks to the health of piscivorous wildlife.

Indiana Dunes National Lakeshore (INDU)

We studied three water bodies at INDU: Great Marsh, Long Lake, and Middle Lagoon (see Table 1). The Great Marsh, an interdunal wetland on the Lake Michigan shoreline, is undergoing ecological restoration to increase the diversity of native plants and animals and to provide habitat for migratory birds. Fish and larval dragonflies were sampled in Great Marsh and Long Lake in 2008 during the pilot study. The aquatic food webs in the three water bodies were sampled annually during 2010–2012. In Long Lake and Middle Lagoon, water, seston, and zooplankton were sampled near the center of each lake basin. In Great Marsh, water and seston were sampled from multiple sites within 3 m of the shoreline.

These surface waters generally had high specific conductance (range 336–659 µS/cm), high pH (range 8.1–9.4), and concentrations of dissolved oxygen (DO) (range 8.1–9.4 mg/L) that were slightly below saturation at the times of our sampling (Table 18). Waters in Long Lake and Middle Lagoon had moderate concentrations of dissolved organic carbon (range 4.9–7.6 mg/L), whereas Great Marsh had high DOC (22 ± 2 mg/L), which is typical of wetland systems. Long Lake and Great Marsh had moderate concentrations of sulfate (range 2.5–3.8), whereas Middle Lagoon had very high sulfate levels (17.7 ± 1.3 mg/L) (Table 18). In Long Lake, episodes of oxygen depletion in summer occurred frequently during our study, and the fish assemplage in the lake is consequently limited to a few species that can tolerate very low levels of dissolved oxygen.

Table 18. Summary of water quality measurements (mean ± SE) in three water bodies at Indiana Dunes National Lakeshore, derived from *in situ* measurements and from analyses of water samples taken during early spring of 2010–2012.

Water body	Temperature (°C)	DO [1] (mg/L)	Specific conductance [2] (µS/cm)	pH (s.u.)	Sulfate [3] (mg/L)	DOC (mg/L)
Great Marsh	15.5 ± 1.0	8.1 ± 0.4	336 ± 38	8.0 ± 0.3	3.8 ± 1.4	22.2 ± 2.0
Long Lake	16.4 ± 0.9	8.4	352	8.0 ± 0.2	2.5	7.6 ± 0.5
Middle Lagoon	12.9 ± 2.7	9.4 ± 0.6	659	8.4 ± 0.2	17.7 ± 1.3	4.9 ± 0.2

[1] Dissolved oxygen (DO) in Long Lake was measured in 2010 and 2012.

[2] Specific conductance in Long Lake and Middle Lagoon was measured in 2010 and 2012.

[3] Sulfate in Long Lake was measured in 2011 and 2012.

Mercury in Water Bodies and Food Webs

Soil

Surficial soils, collected at nearshore margins of Long Lake and Middle Lagoon, had total mercury levels ranging from 3.1 to 26.7 ng/g dry weight (Table 19). Total mercury was positively related to percent loss on ignition (a surrogate measure of organic matter content), a pattern also observed in surficial sediment. The fraction of total mercury present as methylmercury ranged from 0.4% to 1.5%.

Table 19. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in soils sampled near two water bodies in Indiana Dunes National Lakeshore. Soils were not collected from the Great Marsh. Means are reported for surface soil (upper 5 cm of cores) collected in 2012 within 5 m of the shoreline.

		Total Hg (ng/g dry weight)		MeHg (ng/g dry weight)		MeHg	Loss on ignition (%)	
Water body	n[1]	*mean*	*SE*	*mean*	*SE (range)*	(mean %)	*mean*	*range*
Long Lake	4	3.1	0.8	0.048	0.025	1.5	1.5	0.8–2.9
Middle Lagoon	2	26.7	—	0.096	(0.02–0.17)	0.4	2.2	0.4–4.1

[1] In Middle Lagoon, one sample was analyzed for total Hg and two for MeHg.

Sediment

Surficial sediment was sampled from nearshore sites at Great Marsh, Long Lake, and Middle Lagoon. The concentrations of total mercury in sediment ranged from 2.2 to 25.8 ng/g dry weight, and were positively related to percent loss on ignition. Methylmercury levels in surficial sediment were much higher in Great Marsh (mean 2.4 ng/g dry weight) than in Long Lake (0.15 ng/g) and Middle Lagoon (0.03 ng/g). Similarly, the percent of total mercury present as methylmercury, an indicator of microbial mercury methylation in surficial sediment, was greater in Great Marsh (4.6%) than that in either Long Lake (2.1%) or Middle Lagoon (1.5%) (Table 20). This pattern was

expected, given that wetlands, which are most prominent around Great Marsh, are sites of active microbial methylmercury production.

Table 20. Mean total mercury (Hg), methylmercury (MeHg), percent MeHg, and loss on ignition in surficial sediments (upper 5 cm) sampled from water bodies in Indiana Dunes National Lakeshore during 2010–2012. Surficial sediments were sampled from locations of concurrent larval dragonfly collection, within 2 m of the shoreline.

	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			MeHg (mean %)	Loss on ignition (%)	
Water body	***n***	***mean***	***SE***	***n***	***mean***	***SE***		***mean***	***range***
Great Marsh	7	25.8	5.9	5	2.41	1.02	4.6	21.5	11–32
Long Lake	7	5.9	1.2	4	0.15	0.04	2.1	7.2	1.4–18
Middle Lagoon	5	2.2	0.6	4	0.03	0.02	1.5	1.1	0.6–1.6

Water

Concentrations of total mercury in water averaged from 1.1 to 2.6 ng/L in unfiltered samples and from 0.7 to 2.1 ng/L in filtered samples. Filter-passing total mercury accounted for 77% ± 7% (SE) of the total mercury present in unfiltered samples (Table 21). Mean concentrations of methylmercury ranged from 0.07 to 0.22 ng/L in unfiltered samples and from 0.044 to 0.17 ng/L in filtered samples, with filter-passing methylmercury accounting for 63% ± 8% of the total methylmercury in unfiltered water. Methylmercury accounted for 9.1 ± 1.6% of the total mercury in unfiltered samples and for 8.8% ± 0.7% of the total mercury in filtered samples. The Great Marsh had the highest concentrations of both total mercury (2.6 ng/L) and methylmercury (0.22 ng/L), largely because of the higher abundance of dissolved organic matter (a correlate of DOC), which binds mercury and keeps it in the water column.

Table 21. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water sampled from three water bodies in Indiana Dunes National Lakeshore. Samples were collected near the center of each lake or marsh pond at a depth of 0.5 to 2 m. The number of samples collected and analyzed during 2010–2012 is indicated by *n*.

	Total Hg (ng/L)					MeHg (ng/L)				
	Unfiltered			***Filtered***		***Unfiltered***			***Filtered***	
Water body	***n***	*mean*	*SE*	*mean*	*SE*	***n***	*mean*	*SE*	*mean*	*SE*
Great Marsh	7	2.6	0.1	2.1	—[1]	7	0.22	0.08	0.17	0.02
Long	6	1.4	0.4	1.2	0.4	5	0.11	0.02	0.055	—[1]
Middle Lagoon	6	1.1	0.2	0.7	0.2	6	0.07	0.03	0.044	0.018

[1] Samples are reported for 2011 and 2012 only.

Seston

The total mercury content of seston (suspended particulates in water) averaged from 46 ng/g dry weight in Long Lake to 70 ng/g in Great Marsh, whereas methylmercury averaged from 7 to 14 ng/g

(Table 22). The fraction of total mercury present as methylmercury in seston averaged from 16% in Great Marsh to 57% in Middle Lagoon. In 2010, we had only enough cleaned filters to sample seston for methylmercury, which was considered to be an analyte of much higher priority than total mercury.

Table 22. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from waters in Indiana Dunes National Lakeshore.

Water body	Total Hg[1] (ng/g dry weight)			MeHg (ng/g dry weight)			MeHg (% mean[3])
	n[2]	*mean*	*range*	*n*[2]	*mean*	*SE*	
Great Marsh	3	70.2	49.3–99.6	5	7.2	2.3	15.7
Long Lake	3	45.6	37.6–58.0	5	8.4	1.7	20.4
Middle Lagoon	4	58.1	14.4–99.0	7	13.9	7.8	56.9

[1] Total Hg was not measured in seston sampled in 2010.

[2] n is the number of samples collected and analyzed for total Hg during 2011–2012 and for MeHg during 2010–2012.

[3] Calculated from 2011 and 2012 mean paired values only.

Zooplankton

Bulk zooplankton were sampled from Long Lake and Middle Lagoon (Table 23); we were unable to obtain samples of zooplankton from Great Marsh because of the shallow depth of water and the abundant woody debris and vegetative material in the water column there. Concentrations of total mercury averaged 51 ng/g dry weight in Long Lake and 60 ng/g in Middle Lagoon, whereas methylmercury in zooplankton averaged 28 ng/g dry weight in Long Lake and 18 ng/g in Middle Lagoon. The fraction of total mercury present as methylmercury in zooplankton averaged 50% in Long Lake and 41% in Middle Lagoon.

Table 23. Total mercury, methylmercury (MeHg), and percent MeHg in bulk zooplankton sampled from two water bodies in Indiana Dunes National Lakeshore during 2010–2012. Zooplankton were not sampled in Great Marsh.

Water body	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
	n[1]	*mean*	*SE*	*n*[1]	*mean*	*SE*	
Long Lake	4	50.6	6.5	5	28.2	6.2	50.4
Middle Lagoon	6	60.1	34.1	6	17.9	5.5	41.4

[1] n is the number of samples collected and analyzed during 2010–2012.

Larval Dragonflies

Larvae of the families Aeshnidae and Libellulidae were the most widely distributed dragonflies collected at INDU, inhabiting all three water bodies and two sites in Great Marsh and accounting for 80% of the 160 larvae analyzed (Table 24). Larvae from two other dragonfly families, including 31

corduliids and 1 gomphid, were sampled from Middle Lagoon. Mean concentrations of methylmercury in larval dragonflies from the three water bodies, with data from the two Great Marsh sites grouped, ranged from 47 to 51 ng/g dry weight in aeshnids and from 22 to 33 ng/g in libellulids. Methylmercury accounted for more than 65% of the total mercury in dragonfly larvae for most families and water bodies (Table 24). Mean percent methylmercury in larvae from the three water bodies ranged from 40% to 97%.

Table 24. Total mercury, methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Indiana Dunes National Lakeshore.

Water body (and site)	Family	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg	
		n	*mean*	*SE*	*n*	*mean*	*SE*	*mean*	*SE*
Great Marsh[1] (GRMA-2)	Aeshnidae	2	64	24	2	66	24	104	1.8
	Libellulidae	18	47	6.1	18	39	6.5	81	8.3
(GRMA-3)	Aeshnidae	1	24	—	1	20	—	83	—
	Libellulidae	24	34	6.0	18	24	4.4	66	6.5
Long Lake	Aeshnidae	11	52	4.2	11	50	4.1	97	2.9
	Libellulidae	39	32	2.3	42	22	2.0	66	3.5
Middle Lagoon	Aeshnidae	4	55	11	4	47	9.2	87	4.7
	Libellulidae	26	39	3.5	26	33	2.3	89	4.3
	Corduliidae	31	49	4.1	31	39	3.6	79	3.0
	Gomphidae	1	14	—	1	5.5	—	40	—

[1] Sites in Great Marsh are delineated as follows: GRMA-2 included channel habitat located south of Beverly Drive and west of Broadway; GRMA-3 included nearshore habitat in an open water site north of Beverly Drive and east of East State Park Road.

Whole Prey Fish

Small prey fishes were sampled from Great Marsh, Long Lake, and Middle Lagoon. 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 our sampling in Great Marsh and Long Lake. In comparison, Middle Lagoon contained a much more diverse assemblage of fishes than either Great Marsh or Long Lake.

Concentrations of total mercury in whole prey fishes and adult predatory fish from the three water bodies at INDU were generally low relative to the mercury levels in the other five national park units studied. Mercury levels in small, whole green sunfish and central mudminnow were generally higher in Great Marsh than in Long Lake and Middle Lagoon (Table 25). In green sunfish, concentrations averaged 34 and 63 ng/g wet weight at two sites in Great Marsh, 23 ng/g in Long Lake, and 25 ng/g in Middle Lagoon. In whole central mudminnows, concentrations of mercury averaged from 24 to 59 ng/g at four sites in Great Marsh, and averaged 22 ng/g in Long Lake and 31 ng/g in Middle Lagoon.

In other whole prey fishes from Middle Lagoon, mercury averaged 47 ng/g in small bluegill, 27 ng/g in Iowa darter, and 13 ng/g in a single small yellow perch (Table 25).

Table 25. Fish length and concentration of total mercury (Hg) in whole prey fish sampled in 2008 and 2010–2012 from Indiana Dunes National Lakeshore.

Water body and site	Species	n	Total length (mm)		Hg (ng/g wet weight)[1]	
			mean	*range*	*mean*	*range*
Great Marsh[2]						
GRMA-1	central mudminnow	61	75	24–114	26	7–79
GRMA-2	central mudminnow	107	71	20–123	38	11–84
GRMA-3	central mudminnow	24	68	21–96	24	11–58
GRMA-4	central mudminnow	59	76	41–133	59	17–134
GRMA-1	green sunfish	2	47	43–51	34	26–42
GRMA-2	green sunfish	2	42	40–44	63	61–64
Long Lake	central mudminnow	82	78	43–127	22	8–49
	green sunfish	51	37	30–54	23	10–44
Middle Lagoon	bluegill	14	49	42–59	47	32–75
	central mudminnow	29	57	43–83	31	14–72
	green sunfish	47	54	22–114	25	13–60
	Iowa darter	51	45	37–59	27	12–82
	yellow perch	1	69	—	13	—

[1] Concentrations are in nanograms per gram (ng/g), which are equivalent to parts per billion.

[2] Sites in Great Marsh are delineated as follows: GRMA-1 included open water and nearshore areas located south of Beverly Drive and just east of Broadway; GRMA-2 included channel habitat and adjacent inundated floodplain located south of Beverly Drive and west of Broadway; GRMA-3 included open water habitat in standing, dead timber north of Beverly Drive and east of East State Park Road; GRMA-4 included inundated floodplain forest located south of Beverly Drive and just east of East State Park Road.

Predatory and Adult Fish (Axial Muscle)

Axial muscle (skinless fillets) from 97 adult fish, including eight species, was analyzed for total mercury (Table 26). In Great Marsh, the concentrations of mercury in grass pickerel averaged 128 ng/g wet weight, ranging from 39 to 272 ng/g. In Long Lake, mercury levels in fish were low, averaging 13 ng/g (range 10–16 ng/g) in common carp and 43 ng/g (range 28–56 ng/g) in black bullhead. Periods of oxygen depletion and low concentrations of dissolved oxygen probably render Long Lake unsuitable as a habitat for long-lived piscivorous fishes (Garza et al. 2002).

In Middle Lagoon, concentrations of mercury in fillets were highest in three fish species that are largely piscivorous as adults (Table 26); these included grass pickerel (mean 115 ng/g wet weight), largemouth bass (mean 169 ng/g), and a single channel catfish (222 ng/g). Mercury levels were substantially lower in coexisting omnivorous fishes that feed largely on invertebrates; these included gizzard shad (mean 29 ng/g), bluegill (mean 29 ng/g), a single common carp (15 ng/g) and a small yellow perch (69 ng/g).

Table 26. Fish length and concentration of total mercury (Hg) in axial muscle (skinless fillets) of adult fish sampled from three water bodies in Indiana Dunes National Lakeshore during 2010–2012.

			Total length (mm)		Hg concentration[1] (ng/g wet weight)	
Study area	**Species**	**n**	***mean***	***range***	***mean***	***range***
Great Marsh	grass pickerel[2]	22	142	112–214	128	39–272
Long Lake	common carp	12	186	152–217	13	10–16
	black bullhead	7	192	176–203	43	28–56
Middle Lagoon	gizzard shad	11	334	310–352	29	19–42
	common carp	1	165	—	15	—
	bluegill	9	123	89–153	29	22–43
	yellow perch	1	148	—	69	—
	channel catfish	1	485	—	221	—
	grass pickerel	12	188	87–338	115	39–259
	largemouth bass	21	363	239–494	169	93–322

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

[2] Data include a single grass pickerel sampled from Great Marsh in May 2008.

Ecological and Health Risks of Methylmercury

The whole-body concentrations of mercury in prey fish from the three water bodies at INDU (see Table 25) were well below the estimated whole-body threshold of 200 ng/g wet weight (Beckvar et al. 2005) associated with sublethal and reproductive effects in fish. Similarly, mercury concentrations in the axial muscle tissue of adult predatory fish—including grass pickerel from Great Marsh and largemouth bass, grass pickerel, and channel catfish from Middle Lagoon (see Table 26)—were well below the benchmark level of 500 ng/g wet weight associated with sub-lethal and reproductive effects in freshwater fish (Sandheinrich and Wiener 2011).

Mean concentrations of total mercury in whole prey fish did exceed the estimated dietary threshold of 40 ng/g wet weight associated with diminished reproduction of piscivorous fish (Depew et al. 2012a) in 3 of the 12 site- and species-specific samples in Table 25. Central mudminnow and green sunfish—each from a site in Great Marsh and small bluegill from Middle Lagoon—had mean concentrations exceeding the estimated 40 ng/g threshold value for reproductive effects on piscivorous fish.

The screening-level dietary benchmark for belted kingfisher (30 ng/g wet weight in whole prey fish) was exceeded in 57% of the individual prey fish from Great Marsh, in 34% of the prey fish from Middle Lagoon, and in 17% of the prey fish from Long Lake. Mean concentrations of mercury in whole prey fish were less than the screening-level dietary benchmark for American mink (70 ng/g wet weight) in all three water bodies and in all fish species analyzed (see Table 25). Few individual prey fish had mercury concentrations exceeding the screening-level dietary benchmark for American

mink; these included 21 (8%) of the central mudminnows from Great Marsh, and three (2%) of the prey fish from Middle Lagoon. Mercury levels did not exceed 70 ng/g in any of the prey fish from Long Lake.

The belted kingfisher and American mink are considered to be highly sensitive to methylmercury. Common loons, which are moderately sensitive to methylmercury, do not nest on water bodies at INDU. However, the mean concentrations of mercury in whole prey fishes at INDU were far below the dietary benchmarks associated with behavioral effects (100 ng/g wet weight in prey fish) and diminished reproductive success (180 ng/g in prey fish) in adult common loons. Our findings indicate that ecological risks of methylmercury at INDU would be small for all but the most highly mercury-sensitive piscivores feeding on small fish in water bodies within the park unit.

Only one of the 97 adult fish analyzed had a mercury concentration exceeding the USEPA fish-tissue criterion for methylmercury (300 ng/g wet weight), which was derived to protect the health of humans who eat noncommercial fish. This fish, a large largemouth bass (total length 494 mm, weight 1.92 kg) from Middle Lagoon, had a concentration of 322 ng/g wet weight in axial muscle tissue. The concentrations of mercury in axial fillets of largemouth bass, grass pickerel, and channel catfish from Middle Lagoon were high enough to warrant limited frequency of consumption of these fishes by pregnant women, by women who may become pregnant, and by children under 15 years of age, based on the fish consumption guidelines recommended by the Great Lakes Fish Advisory Workgroup (compare Tables 8 and 26).

Lead and Organic Contaminants

Selected whole fish collected from the three water bodies at INDU during 2010–2012 were analyzed for total lead and organic contaminants. These included (1) five composite samples of whole grass pickerel from Great Marsh and Middle Lagoon, each containing 2 to 4 fish; (2) five composite samples (four fish each) of whole largemouth bass and two composite samples (four fish) of gizzard shad from Middle Lagoon; and (3) two composite samples of black bullhead (three fish each) and two composite samples (four fish each) of whole common carp from Long Lake (Appendix K, Table K-2). Samples collected in 2010, 2011, and 2012 were analyzed for DDT and metabolites (DDE and DDD), 95 polychlorinated biphenyl congeners (PCBs), and 16 perfluorinated compounds (PFCs). Total lead (Pb) was analyzed only in samples collected in 2010, and polybrominated diphenyl ethers (PBDEs) were analyzed in samples collected in 2010 and 2011 (Appendix L, Table L-3).

Concentrations of DDT, DDE, DDD, PCBs, and PBDEs were below limits of detection in grass pickerel from Great Marsh and in black bullhead and common carp from Long Lake. DDT was not detected in gizzard shad, grass pickerel, or largemouth bass from Middle Lagoon, while DDD and DDE had maximum concentrations of 160 and 570 ng/g wet weight, respectively, in gizzard shad from Middle Lagoon. In samples from Middle Lagoon with detectable concentrations, total PCBs ranged from 11 ng/g wet weight in grass pickerel to 446 ng/g in gizzard shad, and total PBDEs ranged from 2 ng/g in grass pickerel to 22 ng/g in gizzard shad. Concentrations of total perfluoro sulfonates and perfluoro acids were less than 10 ng/g wet weight in whole fish from Great Marsh and Long Lake. In Middle Lagoon, maximum concentrations of perfluoro sulfonates and perfluoro acids were 130 ng/g in largemouth bass and 32 ng/g in gizzard shad, respectively. Lead concentrations

ranged from 13 ng/g wet weight in whole grass pickerel from the Great Marsh to 304 ng/g in whole gizzard shad from Middle Lagoon.

The concentrations of total DDT, total PCBs, total PBDEs, and PFOS in whole fish from Great Marsh and Long Lake were below limits of detection or were substantially less than reported benchmark concentrations associated with adverse effects on piscivorous birds and mammals (Table 9). With the exception of gizzard shad, the concentrations of total DDT, total PCBs, total PBDEs, and PFOS in fish from Middle Lagoon were also less than reported benchmarks. In gizzard shad, however, maximum concentrations of total DDT (ΣDDT metabolites) and total PCB (sum of congeners) exceeded screening-level benchmark concentrations associated with altered health and reproduction in fish, belted kingfisher, and American mink. These findings suggest that fish and piscivorous wildlife may be at risk from these two legacy contaminants in Middle Lagoon.

Fillets of fish from Middle Lagoon were not analyzed for organic contaminants and lead. Given that concentrations of DDD, DDE, PCBs, and PFOS were high in some *whole fish* sampled from Middle Lagoon during 2010–2012, we recommend that skin-on fillets of selected sport fishes from Middle Lagoon be analyzed for these contaminants. Candidate species for sampling and analyses include largemouth bass, grass pickerel, bluegill, and possibly channel catfish.

Isle Royale National Park (ISRO)

Four lakes were studied at ISRO: Angleworm, Harvey, Richie, and Sargent (see Table 1). Piscivorous fish, prey fish, and larval dragonflies were sampled from each lake in 2009, and more intensive sampling of the aquatic food web in each lake was done annually during 2010–2012. Water, seston, and zooplankton were sampled near the center of each lake basin. Water in the four lakes generally had low to moderate specific conductance (range 53–93 µS/cm), high pH (range 8.0–8.4), and dissolved oxygen concentrations near saturation (range 11.0–11.9 mg/L) at the times of sampling. Mean dissolved organic carbon ranged from 5.6 to 9.2 mg/L, and mean concentrations of sulfate ranged from 3.1 to 4.7 mg/L (Table 27).

Table 27. Summary of water quality measurements (mean ± SE) in four lakes at Isle Royale National Park, derived from annual *in situ* measurements and from analyses of water sampled during 2010–2012.

Lake	Temperature (°C)	DO[1] (mg/L)	Conductivity (µS/cm)	pH[2] (s.u.)	Sulfate (mg/L)	DOC[2] (mg/L)
Angleworm	15.1 ± 0.7	11.9	53.1 ± 0.8	8.0 ± 0.1	3.1 ± 0.1	5.6 ± 0.3
Harvey	17.6 ± 1.8	11.0	91.8 ± 1.9	8.4 ± 0.1	3.3 ± 0.2	9.2 ± 1.1
Richie	16.3 ± 2.0	11.6	82.4 ±1.7	8.1 ± 0.01	4.7 ± 1.2	8.6 ± 0.3
Sargent	16.2 ± 2.3	11.0	92.5 ± 1.0	8.3 ± 0.1	4.2 ± 0.3	7.8 ± 0.4

[1] Dissolved oxygen (DO) was measured in 2010 and 2011.

[2] DOC is dissolved organic carbon and s.u. is standard pH units.

Mercury in Water Bodies and Food Webs

Soil

Surficial soil was collected at nearshore margins of each lake. Mean concentrations of total mercury in soils ranged from 27 to 50 ng/g dry weight and methylmercury ranged from 0.14 to 0.49 ng/g dry weight (Table 28). Total mercury was positively correlated with percent loss on ignition (a surrogate measure of organic matter content), a pattern also observed in surficial sediment. The fraction of total mercury present as methylmercury ranged from 0.3% to 1.7% (Table 28).

Table 28. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in soils sampled near lakes in Isle Royale National Park. Means are reported for surface soil (upper 5 cm of core) collected in 2012 within 5 m of each lake margin.

		Total Hg (ng/g dry weight)		MeHg (ng/g dry weight)		Percent MeHg (mean)	Loss on ignition (%)	
Lake	**n**	***mean***	***range***	***mean***	***range***		***mean***	***range***
Angleworm	2	49.8	47.4–52.2	0.17	0.16–0.17	0.34	11.9	10.0–13.9
Harvey	2	49.1	18.9–79.3	0.27	0.07–0.46	0.54	12.0	3.2–20.8
Richie	2	26.5	17.4–35.6	0.14	0.06–0.22	0.51	6.9	3.0–10.7
Sargent	2	29.2	15.9–42.4	0.49	0.18–0.80	1.7	16.7	7.1–26.3

Sediment

Surficial sediment was sampled from nearshore locations at each lake. Mean concentrations of total mercury in sediment ranged from 4.0 ng/g dry weight in Sargent Lake to 8.6 ng/g in Lake Harvey, and were positively related to percent loss on ignition (Table 29). Mean concentrations of methylmercury in sediment ranged from 0.05 ng/g dry weight in Sargent Lake to 0.51 ng/g in Lake Harvey. The fraction of total mercury present as methylmercury, an indirect indicator of microbial mercury methylation in surficial sediment, ranged from 1.3% to 2.6%.

Table 29. Total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in surficial sediments (upper 5 cm) sampled from four lakes in Isle Royale National Park during 2010–2012. Surficial sediments were sampled from locations of concurrent larval dragonfly collection, within 2 m of the shoreline.

	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)	Loss on ignition (%)	
Lake	***n***	***mean***	***SE***	***n***	***mean***	***SE***		***mean***	***range***
Angleworm	7	7.7	2.6	4	0.28	0.22	2.6	5.9	1.6–13
Harvey	7	8.6	3.5	4	0.51	0.42	2.4	3.0	1.9–5.0
Richie	7	5.1	0.7	4	0.10	0.05	1.7	1.5	1.4–1.6
Sargent	7	4.0	1.0	5	0.050	0.02	1.3	1.0	0.6–1.3

Water

Mean concentrations of total mercury in lake water ranged from 1.0 to 1.5 ng/L in unfiltered samples and from 0.6 to 0.8 ng/L in filtered samples (Table 30). Filter-passing mercury accounted for 56% ± 1% (SE) of the total mercury in unfiltered samples (Table 30). Mean concentrations of methylmercury ranged from 0.04 to 0.15 ng/L in unfiltered samples and from 0.03 to 0.13 ng/L in filtered samples, with filter-passing methylmercury accounting for 74% ± 5% of the total methylmercury in unfiltered water. Methylmercury accounted for 6.2% ± 1.0% of the total mercury in unfiltered samples and for 8.4% ± 1.6% of the total mercury in filtered samples. Lake Harvey had the highest mean concentration of both total mercury (1.5 ng/L) and methylmercury (0.15 ng/L), with aqueous methylmercury levels two- to four-times those in the other three lakes at ISRO.

Table 30. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water from four lakes in Isle Royale National Park. Samples were collected near the center of each lake at a depth of 1–2 m.

	Total Hg (ng/L)					MeHg (ng/L)				
		Unfiltered		*Filtered*			*Unfiltered*		*Filtered*	
Lake	***n*[1]**	*mean*	*SE*	*mean*	*SE*	***n*[1]**	*mean*	*SE*	*mean*	*SE*
Angleworm	6	1.12	0.32	0.61	0.12	6	0.040	0.011	0.031	0.010
Harvey	4	1.47	—[2]	0.79	—[2]	6	0.154	0.028	0.129	0.031
Richie	6	1.08	0.18	0.60	0.12	6	0.056	0.008	0.035	0.009
Sargent	6	0.96	0.12	0.57	0.07	5	0.063	0.024	0.045	0.018

[1] n is the number of water samples collected and analyzed during 2010–2012.

[2] Samples are reported for 2010 and 2012 only.

Seston

The mean concentration of total mercury in seston (suspended particulates in water) ranged from 103 to 154 ng/g dry weight, and the mean concentration of methylmercury ranged from 2.2 to 14 ng/g dry weight (Table 31). The fraction of total mercury present as methylmercury in seston was 14% in Lake Harvey, much greater than that in seston from the other three lakes, which ranged from 2.1% to 5.2% methylmercury. The mean concentration of methylmercury in seston was also highest in Lake Harvey, more than twice the levels in seston from the other three lakes (Table 31).

Zooplankton

Mean concentrations of total mercury in bulk zooplankton from ISRO lakes ranged from 80 ng/g dry weight in Sargent Lake to 154 ng/g in Lake Harvey, and mean concentrations of methylmercury ranged from 18 ng/g dry weight in Sargent Lake to 93 ng/g in Lake Harvey (Table 32). The fraction of total mercury present as methylmercury in zooplankton ranged from 25% to 53% in the four lakes. Methylmercury levels in zooplankton from Lake Harvey (93 ng/g) were more than twice those in the other ISRO lakes, a pattern consistent with that observed in water and seston (see Tables 30 and 31). These findings indicate that mercury in Lake Harvey is more readily methylated, resulting in greater accumulation of methylmercury into its aquatic food web.

Table 31. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from four lakes in Isle Royale National Park.

Lake	Total Hg[1] (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
	n[2]	*mean*	*range*	*n*[2]	*mean*	*SE*	
Angleworm	4	141	85–189	7	2.23	0.74	2.1
Harvey	3	105	82–154	6	13.5	1.3	13.9
Richie	4	103	71–123	8	4.93	0.67	5.2
Sargent	4	154	66–238	7	4.45	1.52	4.2

[1] Total Hg was not measured in seston sampled in 2010.

[2] n is the number of samples collected and analyzed for total Hg during 2011–2012 and for MeHg during 2010–2012.

Table 32. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in bulk zooplankton from four lakes in Isle Royale National Park during 2010–2012.

Lake	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
	n[1]	*mean*	*SE*	*n*[1]	*mean*	*SE*	
Angleworm	7	81.7	12.8	8	45.4	36.7	52.2
Harvey	6	154	42.0	5	92.5	33.0	52.9
Richie	9	92.1	37.0	9	26.0	8.8	30.9
Sargent	7	79.9	28.3	7	17.7	2.5	25.3

[1] n is the number of samples collected and analyzed during 2010–2012.

Larval Dragonflies

Larvae of the families Gomphidae, Corduliidae, and Aeshnidae were the most widely distributed dragonflies in our samples from ISRO, inhabiting all four lakes and accounting for 84% of the 414 larvae analyzed (Table 33). The gomphids were the most abundant of these three families, representing 74% of all larvae analyzed. Mean concentrations of methylmercury ranged from 33 to 85 ng/g dry weight in gomphids, from 40 to 115 ng/g in corduliids, and from 67 to 115 ng/g in aeshnids. Larvae from two other families of dragonflies, including 44 macromiids and 22 libellulids, were also analyzed. Members of all five dragonfly families were collected from Lake Harvey, where mean concentrations of methylmercury in each family exceeded those in the other three lakes studied at ISRO. Mean concentrations in larvae from Lake Harvey ranged from 85 ng/g dry weight in gomphids to 152 ng/g in macromiids. Methylmercury accounted for more than 63% of the total mercury in dragonfly larvae for most taxa and lakes (Table 33). Across the four lakes, percent methylmercury averaged from 63% to 70% in gomphid larvae and from 71% to 101% in macromiid larvae. We note that calculated values exceeding 100% for percent methylmercury can result from uncertainties in measured concentrations of total mercury and methylmercury.

Table 33. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Isle Royale National Park.

		Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg	
Lake	**Family**	***n***	***mean***	***SE***	***n***	***mean***	***SE***	***mean***	***SE***
Angleworm	Aeshnidae	3	104	31	3	75	19	77	13
	Libellulidae	4	60	2.3	4	51	1.1	85	3.9
	Corduliidae	5	51	4.1	5	40	4.4	77	3.0
	Gomphidae	83	50	1.5	91	33	1.4	63	2.2
	Macromiidae	2	48	0.7	2	35	4.6	73	8.8
Harvey	Aeshnidae	5	131	35	5	115	33	85	7.1
	Libellulidae	1	105	—	4	133	25	57	—
	Corduliidae	5	138	23	6	115	16	80	3.5
	Gomphidae	37	95	3.6	41	85	13	70	3.3
	Macromiidae	14	151	7.2	14	152	7.5	101	1.8
Richie	Aeshnidae	1	134	—	1	98	—	73	—
	Libellulidae	14	95	10	14	67	8.1	70	2.6
	Corduliidae	13	80	4.4	13	54	4.2	70	6.2
	Gomphidae	72	55	2.3	72	36	1.8	68	2.6
Sargent	Aeshnidae	7	72	3.4	7	67	5.6	78	1.5
	Corduliidae	1	88	—	1	80	—	91	—
	Gomphidae	103	56	1.3	103	36	1.2	64	1.7
	Macromiidae	28	57	2.8	28	40	1.9	71	2.6

Whole Prey Fish

Yellow perch—a regionally widespread and important prey fish—were sampled from Angleworm, Harvey, Richie, and Sargent lakes during 2009–2012 and analyzed for total mercury. Mean concentrations in both small (<100 mm) and larger (≥100 mm) whole yellow perch from Lake Harvey substantially exceeded those in yellow perch from the other three lakes (Table 34). The mean concentration in small yellow perch from Lake Harvey (115 ng/g wet weight) was five-fold that in Angleworm Lake (22 ng/g) and about three-fold those in Richie (37 ng/g) and Sargent lakes (39 ng/g).

Predatory Fish (Axial Muscle)

Axial muscle tissue (skinless fillets) from a total of 265 piscivorous fish—including 176 northern pike from three lakes (Angleworm, Richie, and Sargent), 80 large yellow perch from Lake Harvey, and nine large yellow perch from Lake Richie—were analyzed for total mercury (Table 35). Mercury levels were highest in yellow perch from Lake Harvey, averaging 688 ng/g wet weight and ranging

from 94 to 1,453 ng/g. Concentrations in large yellow perch from Lake Richie were much lower, averaging 76 ng/g and ranging from 51 to 111 ng/g. In northern pike, mercury levels were highest in Sargent Lake (mean 427 ng/g, range 92–1,379 ng/g wet weight). Concentrations were lower in northern pike from Angleworm Lake (mean 240 ng/g, range 59–843 ng/g) and Lake Richie (mean 200 ng/g, range 97–648 ng/g).

Table 34. Fish length and concentration of total mercury (Hg) in whole yellow perch sampled during 2009–2012 from four lakes in Isle Royale National Park.

Lake	Total length group	n	Total length (mm)		Hg (ng/g wet weight)[1]	
			mean	*range*	*mean*	*range*
Angleworm	<100 mm	49	69	47–95	22	9–42
	≥100 mm	1	102	—	33	—
	all lengths	50	70	47–102	22	9–42
Harvey	<100 mm	14	88	70–98	115	54–210
	≥100 mm	102	158	100–337	227	49–1,094
	all lengths	116	150	70–337	213	49–1,094
Richie	<100 mm	57	66	48–96	37	24–57
	≥100 mm	21	146	103–225	42	24–82
	all lengths	78	87	48–225	39	24–82
Sargent	<100 mm	80	62	51–85	39	19–72
	≥100 mm	9	117	106–144	34	28–40
	all lengths	89	68	51–144	39	19–72

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

Table 35. Fish length and concentration of total mercury (Hg) in axial muscle of piscivorous fishes sampled in 2009–2012 from four lakes in Isle Royale National Park.

Lake	Species	n	Total length (mm)		Hg concentration[1] (ng/g wet wt)		Percent (number) of fish exceeding benchmarks[2]	
			mean	*range*	*mean*	*range*	*Human health USEPA (300 ng/g)*	*Fish health and reprod. (500 ng/g)*
Angleworm	northern pike	57	554	338–696	240	59–843	26 (15)	5 (3)
Harvey	yellow perch	80	236	128–347	688	94–1453	80 (64)	61 (49)
Richie	northern pike	64	496	304–631	200	97–648	11 (7)	3 (2)
	yellow perch	9	187	161–225	76	51–111	0 (0)	0 (0)
Sargent	northern pike	55	609	283–746	427	92–1379	80 (44)	27 (15)

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

[2] Fish with Hg concentration exceeding the USEPA fish-tissue criterion for methylmercury (300 ng/g) and an estimated benchmark level (500 ng/g) for adverse effects on fish health and reproduction.

Ecological and Health Risks of Methylmercury

Concentrations of mercury in axial muscle in 49 (61%) of the 80 large yellow perch from Lake Harvey that were analyzed (see Table 35) exceeded 500 ng/g wet weight, a benchmark level associated with altered biochemical processes, damage to cells and tissues, and reduced reproduction of fish. Mercury levels in 15 (27%) of 55 northern pike from Sargent Lake exceeded the 500 ng/g benchmark. Few (≤5%) of the northern pike from Angleworm and Richie lakes had concentrations exceeding the fish-health benchmark (see Table 35).

In Lake Harvey, mean concentrations of mercury in whole yellow perch of all total length groups substantially exceeded the estimated dietary threshold of 40 ng/g wet weight associated with diminished reproduction of piscivorous fish (Depew et al. 2012a), whereas mean concentrations in yellow perch from Angleworm, Richie, and Sargent lakes were generally below the 40 ng/g benchmark (see Table 34). However, mercury levels in several individual whole yellow perch from Richie and Sargent lakes exceeded the 40 ng/g dietary threshold for reproduction of piscivorous fish (Table 36). Only 1 of 50 whole yellow perch from Angleworm Lake exceeded the 40 ng/g benchmark.

Table 36. Percentages of whole yellow perch from four lakes in Isle Royale National Park with mercury levels exceeding screening dietary benchmarks for belted kingfisher (30 ng/g wet weight), piscivorous fish (40 ng/g), and American mink (70 ng/g).

		Total length (mm)		Percent of yellow perch with Hg exceeding dietary benchmarks for piscivorous fish and wildlife		
Lake	n	*length group*	*length range*	*Belted kingfisher (30 ng/g)*	*Piscivorous fish (40 ng/g)*	*American mink (70 ng/g)*
Angleworm	49	<100	47–95	16	2	0
	1	≥100	102	100	0	0
	50	all fish	47–102	18	2	0
Harvey	14	<100	70–98	100	100	86
	102	≥100	100–337	100	100	97
	116	all fish	70–337	100	100	96
Richie	57	<100	48–96	79	33	0
	21	≥100	103–225	86	43	10
	78	all fish	48–225	81	36	3
Sargent	80	<100	51–85	80	45	1
	9	≥100	106–144	78	0	0
	89	all fish	51–144	80	40	1

The screening-level dietary benchmark for belted kingfisher (30 ng/g wet weight in whole prey fish) was substantially exceeded in all of the yellow perch from Lake Harvey (Tables 34 and 36), exceeded in about 80% of the perch from Richie and Sargent lakes, and in 18% from Angleworm Lake (Tables 34 and 36). Mercury levels in almost all of the whole yellow perch from Lake Harvey exceeded the screening-level dietary benchmark of 70 ng/g wet weight for American mink (Table

36). Few individual perch from Richie and Sargent lakes and none from Angleworm Lake had mercury concentrations exceeding the dietary benchmark for American mink.

Many of the whole yellow perch analyzed from the four lakes at ISRO (see Table 34) were within the length range of fish commonly eaten by adult common loons (100–250 mm; Barr 1996, Wiener et al. 2012a). In Lake Harvey, the mean concentration of mercury in whole yellow perch longer than 100 mm was 227 ng/g wet weight, exceeding the benchmark prey fish concentration (180 ng/g wet weight) causing significant reproductive impairment in adult common loons (Depew et al. 2012b). Concentrations in some yellow perch from Lake Harvey exceeded 400 ng/g, a prey fish concentration associated with complete reproductive failure of adult common loons (Depew et al. 2012b).

The USEPA tissue residue criterion for methylmercury (300 ng/g wet weight), derived to protect the health of humans who eat noncommercial fish, was exceeded in 80% of the yellow perch from Lake Harvey. In Sargent Lake, mercury concentrations in axial muscle of northern pike exceeded the USEPA criterion in 80% of 55 fish. Mercury levels in northern pike from Lake Richie and Angleworm Lake exceeded the USEPA criterion in 22 (18%) of the fish from the two lakes (Table 35). The concentrations of mercury in axial fillets of yellow perch and northern pike from all study lakes at ISRO were high enough to warrant limited frequency of consumption of these fishes by pregnant women, by women who may become pregnant, and by children under 15 years of age, based on the fish consumption guidelines recommended by the Great Lakes Fish Advisory Workgroup (compare Tables 8 and 35).

Lead and Organic Contaminants

In contrast to the results for mercury, the concentrations of legacy contaminants (DDT, DDE, DDD, PCBs, and Pb) and emerging contaminants (PBDEs, and PFCs) in piscivorous fish from the four lakes at ISRO were low, commonly below limits of detection.

Axial Muscle

Analytical results for organic contaminants and lead in axial muscle (skinless fillets) of fish collected in 2009, which were reported by Wiener et al. (2013), are briefly summarized here. Eight composite samples of northern pike from Richie, Sargent, and Angleworm lakes—each sample containing an equivalent mass of axial muscle from four fish of similar total length—were analyzed (Appendix K, Table K-1). Two composite samples of large yellow perch from Lake Harvey—one containing axial muscle from three fish and the other four fish of similar total length—were also analyzed. Concentrations of PCBs, PBDEs, DDT, DDE, and DDD in all axial muscle samples from ISRO were below limits of detection, which were 0.5–16 ng/g wet weight for PCBs, 1.0–2.0 ng/g for PBDEs, and 10 ng/g for total DDT (Appendix L, Table L-4). The concentrations of PFCs were below reporting levels (0.5–2.0 ng/g wet weight) in northern pike from Lake Richie and were low in fish from Sargent, Angleworm, and Harvey lakes (range 0.6–2.1 ng/g wet weight). The concentrations of these legacy and emerging organic contaminants in axial fillets of fish from the study lakes at ISRO do not pose significant risks to human health, based on guidelines for human consumption of sport fish (see Table 8). Lead concentrations in axial muscle 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.

Whole Fish

Eighteen composite samples of whole northern pike from Angleworm, Richie, and Sargent lakes, and six composite samples of whole yellow perch from Lake Harvey were collected in 2010, 2011, and 2012 and analyzed for organic contaminants and lead; each of these composite samples contained three to four fish of similar size (Appendix K, Table K-2). Samples collected in 2010 and 2012 were analyzed for DDT and metabolites (DDE and DDD), 95 polychlorinated biphenyl congeners (PCBs), and 16 perfluorinated compounds (PFCs). Total lead (Pb) and polybrominated diphenyl ethers (PBDEs) were analyzed only in samples collected in 2010. Samples taken in 2011 were analyzed only for PFCs (i.e., these fish were not analyzed for total lead or other organic contaminants).

Concentrations of DDT, DDE, and DDD in all whole-fish samples from ISRO were below limits of detection (LOD, 10 ng/g wet weight for total DDT; Appendix L, Table L-5). With the exception of one congener of PBDE in yellow perch from Lake Harvey and two congener groups of PCBs in northern pike from Lake Richie and Sargent Lake, concentrations of PBDEs and PCBs were below limits of detection (1.0–2.0 ng/g for PBDEs, 1–3.5 ng/g for PCBs); the congeners detected had concentrations of 1 to 2.7 ng/g. The concentrations of PFCs were low in whole fish from all lakes sampled (range 0.12–5.1 ng/g). Lead concentrations were also low, averaging 13 ng/g wet weight (range 12–14 ng/g) in whole yellow perch and 15 ng/g (range 12–22 ng/g) in whole northern pike.

The concentrations of the legacy and emerging organic contaminants measured in whole fish from ISRO lakes were substantially less than reported benchmark concentrations associated with adverse effects on piscivorous birds or mammals (see Table 9) and do not pose significant risks to the health of piscivorous wildlife.

Pictured Rocks National Lakeshore (PIRO)

We studied five lakes at PIRO: Beaver, Chapel, Grand Sable, Legion, and Miners lakes (see Table 1). Fish and larval dragonflies were sampled in each lake in 2008 for the pilot study, followed by more intensive sampling of food webs annually during 2010–2012. Waters in these lakes spanned a broad range in specific conductance, with mean values ranging from 9 µS/cm in Legion Lake to 309 µS/cm in Miners Lake. Lake pH also varied widely, from acidic conditions (mean pH 5.2) in Legion Lake to basic pH (range 7.9–8.5) in the other four lakes (Table 37). Near-surface waters in all lakes were undersaturated with dissolved oxygen (range in mean DO, 5.7–7.9 mg/L) at the time of measurement. The lakes had low to moderate concentrations of dissolved organic carbon (mean DOC, 2.0–8.4 mg/L) and sulfate (range 2.0–9.9 mg/L) (Table 37). The chemical composition of Legion Lake, a topographically perched seepage lake (no inflowing stream), was similar to that of rainwater—poorly buffered with low pH and low specific conductance—and differed substantially from the other four lakes.

Table 37. Summary of water quality measurements (mean ± SE) in five lakes at Pictured Rocks National Lakeshore, derived from annual *in situ* measurements and from analyses of water samples during 2010–2012.

Lake	Temperature (°C)	DO[1] (mg/L)	Conductivity (µS/cm)	pH[2] (s.u.)	Sulfate (mg/L)	DOC[2] (mg/L)
Beaver	17.7 ± 1.7	6.8	170 ± 3	8.5 ± 0.04	6.8 ± 1.2	3.8 ± 0.8
Chapel	19.1 ± 2.9	7.4	182 ± 15	8.4 ± 0.1	9.9 ± 2.4	8.4 ± 1.7
Grand Sable	16.0 ± 2.1	7.7	114 ± 3	7.9 ± 0.5	3.6 ± 0.7	5.5 ± 1.4
Legion	18.1 ± 2.0	5.7	9.0 ± 0.6	5.2 ± 0.1	2.0 ± 0.2	2.0 ± 0.1
Miners	13.6 ± 2.3	7.9	309 ± 17	7.9 ± 0.6	6.6 ± 0.4	5.9 ± 2.0

[1] Dissolved oxygen (DO) was measured in 2010 and 2011.

[2] DOC is dissolved organic carbon, and s.u. is standard pH units.

Mercury in Lakes and Food Webs

Soil

Surficial soils were collected in 2012 along the nearshore margins of each lake. Total mercury concentrations in soils from the five lakes were positively correlated with percent loss on ignition—a surrogate measure of organic matter content—a pattern also observed in lacustrine sediments. Soils from four of the five lakes (Beaver, Chapel, Grand Sable, and Miners lakes) had total mercury ranging from 18 to 147 ng/g dry weight and methylmercury ranging from 0.01 to 0.74 ng/g dry weight (Table 38); the fraction of total mercury present as methylmercury ranged from about 0.1% to 0.6% in soils from these four lakes. Soils from Legion Lake had higher organic matter content, higher concentrations of total mercury (198 ng/g), and much higher methylmercury (4.7 ng/g) and percent methylmercury (2.4%) than soils from the other four lakes.

Table 38. Total mercury, methylmercury (MeHg), percent MeHg, and percent loss on ignition in soil sampled near lakes in Pictured Rocks National Lakeshore. Concentrations are reported for soil composited from the top strata (upper 5 cm) of five cores taken in 2012 within 5 m of each lake margin.

Lake	Total Hg (ng/g dry weight)	MeHg (ng/g dry weight)	Percent MeHg	Loss on ignition (%)
Beaver	17.8	0.014	0.08	7.4
Chapel	147	0.74	0.51	51.1
Grand Sable	22.8	0.09	0.37	5.5
Legion	198	4.71	2.4	70.6
Miners	44.0	0.25	0.57	13.4

Sediment

Surficial sediment was sampled from nearshore locations at each lake. Total mercury was generally low (range 0.6–6.9 ng/g dry weight) and positively related to percent loss on ignition (Table 39).

Methylmercury content in sediment ranged from 0.02 to 0.34 ng/g dry weight. The fraction of total mercury present as methylmercury, an indirect indicator of microbial mercury methylation in surficial sediment, ranged from 2.9% to 8.3%. Sediment from Legion Lake had higher organic matter content, total mercury concentration, methylmercury concentration, and percent methylmercury than the sediments from the other four lakes, a pattern also observed in soils.

Table 39. Mean total mercury (Hg), methylmercury (MeHg), percent MeHg, and loss on ignition in surficial sediments (upper 5 cm) sampled from lakes in Pictured Rocks National Lakeshore during 2010–2012. Surficial sediments were sampled from locations of concurrent larval dragonfly collection, within 2 m of the shoreline.

	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)	Loss on ignition (%)	
Lake	***n***	***mean***	***SE***	***n***	***mean***	***SE***		***mean***	***range***
Beaver	7	0.64	0.17	4	0.016	0.004	2.9	0.8	0.4–1.6
Chapel	7	3.57	1.19	4	0.085	0.068	2.8	1.6	0.5–2.8
Grand Sable	6	1.52	—[1]	5	0.070	0.032	3.2	0.6[1]	0.5–0.7
Legion	6	6.94	—[1]	3	0.341	—[1]	8.3	2.9[1]	2.5–3.3
Miners	7	3.61	1.49	5	0.162	0.046	6.8	1.4	1.0–2.5

[1] Samples are reported for 2011 and 2012 only.

Water

Total mercury concentrations in lake water ranged from about 1.0 to 3.0 ng/L in unfiltered samples and from 0.6 to 2.3 ng/L in 0.45-µm filtered samples. Filter-passing total mercury accounted for 60% ± 7% (SE) of the total mercury present in unfiltered samples (Table 40). Mean concentrations of methylmercury ranged from 0.04 to 0.23 ng/L in unfiltered samples and from 0.02 to 0.12 ng/L in filtered samples, with filter-passing methylmercury accounting for 53% ± 4% of the total methylmercury present in unfiltered water. Methylmercury accounted for 6.8% ± 0.9% of the total mercury in unfiltered samples and for 6.7% ± 1.4% of the total mercury in filtered samples. Chapel and Miners lakes had higher aqueous concentrations of total mercury and methylmercury than the other lakes studied at PIRO, with methylmercury concentrations from two- to five-fold those in the other three lakes.

Seston

Total mercury in seston (suspended particulates in water) ranged from 44 ng/g dry weight in Beaver Lake to 224 ng/g in Chapel Lake (Table 41). Concentrations of methylmercury in seston were greater in Legion (34 ng/g dry weight) and Chapel (13 ng/g) lakes than in Beaver, Grand Sable, and Miners lakes (range, 5.7 to 6.7 ng/g).

Table 40. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water sampled from lakes in Pictured Rocks National Lakeshore. Samples were collected near the center of each lake at a depth of 1–2 m.

	Total Hg (ng/L)					MeHg (ng/L)				
		Unfiltered		*Filtered*			*Unfiltered*		*Filtered*	
Lake	***n*[1]**	*mean*	*SE*	*mean*	*SE*	***n*[1]**	*mean*	*SE*	*mean*	*SE*
Beaver	6	0.98	0.11	0.56	0.13	6	0.041	0.004	0.022	0.008
Chapel	6	2.98	0.72	2.27	0.73	6	0.229	0.053	0.115	0.046
Grand Sable	6	1.52	0.19	1.15	0.19	6	0.111	0.018	0.074	0.025
Legion	6	1.50	0.29	0.57	—[2]	6	0.070	0.012	0.029	0.008
Miners	6	2.31	0.52	1.28	0.59	5	0.215	0.056	0.119	0.042

[1] n is the number of water samples collected and analyzed during 2010–2012.

[2] Samples are reported only for 2010 and 2012.

Table 41. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from five lakes in Pictured Rocks National Lakeshore.

	Total Hg[1] (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
Lake	***n*[2]**	***mean***	***range***	***n*[2]**	***mean***	***SE***	
Beaver	2	44.2	35.7–52.7	7	6.7	1.7	11.9
Chapel	2	224	156–292	6	12.8	2.6	6.9
Grand Sable	2	53.3	44.1–62.5	6	5.7	0.6	9.8
Legion	2	148	130–167	5	33.8	5.0	23.0
Miners	2	188	137–239	6	6.6	1.4	2.9

[1] Total Hg was not measured in seston sampled in 2010.

[2] n is the number of samples collected and analyzed for total Hg during 2011–2012 and for MeHg during 2010–2012.

The fraction of total mercury present as methylmercury in seston ranged from about 3% to 23%. Seston from Legion Lake had the highest concentration of methylmercury (34 ng/g) and the highest percent methylmercury (23%), values two- to six-times those for seston from the other lakes at PIRO, a pattern similar to that observed in soils and sediments.

Zooplankton

Concentrations of total mercury and methylmercury in bulk zooplankton were substantially higher in Chapel and Legion lakes than in Beaver, Grand Sable, and Miners lakes (Table 42). The fraction of total mercury present as methylmercury in zooplankton did not vary greatly among the five lakes, with percent methylmercury averaging from 33% in Grand Sable and Miners lakes to 53% in Legion Lake. The higher concentrations of methylmercury in Chapel and Legion lakes, relative to the other three lakes, are consistent with the pattern observed in other components of the lower food web.

Table 42. Total mercury, methylmercury (MeHg), and percent MeHg in bulk zooplankton sampled from lakes in Pictured Rocks National Lakeshore during 2010–2012.

Lake	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
	n [1]	*mean*	*SE*	*n* [1]	*mean*	*SE*	
Beaver	6	63.2	18.4	7	28.2	5.2	45.8
Chapel	5	271	145	6	124	75.9	41.9
Grand Sable	6	69.6	34.8	6	18.3	7.4	32.8
Legion	6	231	85.1	5	133	61.4	53.4
Miners	4	94.4	28.0	6	29.4	19.7	32.8

[1] n is the number of samples collected and analyzed during 2010–2012.

Larval Dragonflies

Larvae from all six of the dragonfly families known to occur in the western Great Lakes region were collected at PIRO. Larvae of the families Gomphidae, Corduliidae, and Aeshnidae were the most widely distributed, inhabiting all five study lakes and accounting for 73% of the 566 larvae analyzed (Table 43). Of these three families, the gomphids were the most abundant, representing 46% of all the larvae analyzed. Mean concentration of methylmercury in individual lakes ranged from 39 to 125 ng/g dry weight in gomphids, from 89 to 199 ng/g in corduliids, and from 75 to 249 ng/g dry in aeshnids. Larvae from three other dragonfly families, including 35 cordulegastrids, 43 libellulids, and 73 macromiids were also analyzed. The cordulegastrids had the two highest concentrations of methylmercury observed in our study, averaging 404 ng/g dry weight in Grand Sable Lake and 266 ng/g in Chapel Lake. Larvae in the other four dragonfly families (aeshnids, corduliids, gomphids and macromiids) from Grand Sable Lake had much lower methylmercury concentrations, averaging from 58 to 89 ng/g dry weight. In Chapel Lake, however, concentrations of methylmercury in other dragonfly families were also relatively high, averaging 100 ng/g dry weight in gomphids, 122 ng/g in macromiids, 167 ng/g in aeshnids, and 199 ng/g in corduliids. Methylmercury accounted for more than 75% of the total mercury in dragonfly larvae for most taxa and lakes (Table 43). Across the five lakes, mean percent methylmercury ranged from 54% to 85% in the gomphids and from 77% to 100% in corduliids.

Whole Prey Fish

We quantified total mercury in a total of six species of prey fish from the five study lakes at PIRO. Mercury levels were low in whole mottled sculpin, which were sampled from four of the five lakes, with mean concentrations ranging from 18 to 25 ng/g wet weight (Table 44). Moreover, mottled sculpin did not exhibit the variation in mercury levels among lakes that was evident in coexisting prey fishes, leading us to question the utility of the mottled sculpin as a biosentinel for mercury. Therefore, our evaluation of mercury in prey fish from PIRO lakes is based on results for the other five species—yellow perch, rock bass, Iowa darter, johnny darter, and central mudminnow.

Table 43. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Pictured Rocks National Lakeshore.

		Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg	
Lake	**Family**	***n***	***mean***	***SE***	***n***	***mean***	***SE***	***mean***	***SE***
Beaver	Aeshnidae	23	89	6.6	23	75	6.3	83	3.9
	Corduliidae	17	105	13	17	97	12	92	1.8
	Gomphidae	103	71	2.3	103	52	2.0	75	1.8
	Macromiidae	56	81	4.2	56	56	3.9	70	2.8
Chapel	Aeshnidae	4	182	35	4	167	34	92	7.4
	Cordulegastridae	18	294	20	18	265	21	91	3.8
	Corduliidae	2	191	61	2	199	82	100	11
	Gomphidae	40	123	6.2	41	100	7.5	80	3.4
	Macromiidae	6	152	18	6	122	23	78	6.9
Grand Sable	Aeshnidae	18	108	6.8	17	86	8.1	78	5.1
	Cordulegastridae	5	498	136	5	404	91	86	6.3
	Corduliidae	4	112	21	4	89	27	77	11
	Gomphidae	95	73	2.8	109	58	2.0	85	2.4
	Macromiidae	11	112	4.9	11	86	5.4	77	5.0
Legion	Aeshnidae	31	269	16	32	249	17	92	2.2
	Corduliidae	19	220	9.4	19	183	13	82	2.9
	Gomphidae	4	110	54	4	39	4.5	54	14
	Libellulidae	23	196	14	28	179	11	95	1.7
Miners	Aeshnidae	34	109	6.3	34	92	5.3	87	3.0
	Cordulegastridae	11	168	11	12	129	8.3	78	5.2
	Corduliidae	1	193	—	1	179	—	93	—
	Gomphidae	5	165	18	5	125	26	75	9.2
	Libellulidae	14	115	5.5	15	101	6.9	86	4.0

Mercury levels in whole prey fish varied substantially among lakes and were highest in Chapel Lake (Table 44). In yellow perch from Chapel Lake, mean concentrations were 184 ng/g wet weight in small perch (total length <100 mm) and 283 ng/g in large perch (total length ≥100 mm), substantially greater than mean concentrations in yellow perch from three other lakes. For comparison, mean concentrations in small perch were 40 ng/g in Beaver Lake and 76 ng/g in Grand Sable Lake. In large yellow perch, mercury averaged 87 ng/g in Miners Lake, 125 ng/g in Grand Sable Lake, and 163 ng/g in Beaver Lake. Whole rock bass from Chapel Lake also contained higher concentrations of mercury (mean 244 ng/g wet weight) than rock bass from Beaver Lake (mean 98 ng/g) and Grand

Sable Lake (124 ng/g). Mercury levels in whole Iowa darter and johnny darter were also higher in Chapel Lake than in Beaver and Grand Sable lakes (Table 44).

Table 44. Fish length and concentration of total mercury (Hg) in whole prey fish sampled during 2008 and 2010–2012 from five lakes in Pictured Rocks National Lakeshore.

			Total length (mm)		Hg (ng/g wet weight)[1]	
Lake	**Species**	**n**	***mean***	***range***	***mean***	***range***
Beaver	Iowa darter	40	48	34–62	58	20–111
	johnny darter	41	50	38–73	26	11–45
	mottled sculpin	56	52	39–74	25	13–42
	rock bass	4	172	137–190	98	86–118
	yellow perch					
	<100 mm	59	60	49–99	40	20–74
	≥100 mm	24	218	165–292	163	99–263
	all total lengths	83	106	49–292	76	20–263
Chapel	central mudminnow	5	60	53–66	131	91–174
	Iowa darter	46	54	31–63	88	36–187
	johnny darter	28	53	33–70	61	23–106
	mottled sculpin	3	50	45–56	18	17–19
	rock bass	49	147	42–192	244	42–841
	yellow perch					
	<100 mm	5	88	69–98	184	62–291
	≥100 mm	64	145	100–285	283	64–872
	all total lengths	69	141	69–285	276	62–872
Grand Sable	Iowa darter	51	46	28–58	54	16–100
	johnny darter	60	43	35–57	42	7–76
	mottled sculpin	42	50	35–77	22	12–49
	rock bass	4	150	136–171	124	75–177
	yellow perch					
	<100 mm	24	71	62–87	76	57–105
	≥100 mm	44	135	102–239	125	74–330
	all total lengths	68	113	62–239	107	57–330
Legion	central mudminnow	101	81	52–124	121	43–289
Miners	mottled sculpin	25	54	39–65	19	12–35
	yellow perch ≥100 mm	28	231	134–293	87	38–220

[1] Concentrations are in nanograms per gram (ng/g), which are equivalent to parts per billion.

The central mudminnow is the only species of fish known to inhabit Legion Lake, a small, clear-water, seepage lake with low DOC and low pH. Concentrations of mercury in 101 whole central mudminnows from Legion Lake averaged 121 ng/g wet weight, ranged from 43 to 289 ng/g, and were positively correlated with fish length (Figure 2). This is a commonly observed pattern. Mercury levels in five small central mudminnows (total length range, 53–66 mm) from Chapel Lake averaged 131 ng/g wet weight (SE 15 ng/g) and ranged from 91 to 174 ng/g. For comparison, the mean concentration in 28 central mudminnows from Legion Lake within a similar size range (52–66 mm)

was notably less (mean 77 ng/g, SE 4 ng/g) than that in small central mudminnows from Chapel Lake.

Predatory Fish (Axial Muscle)

We determined concentrations of total mercury in axial muscle (skinless fillets) from 460 adult predatory fish collected during 2008 and 2010–2012 from four lakes at PIRO (Table 45). Fishes analyzed included northern pike, smallmouth bass, walleye, large rock bass, and large yellow perch, all of which are considered to be largely piscivorous. We did not analyze axial muscle of fish from Legion Lake, which contained only central mudminnow, an omnivorous species.

Table 45. Total mercury (Hg) in axial muscle (skinless fillets) and length of predatory fish sampled from four lakes in Pictured Rocks National Lakeshore in 2008 and 2010–2012.

			Total length (mm)		Hg concentration (ng/g wet weight)[1]		Percent (number) of fish exceeding benchmarks[2]	
Lake	**Species**	**n**	***mean***	***range***	***mean***	***range***	***Human health USEPA (300 ng/g)***	***Fish health and reprod. (500 ng/g)***
Beaver	northern pike	64	652	345–971	357	155–668	58 (37)	19 (12)
	walleye	33	419	275–557	425	194–1,034	46 (15)	33 (11)
	smallmouth bass	5	347	261–410	263	119–402	40 (2)	0
	rock bass	4	172	137–190	153	129–182	0	0
	yellow perch	33	211	118–292	256	156–436	21 (7)	0
Chapel	rock bass	69	159	95–231	498	111–1,500	70 (49)	44 (31)
	yellow perch	42	180	132–285	604	178–1,405	81 (34)	69 (29)
Grand Sable	northern pike	61	616	356–928	628	230–1,693	95 (58)	62 (38)
	rock bass	4	150	136–171	250	177–358	25 (1)	0
	smallmouth bass	31	331	234–456	548	229–1,497	81 (25)	45 (14)
	yellow perch	12	185	154–239	275	140–561	33 (4)	17 (2)
Miners	northern pike	57	509	370–805	255	126–737	23 (13)	2 (1)
	yellow perch	45	230	134–293	117	53–292	0	0

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

[2] Fish with Hg concentration exceeding the USEPA fish-tissue criterion for methylmercury (300 ng/g) and an estimated benchmark level (500 ng/g) for adverse effects on fish health and reproduction.

Concentrations of mercury in predatory fish were highest in Chapel and Grand Sable lakes and lowest in Miners Lake. In Chapel Lake, mercury levels in yellow perch (mean 604 ng/g wet weight, range 178–1,405 ng/g) and rock bass (mean 498 ng/g, range 111–1,500 ng/g) were unusually high for these species. For comparison, mean concentrations in yellow perch and rock bass from Grand Sable, the other PIRO lake with high mercury levels in fish, were about half those in yellow perch and rock bass from Chapel Lake (Table 45).

Ecological and Health Risks of Methylmercury

Mercury levels in axial muscle tissue equaled or exceeded 500 ng/g wet weight (an estimated benchmark concentration associated with altered biochemical processes, damage to cells and tissues, and reduced reproduction of fish) in 138 (30%) of the 460 predatory fish analyzed from PIRO (see Table 45). This total included 60 of 111 fish (54%) from Chapel Lake, 54 (50%) from Grand Sable Lake, 23 (17%) from Beaver Lake, and one fish (1%) from Miners Lake. In central mudminnows from Legion Lake, the whole-body concentration of mercury in six (6%) of the 101 whole fish analyzed exceeded 200 ng/g wet weight, an estimated threshold associated with sublethal and reproductive effects in fish (Beckvar et al. 2005).

Mean concentrations of mercury in whole yellow perch, a regionally important prey fish, exceeded the estimated dietary threshold (40 ng/g wet weight in prey fish; Depew et al. 2012a) for reproductive effects on piscivorous fish in all four lakes that contained yellow perch (Table 46). In Chapel Lake, this reproductive benchmark for piscivorous fish was greatly exceeded in both small (<100 mm) and larger (≥100 mm) yellow perch (see Table 44). The dietary threshold of 40 ng/g for reproductive effects on piscivorous fish was also exceeded in whole rock bass and Iowa darter from Chapel, Beaver, and Grand Sable lakes; in central mudminnow from Chapel and Legion lakes; and in johnny darter from Chapel and Grand Sable lakes.

The screening-level dietary benchmark for belted kingfisher (30 ng/g wet weight in whole prey fish) was exceeded in all or nearly all prey fish species analyzed, except mottled sculpin, from Chapel, Grand Sable, Miners, and Legion lakes (Table 46). In Beaver Lake, the 30-ng/g benchmark was exceeded in most Iowa darter, yellow perch, and rock bass. For American mink, the screening-level dietary benchmark (70 ng/g wet weight in whole prey fish) was exceeded in all or most of the rock bass (Beaver, Chapel, and Grand Sable lakes), large yellow perch ≥100 mm (Beaver, Chapel, Grand Sable, and Miners lakes), and central mudminnow (Chapel and Legion lakes) (Table 46).

Mercury levels in yellow perch, a preferred prey of adult common loons, exceeded dietary benchmarks for adult common loons in three lakes at PIRO. Adult common loons generally consume prey fish in the total-length range of 100–250 mm (Barr 1996, Merrill et al. 2005). Mean concentrations of mercury in larger (≥100 mm) whole yellow perch from Chapel (283 ng/g), Beaver (163 ng/g), and Grand Sable (125 ng/g) lakes exceeded the estimated dietary threshold (100 ng/g wet weight in prey fish; Depew et al. 2012b) for adverse behavioral impacts of methylmercury in adult common loons (see Table 44). In Chapel Lake, mercury levels in whole yellow perch also exceeded the dietary benchmark (180 ng/g wet weight in prey fish; Depew et al. 2012b) associated with significant reproductive impairment of adult common loons.

The central mudminnow is the presumed prey of common loons that forage on Legion Lake. Concentrations of mercury in 101 whole central mudminnows sampled from the lake during 2008 and 2010–2012 averaged 121 ng/g wet weight; this mean concentration exceeds the estimated dietary threshold (100 ng/g wet weight in prey fish) for adverse behavioral impacts of methylmercury in adult loons, but is less than the dietary benchmark concentration (180 ng/g wet weight in prey fish) associated with significant reproductive impairment of adult loons (Depew et al. 2012b).

Table 46. Percentages of whole prey fish from five lakes in Pictured Rocks National Lakeshore with mercury levels exceeding screening dietary benchmarks for belted kingfisher (30 ng/g wet weight), piscivorous fish (40 ng/g), and American mink (70 ng/g).

Lake	Species	n	Total length (range, mm)	Percent of fish with Hg exceeding dietary benchmarks for piscivorous fish and wildlife		
				Belted kingfisher (30 ng/g)	*Piscivorous fish (40 ng/g)*	*American mink (70 ng/g)*
Beaver	Iowa darter	40	34–62	80	70	35
	johnny darter	41	38–73	32	7	0
	mottled sculpin	56	39–74	37	5	0
	rock bass	4	137–190	100	100	100
	yellow perch					
	<100 mm	59	49–99	68	44	3
	≥100 mm	24	165–292	100	100	100
	all lengths	83	49–292	77	60	31
Chapel	central mudminnow	5	53–66	100	100	100
	Iowa darter	46	31–63	100	96	52
	johnny darter	28	33–70	96	89	25
	mottled sculpin	3	45–56	0	0	0
	rock bass	49	42–192	100	100	90
	yellow perch					
	<100 mm	5	69–98	100	100	80
	≥100 mm	64	100–285	100	100	98
	all lengths	69	69–285	100	100	97
Grand Sable	Iowa darter	51	28–58	92	80	14
	johnny darter	60	35–57	87	57	3
	mottled sculpin	42	35–77	7	2	0
	rock bass	4	136–171	100	100	100
	yellow perch					
	<100 mm	24	62–87	100	100	75
	≥100 mm	44	102–239	100	100	100
	all lengths	68	62–239	100	100	91
Legion	central mudminnow	101	52–124	100	100	89
Miners	mottled sculpin	25	39–65	4	0	0
	yellow perch ≥100 mm	28	134–293	100	93	61

However, the mercury to fish length relation illustrated in Figure 2 indicates that the dietary mercury exposure and assocated ecological risks of mercury to adult common loons foraging on Legion Lake depend strongly on the size of mudminnows eaten by loons. Adult common loons commonly eat prey fish ranging from 100 to 250 mm in length (Barr 1996, Merrill et al. 2005). If foraging adult common loons select mudminnows larger than 100 mm in Legion Lake, their dietary exposure to methylmercury will be greater and the potential for adverse effects significantly increased, based on

the toxicological benchmarks by Depew et al. (2012b) for behavioral and reproductive effects of dietary mercury in adult common loons.

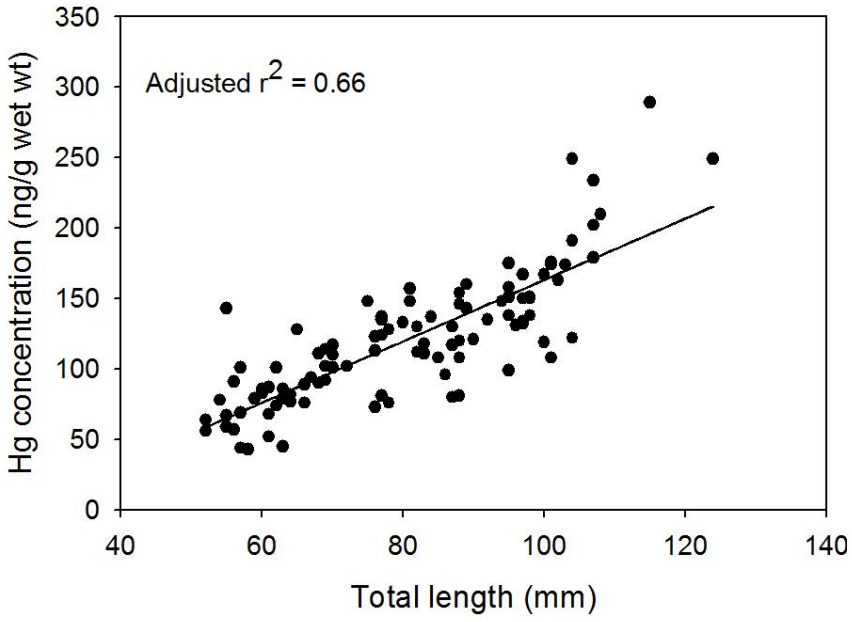


Figure 2. Concentrations of total mercury in whole central mudminnows from Legion Lake in relation to total length of the fish. Fish were sampled from the lake during 2008 and 2010–2012.

The USEPA fish-tissue criterion for methylmercury (300 ng/g wet weight), which was derived to protect the health of humans who eat noncommercial fish, was exceeded in 88 of 108 predatory fish (81%) from Grand Sable Lake, including 95% of the northern pike and 81% of the smallmouth bass (see Table 45). In Chapel Lake, the USEPA fish-tissue criterion was exceeded in 83 (75%) of 111 predatory fish (see Table 45), which included 81% of 34 large yellow perch and 70% of 49 rock bass. Numbers and percentages of predatory fish exceeding the USEPA criterion in other lakes included 61 of 139 (44%) fish from Beaver Lake, and 13 of 102 (13%) fish from Miners Lake. The concentrations of mercury in axial fillets of predatory fish from Chapel, Grand Sable, Beaver, and Miners lakes were high enough to warrant limited frequency of consumption of these fishes by pregnant women, by women who may become pregnant, and by children under 15 years of age, based on the fish consumption guidelines recommended by the Great Lakes Fish Advisory Workgroup (compare Tables 8 and 45).

Lead and Organic Contaminants

In contrast to the results for mercury, the concentrations of legacy contaminants (DDT, DDE, DDD, PCBs, and Pb) and emerging contaminants (PBDEs and PFCs) in predatory fish from lakes at PIRO were low, commonly below analytical limits of detection.

Axial Muscle

Analytical results for organic contaminants and lead in axial muscle (skinless fillets) of fish collected in 2009, which were reported by Wiener et al. (2013), are briefly summarized here. Fifteen samples of predatory fish—including 10 individual northern pike, three composite (multiple fish) samples of

northern pike, one individual walleye, and one individual smallmouth bass—were analyzed for organic contaminants and total lead (Appendix K, Table K-1). 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 L, Table L-6). Concentrations of PCB congeners were also very low and were detected only in a 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 eight of nine analytes; concentrations of perfluoro-1-octanesulfonate (PFOS) were low and ranged from 0.77 to 1.6 ng/g. The concentrations of these legacy and emerging organic contaminants in axial fillets of fish from the study lakes at PIRO do not pose significant risks to human health, based on published guidelines for human consumption of sport fish (see Table 8). 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.

Whole Fish

Twelve composite samples of whole northern pike from Beaver, Grand Sable, and Miners lakes; five composite samples of whole rock bass from Chapel Lake; four composite samples of whole smallmouth bass from Beaver and Grand Sable lakes; two composite samples of whole walleye from Beaver Lake; and one composite sample of whole yellow perch from Chapel Lake were collected in 2010, 2011, and 2012 and analyzed for organic contaminants and lead. Each composite sample contained three to five fish of similar size (Appendix K, Table K-2). Samples collected in 2010 and 2012 were analyzed for DDT and metabolites (DDE and DDD), 95 polychlorinated biphenyl congeners (PCBs), and 16 perfluorinated compounds (PFCs) and polybrominated diphenyl ethers (PBDEs). Total lead (Pb) was analyzed only in samples collected in 2010. Samples taken in 2011 were analyzed for PFCs, PBDEs, and PCBs.

Concentrations of DDT and DDD were below limits of detection (10 ng/g wet weight for total DDT), and concentrations of DDE ranged from below limits of detection to a maximum of 31 ng/g (Appendix L, Table L-7). Congeners of most PBDEs were either not detected or were below the reporting limits (<5 ng/g wet weight). For those PBDEs detected in samples, concentrations were less than 5 ng/g. Concentrations of PCB congeners were also very low to below reporting limits (1.0–3.5 ng/g). In the ten composite samples where PCBs were detected, concentrations of total PCBs ranged from 2.5 ng/g in northern pike from Beaver Lake to 61.2 ng/g in northern pike from Grand Sable Lake. Concentrations of most PFCs were below the reporting limit of 0.12 ng/g; the maximum concentration detected in the whole-fish samples was 6.5 ng/g of perfluoro-1-octanesulfonate (PFOS) in smallmouth bass from Grand Sable Lake. Concentrations of lead were nondetectable to low (maximum 13 ng/g wet weight) in northern pike and walleye and ranged from 24 to 47 ng/g in rock bass and smallmouth bass.

The concentrations of these organic contaminants in whole fish from PIRO lakes do not pose significant risk to the health of fish and wildlife. Concentrations of DDT, PCBs, PBDEs, and PFOS either were not detected, were below reporting limits or averaged substantially less than benchmark concentrations associated with altered health and reproduction in wildlife (see Table 9).

Sleeping Bear Dunes National Lakeshore (SLBE)

We studied four lakes at SLBE: Bass Lake in Benzie County, Bass Lake in Leelanau County, Manitou Lake on North Manitou Island, and Round Lake (see Table 1). Fish and larval dragonflies were sampled in each lake in 2008 during the pilot study, followed by more intensive, annual sampling of food webs during 2010–2012. Lake water, seston, and zooplankron were sampled near the center of each lake basin.

Water quality varied little among the four lakes at SLBE, relative to the variation observed among study lakes at the other park units. Near-surface waters in the four lakes had narrow ranges of mean specific conductance (range 274–335 μS/cm) and pH (range 8.5–8.7). All lakes were near saturation with regards to concentration of dissolved oxygen (range 10.0–11.4 mg/L) at the time of measurement. Mean dissolved organic carbon (DOC) in the four lakes ranged from 4.1 to 8.9 mg/L, and mean concentrations of sulfate ranged from 5.8 to 10.4 mg/L (Table 47).

Table 47. Summary of water quality measurements (mean ± SE) in lakes at Sleeping Bear Dunes National Lakeshore, derived from annual *in situ* measurements and from analyses of water samples taken during 2010–2012.

Lake	Temperature (°C)	DO[1] (mg/L)	Conductivity (μS/cm)	pH[2] (s.u.)	Sulfate (mg/L)	DOC[2] (mg/L)
Bass (Benzie)	16.6 ± 1.4	11.4	331 ± 5	8.5 ± 0.1	8.6 ± 0.5	4.1 ± 0.3
Bass (Leelanau)	15.1 ± 1.1	11.2	278 ± 45	8.6 ± 0.3	5.8 ± 0.8	8.9 ± 0.3
Manitou	16.2 ± 0.7	10.0	274 ± 2	8.7 ± 0.3	10.4 ± 0.9	5.5 ± 0.3
Round	15.8 ± 1.0	11.1	335 ± 4	8.5 ± 0.2	9.5 ± 0.8	6.4 ± 0.4

[1] Dissolved oxygen (DO) was measured during 2010 and 2011.

[2] DOC is dissolved organic carbon, and s.u. is standard pH units.

Mercury in Lakes and Food Webs

Soil

Surficial soils were collected at nearshore margins of each lake. Total mercury in soils ranged from 2.3 to 61 ng/g dry weight, and methylmercury ranged from 0.03 to 0.47 ng/g dry weight (Table 48). Total mercury was positively related to percent loss on ignition (a surrogate measure of organic matter content), a pattern also observed in surficial sediments from the four lakes. The fraction of total mercury present as methylmercury in soils ranged from 0.5% to 1.4%.

Sediment

Surficial sediments were sampled from nearshore sites at each lake. Total mercury in sediment from the four lakes averaged from 3.2 to 19 ng/g dry weight and was positively related to percent loss on ignition (Table 49). The concentration of methylmercury averaged from 0.05 to 1.64 ng/g dry weight. The fraction of total mercury present as methylmercury, an indirect indicator of microbial mercury methylation in surficial sediment, averaged from 0.8% to 5.2%.

Table 48. Total mercury, methylmercury (MeHg), percent MeHg, and percent loss on ignition in soil sampled near lakes in Sleeping Bear Dunes National Lakeshore. Concentrations are reported for soil composited from the top strata (upper 5 cm) of five cores collected in 2012 within 5 m of each lake margin.

Lake	Total Hg (ng/g dry weight)	MeHg (ng/g dry weight)	Percent MeHg	Loss on ignition (%)
Bass (Benzie)	40.9	0.47	1.2	11.0
Bass (Leelanau)	2.3	0.03	1.4	0.8
Manitou	61.3	0.29	0.47	11.4
Round	22.3	0.27	1.2	8.1

Table 49. Mean total mercury (Hg), methylmercury (MeHg), percent MeHg, and loss on ignition in surficial sediments (upper 5 cm) sampled from lakes in Sleeping Bear Dunes National Lakeshore during 2010–2012. Surficial sediments were sampled from locations of concurrent larval dragonfly collection, within 2 m of the shoreline.

	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)	Loss on ignition (%)	
Lake	*n*	*mean*	*SE*	*n*	*mean*	*SE*		*mean*	*range*
Bass (Benzie)	7	19.2	15.4	4	1.26	1.16	4.0	10	0.8–28
Bass (Leelanau)	7	3.2	1.2	5	0.13	0.12	2.7	1.9	0.9–3.9
Manitou	5	11.7	6.4	4	0.05	0.02	0.8	11	0.7–30
Round	7	13.3	10.6	4	1.64	1.63	5.2	5.6	0.5–16

Water

Concentrations total mercury in lake water averaged from 0.7 to 1.5 ng/L in unfiltered samples and from 0.4 to 1.1 ng/L in 0.45-μm filtered samples. Filter-passing mercury accounted for 69% ± 8% (SE) of the total mercury present in unfiltered samples (Table 50). Mean concentrations of methylmercury averaged from 0.06 to 0.10 ng/L in unfiltered samples and from 0.04 to 0.05 ng/L in filtered samples, with filter-passing methylmercury accounting for 54% ± 3% of the total methylmercury present in unfiltered water. Methylmercury accounted for 7.8% ± 0.6% of the total mercury in unfiltered samples and for 7.6% ± 2.2% of the total mercury in filtered samples.

Seston

Mean concentrations of total mercury in seston (suspended particulates in water) ranged from 34 to 88 ng/g dry weight, and methylmercury averaged from 5.3 to 6.6 ng/g (Table 51). The fraction of total mercury present as methylmercury in seston ranged from 5.0 to 19%.

Zooplankton

Total mercury concentrations in bulk zooplankton from the four lakes averaged from 87 to 137 ng/g dry weight, and methylmercury averaged from 25 to 61 ng/g dry weight (Table 52). The fraction of total mercury present as methylmercury in zooplankton ranged from 25% to 50%. Zooplankton from

Round Lake had the highest concentration of methylmercury (61 ng/g), nearly twice that in samples from the other three lakes.

Table 50. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and filtered water (0.45 µm) sampled from four lakes in Sleeping Bear Dunes National Lakeshore. Samples were taken near the center of each lake from a depth of 1–2 m.

	Total Hg (ng/L)					MeHg (ng/L)				
	Unfiltered			*Filtered*		*Unfiltered*			*Filtered*	
Lake	***n*[1]**	*mean*	*SE*	*mean*	*SE*	***n*[1]**	*mean*	*SE*	*mean*	*SE*
Bass (Benzie)	5	1.07	0.03	0.69	0.10	6	0.085	0.012	0.047	0.013
Bass (Leelanau)	6	1.20	0.15	1.12	—[2]	6	0.087	0.009	0.038	0.012
Manitou	5	0.69	0.08	0.39	0.16	6	0.061	0.010	0.037	0.015
Round	6	1.50	0.30	0.93	0.12	5	0.099	0.024	0.054	0.011

[1] n is the number of water samples collected and analyzed during 2010–2012.

[2] Filtered samples were collected during 2011–2012.

Table 51. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from four lakes in Sleeping Bear Dunes National Lakeshore.

	Total Hg[1] (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
Lake	***n*[2]**	***mean***	***range***	***n*[2]**	***mean***	***SE***	
Bass (Benzie)	2	62.7	56–69	6	5.7	1.3	10.3
Bass (Leelanau)	2	88.0	61–115	6	5.3	1.3	5.0
Manitou	2	34.0	29–39	6	6.6	1.7	18.8
Round	2	88.2	76–100	5	6.1	1.6	6.3

[1] Total Hg was not measured in seston sampled in 2010.

[2] n is the number of samples collected and analyzed for total Hg during 2011–2012 and for MeHg during 2010–2012.

Table 52. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in bulk zooplankton from lakes in Sleeping Bear Dunes National Lakeshore during 2010–2012.

	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
Lake	***n*[1]**	***mean***	***SE***	***n*[1]**	***mean***	***SE***	
Bass (Benzie)	4	137	68.3	5	32.3	6.3	34.1
Bass (Leelanau)	4	86.8	24.7	5	26.2	14.2	24.9
Manitou	5	89.3	52.2	5	24.6	5.7	40.9
Round	5	137	42.3	5	60.7	8.3	49.9

[1] n is the number of samples collected and analyzed during 2010–2012.

Larval Dragonflies

Larvae of the families Gomphidae, Corduliidae, and Aeshnidae were the most widely distributed dragonflies at SLBE, inhabiting all four lakes and accounting for 81% of the 546 larvae analyzed (Table 53). Gomphids were most abundant, representing 71% of all larvae analyzed from the park. Mean concentration of methylmercury in these three families ranged 18–46 ng/g dry weight in gomphids, 31–79 ng/g in corduliids, and 47–222 ng/g in aeshnids. Larvae from two other families—27 macromiids and 22 libellulids—were also analyzed. The mean concentration of methylmercury in aeshnids from Round Lake was higher (222 ng/g dry weight) than that in all other dragonfly families analyzed from SLBE, though the standard error (119 ng/g) of this mean was much greater than that for other families (Table 53).

Table 53. Total mercury, methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Sleeping Bear Dunes National Lakeshore.

		Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg	
Lake	**Family**	***n***	***mean***	***SE***	***n***	***mean***	***SE***	***mean***	***SE***
Bass (Benzie)	Aeshnidae	15	84	11	15	72	11	83	3.5
	Libellulidae	3	150	29	3	129	24	87	1.7
	Corduliidae	10	90	9.5	10	79	11	85	2.4
	Gomphidae	66	58	5.5	63	46	4.6	74	2.3
	Macromiidae	13	68	8.7	13	59	9.1	86	5.2
Bass (Leelanau)	Aeshnidae	2	63	2.6	2	47	4.4	75	3.8
	Corduliidae	12	51	3.8	12	42	3.9	82	3.7
	Gomphidae	133	47	1.3	134	35	1.2	75	1.5
	Macromiidae	11	56	2.6	11	53	4.6	93	6.2
	Libellulidae	5	32	4.5	5	24	5.0	70	5.9
Manitou	Aeshnidae	27	77	3.0	27	57	3.5	74	3.4
	Corduliidae	30	36	1.9	28	31	2.3	83	2.7
	Gomphidae	95	40	2.9	95	31	2.3	76	2.0
	Macromiidae	3	64	3.8	3	55	8.4	85	8.4
Round	Aeshnidae	5	242	129	5	222	119	90	3.0
	Corduliidae	10	49	19	10	40	19	75	3.2
	Gomphidae	92	28	1.8	92	18	1.6	60	2.9
	Libellulidae	14	64	17	14	52	14	76	3.9

In contrast, mean concentrations in other families of dragonflies sampled from Round Lake were among the lowest observed at SLBE. The concentration in gomphid larvae from Round Lake, for

example, averaged 18 ng/g dry weight. With the exception of aeshnids from Round Lake, concentrations in dragonfly families were higher in Bass Lake (Benzie County)—averaging 46 ng/g dry weight in gomphids, 59 ng/g in macromiids, 72 ng/g in aeshnids, 79 ng/g in corduliids, and 129 ng/g in libellulids—than in the other three lakes at SLBE. Methylmercury accounted for more than 70% of the total mercury in dragonfly larvae for most families and study lakes at SLBE (Table 53). Among the four lakes, mean percent methylmercury ranged from 60% to 76% in gomphids and from 85% to 93% in macromiids.

Four dragonfly families (aeshnids, corduliids, gomphids, and macromiids) were collected and analyzed from Lake Manitou on North Manitou Island (Lake Michigan). More than 10 km of open water separates the island from the Michigan mainland; thus, the assemblage of dragonflies in Lake Manitou are distant from those in the three mainland study lakes at SLBE. Mean concentrations of methylmercury in dragonflies from Lake Manitou ranged from 31 ng/g in corduliids and gomphids to 57 ng/g in aeshnids.

Whole Prey Fish

We quantified mercury in six species of prey fish from SLBE. All six species were collected from Bass Lake (Benzie), five species were collected from Round Lake, and two from Bass Lake (Leelanau) and Lake Manitou. Yellow perch were sampled from all four lakes and Iowa darter from three lakes. Each of the remaining four species (bluegill, rock bass, johnny darter, and central mudminnow) was sampled from two lakes.

Mercury levels were generally highest in prey fish from Bass Lake (Benzie) and lowest in Round Lake (Table 54). In small yellow perch (total length <100 mm), concentrations averaged 60 ng/g wet weight in Bass Lake (Benzie), 17 ng/g in Round Lake, 25 ng/g in Bass Lake (Leelanau), and 33 ng/g in Lake Manitou. In Iowa darter, mean concentrations were 82 ng/g wet weight in Bass Lake (Benzie), 23 ng/g in Round Lake, and 30 ng/g in Lake Manitou. Mean concentrations in rock bass (142 ng/g), bluegill (82 ng/g), and johnny darter (24 ng/g) from Bass Lake (Benzie) exceeded those in rock bass (92 ng/g) from Bass Lake (Leelanau) and in bluegill (32 ng/g) and johnny darter (14 ng/g) from Round Lake. In contrast, mercury levels in central mudminnows were similar in Bass Lake (Benzie) and Round Lake (Table 54).

Predatory Fish (Axial Muscle)

In axial muscle tissue (skinless fillets), mercury levels were highest in predatory fish from Bass Lake (Benzie), averaging 569 ng/g wet weight (range 206–1762 ng/g) in northern pike and 543 ng/g (range 234–912 ng/g) in largemouth bass (Table 55). In Lake Manitou, mercury in smallmouth bass averaged 369 ng/g and ranged from 109 to 916 ng/g. Concentrations of mercury were lower in predatory fish from Round Lake and Bass Lake (Leelanau). In Round Lake, mercury averaged 272 ng/g (range 107–650 ng/g) in largemouth bass and was 127 ng/g in a single smallmouth bass. In Bass Lake (Leelanau), mercury averaged 176 ng/g (range 89–411 ng/g) in northern pike and 274 ng/g (range 113–708 ng/g) in largemouth bass. Within a given lake, mean concentrations of mercury in fillets were generally much lower in black crappie, rock bass, and large yellow perch than those in coexisting largemouth bass, smallmouth bass, and northern pike (Table 55).

Table 54. Fish length and concentrations of total mercury (Hg) in whole prey fish sampled from four lakes in Sleeping Bear Dunes National Lakeshore during 2008 and 2010–2012.

			Total length (mm)		Hg (ng/g wet weight) [1]	
Lake	**Species**	**n**	***mean***	***range***	***mean***	***range***
Bass (Benzie)	bluegill	42	37	29–54	82	24–157
	central mudminnow	21	62	38–88	29	14–72
	Iowa darter	40	45	31–56	82	43–284
	johnny darter	3	54	48–61	24	11–39
	rock bass	16	200	115–243	142	71–246
	yellow perch <100 mm	24	69	59–77	60	30–107
Bass (Leelanau)	yellow perch					
	<100 mm	72	67	48–99	25	15–43
	≥100 mm	11	117	100–145	32	24–38
	all lengths	83	74	48–145	26	15–43
	rock bass	2	205	194–216	92	57–126
Manitou	Iowa darter	73	52	39–63	30	16–48
	yellow perch					
	<100 mm	42	69	55–93	33	18–52
	≥100 mm	26	190	115–264	74	27–139
	all lengths	68	115	55–264	49	18–139
Round	bluegill	61	38	21–71	32	10–74
	central mudminnow	50	59	44–78	34	12–71
	Iowa darter	10	46	44–51	23	10–41
	johnny darter	25	50	39–63	14	9–24
	yellow perch					
	<100 mm	4	78	74–82	17	10–27
	≥100 mm	9	280	100–319	48	31–64
	all lengths	13	218	74–319	39	10–64

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

Ecological and Health Risks of Methylmercury

Concentrations in 25% of the smallmouth bass from Lake Manitou exceeded the estimated benchmark tissue level (500 ng/g wet weight) associated with adverse effects of methylmercury exposure, including altered biochemical processes, damage to cells and tissues, and reduced reproduction in fish (see Table 55). In Bass Lake (Benzie), concentrations in 41% of the northern pike and in 54% of the largemouth bass exceeded the 500-ng/g benchmark. The fish-health benchmark was exceeded in 8% of the largemouth bass from Bass Lake (Leelanau) and in 7% of the largemouth bass from Round Lake. Mercury levels in black crappie, rock bass, and large yellow perch from the lakes at SLBE were below the fish-health benchmark (see Table 55).

Table 55. Fish length and concentration of total mercury (Hg) in axial muscle of predatory fish collected during 2008 and 2010–2012 from four lakes in Sleeping Bear Dunes National Lakeshore.

		Total length (mm)		Hg (ng/g wet weight)[1]		Percent (number) of fish exceeding benchmarks[2]	
Lake and species of fish	**n**	***mean***	***range***	***mean***	***range***	***Human health USEPA (300 ng/g)***	***Fish health and reprod. (500 ng/g)***
Bass Lake (Benzie)							
largemouth bass	61	327	219–414	543	234–912	92 (56)	54 (33)
northern pike	17	500	366–833	569	206–1,762	77 (13)	41 (7)
black crappie	15	196	168–262	198	89–291	0	0
rock bass	16	200	115–243	259	144–467	19 (3)	0
Bass Lake (Leelanau)							
largemouth bass	36	337	230–462	274	113–708	31 (11)	8 (3)
northern pike	45	504	285–656	176	89–411	2 (1)	0
rock bass	2	205	194–216	141	85–196	0	0
Lake Manitou							
smallmouth bass	71	380	247–477	369	109–916	51 (36)	25 (18)
yellow perch	24	211	154–264	133	79–296	0	0
Round Lake							
largemouth bass	56	304	223–400	272	107–650	30 (17)	7 (4)
smallmouth bass	1	321	—	127	—	0	0
yellow perch	8	303	289–319	84	58–106	0	0

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

[2] Fish with Hg concentration exceeding the USEPA fish-tissue criterion for methylmercury (300 ng/g) and an estimated benchmark level (500 ng/g) for adverse effects on fish health and reproduction.

Mercury levels in whole yellow perch, a regionally important prey fish, exceeded the estimated dietary threshold for reproductive effects on piscivorous fish (40 ng/g wet weight in prey fish; Depew et al. 2012a) in most small (<100 mm) perch from Bass Lake (Benzie) and in about 80% of the larger (≥100 mm) perch from Round Lake and Lake Manitou (Table 56). Concentrations were generally below the 40-ng/g threshold in yellow perch from Bass Lake (Leelanau) and in small yellow perch from Round Lake and Lake Manitou. The 40-ng/g threshold was also exceeded in most small whole bluegill and in all Iowa darter and rock bass from Bass Lake (Benzie).

Yellow perch are the preferred prey of adult common loons, which generally eat prey fish in the total-length range of 100–250 mm (Barr 1996, Merrill et al. 2005). Mean concentrations of mercury in both small (<100 mm) and larger (≥100 mm) whole yellow perch from all four lakes at SLBE were substantially below the estimated dietary benchmark levels (Depew et al. 2012b) for adverse behavioral (100 ng/g wet weight in prey fish) and reproductive effects (180 ng/g) in adult common loons (see Table 54).

Table 56. Percentages of whole prey fish from four lakes in Sleeping Bear Dunes National Lakeshore with mercury levels exceeding screening dietary benchmarks for belted kingfisher (30 ng/g wet weight), piscivorous fish (40 ng/g), and American mink (70 ng/g).

Lake	Species	n	Total length (range, mm)	Percent of fish with Hg exceeding dietary benchmarks for piscivorous fish and wildlife		
				Belted kingfisher (30 ng/g)	*Piscivorous fish (40 ng/g)*	*American mink (70 ng/g)*
Bass (Benzie)	bluegill	42	29–54	95	79	64
	central mudminnow	21	38–88	38	10	5
	Iowa darter	40	31–56	100	100	50
	johnny darter	3	48–61	33	0	0
	rock bass	16	115–243	100	100	100
	yellow perch <100 mm	24	59–77	96	79	25
Bass (Leelanau)	yellow perch					
	<100 mm	72	48–99	24	1	0
	≥100 mm	11	100–145	55	0	0
	all lengths	83	48–145	28	1	0
	rock bass	2	194–216	100	100	50
Manitou	Iowa darter	73	39–63	45	8	0
	yellow perch					
	<100 mm	42	55–93	55	17	0
	≥100 mm	26	115–264	96	81	54
	all lengths	68	55–264	71	41	21
Round	bluegill	61	21–71	51	23	2
	central mudminnow	50	44–78	60	30	2
	Iowa darter	10	44–51	20	10	0
	johnny darter	25	39–63	0	0	0
	yellow perch					
	<100 mm	4	74–82	0	0	0
	≥100 mm	9	100–319	100	78	0
	all lengths	13	74–319	69	54	0

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

The screening-level dietary benchmark for belted kingfisher (30 ng/g wet weight in whole prey fish) was exceeded in all or nearly all of the bluegill, Iowa darter, small yellow perch, and rock bass from Bass Lake (Benzie) (Table 56). Mercury levels in about half of the Iowa darter and small yellow perch in Lake Manitou and in about half of the bluegill and central mudminnow from Round Lake also exceeded 30 ng/g. Mercury levels in most of the small yellow perch from Bass Lake (Leelanau) and in most or all of the Iowa darter, Johnny darter, and small yellow perch from Round Lake were below the 30-ng/g benchmark.

The screening-level dietary benchmark for American mink (70 ng/g wet weight in whole prey fish) was exceeded in 50% or more of the bluegill, Iowa darter, and rock bass from Bass Lake (Benzie),

rock bass from Bass Lake (Leelanau), and larger yellow perch (≥100 mm) from Lake Manitou (Table 56). Mercury levels in nearly all of the other prey fishes analyzed were below the 70-ng/g benchmark (Table 56).

In Bass Lake (Benzie), the USEPA fish-tissue criterion for methylmercury (300 ng/g wet weight)—derived to protect the health of humans who eat noncommercial fish—was exceeded in 77% of the northern pike, in 92% of the largemouth bass, and in 19% of the rock bass (see Table 55). In Lake Manitou, concentrations in 51% of the smallmouth bass exceeded the USEPA fish-tissue criterion for methylmercury. In largemouth bass, the USEPA criterion was exceeded in 30% of the fish from Round Lake and in 31% from Bass Lake (Leelanau), whereas only 1 of 45 northern pike from Bass Lake (Leelanau) exceeded the USEPA fish-tissue criterion. Except for three of the rock bass from Bass Lake (Benzie), mercury levels in black crappie, rock bass, and large yellow perch from the lakes at SLBE were less than the USEPA criterion (see Table 55). The concentrations of mercury in axial fillets of predatory fish from all four study lakes at SLBE were high enough to warrant limited frequency of consumption of these fishes by pregnant women, by women who may become pregnant, and by children under 15 years of age, based on the fish consumption guidelines recommended by the Great Lakes Fish Advisory Workgroup (compare Tables 8 and 55).

Lead and Organic Contaminants

In contrast to the results for mercury, the concentrations of legacy contaminants (DDT, DDE, DDD, PCBs, and Pb) and emerging contaminants (PBDEs and PFCs) in predatory fish from the lakes at SLBE were low, commonly below limits of detection.

Axial Muscle

Analytical results for organic contaminants and lead in axial muscle (skinless fillets) of fish collected in 2008, which were reported by Wiener et al. (2013), are briefly summarized here. Sixteen samples of axial muscle from the four lakes at SLBE were analyzed for organic contaminants and total lead (Appendix K, Table K-1). These samples included northern pike (three samples of individual fish and one composite sample), largemouth bass (one individual fish and five composite samples), and smallmouth bass (three individual fish and three composite samples).

Concentrations of PBDEs and PCBs in axial muscle tissue were low (Appendix L, Table L-8). 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 (10 ng/g wet weight for total DDT) in all samples. Concentrations of most PFCs were below reporting limits (range, <0.5 to <2.0 ng/g); low concentrations of perfluoro-1-octanesulfonate 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). The concentrations of these legacy and emerging organic contaminants in axial fillets of fish from the study lakes at SLBE do not pose significant risks to human health, based on published guidelines for human consumption of sport fish (see Table 8). Concentrations of lead were also low in axial fillets, 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.

Whole Fish

Thirteen composite samples of largemouth bass from Bass Lake (Benzie), Bass Lake (Leelanau), and Round Lake; five composite samples of northern pike from Bass Lake (Benzie) and Bass Lake (Leelanau); and six composite samples of smallmouth bass from Lake Manitou were collected in 2010, 2011, and 2012 and analyzed for organic contaminants and lead. Each of these composite samples contained four whole fish of similar size (Appendix K, Table K-2).

Concentrations of PBDEs and PCBs were low in whole fish from SLBE (Appendix L, Table L-9). Only 3 of 17 PBDE congeners were detected in largemouth bass (concentration range 1.0–6.4 ng/g wet weight) from Bass Lake (Leelanau), Bass Lake (Benzie), and Round Lake; in smallmouth bass (1.1–3.9 ng/g) from Lake Manitou; and in northern pike (1.1–2.6 ng/g) from Bass Lake (Leelanau). Few PCB congeners were detected (range 0.74–7.1 ng/g wet weight) in largemouth bass from Bass Lake (Leelanau), Bass Lake (Benzie), and Round Lake; in smallmouth bass from Lake Manitou; and in northern pike from Bass Lake (Leelanau). Concentrations of DDT and DDD were below limits of detection (10 ng/g wet weight for total DDT) in all samples, whereas DDE was detected at low levels (range 10–28 ng/g) in largemouth bass from Bass Lake (Leelanau), Bass Lake (Benzie), and Round Lake, and in smallmouth bass (14 ng/g) from Lake Manitou. Low concentrations of PFCs were detected (range 0.16–21 ng/g wet weight) in smallmouth bass from Lake Manitou; in largemouth bass from Round Lake, Bass Lake (Benzie) and Bass Lake (Leelanau); and in northern pike from Bass Lake (Benzie) and Bass Lake (Leelanau). Concentrations of lead were also low, averaging 16 ng/g wet weight (range 12–19 ng/g) in whole largemouth bass and 83 ng/g (range 54–112 ng/g) in smallmouth bass.

The concentrations of organic contaminants determined in whole fish from lakes at SLBE are substantially below reported benchmark concentrations associated with adverse effects on piscivorous birds or mammals (see Table 9) and do not pose significant risks to the health of piscivorous wildlife.

Voyageurs National Park (VOYA)

We studied four lakes at VOYA, each of which was sampled annually during 2009–2012. Three lakes (Brown, Peary, and Ryan) are small interior lakes (14–45 ha; see Table 1) on the Kabetogama Peninsula, while Sand Point Lake is a much larger (3,580 ha), deeper basin within the Namakan Reservoir (Kallemeyn et al. 2003). Waters in the four lakes had low specific conductance (range 22–66 μS/cm) and circumneutral pH (range 6.6–7.7) (Table 57). All four lakes were near saturation with regards to dissolved oxygen (range 10.4–11.3 mg/L) at the times of our measurements. Mean dissolved organic carbon (DOC) ranged from 9.2 to 13.2 mg/L, and mean concentrations of sulfate were low, ranging from 1.5 to 5.0 mg/L.

Table 57. Summary of water quality measurements (mean ± SE) in four lakes at Voyageurs National Park, derived from annual *in situ* measurements and from analyses of water samples collected during 2010–2012.

Lake	Temperature (°C)	DO[1] (mg/L)	Conductivity (µS/cm)	pH (s.u.)	Sulfate (mg/L)	DOC (mg/L)
Brown	15.7 ± 0.5	10.4	22.0 ± 0.8	6.9 ± 0.02	1.5 ± 0.1	9.6 ± 0.7
Peary	15.9 ± 0.1	10.7	25.6 ± 1.8	7.3 ± 0.1	2.2 ± 0.8	9.2 ± 0.7
Ryan	15.4 ± 0.4	10.6 ± 0.5	27.9 ± 3.3	6.6 ± 0.2	3.1 ± 0.1	11.4 ± 0.8
Sand Point[2]	15.7 ± 0.5	11.3	65.5 ± 3.9	7.7 ± 0.1	5.0	13.2

[1] Dissolved oxygen (DO) was measured in 2010 and 2011 in Brown, Peary, and Sand Point lakes and in 2010, 2011, and 2012 in Ryan Lake.

[2] Sulfate and dissolved organic carbon (DOC) in Sand Point Lake were measured in 2010 and 2012.

Mercury in Lakes and Food Webs

Soil

Surficial soils were collected at nearshore margins of each lake during 2012. Concentrations of total mercury averaged from 2.4 to 45 ng/g dry weight, and methylmercury averaged from 0.02 to 0.35 ng/g dry weight (Table 58). Total mercury was positively related to loss on ignition (a surrogate measure of organic matter content), a pattern also observed in lake sediment. The fraction of total mercury present as methylmercury ranged from 0.4% to 1.0%.

Table 58. Total mercury, methylmercury (MeHg), percent MeHg, and percent loss on ignition in soils sampled near lakes in Voyageurs National Park. Means are reported for surface soil (upper 5 cm of core) collected in 2012 within 5 m of the lake margin.

		Total Hg (ng/g dry weight)		MeHg (ng/g dry weight)		Percent MeHg	Loss on ignition (%)	
Lake	n	*mean*	*range*	*mean*	*range*	(mean)	*mean*	*range*
Brown	3	34	24–43	0.35	0.31–0.38	1.0	13	7–17
Peary	3	45	30–72	0.17	0.12–0.22	0.4	15	5–36
Ryan	3	25	19–32	0.22	0.07–0.37	0.9	5.1	4.6–6.2
Sand Point	2	2.4	1.0–3.8	0.023	—[1]	1.0	0.6	0.3–1.0

[1] One sample was analyzed for MeHg.

Sediment

Surficial sediments were sampled annually from nearshore locations at each lake during 2010–2012. Concentrations of total mercury averaged from 3.7 to 23 ng/g dry weight in the four lakes and were positively related to percent loss on ignition (Table 59). The mean concentration of methylmercury in sediment ranged from 0.10 to 3.9 ng/g dry weight. The fraction of total mercury present as methylmercury, an indirect indicator of microbial mercury methylation in surficial sediment,

averaged 2.3% in Sand Point Lake and was substantially higher in the other three inland lakes, ranging from 9.6% to 12%.

Table 59. Mean total mercury (Hg), methylmercury (MeHg), percent MeHg, and percent loss on ignition in surficial sediments (upper 5 cm) sampled from lakes in Voyageurs National Park during 2010–2012. Surficial sediments were sampled from locations of concurrent larval dragonfly collection, within 2 m of the shoreline.

	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)	Loss on ignition (%)	
Lake	***n***	***mean***	***SE***	***n***	***mean***	***SE***		***mean***	***range***
Brown	7	11.6	1.4	4	1.59	0.77	12.1	6.7	3.1–11
Peary	7	18.1	15.6	5	3.93	3.87	10.1	20	0.8–58
Ryan	7	22.5	15.8	5	3.46	2.76	9.6	10	1.8–27
Sand Point	7	3.7	0.5	5	0.10	0.05	2.3	1.3	0.6–2.2

Water

Lake water was sampled annually during 2010–2012, near the center of each lake basin. Mean concentrations of total mercury in water ranged from 2.0 to 4.0 ng/L in unfiltered samples and from 1.4 to 2.7 ng/L in 0.45-µm filtered samples. Filter-passing total mercury accounted for 76% ± 4% (SE) of the mercury present in unfiltered samples (Table 60). Mean concentrations of methylmercury ranged from 0.16 to 0.18 ng/L in unfiltered samples and from 0.07 to 0.16 ng/L in filtered samples, with filter-passing methylmercury averaging 67% ± 11% of the total methylmercury present in unfiltered water. Methylmercury accounted for 6.5% ± 1.1% of the total mercury in unfiltered samples and for 5.8% ± 1.0% of the total mercury in filtered samples.

Table 60. Total mercury (Hg) and methylmercury (MeHg) in unfiltered water and 0.45-µm filtered water from lakes in Voyageurs National Park. Samples were collected near the center of each lake at a depth of 1–2 m.

	Total Hg (ng/L)					MeHg (ng/L)				
	Unfiltered			***Filtered***		***Unfiltered***			***Filtered***	
Lake	***n*[1]**	*mean*	*SE*	*mean*	*SE*	***n*[1]**	*mean*	*SE*	*mean*	*SE*
Brown	5	2.2	0.1	1.9	0.1	6	0.18	0.02	0.16	0.03
Peary	6	2.0	0.1	1.4	0.2	6	0.18	0.03	0.07	0.01
Ryan	6	4.0	0.1	2.7	—[2]	6	0.16	0.03	0.10	—[2]
Sand Point	6	3.4	0.4	2.7	0.7	6	0.18	0.03	0.14	0.01

[1] n is the number of water samples collected and analyzed during 2010–2012.

[2] Samples are reported only for 2010 and 2012.

Seston

Total mercury in seston (suspended particulates in water) averaged from 75 to 347 ng/g dry weight, and methylmercury averaged from 7.5 to 28 ng/g (Table 61). The fraction of total mercury present as methylmercury in seston ranged from 7% to 13%. The values for both concentration and percent methylmercury are considered moderate to high for the Great Lakes region, particularly for Brown Lake.

Table 61. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in seston (suspended particles) from lakes in Voyageurs National Park.

	Total Hg[1] (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
Lake	*n*[2]	*mean*	*range*	*n*[2]	*mean*	*SE*	
Brown	2	166	113–219	7	28.3	9.1	12.8
Peary	2	211	180–242	6	17.9	7.2	10.0
Ryan	2	347	294–400	6	19.0	6.3	7.0
Sand Point	2	75	40–111	7	7.5	1.6	11.7

[1] Total Hg was not measured in seston sampled in 2010.

[2] n is the number of samples collected and analyzed for total Hg during 2011–2012 and for MeHg during 2010–2012.

Zooplankton

Concentrations of total mercury in bulk zooplankton averaged from 97 to 251 ng/g dry weight in the four lakes, and methylmercury averaged from 39 to138 ng/g (Table 62). The fraction of total mercury present as methylmercury in zooplankton ranged from 40% to 62%. Values for both methylmercury concentration and percent methylmercury in zooplankton are considered to be moderate to high for the Great Lakes region. Concentrations of both total mercury and methylmercury in seston and zooplankton were higher in the three inland lakes (Brown, Peary, and Ryan) than in Sand Point Lake.

Table 62. Total mercury, methylmercury (MeHg), and percent MeHg in bulk zooplankton from four lakes in Voyageurs National Park during 2010–2012.

	Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg (mean)
Lake	*n*[1]	*mean*	*SE*	*n*[1]	*mean*	*SE*	
Brown	5	163	63	6	92	38	61
Peary	6	195	129	6	138	104	62
Ryan	6	251	95	5	129	53	40
Sand Point	6	97	50	6	39	18	45

[1] n is the number of samples collected and analyzed during 2010–2012.

Larval Dragonflies

The Gomphidae, Corduliidae, Aeshnidae, and Macromiidae were the most widely distributed families of dragonflies collected at VOYA, inhabiting all four lakes and accounting for 90% of the 720 larvae analyzed (Table 63). Gomphids were most abundant, representing 59% of all larvae analyzed. Mean concentration of methylmercury in the four families ranged 74–95 ng/g dry weight in gomphids, 70–181 ng/g in corduliids, 98–172 ng/g in aeshnids, and 70–204 ng/g in macromiids. Seventy-five libellulids from three lakes were also analyzed, with mean concentrations of methylmercury ranging from 64 to 109 ng/g. In Peary Lake, mean methlymercury concentrations in all dragonfly families were less than 100 ng/g dry weight, whereas the other lakes had three or more dragonfly families with mean concentrations greater than 100 ng/g. Methylmercury accounted for more than 70% of the total mercury in dragonfly larvae for all families and lakes (Table 63). Across the four lakes, percent methylmercury averaged from 71% to 89% in aeshnids, from 80% to 90% in corduliids, from 74% to 85% in gomphids, from 84% to 92% in libellulids, and from 85% to 95% in macromiids.

Table 63. Total mercury (Hg), methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Voyageurs National Park.

		Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg	
Lake	**Family**	***n***	***mean***	***SE***	***n***	***mean***	***SE***	***mean***	***SE***
Brown	Aeshnidae	26	214	13	26	172	10	81	2.6
	Corduliidae	43	199	14	43	181	12	90	1.5
	Gomphidae	72	105	4.3	72	83	4.5	82	8.0
	Libellulidae	36	102	4.4	36	90	5.8	86	2.8
	Macromiidae	11	172	15	8	142	21	85	4.2
Peary	Aeshnidae	14	119	9.6	14	98	6.7	84	3.6
	Corduliidae	13	76	5.5	15	70	9.1	80	6.3
	Gomphidae	94	81	1.8	108	74	3.1	85	1.7
	Libellulidae	20	76	4.0	20	64	4.8	84	3.4
	Macromiidae	4	82	8.5	4	70	5.8	87	4.4
Ryan	Aeshnidae	20	184	8.7	20	162	7.6	89	2.2
	Corduliidae	31	158	8.5	29	137	8.2	83	2.5
	Gomphidae	98	120	3.3	94	95	3.3	80	2.2
	Libellulidae	19	120	7.1	19	109	6.1	92	2.4
	Macromiidae	7	138	14	7	122	15	89	5.6

Table 63 (continued). Total mercury (Hg), methylmercury (MeHg), and percent MeHg in families of larval dragonflies collected during 2008 and 2010–2012 from Voyageurs National Park.

		Total Hg (ng/g dry weight)			MeHg (ng/g dry weight)			Percent MeHg	
Lake	**Family**	***n***	***mean***	***SE***	***n***	***mean***	***SE***	***mean***	***SE***
Sand Point	Aeshnidae	4	188	16	4	129	9.4	71	10
	Corduliidae	35	178	13	36	157	13	88	1.7
	Gomphidae	137	114	2.4	137	84	2.7	74	1.9
	Macromiidae	10	217	15	10	204	11	95	2.7

Whole Prey Fish

Yellow perch, a regionally widespread and abundant prey fish, were sampled from Brown, Peary, Ryan, and Sand Point lakes during 2009–2012 and analyzed whole for total mercury. Mean concentrations of mercury in small yellow perch (<100 mm) were substantially lower in Peary Lake (36 ng/g wet weight) than those in the other three lakes, which ranged from 101 to 107 ng/g (Table 64). Mercury concentrations in 11 whole Iowa darters (total length: mean 48 mm, range 40–60 mm) from Ryan Lake averaged 131 ng/g and ranged from 57 to 224 ng/g. Mercury concentrations were 52 ng/g in each of two whole johnny darters (total lengths, 37 and 51 mm) from Sand Point Lake.

Table 64. Fish length and concentration of total mercury (Hg) in whole yellow perch sampled in 2009–2012 from lakes in Voyageurs National Park.

			Total length (mm)		Hg (ng/g wet weight)[1]	
Lake	**Total length group**	**n**	***mean***	***range***	***mean***	***range***
Brown	<100 mm	111	54	42–97	101	32–175
	≥100 mm	4	116	104–138	161	73–310
	all lengths	115	56	42–138	103	32–310
Peary	<100 mm	116	48	37–90	36	15–58
	≥100 mm	3	104	102–106	71	57–84
	all lengths	119	49	37–106	37	15–84
Ryan	<100 mm	98	59	41–97	107	53–198
	≥100 mm	4	110	104–115	178	112–276
	all lengths	102	61	41–115	110	53–276
Sand Point	<100 mm	129	59	47–99	104	48–196
	≥100 mm	2	112	103–121	104	79–129
	all lengths	131	60	47–121	104	48–196

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

Predatory Fish (Axial Muscle)

We analyzed axial muscle tissue (skinless fillets) from 248 adult northern pike sampled during 2009–2012 for total mercury (Table 65). Mercury levels were highest in northern pike from Ryan Lake,

averaging 1,071 ng/g and ranging from 354 to 2192 ng/g wet weight. Concentrations were lowest in northern pike from Peary Lake, averaging 506 ng/g and ranging from 180 to 1,329 ng/g. Mercury levels were intermediate in northern pike from Sand Point Lake (mean 773 ng/g, range 217–2,372 ng/g) and Brown Lake (mean 860 ng/g, range 336–3,305 ng/g). Concentrations of mercury were high in axial muscle tissue from three walleyes from Sand Point Lake, averaging 1,138 ng/g and ranging from 980 to 1,304 ng/g (Table 65).

Table 65. Fish length and concentrations of total mercury (Hg) in axial muscle tissue of predatory fish collected during 2009–2012 from four lakes in Voyageurs National Park.

			Total length (mm)		Hg concentration (ng/g wet weight)[1]		Percent (number) of fish exceeding benchmarks[2]	
Lake	Species	n	*mean*	*range*	*mean*	*range*	*Human health USEPA (300 ng/g)*	*Fish health and reprod. (500 ng/g)*
Brown	northern pike	50	487	312–639	860	336–3,305	100 (50)	90 (45)
Peary	northern pike	70	552	398–780	506	180–1,329	87 (61)	40 (28)
Ryan	northern pike	69	485	358–589	1071	354–2,192	100 (69)	90 (62)
Sand Point	northern pike	59	501	248–810	773	217–2,372	90 (53)	54 (32)
	walleye	3	409	384–433	1138	980–1,304	100 (3)	100 (3)

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

[2] Fish with Hg concentration exceeding the USEPA fish-tissue criterion for methylmercury (300 ng/g) and an estimated benchmark level (500 ng/g) for adverse effects on fish health and reproduction.

Trends

Long-term studies of mercury at VOYA (e.g., Sorensen et al. 2005, Wiener et al. 2006, Brigham et al. 2014) allow an assessment of temporal trends that is not presently feasible with data available for the other parks studied. Analyses of sediment cores and forest soils have shown that atmospheric deposition is the dominant pathway for entry of mercury into Voyageurs National Park and that most of the mercury present in lakes and watersheds in the park is from anthropogenic sources (Wiener et al. 2006). The wet deposition of total mercury, sulfate, and hydrogen ion have decreased in northern Minnesota during 1998–2012, and concurrent patterns in methylmercury concentrations in four inland lakes at VOYA—including three of the lakes in the present study—were examined by Brigham et al. (2014). Concentrations of methylmercury in water and of total mercury in small yellow perch decreased during 2001–2012 in two of the four lakes (Peary and Ryan), but increased in one lake (Brown). No trends were evident in the fourth lake (Shoepack) during the same time interval, possibly because disturbances caused by a forest fire and beaver activity in the watershed that may have influenced the microbial methylation of mercury and the subsequent bioaccumulation of methylmercury in the food web in that lake.

Ecological and Health Risks of Methylmercury

It can be reasonably inferred that methylmercury exposure is adversely affecting the health and reproduction of piscivorous fishes in VOYA lakes, based on mercury levels in northern pike, walleye, and prey fish. In northern pike, mean concentrations of mercury in axial muscle tissue (see

Table 65) exceeded 500 ng/g wet weight, a benchmark level associated with altered biochemical processes, damage to cells and tissues, and reduced reproduction of fishes. In individual fish, the 500-ng/g benchmark was exceeded in 167 (67%) of the 248 northern pike from the four lakes (see Table 65) and in all of the walleyes from Sand Point Lake. Mean concentrations of mercury in whole yellow perch in three of the four lakes at VOYA (see Table 64), in whole Iowa darters from Ryan Lake (131 ng/g), and in johnny darters from Sand Lake (52 ng/g) exceeded the estimated dietary threshold (40 ng/g wet weight in prey fish; Depew et al. 2012a) for reproductive effects of methylmercury in piscivorous fish. The yellow perch is very important in the diets of northern pike (Soupir et al. 2000) and walleye (Colby et al. 1979), and it can be reasonably inferred that predation on yellow perch is an important trophic pathway for methylmercury exposure of these piscivores in many lakes at VOYA.

Yellow perch are also the preferred prey of adult common loons, which generally eat prey fish in the total-length range of 100–250 mm (Barr 1996, Merrill et al. 2005). Concentrations of mercury in both small (<100 mm) and larger (≥100 mm) whole yellow perch from three lakes (Brown, Ryan, and Sand Point; see Table 64) exceeded the estimated dietary threshold (100 ng/g wet weight in prey fish; Depew et al. 2012b) for adverse behavioral impacts of methylmercury in adult common loons. About half of the whole yellow perch analyzed from Brown, Ryan, and Sand Point lakes had mercury concentrations exceeding the estimated dietary threshold of 100 ng/g for behavioral impacts on adult common loons (Table 66).

Table 66. Percentages of whole yellow perch from four lakes in Voyageurs National Park with mercury levels exceeding dietary benchmarks for belted kingfishers (30 ng/g wet weight), American mink (70 ng/g), and adult common loons (100 ng/g).

		Total length (mm)		Percent of yellow perch with Hg exceeding dietary benchmarks for piscivorous fish and wildlife		
Lake	**N**	***length group***	***length range***	***Belted kingfisher (30 ng/g)***	***American mink (70 ng/g)***	***Common loon (100 ng/g)***
Brown	111	<100	42–97	100	94	48
	4	≥100	104–138	100	100	75
	115	all fish	42–138	100	94	49
Peary	116	<100	37–90	72	0	0
	3	≥100	102–106	100	67	0
	119	all fish	37–106	72	2	0
Ryan	98	<100	41–97	100	93	55
	4	≥100	104–115	100	100	100
	102	all fish	41–115	100	93	57
Sand Point	129	<100	47–99	100	87	50
	2	≥100	103–121	100	100	50
	131	all fish	47–121	100	87	50

In addition, mean concentrations of mercury in yellow perch with total lengths of 100 mm or greater were 161 ng/g wet weight in Brown Lake and 178 ng/g in Ryan Lake, levels near the dietary

benchmark (180 ng/g wet weight in prey fish) associated with significant reproductive impairment of adult common loons (Depew et al. 2012b). None of the whole yellow perch from Peary Lake had mercury concentrations exceeding the estimated dietary threshold of 100 ng/g for behavioral impacts on adult common loons.

The screening-level dietary benchmark for belted kingfisher (30 ng/g wet weight in whole prey fish) was exceeded in all prey fish (yellow perch, Iowa darter, and johnny darter) analyzed from Brown, Ryan, and Sand Point lakes and in 72% of the yellow perch from Peary Lake (Table 66). The screening-level dietary benchmark for American mink (70 ng/g wet weight in whole prey fish) was exceeded in about 90% of the whole yellow perch analyzed from Brown, Ryan, and Sand Point lakes (Table 66). Few (2%) of the yellow perch from Peary Lake had mercury levels exceeding the benchmark for American mink.

The high mercury levels in fillets of piscivorous fish from VOYA lakes also pose health risks to humans who consume game fish from these water bodies. Mean concentrations of mercury in northern pike from all four lakes and in walleye from Sand Point Lake substantially exceeded the USEPA fish-tissue criterion of 300 ng/g wet weight, which was derived to protect the health of humans who eat noncommercial fish. Moreover, the USEPA criterion was exceeded in 233 (94%) of the 248 northern pike analyzed from the four lakes and was substantially exceeded in the three walleyes from Sand Point Lake. The fish consumption guidelines recommended by the Great Lakes Fish Advisory Workgroup indicate that pregnant women, women who may become pregnant, and children under 15 years of age should greatly limit (e.g., one meal per month) or completely avoid consumption of predatory game fish from the four study lakes at VOYA (compare Tables 8 and 65).

Lead and Organic Contaminants

In contrast to the results for mercury, the concentrations of legacy contaminants (DDT, DDE, DDD, PCBs, and Pb) and emerging contaminants (PBDEs, and PFCs) in northern pike from the lakes at VOYA were low, commonly below limits of detection.

Axial Muscle

Analytical results for organic contaminants and lead in axial muscle (skinless fillets) of fish collected in 2009, which were reported by Wiener et al. (2013), are briefly summarized here. Ten composite samples of northern pike from the four lakes at VOYA—each composite containing an equivalent mass of axial muscle from four or five fish of similar length from a single lake—were analyzed for organic contaminants and total lead (Appendix K, Table K-1). 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 L, Table L-10). 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. The concentrations of these legacy and emerging organic contaminants in axial fillets of fish from the four lakes at VOYA do not pose significant risks to human health, based on published guidelines for human consumption of sport fish (see Table 8). Lead concentrations were also low, averaging 8 ng/g wet weight (range 2–31 ng/g) in northern pike from the four lakes.

Whole fish

Twenty-five composite samples of whole northern pike sampled from the four lakes in 2010, 2011, and 2012 were analyzed for selected organic contaminants and total lead. Each of these composite samples contained three to four fish of similar size (Appendix K, Table K-2).

Concentrations of DDT, DDE, DDD, and PCBs in all samples of whole northern pike were below limits of detection, which were 10 ng/g wet weight for total DDT and 1–3.5 ng/g wet weight for PCBs (Appendix L, Table L-11). Concentrations of PFCs and PBDEs in northern pike from each lake were either below reporting levels (PFC range, 0.12–0.50 ng/g wet weight; PBDE range, 1.0–2.0 ng/g) or were low (PFC range, 0.13–2.9 ng/g wet weight; PBDE range, 1.0–1.7 ng/g). Concentrations of lead were also low, averaging 10 ng/g wet weight (range 6–18 ng/g) in whole northern pike from the four lakes. The concentrations of legacy and emerging organic contaminants analyzed in whole northern pike from lakes at VOYA are substantially below reported benchmark concentrations associated with adverse effects on piscivorous birds or mammals (see Table 9) and do not pose significant risks to the health of piscivorous wildlife.

Regional Assessment of Bioaccumulative Contaminants

Mercury

Total Mercury in Surficial Sediment and Soil

Concentrations of total mercury in surficial bed sediment and adjacent soils from the six park units were generally typical of those in the western Great Lakes region. Much of the variation in total mercury within and among park units was related to variability in the organic matter content of soils and sedments, as indicated by the linear relation between mercury concentration and percent loss on ignition (a surrogate measure of organic matter content; Figure 3), a pattern commonly observed in soil and surficial sediment.

At GRPO, mercury levels in soil and sedment, expressed as a function of organic content, were substantially greater (about four-fold) those in samples collected concurrently from the other five park units (Figure 3). The ratios of total mercury to organic content in soils and sediments from the other five national parks were similar, with estimated soil Hg:C molar ratios of about 3.8 x 10-8 (Rolfhus et al. 2015a).

We hypothesize that the localized enrichment of mercury in soils and sediments at GRPO resulted in part from the use of vermilion in historic fur trading (Rolfhus et al. 2015a). Vermilion, a synthetic mercuric sulfide pigment derived from cinnabar ore, was a principal trade item and gift in the 18th century fur trade. For example, the Northwest Fur Company inventoried more than 100 pounds (45 kg) of vermilion in goods remaining at Grand Portage after seasonal trading in 1797 (White 2004). Moreover, concentrations total mercury in C-horizon soils at three locations along the historic trail were 1.7 to 2.1-fold those in A-horizon soils, with no apparent local geogenic source (Laurel Woodruff, US Geological Survey, St. Paul, MN, personal communication).

Atmospheric deposition is the primary modern pathway for entry of mercury into ecosystems within the western Great Lakes Region encompassing the six park units. The analyses of dated lacustrine

sediments show that most of this atmospherically deposited mercury is from anthropogenic emissions (Swain et al. 1992, Wiener et al. 2006, Engstrom et al. 2007, Drevnick et al. 2012).

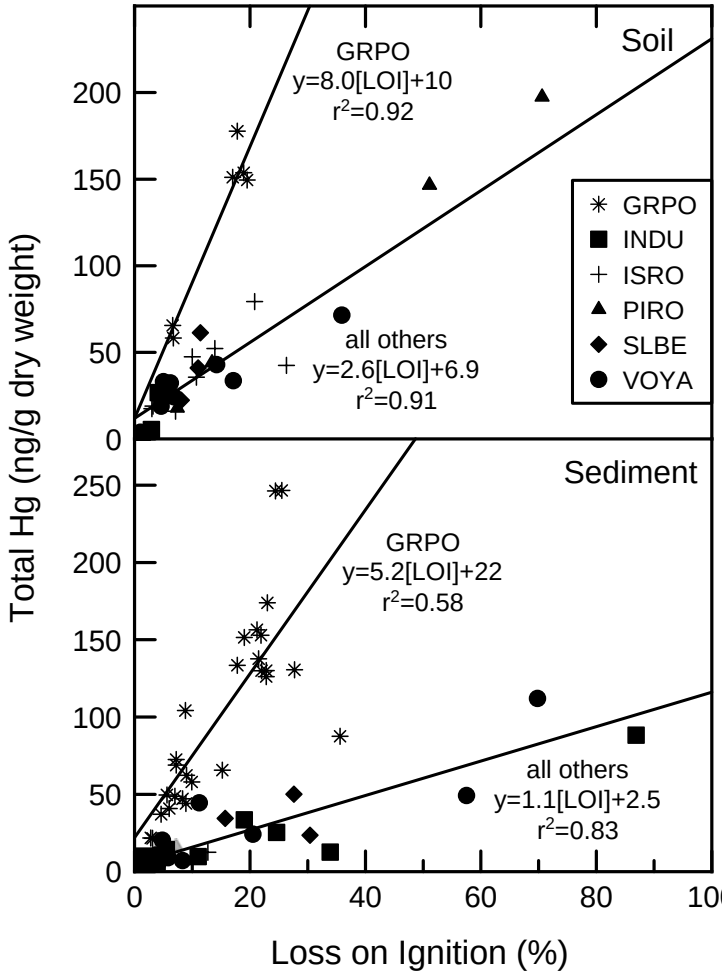


Figure 3. Relation of total mercury (Hg) in surficial soil (upper panel) and sediment (lower panel) to percent loss on ignition (a surrogate measure of organic matter content) in six national park units in the Great Lakes region. The provisional estimate for Hg in soil from Grand Portage Creek at GRPO (Table 11) was not included in the figure.

Total Mercury in Surface Water

Aqueous concentrations of total mercury provide an approximate measure of mercury contamination in natural waters because of variation among water bodies in the fraction present as methylmercury. Lakes within five of the park units (excluding GRPO streams) had concentrations of unfiltered and filter-passing total mercury that were typical of the western Great Lakes region (Wiener et al. 2006). Concentrations of filter-passing total mercury in water from the six park units were correlated with dissolved organic carbon (Figure 4), a finding in agreement with other research showing that the hydrologic transport of organic matter from watersheds influences total mercury levels in water. In GRPO streams, the concentrations of total mercury were at the upper end of the range reported for

streams across the region (Rolfhus et al. 2015a) and were generally greater than those in lakes (Figure 4). At INDU, the concentrations of total mercury in the Great Marsh were typical of those in regional wetland environments (Brigham et al. 2009).

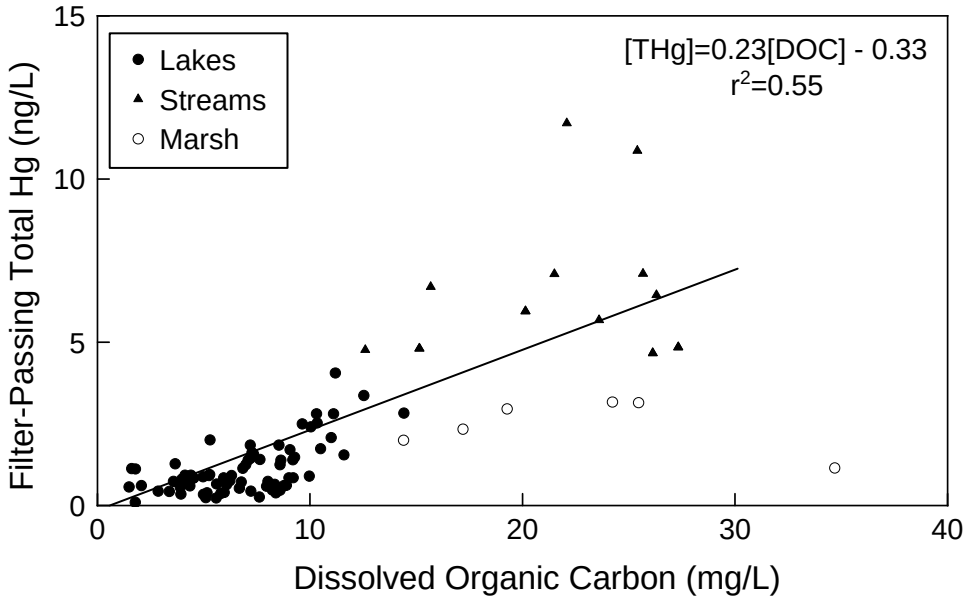


Figure 4. Relation of filter-passing total mercury (Hg) in water to dissolved organic carbon (DOC) in water bodies at six national park units in the Great Lakes region. All of the streams were at GRPO and the Great Marsh (marsh) is at INDU.

Methylmercury in Lower Food Web

Our analyses of methylmercury in sediments, soils, and water indicated active microbial methylation of inorganic mercury, with detectable levels of methylmercury in all sampled components of the lower food web. The concentrations of methylmercury in the lower food web varied substantially among the 23 water bodies studied, both within and among the six park units (Figure 5). The methylmercury concentrations in soil and sediment were consistent with other regional observations, except for the unusually high levels observed along streams at GRPO (Rolfhus et al. 2015a). Organic matter content explained 68% and 73% of the variation in methylmercury concentrations in sediment and soil, respectively, among lakes studied in the other five park units. As with total mercury, the soil and sediment from GRPO had three to four times the amount of methylmercury per amount of organic carbon than the mean for the other five parks. Water at GRPO also had higher methylmercury concentrations than water at the other parks. Streams generally have higher methylmercury concentrations than lakes, and the GRPO values were also at the high end of the range of concentrations reported in stream waters across the region (Rolfhus et al. 2015a).

Methylmercury concentrations in filtered lake water were higher in the two park units in the northwestern portion of the studied region (VOYA and GRPO) than in the two parks in the southeastern part of the study area (INDU and SLBE), whereas concentrations at ISRO and PIRO were intermediate (see Figure 5). This spatial pattern in aqueous methylmercury does not parallel the distribution of anthropogenic emissions or wet deposition of total mercury in the Great Lakes region,

given that atmospheric emissions and concentrations of total mercury in wet deposition are greatest in the area south and east of Lake Michigan (Risch et al. 2012a, Wiener et al. 2012b, Gratz et al. 2013).

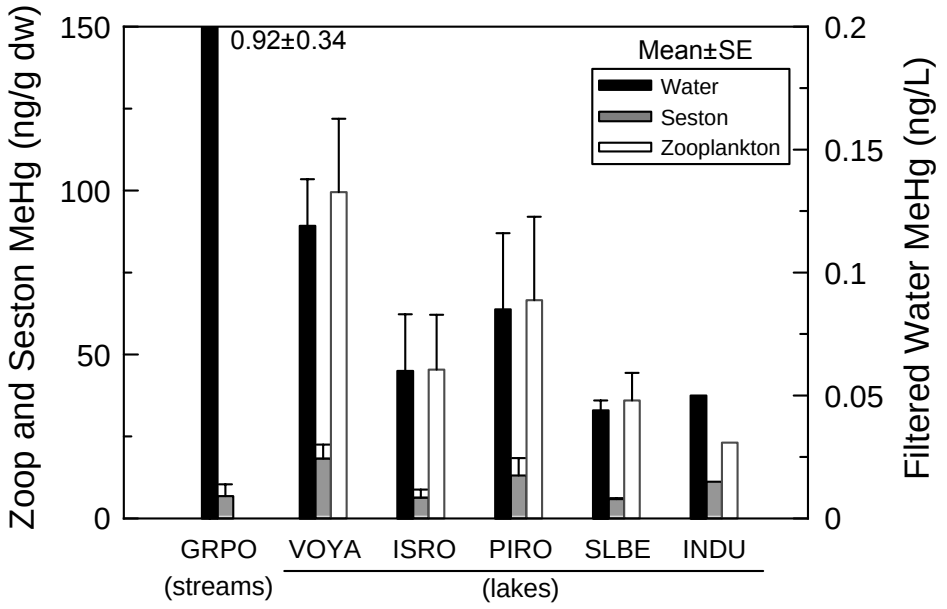


Figure 5. Concentrations of methylmercury (MeHg) in three components of the lower aquatic food web in six national park units in the western Great Lakes region. Bars represent the mean (± SE) for all waters within each park, with each lake or stream averaged during 2010–2012. GRPO = Grand Portage, VOYA = Voyageurs, ISRO = Isle Royale, PIRO = Pictured Rocks, SLBE = Sleeping Bear Dunes, INDU = Indiana Dunes.

The relation between concentrations of methylmercury in filtered water and dissolved organic carbon was weaker than that for total mercury, indicating that multiple factors were likely influencing methylmercury levels in park waters. Variables usually associated with high methylmercury levels in water and aquatic food webs include low pH, wetland and forest cover, dissolved sulfate, dissolved organic carbon, water-level fluctuation, low biotic productivity, and food web structure (Chen and Folt 2005; Sorensen et al. 2005; Wiener et al. 2003, 2006; Brigham et al. 2009; Chasar et al. 2009; Evers et al. 2011b; Chen et al. 2012). Results for specific lakes with elevated methylmercury levels in water and plankton in our study indicate that a variety of factors likely enhanced microbial production of methylmercury; these factors include high DOC and moderately low pH at Brown and Ryan lakes (VOYA), high DOC at Lake Harvey (ISRO), high sulfate at Chapel Lake (PIRO), and low pH at Legion Lake (PIRO).

Both methylmercury concentration and the percent of total mercury present as methylmercury increased through the lower food web. The percent methylmercury in abiotic and food web components (mean ± SE), metrics often used as indicators of ecosystem "methylation efficiency," were 1.0 ± 0.1% in soil across all park units, 4.0 ± 0.6% in bulk sediment, 8.9 ± 1.2% in filtered

water, 12 ± 2.3% in seston, and 43 ± 2.5% in bulk zooplankton. Percent methylmercury in these components were within the ranges of regional values (Rolfhus et al. 2011) and did not vary greatly by park unit.

The greatest trophic-step increase in methylmercury concentration in the aquatic food webs was between water and seston, a widely reported pattern. Methylmercury levels in seston were variable, but showed a weak positive relation to the filtered water values. This variability is to be expected, given the variety of living and detrital material that is sampled in suspension, as well as its varying capacity to bind methylmercury (Rolfhus et al. 2011). Bulk zooplankton showed a much stronger correlation with methylmercury in filtered water (Figure 6), indicating a general "bottom-up" control of methylmercury content in the food web. Thus, factors affecting the production and transport of methylmercury in aquatic systems strongly influence concentrations in prey fish and predatory fish.

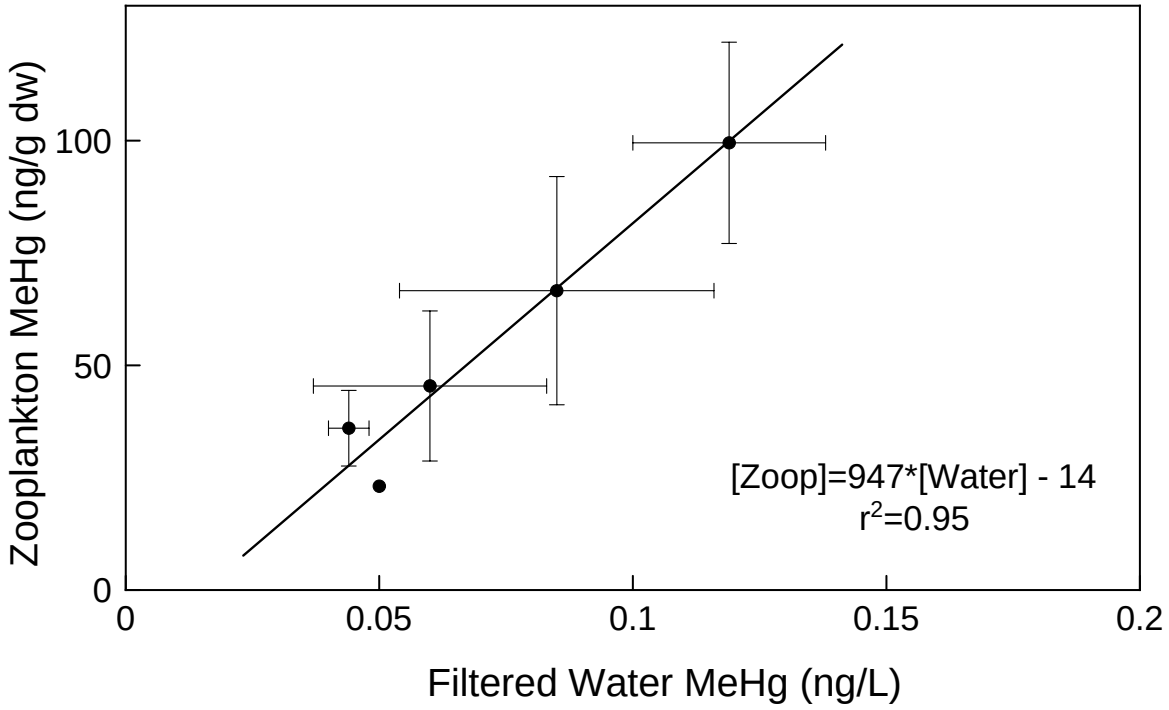


Figure 6. Relation of park mean concentration of methylmercury (MeHg) in bulk zooplankton to that in 0.45-µm filtered water from lakes and Middle Lagoon. Points and error bars represent the mean ± SE for all waters within each park, with each lake averaged during 2010-2012.

Larval Dragonflies as Biosentinels of Methylmercury in Food Webs

Published findings from this and other studies show that larval dragonflies are useful biosentinels of methylmercury in aquatic food webs in the western Great Lakes region (Haro et al. 2013, Haro 2014, Jeremiason et al. 2016). Mean concentrations of methylmercury in three regionally widespread families of dragonfly (Aeshnidae, Corduliidae, and Gomphidae; data grouped by family and park unit) were highest at GRPO, PIRO, and VOYA. Most of the mercury present in larvae was methylmercury, with percent methylmercury in larval dragonflies (data for all families combined; mean with 95% confidence interval) averaging 92.9 ± 2.0% at GRPO, 82.5 ± 2.0% at VOYA, 79.7 ±

1.7% at PIRO, 76.9 ± 4.1% at INDU, 74.4 ± 1.7% at SLBE, and 69.3 ± 2.0% at ISRO. The high percent methylmercury in larvae at GRPO coincided with the highest percent methylmercury in unfiltered water, but the other park means did not show a consistent pattern between percent methylmercury in dragonflies and water. Based on these findings, we conclude that the determination of total mercury in dragonflies, which requires substantially less effort and cost than determination of methylmercury, would provide reasonable, indirect estimates of methylmercury in larval dragonflies in the western Great Lakes region. Within a given dragonfly taxon, mercury levels in larval dragonflies generally reflected those in coexisting fish across the water bodies studied (Figure 7).

All of the water bodies included in the present study supported self-sustaining fish populations. However, dragonflies emerging as adults from fishless marshes and bogs provide a potentially important pathway for dietary exposure of terrestrial insectivores to methylmercury (Chumchal and Drenner 2015). Moreover, recent studies have shown that some invertivorous passerine songbirds that feed in wetland habitats are at risk to methylmercury exposure (Gann et al. 2015, Jackson et al. 2015).

Regional Patterns in Biomagnification of Methylmercury

To assess the biomagnification of methylmercury in food webs, we calculated bioaccumulation factors for methylmercury in seston, bulk zooplankton, and larval dragonflies relative to concentrations of methylmercury in unfiltered water from the water bodies studied in the six park units (Figure 8). For prey fish, we calculated bioaccumulation factors based on whole-body concentrations of total mercury, which exists almost entirely as methylmercury in whole prey fish. Prey fish data in this analysis were limited to small, presumed age-1 fish of four regionally widespread species (based on length-frequency distributions of these prey fish in our samples), including central mudminnow (total length ≤70 mm), Iowa darter (≤55 mm), longnose dace (≤80 mm), and yellow perch (≤70 mm).

Patterns in the bioaccumulation of methylmercury in these food components were generally similar among five of the park units in our study (INDU, ISRO, PIRO, SLBE, and VOYA). However, at GRPO streams, bioaccumulation factors for dragonfly larvae and prey fish were lower than those for the lentic water bodies sampled at other park units (Figure 8), suggesting that the transfer of methylmercury from water to seston was less efficient in GRPO streams than in the other water bodies studied (mostly lakes). This may result partly from the high concentrations of dissolved organic matter in stream water at GRPO (DOC 15–26 mg/L), which can supress seston:water bioaccumulation factors (partition coefficients) because of the competitive sorption of methylmercury to dissolved organic matter (Rolfhus et al. 2011, Tsui and Finlay 2011).

Our findings show that concentrations of methylmercury in lower trophic levels of aquatic food webs in the parks strongly influence methylmercury levels in fish, as well as the dietary methylmercury exposure of piscivorous wildlife supported by these food webs. In addition to the observed “bottom-up” forcing imposed by methylmercury concentrations in water, variation in food web structure (e.g., the number of trophic levels) can be expected to influence the trophic transfer of methylmercury in these ecosystems.

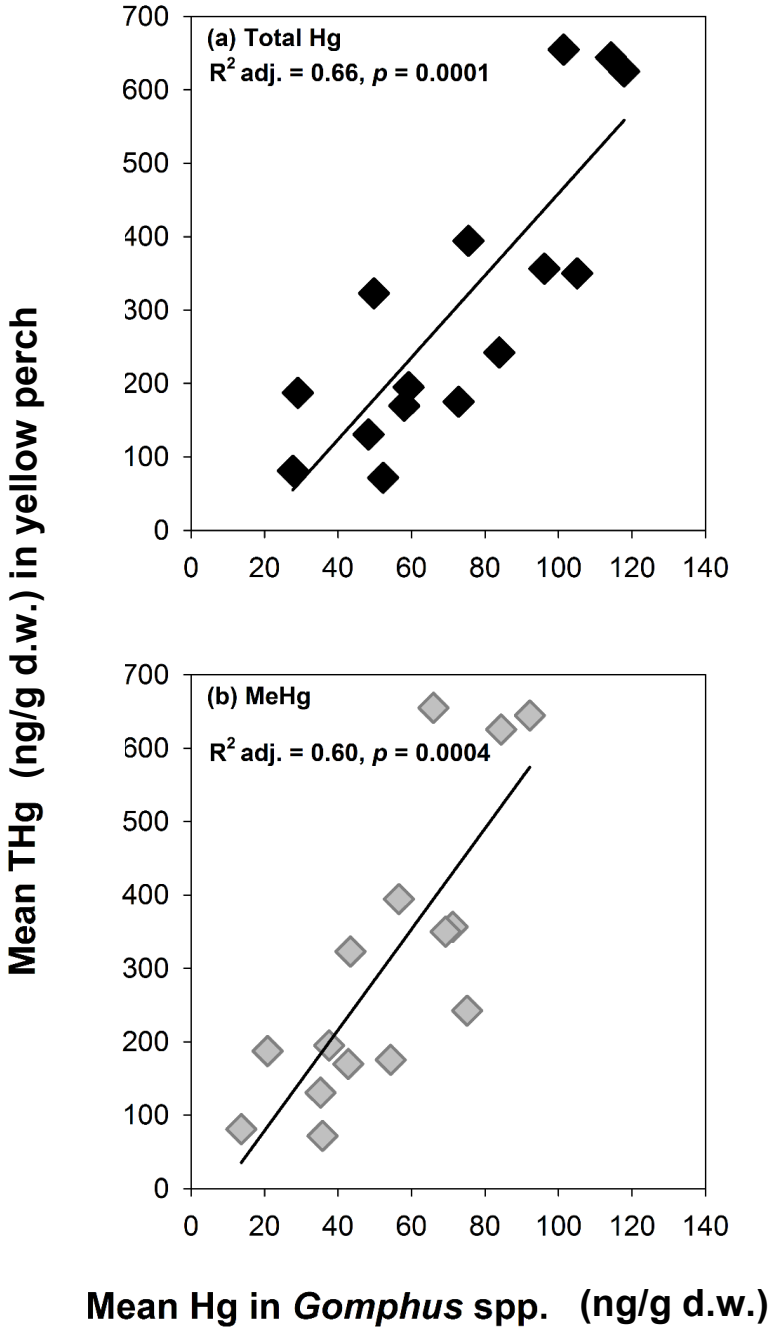


Figure 7. Linear regression between mean concentration of total mercury (THg) in small, whole yellow perch (<76 mm) and mean concentrations of (a) THg and (b) MeHg in coexisting larval *Gomphus* across 15 lakes in the northwestern Great Lakes region. Data for all coexisting species of *Gomphus* were combined to estimate the unweighted mean concentrations of THg and MeHg in larvae for each lake. Reprinted with permission from "Haro, R.J., S.W. Bailey, R.M. Northwick, K.R. Rolfhus, M.B. Sandheinrich, and J.G. Wiener. 2013. Burrowing dragonfly larvae as biosentinels of methylmercury in freshwater food webs. Environmental Science and Technology 47:8148-8156" (Copyright 2013; American Chemical Society).

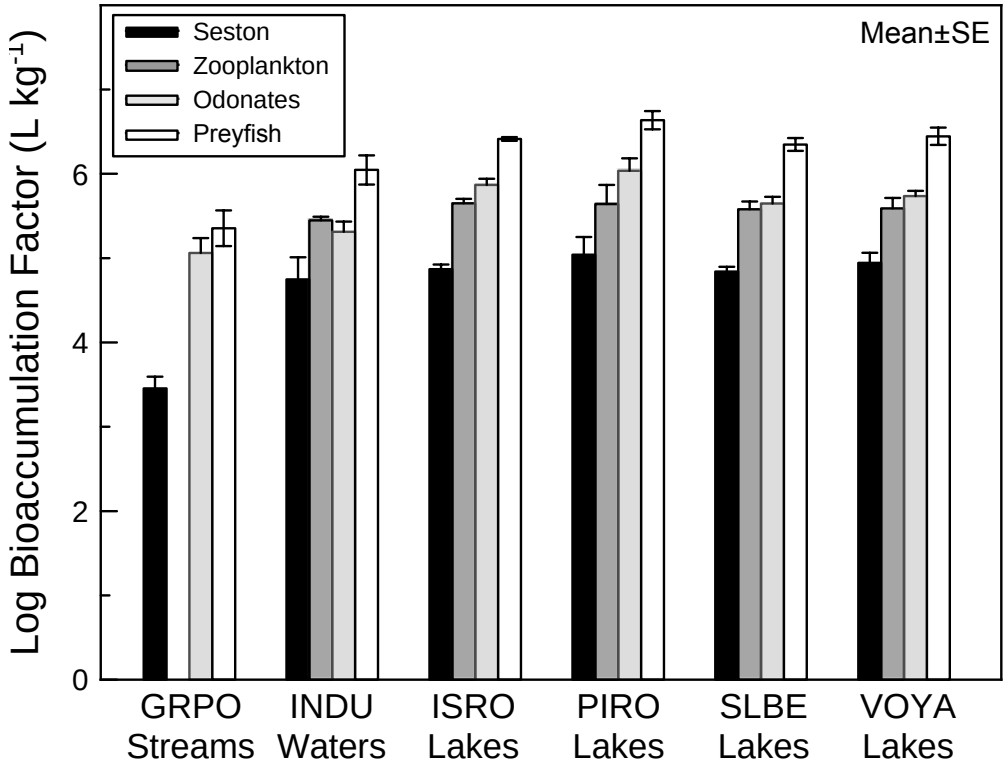


Figure 8. Bioaccumulation factors for methylmercury in seston, bulk zooplankton, larval dragonflies (Odonates), and selected prey fish, relative to concentrations in unfiltered water in six national park units in the western Great Lakes region. Mean (±SE) log10 bioaccumulation factors are for samples collected during 2010-2012. Prey fish data used in the figure were limited to presumed age-1 fish of four species, including central mudminnow (total length ≤70 mm), Iowa darter (≤55 mm), longnose dace (≤80 mm), and yellow perch (≤70 mm). GRPO = Grand Portage, INDU = Indiana Dunes, ISRO = Isle Royale, PIRO = Pictured Rocks, SLBE = Sleeping Bear Dunes, VOYA = Voyageurs.

Mercury in Fish and Risks to Piscivores

The accumulation of mercury in fish varied substantially among the 23 water bodies studied, both within and among the six park units. Concentrations of mercury in axial muscle of adult fish from several lakes substantially exceeded 300 ng/g wet weight, which is the tissue residue criterion for methylmercury established by the U.S. Environmental Protection Agency to protect the health of humans who eat noncommercial fish. Mean concentrations of mercury in axial fillets of predatory fish exceeded the USEPA criterion in 11 lakes, including four lakes at VOYA, three at PIRO, two at ISRO, and two at SLBE (see Table 67). Concentrations of mercury in axial fillets of one or more individual predatory fish from 17 water bodies—including fish from four lakes at VOYA, four lakes at PIRO, four lakes at ISRO, and four lakes at SLBE—exceeded the USEPA tissue residue criterion. None of the individual fish from streams at GRPO and only one fish from INDU exceeded the USEPA criterion. The small streams and beaver pond at GRPO do not provide habitat suitable for supporting long-lived piscivorous fish; if present, it would be reasonable to expect such piscivores to bioaccumulate concentrations of methylmercury exceeding the USEPA criterion, based on the mercury levels observed in resident prey fishes.

Fish in some of the water bodies have bioaccumulated mercury (as methylmercury) to toxicologically significant levels. In some predatory fish, concentrations of mercury in axial muscle tissue exceeded 500 ng/g wet weight, an estimated benchmark concentration associated with altered biochemical processes, damage to cells and tissues, and diminished reproduction in freshwater fish. Mean concentrations in axial muscle tissue exceeded this benchmark level in predatory fish from a total of eight lakes from the four park units, including all four lakes at VOYA, two at PIRO, one at ISRO, and one at SLBE (see Table 67). Concentrations in axial muscle tissue of one or more individual predatory fish from a total of 16 lakes in four park units (ISRO, PIRO, SLBE, and VOYA) exceeded this benchmark.

Table 67. Number of water bodies at six national park units with mercury levels in axial muscle tissue of adult fish exceeding benchmarks for risks to human health (300 ng/g wet weight) and to fish health and reproduction (500 ng/g wet weight).

		Number of water bodies with Hg in fish exceeding 300 ng/g		Number of water bodies with Hg in fish exceeding 500 ng/g	
Park unit	**No. of water bodies studied**	***In one or more individual fish***	***In mean for one or more species***	***In one or more individual fish***	***In mean for one or more species***
GRPO	3	0	0	0	0
INDU	3	1	0	0	0
ISRO	4	4	2	4	1
PIRO	5	4	3	4	2
SLBE	4	4	2	4	1
VOYA	4	4	4	4	4
All six park units	23	17	11	16	8

Concentrations of mercury in whole prey fish from several water bodies across the region exceeded screening-level dietary benchmarks for belted kingfisher and American mink, two piscivores that are highly sensitive to methylmercury exposure. The screening-level benchmark for belted kingfisher (30 ng/g wet weight in whole prey fish) was exceeded in 39% (INDU) to 93% (VOYA) of prey fish less than 100 mm in total length (Figure 9), the size of prey typically consumed by this species (Lazorchak et al. 2003).

American mink and common loons can consume fish larger than 100 mm, with adult loons generally consuming fish in the total length range of 100 to 250 mm (Barr 1996, Merrill et al. 2005). The screening-level benchmark for American mink (70 ng/g wet weight in whole prey fish) was exceeded in 4% (INDU) to 45% (PIRO) of prey fish less than 250 mm total length (Figure 10). In some water bodies, concentrations of mercury in whole prey fish exceeded the estimated dietary thresholds for adverse impacts of methylmercury on the common loon, an iconic species that is moderately sensitive to methylmercury exposure. A relatively small percentage (7% or less) of prey fish less than 250 mm in total length at GRPO, INDU, and SLBE exceeded the dietary threshold (100 ng Hg/g wet weight) for adult common loons, whereas 27% of the prey fish at ISRO, 31% at PIRO, and 43% at VOYA exceeded this estimated threshold (Figure 10).

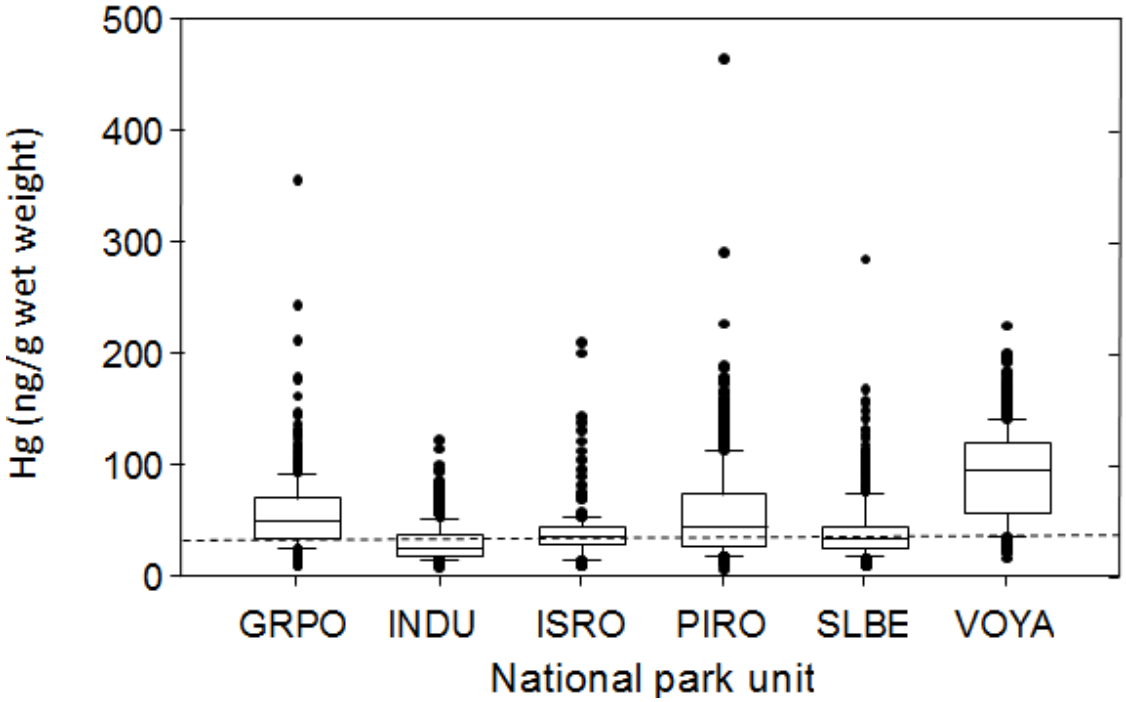


Figure 9. Box and whisker plots of distribution of total mercury levels in whole prey fish < 100 mm in total length from six park units in the western Great Lakes region. Each box represents the first through third quartiles of the data in each park. The horizontal line within each box represents the median value and the whiskers or bars extend to the 10th (lower bars) and 90th percentile (upper bar) of the data. Individual dots represent outliers beyond the central 80% of the data. The dotted horizontal line represents the concentration of mercury in whole prey that are threshold dietary concentrations for health and reproduction in belted kingfisher (30 ng/g; Lazorchak et al. 2003). GRPO = Grand Portage, INDU = Indiana Dunes, ISRO = Isle Royale, PIRO = Pictured Rocks, SLBE = Sleeping Bear Dunes, VOYA = Voyageurs.

Sensitivity of Park Ecosystems to Mercury Pollution

Our results support prior studies showing that the northern Great Lakes region is a mercury-sensitive area in which inorganic mercury is readily methylated, bioaccumulated as methylmercury, and biomagnified in food webs to high, potentially harmful concentrations in fish (Evers et al. 2011a, 2011b; Monson et al. 2011; Sandheinrich et al. 2011; Wiener et al. 2012b). Multiple 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 methylmercury export 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 in northern parts of the region (Eilers et al. 1988).

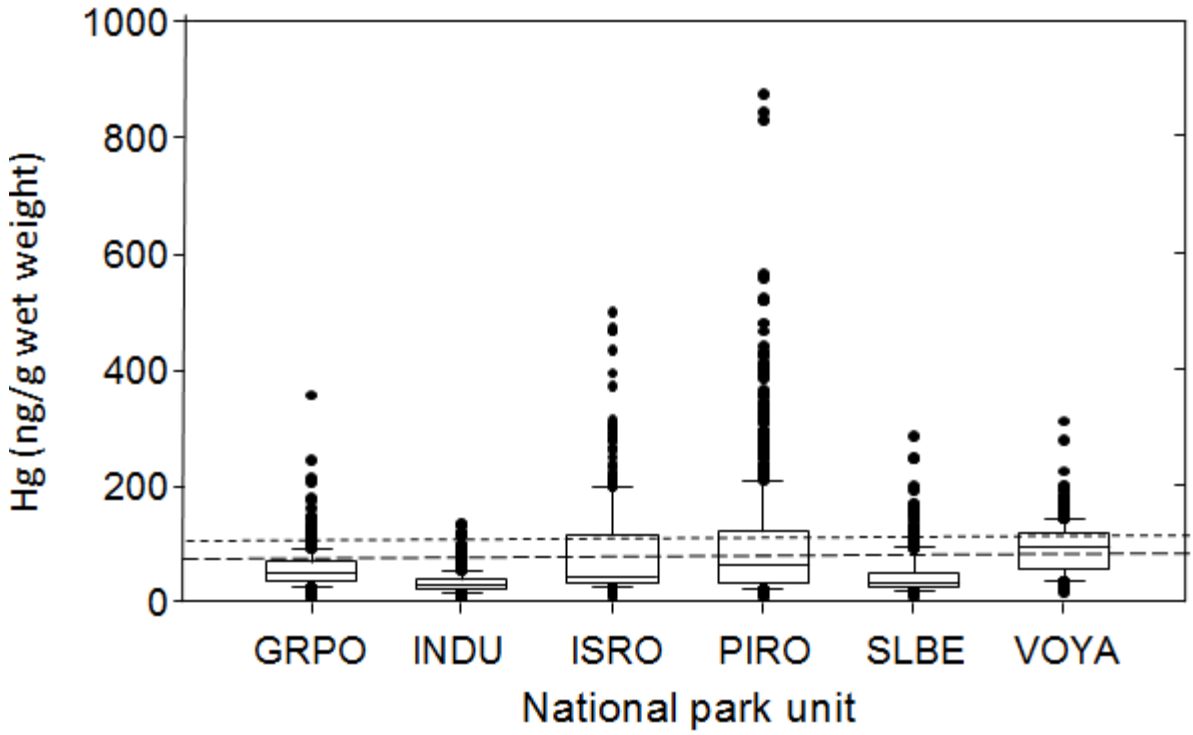


Figure 10. Bar and whisker plots of distribution of total mercury levels in whole prey fish < 250 mm in total length from six park units in the western Great Lakes region. Each box represents the first through third quartiles of the data in each park. The horizontal line within each box represents the median value and the whiskers or bars represent the 10th (lower bars) and 90th percentile (upper bar) of the data. Individual dots represent outliers beyond the central 80% of the data. The dashed and dotted horizontal lines represent the concentration of mercury in whole prey that are threshold dietary concentrations for effects on the health and reproduction in American mink (70 ng/g; Lazorchak et al. 2003) and on behavior in common loon (100 ng/g; Depew et al. 2012b). GRPO = Grand Portage, INDU = Indiana Dunes, ISRO = Isle Royale, PIRO = Pictured Rocks, SLBE = Sleeping Bear Dunes, VOYA = Voyageurs.

Variation in the mercury sensitivity of landscapes as receptors of mercury from atmospheric deposition is illustrated by a comparison of concentrations in central mudminnows sampled during 2008–2009 from three national park units: GRPO, INDU, and PIRO. Contemporary rates of wet and dry deposition of total 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. 2013) than at PIRO in the Upper Peninsula of Michigan and GRPO in northeastern Minnesota. However, concentrations of mercury in central mudminnows from PIRO and GRPO exceeded those in fish from INDU (Figure 11). 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. Low pH and low biotic productivity are two factors that probably contribute to the high mercury concentrations in central mudminnows inhabiting Legion Lake and Snow Creek.

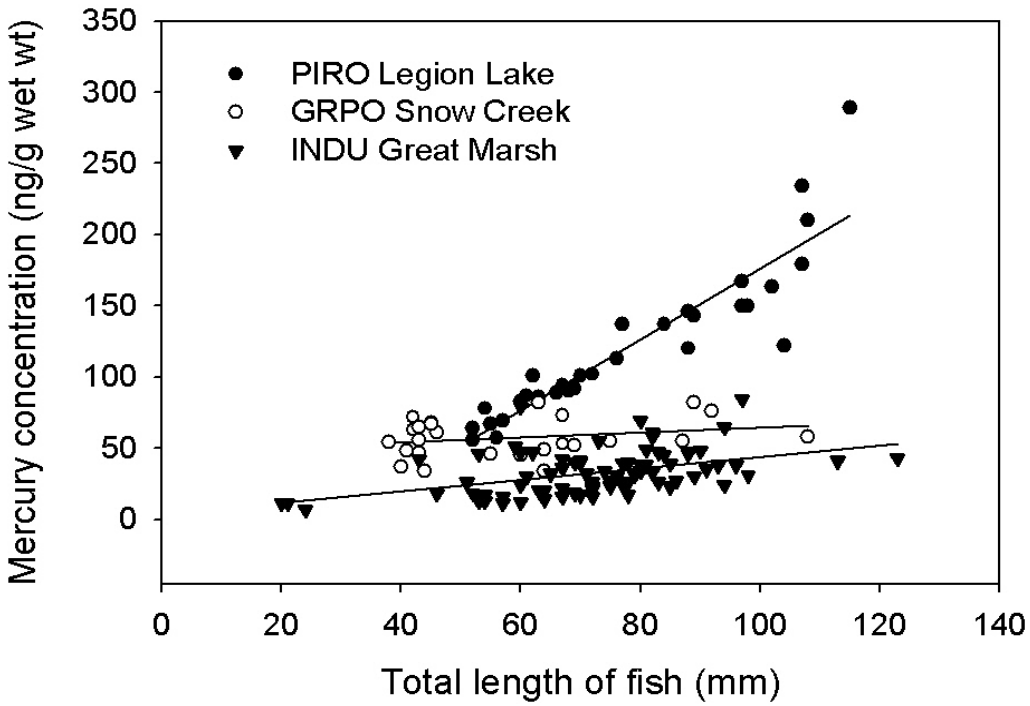


Figure 11. Concentrations of mercury as a function of total length in whole central mudminnows sampled from water bodies at three national park units in the western Great Lakes region. PIRO = Pictured Rocks, GRPO = Grand Portage, INDU = Indiana Dunes.

Potential Effects of Climate Change

Changes in climate can be expected to significantly affect the hydrologic transport, microbial methylation, and bioaccumulation of mercury in northern temperate and boreal landscapes of the Great Lakes region. Annual mean temperature has increased rapidly in national park units across the western Great Lakes region (Monahan and Fisichelli 2014), and decreases in the duration of annual ice cover indicate that lakes and rivers are warming in response (Magnuson et al. 2000). The rate of microbial methylation of mercury increases with increasing temperature to a maximum at about 35ºC (Callister and Winfrey 1986), and detailed studies of Canadian lakes show that increasing lake temperature can be expected to increase both the microbial production of methylmercury in epilimnetic sediments (Ramlal et al. 1993) and the concentrations of methylmercury bioaccumulated by fish (Bodaly et al. 1993). Manipulative field experiments have shown that the concentrations of methylmercury in aquatic food webs increase rapidly in response to increases in methylmercury production and its entry into the base of the food web (Paterson et al. 1998, Bodaly and Fudge 1999). Therefore, warming temperatures could exacerbate the mercury problem in the Great Lakes region.

Many of the key processes and environmental variables that influence the biogeochemistry, methylation, and transport of mercury are also influenced by climate change, and the overall effect of such changes on methylmercury levels in aquatic food webs are not readily predicted. For example, both inorganic Hg(II) and methylmercury in fresh waters associate strongly with dissolved organic matter, which increases in response to a warming climate. Keller et al. (2008) found that temporal trends in air temperature explained much of the inter-annual variation in concentrations of DOC in 12

small boreal shield lakes in Ontario, with DOC increasing with average air temperature. Based on their findings, Keller et al. (2008) estimated that a 1°C increase in air temperature could increase DOC concentrations by 0.5 to 2.3 mg/L in their study lakes.

Climate-related changes across the Great Lakes region also include altered patterns of precipitation and increased frequency of flooding (Mallakpour and Villarini 2015), as well as associated fluctuations in water levels. Extreme hydrologic events that inundate low-elevation terrestrial and wetland areas could be followed by episodes of rapid microbial methylation of mercury, particularly in flooded areas that are subjected to alternating periods of wetting and drying (St. Louis et al. 2004, Rolfhus et al. 2015b). Conversely, in some areas such as northern Minnesota and Michigan, an eventual loss of wetland habitat in response to changing climate could reduce methylmercury production on some landscapes (Garris et al. 2015).

Lead and Organic Contaminants

Spatial Variation in Contamination of Fish

Patterns in the concentration of lead and organic contaminants were generally similar among five of the park units (GRPO, ISRO, PIRO, SLBE, and VOYA). In the axial muscle of fish collected during 2008–2009, the concentrations of legacy contaminants (DDT and metabolites, PCBs, and total lead) and emerging contaminants (PBDEs and PFCs) 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 of axial fillets. PCBs were detected in five samples, PBDEs in four, and PFCs in 39 of the 60 samples. Total lead was detected in all 60 samples of axial fillets, but concentrations were low, ranging from 2 to 31 ng/g wet weight.

In composite samples of whole fish collected during 2010–2012, concentrations of lead and organic contaminants from five of the six park units (GRPO, ISRO, PIRO, SLBE, and VOYA) were also low or below limits of detection. DDT and its metabolites were below the limit of detection in 54 of 71 samples from these five park units, with a maximum concentration of 31 ng DDE/g wet weight in smallmouth bass from Grand Sable Lake in PIRO. PCBs were detected in 34 of 94 samples; the maximum concentration of total PCB was 61.2 ng/g in northern pike from Grand Sable Lake in PIRO. Total PBDEs were detected in 30 of 71 samples; the maximum total PBDE was 10.3 ng/g in largemouth bass from Bass Lake (Leelanau County) at SLBE. PFCs were detected in most (102 of 105) whole-body samples, but concentrations were typically less than 5 ng/g wet weight. Total lead was also detected in most (36 of 37) samples of whole fish. The concentration of total lead was less than 50 ng/g wet weight in all but a single sample that had 112 ng/g (smallmouth bass from Lake Manitou at SLBE).

In contrast to the five park units to the north and northwest, the concentrations of legacy contaminants (DDT and metabolites, PCBs, and total lead) were elevated in whole fish from Middle Lagoon at INDU. Maximum concentrations of DDE, total PCBs, and total lead were 570, 446, and 304 ng/g wet weight, respectively, in whole gizzard shad from Middle Lagoon, whereas concentrations of these legacy contaminants were low or below limits of detection in fish from Great Marsh and Long Lake. Levels of emerging contaminants (PBDEs and PFCs) were also elevated in

fish from Middle Lagoon, with maxima of 21.6 ng/g wet weight for total PBDE and 130 ng/g for PFOS.

Risks to Piscivores

In five park units (GRPO, ISRO, PIRO, SLBE, and VOYA), measured concentrations of organic contaminants in axial fillets did not exceed concentrations at which limited consumption of these fishes by humans would be advised. Similarly, concentrations of organic contaminants in whole fish from these five park units did not exceed screening-level benchmark levels associated with adverse effects on piscivorous birds and mammals and probably do not pose significant risks to the health of piscivorous wildlife.

At INDU, the concentrations of total DDT, total PCBs, total PBDEs, and PFOS in whole fish from Great Marsh and Long Lake were below limits of detection or were substantially less than reported benchmark concentrations associated with adverse effects on piscivorous birds and mammals (see Table 9). The concentrations of total PCBs, total PBDEs, and PFOS in fish from Middle Lagoon exceeded those in fish from Great Marsh and Long Lake, but were less than reported toxicological benchmarks. However, maximum concentrations of DDD and DDE in gizzard shad from Middle Lagoon yielded an estimate of total DDT (ΣDDT, defined as the sum of DDT, DDE, and DDD) exceeding screening-level benchmark concentrations associated with altered health and reproduction in fish, belted kingfisher, and American mink. Therefore, piscivorous wildlife and fish in Middle Lagoon at INDU may be at risk from residues of the legacy pesticide DDT.

Fillets of fish from INDU were not analyzed for organic contaminants and lead, so an assessment of risk to human consumers is not possible. Given that concentrations of DDD, DDE, PCBs, and PFOS were high in some whole fish sampled from Middle Lagoon during 2010–2012, it would be prudent to assess potential health risks associated with consumption of sport fish from Middle Lagoon.

Conclusions

Concentrations of methylmercury in aquatic food webs varied several-fold among 23 water bodies sampled during 2010–2012 in six U.S. national park units in the western Great Lakes region. The 23 study sites included three streams at GRPO, three sites at INDU (Great Marsh, Long Lake, and Middle Lagoon), four lakes at ISRO, five lakes at PIRO, four lakes at SLBE, and four lakes at VOYA. Variation in methylmercury levels was observed in both physical and biotic components of the food webs, both among and within the six park units.

Mercury concentrations in axial muscle tissue (skinless fillets) of adult fish from several water bodies substantially exceeded the U.S. Environmental Protection Agency tissue residue criterion for methylmercury (300 ng/g or parts per billion on a wet-weight basis), which was established to protect the health of humans who eat noncommercial fish. Average concentrations of mercury in axial fillets of predatory fish exceeded the USEPA criterion in 11 of the 23 water bodies, including four lakes at VOYA, three at PIRO, two at ISRO, and two at SLBE. None of the fish from streams at GRPO and only one fish from INDU exceeded the criterion.

Fish in some park units and water bodies have bioaccumulated mercury to levels considered harmful to fish health. Concentrations of mercury in axial muscle tissue in some predatory fish exceeded 500 ng/g wet weight, a benchmark level associated with altered biochemical processes, damage to cells and tissues, and diminished reproduction in freshwater fish. Mean concentrations exceeded this benchmark level in fish from a total of eight water bodies in four park units, including all lakes at VOYA, two lakes at PIRO, one lake at ISRO, and one lake at SLBE.

Whole prey fish from some water bodies had concentrations of mercury considered harmful to fish-eating wildlife. The fraction of small (<100 mm in total length), whole prey fish exceeding the dietary benchmark of 30 ng/g wet weight for belted kingfisher—a piscivorous bird that is highly sensitive to methylmercury—ranged from 39% at INDU to 93% at VOYA. The estimated dietary threshold for adverse effects on the behavior of adult common loons (100 ng Hg/g wet weight), which are moderately sensitive to methylmercury, was exceeded in 27% of the whole prey fish at ISRO, 31% of the prey fish at PIRO, and 43% at VOYA. Small prey fish in streams at GRPO had mercury concentrations that could adversely affect belted kingfisher and mink, two species considered highly sensitive to methylmercury exposure. Based on these findings, we conclude that methylmercury exposure is adversely affecting the health and reproduction of fish and wildlife supported by aquatic food webs in multiple national park units across the western Great Lakes region.

Patterns in concentrations of methylmercury in the lower food web indicated bottom-up control of methylmercury bioaccumulation. Therefore, factors that affect the microbial production of methylmercury and its concentration in components of the lower food web (water, seston, and zooplankton) will strongly influence levels of methylmercury in all trophic levels, including fish and piscivorous wildlife. Furthermore, the bottom-up control of methylmercury concentrations from the base of these aquatic food webs indicates that the contamination of biotic resources within individual

park waters will be closely linked to the atmospheric deposition of mercury, particularly in water bodies and landscapes that are sites of active mercury methylation.

This study provides further evidence that the northern Great Lakes region is a mercury-sensitive geographic area. The high methylmercury levels measured in biota in the present study indicate that a significant fraction of the inorganic mercury entering the park units in atmospheric deposition is being microbially methylated, bioaccumulated as methylmercury, and biomagnified to potentially harmful concentrations. More specifically, our findings indicate that the each of the five northernmost park units (GRPO, ISRO, PIRO, SLBE, and VOYA) contains mercury-sensitive landscapes or water bodies with high rates of microbial production of methylmercury, which enters aquatic food webs and biomagnifies to high concentrations in upper trophic levels.

Atmospheric deposition is the dominant modern pathway for entry of mercury into national park units in this region, and on-site geologic (natural) sources of mercury are generally very small. At GRPO, the total concentrations of mercury in soil and sediment relative to organic matter content were notably higher than those at the other five park units, possibly due to legacy mercury contamination along the Grand Portage trail from the use of vermilion in the fur trade.

We concude that management and regulatory actions that reduce regional and national emissions of mercury to the atmosphere will decrease methylmercury contamination of food webs, benefiting fish and wildlife in national park units and other lands within this mercury-sensitive region. This conclusion is supported by findings from the present study, as well as a steadily increasing body of scientific evidence showing that much of the mercury bioaccumulating as methylmercury in aquatic food webs is derived from atmospheric deposition.

Our findings also show that whole larval dragonflies are useful biosentinels of methylmercury in aquatic food webs across the western Great Lakes region. Most of the mercury in larvae was methylmercury, and methylmercury levels in three regionally widespread families (Aeshnidae, Corduliidae, and Gomphidae) were highest at GRPO, PIRO, and VOYA.

Concentrations of legacy contaminants (DDT, DDE, and DDD; PCBs; total lead) and emerging contaminants (PBDEs and PFCs) were either nondetectable or very low in axial muscle (skinless fillets) of fish collected during 2008–2009 from five park units (GRPO, ISRO, PIRO, SLBE, and VOYA). The measured concentrations and limits of detection for these contaminants were much lower than levels considered harmful to the health of fish-eating humans.

Concentrations of legacy contaminants (DDT and metabolites, PCBs, and total lead) and emerging contaminants (PBDEs and PFCs) in whole fish collected during 2010–2012 from GRPO, ISRO, PIRO, SLBE, VOYA, and two of three water bodies at INDU (Great Marsh and Long Lake) were also low or below limits of detection. Concentrations of organic contaminants in whole fish at these sites did not exceed benchmark values associated with adverse effects on piscivorous birds and mammals, and probably do not pose significant risks to wildlife. In contrast, concentrations of DDT metabolites, PCBs, and total lead were much higher in whole fish from Middle Lagoon (INDU). Levels of total PCBs, total PBDEs, and PFOS in fish from Middle Lagoon were less than established

toxicological benchmarks for fish and wildlife. However, high concentrations of DDE and DDD contributed to an estimate of total DDT that exceeded screening-level benchmark concentrations associated with altered health and reproduction in fish, belted kingfisher, and American mink. Legacy contamination of Middle Lagoon with DDE and DDD may pose risks to fish and piscivorous wildlife.

Recommendations

Provide fish consumption advice to communicate the health risks (and benefits) of eating fish to persons who harvest or consume fish from the park units. We recommend that such information focus on mercury and that advice be provided for individual water bodies because of the large variation in mercury levels in fillets of sport fish among park units and water bodies. We also encourage application of the protocol for mercury-based fish consumption advice developed for mercury by the Great Lakes Fish Advisory Workgroup (2007), which is composed of environmental health specialists from the eight Great Lakes states. Park managers are encouraged to quantify mercury levels in sport fish from any intensively fished lakes that have not yet been surveyed.

Survey bioaccumulative organic contaminants in sport fish from Middle Lagoon at INDU. Our analyses of organic contaminants in whole fish sampled from Middle Lagoon during 2010–2012 revealed high concentrations of DDD, DDE, PCBs, and PFOS in some fish. No edible fillets from the fishes collected in Middle Lagoon were analyzed. We recommend that fillets of selected sport fish from the lagoon be analyzed for these bioaccumulative organic contaminants. Candidate species of fish for sampling and analyses include largemouth bass, grass pickerel, bluegill, and channel catfish.

We do not recommend further monitoring of PBDEs and PFCs, based on the non-detectable to low concentrations of these emerging contaminants in fish sampled during 2008–2012 from the other water bodies in the six park units. However, planners at parks throughout the Great Lakes Inventory and Monitoring Network are encouraged to be alert for new scientific information concerning the potential toxicity of other emerging, bioaccumulative compounds, as well as trends in their environmental concentrations, commercial production, use, and disposal.

Assess exposure and reproductive effects of methylmercury on fish-eating wildlife in the parks. Concentrations of mercury in whole prey fish from several water bodies in the six park units exceeded screening-level dietary benchmarks for piscivores that are highly sensitive or moderately sensitive to methylmercury exposure. We recommend that the exposure and ecotoxicological impacts of mercury be examined in piscivorous wildlife that feed in selected water bodies in these national park units.

Use larval dragonflies as biosentinels of methylmercury in aquatic food webs. Findings from this study show the utility and advantages of larval dragonflies as biosentinels of methylmercury in aquatic food webs across the western Great Lakes region. The sampling of larval dragonflies provides an excellent opportunity for citizen science, and we commend the National Park Service for involving citizen scientists in sampling larval dragonflies to assess mercury contamination in our national parks. To the extent possible, the Great Lakes Inventory and Monitoring Network should extend the monitoring of larval dragonflies as a biosentinel for mercury to all parks in the network. Moreover, the present study focused on water bodies containing fish, yet dragonflies emerging as adults from fishless water bodies—including marshes, bogs, and other wetlands that can be important sites of methylmercury production on the landscape—provide a trophic pathway for exposing terrestrial invertivores to methylmercury. We recommend that the use of larval dragonflies as biosentinels be extended to such fishless waters. We also recommend that the sampling and analysis

of larval dragonflies be focused on late instars to prevent the confounding of spatiotemporal patterns in mercury concentrations that would occur if the age of the larvae analyzed varied substantially among water bodies or years.

Encourage and support regional and national actions to reduce anthropogenic emissions of mercury to the atmosphere. Reduction in mercury emissions is an effective approach for reducing biotic exposure to methylmercury and for decreasing the associated ecological and health risks of this highly toxic contaminant in the western Great Lakes region and elsewhere.

Periodically reassess the status of mercury contamination of fish in national park units across the Great Lakes region. During the coming years and decades, temporal changes in mercury concentrations in aquatic food webs and fish can be reasonably expected in response to reduced mercury emissions from coal-burning power plants (via controls enacted through the USEPA Mercury and Air Toxics Standards) and in response to changes in the hydrologic transport, methylation, and bioaccumulation of mercury caused by a changing climate. Given the high mercury levels in fish in several park units and water bodies observed in the present study, we recommend that mercury contamination of fish be periodically reassessed by sampling at 5-year to 10-year intervals. We recommend that this effort focus on quantifying mercury in piscivorous fish or prey fish from select water bodies in the five northernmost park units across the region. Results of such monitoring can be used to reassess ecological risks to piscivorous wildlife and potential health risks to persons who harvest or consume fish from the parks.

Continue trend monitoring of mercury in lakes at Voyageurs National Park. We recommend that the National Park Service continue to facilitate the monitoring of mercury in small yellow perch and lake water to extend the trend analysis recently reported by Brigham et al. (2014). This study, which has been a multi-institutional effort involving scientists from federal agencies, academia, and the National Atmospheric Deposition Program, has provided a cost-effective and scientifically defensible approach for assessing responses of lakes to temporal changes in atmospheric mercury deposition.

Literature Cited

Abbasi, G., A. M. Buser, A. Soehl, M. W. Murray, and M. L. Diamond. 2015. Stocks and flows of PBDEs in products from use to waste in the U.S. and Canada from 1970 to 2020. Environmental Science and Technology 49:1521–1528.

Abbott, J. C. 2007. Odonata Central: An online resource for the Odonata of North America. Austin, Texas. Available from http://www.odonatacentral.com (accessed 26 January 2012).

Ackerman, J. T., C. A. Hartman, C. A. Eagles-Smith, M. P. Herzog, J. Davis, G. Ichikawa, and A. Bonnema. 2015. Estimating exposure of piscivorous birds and sport fish to mercury in California lakes using prey fish monitoring—A predictive tool for managers. U.S. Geological Survey Open-File Report 2015-1106. Available from http://dx.doi.org/10.3133/ofr20151106.

Adams, W. J., R. Blust, U. Borgmann, K. V. Brix, D. K. DeForest, A. S. Green, J. S. Meyer, J. C. McGeer, P. R. Paquin, P. S. Rainbow, and C. M. Wood. 2011. Utility of tissue residues for predicting effects of metals on aquatic organisms. Integrated Environmental Assessment and Management 7:75–98.

Ahrens, L., and M. Bundschuh. 2014. Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. Environmental Toxicology and Chemistry 33:1921–1929.

Airaksinen, R., A. Hallikainen, P. Rantakokko, P. Ruokojärvi, P. J. Vuorinen, J. Mannio, and H. Kiviranta. 2015. Levels and congener profiles of PBDEs in edible Baltic, freshwater, and farmed fish in Finland. Environmental Science and Technology 49:3851–3859.

Anderson, H. A., J. F. Amrhein, P. Shubat, and J. Hesse. 1993. Protocol for a uniform Great Lakes sport fish consumption advisory. Great Lakes Fish Advisory Task Force. Available from http://www.fish.state.pa.us/images/fisheries/fcs/pcb_fishtech.pdf (accessed 29 October 2014).

Anderson, W. L., S. P. Havera, and B. W. Zercher. 2000. Ingestion of lead and nontoxic shotgun pellets by ducks in the Mississippi Flyway. Journal of Wildlife Management 64:848–857.

Barr, J. F. 1996. Aspects of common loon (*Gavia immer*) feeding biology on its breeding ground. Hydrobiologia 321:119–144.

Basu, N., A. M. Scheuhammer, S. J. Bursian, J. Elliott, K. Rouvinen-Watt, and H. M. Chan. 2007. Mink as a sentinel species in environmental health. Environmental Research 103:130–144.

Batterman, S., S. Chernyak, E. Gwynn, D. Cantonwine, C. Jia, L. Begnoche, and J. Hickey. 2007. Trends of brominated diphenyl ethers in fresh and archived Great Lakes fish. Chemosphere 69:444–457.

Becker, G. C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, Wisconsin.

Beckvar, N., and G. R. Lotufo. 2011. DDT and other organohalogen pesticides in aquatic organisms. Pages 47–101 *in* W. N. Beyer and J. P. Meador, editors. Environmental contaminants in biota: Interpreting tissue concentrations, 2nd edition. CRC Press/Taylor and Francis, Boca Raton, Florida.

Beckvar, N., T. M. Dillon, and L. B. Read. 2005. Approaches for linking whole-body fish tissue residues of mercury or DDT to biological effects thresholds. Environmental Toxicology and Chemistry 24:2094–2105.

Benoit, J., C. Gilmour, A. Heyes, R. P. Mason, and C. Miller. 2003. Geochemical and biological controls over methylmercury production and degradation in aquatic ecosystems. Pages 262–297 *in* Y. Chai and O. C. Braids, editors. Biogeochemistry of environmentally important trace elements. American Chemical Society, Washington, D.C.

Bethke, B. J., and D. F. Staples. 2015. Changes in relative abundance of several Minnesota fishes from 1970 to 2013. Transactions of the American Fisheries Society 144:68–80.

Bloom, N. S. 1992. On the chemical form of mercury in edible fish and marine invertebrate tissue. Canadian Journal of Fisheries and Aquatic Sciences 49:1010–1017.

Blus, L. J. 2003. Organochlorine pesticides. Pages 313–339 *in* D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr., and J. Cairns, Jr., editors, Handbook of ecotoxicology, 2nd edition, CRC Press, Boca Raton, Florida.

Blus, L. J. 2011. DDT, DDE, and DDD in birds. Pages 425–444 *in* W. N. Beyer and J. P. Meador, editors. Environmental contaminants in biota: Interpreting tissue concentrations, 2nd edition. CRC Press/Taylor and Francis, Boca Raton, Florida.

Bodaly, R. A., and R. J. P. Fudge. 1999. Uptake of mercury by fish in an experimental boreal reservoir. Archives of Environmental Contamination and Toxicology 37:103–109.

Bodaly, R. A., J. W. M. Rudd, R. J. P. Fudge, and C. A. Kelly. 1993. Mercury concentrations in fish related to size of remote Canadian Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences 50:980–987.

Borum, D., M. K. Manibusan, R. Schoeny, and E. L. Winchester. 2001. Water quality criterion for the protection of human health: Methylmercury. U.S. Environmental Protection Agency Report EPA-823-R-01-001, Office of Water, Washington, D.C.

Bowerman, W. W., J. P. Giesy, D. A. Best, and V. J. Kramer. 1995. A review of factors affecting productivity of bald eagles in the Great Lakes region: Implications for recovery. Environmental Health Perspectives 103(Suppl. 4):51–59.

Bradley, P. M., C. A. Journey, M. E. Brigham, D. A. Burns, D. T. Button, and K. Riva-Murray. 2013. Intra- and inter-basin mercury comparisons: Importance of basin scale and time-weighted methylmercury estimates. Environmental Pollution 172:42–52.

Branfireun, B. A., D. P. Krabbenhoft, H. Hintelmann, R. J. Hunt, J. P. Hurley, and J. W. M. Rudd. 2005. Speciation and transport of newly deposited mercury in a boreal forest wetland: A stable mercury isotope approach. Water Resources Research 41:W06016, doi:10.1029/2004WR003219.

Breivik, K., F. Wania, D. C. G. Muir, M. Alaee, S. Backus, and G. Pacepavicius. 2006. Empirical and modeling evidence of the long-range atmospheric transport of decabromodiphenyl ether. Environmental Science and Technology 40:4612–4618.

Brigham, M. E., D. A. Wentz, G. R. Aiken, and D. P. Krabbenhoft. 2009. Mercury cycling in stream ecosystems. 1. Water column chemistry and transport. Environmental Science and Technology 43:2720–2725.

Brigham M. E., M. B. Sandheinrich, D. A. Gay, R. P. Maki, D. P. Krabbenhoft, and J. G. Wiener. 2014. Lacustrine responses to decreasing wet mercury deposition rates—Results from a case study in northern Minnesota. Environmental Science and Technology 48:6115–6123.

Burgess, N. M., and M. W. Meyer. 2008. Methylmercury exposure associated with reduced productivity in common loons. Ecotoxicology 17:83–91.

Bursian, S. J., J. Kern, R. E. Remington, J. E. Link, and S. D. Fitzgerald. 2013. Dietary exposure of mink (*Mustela vison*) to fish from the upper Hudson River, New York, USA: Effects on reproduction and offspring growth and mortality. Environmental Toxicology and Chemistry 32:780–793.

Calafat, A. M., Z. Kuklenyik, J. A. Reidy, S. P. Caudill, J. S. Tully, and L. L. Needham. 2007. Serum concentrations of 11 polyfluoroalkyl compounds in the U.S. population: Data from the National Health and Nutrition Examination Survey (NHANES) 1999–2000. Environmental Science and Technology 41:2237–2242.

Callister S. M., and M. R. Winfrey. 1986. Microbial methylation of mercury in Upper Wisconsin River sediments. Water, Air, and Soil Pollution 29:453–465.

Carpenter, D. O. 2006. Polychlorinated biphenyls (PCBs): Routes of exposure and effects on human health. Reviews in Environmental Health 21:1–23.

Chadwick, E. A., V. R. Simpson, A. E. L. Nicholls, and F. M. Slater. 2011. Lead levels in Eurasian otters decline with time and reveal interactions between sources, prevailing weather, and stream chemistry. Environmental Science and Technology 45:1911–1916.

Chasar, L. C., B. C. Scudder, A. R. Stewart, A. H. Bell, and G. R. Aiken. 2009. Mercury cycling in stream ecosystems. 3. Trophic dynamics and methylmercury bioaccumulation. Environmental Science and Technology 43:2733–2739.

Chen, C. Y., and C. L. Folt. 2005. High plankton densities reduce mercury biomagnification. Environmental Science and Technology 39:115–121.

Chen, C., N. Kamman, J. Williams, D. Bugge, V. Taylor, B. Jackson, and E. Miller. 2012. Spatial and temporal variation in mercury bioaccumulation by zooplankton in Lake Champlain (North America). Environmental Pollution 161:343–349.

Chen. D., P. Martin, N. M. Burgess, L. Champoux, J. E. Elliott, D. J. Forsyth, A. Idrissi, and R. J. Letcher. 2013. European starlings (*Sturnus vulgaris*) suggest that landfills are an important source of bioaccumulative flame retardants to Canadian terrestrial ecosystems. Environmental Science and Technology 47:12238–12247.

Choy, E. S., P. V. Hodson, L. M. Campbell, A. R. Fowlie, and J. Ridal. 2008. Spatial and temporal trends of mercury concentrations in young-of-the-year spottail shiners (*Notropis hudsonius*) in the St. Lawrence River at Cornwall, ON. Archives of Environmental Contamination and Toxicology 54:473–481.

Chumchal, M. M., and R. W. Drenner. 2015. An environmental problem hidden in plain sight? Small human-made ponds, emergent insects, and mercury contamination of biota in the Great Plains. Environmental Toxicology and Chemistry 34:1197–1205.

Clarkson, T. W., and L. Magos. 2006. The toxicology of mercury and its chemical compounds. Critical Reviews in Toxicology 36:609–662.

Colborn, T., F. S. vom Saal, and A. M. Soto. 1993. Developmental effects of endocrine disrupting chemicals in wildlife and humans. Environmental Health Perspectives 101:378–384.

Colby, P. J., R. E. McNicol, and R. A. Ryder. 1979. Synopsis of biological data on the walleye *Stizostedion vitreum vitreum* (Mitchill 1818). Food and Agriculture Organization of the United Nations, FAO Fisheries Synopsis No. 119. Rome, Italy.

Colombo, M. J., J. Ha, J. R. Reinfelder, T. Barkay, and N. Yee. 2013. Anaerobic oxidation of Hg(0) and methylmercury formation by *Desulfovibrio desulfuricans* ND132. Geochimica Cosmochimica Acta 112:166–177.

Conder, J. M., R. A. Hoke, W. De Wolf, M. H. Russell, and R. C. Buck. 2008. Are PFCAs bioaccumulative? A critical review and comparison with regulatory criteria and persistent lipophilic compounds. Environmental Science and Technology 42:995–1003.

Corbet, P. S. 1999. Dragonflies: Behavior and Ecology of Odonata. Comstock Publishing Associates, Ithaca, New York.

Crump, K. L., and V. L. Trudeau. 2009. Mercury-induced reproductive impairment in fish. Environmental Toxicology and Chemistry 28:895–907.

Custer, C. M., T. W. Custer, P. M. Dummer, M. A. Etterson, W. E. Thogmartin, Q. Wu, K. Kannan, A. Trowbridge, and P. C. McKann. 2014. Exposure and effects of perfluoroalkyl substances in tree swallows nesting in Minnesota and Wisconsin, USA. Archives of Environmental Contamination and Toxicology 66:120–138.

Davis, W. J. 1982. Territory size in *Megaceryle alcyon* along a stream habitat. Auk 99:353–362.

Delinsky, A. D., M. J. Strynar, S. F. Nakayama, J. L. Varns, X. Ye, P. J. McCann, and A. B. Lindstrom. 2009. Determination of ten perfluorinated compounds in bluegill sunfish (*Lepomis macrochirus*) fillets. Environmental Research 109:975–984.

Delinsky, A. D., M. J. Strynar, P. J. McCann, J. L. Varns, L. McMillan, S. F. Nakayama, and A. B. Lindstrom. 2010. Geographical distribution of perfluorinated compounds in fish from Minnesota lakes and rivers. Environmental Science and Technology 44:2549–2554.

Depew, D. C., N. Basu, N. M. Burgess, L. M. Campbell, E. W. Devlin, P. E. Drevnick, C. R. Hammerschmidt, C. A. Murphy, M. B. Sandheinrich, and J. G. Wiener. 2012a. Toxicity of dietary methylmercury to fish: Derivation of ecologically meaningful threshold concentrations. Environmental Toxicology and Chemistry 31:1536–1547.

Depew, D. C., N. Basu, N. M. Burgess, L. M. Campbell, D. C. Evers, K. A. Grasman, and A. M. Scheuhammer. 2012b. Derivation of screening benchmarks for dietary methylmercury exposure for the common loon (*Gavia immer*): Rationale for use in ecological risk assessment. Environmental Toxicology and Chemistry 31:2399–2407.

Depew, D. C., N. M. Burgess, and L. M. Campbell. 2013. Spatial patterns of methylmercury risks to common loons and piscivorous fish in Canada. Environmental Science and Technology 47:13093–13103.

DeVries, D. R., and R. V. Frie. 1996. Determination of age and growth. Pages 483–512 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Dillon, T., N. Beckvar, and J. Kern. 2010. Residue-based mercury dose-response in fish: An analysis using lethality-equivalent test endpoints. Environmental Toxicology and Chemistry 29:2559–2565.

Drenner, R. W., M. M. Chumchal, C. M. Jones, M. B. Lehmann, D. A. Gay, and D. I. Donato. 2013. Effects of mercury deposition and coniferous forests on the mercury contamination of fish in the south central United States. Environmental Science and Technology 47:1274–1279.

Drevnick, P. E., D. R. Engstrom, C.T. Driscoll, E. B. Swain, S. J. Balogh, N. C. Kamman, D. T. Long, D. G. C. Muir, M. J. Parsons, K. R. Rolfhus, and R. Rossmann. 2012. Spatial and temporal patterns of mercury accumulation in lacustrine sediments across the Laurentian Great Lakes region. Environmental Pollution 161:252–260.

Dreyer, A., I. Weinber, C. Temme, and R. Ebinghuas. 2009. Polyfluorinated compounds in the atmosphere of the Atlantic and Southern Oceans: Evidence for global distribution. Environmental Science and Technology 43:6507–6514.

Driscoll, C. T., R. P. Mason, H. M. Chan, D. J. Jacob, and N. Pirrone. 2013. Mercury as a global pollutant: Sources, pathways, and effects. Environmental Science and Technology 47:4967–4983.

Drysdale, C., N. M. Burgess, A. d'Entremont, J. Carter, and G. Brun. 2005. Mercury in brook trout, white perch and yellow perch in Kejimkujik National Park and National Historic Site. Pages 321–346 *in* A. N. Rencz, N. J. O'Driscoll, and D. R. S. Lean, editors, Mercury cycling in a wetland dominated ecosystem: A multidisciplinary study. SETAC Press, Pensacola, Florida.

Dunlap, C. E., C. N. Alpers, R. Bouse, H. E. Taylor, D. M. Unruh, and A. R. Flegal. 2008. The persistence of lead from past gasoline emissions and mining drainage in a large riparian system: Evidence from lead isotopes in the Sacramento River, California. Geochimica et Cosmochimica Acta 72:5935–5948.

Dykstra, C. R., W. T. Route, M. W. Meyer, and P. W. Rasmussen. 2010. Contaminant concentrations in bald eagles nesting on Lake Superior, the upper Mississippi River, and the St. Croix River. Journal of Great Lakes Research 36:561–569.

Eagles-Smith, C. A., G. Herring, B. L. Johnson, and R. Graw. 2013. Mercury bioaccumulation in fishes from subalpine lakes of the Wallowa-Whitman National Forest, northeastern Oregon and western Idaho. U.S. Geological Survey Open-File Report 2013-1148.

Eilers, J. M., D. F. Brakke, and D. H. Landers. 1988. Chemical and physical characteristics of lakes in the upper Midwest, United States. Environmental Science and Technology 22:164–172.

Elias, J. E., and R. A. Damstra. 2011. Monitoring water quality of inland lakes, Great Lakes Network, 2009 and 2010: Data summary report. Natural Resource Data Series NPS/GLKN/NRDS—2011/163. National Park Service, Fort Collins, Colorado.

Elias, J. E., and R. A. Damstra. 2012. Monitoring water quality of inland lakes, Great Lakes Network, 2011: Data summary report. Natural Resource Data Series NPS/GLKN/NRDS—2012/363. National Park Service, Fort Collins, Colorado.

Eng, M. L., T. D. Williams, R. J. Letcher, and J. E. Elliott. 2014. Assessment of concentrations and effects of organohalogen contaminants in a terrestrial passerine, the European starling. Science of the Total Environment 473-474:589–596.

Engstrom, D. R., S. J. Balogh, and E. B. Swain. 2007. History of mercury inputs to Minnesota lakes: Influences of watershed disturbance and localized atmospheric deposition. Limnology and Oceanography 52:2467–2483.

Evers, D. C., N. M. Burgess, L. Champoux, B. Hoskins, A. Major, W. M. Goodale, R. J. Taylor, R. Poppenga, and T. Daigle. 2005. Patterns and interpretation of mercury exposure in freshwater avian communities in northeastern North America. Ecotoxicology 14:193–221.

Evers, D. C., J. G. Wiener, N. Basu, R. A. Bodaly, H. A. Morrison, and K. A. Williams. 2011a. Mercury in the Great Lakes region: Bioaccumulation, spatiotemporal patterns, ecological risks, and policy. Ecotoxicology 20:1487–1499.

Evers, D. C., J. G. Wiener, C. T. Driscoll, D. A. Gay, N. Basu, B. A. Monson, K. F. Lambert, H. A. Morrison, J. T. Morgan, K. A. Williams, and A. G. Soehl. 2011b. Great Lakes Mercury connections: The extent and effects of mercury pollution in the Great Lakes region. Biodiversity Research Institute Report BRI 2011-18, Gorham, Maine.

Faber-Langendoen, D., N. Aaseng, K. Hop, and M. Lew-Smith. 2007. Field Guide to the Plant Community Types of Voyageurs National Park. U.S. Geological Survey Techniques and Methods 2–A4. U.S. Geological Survey, Reston, Virginia.

Fang, S., X. Chen, S. Zhao, Y. Zhang, W. Jiang, L. Yang, and L. Zhu. 2014. Trophic magnification and isomer fractionation of perfluoroalkyl substances in the food web of Taihu Lake, China. Environmental Science and Technology 48:2173–2182.

Franson, J. C., and D. J. Pain. 2011. Lead in birds. Pages 563–593 *in* W. N. Beyer and J. P. Meador, editors. Environmental contaminants in biota: Interpreting tissue concentrations, 2nd edition. CRC Press/Taylor and Francis, Boca Raton, Florida.

Franson, J. C., and R. E. Russell. 2014. Lead and eagles: Demographic and pathological characteristics of poisoning, and exposure levels associated with other causes of mortality. Ecotoxicology 23:1722–1731.

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and J. Wickham. 2011. Completion of the 2006 National Land Cover Database for the conterminous United States. Photogrammetric Engineering and Remote Sensing 77:858–864.

Fujii, Y., T. Sakurada, K. H. Harada, A. Koizumi, O. Kimura, T. Endo, and K. Haraguchi. 2015. Long-chain perfluoroalkyl carboxylic acids in Pacific cods from coastal areas in northern Japan: A major source of human dietary exposure. Environmental Pollution 199:35–41.

Fullhart, H. G., B. G. Parsons, D. W. Willis, and J. R. Reed. 2002. Yellow perch piscivory and its possible role in structuring littoral zone fish communities in small Minnesota lakes. Journal of Freshwater Ecology 17:37–43.

Gann, G. L., C. H. Powell, M. M. Chumchal, and R. W. Drenner. 2015. Hg-contaminated terrestrial spiders pose a potential risk to songbirds at Caddo Lake (Texas/Louisiana, USA). Environmental Toxicology and Chemistry 34:303–306.

Garris, H. W., R. J. Mitchell, L. H. Fraser, and L. R. Barrett. 2015. Forecasting climate change impacts on the distribution of wetland habitat in the Midwestern United States. Global Change Biology 21:766–776.

Garza, E. L., M. B. Nevers, and R. L. Whitman. 2002. Ecological characterization of Long Lake, Porter and Lake counties, Indiana. U.S. Geological Survey Report, Lake Michigan Ecological Research Station, Porter, Indiana.

Gauthier, L. T., C. E. Hebert, D. V. C. Weseloh, and R. J. Letcher. 2008. Dramatic changes in the temporal trends of polybrominated diphenyl ethers (PBDEs) in herring gull eggs from the Laurentian Great Lakes: 1982–2006. Environmental Science and Technology 42:1524–1530.

Gewurtz, S. B., A. O. De Silva, S. M. Backus, D. J. McGoldrick, M. J. Keir, J. Small, L. Melymuk, and D. C. G. Muir. 2012. Perfluoroalkyl contaminants in Lake Ontario lake trout: Detailed examination of current status and long-term trends. Environmental Science and Technology 46:5842–5850.

Giesy, J. P., and K. Kannan. 2001. Global distribution of perfluorooctane sulfonate in wildlife. Environmental Science and Technology 35:1339–1342.

Gilchrist, T. T., R. J. Letcher, P. Thomas, and K. J. Fernie. 2014. Polybrominated diphenyl ethers and multiple stressors influence the reproduction of free-ranging tree swallows (*Tachycineta bicolor*) nesting at wastewater treatment plants. Science of the Total Environment 472:63–71.

Gilmour, C. C., M. Podar, A. L. Bullock, A. M. Graham, S. D. Brown, A. C. Somenahally, A. Johs, R. A. Hurt, Jr., K. L. Bailey, and D. A. Elias. 2013. Mercury methylation by novel microorganisms from new environments. Environmental Science and Technology 47:11810–11820.

Gorman, O., L. Kallemeyn, and R. Maki. 2014. Biogeographic patterns of inland lake fish communities at Isle Royale, Voyageurs, and Sleeping Bear Dunes national park units. Natural Resource Technical Report NPS/GLKN/NRTR—2014/893. National Park Service, Fort Collins, Colorado.

Graeb, B. D. S., M. T. Mangan, J. C. Jolley, D. H. Wahl, and J. M. Dettmers. 2006. Ontogenetic changes in prey preference and foraging ability of yellow perch: Insights based on relative energetic return of prey. Transactions of the American Fisheries Society 135:1493–1498.

Gratz, L. E., G. J. Keeler, F. J. Marsik, J. A. Barres, and J. T. Dvonch. 2013. Atmospheric transport of speciated mercury across southern Lake Michigan: Influence from emission sources in the Chicago/Gary urban area. Science of the Total Environment 448:84–95.

Great Lakes Fish Advisory Workgroup. 2007. A protocol for mercury-based fish consumption advice: An addendum to the 1993 protocol for a uniform Great Lakes sport fish consumption advisory. Wisconsin Department of Health Services, Madison, Wisconsin. Available from http://www.dhs.wisconsin.gov/eh/fish/FishFS/2007Hg_Add_Final_05_07.pdf (accessed 16 March 2011).

Greenfield, B. K., and A. Jahn. 2010. Mercury in San Francisco Bay forage fish. Environmental Pollution 158:2716–2724.

Grieb, T. M., C. T. Driscoll, S. P. Gloss, C. L. Schofield, G. L. Bowie, and D. B. Porcella. 1990. Factors affecting mercury accumulation in fish in the upper Michigan peninsula. Environmental Toxicology and Chemistry 9:919–930.

Grier, J. W. 1982. Ban of DDT and subsequent recovery of reproduction in bald eagles. Science 218:1232–1235.

Hale, R. C., M. J. La Guardia, E. Harvey, M. O. Gaylor, and T. M. Mainor. 2006. Brominated flame retardant concentrations and trends in abiotic media. Chemosphere 64:181–186.

Hammerschmidt, C. R., and W. F. Fitzgerald. 2005. Methylmercury in mosquitoes related to atmospheric mercury deposition and contamination. Environmental Science and Technology 39:3034–3039.

Hammerschmidt, C. R., J. G. Wiener, B. E. Frazier, and R. G. Rada. 1999. Methylmercury content of eggs in yellow perch related to maternal exposure in four Wisconsin lakes. Environmental Science and Technology 33:999–1003.

Hansen, L. G. 1987. Environmental toxicology of polychlorinated biphenyls. Pages 15–48 *in* S. Safe, editor. Polychlorinated biphenyls (PCBs): Mammalian and environmental toxicology. Environmental Toxin Series 1, Springer-Verlag, Berlin, Germany.

Haro, R. J. 2014. All along the watchtower: Larval dragonflies are promising biological sentinels for monitoring methylmercury contamination. Park Science 31:70–73.

Haro, R. J., S. W. Bailey, R. M. Northwick, K. R. Rolfhus, M. B. Sandheinrich, and J. G. Wiener. 2013. Burrowing dragonfly larvae as biosentinels of methylmercury in freshwater food webs. Environmental Science and Technology 47:8148–8156.

Harris, R. C., J. W. M. Rudd, M. Amyot, C. L. Babiarz, K. G. Beaty, P. J. Blanchfield, R. A. Bodaly, B. A. Branfireun, C. C. Gilmour, J. A. Graydon, A. Heyes, H. Hintelmann, J. P. Hurley, C. A. Kelly, D. P. Krabbenhoft, S. E. Lindberg, R. P. Mason, M. J. Paterson, C. L. Podemski, A. Robinson, K. A. Sandilands, G. R. Southworth, V. L. St. Louis, and M. T. Tate. 2007. Whole-ecosystem study shows rapid fish-mercury response to changes in mercury deposition. Proceedings of the National Academy of Sciences (USA) 104:16586–16591.

Heinz, G. H., D. J. Hoffman, J. D. Klimstra, and K. R. Stebbins. 2009a. Rapid increases in mercury concentrations in the eggs of mallards fed methylmercury. Environmental Toxicology and Chemistry 28:1979–1981.

Heinz, G. H., D. J. Hoffman, J. D. Klimstra, K. R. Stebbins, S. L. Kondrad, and C. A. Erwin. 2009b. Species differences in the sensitivity of avian embryos to methylmercury. Archives of Environmental Contamination and Toxicology 56:129–138.

Henny, C. J. 2003. Effects of mining lead on birds: A case history at Coeur d'Alene Basin, Idaho. Pages 755–766 *in* D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr., and J. Cairns, Jr., editors, Handbook of ecotoxicology, 2nd edition, CRC Press, Boca Raton, Florida.

Henny, C. J., J. L. Kaiser, and R. A. Grove. 2009. PCDDs, PCDFs, PCBs, OC pesticides and mercury in fish and osprey eggs from Willamette River, Oregon (1993, 2001 and 2006) with calculated biomagnification factors. Ecotoxicology 18:151–173.

Heyes, A., R. P. Mason, E. H. Kim, and E. Sunderland. 2006. Mercury methylation in estuaries: Insights from using measuring rates using stable mercury isotopes. Marine Chemistry 102:134–147.

Hilsenhoff, W. L. 1995. Aquatic Insects of Wisconsin. Keys to Wisconsin Genera and Notes on Biology, Habitat, Distribution and Species. Publication Number 3 (G3648), Natural History Museum Contributions, University of Wisconsin-Madison, Madison, Wisconsin.

Hodson, P. V. 1986. The effects on aquatic biota of exposure to lead. Pages 203–224 *in* P. M. Stokes, editor. Pathways, cycling and transformation of lead in the environment. Royal Society of Canada, Commission on Lead in the Environment, Toronto, Ontario.

Hodson, P. V., D. G. Dixon, D. J. Spry, D. M. Whittle, and J. B. Sprague. 1982. Effect of growth rate and size of fish on rate of intoxication by waterborne lead. Canadian Journal of Fisheries and Aquatic Sciences 39:1243–1251.

Holzer, J., T. Goen, P. Just, R. Reupert, K. Rauchfuss, M. Kraft, J. Muller, and M. Wilhelm. 2011. Perfluorinated compounds in fish and blood of anglers at Lake Möhne, Sauerland area, Germany. Environmental Science and Technology 45:8046–8052.

Houde, M., J. W. Martin, R. J. Letcher, K. R. Solomon, and D. C. G. Muir. 2006. Biological monitoring of polyfluoroalkyl substances: A review. Environmental Science and Technology 40:3463–3473.

Houde, M., D. C. G. Muir, K. A. Kidd, S. Guildford, K. Drouillard, M. S. Evans, X. Wang, D. M. Whittle, D. Haffner, and H. Kling. 2008. Influence of lake characteristics on the biomagnification of persistent organic pollutants in lake trout food webs. Environmental Toxicology and Chemistry 27:2169–2178.

Houde, M., A. O. De Silva, D. C. G. Muir, and R. J. Letcher. 2011. Monitoring of perfluorinated compounds in aquatic biota: An updated review. Environmental Science and Technology 45:7962–7973.

Hurley, J. P., J. M. Benoit, C. L. Babiarz, M. M. Shafer, A. W. Andren, J. R. Sullivan, R. Hammond, and D. A. Webb. 1995. Influences of watershed characteristics on mercury levels in Wisconsin rivers. Environmental Science and Technology 29:1867–1875.

Jackson, A. K., D. C. Evers, E. Adams, D. Cristol, C. Eagles-Smith, S. Edmonds, C. Gray, B. Hoskins, O. Lane, A. Sauer, and T. Tear. 2015. Songbirds as sentinels of mercury in terrestrial habitats of eastern North America. Ecotoxicology 24:453–467.

Jeremiason, J. D., T. K. Reiser, R. A. Weitz, M. E. Berndt, and G. R. Aiken. 2016. Aeshnid dragonfly larvae as bioindicators of methylmercury contamination in aquatic systems impacted by elevated sulfate loading. Ecotoxicology 25:456–468.

Ji, K., Y. Kim, S. Oh, B. Ahn, H. Jo, and K. Choi. 2008. Toxicity of perfluorooctane sulfonic acid and perfluorooctanoic acid on freshwater macroinvertebrates (*Daphnia magna* and *Moina macrocopa*) and fish (*Oryzias latipes*). Environmental Toxicology and Chemistry 27:2159–2168.

Johnson, C. K., T. R. Kelly, and B. A. Rideout. 2013. Lead in ammunition: A persistent threat to health and conservation. EcoHealth 10:455–464.

Johnson, R. K., T. Wiederholm, and D. M. Rosenberg. 1993. Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates. Pages 40–158 *in* D. M. Rosenberg and V. H. Resh, editors. Freshwater biomonitoring and benthic macroinvertebrates, Springer, London, United Kingdom.

Kallemeyn, L. 2000. A comparison of fish communities from 32 inland lakes in Isle Royale National Park, 1929 and 1995–1997. U.S. Geological Survey, Biological Science Report 0004, National Technical Information Service, Springfield, Virginia.

Kallemeyn, L. W., K. L. Holmberg, J. A. Perry, and B. Y. Odde. 2003. Aquatic synthesis for Voyageurs National Park. U.S. Geological Survey, Information and Technology Report USGS/BRD/ITR-2003-0001.

Keast, A. 1985. The piscivore feeding guild of fishes in small freshwater ecosystems. Environmental Biology of Fishes 12:119–129.

Keast, A., and L. Welsh. 1968. Daily feeding periodicities, food uptake rates, and dietary changes with hour of day in some lake fishes. Journal of the Fisheries Research Board of Canada 25:1133–1144.

Keller, W., A. M. Paterson, K. M. Somers, P. J. Dillon, J. Heneberry, and A. Ford. 2008. Relationships between dissolved organic carbon concentrations, weather, and acidification in small Boreal Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences 65:786–795.

Kelly, J. F., E. S. Bridge, and M. J. Hamas. 2009. Belted kingfisher (*Megaceryle alcyon*). *In* A. Poole, editor. The birds of North America online. Cornell Lab of Ornithology, Ithaca, New York. Available from http://bna.birds.cornell.edu/bna/species/084 (accessed 17 July 2014).

Kenow, K. P., M. W. Meyer, R. Rossmann, A. Gendron-Fitzpatrick, and B. R. Gray. 2011. Effects of injected methylmercury on the hatching of common loon (*Gavia immer*) eggs. Ecotoxicology 20:1684–1693.

Kidd, K. A., H. A. Bootsma, R. H. Hesslein, D. C. G. Muir, and R. E. Hecky. 2001. Biomagnification of DDT through the benthic and pelagic food webs of Lake Malawi, east Africa: Importance of trophic level and carbon source. Environmental Science and Technology 35:14–20.

Kimbrough, R. D. 1987. Human health effects of polychlorinated biphenyls (PCBs) and polybrominated biphenyls (PBBs). Annual Review of Pharmacology and Toxicology 27:87–111.

Klasing, S., and R. K. Brodberg. 2008. Development of fish contaminant goals and advisory tissue levels for common contaminants in California sport fish: Chlordane, DDTs, dieldrin, methylmercury, PCBs, selenium, and toxaphene. Office of Environmental Health Hazard Assessment. Sacramento, California. Available from http://oehha.ca.gov/fish/gtlsv/pdf/FCGsATLs27June2008.pdf (accessed 25 January 2016).

Klasing, S., and R. Brodberg. 2011. Development of fish contaminant goals and advisory tissue levels for common contaminants in California sport fish: Polybrominated diphenyl ethers (PBDEs). Office of Environmental Health Hazard Assessment, Oakland, California. Available from http://oehha.ca.gov/fish/gtlsv/pdf/PBDEs052311.pdf (accessed 21 January 2016).

Kong, D., M. MacLeod, H. Hung, and I. T. Cousins. 2014. Statistical analysis of long-term monitoring data for persistent organic pollutants in the atmosphere at 20 monitoring stations broadly indicates declining concentrations. Environmental Science and Technology 48:12492–12499.

Krabbenhoft, D., D. Engstrom, C. Gilmour, R. Harris, J. Hurley, and R. Mason. 2007. Monitoring and evaluating trends in sediment and water indicators. Pages 47–86 *in* R. Harris, D. P. Krabbenhoft, R. Mason, M. W. Murray, R. Reash, and T. Saltman, editors. Ecosystem responses to mercury contamination: Indicators of change. CRC Press/Taylor and Francis, Boca Raton, Florida.

Kraft, G. J., D. J. Mechenich, C. Mechenich, J. E. Cook, and S. M. Seiler. 2010. Assessment of natural resource conditions: Isle Royale National Park. Natural Resource Report NPS/NRPC/WRD/NRR—2010/237. National Park Service, Fort Collins, Colorado.

Kraft, G. J., D. J. Mechenich, C. Mechenich, M. D. Waterhouse, J. McNelly, J. Dimick, and J. Cook. 2014. Natural resource condition assessment: Grand Portage National Monument. Natural Resource Report NPS/GRPO/NRR—2014/783. National Park Service, Fort Collins, Colorado.

Lafrancois, B. M., and J. Glase. 2005. Aquatic studies in national parks of the upper Great Lakes States: Past efforts and future directions. National Park Service, Water Resources Division Technical Report NPS/NRWRD/NRTR-2005/334, Denver, Colorado. Available from http://science.nature.nps.gov/im/units/GLKN/monitorreportpubs.cfm (accessed 16 January 2012).

La Guardia, M. J., R. C. Hale, and E. Harvey. 2006. Detailed polybrominated diphenyl ether (PBDE) congener composition of the widely used penta-, octa-, and deca-PBDE technical flame-retardant mixtures. Environmental Science and Technology 40:6247–6254.

Lau, C., K. Anitole, C. Hodes, D. Lai, A. Pfahles-Hutchens, and J. Seed. 2007. Perfluoroalkyl acids: A review of monitoring and toxicological findings. Toxicological Sciences 99:366–394.

Law, K., T. Halldorson, R. Danell, G. Stern, S. Gewurtz, M. Alaee, C. Marvin, M. Whittle, and G. Tomy. 2006. Bioaccumulation and trophic transfer of some brominated flame retardants in Lake Winnipeg (Canada) food web. Environmental Toxicology and Chemistry 25:2177–2186.

Lazorchak, J. M., F. H. McCormick, T. R. Henry, and A. T. Herlihy. 2003. Contamination of fish in streams of the mid-Atlantic region: An approach to regional indicator selection and wildlife assessment. Environmental Toxicology and Chemistry 22:545–553.

Leonards, P. E. G., T. H. de Vries, W. Minnaard, S. Stuijfzand, P. de Voogt, W. P. Cofino, N. M. van Straalen, and B. van Hattum. 1995. Assessment of experimental data on PCB-induced reproduction inhibition in mink, based on an isomer- and congener-specific approach using 2,3,7,8-tetrachlorodibenzo-p-dioxin toxic equivalency. Environmental Toxicology and Chemistry 14:639–652.

Lepak, R. F., R. Yin, D. P. Krabbenhoft, J. M. Ogorek, J. F. DeWild, T. M. Holsen, and J. P. Hurley. 2015. Use of stable isotope signatures to determine mercury sources in the Great Lakes. Environmental Science and Technology Letters 2:335–341.

Letcher, R. J., G. Su, J. N. Moore, L. L. Williams, P. A. Martin, S. R. de Solla, and W. W. Bowerman. 2015. Perfluorinated sulfonate and carboxylate compounds and precursors in herring gull eggs from across the Laurentian Great Lakes of North America: Temporal and recent spatial comparisons and exposure implications. Science of the Total Environment 538:468–477.

Liao, H., C. L. Pierce, and J. G. Larscheid. 2002. Diet dynamics of the adult piscivorous fish community in Spirit Lake, Iowa, USA 1995–1997. Ecology of Freshwater Fish 11:178–189.

Lind, Y., A. Bignert, and T. Odsjö. 2006. Decreasing lead levels in Swedish biota revealed by 36 years (1969–2004) of environmental monitoring. Journal of Environmental Monitoring 8:824–834.

Lindstrom, A. B., M. J. Strynar, and E. L. Libelo. 2011. Polyfluorinated compounds: Past, present, and future. Environmental Science and Technology 45:7954–7961.

Lucia, M., N. Verboven, H. Strøm, C. Miljeteig, M. V. Gavrilo, B. M. Braune, D. Boertmann, and G. W. Gabrielsen. 2015. Circumpolar contamination in eggs of the high-arctic ivory gull *Pagophila eburnean*. Environmental Toxicology and Chemistry 34:1552–1561.

Lyche, J. L., C. Rosseland, G. Berge, and A. Polder. 2015. Human health risk associated with brominated flame-retardants (BFRs). Environment International 74:170–180.

Ma, W. C. 2011. Lead in mammals. Pages 595–607 *in* W. N. Beyer and J. P. Meador, editors. Environmental contaminants in biota: Interpreting tissue concentrations, 2nd edition. CRC Press/Taylor and Francis, Boca Raton, Florida.

Ma, Y., A. Salamova, M. Venier, and R. A. Hites. 2013. Has the phase-out of PBDEs affected their atmospheric levels? Trends of PBDEs and their replacements in the Great Lakes atmosphere. Environmental Science and Technology 47:11457–11464.

Magnuson J. J., D. M. Robertson, B. J. Benson, R. H. Wynne, D. M. Livingstone, T. Arai, R. A. Assel, R. G. Barry, V. Card, E. Kuusisto, N. G. Granin, T. D. Prowse, K. M. Stewart, and V. S. Vuglinski. 2000. Historical trends in lake and river ice cover in the northern hemisphere. Science 289:1743–1746.

Mahler, B. J., P. C. Van Metre, and E. Callender. 2006. Trends in metals in urban and reference lake sediments across the United States, 1970 to 2001. Environmental Toxicology and Chemistry 25:1698–1709.

Mallakpour, I., and G. Villarini. 2015. The changing nature of flooding across the central United States. Nature Climate Change 5:250–254.

McElroy, A. E., M. G. Barron, N. Beckvar, S. B. Kane Driscoll, J. P. Meador, T. F. Parkerton, T. G. Preuss, and J. A. Steevens. 2011. A review of the tissue residue approach for organic and organometallic compounds in aquatic organisms. Integrated Environmental Assessment and Management 7:50–74.

McKelvey, W., and E. Oken. 2012. Mercury and public health: An assessment of human exposure. Pages 267–287 *in* M. S. Bank, editor. Mercury in the environment: Pattern and process. University of California Press, Berkeley, California.

Mechenich, C., D. J. Mechenich, S. W. Szczytko, J. E. Cook, and G. J. Kraft. 2009. Assessment of natural resource conditions: Sleeping Bear Dunes National Lakeshore. Natural Resource Report NPS/NRPC/WRD/NRR—2009/097. National Park Service, Fort Collins, Colorado.

Melymuk, L., M. Robson, S. A. Csiszar, P. A. Helm, G. Kaltenecker, S. Backus, L. Bradley, B. Gilbert, P. Blanchard, L. Jantunen, and M. L. Diamond. 2014. From the city to the lake: Loadings of PCBs, PBDEs, PAHs and PCMs from Toronto to Lake Ontario. Environmental Science and Technology 48:3732–3741.

Mergler, D., H. A. Anderson, L. H. M. Chan, K. R. Mahaffey, M. Murray, M. Sakamoto, and A. H. Stern. 2007. Methylmercury exposure and health effects in humans: A worldwide concern. Ambio 36:3–11.

Merrill, E. H., J. J. Hartigan, and M. W. Meyer. 2005. Does prey biomass or mercury exposure affect loon chick survival in Wisconsin? Journal of Wildlife Management 69:57–67.

MN DNR (Minnesota Department of Natural Resources). 2006. Tomorrow's habitat for the wild and rare: An action plan for Minnesota wildlife. Comprehensive Wildlife Conservation Strategy, North Shore Highlands Subsection Profile, Minnesota Department of Natural Resources, Division of Ecological Services, St. Paul, Minnesota.

Monahan, W. B., and N. A. Fisichelli. 2014. Climate exposure of US national parks in a new era of change. PLoS ONE 9(7): e101302. doi:10.1371/journal.pone.0101302.

Monson, B. A., D. F. Staples, S. P. Bhavsar, T. M. Holsen, C. S. Schrank, S. K. Moses, D. J. McGoldrick, S. M. Backus, and K. A. Williams. 2011. Spatiotemporal trends of mercury in walleye and largemouth bass from the Laurentian Great Lakes region. Ecotoxicology 20:1555–1567.

Mora, M. A., B. Durgin, L. B. Hudson, and E. Jones. 2016. Temporal and latitudinal trends of p,p'-DDE in eggs and carcass of North American birds from 1980 to 2005. Environmental Toxicology and Chemistry 35:1340–1348.

Munthe, J., R. A. Bodaly, B. A. Branfireun, C. T. Driscoll, C. C. Gilmour, R. Harris, M. Horvat, M. Lucotte, and O. Malm. 2007. Recovery of mercury-contaminated fisheries. Ambio 36:33–44.

Needham, J. G., J. J. Westfall, Jr., and M. J. May. 2000. Dragonflies of North America, revised edition. Scientific Publications, Gainesville, Florida.

Nelson, J. S., E. J. Crossman, H. Espinosa-Pérez, L. T. Findley, C. R. Gilbert, R. N. Lea, and J. D. Williams. 2004. Common and Scientific Names of Fishes from the United States, Canada, and Mexico, 6th edition. American Fisheries Society, Special Publication 29, Bethesda, Maryland.

Newsted, J. L., P. D. Jones, K. Coady, and J. P. Giesy. 2005. Avian toxicity reference values for perfluorooctane sulfonate. Environmental Science and Technology 39:9357–9362.

Nriagu, J. O. 1990. The rise and fall of leaded gasoline. Science of the Total Environment 92:13–28.

Odsjö, T., and J. Sondell. 2014. Eggshell thinning of osprey (*Pandion haliaetus*) breeding in Sweden and its significance for egg breakage and breeding outcome. Science of the Total Environment 470-471:1023–1029.

Olson, M. L., L. B. Cleckner, J. P. Hurley, D. P. Krabbenhoft, and T.W. Heelan. 1997. Resolution of matrix effects on analysis of total and methyl mercury in aqueous samples from the Florida Everglades. Fresenius Journal of Analytical Chemistry 358:392–398.

Ontario Ministry of the Environment. 2013. Guide to eating Ontario sport fish, 2013–2014, 27th edition (revised). Public Information Centre, Toronto, Ontario. Available from https://www.ontario.ca/environment-and-energy/guide-eating-ontario-sport-fish (accessed 22 October 2014).

Orihel, D. M., M. J. Paterson, P. J. Blanchfield, R. A. Bodaly, and H. Hintelmann. 2007. Experimental evidence of a linear relationship between inorganic mercury loading and methylmercury accumulation by aquatic biota. Environmental Science and Technology 41:4952–4958.

Pan, C. G., J. L. Zhao, Y. S Liu, Q. Q. Zhang, Z. F. Chen, H. J. Lai, F. J. Peng, S. S. Liu, and G. G. Ying. 2014. Bioaccumulation and risk assessment of per- and polyfluoroalkyl substances in wild freshwater fish from rivers in the Pearl River Delta region, South China. Ecotoxicology and Environmental Safety 107:192–199.

Parks, J. M., A. Johs, M. Podar, R. Bridou, R. A. Hurt Jr, S. D. Smith, S. J. Tomanicek, Y. Qian, S. D. Brown, C. C. Brandt, A. V. Palumbo, J. C. Smith, J. D. Wall, D. A. Elias, and L. Liang. 2013. The genetic basis for bacterial mercury methylation. Science 339:1332–1335.

Paszkowski, C. A., and W. M. Tonn. 1994. Effects of prey size, abundance, and population structure on piscivory by yellow perch. Transactions of the American Fisheries Society 123:855–865.

Paterson, M. J., J. W. M. Rudd, and V. St. Louis. 1998. Increases in total and methylmercury in zooplankton following flooding of a peatland reservoir. Environmental Science and Technology 32:3868–3874.

Pattee, O. H., and D. J. Pain. 2003. Lead in the environment. Pages 373–408 *in* D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr., and J. Cairns, Jr., editors. Handbook of ecotoxicology, 2nd edition, CRC Press, Boca Raton, Florida.

Paul, A. G., K. C. Jones, and A. J. Sweetman. 2009. A first global production, emission, and environmental inventory for perfluorooctane sulfonate. Environmental Science and Technology 43:386–392.

Pérez-Fuentetaja, A., S. A. Mackintosh, L. R. Zimmerman, M. D. Clapsadl, M. Alaee, and D. S. Aga. 2015. Trophic transfer of flame retardants (PBDEs) in the food web of Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences 72:1886–1896.

Perroy, R. L., C. S. Belby, and C. J. Mertens. 2014. Mapping and modeling three dimensional lead contamination in the wetland sediments of a former trap-shooting range. Science of the Total Environment 487:72–81.

Pickhardt, P. C., M. Stepanova, and N. S. Fisher. 2006. Contrasting uptake routes and tissue distributions of inorganic and methylmercury in mosquitofish (*Gambusia affinis*) and redear sunfish (*Lepomis microlophus*). Environmental Toxicology and Chemistry 25:2132–2142.

Prevedouros, K., I. T. Cousins, R. C. Buck, and S. H. Korzeniowski. 2006. Sources, fate and transport of perfluorocarboxylates. Environmental Science and Technology 40:32–44.

Ramlal, P. S., C. A., Kelly, J. W. M. Rudd, and A. Furutani. 1993. Sites of methyl mercury production in remote Canadian Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences 50:972–979.

Rasmussen, P. W., C. Schrank, and M. C. W. Williams. 2014. Trends of PCB concentrations in Lake Michigan coho and Chinook salmon, 1975–2010. Journal of Great Lakes Research 40:748–754.

Rayne, S., M. G. Ikonomou, and B. Antcliffe. 2003. Rapidly increasing polybrominated diphenyl ether concentrations in the Columbia River system from 1992 to 2000. Environmental Science and Technology 36:2847–2854.

Redig, P. T., D.R. Smith, and L. Cruz-Martinez. 2009. Potential sources of lead exposure for bald eagles: A retrospective study. *In* R.T. Watson, M. Fuller, M. Pokras, and W.G. Hunt, editors. Ingestion of lead from spent ammunition: Implications for wildlife and humans, The Peregrine Fund, Boise, Idaho.

Renberg, I., M. L. Brännvall, R. Bindler, and O. Emteryd. 2000. Atmospheric lead pollution history during four millennia (2000 BC to 2000 AD) in Sweden. Ambio 29:150–156.

Rice, C. P., P. W. O'Keefe, and T. J. Kubiak. 2003. Sources, pathways, and effects of PCBs, dioxins, and dibenzofurans. Pages 501–573 *in* D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr., and J. Cairns, Jr., editors. Handbook of ecotoxicology, 2nd edition, CRC Press, Boca Raton, Florida.

Risch, M. R., D. A. Gay, K. K. Fowler, G. J. Keeler, S. M. Backus, P. Blanchard, J. A. Barres, and J. T. Dvonch. 2012a. Spatial patterns and temporal trends in mercury concentrations, precipitation depths, and mercury wet deposition in the North American Great Lakes region, 2002–2008. Environmental Pollution 161:261–271.

Risch, M. R., J. F. DeWild, D. P. Krabbenhoft, R. K. Kolka, and L. Zhang. 2012b. Litterfall mercury dry deposition in the eastern USA. Environmental Pollution 161:284–290.

Robson, M., L. Melymuk, L. Bradley, B. Treen, and S. Backus. 2013. Wet deposition of brominated flame retardants to the Great Lakes basin—Status and trends. Environmental Pollution 182:299–306.

Rolfhus, K. R., B. D. Hall, B. A. Monson, M. J. Paterson, and J. D. Jeremiason. 2011. Assessment of mercury bioaccumulation within the pelagic food web of lakes in the western Great Lakes region. Ecotoxicology 20:1520–1529.

Rolfhus, K. R., J. G. Wiener, R. J. Haro, M. B. Sandheinrich, S. W. Bailey, and B. R. Seitz. 2015a. Mercury in streams at Grand Portage National Monument (Minnesota, USA): Assessment of ecosystem sensitivity and ecological risk. Science of the Total Environment 514:192–201.

Rolfhus, K. R., J. P. Hurley, R. A. Bodaly, and G. Perrine. 2015b. Production and retention of methylmercury in inundated boreal forest soils. Environmental Science and Technology 49:3482–3489.

Roos, A., U. Berger, U. Järnberg, J. van Dijk, and A. Bignert. 2013. Increasing concentrations of perfluoroalkyl acids in Scandinavian otters (*Lutra lutra*) between 1972 and 2011: A new threat to the otter population? Environmental Science and Technology 47:11757–11765.

Route, B., and J. Elias, editors. 2007. Long-term ecological monitoring plan: Great Lakes Inventory and Monitoring Network. National Park Service, Natural Resource Report NPS/GLKN/NRR¬—2007/001, Ashland, Wisconsin. Available from http://science.nature.nps.gov/im/units/GLKN/Vital_Signs_Monitoring.cfm (accessed 16 January 2012).

Route, B., W. Bowerman, and K. Kozie. 2009. Protocol for monitoring environmental contaminants in bald eagles, Version 1.2: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR—2009/092. National Park Service, Fort Collins, Colorado. Available from http://science.nature.nps.gov/im/units/GLKN/protocolreportpubs.cfm (accessed 16 January 2012).

Route, B., P. Rasmussen, R. Key, M. Meyer, and M. Martell. 2011. Spatial patterns of persistent contaminants in bald eagle nestlings at three national parks in the upper Midwest: 2006–2009. Natural Resource Technical Report NPS/GLKN/NRTR—2011/431. National Park Service, Fort Collins, Colorado. Available from http://science.nature.nps.gov/im/units/GLKN/monitorreportpubs.cfm (accessed 16 January 2012).

Route, W. T., C. R. Dykstra, P. W. Rasmussen, R. L. Key, M. W. Meyer, and J. Mathew. 2014a. Patterns and trends in brominated flame retardants in bald eagle nestlings from the Upper Midwestern United States. Environmental Science and Technology 48:12516–12524.

Route, W. T., R. L. Key, R. E. Russell, A. B. Lindstrom, and M. J. Strynar. 2014b. Spatial and temporal patterns in concentrations of perfluorinated compounds in bald eagle nestlings in the Upper Midwestern United States. Environmental Science and Technology 48:6653–6660.

Russell, R. E., and J. C. Franson. 2014. Causes of mortality in eagles submitted to the National Wildlife Health Center 1975–2013. Wildlife Society Bulletin 38:697–704.

Rutkiewicz, J., D. H. Nam, T. Cooley, K. Neumann, I.B. Padilla, W. Route, S. Strom, and N. Basu. 2011. Mercury exposure and neurochemical impacts in bald eagles across several Great Lakes states. Ecotoxicology 20:1669–76.

Salamova, A., J. J. Pagano, T. M. Holsen, and R. A. Hites. 2013. Post-1990 temporal trends of PCBs and organochlorine pesticides in the atmosphere and in fish from lakes Erie, Michigan, and Superior. Environmental Science and Technology 47:9109–9114.

Salyer, J. C., and K. F. Lagler. 1949. The eastern belted kingfisher, *Megaceryle alcyon* (Linnaeus), in relation to fish management. Transactions of the American Fisheries Society 76:97–117.

Sanders, S., and J. Grochowski. 2013. Forest vegetation monitoring at Indiana Dunes National Lakeshore. Natural Resource Technical Report NPS/GLKN/NRTR—2013/ 779. National Park

Service, Fort Collins, Colorado. Available from http://science.nature.nps.gov/im/units/glkn/index.cfm (accessed 6 January 2015).

Sanders, S. and J. Kirschbaum. 2015. Forest health monitoring at Grand Portage National Monument: 2014 field season. Natural Resource Report NPS/GLKN/NRR—2015/1072. National Park Service, Fort Collins, Colorado. Available from http://science.nature.nps.gov/im/units/glkn/index.cfm (accessed 22 December 2015).

Sanderson, G. C., and F. C. Bellrose. 1986. A review of the problem of lead poisoning in waterfowl. Illinois Natural History Survey, Special Publication 4, Champaign, Illinois.

Sandheinrich, M. B., and J. G. Wiener. 2011. Methylmercury in freshwater fish—Recent advances in assessing toxicity of environmentally relevant exposures. Pages 169–190 *in* W. N. Beyer and J. P. Meador, editors. Environmental contaminants in biota: Interpreting tissue concentrations, 2nd edition. CRC Press/Taylor and Francis, Boca Raton, Florida.

Sandheinrich, M. B., S. P. Bhavsar, R. A. Bodaly, P. E. Drevnick, and E. A. Paul. 2011. Ecological risk of methylmercury to piscivorous fish of the Great Lakes region. Ecotoxicology 20:1577–1587.

Sappington, K. G., T. S. Bridges, S. P. Bradbury, R. J. Erickson, A. J. Hendriks, R. P. Lanno, J. P. Meador, D. R. Mount, M. H. Salazar, and D. J. Spry. 2011. Application of the tissue residue approach in ecological risk assessment. Integrated Environmental Assessment and Management 7:116–140.

Scheuhammer, A. M., and S. L. Norris. 1996. The ecotoxicology of lead shot and lead fishing weights. Ecotoxicology 5:279–295.

Scheuhammer, A. M., M. W. Meyer, M. B. Sandheinrich, and M. W. Murray. 2007. Effects of environmental methylmercury on the health of wild birds, mammals, and fish. Ambio 36:12–18.

Scheuhammer, A. M., N. Basu, D. C. Evers, G. H. Heinz, M. B. Sandheinrich, and M. S. Bank. 2012. Ecotoxicology of mercury in fish and wildlife: Recent advances. Pages 223–238 *in* M. S. Bank, editor. Mercury in the environment: Pattern and process. University of California Press, Berkeley, California.

Schmitt, C. J., and W. G. Brumbaugh. 2007. Evaluation of potentially nonlethal sampling methods for monitoring mercury concentrations in smallmouth bass (*Micropterus dolomieu*). Archives of Environmental Contamination and Toxicology 53:84–95.

Schmitt, C. J., J. L. Zajicek, T. W. May, and D. F. Cowman. 1999. Organochlorine residues and elemental contaminants in U.S. freshwater fish, 1976–1986: National Contaminant Biomonitoring Program. Reviews in Environmental Contamination and Toxicology 162:43–104.

Sellers, P., C. A. Kelly, and J. W. M. Rudd. 2001. Fluxes of methylmercury to the water column of a drainage lake: The relative importance of internal and external sources. Limnology and Oceanography 46:623–631.

Sherman, L. S., J. D. Blum, J. T. Dvonch, L. E. Gratz, and M. S. Landis. 2015. The use of Pb, Sr, and Hg isotopes in Great Lakes precipitation as a tool for pollution source attribution. Science of the Total Environment 502:362–374.

Smithwick, M., R. J. Norstrom, S. A. Mabury, K. Solomon, T. J. Evans, I. Stirling, M. K. Taylor, and D. C. G. Muir. 2006. Temporal trends of perfluoroalkyl contaminants in polar bears (*Ursus maritimus*) from two locations in the North American Arctic, 1972–2002. Environmental Science and Technology 40:1139–1143.

Sofuoglu, S. C., A. Sofuoglu, T. M. Holsen, C. M. Alexander, and J. J. Pagano. 2013. Atmospheric concentrations and potential sources of PCBs, PBDEs, and pesticides to Acadia National Park. Environmental Pollution 177:116–124.

Song, M., S. Chu, R. J. Letcher, and R. Seth. 2006. Fate, partitioning, and mass loading of polybrominated diphenyl ethers (PBDEs) during the treatment processing of municipal sewage. Environmental Science and Technology 40:6241–6246.

Sorensen, J. A., L. W. Kallemeyn, and M. Sydor. 2005. Relationship between mercury accumulation in young-of-the-year yellow perch and water-level fluctuations. Environmental Science and Technology 39:9237–9243.

Soupir, C. A., M. L. Brown, and L. W. Kallemeyn. 2000. Trophic ecology of largemouth bass and northern pike in allopatric and sympatric assemblages in northern boreal lakes. Canadian Journal of Zoology 78:1759–1766.

Spears, B. L., and J. Isanhart. 2014. Polybrominated diphenyl ethers in bald (*Haliaeetus leucocephalus*) and golden (*Aquila chrysaetos*) eagles from Washington and Idaho, USA. Environmental Toxicology and Chemistry 33:2795–2801.

Spry, D. J., and J. G. Wiener. 1991. Metal bioavailability and toxicity to fish in low-alkalinity lakes: a critical review. Environmental Pollution 71:243–304.

St. Louis, V. L., J. W. M. Rudd, C. A. Kelly, R. A. Bodaly, M. J. Paterson, K. G. Beaty, R. H. Hesslein, A. Heyes, and A. R. Majewski. 2004. The rise and fall of mercury methylation in an experimental reservoir. Environmental Science and Technology 38:1348–1358.

Streets, S. S., S. A. Henderson, A. D. Stoner, D. L. Carlson, M. F. Simcik, and D. L. Swackhammer. 2006. Partitioning and bioaccumulation of PBDEs and PCBs in Lake Michigan. Environmental Science and Technology 40:7263–7269.

Stromberg, U., T. Lundh, and S. Skerfving. 2008. Yearly measurements of blood lead in Swedish children since 1978: The declining trend continues in the petrol-lead-free period 1995–2007. Environmental Research 107:332–335.

Swain, E. B., D. R. Engstrom, M. E. Brigham, T. A. Henning, and P. L. Brezonik. 1992. Increasing rates of atmospheric mercury deposition in midcontinental North America. Science 257:784–787.

Tan, S. W., J. C. Meiller, and K. R. Mahaffey. 2009. The endocrine effects of mercury in humans and wildlife. Critical Reviews in Toxicology 39:228–269.

Tao, L., K. Kannan, N. Kajiwara, M. M. Costa, G. Fillmann, S. Takahashi, and S. Tanabe. 2006. Perfluorooctanesulfonate and related fluorochemicals in albatrosses, elephant seals, penguins, and polar skuas from the Southern Ocean. Environmental Science and Technology 40:7642 7648.

Tennessen, K. J. 2007. Odonata. Pages 237–294 *in* R. W. Merritt, K. W. Cummins, and M. Berg, editors. An introduction to the aquatic insects of North America, 4th edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Tonn, W. M., and C. A. Paszkowski. 1986. Size-limited predation, winterkill, and the organization of *Umbra-Perca* fish assemblages. Canadian Journal of Fisheries and Aquatic Sciences 43:194–202.

Trefry, J. H., S. Metz, R.P. Trocine, and T. A. Nelsen. 1985. A decline in lead transport by the Mississippi River. Science 230:439–441.

Tremblay, A., B. Ludwig, M. Meili, L. Cloutier, and P. Pichet. 1996. Total mercury and methylmercury contents of insects from boreal lakes: Ecological, spatial and temporal patterns. Water Quality Research Journal of Canada 31:851–873.

Trudel, M., and J. B. Rasmussen. 1997. Modeling the elimination of mercury by fish. Environmental Science and Technology 31:1716–1722.

Tsui, M. T. K., and J. C. Finlay. 2011. Influence of dissolved organic carbon on methylmercury bioavailability across Minnesota stream ecosystems. Environmental Science and Technology 45:5981–5987.

USEPA (U.S. Environmental Protection Agency). 1996. Method 1638: Determination of trace elements in ambient waters by inductively coupled plasma-mass spectrometry. U.S. Environmental Protection Agency, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 1998. Method 1630: Methyl mercury in water by distillation, aqueous ethylation, purge and trap, and cold vapor atomic fluorescence spectrometry. U.S. Environmental Protection Agency, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2000. Guidance for assessing chemical contaminant data for use in fish advisories. Volume 1: Fish sampling and analysis. 3rd ed. U.S. Environmental Protection Agency, Report EPA 823-B-00-007, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2001. Appendix to Method 1631: Total mercury in tissue, sludge, sediment, and soil by acid digestion and BrCl oxidation. U.S. Environmental Protection Agency, Report EPA 821-R-01-13, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2007a. 2005/2006 national listing of fish advisories. Fact Sheet EPA-823-F-07-003. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2007b. Method 7473: Mercury in solids and solutions by thermal decomposition, amalgamation, and atomic absorption spectrophotometry. U.S. Environmental Protection Agency, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2011. 2010 biennial national listing of fish advisories. Fact Sheet EPA-820-F-11-014. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2013. Level III and IV ecoregions of the continental United States (map scale 1:3,000,000). U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, Oregon. Available from http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm (accessed 16 February 2015).

U.S. Fish and Wildlife Service. 2006. Comprehensive conservation plan: Upper Mississippi River National Wildlife and Fish Refuge. U.S. Fish and Wildlife Service, Winona, Minnesota. Available from http://www.fws.gov/midwest/planning/uppermiss/index.html (accessed 17 October 2014).

Ullah, S., S. Huber, A. Bignert, and U. Berger. 2014. Temporal trends of perfluoroalkane sulfonic acids and their sulfonamide-based precursors in herring from the Swedish west coast 1991–2011 including isomer-specific considerations. Environment International 65:63–72.

Van Walleghem, J. L. A., P. L. Blanchfield, and H. Hintelmann. 2007. Elimination of mercury by yellow perch in the wild. Environmental Science and Technology 41:5895–5901.

Van Walleghem, J. L. A., P. J. Blanchfield, L. E. Hrenchuk, and H. Hintelmann. 2013. Mercury elimination by a top predator, *Esox lucius*. Environmental Science and Technology 47:4147–4154.

Vonderheide, A. P., K. E. Mueller, J. Meija, and G. L. Welsh. 2008. Polybrominated diphenyl ethers: Causes for concern and knowledge gaps regarding environmental distribution and toxicity. Science of the Total Environment 400:425–436.

Walters, D. M., K. A. Blocksom, J. M. Lazorchak, T. Jicha, T. R. Angradi, and D. W. Bolgrien. 2010. Mercury contamination in fish in midcontinent great rivers of the United States: Importance of species traits and environmental factors. Environmental Science and Technology 44: 2947–2953.

White, B. M. 2004. Grand Portage National Monument historic documents study. Unpublished report from Turnstone Historical Research, St. Paul, Minnesota. Available from http://www.nps.gov/grpo/forteachers/upload/White_2004.pdf.

Wiemeyer, S. N., T. G. Lamont, C. M. Bunck, C. R. Sindelar, F. J. Gramlich, J. D. Fraser, and M. A. Byrd. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs (1969–1979) and their relationships to shell thinning and reproduction. Archives of Environmental Contamination and Toxicology 13:529–549.

Wiener, J. G., and M. B. Sandheinrich. 2010. Contaminants in the upper Mississippi River: Historic trends, responses to regulatory controls, and emerging concerns. Hydrobiologia 640:49–70.

Wiener, J. G., C. R. Fremling, C. E. Korschgen, K. P. Kenow, E. M. Kirsch, S. J. Rogers, Y. Yin, and J. S. Sauer. 1998. Mississippi River. Pages 351–384 *in* M. J. Mac, P. A. Opler, C. E. Puckett-Haecker, and P. D. Doran, editors. Status and trends of the nation's biological resources, Volume 1. U.S. Geological Survey, Reston, Virginia.

Wiener, J. G., D. P. Krabbenhoft, G. H. Heinz, and A. M. Scheuhammer. 2003. Ecotoxicology of mercury. Pages 409–463 *in* D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr., and J. Cairns, Jr., editors. Handbook of ecotoxicology, 2nd edition. CRC Press, Boca Raton, Florida.

Wiener, J. G., B. C. Knights, M. B. Sandheinrich, J. D. Jeremiason, M. E. Brigham, D. R. Engstrom, L. G. Woodruff, W. F. Cannon, and S. J. Balogh. 2006. Mercury in soils, lakes, and fish in Voyageurs National Park: Importance of atmospheric deposition and ecosystem factors. Environmental Science and Technology 40:6261–6268.

Wiener, J. G., R. A. Bodaly, S. S. Brown, M. Lucotte, M. C. Newman, D. B. Porcella, R. J. Reash, and E. B. Swain. 2007. Monitoring and evaluating trends in methylmercury accumulation in aquatic biota. Pages 87–122 *in* R. Harris, D. P. Krabbenhoft, R. Mason, M. W. Murray, R. Reash, and T. Saltman, editors. Ecosystem responses to mercury contamination: Indicators of change. CRC Press/Taylor and Francis, Boca Raton, Florida.

Wiener, J. G., M. B. Sandheinrich, S. P. Bhavsar, J. R. Bohr, D. C. Evers, B. A. Monson, and C. S. Schrank. 2012a. Toxicological significance of mercury in yellow perch in the Laurentian Great Lakes region. Environmental Pollution 161:350–357.

Wiener, J. G., D. C. Evers, D. A. Gay, H. A. Morrison, and K. A. Williams. 2012b. Mercury contamination in the Laurentian Great Lakes region: Introduction and overview. Environmental Pollution 161:243–251.

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.

Williams, M. C. W., and C. S. Schrank. 2015. Polybrominated diphenyl ethers (PBDEs) in Wisconsin fish: 2002–2012. Wisconsin Department of Natural Resources, Fisheries Management Administrative Report No. 77, Madison, Wisconsin. Available from http://dnr.wi.gov/topic/fishing/documents/consumption/PDBEWisFishADReport77.pdf (accessed 19 January 2016).

Wu, J. P., X. J. Luo, Y. Zhang, M. Yu, S. J. Chen, B. X. Mai, and Z. Y. Yang. 2009. Biomagnification of polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls in a highly contaminated freshwater food web from South China. Environmental Pollution 157:904–909.

Xu, J., C. S. Guo, Y. Zhang, and W. Meng. 2014. Bioaccumulation and trophic transfer of perfluorinated compounds in a eutrophic freshwater food web. Environmental Pollution 184:254–261.

Ye, X., M. J. Strynar, S. F. Nakayama, J. Varns, L. Helfant, J. Lazorchak, and A. B. Lindstrom. 2008. Perfluorinated compounds in whole fish homogenates from the Ohio, Missouri, and upper Mississippi Rivers, USA. Environmental Pollution 156:1227–1232.

Yeardley, R. B., Jr. 2000. Use of small forage fish for regional streams wildlife risk assessment: Relative bioaccumulation of contaminants. Environmental Monitoring and Assessment 65:559–585.

Zhang, R., J. Guo, F. Wu, Y. Mu, J. P. Giesy, H. Chang, X. Zhao, and C. Feng. 2014. Toxicity reference values for polybrominated diphenyl ethers: Risk assessment for predatory birds and mammals from two Chinese lakes. Reviews of Environmental Contamination and Toxicology 229:111–137.

Zhou, Z., Y. Shi, R. Vestergren, T. Wang, Y. Liang, and Y. Cai. 2014. Highly elevated serum concentrations of perfluoroalkyl substances in fishery employees from Tangxun Lake, China. Environmental Science and Technology 48:3864–3874.

Zou, M., Y. Ran, J. Gong, B. Mai, and E. Y. Zeng. 2007. Polybrominated diphenyl ethers in watershed soils of the Pearl River Delta, China: Occurrence, inventory, and fate. Environmental Science and Technology 41:8262–8267.

Appendix A. Land cover of watersheds containing water bodies studied at six national park units in the Great Lakes Inventory and Monitoring Network.

National park unit and water body	Percent of total basin area, by land cover class [1]												
	open water	developed	barren land	deciduous forest	evergreen forest	mixed forest	shrub/scrub	grassland/ herbaceous	pasture/hay	cultivated crops	woody wetlands	emergent herbaceous wetlands	other
GRPO [2]													
Grand Portage Creek				19.2	32.4	16.7	12.6				13.5	1.7	3.9
Poplar Creek				11.2	38.0	16.4	8.2				23.6	1.6	1.0
Snow Creek				13.0	34.2	26.0	9.4				11.7	4.6	1.1
INDU													
Great Marsh		25.5		23.1			3.1	2.0		2.9	42.6	0.8	
Long Lake	8.7	24.7	9.0	24.4			0.4	0.5			31.0	1.3	
Middle Lagoon	27.5	46.1	9.0	12.4				0.7			0.2	4.1	
ISRO													
Angleworm Lake	18.0			36.2	5.5	27.5	10.9				1.4	0.4	
Lake Harvey	19.0			14.0	16.3	37.7	0.1				10.9	2.0	
Lake Ritchie	14.0			16.5	20.1	35.6	2.8				10.0	1.0	
Sargent Lake	14.7			26.6	14.0	35.7	0.7				6.8	1.5	

[1] Land cover data were derived from the National Land Cover Database (Fry et al. 2011).

[2] For GRPO, land cover attributes were calculated for the portion of each basin upstream from the most downstream sampling station in each stream. Estimates for GRPO were derived with high-resolution (1 m) LiDar data from MNGEO, a database from the State of Minnesota.

Appendix A (continued). Land cover of watersheds containing water bodies studied at six national park units in the Great Lakes Inventory and Monitoring Network.

National park unit and water body	Percent of total basin area, by land cover class [1]												
	open water	developed	barren land	deciduous forest	evergreen forest	mixed forest	shrub/scrub	grassland/ herbaceous	pasture/hay	cultivated crops	woody wetlands	emergent herbaceous wetlands	other
PIRO													
Beaver Lake	11.1	0.3	0.1	59.0	11.3	3.7	0.1	0.4			13.5	0.5	
Chapel Lake	1.3	0.1		73.5	0.1	1.8					22.6	0.6	
Grand Sable Lake	6.5	1.2	3.6	72.2	2.8	1.4	0.1	2.3		0.2	9.5	0.2	
Legion Lake	14.5			65.5	0.6	1.7					16.6	1.1	
Miners Lake	0.4	2.0		76.2	0.2	1.2	0.8	0.5	0.3	0.9	17.0	0.5	
SLBE													
Bass Lake (Benzie Co.)	39.1	1.2		20.6	22.0	12.1					5.0		
Bass Lake (Leelanau Co.)	5.0	3.8		50.5	3.4	2.4	1.6	8.8	4.7	13.5	5.6	0.7	
Lake Manitou	13.2	0.1	0.1	82.0		0.4	0.5				3.1	0.6	
Round Lake	10.2	3.3		32.4		9.4					26.1	18.6	
VOYA													
Brown Lake	13.4			42.2	4.1	23.7	2.6				10.6	3.4	
Peary Lake	13.6			37.5	3.6	28.8	2.5	0.1			11.4	2.5	
Ryan Lake	12.7			17.6	23.8	39.2					6.7		
Sand Point Lake	17.4	0.6	0.1	9.3	17.6	32.8	3.6	1.3			15.8	0.9	0.6

[1] Land cover data were derived from the National Land Cover Database (Fry et al. 2011).

[2] For GRPO, land cover attributes were calculated for the portion of each basin upstream from the most downstream sampling station in each stream. Estimates for GRPO were derived with high-resolution (1 m) LiDar data from MNGEO, a database from the State of Minnesota.

Appendix B. Common and scientific names of fishes analyzed in this study, following standardized nomenclature by the American Fisheries Society.

Family	Species common name[1]	Species scientific name[1]
Clupeidae	gizzard shad	*Dorosoma cepedianum*
Cyprinidae	creek chub	*Semotilus atromaculatus*
	blacknose dace	*Rhinichthys atratulus*
	longnose dace	*Rhinichthys cataractae*
	fathead minnow	*Pimephales promelas*
	common carp	*Cyprinus carpio*
Esocidae	northern pike	*Esox lucius*
	grass pickerel	*Esox americanus*
	central mudminnow	*Umbra limi*
Salmonidae	rainbow trout	*Oncorhynchus mykiss*
Ictaluridae	black bullhead	*Ameiurus melas*
	channel catfish	*Ictalurus punctatus*
Gasterosteidae	brook stickleback	*Culaea inconstans*
Centrarchidae	green sunfish	*Lepomis cyanellus*
	bluegill	*Lepomis macrochirus*
	rock bass	*Ambloplites rupestris*
	black crappie	*Pomoxis nigromaculatus*
	smallmouth bass	*Micropterus dolomieu*
	largemouth bass	*Micropterus salmoides*
Percidae	Iowa darter	*Etheostoma exile*
	johnny darter	*Etheostoma nigrum*
	yellow perch	*Perca flavescens*
	walleye	*Sander vitreus*
Cottidae	mottled sculpin	*Cottus bairdii*
	slimy sculpin	*Cottus cognatus*

[1] Nomenclature of fishes follows Nelson et al. (2004).

Appendix C. Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg* conc, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in composite samples of soils collected during 2012 from six park units in the Great Lakes Inventory and Monitoring Network. Analytical results are listed alphabetically by park unit and water body (n = number of composite samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) denote samples not analyzed for total mercury.

Park unit	Water body (site)	n	Variable	Mean or value	Range (raw data)	
					Min	*Max*
GRPO	Grand Portage Creek	2	MeHg conc	2.26	1.99	2.54
		0	THg conc	--		
		0	%MeHg	--		
		2	LOI	7.2	4.9	9.4
GRPO	Poplar Creek	2	MeHg conc	1.58	1.58	1.59
		2	THg conc	61.9	58.2	65.5
		2	%MeHg	2.57	2.41	2.73
		2	LOI	6.7	6.6	6.7
GRPO	Snow Creek	2	MeHg conc	1.58	1.58	1.59
	(beaver pond)	2	THg conc	152	150	154
		1	%MeHg	1.06		
		2	LOI	19.2	18.9	19.5
GRPO	Snow Creek	2	MeHg conc	2.90	2.65	3.16
	(lower reach)	2	THg conc	164	151	178
		2	%MeHg	1.79	1.49	2.09
		2	LOI	17.4	17.0	17.8
INDU [1]	Long Lake	4	MeHg conc	0.048	0.014	0.121
		4	THg conc	3.10	2.15	5.37
		4	%MeHg	1.30	0.651	2.25
		4	LOI	1.5	0.8	2.9
INDU	Middle Lagoon	2	MeHg conc	0.096	0.018	0.174
		1	THg conc	26.7		
		1	%MeHg	0.651		
		2	LOI	2.2	0.4	4.1

Appendix C (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg* conc, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in composite samples of soils collected during 2012 from six park units in the Great Lakes Inventory and Monitoring Network. Analytical results are listed alphabetically by park unit and water body (n = number of composite samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) denote samples not analyzed for total mercury.

Park unit	Water body (site)	n	Variable	Mean or value	Range (raw data)	
					Min	*Max*
ISRO	Angleworm Lake	2	MeHg conc	0.169	0.168	0.170
		2	THg conc	49.8	47.4	52.2
		2	%MeHg	0.340	0.326	0.354
		2	LOI	11.9	10.0	13.9
ISRO	Lake Harvey	2	MeHg conc	0.265	0.073	0.457
		2	THg conc	49.1	18.9	79.3
		2	%MeHg	0.482	0.387	0.576
		2	LOI	12.0	3.2	20.8
ISRO	Lake Richie	2	MeHg conc	0.136	0.056	0.215
		2	THg conc	26.5	17.4	35.6
		2	%MeHg	0.463	0.323	0.603
		2	LOI	6.9	3.0	10.7
ISRO	Sargent Lake	2	MeHg conc	0.493	0.183	0.803
		2	THg conc	29.2	15.9	42.4
		2	%MeHg	1.52	1.15	1.89
		2	LOI	16.7	7.1	26.3
PIRO	Beaver Lake	1	MeHg conc	0.014		
		1	THg conc	17.8		
		1	%MeHg	0.078		
		1	LOI	7.4		
PIRO	Chapel Lake	1	MeHg conc	0.743		
		1	THg conc	147		
		1	%MeHg	0.507		
		1	LOI	51.1		
PIRO	Grand Sable Lake	1	MeHg conc	0.085		
		1	THg conc	22.8		
		1	%MeHg	0.373		
		1	LOI	5.5		
PIRO	Legion Lake	1	MeHg conc	4.71		
		1	THg conc	198		
		1	%MeHg	2.39		
		1	LOI	70.6		

Appendix C (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg* conc, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in composite samples of soils collected during 2012 from six park units in the Great Lakes Inventory and Monitoring Network. Analytical results are listed alphabetically by park unit and water body (n = number of composite samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) denote samples not analyzed for total mercury.

Park unit	Water body (site)	n	Variable	Mean or value	Range (raw data)	
					Min	*Max*
PIRO	Miners Lake	1	MeHg conc	0.250		
		1	THg conc	44.0		
		1	%MeHg	0.568		
		1	LOI	13.4		
SLBE	Bass Lake	1	MeHg conc	0.469		
	(Benzie)	1	THg conc	40.9		
		1	%MeHg	1.15		
		1	LOI	11.0		
SLBE	Bass Lake	1	MeHg conc	0.033		
	(Leelanau)	1	THg conc	2.32		
		1	%MeHg	1.42		
		1	LOI	0.8		
SLBE	Lake Manitou	1	MeHg conc	0.288		
		1	THg conc	61.3		
		1	%MeHg	0.470		
		1	LOI	11.4		
SLBE	Round Lake	1	MeHg conc	0.270		
		1	THg conc	22.3		
		1	%MeHg	1.21		
		1	LOI	8.1		
VOYA	Brown Lake	2	MeHg conc	0.348	0.312	0.383
		3	THg conc	33.6	24.3	42.9
		2	%MeHg	1.25	0.927	1.57
		3	LOI	12.7	6.8	17.1
VOYA	Peary Lake	2	MeHg conc	0.173	0.122	0.224
		3	THg conc	45.0	30.3	71.5
		2	%MeHg	0.541	0.403	0.678
		3	LOI	15.4	5.0	35.9
VOYA	Ryan Lake	2	MeHg conc	0.220	0.072	0.368
		3	THg conc	24.9	18.9	32.3
		2	%MeHg	0.722	0.305	1.14
		3	LOI	5.1	4.6	6.2

Appendix C (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg* conc, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in composite samples of soils collected during 2012 from six park units in the Great Lakes Inventory and Monitoring Network. Analytical results are listed alphabetically by park unit and water body (n = number of composite samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) denote samples not analyzed for total mercury.

Park unit	Water body (site)	n	Variable	Mean or value	Range (raw data)	
					Min	*Max*
VOYA	Sand Point Lake	1	MeHg conc	0.023		
		2	THg conc	2.39	0.950	3.84
		1	%MeHg	0.599		
		2	LOI	0.6	0.3	1.0

Appendix D. Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in surficial sediment sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are organized alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury or LOI.

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
GRPO	Grand Portage Creek	5	MeHg conc	1.57	0.213	0.660	0.099	1.57
		6	THg conc	--	37.6	35.8	21.6	48.7
		4	%MeHg	--	0.98	1.56	0.46	2.72
		6	LOI	--	6.66	4.88	2.82	8.85
GRPO	Poplar Creek	4	MeHg conc	0.770	1.11	0.826	0.761	1.11
		7	THg conc	65.6	67.9	49.5	40.8	72.5
		4	%MeHg	1.17	1.58	1.86	1.17	2.18
		7	LOI	15.2	7.76	7.17	5.60	15.2
GRPO	Snow Creek	4	MeHg conc	2.49	1.07	1.55	1.07	2.49
	(beaver pond)	7	THg conc	87.6	131	215	87.6	247
		4	%MeHg	2.84	0.801	0.819	0.644	2.84
		7	LOI	35.6	22.5	23.0	17.8	35.6
GRPO	Snow Creek	5	MeHg conc	2.02	2.29	1.15	0.763	2.29
	(lower reach)	7	THg conc	104	131	161	104	174
		5	%MeHg	1.94	1.66	0.718	0.488	1.94
		7	LOI	8.80	22.4	22.0	8.80	23.0
INDU	Great Marsh	5	MeHg conc	1.10	12.5	0.631	0.180	12.5
		6	THg conc	9.72	35.6	29.5	4.22	88.3
		4	%MeHg	1.85	14.1	2.31	1.11	14.1
		5	LOI	11.0	31.6	21.8	2.38	86.9
INDU	Long Lake	4	MeHg conc	0.200	0.063	0.183	0.063	0.270
		7	THg conc	8.16	5.39	4.08	1.93	12.6
		4	%MeHg	2.82	0.627	2.94	0.627	3.50
		7	LOI	18.0	1.41	2.35	0.79	33.9

Appendix D (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in surficial sediment sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are organized alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury or LOI.

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
INDU	Middle Lagoon	4	MeHg conc	0.011	0.013	0.079	0.011	0.101
		5	THg conc	1.10	3.22	2.42	1.10	4.37
		4	%MeHg	1.00	0.304	3.31	0.304	4.40
		5	LOI	0.60	1.55	1.22	0.60	1.87
ISRO	Angleworm Lake	4	MeHg conc	0.720	0.094	0.022	0.013	0.720
		7	THg conc	12.5	6.58	3.89	3.04	12.5
		4	%MeHg	5.75	1.56	0.540	0.262	5.75
		7	LOI	12.7	3.30	1.64	1.27	12.7
ISRO	Lake Harvey	3	MeHg conc	1.35	0.157	0.066	0.066	1.35
		7	THg conc	15.5	5.68	4.66	2.69	15.5
		3	%MeHg	8.69	2.87	1.26	1.26	8.69
		7	LOI	5.00	1.91	1.94	1.48	5.00
ISRO	Lake Richie	4	MeHg conc	0.200	0.039	0.045	0.025	0.200
		7	THg conc	6.43	4.57	4.42	3.44	6.43
		4	%MeHg	3.11	0.92	1.18	0.485	3.11
		7	LOI	1.40	1.58	1.59	1.06	2.19
ISRO	Sargent Lake	5	MeHg conc	0.080	0.018	0.066	0.018	0.092
		7	THg conc	5.69	2.34	3.84	2.21	5.69
		5	%MeHg	1.41	0.786	1.68	0.786	1.97
		7	LOI	1.00	0.61	1.31	0.44	1.38
PIRO	Beaver Lake	4	MeHg conc	0.012	0.011	0.025	0.011	0.029
		7	THg conc	0.304	0.787	0.827	0.304	0.910
		4	%MeHg	3.95	1.47	3.22	1.47	4.14
		7	LOI	1.60	0.40	0.50	0.36	1.60
PIRO	Chapel Lake	4	MeHg conc	0.220	0.010	0.027	0.010	0.220
		7	THg conc	4.65	4.85	1.20	0.74	11.0
		4	%MeHg	4.73	0.623	2.91	0.623	4.73
		7	LOI	2.80	1.64	0.49	0.26	3.66
PIRO	Grand Sable Lake	5	MeHg conc	0.097	0.006	0.106	0.006	0.134
		6	THg conc	--	1.29	1.75	0.966	2.08
		4	%MeHg	--	0.423	5.96	0.423	7.45
		6	LOI	--	0.45	0.69	0.36	0.81

Appendix D (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in surficial sediment sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are organized alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury or LOI.

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
PIRO	Legion Lake	3	MeHg conc	--	0.417	0.265	0.252	0.417
		6	THg conc	--	7.62	6.26	1.51	15.4
		3	%MeHg	--	8.55	8.12	1.64	14.6
		6	LOI	--	3.34	2.48	0.52	7.21
PIRO	Miners Lake	5	MeHg conc	0.128	0.104	0.254	0.041	0.618
		7	THg conc	1.57	6.52	2.75	0.32	12.3
		5	%MeHg	8.14	2.38	9.79	2.38	12.8
		7	LOI	0.70	2.48	0.97	0.20	4.88
SLBE	Bass Lake	4	MeHg conc	3.58	0.146	0.040	0.027	3.58
	(Benzie)	7	THg conc	50.1	4.58	3.01	1.51	50.1
		4	%MeHg	7.15	3.54	1.26	1.25	7.15
		7	LOI	27.6	1.61	0.83	0.32	27.6
SLBE	Bass Lake	5	MeHg conc	0.370	0.017	0.008	0.007	0.37
	(Leelanau)	7	THg conc	5.39	2.54	1.53	0.67	5.39
		5	%MeHg	6.87	0.60	0.69	0.39	6.87
		7	LOI	3.90	1.00	0.94	0.51	3.90
SLBE	Lake Manitou	4	MeHg conc	0.088	0.040	0.017	0.001	0.088
		5	THg conc	10.4	23.5	1.37	1.17	23.5
		4	%MeHg	0.850	0.169	1.43	0.044	2.81
		5	LOI	3.30	30.4	0.65	0.41	30.4
SLBE	Round Lake	4	MeHg conc	4.91	0.009	0.011	0.008	4.91
		7	THg conc	34.5	1.53	3.96	0.793	34.5
		4	%MeHg	14.2	0.550	0.941	0.273	14.2
		7	LOI	15.7	0.66	0.50	0.27	15.7
VOYA	Brown Lake	4	MeHg conc	2.34	2.36	0.053	0.025	2.36
		7	THg conc	9.03	13.8	12.0	7.10	24.2
		4	%MeHg	25.9	9.76	0.72	0.30	25.9
		7	LOI	5.80	11.2	3.06	2.22	20.5
VOYA	Peary Lake	5	MeHg conc	11.7	0.034	0.090	0.034	11.7
		7	THg conc	49.2	1.37	3.58	0.83	49.2
		5	%MeHg	23.7	3.26	3.36	1.97	23.7
		7	LOI	57.5	0.82	1.54	0.41	57.5

Appendix D (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), percent of total mercury present as methylmercury (*%MeHg*), and loss on ignition (*LOI, %*) in surficial sediment sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are organized alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury or LOI.

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
VOYA	Ryan Lake	5	MeHg conc	0.920	8.97	0.485	0.170	8.97
		7	THg conc	6.52	54.1	6.70	3.18	112
		5	%MeHg	14.1	8.00	6.59	5.35	14.1
		7	LOI	1.80	27.5	2.14	0.88	69.9
VOYA	Sand Point Lake	5	MeHg conc	0.190	0.039	0.056	0.022	0.190
		7	THg conc	4.59	2.78	3.71	2.09	5.08
		5	%MeHg	4.14	0.993	1.89	0.438	4.14
		7	LOI	1.20	0.64	2.17	0.53	3.28

Appendix E. Concentrations of total mercury (*THg conc*, ng/L) and methylmercury (*MeHg conc*, ng/L), and percent of total mercury present as methylmercury (*%MeHg*) in samples of unfiltered (*U*) and 0.45-µm filtered (*F*) water collected during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are presented alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury.

Park unit	Water body (site)	n	Sample type and variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
GRPO	Grand Portage Creek	3	U MeHg conc	0.553	0.854	0.309	0.309	0.854
		3	U THg conc	6.50	9.25	10.2	6.50	10.2
		3	U %MeHg	8.51	9.23	3.03	3.03	9.23
		3	F MeHg conc	0.411	0.369	0.269	0.269	0.411
		3	F THg conc	4.77	6.70	4.81	4.77	6.70
		3	F %MeHg	8.62	5.51	5.59	5.51	8.62
GRPO	Poplar Creek	3	U MeHg conc	0.820	0.751	0.725	0.725	0.820
		2	U THg conc	--	16.2	17.5	16.2	17.5
		2	U %MeHg		4.63	4.14	4.14	4.63
		2	F MeHg conc	0.661	--	0.472	0.472	0.661
		3	F THg conc	7.09	11.7	5.95	5.95	11.7
		2	F %MeHg	9.32		7.93	7.93	9.32
GRPO	Snow Creek	3	U MeHg conc	2.33	3.08	2.69	2.33	3.08
	(beaver pond)	3	U THg conc	9.25	10.1	9.12	9.12	10.1
		3	U %MeHg	25.1	30.6	29.5	25.1	30.6
		3	F MeHg conc	1.45	2.30	1.94	1.45	2.30
		3	F THg conc	5.68	7.10	4.67	4.67	7.10
		3	F %MeHg	25.5	32.4	41.4	25.5	41.4
GRPO	Snow Creek	2	U MeHg conc	2.29	--	1.50	1.50	2.29
	(lower reach)	3	U THg conc	7.65	13.5	8.29	7.65	13.5
		2	U %MeHg	29.9		18.1	18.1	29.9
		3	F MeHg conc	0.448	1.10	0.999	0.448	1.10
		3	F THg conc	6.45	10.9	4.85	4.85	10.9
		3	F %MeHg	6.95	10.2	20.6	6.95	20.6

Appendix E (continued). Concentrations of total mercury (*THg conc*, ng/L) and methylmercury (*MeHg conc*, ng/L), and percent of total mercury present as methylmercury (*%MeHg*) in samples of unfiltered (*U*) and 0.45-µm filtered (*F*) water collected during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are presented alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury.

Park unit	Water body (site)	n	Sample type and variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
INDU	Great Marsh	7	U MeHg conc	0.262	0.249	0.165	0.098	0.426
		7	U THg conc	3.16	2.96	1.68	1.51	3.45
		6	U %MeHg	8.31	7.43	9.91	3.09	13.5
		4	F MeHg conc	--	0.216	0.140	0.139	0.238
		3	F THg conc	--	2.58	1.15	1.15	3.15
		3	F %MeHg	--	8.60	12.2	7.56	12.2
INDU	Long Lake	5	U MeHg conc	0.131	0.077	0.136	0.060	0.201
		6	U THg conc	1.96	1.73	0.550	0.390	2.49
		3	U %MeHg	6.66	4.46	24.6	4.46	24.6
		3	F MeHg conc	--	0.033	0.077	0.023	0.077
		4	F THg conc	1.25	1.72	0.470	0.470	1.85
		2	F %MeHg		1.92	16.4	1.92	16.4
INDU	Middle Lagoon	6	U MeHg conc	0.130	0.044	0.038	0.022	0.182
		6	U THg conc	1.38	1.19	0.580	0.350	1.56
		3	U %MeHg	9.45	3.66	6.47	3.66	9.45
		6	F MeHg conc	0.079	0.020	0.034	0.007	0.106
		6	F THg conc	0.885	0.935	0.305	0.270	0.950
		3	F %MeHg	8.87	2.14	11.0	2.14	11.0
ISRO	Angleworm Lake	6	U MeHg conc	0.061	0.022	0.038	0.014	0.068
		6	U THg conc	0.980	0.635	1.73	0.580	2.20
		3	U %MeHg	6.22	3.46	2.20	2.20	6.22
		5	F MeHg conc	0.049	0.013	0.032	0.008	0.049
		6	F THg conc	0.635	0.385	0.805	0.370	0.880
		3	F %MeHg	7.72	3.38	3.91	3.38	7.72
ISRO	Lake Harvey	6	U MeHg conc	0.110	0.205	0.146	0.109	0.250
		4	U THg conc	1.41	--	1.53	1.29	1.56
		2	U %MeHg	7.80		9.54	7.80	9.54
		6	F MeHg conc	0.103	0.190	0.093	0.089	0.220
		4	F THg conc	0.665	--	0.915	0.590	0.930
		2	F %MeHg	15.5		10.1	10.1	15.5

Appendix E (continued). Concentrations of total mercury (*THg conc*, ng/L) and methylmercury (*MeHg conc*, ng/L), and percent of total mercury present as methylmercury (*%MeHg*) in samples of unfiltered (*U*) and 0.45-µm filtered (*F*) water collected during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are presented alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury.

Park unit	Water body (site)	n	Sample type and variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
ISRO	Lake Richie	6	U MeHg conc	0.066	0.040	0.064	0.029	0.068
		6	U THg conc	1.30	0.725	1.21	0.710	1.50
		3	U %MeHg	5.06	5.45	5.31	5.06	5.45
		6	F MeHg conc	0.052	0.023	0.031	0.017	0.052
		6	F THg conc	0.370	0.615	0.800	0.260	0.850
		3	F %MeHg	14.1	3.74	3.88	3.74	14.1
ISRO	Sargent Lake	5	U MeHg conc	0.110	0.031	0.047	0.031	0.113
		6	U THg conc	0.820	0.845	1.21	0.540	1.29
		3	U %MeHg	13.4	3.67	3.90	3.67	13.4
		6	F MeHg conc	0.081	0.023	0.031	0.017	0.092
		6	F THg conc	0.485	0.520	0.715	0.390	0.740
		3	F %MeHg	16.6	4.33	4.34	4.33	16.6
PIRO	Beaver Lake	6	U MeHg conc	0.046	0.033	0.044	0.031	0.053
		6	U THg conc	0.895	1.21	0.835	0.590	1.28
		3	U %MeHg	5.08	2.70	5.27	2.70	5.27
		6	F MeHg conc	0.035	0.007	0.023	0.003	0.037
		6	F THg conc	0.505	0.795	0.365	0.350	0.830
		3	F %MeHg	6.93	0.881	6.16	0.881	6.93
PIRO	Chapel Lake	6	U MeHg conc	0.291	0.271	0.124	0.122	0.456
		6	U THg conc	2.49	4.39	2.05	2.00	4.50
		3	U %MeHg	11.7	6.18	6.02	6.02	11.7
		6	F MeHg conc	0.071	0.206	0.067	0.058	0.216
		6	F THg conc	1.70	3.72	1.40	1.35	4.06
		3	F %MeHg	4.18	5.55	4.79	4.18	5.55
PIRO	Grand Sable Lake	6	U MeHg conc	0.104	0.146	0.084	0.046	0.161
		6	U THg conc	1.35	1.90	1.31	1.10	1.94
		3	U %MeHg	7.70	7.68	6.44	6.44	7.70
		6	F MeHg conc	0.062	0.122	0.039	0.031	0.127
		6	F THg conc	1.08	1.52	0.86	0.800	1.62
		3	F %MeHg	5.77	8.02	4.48	4.48	8.02

Appendix E (continued). Concentrations of total mercury (*THg conc*, ng/L) and methylmercury (*MeHg conc*, ng/L), and percent of total mercury present as methylmercury (*%MeHg*) in samples of unfiltered (*U*) and 0.45-µm filtered (*F*) water collected during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are presented alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury.

Park unit	Water body (site)	n	Sample type and variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
PIRO	Legion Lake	6	U MeHg conc	0.069	0.051	0.091	0.047	0.111
		6	U THg conc	2.06	1.38	1.07	0.900	2.28
		3	U %MeHg	3.36	3.71	8.50	3.36	8.50
		6	F MeHg conc	0.018	0.025	0.045	0.008	0.060
		4	F THg conc	0.610	--	0.525	0.100	1.12
		2	F %MeHg	2.87		8.48	2.87	8.48
PIRO	Miners Lake	5	U MeHg conc	0.184	0.324	0.138	0.104	0.343
		6	U THg conc	2.26	3.24	1.45	1.22	3.29
		3	U %MeHg	8.16	10.0	9.55	8.16	10.0
		5	F MeHg conc	0.171	0.323	0.068	0.060	0.323
		6	F THg conc	0.605	2.46	0.790	0.560	2.50
		3	F %MeHg	28.3	13.2	8.54	8.54	28.3
SLBE	Bass Lake	5	U MeHg conc	0.078	0.070	0.108	0.051	0.145
	(Benzie)	6	U THg conc	1.13	1.04	1.03	0.840	1.42
		3	U %MeHg	6.90	6.68	10.4	6.68	10.4
		6	F MeHg conc	0.066	0.022	0.053	0.021	0.067
		6	F THg conc	0.585	0.885	0.610	0.430	0.930
		3	F %MeHg	11.2	2.43	8.61	2.43	11.2
SLBE	Bass Lake	6	U MeHg conc	0.070	0.091	0.099	0.051	0.134
	(Leelanau)	6	U THg conc	0.920	1.43	1.24	0.820	1.49
		3	U %MeHg	7.61	6.33	8.02	6.33	8.02
		6	F MeHg conc	0.056	0.016	0.043	0.011	0.060
		4	F THg conc	--	1.44	0.795	0.740	1.48
		2	F %MeHg		1.08	5.41	1.08	5.41
SLBE	Lake Manitou	4	U MeHg conc	0.059	0.044	0.080	0.044	0.093
		6	U THg conc	0.600	0.860	0.615	0.410	0.940
		3	U %MeHg	9.83	5.12	12.9	5.12	12.9
		5	F MeHg conc	0.067	0.022	0.021	0.010	0.067
		5	F THg conc	0.240	0.700	0.215	0.200	0.760
		3	F %MeHg	27.9	3.14	9.77	3.14	27.9

Appendix E (continued). Concentrations of total mercury (*THg conc*, ng/L) and methylmercury (*MeHg conc*, ng/L), and percent of total mercury present as methylmercury (*%MeHg*) in samples of unfiltered (*U*) and 0.45-µm filtered (*F*) water collected during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network. Data are presented alphabetically by park unit and water body (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for mercury.

Park unit	Water body (site)	n	Sample type and variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
SLBE	Round Lake	6	U MeHg conc	0.146	0.074	0.077	0.058	0.200
		5	U THg conc	2.08	1.33	1.10	1.01	2.08
		3	U %MeHg	7.02	5.53	6.99	5.53	7.02
		6	F MeHg conc	0.075	0.046	0.040	0.038	0.100
		5	F THg conc	0.720	1.14	0.925	0.660	1.14
		3	F %MeHg	10.4	3.99	4.32	3.99	10.4
VOYA	Brown Lake	6	U MeHg conc	0.206	0.158	0.168	0.135	0.245
		5	U THg conc	2.11	2.45	2.13	1.97	2.45
		3	U %MeHg	9.75	6.45	7.88	6.45	9.75
		4	F MeHg conc	0.204	0.161	0.114	0.113	0.204
		4	F THg conc	1.85	2.10	1.71	1.71	2.12
		3	F %MeHg	11.0	7.67	6.67	6.67	11.0
VOYA	Peary Lake	6	U MeHg conc	0.209	0.192	0.125	0.119	0.255
		6	U THg conc	1.89	2.18	1.92	1.47	2.30
		3	U %MeHg	11.1	8.80	6.48	6.48	11.1
		5	F MeHg conc	0.099	0.070	0.054	0.044	0.099
		5	F THg conc	1.25	1.73	1.35	1.25	1.74
		3	F %MeHg	7.92	4.06	3.98	3.98	7.92
VOYA	Ryan Lake	6	U MeHg conc	0.131	0.214	0.131	0.113	0.218
		5	U THg conc	3.99	3.89	4.06	2.83	5.15
		3	U %MeHg	3.28	5.49	3.23	3.23	5.49
		4	F MeHg conc	0.122	--	0.081	0.079	0.123
		4	F THg conc	2.67	--	2.74	2.53	2.81
		2	F %MeHg	4.57		2.94	2.94	4.57
VOYA	Sand Point Lake	6	U MeHg conc	0.132	0.237	0.182	0.118	0.273
		6	U THg conc	2.71	3.68	3.92	2.30	3.95
		3	U %MeHg	4.86	6.43	4.64	4.64	6.43
		4	F MeHg conc	0.135	0.161	0.131	0.117	0.161
		4	F THg conc	1.55	3.77	2.89	1.55	3.77
		3	F %MeHg	8.71	4.27	4.52	4.27	8.71

Appendix F. Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in seston, listed alphabetically by park unit and water body, sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for total mercury.

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
GRPO	Grand Portage Creek	3	MeHg conc	1.27	1.15	1.18	1.15	1.27
		2	THg conc	--	60.6	39.8	39.8	60.6
		2	%MeHg		1.90	2.96		
GRPO	Poplar Creek	3	MeHg conc	0.41	2.15	1.07	0.41	2.15
		2	THg conc	--	133	15.8	15.8	133
		2	%MeHg		1.62	6.77		
GRPO	Snow Creek	3	MeHg conc	16.2	24.1	8.28	8.28	24.1
	(beaver pond)	2	THg conc	--	200	76.7	76.7	200
		2	%MeHg		12.1	10.8		
GRPO	Snow Creek	2	MeHg conc	12.9		4.41	4.41	12.9
	(lower reach)	2	THg conc	--	348	134	134	348
		1	%MeHg			3.30		
INDU	Great Marsh	5	MeHg conc	6.85	9.84	0.67	0.67	13.4
		3	THg conc	--	65.9	99.6	49.3	99.6
		3	%MeHg		17.4	0.67		
INDU	Long Lake	5	MeHg conc	6.45	7.00	11.9	3.97	11.9
		3	THg conc	--	37.6	53.6	37.6	58.0
		2	%MeHg		18.6	22.2		
INDU	Middle Lagoon	7	MeHg conc	3.27	9.23	29.1	2.49	40.9
		4	THg conc	--	88.1	28.2	14.4	99.0
		2	%MeHg		10.5	103		
ISRO	Angleworm Lake	7	MeHg conc	0.835	2.54	3.33	0.130	5.33
		4	THg conc	--	122	160	85.2	189
		2	%MeHg		2.08	2.09		
ISRO	Lake Harvey	6	MeHg conc	11.9	16.0	12.5	1.90	21.9
		3	THg conc	--	127	81.9	81.9	154
		2	%MeHg		12.6	15.2		

Appendix F (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in seston, listed alphabetically by park unit and water body, sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for total mercury.

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
ISRO	Lake Richie	8	MeHg conc	4.12	4.42	6.25	2.84	6.90
		4	THg conc	--	83.3	123	71.0	123
		2	%MeHg		5.31	5.09		
ISRO	Sargent Lake	7	MeHg conc	2.35	3.61	7.40	1.69	8.27
		4	THg conc	--	69.1	238	66.2	238
		2	%MeHg		5.23	3.10		
PIRO	Beaver Lake	7	MeHg conc	9.99	4.84	5.20	3.03	11.3
		2	THg conc	--	52.7	35.7	35.7	52.7
		2	%MeHg		9.18	14.6		
PIRO	Chapel Lake	6	MeHg conc	13.0	8.31	17.2	7.74	23.4
		2	THg conc	--	292	156	156	292
		2	%MeHg		2.85	11.0		
PIRO	Grand Sable Lake	6	MeHg conc	6.95	5.19	5.00	3.08	7.63
		2	THg conc	--	62.5	44.1	44.1	62.5
		2	%MeHg		8.30	11.3		
PIRO	Legion Lake	5	MeHg conc	36.5	24.1	40.8	18.3	44.7
		2	THg conc	--	167	130	130	167
		2	%MeHg		14.4	31.5		
PIRO	Miners Lake	6	MeHg conc	8.85	7.03	3.92	3.33	11.4
		2	THg conc	--	239	137	137	239
		2	%MeHg		2.94	2.85		
SLBE	Bass Lake	6	MeHg conc	4.72	4.15	8.24	3.32	13.2
	(Benzie)	2	THg conc	--	69.0	56.3	56.3	69.0
		2	%MeHg		6.02	14.6		
SLBE	Bass Lake	6	MeHg conc	8.01	3.97	4.01	0.65	9.01
	(Leelanau)	2	THg conc	--	115	61.2	61.2	115
		2	%MeHg		3.46	6.54		
SLBE	Lake Manitou	6	MeHg conc	8.00	3.24	8.59	0.95	10.6
		2	THg conc	--	38.5	29.4	29.4	38.5
		2	%MeHg		8.41	29.2		
SLBE	Round Lake	5	MeHg conc	6.72	8.58	3.03	1.95	14.8
		2	THg conc	--	100	76.3	76.3	100
		2	%MeHg		8.58	3.97		

Appendix F (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in seston, listed alphabetically by park unit and water body, sampled during 2010–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of samples analyzed, Min = minimum value, Max = maximum value). Dashes (--) indicate samples not analyzed for total mercury.

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
VOYA	Brown Lake	7	MeHg conc	46.5	18.9	19.4	15.2	77.8
		2	THg conc	--	113	219	113	219
		2	%MeHg		16.8	8.87		
VOYA	Peary Lake	6	MeHg conc	9.10	32.2	12.3	5.50	49.5
		2	THg conc	--	242	180	180	242
		2	%MeHg		13.3	6.80		
VOYA	Ryan Lake	6	MeHg conc	12.2	31.5	13.2	3.53	40.4
		2	THg conc	--	294	400	294	400
		2	%MeHg		10.7	3.29		
VOYA	Sand Point Lake	7	MeHg conc	6.29	10.7	5.53	4.61	12.7
		2	THg conc	--	111	40.2	40.2	111
		2	%MeHg		9.61	13.7		

Appendix G. Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in bulk zooplankton, listed alphabetically by park unit and water body sampled during 2010–2012 from parks in the Great Lakes Inventory and Monitoring Network (n = number of samples analyzed, Min = minimum value, Max = maximum value).

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
INDU	Long Lake	5	MeHg conc	40.1	25.2	19.3	19.3	48.1
		4	THg conc	63.7	43.9	44.3	42.1	63.7
		4	%MeHg	50.2	57.3	43.6	43.6	57.5
INDU	Middle Lagoon	6	MeHg conc	27.2	18.3	8.30	8.30	34.4
		6	THg conc	128	31.6	20.7	20.7	196
		6	%MeHg	24.9	59.3	40.1	12.3	70.1
ISRO	Angleworm Lake	8	MeHg conc	119	10.8	6.7	5.6	132
		7	THg conc	102	58.4	84.3	41.4	102
		7	%MeHg	129	19.8	7.95	6.63	129
ISRO	Lake Harvey	5	MeHg conc	149	92.9	35.2	35.2	178
		6	THg conc	234	136	91.2	89.8	234
		4	%MeHg	52.0	68.7	38.2	38.2	74.3
ISRO	Lake Richie	9	MeHg conc	43.4	19.3	15.2	12.0	54.0
		9	THg conc	166	47.9	62.9	36.2	192
		9	%MeHg	26.6	41.9	24.2	19.1	57.9
ISRO	Sargent Lake	7	MeHg conc	22.7	15.8	14.8	7.52	26.9
		7	THg conc	136	43.3	60.8	32.0	166.4
		7	%MeHg	16.9	34.9	24.3	16.2	44.4
PIRO	Beaver Lake	7	MeHg conc	38.6	24.6	21.5	9.6	58.1
		6	THg conc	98.7	37.1	53.9	36.5	115
		6	%MeHg	31.2	66.6	39.7	11.6	84.4
PIRO	Chapel Lake	5	MeHg conc	275	40.9	55.1	36.8	392
		5	THg conc	561	112	140	82.6	587
		5	%MeHg	48.2	38.2	39.3	29.8	66.7

Appendix G (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in bulk zooplankton, listed alphabetically by park unit and water body sampled during 2010–2012 from parks in the Great Lakes Inventory and Monitoring Network (n = number of samples analyzed, Min = minimum value, Max = maximum value).

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
PIRO	Grand Sable Lake	7	MeHg conc	33.0	12.3	9.80	8.40	57.2
		6	THg conc	138	22.2	49.0	18.8	151
		6	%MeHg	23.5	54.8	20.1	9.21	56.6
PIRO	Legion Lake	6	MeHg conc	251	106	43.6	36.2	284
		6	THg conc	393	195	105	96.3	460
		6	%MeHg	64.3	54.4	41.3	37.6	66.9
PIRO	Miners Lake	5	MeHg conc	68.7	6.24	13.4	6.24	75.0
		4	THg conc	118	127	38.5	38.5	127
		4	%MeHg	58.8	4.93	34.8	4.93	64.0
SLBE	Bass Lake	5	MeHg conc	38.2	19.8	39.1	18.0	52.7
	(Benzie)	4	THg conc	274	61.4	77.0	57.4	274
		4	%MeHg	19.3	32.2	50.8	19.3	50.8
SLBE	Bass Lake	5	MeHg conc	54.3	16.3	8.10	8.10	59.8
	(Leelanau)	4	THg conc	136	63.4	60.8	60.2	136
		4	%MeHg	35.7	25.7	13.3	13.3	35.7
SLBE	Lake Manitou	5	MeHg conc	36.1	18.3	19.5	16.1	51.6
		5	THg conc	194	34.1	40.0	30.3	300
		5	%MeHg	20.3	53.7	48.8	17.2	54.3
SLBE	Round Lake	5	MeHg conc	74.6	61.5	46.0	39.5	110
		5	THg conc	222	92.0	98.2	81.4	349
		5	%MeHg	36.6	66.3	46.8	31.5	71.0
VOYA	Brown Lake	6	MeHg conc	166	70.4	40.6	27.2	209
		5	THg conc	289	91.3	110	91.3	300
		5	%MeHg	58.2	88.5	36.0	29.8	88.5
VOYA	Peary Lake	6	MeHg conc	346	30.2	37.0	26.8	390
		6	THg conc	453	46.4	85.1	46.2	558
		6	%MeHg	78.4	65.1	43.4	42.2	86.9
VOYA	Ryan Lake	5	MeHg conc	229	112	46.7	45.5	229
		6	THg conc	441	158	155	148	590
		5	%MeHg	38.7	70.4	30.2	29.7	78.9

Appendix G (continued). Concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in bulk zooplankton, listed alphabetically by park unit and water body sampled during 2010–2012 from parks in the Great Lakes Inventory and Monitoring Network (n = number of samples analyzed, Min = minimum value, Max = maximum value).

Park unit	Water body (site)	n	Variable	Annual means			Range (raw data)	
				2010	*2011*	*2012*	*Min*	*Max*
VOYA	Sand Point Lake	6	MeHg conc	73.3	28.7	14.8	13.6	81.5
		6	THg conc	197	41.2	54.4	35.6	226
		6	%MeHg	37.5	71.0	27.2	24.6	80.6

Appendix H. Summary statistics for total length (*Length*, mm), percent moisture (*Moisture*, %), concentrations of total mercury (*THg conc*, ng/g dry weight) and methylmercury (*MeHg conc*, ng/g dry weight), and percent of total mercury present as methylmercury (*%MeHg*) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Grand Portage Creek	*Aeshna umbrosa*	Length	4	30.0	9.1	4.6	30.3	21.1	38.2	-5.8	0.0
			Moisture		79.4	1.2	0.6	79.7	77.7	80.5	2.5	-1.4
			THg conc		183.5	45.3	22.6	194.4	122.3	223.0	0.0	-1.0
			MeHg conc		171.8	42.8	21.4	181.7	114.0	209.8	0.1	-1.0
			%MeHg		93.6	0.4	0.2	93.5	93.1	94.1	-2.3	0.5
GRPO	Grand Portage Creek	*Boyeria vinosa*	Length	6	30.6	3.5	1.4	31.9	25.2	33.8	-1.2	-0.9
			Moisture		73.4	3.1	1.3	72.3	71.5	79.5	5.0	2.2
			THg conc		147.8	33.3	13.6	133.5	119.0	208.6	2.0	1.5
			MeHg conc		124.4	35.9	14.7	113.9	86.8	177.6	-1.2	0.7
			%MeHg		83.3	9.1	3.7	84.8	72.9	96.9	-0.5	0.2
GRPO	Grand Portage Creek	*Cordulegaster maculata*	Length	10	35.7	3.0	1.0	37.1	28.5	39.0	3.3	-1.7
			Moisture		79.4	2.6	0.8	80.2	72.9	82.1	4.9	-2.0
			THg conc		168.4	23.7	7.5	170.9	130.4	200.5	-1.3	-0.3
			MeHg conc		159.4	19.7	6.2	162.8	127.9	183.0	-1.3	-0.2
			%MeHg		95.1	7.0	2.2	93.9	86.1	106.7	-1.2	0.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Grand Portage Creek	*Somatochlora minor*	Length	9	18.9	0.6	0.2	19.2	17.6	19.5	1.6	-1.4
			Moisture		79.2	1.9	0.6	78.9	76.1	82.8	1.0	0.4
			THg conc		148.7	56.5	20.0	121.4	97.2	239.5	-0.9	1.0
			MeHg conc		136.4	44.3	14.8	118.5	90.1	226.5	0.8	1.1
			%MeHg		90.6	14.0	4.9	94.0	58.5	101.4	4.9	-2.1
GRPO	Poplar Creek	*Aeshna umbrosa*	Length	16	30.3	4.5	1.1	30.1	23.1	38.7	-0.3	0.3
			Moisture		84.4	5.5	1.4	86.2	74.4	91.5	-0.9	-0.6
			THg conc		135.9	42.2	10.5	148.3	72.0	201.8	-1.0	-0.2
			MeHg conc		124.6	38.9	9.7	122.0	68.2	199.2	-0.6	0.3
			%MeHg		94.6	24.0	6.0	93.3	61.7	163.1	3.8	1.4
GRPO	Poplar Creek	*Boyeria grafiana*	Length	3	33.2	1.5	0.9	33.0	31.8	34.8	—	0.7
			Moisture		74.3	0.9	0.5	74.4	73.4	75.2	—	-0.5
			THg conc		93.3	5.9	3.4	94.9	86.8	98.3	—	-1.1
			MeHg conc		84.6	8.5	4.9	89.1	74.8	89.9	—	-1.7
			%MeHg		90.5	4.3	2.5	90.6	86.2	94.8	—	0.0
GRPO	Poplar Creek	*Cordulegaster maculata*	Length	12	29.6	4.5	1.3	29.0	23.5	36.6	-1.3	0.2
			Moisture		77.3	4.3	1.2	76.6	72.2	84.2	-1.3	0.4
			THg conc		125.8	24.4	7.0	134.6	88.8	166.7	-0.9	-0.3
			MeHg conc		118.1	28.1	8.1	118.2	75.2	172.0	-0.5	0.3
			%MeHg		95.2	22.6	6.5	94.8	69.4	157.0	5.3	1.9

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Poplar Creek	*Epitheca canis*	Length	14	21.1	0.7	0.2	21.1	19.6	22.1	-0.1	-0.5
			Moisture		82.5	2.4	0.6	82.5	78.8	87.4	0.0	0.6
			THg conc		206.8	43.8	11.7	195.1	140.6	289.8	0.0	0.7
			MeHg conc		197.8	40.8	10.9	193.3	129.8	283.6	0.5	0.4
			%MeHg		96.5	11.7	3.1	99.8	64.3	108.1	3.9	-1.9
AGRPO	Poplar Creek	*Libellula quadrimaculata*	Length	1	18.5	—	—	18.5	18.5	18.5	—	—
			Moisture		80.1	—	—	80.1	80.1	80.1	—	—
			THg conc		177.4	—	—	177.4	177.4	177.4	—	—
			MeHg conc		111.3	—	—	111.3	111.3	111.3	—	—
			%MeHg		62.7	—	—	62.7	62.7	62.7	—	—
GRPO	Poplar Creek	*Somatochlora minor*	Length	17	18.8	1.6	0.4	19.0	15.6	21.3	-0.3	-0.6
			Moisture		78.9	3.0	0.7	78.2	75.0	85.3	-0.4	0.5
			THg conc		183.3	94.6	23.0	148.3	104.9	500.4	8.1	2.6
			MeHg conc		174.9	105.5	24.9	145.3	86.5	538.3	8.5	2.7
			%MeHg		95.2	12.2	3.0	93.9	59.7	109.3	3.6	-1.5
GRPO	Snow Creek (lower reach)	*Aeshna clepsydra*	Length	3	28.6	0.7	0.4	28.4	28.1	29.4	—	1.3
			Moisture		87.9	3.1	1.8	89.5	84.3	89.9	—	-1.7
			THg conc		245.2	27.3	15.7	260.8	213.7	261.0	—	-1.7
			MeHg conc		167.6	90.2	52.1	177.6	72.8	252.4	—	-0.5
			%MeHg		69.3	36.5	21.1	83.1	27.9	96.8	—	-1.5

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Snow Creek (lower reach)	*Aeshna interrupta*	Length	2	37.4	1.7	1.2	37.4	36.2	38.6	—	—
			Moisture		87.5	5.7	4.0	87.5	83.4	91.5	—	—
			THg conc		222.7	28.9	20.4	222.7	202.3	243.1	—	—
			MeHg conc		148.1	85.3	60.3	148.1	87.8	208.4	—	—
			%MeHg		64.6	29.9	21.2	64.6	43.4	85.7	—	—
GRPO	Snow Creek (lower reach)	*Aeshna umbrosa*	Length	5	32.0	3.7	1.7	30.5	29.4	38.5	4.5	2.1
			Moisture		85.3	8.3	4.2	88.0	73.4	91.7	2.0	-1.5
			THg conc		218.3	35.0	15.7	197.4	188.3	266.9	-1.9	0.8
			MeHg conc		197.4	29.6	13.2	190.9	156.6	227.1	-1.2	-0.3
			%MeHg		90.7	6.4	2.8	93.1	83.2	96.7	-3.0	-0.4
GRPO	Snow Creek (lower reach)	*Aeshna verticalis*	Length	1	30.2	—	—	30.2	30.2	30.2	—	—
			Moisture		91.8	—	—	91.8	91.8	91.8	—	—
			THg conc		292.8	—	—	292.8	292.8	292.8	—	—
			MeHg conc		301.7	—	—	301.7	301.7	301.7	—	—
			%MeHg		103.0	—	—	103.0	103.0	103.0	—	—
GRPO	Snow Creek (lower reach)	*Epitheca canis*	Length	10	21.4	1.2	0.4	21.2	19.8	23.4	-0.8	0.5
			Moisture		81.7	1.7	0.5	82.0	78.8	83.6	-0.6	-0.7
			THg conc		165.3	16.8	5.3	166.8	130.6	194.6	1.8	-0.5
			MeHg conc		156.7	20.2	6.4	159.8	116.6	187.2	0.7	-0.7
			%MeHg		94.8	7.0	2.2	96.0	78.1	102.8	3.7	-1.6

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Snow Creek (lower reach)	*Somatochlora williamsoni*	Length	6	22.4	0.5	0.2	22.5	21.5	23.0	0.0	-0.8
			Moisture		78.2	1.8	0.7	78.3	76.2	80.5	-2.3	0.1
			THg conc		173.5	19.8	8.1	169.0	152.3	201.0	-1.9	0.4
			MeHg conc		172.8	26.2	10.7	163.8	146.5	211.1	-1.4	0.7
			%MeHg		99.3	4.2	1.7	97.6	95.4	105.0	-1.8	0.7
GRPO	Snow Creek (beaver pond)	*Aeshna clepsydra*	Length	3	28.8	3.2	1.9	27.9	26.0	32.3	—	1.1
			Moisture		82.3	3.9	2.3	84.3	77.7	84.8	—	-1.7
			THg conc		151.3	43.0	24.8	139.5	115.5	199.0	—	1.1
			MeHg conc		151.8	41.4	23.9	136.5	120.4	198.7	—	1.4
			%MeHg		100.6	3.2	1.9	99.9	97.9	104.2	—	1.0
GRPO	Snow Creek (beaver pond)	*Aeshna umbrosa*	Length	4	30.9	3.6	1.8	29.8	27.7	36.1	2.8	1.5
			Moisture		88.9	5.3	2.6	86.6	85.7	96.7	3.6	1.9
			THg conc		135.4	38.5	19.2	131.1	101.4	177.8	-4.7	0.2
			MeHg conc		111.7	19.8	9.9	111.2	90.8	133.9	-3.4	0.1
			%MeHg		84.7	11.6	5.8	87.1	68.7	96.0	1.5	-1.1
GRPO	Snow Creek (beaver pond)	*Arigomphus cornutus*	Length	1	31.4	—	—	31.4	31.4	31.4	—	—
			Moisture		66.4	—	—	66.4	66.4	66.4	—	—
			THg conc		69.9	—	—	69.9	69.9	69.9	—	—
			MeHg conc		53.8	—	—	53.8	53.8	53.8	—	—
			%MeHg		76.9	—	—	76.9	76.9	76.9	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Snow Creek (beaver pond)	*Cordulia shurtleffi*	Length	4	19.9	2.8	1.4	21.0	15.8	21.9	3.1	-1.8
			Moisture		82.9	3.2	1.6	82.3	80.3	86.9	-2.8	0.6
			THg conc		91.0	27.1	13.5	91.0	58.3	123.8	0.7	0.0
			MeHg conc		92.0	34.0	17.0	94.8	48.5	129.9	0.6	-0.5
			%MeHg		99.1	10.7	5.4	103.1	83.3	106.7	3.1	-1.7
GRPO	Snow Creek (beaver pond)	*Epitheca canis*	Length	22	20.6	0.8	0.2	20.5	19.5	22.5	-0.6	0.4
			Moisture		79.3	1.6	0.3	79.3	75.9	81.8	-0.3	-0.4
			THg conc		144.3	37.0	7.9	142.6	63.9	204.8	-0.5	-0.2
			MeHg conc		138.9	42.5	9.1	148.2	49.4	215.3	-0.2	-0.5
			%MeHg		95.2	12.3	2.6	97.4	54.3	110.0	4.9	-1.8
GRPO	Snow Creek (beaver pond)	*Leucorrhinia frigida*	Length	15	15.9	0.7	0.2	15.9	14.6	17.2	0.3	-0.1
			Moisture		83.3	3.0	0.8	82.7	80.1	92.9	7.5	2.4
			THg conc		123.3	41.2	10.6	118.2	64.4	188.0	-1.1	0.1
			MeHg conc		107.6	43.6	11.3	109.5	37.5	193.0	-0.4	0.4
			%MeHg		86.2	14.6	3.8	89.1	46.9	104.0	3.0	-1.5
GRPO	Snow Creek (beaver pond)	*Leucorrhinia intacta*	Length	38	16.6	0.7	0.1	16.7	15.4	18.0	-0.7	0.1
			Moisture		82.2	2.1	0.3	82.7	77.5	86.6	-0.5	-0.4
			THg conc		139.5	43.9	7.1	119.6	83.1	218.7	-1.4	0.4
			MeHg conc		131.8	45.6	7.4	115.2	79.0	237.9	-0.2	1.0
			%MeHg		95.3	14.3	2.3	99.6	55.2	115.5	1.3	-1.4

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Snow Creek (beaver pond)	*Libellula quadrimaculata*	Length	5	20.6	0.9	0.4	20.3	19.7	22.1	0.7	1.1
			Moisture		79.6	1.6	0.7	78.7	78.0	81.7	-1.8	0.7
			THg conc		128.8	70.3	31.4	133.3	61.9	229.7	-0.7	0.6
			MeHg conc		115.1	71.2	31.8	116.6	53.1	227.2	1.1	1.1
			%MeHg		87.5	7.0	3.1	86.5	80.0	98.9	2.5	1.3
GRPO	Snow Creek (beaver pond)	*Somatochlora tenebrosa*	Length	1	21.8	—	—	21.8	21.8	21.8	—	—
			Moisture		77.5	—	—	77.5	77.5	77.5	—	—
			THg conc		119.0	—	—	119.0	119.0	119.0	—	—
			MeHg conc		118.8	—	—	118.8	118.8	118.8	—	—
			%MeHg		99.8	—	—	99.8	99.8	99.8	—	—
GRPO	Snow Creek (beaver pond)	*Somatochlora williamsoni*	Length	3	19.3	0.7	0.4	19.3	18.6	20.1	—	0.1
			Moisture		80.3	2.0	1.2	80.7	78.1	82.2	—	-0.7
			THg conc		185.3	17.9	10.3	177.6	172.5	205.8	—	1.6
			MeHg conc		173.8	13.8	7.9	167.0	164.8	189.6	—	1.7
			%MeHg		93.9	2.5	1.5	92.8	92.2	96.8	—	1.6
INDU	Great Marsh (GRMA-2)	*Aeshna interrupta*	Length	1	31.6	—	—	31.6	31.6	31.6	—	—
			Moisture		92.6	—	—	92.6	92.6	92.6	—	—
			THg conc		88.7	—	—	88.7	88.7	88.7	—	—
			MeHg conc		90.6	—	—	90.6	90.6	90.6	—	—
			%MeHg		102.2	—	—	102.2	102.2	102.2	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Great Marsh (GRMA-2)	*Anax junius*	Length	1	34.2	—	—	34.2	34.2	34.2	—	—
			Moisture		79.5	—	—	79.5	79.5	79.5	—	—
			THg conc		39.8	—	—	39.8	39.8	39.8	—	—
			MeHg conc		42.1	—	—	42.1	42.1	42.1	—	—
			%MeHg		105.8	—	—	105.8	105.8	105.8	—	—
INDU	Great Marsh (GRMA-2)	*Pachydiplax longipennis*	Length	8	17.1	0.7	0.2	17.3	16.1	18.0	-0.5	-0.7
			Moisture		83.2	4.3	1.5	81.4	78.9	89.8	-1.5	0.6
			THg conc		68.0	25.0	8.8	59.8	42.8	116.3	0.6	1.1
			MeHg conc		62.7	24.3	8.6	65.4	13.7	98.2	2.4	-0.9
			%MeHg		101.2	42.9	15.2	101.0	15.7	157.8	1.7	-1.0
INDU	Great Marsh (GRMA-2)	*Plathemis lydia*	Length	10	18.9	0.9	0.3	18.9	17.6	20.7	0.1	0.5
			Moisture		82.1	4.3	1.4	81.9	74.8	87.9	-0.8	-0.4
			THg conc		30.1	9.1	2.9	27.2	21.2	53.6	5.4	2.2
			MeHg conc		19.9	9.5	3.0	18.6	10.5	43.1	4.0	1.7
			%MeHg		64.2	15.2	4.8	63.6	43.4	86.5	-1.8	0.1
INDU	Great Marsh (GRMA-3)	*Anax junius*	Length	1	35.8	—	—	35.8	35.8	35.8	—	—
			Moisture		84.0	—	—	84.0	84.0	84.0	—	—
			THg conc		24.4	—	—	24.4	24.4	24.4	—	—
			MeHg conc		20.2	—	—	20.2	20.2	20.2	—	—
			%MeHg		82.9	—	—	82.9	82.9	82.9	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Great Marsh (GRMA-3)	*Erythemis simplicicollis*	Length	5	15.1	0.5	0.2	15.1	14.3	15.7	0.8	-0.7
			Moisture		80.4	3.9	1.7	78.7	77.7	87.1	3.7	1.9
			THg conc		28.7	4.8	2.1	26.8	23.0	35.0	-1.4	0.3
			MeHg conc		18.9	8.2	3.7	17.3	12.1	32.2	1.7	1.3
			%MeHg		63.8	17.6	7.9	63.2	45.3	92.0	1.9	1.2
INDU	Great Marsh (GRMA-3)	*Libellula pulchella*	Length	13	24.3	0.9	0.3	24.4	23.1	25.9	-0.9	0.0
			Moisture		88.4	3.9	1.1	89.0	76.9	91.9	6.9	-2.3
			THg conc		23.3	4.5	1.3	22.5	16.0	32.4	0.0	0.4
			MeHg conc		11.6	2.9	0.8	11.1	8.1	16.8	-1.1	0.5
			%MeHg		50.4	9.8	2.7	50.6	33.2	69.2	0.0	0.0
INDU	Great Marsh (GRMA-3)	*Libellula quadrimaculata*	Length	1	19.5	—	—	19.5	19.5	19.5	—	—
			Moisture		75.4	—	—	75.4	75.4	75.4	—	—
			THg conc		19.3	—	—	19.3	19.3	19.3	—	—
			MeHg conc		13.6	—	—	13.6	13.6	13.6	—	—
			%MeHg		70.3	—	—	70.3	70.3	70.3	—	—
INDU	Great Marsh (GRMA-3)	*Pachydiplax longipennis*	Length	5	17.3	1.3	0.6	17.0	16.0	19.5	2.7	1.5
			Moisture		85.8	5.6	2.5	85.8	80.2	93.3	-1.6	0.4
			THg conc		72.2	50.6	22.6	66.2	27.3	155.7	2.3	1.4
			MeHg conc		61.1	16.0	7.2	57.3	44.4	87.8	3.0	1.4
			%MeHg		107.7	47.5	21.2	90.2	56.4	162.6	-2.7	0.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Long Lake	*Anax junius*	Length	11	39.1	4.9	1.5	42.5	32.1	44.0	-2.1	-0.3
			Moisture		83.8	3.5	1.1	83.9	79.1	89.8	-1.0	0.1
			THg conc		51.5	14.0	4.2	51.2	31.3	87.7	5.0	1.6
			MeHg conc		49.7	13.7	4.1	49.0	33.7	83.8	3.6	1.6
			%MeHg		96.8	9.6	2.9	95.6	83.5	109.6	-1.3	-0.2
INDU	Long Lake	*Erythemis simplicicollis*	Length	8	14.2	0.3	0.1	14.2	13.7	14.9	2.3	0.5
			Moisture		82.3	6.3	2.2	78.9	76.7	92.8	-1.3	0.8
			THg conc		42.5	13.3	4.7	38.9	29.9	71.6	3.3	1.7
			MeHg conc		39.5	12.5	4.4	36.9	29.3	68.8	5.6	2.2
			%MeHg		93.4	9.4	3.3	92.3	83.0	111.6	0.7	1.0
INDU	Long Lake	*Leucorrhinia frigida*	Length	4	14.8	1.3	0.6	15.2	13.0	15.8	2.6	-1.6
			Moisture		82.1	5.1	2.5	83.2	75.4	86.4	-0.9	-0.9
			THg conc		24.1	7.2	3.6	24.6	14.9	32.4	1.0	-0.4
			MeHg conc		14.4	5.2	2.6	15.3	7.3	19.5	1.3	-1.0
			%MeHg		58.3	6.5	3.3	60.5	48.8	63.5	3.2	-1.7
INDU	Long Lake	*Leucorrhinia intacta*	Length	7	14.8	0.7	0.3	14.5	14.3	16.2	1.6	1.5
			Moisture		80.6	3.3	1.2	80.4	75.7	84.3	-1.2	-0.3
			THg conc		24.0	5.5	2.1	23.1	15.9	33.5	0.9	0.4
			MeHg conc		13.8	3.9	1.5	12.8	10.0	20.2	-0.6	1.0
			%MeHg		60.2	20.9	7.9	53.4	38.5	89.1	-1.3	0.6

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Long Lake	*Pachydiplax longipennis*	Length	20	14.6	1.5	0.3	14.5	12.0	17.1	-0.4	0.0
			Moisture		86.4	5.3	1.1	88.0	71.5	92.7	2.1	-1.4
			THg conc		32.8	15.7	3.5	29.9	9.2	71.6	0.3	0.6
			MeHg conc		20.2	9.8	2.1	23.0	5.6	35.8	-1.4	0.0
			%MeHg		57.6	18.4	4.1	53.1	24.5	104.9	2.0	1.1
INDU	Middle Lagoon	*Anax junius*	Length	4	29.0	8.8	4.4	29.4	20.6	36.6	-5.8	0.0
			Moisture		87.9	0.9	0.4	88.3	86.7	88.6	2.5	-1.6
			THg conc		54.7	21.8	10.9	50.6	32.6	84.7	2.1	1.1
			MeHg conc		47.3	18.4	9.2	43.9	29.3	72.2	0.7	0.9
			%MeHg		87.1	9.4	4.7	87.4	75.6	98.1	0.4	-0.2
INDU	Middle Lagoon	*Arigomphus cornutus*	Length	1	33.8	—	—	33.8	33.8	33.8	—	—
			Moisture		82.9	—	—	82.9	82.9	82.9	—	—
			THg conc		13.6	—	—	13.6	13.6	13.6	—	—
			MeHg conc		5.5	—	—	5.5	5.5	5.5	—	—
			%MeHg		40.4	—	—	40.4	40.4	40.4	—	—
INDU	Middle Lagoon	*Celithemis elisa*	Length	1	10.0	—	—	10.0	10.0	10.0	—	—
			Moisture		54.3	—	—	54.3	54.3	54.3	—	—
			THg conc		66.1	—	—	66.1	66.1	66.1	—	—
			MeHg conc		41.0	—	—	41.0	41.0	41.0	—	—
			%MeHg		62.0	—	—	62.0	62.0	62.0	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Middle Lagoon	*Epitheca princeps*	Length	2	16.2	0.4	0.3	16.2	15.9	16.5	—	—
			Moisture		82.0	6.7	4.8	82.0	77.2	86.8	—	—
			THg conc		73.3	44.5	31.4	73.3	41.8	104.7	—	—
			MeHg conc		58.8	47.1	33.3	58.8	25.5	92.1	—	—
			%MeHg		74.5	19.0	13.4	74.5	61.1	88.0	—	—
INDU	Middle Lagoon	*Epitheca spinigera*	Length	29	17.3	0.9	0.2	17.2	15.9	19.3	-0.2	0.5
			Moisture		75.5	48.6	9.0	85.9	-175.9	91.8	28.4	-5.3
			THg conc		47.1	20.8	3.9	43.5	13.3	85.7	-1.0	0.3
			MeHg conc		37.0	18.2	3.4	33.6	9.5	78.0	-0.2	0.6
			%MeHg		78.7	16.6	3.1	78.7	43.2	104.3	-0.6	-0.5
INDU	Middle Lagoon	*Libellula luctuosa*	Length	1	20.6	—	—	20.6	20.6	20.6	—	—
			Moisture		89.6	—	—	89.6	89.6	89.6	—	—
			THg conc		45.1	—	—	45.1	45.1	45.1	—	—
			MeHg conc		37.4	—	—	37.4	37.4	37.4	—	—
			%MeHg		82.9	—	—	82.9	82.9	82.9	—	—
INDU	Middle Lagoon	*Libellula pulchella*	Length	19	17.8	1.7	0.4	17.1	15.9	20.9	-0.8	0.9
			Moisture		85.8	4.3	1.0	85.0	77.0	93.1	-0.5	0.0
			THg conc		38.0	19.5	4.5	31.7	14.6	85.7	1.3	1.3
			MeHg conc		32.8	12.2	2.8	29.6	18.5	65.2	2.1	1.5
			%MeHg		93.6	22.9	5.2	92.6	65.7	161.8	3.4	1.6

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Middle Lagoon	*Libellula quadrimaculata*	Length	1	21.5	—	—	21.5	21.5	21.5	—	—
			Moisture		84.4	—	—	84.4	84.4	84.4	—	—
			THg conc		48.9	—	—	48.9	48.9	48.9	—	—
			MeHg conc		31.6	—	—	31.6	31.6	31.6	—	—
			%MeHg		64.7	—	—	64.7	64.7	64.7	—	—
INDU	Middle Lagoon	*Libellula semifasciata*	Length	4	16.6	0.6	0.3	16.5	16.1	17.5	1.9	1.3
			Moisture		87.5	5.0	2.5	86.4	82.9	94.2	0.3	1.0
			THg conc		35.7	11.3	5.7	35.8	25.2	46.0	-5.9	0.0
			MeHg conc		29.3	14.0	7.0	29.1	15.8	42.9	-5.5	0.0
			%MeHg		78.7	14.8	7.4	78.1	62.9	95.6	-3.0	0.1
ISRO	Angleworm Lake	*Aeshna interrupta*	Length	2	27.5	5.0	3.5	27.5	23.9	31.0	—	—
			Moisture		86.1	2.2	1.6	86.1	84.5	87.6	—	—
			THg conc		132.2	26.3	18.6	132.2	113.7	150.8	—	—
			MeHg conc		92.3	18.9	13.3	92.3	79.0	105.7	—	—
			%MeHg		72.7	28.7	20.3	72.7	52.4	93.0	—	—
ISRO	Angleworm Lake	*Basiaeschna janata*	Length	1	18.1	—	—	18.1	18.1	18.1	—	—
			Moisture		71.6	—	—	71.6	71.6	71.6	—	—
			THg conc		46.3	—	—	46.3	46.3	46.3	—	—
			MeHg conc		39.5	—	—	39.5	39.5	39.5	—	—
			%MeHg		85.3	—	—	85.3	85.3	85.3	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Angleworm Lake	*Cordulia shurtleffi*	Length	1	26.1	—	—	26.1	26.1	26.1	—	—
			Moisture		74.9	—	—	74.9	74.9	74.9	—	—
			THg conc		64.3	—	—	64.3	64.3	64.3	—	—
			MeHg conc		53.0	—	—	53.0	53.0	53.0	—	—
			%MeHg		82.4	—	—	82.4	82.4	82.4	—	—
ISRO	Angleworm Lake	*Didymops transversa*	Length	2	27.0	1.0	0.7	27.0	26.3	27.7	—	—
			Moisture		74.3	1.0	0.7	74.3	73.6	75.1	—	—
			THg conc		47.8	0.7	0.5	47.8	47.3	48.3	—	—
			MeHg conc		35.2	6.5	4.6	35.2	30.6	39.8	—	—
			%MeHg		73.5	12.5	8.8	73.5	64.7	82.3	—	—
ISRO	Angleworm Lake	*Dromogomphus spinosus*	Length	12	34.3	0.7	0.2	34.3	33.1	35.7	0.7	0.2
			Moisture		82.7	3.0	0.9	81.9	78.4	87.4	-1.1	0.1
			THg conc		51.3	10.4	3.0	47.6	38.1	72.7	0.0	0.9
			MeHg conc		20.9	7.9	2.3	21.0	9.3	37.9	0.7	0.6
			%MeHg		42.5	17.5	5.0	45.0	18.3	71.8	-0.9	-0.1
ISRO	Angleworm Lake	*Epitheca spinigera*	Length	4	23.8	0.9	0.4	23.5	23.2	25.1	1.7	1.4
			Moisture		75.8	0.8	0.4	75.9	74.8	76.8	1.4	-0.4
			THg conc		48.1	6.4	3.2	46.3	42.5	57.3	2.8	1.5
			MeHg conc		36.9	7.8	3.9	35.1	29.7	47.5	0.6	1.1
			%MeHg		76.1	6.9	3.5	75.9	69.8	82.9	-5.7	0.0

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Angleworm Lake	*Gomphus exilis*	Length	31	26.8	0.6	0.1	26.9	24.9	28.0	3.5	-1.0
			Moisture		80.6	8.1	1.4	81.1	40.0	88.4	21.8	-4.3
			THg conc		51.3	12.5	2.2	48.7	37.4	107.8	13.9	3.2
			MeHg conc		35.9	14.8	2.6	34.2	4.7	89.3	5.1	1.4
			%MeHg		68.0	20.7	3.7	70.5	9.8	110.5	1.4	-0.9
ISRO	Angleworm Lake	*Gomphus lividus*	Length	19	25.6	1.6	0.3	25.4	22.7	31.4	7.2	1.9
			Moisture		74.3	2.2	0.4	73.7	72.2	82.5	8.2	2.5
			THg conc		53.0	16.0	3.7	48.4	33.6	101.8	3.9	1.7
			MeHg conc		40.9	13.8	2.8	37.7	23.4	81.5	2.3	1.5
			%MeHg		78.6	13.7	3.1	80.9	55.0	107.8	-0.4	0.2
ISRO	Angleworm Lake	*Gomphus spicatus*	Length	20	31.3	1.8	0.4	31.1	28.4	36.0	1.0	0.6
			Moisture		78.8	4.3	0.9	76.6	73.3	86.2	-1.5	0.5
			THg conc		45.4	6.4	1.4	44.8	35.1	58.9	0.0	0.5
			MeHg conc		27.7	5.2	1.1	26.5	20.7	38.2	-0.5	0.7
			%MeHg		61.5	8.8	2.0	60.2	50.0	84.9	1.7	1.3
ISRO	Angleworm Lake	*Hagenius brevistylus*	Length	1	22.9	—	—	22.9	22.9	22.9	—	—
			Moisture		72.8	—	—	72.8	72.8	72.8	—	—
			THg conc		34.3	—	—	34.3	34.3	34.3	—	—
			MeHg conc		28.5	—	—	28.5	28.5	28.5	—	—
			%MeHg		83.2	—	—	83.2	83.2	83.2	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Angleworm Lake	*Ladona julia*	Length	4	23.4	0.9	0.4	23.5	22.3	24.4	0.6	-0.5
			Moisture		81.1	2.1	1.1	81.6	78.4	83.0	-0.9	-0.8
			THg conc		60.0	4.6	2.3	60.2	55.1	64.7	-4.5	-0.1
			MeHg conc		50.5	2.2	1.1	50.5	47.8	53.2	0.6	0.0
			%MeHg		84.5	7.8	3.9	85.8	73.9	92.5	1.2	-0.9
ISRO	Lake Harvey	*Aeshna eremita*	Length	2	33.4	10.4	7.4	33.4	26.1	40.8	—	—
			Moisture		78.1	3.8	2.7	78.1	75.5	80.8	—	—
			THg conc		46.0	15.7	11.1	46.0	34.9	57.1	—	—
			MeHg conc		32.8	0.5	0.3	32.8	32.5	33.2	—	—
			%MeHg		76.0	27.0	19.1	76.0	56.9	95.1	—	—
ISRO	Lake Harvey	*Aeshna umbrosa*	Length	2	28.4	5.1	3.6	28.4	24.8	32.0	—	—
			Moisture		89.3	5.6	4.0	89.3	85.4	93.3	—	—
			THg conc		195.3	12.3	8.7	195.3	186.6	204.0	—	—
			MeHg conc		176.4	1.3	0.9	176.4	175.6	177.3	—	—
			%MeHg		90.5	5.1	3.6	90.5	86.9	94.1	—	—
ISRO	Lake Harvey	*Basiaeschna janata*	Length	1	34.5	—	—	34.5	34.5	34.5	—	—
			Moisture		75.4	—	—	75.4	75.4	75.4	—	—
			THg conc		171.3	—	—	171.3	171.3	171.3	—	—
			MeHg conc		154.0	—	—	154.0	154.0	154.0	—	—
			%MeHg		89.9	—	—	89.9	89.9	89.9	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Lake Harvey	*Cordulia shurtleffi*	Length	2	21.4	0.1	0.1	21.4	21.4	21.5	—	—
			Moisture		82.9	1.7	1.2	82.9	81.7	84.0	—	—
			THg conc		188.2	38.3	27.1	188.2	161.2	215.3	—	—
			MeHg conc		148.4	46.6	33.0	148.4	115.4	181.3	—	—
			%MeHg		77.9	8.9	6.3	77.9	71.6	84.2	—	—
ISRO	Lake Harvey	*Didymops transversa*	Length	14	23.3	3.3	0.9	25.1	17.6	27.4	-1.6	-0.4
			Moisture		77.8	1.7	0.5	78.5	75.1	80.3	-1.0	-0.6
			THg conc		150.7	26.8	7.2	154.0	96.4	212.0	2.0	0.2
			MeHg conc		152.5	28.0	7.5	156.4	90.0	204.8	1.0	-0.5
			%MeHg		101.1	6.9	1.8	100.2	90.7	110.5	-1.4	0.1
ISRO	Lake Harvey	*Epitheca spinigera*	Length	3	23.4	0.6	0.3	23.4	22.9	24.0	-4.6	0.2
			Moisture		80.8	3.8	1.9	81.3	75.8	84.8	-0.1	-0.6
			THg conc		103.9	14.8	8.5	110.3	87.0	114.5	—	-1.6
			MeHg conc		98.2	27.8	13.9	91.2	73.4	136.8	1.4	1.2
			%MeHg		82.3	8.2	4.7	84.4	73.3	89.4	—	-1.0
ISRO	Lake Harvey	*Gomphus exilis*	Length	1	24.4	—	—	24.4	24.4	24.4	—	—
			Moisture		84.6	—	—	84.6	84.6	84.6	—	—
			THg conc		119.8	—	—	119.8	119.8	119.8	—	—
			MeHg conc		102.5	—	—	102.5	102.5	102.5	—	—
			%MeHg		85.6	—	—	85.6	85.6	85.6	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Lake Harvey	*Gomphus spicatus*	Length	35	29.3	3.3	0.5	30.9	19.6	32.8	0.2	-1.0
			Moisture		81.3	3.0	0.5	81.3	72.8	87.1	0.4	-0.5
			THg conc		94.3	22.2	3.8	98.6	8.4	125.6	5.6	-1.9
			MeHg conc		84.6	82.6	13.2	71.6	4.3	533.9	24.0	4.5
			%MeHg		68.5	20.4	3.4	75.5	11.3	101.2	1.3	-1.2
ISRO	Lake Harvey	*Hagenius brevistylus*	Length	1	30.2	—	—	30.2	30.2	30.2	—	—
			Moisture		76.3	—	—	76.3	76.3	76.3	—	—
			THg conc		96.5	—	—	96.5	96.5	96.5	—	—
			MeHg conc		87.9	—	—	87.9	87.9	87.9	—	—
			%MeHg		91.1	—	—	91.1	91.1	91.1	—	—
ISRO	Lake Harvey	*Ladona julia*	Length	1	22.6	1.3	0.7	22.7	21.0	23.9	-3.4	-0.3
			Moisture		82.5	0.8	0.4	82.1	82.0	83.4	—	1.6
			THg conc		105.4	—	—	105.4	105.4	105.4	—	—
			MeHg conc		132.9	50.4	25.2	147.5	60.2	176.4	2.9	-1.5
			%MeHg		57.1	—	—	57.1	57.1	57.1	—	—
ISRO	Lake Richie	*Aeshna umbrosa*	Length	1	30.4	—	—	30.4	30.4	30.4	—	—
			Moisture		91.1	—	—	91.1	91.1	91.1	—	—
			THg conc		134.0	—	—	134.0	134.0	134.0	—	—
			MeHg conc		98.2	—	—	98.2	98.2	98.2	—	—
			%MeHg		73.2	—	—	73.2	73.2	73.2	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Lake Richie	*Cordulia shurtleffi*	Length	1	22.4	—	—	22.4	22.4	22.4	—	—
			Moisture		75.4	—	—	75.4	75.4	75.4	—	—
			THg conc		63.6	—	—	63.6	63.6	63.6	—	—
			MeHg conc		53.0	—	—	53.0	53.0	53.0	—	—
			%MeHg		83.3	—	—	83.3	83.3	83.3	—	—
ISRO	Lake Richie	*Dromogomphus spinosus*	Length	10	34.2	1.2	0.4	34.0	32.5	35.8	-1.5	0.0
			Moisture		81.1	1.4	0.5	81.3	79.0	83.2	-1.3	-0.2
			THg conc		47.5	7.1	2.3	46.4	37.4	65.3	5.1	1.8
			MeHg conc		24.9	5.5	1.7	23.5	18.8	38.7	4.9	2.0
			%MeHg		52.2	5.5	1.7	50.1	45.7	60.7	-1.3	0.5
ISRO	Lake Richie	*Epitheca spinigera*	Length	12	23.7	0.4	0.1	23.6	23.2	24.4	-0.3	0.5
			Moisture		80.4	1.9	0.6	80.5	75.5	83.4	3.7	-1.3
			THg conc		81.9	15.8	4.6	79.1	63.5	120.5	2.2	1.3
			MeHg conc		54.5	16.0	4.6	53.9	35.3	81.6	-1.4	0.3
			%MeHg		68.7	22.8	6.6	62.8	30.8	104.5	-1.0	0.2
ISRO	Lake Richie	*Gomphus exilis*	Length	10	26.7	0.8	0.2	26.7	25.5	27.9	-0.5	-0.1
			Moisture		78.1	2.0	0.6	79.1	74.6	80.2	-0.8	-0.9
			THg conc		48.0	7.4	2.3	48.8	37.2	62.2	0.3	0.3
			MeHg conc		29.3	8.3	2.6	25.5	18.8	45.7	0.4	1.0
			%MeHg		60.4	10.3	3.3	61.8	47.9	75.3	-1.5	0.1

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Lake Richie	*Gomphus spicatus*	Length	47	32.3	1.8	0.3	32.5	24.9	35.0	10.7	-2.9
			Moisture		79.2	3.7	0.5	79.1	61.6	84.4	9.7	-2.2
			THg conc		54.3	16.5	2.4	50.8	28.3	95.6	0.1	0.8
			MeHg conc		39.9	16.0	2.3	36.3	15.3	97.3	2.8	1.4
			%MeHg		74.8	22.1	3.2	76.3	35.0	132.0	0.0	0.3
ISRO	Lake Richie	*Hagenius brevistylus*	Length	5	23.6	8.2	3.6	19.3	17.9	37.6	3.5	1.9
			Moisture		75.5	6.7	3.0	76.8	67.8	83.7	-2.2	-0.1
			THg conc		86.7	45.3	20.3	72.4	50.8	164.0	3.2	1.8
			MeHg conc		33.2	20.3	9.1	35.0	11.5	64.5	1.0	0.9
			%MeHg		48.5	34.5	15.4	59.6	11.9	89.0	-2.5	-0.2
ISRO	Lake Richie	*Ladona julia*	Length	14	23.9	0.7	0.2	23.9	23.0	25.6	1.4	1.0
			Moisture		81.7	1.3	0.4	81.6	79.3	84.0	-0.4	-0.1
			THg conc		94.5	38.8	10.4	93.3	37.4	146.1	-1.5	-0.1
			MeHg conc		66.8	30.3	8.1	61.3	25.4	115.0	-1.1	0.3
			%MeHg		70.4	9.9	2.6	70.7	48.9	83.6	0.2	-0.7
ISRO	Sargent Lake	*Aeshna umbrosa*	Length	1	24.5	—	—	24.5	24.5	24.5	—	—
			Moisture		75.8	—	—	75.8	75.8	75.8	—	—
			THg conc		75.2	—	—	75.2	75.2	75.2	—	—
			MeHg conc		54.0	—	—	54.0	54.0	54.0	—	—
			%MeHg		71.8	—	—	71.8	71.8	71.8	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Sargent Lake	*Basiaeschna janata*	Length	6	37.0	2.3	0.9	36.4	35.1	41.6	5.1	2.2
			Moisture		78.4	4.2	1.7	78.0	74.2	83.0	-2.9	0.1
			THg conc		71.7	9.8	4.0	72.9	55.4	81.8	0.3	-0.9
			MeHg conc		69.2	15.1	6.2	70.9	43.2	85.4	1.2	-1.0
			%MeHg		95.7	10.8	4.4	97.1	77.9	106.5	-0.1	-0.8
ISRO	Sargent Lake	*Didymops transversa*	Length	28	26.9	0.8	0.1	27.0	25.1	28.2	-0.7	-0.3
			Moisture		74.5	3.0	0.6	73.3	71.3	83.2	1.0	1.2
			THg conc		57.5	14.8	2.8	55.6	41.2	117.4	9.8	2.7
			MeHg conc		40.0	9.8	1.9	38.8	19.2	71.5	3.1	1.1
			%MeHg		70.9	14.0	2.6	72.9	35.2	99.8	1.5	-0.8
ISRO	Sargent Lake	*Dromogomphus spinosus*	Length	13	33.6	0.7	0.2	33.5	32.6	35.1	-0.3	0.4
			Moisture		79.4	2.8	0.8	80.3	71.8	82.4	4.3	-1.9
			THg conc		53.5	11.0	3.1	51.6	41.8	80.2	1.7	1.3
			MeHg conc		27.9	6.9	1.9	28.0	16.4	42.0	0.4	0.5
			%MeHg		53.5	15.7	4.4	51.5	32.5	85.4	0.6	0.9
ISRO	Sargent Lake	*Epitheca spinigera*	Length	1	23.9	—	—	23.9	23.9	23.9	—	—
			Moisture		76.6	—	—	76.6	76.6	76.6	—	—
			THg conc		87.9	—	—	87.9	87.9	87.9	—	—
			MeHg conc		80.4	—	—	80.4	80.4	80.4	—	—
			%MeHg		91.4	—	—	91.4	91.4	91.4	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Sargent Lake	*Gomphus exilis*	Length	20	26.3	0.6	0.1	26.2	25.4	28.0	1.7	1.1
			Moisture		78.2	1.5	0.3	77.9	75.9	81.0	-1.0	0.4
			THg conc		55.0	15.4	3.4	51.3	37.9	103.7	5.0	2.1
			MeHg conc		35.1	7.7	1.7	34.7	21.8	46.4	-1.2	-0.1
			%MeHg		66.3	17.4	3.9	68.0	40.6	95.6	-1.2	0.1
ISRO	Sargent Lake	*Gomphus lividus*	Length	2	26.8	0.8	0.5	26.8	26.2	27.3	—	—
			Moisture		72.2	1.6	1.1	72.2	71.1	73.3	—	—
			THg conc		47.0	0.5	0.4	47.0	46.7	47.4	—	—
			MeHg conc		29.3	6.0	4.3	29.3	25.0	33.6	—	—
			%MeHg		62.4	13.6	9.6	62.4	52.8	72.0	—	—
ISRO	Sargent Lake	*Gomphus spicatus*	Length	67	30.9	1.9	0.2	30.9	25.8	34.4	-0.6	-0.3
			Moisture		77.8	3.0	0.4	77.0	73.4	85.7	-0.5	0.7
			THg conc		58.0	12.7	1.5	57.6	35.9	95.6	1.6	1.1
			MeHg conc		37.8	13.7	1.7	34.8	9.1	79.5	1.4	1.0
			%MeHg		65.1	17.3	2.1	64.8	17.9	102.9	-0.2	0.0
ISRO	Sargent Lake	*Hagenius brevistylus*	Length	1	23.1	—	—	23.1	23.1	23.1	—	—
			Moisture		69.8	—	—	69.8	69.8	69.8	—	—
			THg conc		27.9	—	—	27.9	27.9	27.9	—	—
			MeHg conc		23.5	—	—	23.5	23.5	23.5	—	—
			%MeHg		84.3	—	—	84.3	84.3	84.3	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake	*Aeshna interrupta*	Length	1	30.0	—	—	30.0	30.0	30.0	—	—
			Moisture		77.6	—	—	77.6	77.6	77.6	—	—
			THg conc		68.5	—	—	68.5	68.5	68.5	—	—
			MeHg conc		51.3	—	—	51.3	51.3	51.3	—	—
			%MeHg		74.9	—	—	74.9	74.9	74.9	—	—
PIRO	Beaver Lake	*Anax junius*	Length	1	44.5	—	—	44.5	44.5	44.5	—	—
			Moisture		80.9	—	—	80.9	80.9	80.9	—	—
			THg conc		70.2	—	—	70.2	70.2	70.2	—	—
			MeHg conc		38.0	—	—	38.0	38.0	38.0	—	—
			%MeHg		54.1	—	—	54.1	54.1	54.1	—	—
PIRO	Beaver Lake	*Basiaeschna janata*	Length	16	30.6	2.6	0.6	30.6	23.7	35.5	2.2	-0.4
			Moisture		74.1	2.8	0.7	73.2	70.9	81.1	1.5	1.4
			THg conc		100.9	27.3	6.6	106.2	66.5	146.3	-1.7	0.2
			MeHg conc		86.3	26.9	6.5	91.3	26.3	132.0	0.1	-0.4
			%MeHg		83.9	18.9	4.7	83.1	32.4	109.2	2.6	-1.1
PIRO	Beaver Lake	*Boyeria vinosa*	Length	4	26.5	4.1	2.1	26.4	22.3	31.0	-4.4	0.1
			Moisture		79.5	7.2	3.6	76.5	74.7	90.1	3.6	1.9
			THg conc		50.1	15.8	7.9	51.6	33.2	64.0	-5.1	-0.2
			MeHg conc		43.1	14.1	7.1	45.2	26.7	55.4	-3.9	-0.4
			%MeHg		86.9	17.0	8.5	86.3	66.8	108.4	1.4	0.2

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake	*Didymops transversa*	Length	35	26.7	3.8	0.6	25.3	22.4	35.1	-0.1	1.2
			Moisture		79.4	3.3	0.6	78.9	74.6	92.6	6.7	2.1
			THg conc		83.9	33.3	5.6	77.6	46.1	224.3	8.7	2.6
			MeHg conc		56.2	30.7	5.2	50.9	20.9	188.1	9.4	2.6
			%MeHg		67.9	21.9	3.7	74.1	17.1	124.5	0.6	-0.2
PIRO	Beaver Lake	*Dromogomphus spinosus*	Length	34	33.2	0.9	0.1	33.3	30.6	34.5	1.0	-0.6
			Moisture		79.5	2.0	0.4	79.4	75.0	83.3	-0.3	0.2
			THg conc		65.3	17.0	2.9	62.1	44.1	126.4	5.8	2.2
			MeHg conc		40.4	9.2	1.6	39.2	21.4	62.2	0.0	0.4
			%MeHg		63.8	14.6	2.5	64.4	34.8	91.7	-0.5	-0.5
PIRO	Beaver Lake	*Epitheca cynosura*	Length	12	20.3	0.8	0.2	20.4	19.1	21.6	-1.6	0.0
			Moisture		11.2	228.0	65.8	75.9	-712.7	82.3	12.0	-3.5
			THg conc		107.2	61.2	17.7	88.4	58.5	288.1	8.1	2.7
			MeHg conc		98.5	58.0	16.7	77.6	53.2	267.9	7.6	2.6
			%MeHg		91.2	5.5	1.6	90.3	84.5	100.3	-0.8	0.6
PIRO	Beaver Lake	*Epitheca princeps*	Length	3	27.7	0.3	0.2	27.7	27.4	28.1	—	0.7
			Moisture		78.1	1.9	1.1	77.7	76.5	80.1	—	1.0
			THg conc		91.0	32.6	18.8	87.1	60.5	125.4	—	0.5
			MeHg conc		85.8	25.8	14.9	98.8	56.0	102.4	—	-1.7
			%MeHg		96.0	16.1	9.3	92.7	81.7	113.5	—	0.9

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake	*Epitheca spinigera*	Length	2	20.4	0.5	0.4	20.4	20.1	20.8	—	—
			Moisture		76.9	0.0	0.0	76.9	76.9	76.9	—	—
			THg conc		111.8	51.6	36.5	111.8	75.4	148.3	—	—
			MeHg conc		101.5	48.8	34.5	101.5	67.0	136.0	—	—
			%MeHg		90.3	1.9	1.4	90.3	88.9	91.7	—	—
PIRO	Beaver Lake	*Gomphus adelphus*	Length	1	24.4	—	—	24.4	24.4	24.4	—	—
			Moisture		80.0	—	—	80.0	80.0	80.0	—	—
			THg conc		36.8	—	—	36.8	36.8	36.8	—	—
			MeHg conc		37.8	—	—	37.8	37.8	37.8	—	—
			%MeHg		102.9	—	—	102.9	102.9	102.9	—	—
PIRO	Beaver Lake	*Gomphus exilis*	Length	49	25.9	1.3	0.2	25.9	20.6	28.6	4.6	-1.1
			Moisture		80.9	3.8	0.5	80.2	74.4	90.8	-0.2	0.5
			THg conc		69.3	20.9	3.0	62.8	36.1	137.2	1.3	1.1
			MeHg conc		54.7	19.6	2.8	52.2	22.2	134.9	5.6	1.8
			%MeHg		79.9	16.2	2.3	82.0	32.8	101.0	0.5	-0.9
PIRO	Beaver Lake	*Hagenius brevistylus*	Length	19	35.6	2.2	0.5	35.7	29.5	38.6	2.3	-1.1
			Moisture		73.8	3.1	0.7	73.4	66.2	81.9	3.0	0.3
			THg conc		87.3	30.1	6.9	90.0	39.7	177.6	3.7	1.4
			MeHg conc		68.4	23.7	5.4	73.4	21.0	112.3	0.0	-0.5
			%MeHg		79.4	19.5	4.5	87.8	35.1	99.9	0.5	-1.4

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake	*Macromia illnoiensis*	Length	21	27.0	1.8	0.4	27.3	22.0	29.2	3.3	-1.7
			Moisture		75.8	3.0	0.6	74.9	72.0	83.0	0.6	1.0
			THg conc		76.4	27.4	6.0	70.0	46.1	145.5	0.8	1.2
			MeHg conc		56.3	26.9	5.9	54.2	15.3	135.6	3.0	1.3
			%MeHg		72.7	20.4	4.5	80.1	33.2	105.8	-0.9	-0.4
PIRO	Chapel Lake	*Aeshna interrupta*	Length	1	30.2	—	—	30.2	30.2	30.2	—	—
			Moisture		82.5	—	—	82.5	82.5	82.5	—	—
			THg conc		126.6	—	—	126.6	126.6	126.6	—	—
			MeHg conc		116.8	—	—	116.8	116.8	116.8	—	—
			%MeHg		92.3	—	—	92.3	92.3	92.3	—	—
PIRO	Chapel Lake	*Basiaeschna janata*	Length	3	16.6	3.6	2.1	15.2	13.9	20.7	—	1.5
			Moisture		78.2	8.5	4.9	73.4	73.2	88.1	—	1.7
			THg conc		200.9	72.0	41.6	179.8	141.8	281.1	—	1.2
			MeHg conc		184.0	72.3	41.7	154.5	131.2	266.4	—	1.5
			%MeHg		92.2	18.1	10.5	94.8	73.0	108.9	—	-0.6
PIRO	Chapel Lake	*Cordulegaster maculata*	Length	18	29.6	3.8	0.9	29.8	22.0	36.3	0.1	-0.1
			Moisture		77.9	3.7	0.9	78.3	72.4	87.6	2.0	0.9
			THg conc		293.7	83.7	19.7	261.2	184.6	481.5	0.0	0.9
			MeHg conc		265.5	91.0	21.5	241.0	147.1	478.1	0.5	1.0
			%MeHg		90.6	16.1	3.8	96.4	50.8	108.0	0.9	-1.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Chapel Lake	*Didymops transversa*	Length	6	24.9	0.4	0.2	24.9	24.2	25.4	0.6	-0.7
			Moisture		79.7	0.4	0.2	79.6	79.2	80.3	-1.5	0.4
			THg conc		151.7	43.9	17.9	129.5	114.3	213.0	-1.7	0.9
			MeHg conc		122.3	56.0	22.9	100.8	66.0	210.7	-0.6	0.9
			%MeHg		78.2	16.9	6.9	78.7	54.2	104.0	0.6	0.2
PIRO	Chapel Lake	*Epitheca spinigera*	Length	2	19.2	0.6	0.4	19.2	18.8	19.6	—	—
			Moisture		—	—	—	—	—	—	—	—
			THg conc		191.1	86.3	61.0	191.1	130.1	252.2	—	—
			MeHg conc		198.6	115.9	82.0	198.6	116.6	280.6	—	—
			%MeHg		100.5	15.3	10.8	100.5	89.6	111.3	—	—
PIRO	Chapel Lake	*Gomphus exilis*	Length	13	24.7	2.5	0.7	25.8	19.8	27.3	0.1	-1.3
			Moisture		80.9	2.7	0.8	81.2	76.6	87.0	1.1	0.6
			THg conc		134.4	51.0	14.1	117.7	69.7	234.2	-0.3	0.9
			MeHg conc		128.5	52.0	14.4	109.6	65.7	244.6	0.5	1.1
			%MeHg		95.3	6.2	1.7	94.3	86.5	104.5	-1.2	0.0
PIRO	Chapel Lake	*Gomphus spicatus*	Length	20	29.0	2.9	0.6	29.8	24.4	33.6	-1.4	-0.3
			Moisture		78.7	4.5	1.0	78.6	62.9	85.9	7.5	-2.0
			THg conc		106.6	20.9	4.7	106.1	73.4	150.1	-0.5	0.2
			MeHg conc		68.4	20.4	4.5	64.9	32.8	133.4	4.5	1.6
			%MeHg		64.7	20.8	4.7	62.6	32.9	125.3	2.7	1.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Chapel Lake	*Hagenius brevistylus*	Length	7	31.4	6.9	2.6	35.2	18.3	37.2	1.3	-1.3
			Moisture		74.1	3.5	1.3	74.4	67.6	78.6	1.8	-0.9
			THg conc		149.7	37.3	14.1	147.7	108.9	222.8	2.3	1.3
			MeHg conc		139.5	38.9	14.7	132.3	98.0	213.3	1.5	1.2
			%MeHg		93.1	9.2	3.5	92.8	76.5	104.1	0.9	-0.7
PIRO	Grand Sable Lake	*Aeshna interrupta*	Length	1	31.1	—	—	31.1	31.1	31.1	—	—
			Moisture		84.6	—	—	84.6	84.6	84.6	—	—
			THg conc		47.7	—	—	47.7	47.7	47.7	—	—
			MeHg conc		28.5	—	—	28.5	28.5	28.5	—	—
			%MeHg		59.8	—	—	59.8	59.8	59.8	—	—
PIRO	Grand Sable Lake	*Basiaeschna janata*	Length	10	32.2	5.4	1.6	33.7	16.5	36.4	9.4	-3.0
			Moisture		76.4	4.9	1.5	77.0	64.3	82.3	3.1	-1.5
			THg conc		111.4	27.4	8.3	104.4	76.9	161.0	-0.7	0.7
			MeHg conc		98.3	29.8	9.4	96.0	56.2	147.6	-0.5	0.3
			%MeHg		85.9	18.8	5.9	90.5	50.0	109.2	-0.4	-0.7
PIRO	Grand Sable Lake	*Boyeria vinosa*	Length	6	31.2	0.4	0.1	31.2	30.7	31.9	2.7	0.6
			Moisture		82.8	4.1	1.7	83.1	75.2	86.7	2.8	-1.5
			THg conc		110.4	24.0	9.8	113.7	80.2	138.9	-2.0	-0.2
			MeHg conc		74.1	29.0	11.9	75.5	37.2	107.9	-2.4	-0.1
			%MeHg		66.7	21.2	8.6	66.9	40.5	90.8	-2.0	-0.1

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Grand Sable Lake	*Cordulegaster maculata*	Length	5	33.2	3.5	1.6	32.4	29.9	38.2	-1.1	0.7
			Moisture		79.9	6.0	2.7	82.0	69.9	84.6	2.8	-1.7
			THg conc		497.8	304.7	136.3	521.4	78.9	933.5	1.7	0.1
			MeHg conc		404.5	202.5	90.6	488.5	72.8	585.4	1.9	-1.4
			%MeHg		86.1	14.0	6.3	92.3	62.7	97.9	2.5	-1.6
PIRO	Grand Sable Lake	*Didymops transversa*	Length	4	25.8	1.1	0.5	25.9	24.7	26.9	-4.3	-0.1
			Moisture		80.7	2.6	1.3	81.5	77.1	82.9	1.6	-1.4
			THg conc		125.5	8.1	4.0	122.1	120.4	137.6	3.8	1.9
			MeHg conc		81.6	8.5	4.3	82.9	70.3	90.3	0.5	-0.8
			%MeHg		65.2	8.0	4.0	64.1	58.4	74.1	-4.5	0.3
PIRO	Grand Sable Lake	*Dromogomphus spinosus*	Length	36	32.8	2.5	0.4	33.7	24.4	35.9	2.1	-1.4
			Moisture		78.1	4.0	0.7	77.4	72.2	85.1	-1.2	0.3
			THg conc		67.0	12.9	2.2	64.4	47.8	107.4	1.8	1.1
			MeHg conc		56.9	16.4	2.7	53.2	33.4	108.4	2.4	1.3
			%MeHg		84.7	15.1	2.5	86.1	53.9	111.0	-0.9	-0.3
PIRO	Grand Sable Lake	*Epitheca spinigera*	Length	4	20.0	0.7	0.3	20.1	19.2	20.8	-3.3	-0.2
			Moisture		81.0	1.4	0.7	81.1	79.2	82.5	-1.2	-0.3
			THg conc		111.6	42.3	21.2	100.2	73.8	172.2	2.7	1.5
			MeHg conc		89.2	53.1	26.5	72.9	46.2	164.7	2.0	1.5
			%MeHg		77.1	21.3	10.7	83.0	46.5	95.6	2.6	-1.5

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Grand Sable Lake	*Gomphus adelphus*	Length	8	26.0	0.7	0.3	25.9	25.0	27.3	0.3	0.6
			Moisture		79.5	2.0	0.7	79.4	76.5	82.1	-1.2	0.0
			THg conc		79.5	35.0	12.4	63.1	54.5	149.4	1.2	1.5
			MeHg conc		57.5	19.6	6.9	51.2	40.0	99.2	2.7	1.7
			%MeHg		77.4	20.7	7.3	81.3	36.6	104.2	1.5	-1.1
PIRO	Grand Sable Lake	*Gomphus exilis*	Length	48	25.8	1.0	0.1	26.0	22.3	27.8	2.1	-1.0
			Moisture		79.0	3.8	0.5	78.6	72.9	87.8	-0.7	0.3
			THg conc		72.3	21.5	3.1	69.4	20.8	125.1	0.7	0.4
			MeHg conc		57.4	20.1	2.5	52.3	27.8	121.3	1.0	1.1
			%MeHg		87.1	28.9	4.2	90.8	38.3	227.8	11.2	2.3
PIRO	Grand Sable Lake	*Gomphus spicatus*	Length	3	32.1	1.3	0.8	31.4	31.2	33.6	—	1.7
			Moisture		81.8	1.6	0.9	82.5	80.0	82.9	—	-1.6
			THg conc		138.1	104.7	60.4	83.6	71.9	258.8	—	1.7
			MeHg conc		99.8	50.7	29.3	72.9	68.2	158.2	—	1.7
			%MeHg		81.0	17.6	10.2	87.1	61.1	94.8	—	-1.4
PIRO	Grand Sable Lake	*Macromia illnoiensis*	Length	7	27.1	0.6	0.2	27.1	26.0	28.0	1.3	-0.5
			Moisture		77.9	2.4	0.9	77.6	75.2	82.5	1.7	1.2
			THg conc		104.8	14.8	5.6	109.6	85.4	128.2	-0.4	0.1
			MeHg conc		88.2	21.8	8.2	85.4	49.0	118.9	1.4	-0.6
			%MeHg		84.1	16.9	6.4	91.9	49.5	95.8	3.2	-1.9

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Legion Lake	*Aeshna eremita*	Length	8	40.6	2.4	0.8	41.5	35.2	42.7	3.4	-1.8
			Moisture		80.6	3.8	1.3	79.8	76.2	86.9	-1.0	0.4
			THg conc		288.4	34.7	12.3	285.0	238.5	351.3	0.6	0.5
			MeHg conc		255.5	48.8	16.3	250.0	184.2	353.6	1.4	0.9
			%MeHg		88.3	12.4	4.4	84.8	72.1	106.3	-1.6	0.3
PIRO	Legion Lake	*Aeshna interrupta*	Length	6	35.4	3.2	1.3	36.6	30.9	38.3	-1.8	-0.7
			Moisture		84.7	4.6	1.9	85.7	77.8	91.0	0.0	-0.3
			THg conc		221.0	63.7	26.0	199.4	170.4	343.6	3.8	1.9
			MeHg conc		205.1	76.2	31.1	203.0	101.6	336.0	2.2	0.7
			%MeHg		91.9	18.0	7.3	99.0	56.1	103.4	4.9	-2.2
PIRO	Legion Lake	*Aeshna umbrosa*	Length	17	37.4	2.7	0.7	38.0	31.7	40.4	-0.2	-1.0
			Moisture		87.2	3.8	0.9	86.8	78.3	93.1	0.6	-0.4
			THg conc		276.8	106.1	25.7	237.0	112.3	543.0	1.2	1.1
			MeHg conc		261.2	117.0	28.4	219.6	108.6	555.2	1.0	1.2
			%MeHg		93.0	10.4	2.5	96.7	72.1	106.5	-0.3	-0.7
PIRO	Legion Lake	*Arigomphus cornutus*	Length	4	29.4	7.5	3.8	25.7	25.4	40.7	4.0	2.0
			Moisture		74.8	4.7	2.4	74.7	69.6	80.2	-2.4	0.1
			THg conc		109.5	108.1	54.1	59.1	48.3	271.5	4.0	2.0
			MeHg conc		39.0	9.1	4.5	40.3	27.0	48.4	0.9	-0.8
			%MeHg		54.4	27.6	13.8	61.1	15.6	79.5	1.9	-1.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Legion Lake	*Cordulia shurtleffi*	Length	19	20.5	0.4	0.1	20.4	20.1	21.7	2.8	1.6
			Moisture		85.0	2.2	0.5	84.9	81.2	91.3	2.9	1.0
			THg conc		219.6	40.9	9.4	220.9	127.3	311.2	1.3	-0.1
			MeHg conc		183.2	56.3	12.9	173.3	81.4	299.4	0.2	0.6
			%MeHg		82.0	12.6	2.9	80.9	63.9	105.3	-1.1	0.3
PIRO	Legion Lake	*Ladona julia*	Length	12	21.9	0.6	0.1	21.8	21.0	22.9	-1.3	0.0
			Moisture		83.4	1.5	0.4	83.1	81.7	87.1	1.3	1.3
			THg conc		146.0	48.3	13.9	146.7	83.2	215.4	-1.3	0.1
			MeHg conc		143.6	41.6	10.1	147.7	78.1	225.8	-0.6	0.0
			%MeHg		96.1	8.2	2.4	94.2	84.9	109.9	-0.6	0.5
PIRO	Legion Lake	*Leucorrhinia glacialis*	Length	11	17.0	0.7	0.2	17.0	15.8	17.9	-0.4	-0.6
			Moisture		85.9	1.1	0.3	85.9	84.0	87.5	-0.7	-0.2
			THg conc		250.2	36.7	11.1	257.2	201.9	328.7	0.8	0.7
			MeHg conc		234.2	39.4	11.9	231.5	166.3	323.5	2.5	0.7
			%MeHg		93.7	8.3	2.5	95.5	82.1	106.4	-1.2	-0.1
PIRO	Miners Lake	*Aeshna interrupta*	Length	11	37.7	2.8	0.8	38.8	32.2	40.1	1.3	-1.6
			Moisture		86.1	4.0	1.2	87.6	76.4	89.8	2.5	-1.6
			THg conc		120.5	29.3	8.8	113.3	85.9	196.1	4.5	1.9
			MeHg conc		95.4	44.2	13.3	95.1	32.8	208.0	4.4	1.6
			%MeHg		79.2	24.6	7.4	91.2	23.0	106.1	1.4	-1.2

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Miners Lake	*Aeshna umbrosa*	Length	22	31.7	6.5	1.4	31.6	12.9	39.8	3.4	-1.6
			Moisture		83.0	6.7	1.4	84.2	68.1	90.7	-0.3	-0.8
			THg conc		96.8	25.1	5.4	101.7	48.0	137.4	-1.1	-0.1
			MeHg conc		87.7	20.4	4.3	87.2	48.0	132.5	0.0	0.2
			%MeHg		92.0	10.4	2.2	93.1	70.2	107.5	0.0	-0.7
PIRO	Miners Lake	*Boyeria vinosa*	Length	1	32.4	—	—	32.4	32.4	32.4	—	—
			Moisture		77.8	—	—	77.8	77.8	77.8	—	—
			THg conc		243.1	—	—	243.1	243.1	243.1	—	—
			MeHg conc		143.4	—	—	143.4	143.4	143.4	—	—
			%MeHg		59.0	—	—	59.0	59.0	59.0	—	—
PIRO	Miners Lake	*Cordulegaster maculata*	Length	11	28.8	2.3	0.7	29.2	24.2	31.9	-0.1	-0.7
			Moisture		76.6	4.6	1.4	75.8	68.2	87.4	3.6	0.9
			THg conc		167.6	36.9	11.1	178.1	86.8	212.4	1.0	-1.0
			MeHg conc		128.8	28.7	8.3	124.2	86.5	181.9	-0.4	0.5
			%MeHg		77.6	17.2	5.2	75.4	44.9	99.7	-0.5	-0.6
PIRO	Miners Lake	*Ophiogomphus colubrinus*	Length	5	30.4	5.6	2.5	28.0	25.1	36.9	-3.1	0.5
			Moisture		78.3	4.2	1.9	78.7	73.1	82.4	-2.5	-0.2
			THg conc		165.0	40.9	18.3	166.3	120.2	221.1	-1.1	0.4
			MeHg conc		125.3	58.8	26.3	108.1	77.9	227.8	4.2	2.0
			%MeHg		74.6	20.5	9.2	61.3	59.1	103.0	-2.0	0.8

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Miners Lake	*Plathemis lydia*	Length	14	22.1	0.5	0.1	22.0	21.1	23.2	0.3	0.3
			Moisture		81.0	2.1	0.6	80.6	78.1	85.7	0.1	0.5
			THg conc		114.9	20.7	5.5	112.3	80.3	151.4	-0.7	0.1
			MeHg conc		101.4	26.6	6.9	108.5	37.0	144.7	1.6	-1.1
			%MeHg		86.3	14.9	4.0	91.0	46.1	102.6	3.6	-1.9
PIRO	Miners Lake	*Somatochlora williamsoni*	Length	1	22.4	—	—	22.4	22.4	22.4	—	—
			Moisture		80.8	—	—	80.8	80.8	80.8	—	—
			THg conc		192.6	—	—	192.6	192.6	192.6	—	—
			MeHg conc		179.2	—	—	179.2	179.2	179.2	—	—
			%MeHg		93.0	—	—	93.0	93.0	93.0	—	—
SLBE	Bass Lake (Benzie)	*Basiaeschna janata*	Length	14	28.4	2.0	0.5	28.1	26.2	32.4	0.3	1.0
			Moisture		76.9	6.1	1.6	74.6	69.9	86.6	-0.9	0.9
			THg conc		81.3	40.6	10.9	59.0	41.2	164.2	-0.6	0.9
			MeHg conc		70.0	41.2	11.0	51.3	22.3	146.1	-0.9	0.8
			%MeHg		83.1	14.2	3.8	86.2	42.6	100.5	4.9	-1.9
SLBE	Bass Lake (Benzie)	*Boyeria vinosa*	Length	1	28.0	—	—	28.0	28.0	28.0	—	—
			Moisture		82.7	—	—	82.7	82.7	82.7	—	—
			THg conc		127.9	—	—	127.9	127.9	127.9	—	—
			MeHg conc		107.7	—	—	107.7	107.7	107.7	—	—
			%MeHg		84.2	—	—	84.2	84.2	84.2	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Benzie)	*Celithemis elisa*	Length	1	15.2	—	—	15.2	15.2	15.2	—	—
			Moisture		81.9	—	—	81.9	81.9	81.9	—	—
			THg conc		207.9	—	—	207.9	207.9	207.9	—	—
			MeHg conc		175.1	—	—	175.1	175.1	175.1	—	—
			%MeHg		84.2	—	—	84.2	84.2	84.2	—	—
SLBE	Bass Lake (Benzie)	*Didymops transversa*	Length	12	24.6	0.5	0.1	24.5	24.0	25.9	2.0	1.3
			Moisture		75.6	2.2	0.6	74.6	73.4	81.2	3.0	1.7
			THg conc		67.0	32.8	9.5	59.9	31.2	141.3	1.0	1.1
			MeHg conc		57.1	33.6	9.7	51.0	16.6	151.3	6.2	2.2
			%MeHg		84.8	18.6	5.4	82.8	53.1	108.2	-1.2	-0.1
SLBE	Bass Lake (Benzie)	*Dromogomphus spinosus*	Length	10	32.3	1.0	0.3	32.3	30.4	33.9	0.9	-0.2
			Moisture		81.8	3.3	1.0	81.8	75.2	86.3	0.7	-0.8
			THg conc		44.1	11.5	3.6	44.5	25.0	61.9	-0.8	-0.1
			MeHg conc		29.5	11.1	3.5	27.3	15.6	56.8	4.3	1.7
			%MeHg		66.5	12.2	3.9	64.2	45.1	91.7	1.7	0.5
SLBE	Bass Lake (Benzie)	*Epitheca cynosura*	Length	4	19.2	0.5	0.2	19.2	18.6	19.7	-2.4	-0.4
			Moisture		79.2	0.8	0.4	79.0	78.4	80.3	1.2	1.1
			THg conc		89.4	44.5	22.2	69.3	63.2	155.9	3.9	2.0
			MeHg conc		80.4	49.4	24.7	57.2	52.6	154.3	3.9	2.0
			%MeHg		86.8	8.6	4.3	84.8	78.8	99.0	2.5	1.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Benzie)	*Epitheca spinigera*	Length	6	18.4	0.6	0.3	18.5	17.5	19.0	-2.7	-0.2
			Moisture		82.3	3.0	1.2	83.4	76.9	84.9	1.9	-1.5
			THg conc		91.1	20.8	8.5	96.7	65.5	111.8	-2.3	-0.4
			MeHg conc		77.9	23.5	9.6	83.6	49.6	103.6	-2.2	-0.4
			%MeHg		84.1	7.2	2.9	86.3	73.7	92.6	-1.1	-0.6
SLBE	Bass Lake (Benzie)	*Gomphus exilis*	Length	29	24.7	0.9	0.2	24.7	22.8	26.7	-0.3	0.1
			Moisture		79.5	3.6	0.6	80.0	70.5	85.5	-0.4	-0.5
			THg conc		34.4	23.9	4.2	29.5	2.9	106.3	1.6	1.2
			MeHg conc		23.4	14.9	2.8	20.8	5.9	59.4	0.5	1.1
			%MeHg		67.2	18.1	3.4	67.2	34.4	99.5	-1.0	-0.1
SLBE	Bass Lake (Benzie)	*Gomphus graslinellus*	Length	2	22.6	3.8	2.7	22.6	19.9	25.3	—	—
			Moisture		73.5	3.5	2.5	73.5	71.0	76.0	—	—
			THg conc		73.8	34.0	24.0	73.8	49.7	97.8	—	—
			MeHg conc		85.1	59.1	41.8	85.1	43.3	126.9	—	—
			%MeHg		108.4	30.1	21.3	108.4	87.1	129.7	—	—
SLBE	Bass Lake (Benzie)	*Hagenius brevistylus*	Length	22	29.6	7.2	1.5	34.0	13.5	36.7	-0.2	-1.0
			Moisture		74.5	3.1	0.7	73.9	70.1	85.0	5.4	1.7
			THg conc		97.5	50.6	10.8	89.4	5.8	211.3	-0.3	0.4
			MeHg conc		78.5	37.5	8.0	84.2	5.5	164.8	0.2	0.2
			%MeHg		83.3	13.6	2.9	83.8	56.7	105.7	0.0	-0.6

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Benzie)	*Libellula vibrans*	Length	2	21.6	0.6	0.5	21.6	21.1	22.0	—	—
			Moisture		82.5	4.4	3.1	82.5	79.4	85.6	—	—
			THg conc		120.7	12.5	8.8	120.7	111.9	129.6	—	—
			MeHg conc		106.6	14.0	9.9	106.6	96.7	116.5	—	—
			%MeHg		88.2	2.5	1.7	88.2	86.5	89.9	—	—
SLBE	Bass Lake (Benzie)	*Macromia illnoiensis*	Length	1	26.2	—	—	26.2	26.2	26.2	—	—
			Moisture		87.1	—	—	87.1	87.1	87.1	—	—
			THg conc		76.1	—	—	76.1	76.1	76.1	—	—
			MeHg conc		80.1	—	—	80.1	80.1	80.1	—	—
			%MeHg		105.3	—	—	105.3	105.3	105.3	—	—
SLBE	Bass Lake (Leelanau)	*Basiaeschna janata*	Length	2	18.3	0.1	0.1	18.3	18.2	18.4	—	—
			Moisture		81.6	3.8	2.7	81.6	78.9	84.3	—	—
			THg conc		63.0	3.7	2.6	63.0	60.3	65.6	—	—
			MeHg conc		47.2	6.2	4.4	47.2	42.8	51.6	—	—
			%MeHg		74.8	5.4	3.8	74.8	70.9	78.6	—	—
SLBE	Bass Lake (Leelanau)	*Didymops transversa*	Length	5	24.4	0.9	0.4	24.4	23.3	25.5	-1.3	-0.2
			Moisture		76.1	2.1	0.9	76.2	72.8	78.4	1.7	-1.1
			THg conc		58.5	12.1	5.4	57.1	45.7	73.9	-2.2	0.3
			MeHg conc		55.9	13.9	6.2	51.0	41.3	73.9	-2.1	0.5
			%MeHg		95.2	7.2	3.2	99.0	85.7	102.0	-2.4	-0.7

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Leelanau)	*Dromogomphus spinosus*	Length	15	31.1	2.0	0.5	31.3	24.6	33.3	8.8	-2.6
			Moisture		81.4	4.2	1.1	80.1	74.4	87.8	-1.3	0.1
			THg conc		36.9	17.4	4.5	31.5	16.3	89.3	5.6	2.1
			MeHg conc		22.8	8.2	2.1	21.4	11.4	43.2	1.6	0.9
			%MeHg		66.8	18.5	4.8	72.9	19.0	91.9	1.9	-1.2
SLBE	Bass Lake (Leelanau)	*Epitheca cynosura*	Length	5	19.3	1.4	0.6	19.0	17.9	21.3	-1.8	0.5
			Moisture		80.8	2.2	1.0	81.9	77.4	82.6	0.2	-1.2
			THg conc		46.5	16.2	7.2	42.9	29.8	73.3	2.9	1.4
			MeHg conc		36.4	15.4	6.9	36.7	21.3	60.2	0.8	1.0
			%MeHg		77.8	15.8	7.1	82.1	53.5	91.7	0.3	-1.1
SLBE	Bass Lake (Leelanau)	*Epitheca princeps*	Length	7	24.5	0.3	0.1	24.5	24.1	25.0	-0.4	0.4
			Moisture		73.2	1.3	0.5	73.0	71.3	75.0	-0.5	0.1
			THg conc		54.4	10.8	4.1	52.8	41.7	71.0	-1.0	0.6
			MeHg conc		46.3	11.1	4.2	44.6	28.8	62.2	0.1	0.0
			%MeHg		85.0	10.8	4.1	87.6	63.7	98.3	2.7	-1.3
SLBE	Bass Lake (Leelanau)	*Gomphus exilis*	Length	2	24.3	0.4	0.3	24.3	24.0	24.5	—	—
			Moisture		82.3	0.2	0.1	82.3	82.2	82.4	—	—
			THg conc		39.9	5.9	4.1	39.9	35.8	44.0	—	—
			MeHg conc		31.9	3.4	2.4	31.9	29.5	34.3	—	—
			%MeHg		80.3	3.3	2.3	80.3	78.0	82.6	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Leelanau)	*Gomphus graslinellus*	Length	5	21.4	3.2	1.4	22.9	17.0	24.2	-2.1	-0.7
			Moisture		74.4	2.6	1.2	74.3	70.9	77.6	-0.9	-0.1
			THg conc		52.4	10.4	4.6	56.9	37.4	61.9	-1.2	-0.8
			MeHg conc		47.2	15.8	7.1	49.3	20.7	60.3	2.7	-1.6
			%MeHg		89.1	26.1	11.7	83.1	55.4	127.0	1.1	0.4
SLBE	Bass Lake (Leelanau)	*Gomphus spicatus*	Length	38	30.0	1.0	0.2	30.0	27.7	32.4	0.9	0.1
			Moisture		79.0	3.0	0.5	79.0	73.3	83.9	-1.0	0.0
			THg conc		38.9	17.6	2.9	36.4	12.2	90.0	0.7	0.8
			MeHg conc		30.4	14.2	2.3	31.0	6.8	63.3	-0.3	0.4
			%MeHg		76.9	14.6	2.4	77.5	49.3	106.7	-0.6	0.0
SLBE	Bass Lake (Leelanau)	*Hagenius brevistylus*	Length	35	30.8	6.1	1.0	33.8	16.7	35.3	0.1	-1.3
			Moisture		72.1	4.3	0.7	72.9	64.5	80.2	-0.9	0.0
			THg conc		55.0	10.7	1.8	53.5	35.3	78.0	-0.4	0.1
			MeHg conc		45.0	11.6	2.0	44.4	23.9	71.0	-0.1	0.1
			%MeHg		81.8	14.3	2.4	79.7	52.4	111.2	-0.3	-0.1
SLBE	Bass Lake (Leelanau)	*Ladona julia*	Length	5	21.6	1.2	0.6	21.8	19.5	22.8	3.3	-1.6
			Moisture		81.4	2.6	1.2	81.0	78.4	85.7	2.3	1.0
			THg conc		32.3	10.1	4.5	31.6	21.8	45.7	-1.8	0.4
			MeHg conc		23.6	11.3	5.0	23.6	11.6	38.7	-1.6	0.3
			%MeHg		70.0	13.1	5.9	74.8	53.2	84.6	-2.0	-0.4

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Leelanau)	*Macromia illnoiensis*	Length	6	25.0	0.5	0.2	24.8	24.4	25.7	-1.4	0.6
			Moisture		74.1	1.3	0.5	73.4	73.1	76.4	0.7	1.4
			THg conc		54.5	4.7	1.9	53.0	50.2	62.0	-0.4	0.9
			MeHg conc		50.6	17.3	7.0	55.7	18.1	67.0	3.2	-1.7
			%MeHg		91.9	28.1	11.5	104.6	36.1	107.9	4.8	-2.2
SLBE	Bass Lake (Leelanau)	*Progomphus obscurus*	Length	38	27.9	1.3	0.2	28.0	21.8	29.8	12.4	-2.7
			Moisture		75.5	1.9	0.3	75.7	70.0	79.7	1.3	-0.5
			THg conc		50.1	11.1	1.8	47.8	28.7	80.4	0.7	0.8
			MeHg conc		33.5	9.5	1.5	32.6	17.3	55.0	-0.6	0.4
			%MeHg		67.7	16.6	2.7	67.8	36.1	120.4	1.5	0.6
SLBE	Lake Manitou	*Basiaeschna janata*	Length	27	32.0	1.8	0.3	31.5	29.5	35.9	-0.7	0.6
			Moisture		77.2	2.7	0.5	76.6	74.2	89.2	15.1	3.5
			THg conc		77.2	15.5	3.0	75.8	44.3	103.5	-0.5	0.0
			MeHg conc		57.2	18.3	3.5	53.7	29.8	111.7	1.7	0.9
			%MeHg		74.3	17.7	3.4	72.9	39.0	109.0	-0.1	0.0
SLBE	Lake Manitou	*Didymops transversa*	Length	2	25.6	0.3	0.2	25.6	25.4	25.8	—	—
			Moisture		76.0	2.8	2.0	76.0	74.0	78.0	—	—
			THg conc		66.9	6.5	4.6	66.9	62.3	71.5	—	—
			MeHg conc		62.1	11.1	7.8	62.1	54.3	70.0	—	—
			%MeHg		92.5	7.5	5.3	92.5	87.2	97.8	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Lake Manitou	*Dromogomphus spinosus*	Length	56	31.9	1.8	0.2	31.9	28.5	35.1	-1.1	0.0
			Moisture		81.8	3.9	0.5	82.2	74.8	98.2	4.3	1.0
			THg conc		47.9	32.4	4.3	42.6	12.6	228.8	18.3	3.7
			MeHg conc		36.7	25.6	3.4	31.7	6.2	161.4	9.1	2.3
			%MeHg		74.8	21.3	2.9	75.4	22.1	128.5	0.0	-0.1
SLBE	Lake Manitou	*Epitheca cynosura*	Length	17	20.3	0.4	0.1	20.3	19.4	21.2	0.8	0.2
			Moisture		79.4	1.7	0.4	79.7	74.8	81.6	1.3	-1.1
			THg conc		38.9	11.4	2.6	33.9	21.5	62.2	-0.5	0.8
			MeHg conc		35.6	13.1	3.2	32.2	14.3	60.7	-0.2	0.8
			%MeHg		90.5	12.8	3.1	93.0	65.8	107.5	-0.3	-0.8
SLBE	Lake Manitou	*Epitheca spinigera*	Length	11	20.0	0.5	0.1	20.0	19.3	20.8	-0.8	0.3
			Moisture		77.6	2.0	0.6	77.3	74.6	82.4	2.9	1.1
			THg conc		32.3	6.4	1.9	32.7	21.8	41.2	-1.0	-0.3
			MeHg conc		23.2	4.3	1.3	23.6	16.5	32.2	0.9	0.5
			%MeHg		72.5	7.8	2.4	70.5	63.4	92.2	3.8	1.7
SLBE	Lake Manitou	*Gomphus spicatus*	Length	39	31.4	1.4	0.2	31.4	29.1	34.5	-0.8	0.3
			Moisture		80.2	2.1	0.3	80.4	76.1	84.0	-1.0	-0.2
			THg conc		29.8	15.7	2.5	23.8	11.3	73.7	1.0	1.2
			MeHg conc		23.8	15.2	2.4	18.1	4.7	65.5	1.0	1.3
			%MeHg		77.5	17.2	2.8	82.6	29.6	107.8	0.9	-0.9

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Lake Manitou	*Macromia illnoiensis*	Length	1	24.2	—	—	24.2	24.2	24.2	—	—
			Moisture		74.3	—	—	74.3	74.3	74.3	—	—
			THg conc		58.9	—	—	58.9	58.9	58.9	—	—
			MeHg conc		40.8	—	—	40.8	40.8	40.8	—	—
			%MeHg		69.2	—	—	69.2	69.2	69.2	—	—
SLBE	Round Lake	*Aeshna umbrosa*	Length	2	31.3	0.6	0.4	31.3	30.9	31.7	—	—
			Moisture		85.1	12.1	8.5	85.1	76.6	93.7	—	—
			THg conc		542.6	176.3	124.7	542.6	417.9	667.2	—	—
			MeHg conc		500.9	150.6	106.5	500.9	394.4	607.4	—	—
			%MeHg		92.7	2.4	1.7	92.7	91.0	94.4	—	—
SLBE	Round Lake	*Basiaeschna janata*	Length	3	30.4	1.2	0.7	30.5	29.2	31.5	—	-0.3
			Moisture		73.6	2.7	1.6	75.0	70.5	75.3	—	-1.7
			THg conc		41.8	18.2	10.5	42.6	23.1	59.5	—	-0.2
			MeHg conc		36.0	12.6	7.3	38.3	22.4	47.2	—	-0.8
			%MeHg		88.6	8.8	5.1	89.8	79.3	96.7	—	-0.6
SLBE	Round Lake	*Celithemis elisa*	Length	6	14.3	0.5	0.2	14.5	13.5	14.9	1.2	-1.1
			Moisture		79.9	2.6	1.1	79.4	77.2	84.8	3.0	1.5
			THg conc		32.9	14.0	5.7	30.2	16.3	51.4	-1.8	0.3
			MeHg conc		26.7	14.5	5.9	20.9	12.7	47.4	-1.6	0.8
			%MeHg		78.7	12.0	4.9	79.0	61.2	92.2	-1.0	-0.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Round Lake	*Cordulia shurtleffi*	Length	1	18.8	—	—	18.8	18.8	18.8	—	—
			Moisture		81.7	—	—	81.7	81.7	81.7	—	—
			THg conc		217.9	—	—	217.9	217.9	217.9	—	—
			MeHg conc		206.7	—	—	206.7	206.7	206.7	—	—
			%MeHg		94.9	—	—	94.9	94.9	94.9	—	—
SLBE	Round Lake	*Epitheca princeps*	Length	6	23.1	1.1	0.5	22.9	22.0	24.7	-1.5	0.5
			Moisture		73.0	2.8	1.1	72.9	69.8	76.2	-2.2	0.1
			THg conc		31.3	7.8	3.2	32.0	18.8	41.7	0.7	-0.5
			MeHg conc		22.6	8.1	3.3	21.3	11.8	36.0	1.4	0.7
			%MeHg		70.9	8.5	3.5	70.2	63.1	86.3	2.3	1.4
SLBE	Round Lake	*Epitheca spinigera*	Length	3	18.0	0.8	0.4	17.6	17.6	18.9	—	1.7
			Moisture		78.3	3.1	1.8	77.1	75.9	81.9	—	1.5
			THg conc		27.0	3.0	1.7	26.8	24.0	30.1	—	0.3
			MeHg conc		20.4	3.5	2.0	21.7	16.5	23.2	—	-1.4
			%MeHg		75.5	6.3	3.6	77.0	68.6	80.8	—	-1.0
SLBE	Round Lake	*Gomphus exilis*	Length	40	24.2	0.7	0.1	24.2	23.1	25.7	-0.7	0.4
			Moisture		81.0	3.4	0.5	81.0	73.6	86.2	-1.0	-0.3
			THg conc		30.4	11.6	1.8	30.2	9.5	49.9	-0.9	-0.1
			MeHg conc		22.2	11.4	1.8	21.9	2.5	43.5	-1.2	-0.1
			%MeHg		71.7	26.4	4.2	77.1	23.3	116.5	-0.8	-0.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Round Lake	*Gomphus spicatus*	Length	37	29.8	1.2	0.2	29.7	28.0	32.2	-0.7	0.4
			Moisture		80.6	4.0	0.7	80.4	72.5	87.6	-0.7	0.0
			THg conc		23.2	16.6	2.7	19.3	4.9	78.4	2.2	1.5
			MeHg conc		12.0	12.1	2.0	7.5	0.0	49.8	2.6	1.7
			%MeHg		49.1	26.7	4.4	53.4	0.0	102.6	-0.8	0.2
SLBE	Round Lake	*Hagenius brevistylus*	Length	2	26.0	1.6	1.1	26.0	24.8	27.1	—	—
			Moisture		74.1	7.8	5.5	74.1	68.6	79.6	—	—
			THg conc		73.5	71.7	50.7	73.5	22.8	124.1	—	—
			MeHg conc		64.7	65.4	46.2	64.7	18.4	110.9	—	—
			%MeHg		85.1	6.0	4.3	85.1	80.8	89.4	—	—
SLBE	Round Lake	*Ladona julia*	Length	8	20.0	1.2	0.4	19.8	18.5	22.4	0.9	0.9
			Moisture		80.0	2.6	0.9	80.8	75.7	82.6	-0.3	-1.1
			THg conc		87.9	75.0	26.5	75.6	11.1	228.1	0.2	0.9
			MeHg conc		70.3	63.8	22.5	52.4	5.0	181.2	-0.6	0.8
			%MeHg		74.2	16.9	6.0	75.8	45.1	98.2	0.0	-0.3
SLBE	Round Lake	*Progomphus obscurus*	Length	13	27.1	0.7	0.2	27.1	25.6	28.5	2.2	-0.1
			Moisture		76.0	2.6	0.7	76.0	72.6	81.4	0.0	0.5
			THg conc		28.2	6.4	1.8	26.6	20.5	40.4	-0.6	0.6
			MeHg conc		16.3	9.2	2.6	13.6	8.7	33.5	-0.1	1.2
			%MeHg		54.6	17.8	4.9	45.8	37.7	90.4	0.1	1.3

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Brown Lake	*Aeshna eremita*	Length	2	29.2	1.9	1.4	29.2	27.9	30.6	—	—
			Moisture		88.7	4.7	3.3	88.7	85.4	92.0	—	—
			THg conc		204.9	0.6	0.4	204.9	204.5	205.3	—	—
			MeHg conc		122.2	17.2	12.2	122.2	110.1	134.4	—	—
			%MeHg		59.7	8.6	6.0	59.7	53.6	65.7	—	—
VOYA	Brown Lake	*Aeshna interrupta*	Length	6	27.4	3.5	1.4	27.3	23.1	32.1	-1.9	0.1
			Moisture		88.2	3.4	1.4	88.3	82.7	91.6	0.2	-0.7
			THg conc		229.6	87.2	35.6	222.6	124.5	361.9	-0.5	0.4
			MeHg conc		176.0	63.6	26.0	170.8	89.3	281.0	1.4	0.6
			%MeHg		78.0	13.5	5.5	74.7	61.8	95.3	-1.7	0.4
VOYA	Brown Lake	*Aeshna umbrosa*	Length	8	29.0	3.7	1.3	30.3	19.9	31.1	7.4	-2.7
			Moisture		86.1	4.7	1.7	86.7	77.9	91.8	-0.3	-0.7
			THg conc		209.7	65.2	23.0	197.9	129.2	294.1	-1.7	0.2
			MeHg conc		183.4	47.4	16.8	189.3	122.3	259.5	-1.1	0.2
			%MeHg		89.3	10.8	3.8	92.0	70.7	100.2	-0.8	-0.7
VOYA	Brown Lake	*Anax junius*	Length	1	31.7	—	—	31.7	31.7	31.7	—	—
			Moisture		86.0	—	—	86.0	86.0	86.0	—	—
			THg conc		333.3	—	—	333.3	333.3	333.3	—	—
			MeHg conc		211.1	—	—	211.1	211.1	211.1	—	—
			%MeHg		63.3	—	—	63.3	63.3	63.3	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Brown Lake	*Basiaeschna janata*	Length	8	35.7	1.3	0.5	36.0	33.0	36.9	2.7	-1.5
			Moisture		79.1	4.4	1.6	77.6	74.2	87.7	1.0	1.1
			THg conc		180.8	27.8	9.8	186.7	146.2	219.7	-1.5	-0.1
			MeHg conc		149.9	30.4	10.7	147.5	115.6	192.4	-1.7	0.2
			%MeHg		82.8	10.3	3.6	81.9	71.8	105.0	3.2	1.5
VOYA	Brown Lake	*Celithemis elisa*	Length	12	15.3	0.4	0.1	15.2	15.0	16.1	0.5	1.3
			Moisture		84.5	1.9	0.6	84.0	81.1	88.0	-0.4	0.2
			THg conc		124.7	23.5	6.8	130.0	89.6	155.8	-1.6	-0.2
			MeHg conc		127.2	25.5	7.4	132.2	82.9	168.4	-0.4	-0.5
			%MeHg		102.1	9.6	2.8	101.2	88.2	120.2	-0.2	0.5
VOYA	Brown Lake	*Cordulia shurtleffi*	Length	8	21.3	0.9	0.3	21.2	19.8	22.3	-0.8	-0.4
			Moisture		83.0	2.2	0.8	82.6	80.6	86.1	-1.9	0.3
			THg conc		209.1	55.6	19.7	230.7	122.5	265.6	-1.1	-0.8
			MeHg conc		191.0	57.7	20.4	193.5	98.4	283.1	-0.1	0.0
			%MeHg		91.4	12.9	4.6	87.9	75.5	112.3	-0.5	0.7
VOYA	Brown Lake	*Didymops transversa*	Length	8	25.6	0.6	0.2	25.6	24.5	26.5	-1.1	-0.2
			Moisture		78.6	2.6	0.8	79.1	74.0	82.0	-0.6	-0.4
			THg conc		172.5	50.8	15.3	177.3	71.2	239.1	0.4	-0.7
			MeHg conc		142.4	58.5	20.7	141.4	53.5	245.0	0.6	0.3
			%MeHg		84.8	11.8	4.2	80.4	75.0	104.2	-0.3	1.2

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Brown Lake	*Epitheca cynosura*	Length	12	21.0	0.8	0.2	20.8	20.0	22.4	-1.0	0.5
			Moisture		76.7	1.2	0.4	76.6	75.2	79.0	-0.8	0.5
			THg conc		114.1	56.3	16.2	104.2	43.6	197.0	-1.4	0.5
			MeHg conc		113.5	58.4	16.9	100.6	40.2	203.8	-1.3	0.5
			%MeHg		87.8	10.5	3.0	90.1	65.5	98.5	0.5	-1.1
VOYA	Brown Lake	*Epitheca spinigera*	Length	15	22.0	0.5	0.1	22.0	21.2	22.9	-0.2	0.2
			Moisture		81.2	2.5	0.6	82.0	76.0	84.2	0.6	-1.1
			THg conc		232.8	103.5	26.7	199.2	71.9	400.2	-1.1	0.3
			MeHg conc		201.2	80.6	20.8	176.4	66.2	341.1	-0.6	0.4
			%MeHg		88.5	7.7	2.0	90.1	72.8	98.7	-0.7	-0.6
VOYA	Brown Lake	*Gomphus exilis*	Length	38	26.6	0.9	0.1	26.6	25.1	28.6	-0.5	0.1
			Moisture		79.6	3.6	0.6	79.8	72.3	86.0	-0.6	0.0
			THg conc		102.7	36.7	6.0	101.3	31.2	203.6	0.7	0.6
			MeHg conc		76.5	38.4	6.2	71.7	22.6	169.2	-0.3	0.6
			%MeHg		72.5	20.5	3.3	77.8	24.3	97.9	0.6	-1.2
VOYA	Brown Lake	*Gomphus spicatus*	Length	30	31.9	1.7	0.3	31.9	26.2	35.8	3.3	-0.8
			Moisture		80.4	2.7	0.5	79.8	75.8	88.1	0.7	0.7
			THg conc		110.2	36.2	6.6	106.7	42.6	180.2	-0.9	0.2
			MeHg conc		86.2	33.0	6.0	82.4	28.5	163.9	-0.1	0.5
			%MeHg		78.1	13.2	2.4	82.7	33.6	93.5	3.2	-1.6

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Brown Lake	*Hagenius brevistylus*	Length	4	26.8	6.1	3.1	29.5	17.7	30.6	3.7	-1.9
			Moisture		73.0	0.4	0.2	72.9	72.7	73.6	3.3	1.8
			THg conc		96.5	42.0	21.0	116.3	33.5	119.9	4.0	-2.0
			MeHg conc		112.6	66.2	33.1	80.4	77.8	211.9	4.0	2.0
			%MeHg		208.9	282.3	141.1	68.7	65.8	632.3	4.0	2.0
VOYA	Brown Lake	*Ladona julia*	Length	24	22.6	1.2	0.2	22.7	18.3	24.3	6.5	-1.9
			Moisture		83.8	1.8	0.4	83.8	79.6	87.2	0.8	-0.6
			THg conc		90.1	19.2	3.9	93.2	39.1	116.4	1.9	-1.4
			MeHg conc		71.2	20.7	4.2	77.8	22.1	101.8	0.9	-1.1
			%MeHg		77.7	12.8	2.6	80.9	42.5	98.3	1.0	-0.9
VOYA	Brown Lake	*Nasiaeschna pentacantha*	Length	1	44.2	—	—	44.2	44.2	44.2	—	—
			Moisture		77.3	—	—	77.3	77.3	77.3	—	—
			THg conc		322.5	—	—	322.5	322.5	322.5	—	—
			MeHg conc		289.6	—	—	289.6	289.6	289.6	—	—
			%MeHg		89.8	—	—	89.8	89.8	89.8	—	—
VOYA	Brown Lake	*Somatochlora williamsoni*	Length	8	21.6	0.5	0.2	21.4	21.0	22.4	0.4	1.1
			Moisture		81.4	2.6	0.9	81.3	78.3	85.8	-0.8	0.4
			THg conc		254.8	34.5	12.2	247.6	222.1	332.7	4.4	1.9
			MeHg conc		234.6	30.4	10.8	232.0	196.5	296.2	1.9	1.1
			%MeHg		92.4	8.1	2.8	94.0	75.9	104.1	2.7	-1.0

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Peary Lake	*Aeshna clepsydra*	Length	4	35.8	4.3	2.2	36.3	31.0	39.4	-4.9	-0.2
			Moisture		86.1	3.1	1.5	86.2	82.5	89.4	-2.5	-0.2
			THg conc		139.3	54.4	27.2	129.9	84.1	213.2	1.4	0.9
			MeHg conc		100.8	29.0	14.5	96.0	71.4	139.9	1.2	0.9
			%MeHg		75.0	11.6	5.8	75.3	64.2	85.1	-5.9	0.0
VOYA	Peary Lake	*Aeshna interrupta*	Length	1	37.8	—	—	37.8	37.8	37.8	—	—
			Moisture		87.9	—	—	87.9	87.9	87.9	—	—
			THg conc		125.9	—	—	125.9	125.9	125.9	—	—
			MeHg conc		130.6	—	—	130.6	130.6	130.6	—	—
			%MeHg		103.7	—	—	103.7	103.7	103.7	—	—
VOYA	Peary Lake	*Aeshna umbrosa*	Length	6	31.5	4.4	1.8	31.7	26.0	39.2	1.8	0.9
			Moisture		82.9	3.6	1.5	82.5	78.6	87.2	-2.2	0.1
			THg conc		98.4	21.3	8.7	92.8	78.7	132.8	-0.4	0.9
			MeHg conc		84.4	19.5	8.0	83.9	57.5	108.2	-1.3	-0.1
			%MeHg		86.5	14.8	6.0	89.7	66.0	101.8	-2.0	-0.4
VOYA	Peary Lake	*Basiaeschna janata*	Length	2	38.4	3.0	2.1	38.4	36.3	40.5	—	—
			Moisture		76.6	1.4	1.0	76.6	75.6	77.6	—	—
			THg conc		120.6	16.1	11.4	120.6	109.2	132.0	—	—
			MeHg conc		105.9	26.8	18.9	105.9	87.0	124.9	—	—
			%MeHg		87.1	10.5	7.5	87.1	79.7	94.6	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Peary Lake	*Epitheca spinigera*	Length	13	21.9	1.0	0.3	21.8	20.4	23.4	-1.4	0.0
			Moisture		77.1	2.0	0.5	76.8	74.1	80.9	-0.9	0.3
			THg conc		75.7	19.8	5.5	71.6	45.2	110.6	-0.7	0.5
			MeHg conc		70.0	35.3	9.1	63.4	27.7	157.2	1.7	1.2
			%MeHg		79.9	22.8	6.3	87.6	41.8	106.1	-0.8	-0.9
VOYA	Peary Lake	*Gomphus exilis*	Length	43	26.7	1.1	0.1	26.7	20.8	28.1	18.3	-3.4
			Moisture		78.5	3.7	0.6	78.0	71.1	87.8	0.1	0.6
			THg conc		76.1	17.2	2.6	71.6	53.5	131.0	2.0	1.3
			MeHg conc		79.0	41.6	5.8	67.3	30.5	227.7	5.2	2.2
			%MeHg		88.9	15.6	2.4	91.8	43.1	117.6	1.3	-0.9
VOYA	Peary Lake	*Gomphus spicatus*	Length	51	32.9	0.9	0.1	32.9	30.9	34.8	-0.9	0.1
			Moisture		77.4	4.7	0.7	78.0	59.9	84.8	6.7	-2.1
			THg conc		84.4	16.1	2.3	81.6	57.1	133.7	0.5	0.6
			MeHg conc		69.2	18.4	2.5	70.0	40.3	113.7	-0.4	0.4
			%MeHg		81.7	16.0	2.2	77.6	52.9	122.0	-0.4	0.3
VOYA	Peary Lake	*Ladona julia*	Length	20	23.1	1.0	0.2	23.1	21.3	25.1	0.0	0.3
			Moisture		81.5	2.1	0.5	81.6	77.4	85.0	-0.4	-0.1
			THg conc		75.9	17.7	4.0	75.5	54.4	127.0	2.3	1.2
			MeHg conc		64.0	21.6	4.8	64.8	26.6	127.1	2.9	1.1
			%MeHg		84.0	15.3	3.4	85.4	29.7	106.7	8.4	-2.4

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Peary Lake	*Macromia illnoiensis*	Length	4	26.7	0.5	0.2	26.6	26.3	27.4	1.1	1.2
			Moisture		74.0	0.6	0.3	73.8	73.7	74.8	3.6	1.9
			THg conc		81.9	17.1	8.5	83.6	59.9	100.4	0.4	-0.5
			MeHg conc		70.2	11.5	5.8	75.5	52.9	76.8	3.9	-2.0
			%MeHg		86.5	8.9	4.4	86.7	75.6	97.0	0.9	-0.1
VOYA	Peary Lake	*Nasiaeschna pentacantha*	Length	1	31.8	—	—	31.8	31.8	31.8	—	—
			Moisture		75.9	—	—	75.9	75.9	75.9	—	—
			THg conc		153.0	—	—	153.0	153.0	153.0	—	—
			MeHg conc		123.0	—	—	123.0	123.0	123.0	—	—
			%MeHg		80.4	—	—	80.4	80.4	80.4	—	—
VOYA	Ryan Lake	*Aeshna interrupta*	Length	1	30.0	—	—	30.0	30.0	30.0	—	—
			Moisture		83.9	—	—	83.9	83.9	83.9	—	—
			THg conc		166.8	—	—	166.8	166.8	166.8	—	—
			MeHg conc		144.5	—	—	144.5	144.5	144.5	—	—
			%MeHg		86.7	—	—	86.7	86.7	86.7	—	—
VOYA	Ryan Lake	*Aeshna umbrosa*	Length	4	31.1	1.5	0.7	31.3	29.2	32.8	1.7	-0.7
			Moisture		83.6	2.8	1.4	83.0	80.9	87.6	2.1	1.2
			THg conc		164.6	35.8	17.9	155.3	133.0	214.8	1.6	1.3
			MeHg conc		155.0	25.1	12.6	149.6	130.7	190.2	2.1	1.2
			%MeHg		95.0	5.3	2.7	95.5	88.5	100.3	-2.6	-0.4

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Ryan Lake	*Basiaeschna janata*	Length	12	34.3	2.3	0.7	34.7	30.5	37.0	-0.9	-0.6
			Moisture		75.5	2.8	0.8	76.0	71.7	80.5	-0.6	0.1
			THg conc		174.4	26.5	7.6	175.5	122.9	212.1	-0.1	-0.3
			MeHg conc		152.0	24.1	7.0	152.4	116.1	191.3	-0.7	0.2
			%MeHg		87.8	11.0	3.2	88.4	65.7	103.5	0.1	-0.6
VOYA	Ryan Lake	*Celithemis elisa*	Length	13	16.2	0.4	0.1	16.3	15.1	16.8	3.3	-1.5
			Moisture		86.8	1.9	0.5	86.7	84.1	89.5	-1.3	0.1
			THg conc		115.8	26.9	7.5	117.7	67.1	149.5	-1.1	-0.5
			MeHg conc		110.2	25.8	7.2	116.5	57.8	152.5	0.0	-0.5
			%MeHg		95.3	7.9	2.2	94.4	82.1	110.3	-0.3	0.1
VOYA	Ryan Lake	*Cordulia shurtleffi*	Length	4	21.6	0.7	0.3	21.6	20.7	22.3	1.6	-0.7
			Moisture		81.2	2.8	1.4	81.1	78.7	83.8	-5.8	0.0
			THg conc		205.8	36.0	18.0	196.3	173.3	257.3	2.7	1.4
			MeHg conc		188.9	30.8	15.4	177.3	166.9	234.3	3.3	1.8
			%MeHg		92.0	3.1	1.5	91.3	89.0	96.3	2.1	1.2
VOYA	Ryan Lake	*Dromogomphus spinosus*	Length	1	34.6	—	—	34.6	34.6	34.6	—	—
			Moisture		81.9	—	—	81.9	81.9	81.9	—	—
			THg conc		88.9	—	—	88.9	88.9	88.9	—	—
			MeHg conc		45.9	—	—	45.9	45.9	45.9	—	—
			%MeHg		51.6	—	—	51.6	51.6	51.6	—	—

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Ryan Lake	*Epitheca spinigera*	Length	22	22.2	0.7	0.1	22.4	20.4	23.2	1.4	-1.2
			Moisture		79.6	3.5	0.7	79.5	74.4	85.4	-1.5	0.1
			THg conc		139.9	34.0	6.9	145.4	63.6	188.4	-0.4	-0.6
			MeHg conc		117.4	24.6	5.3	110.2	76.8	166.9	-0.6	0.4
			%MeHg		81.1	14.3	3.0	88.4	51.8	100.6	-1.1	-0.6
VOYA	Ryan Lake	*Gomphus exilis*	Length	36	26.7	1.1	0.2	26.8	23.3	28.7	0.7	-0.7
			Moisture		77.8	3.2	0.6	77.5	73.6	85.3	-0.1	0.7
			THg conc		119.6	16.1	2.6	120.0	75.1	154.5	0.4	-0.3
			MeHg conc		97.3	28.1	4.7	101.4	54.7	161.7	-0.5	0.2
			%MeHg		82.9	25.2	4.2	82.8	43.9	157.4	0.8	0.7
VOYA	Ryan Lake	*Gomphus lividus*	Length	13	24.5	3.0	0.8	26.0	21.0	28.9	-1.9	0.0
			Moisture		79.8	5.4	1.5	80.7	72.3	88.2	-1.4	0.0
			THg conc		127.2	19.8	5.5	133.1	97.5	156.4	-1.1	-0.1
			MeHg conc		105.8	20.0	5.6	100.7	71.9	143.0	-0.6	0.3
			%MeHg		83.4	10.7	3.0	81.9	67.8	104.3	-0.4	0.4
VOYA	Ryan Lake	*Gomphus spicatus*	Length	37	32.0	1.9	0.3	32.1	27.3	35.8	0.4	-0.6
			Moisture		79.8	2.8	0.5	79.6	74.3	85.8	-0.1	0.3
			THg conc		107.6	35.0	5.7	108.9	62.8	267.0	11.0	2.5
			MeHg conc		81.0	27.0	4.4	75.0	39.6	133.5	-0.9	0.3
			%MeHg		76.2	19.0	3.1	80.2	26.7	106.4	-0.3	-0.5

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Ryan Lake	*Hagenius brevistylus*	Length	7	34.8	5.3	2.0	36.8	23.1	38.7	5.9	-2.4
			Moisture		74.8	1.8	0.7	75.0	71.4	76.6	3.1	-1.5
			THg conc		183.4	32.2	12.2	188.8	132.1	214.8	-0.8	-0.8
			MeHg conc		143.2	44.1	16.6	139.6	76.2	207.7	-0.2	0.1
			%MeHg		77.9	19.0	7.2	75.7	52.5	99.4	-1.8	-0.2
VOYA	Ryan Lake	*Ladona julia*	Length	6	22.8	1.0	0.4	22.8	21.7	24.4	1.0	0.8
			Moisture		83.6	2.2	0.9	83.5	81.3	86.5	-2.4	0.2
			THg conc		127.5	40.4	16.5	126.9	66.4	186.3	0.7	-0.1
			MeHg conc		105.4	31.0	12.7	108.0	50.3	135.4	1.8	-1.2
			%MeHg		83.3	11.9	4.9	79.4	71.3	103.3	0.4	1.0
VOYA	Ryan Lake	*Macromia illnoiensis*	Length	7	24.6	1.9	0.7	24.9	20.7	26.2	4.6	-2.0
			Moisture		77.5	2.2	0.8	77.6	74.3	81.1	0.5	0.3
			THg conc		137.6	38.0	14.4	126.8	93.6	191.2	-1.8	0.3
			MeHg conc		121.6	40.0	15.1	99.3	78.2	178.9	-1.3	0.8
			%MeHg		88.6	14.9	5.6	90.9	59.0	103.9	2.6	-1.5
VOYA	Ryan Lake	*Nasiaeschna pentacantha*	Length	3	31.7	2.8	1.6	30.8	29.5	34.8	—	1.3
			Moisture		79.6	8.1	4.7	75.3	74.7	88.9	—	1.7
			THg conc		253.0	9.4	5.5	254.8	242.8	261.4	—	-0.8
			MeHg conc		218.8	33.5	19.3	219.9	184.8	251.8	—	-0.1
			%MeHg		86.2	10.1	5.8	86.3	76.1	96.3	—	0.0

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Ryan Lake	*Somatochlora williamsoni*	Length	3	20.9	0.5	0.3	21.0	20.4	21.3	—	-0.8
			Moisture		76.7	0.6	0.3	76.6	76.2	77.4	—	1.1
			THg conc		235.4	32.9	19.0	250.6	197.7	258.0	—	-1.6
			MeHg conc		209.0	49.0	28.3	199.2	165.6	262.2	—	0.9
			%MeHg		88.5	14.3	8.3	83.8	77.2	104.6	—	1.3
VOYA	Sand Point Lake	*Arigomphus cornutus*	Length	1	41.0	—	—	41.0	41.0	41.0	—	—
			Moisture		78.1	—	—	78.1	78.1	78.1	—	—
			THg conc		180.5	—	—	180.5	180.5	180.5	—	—
			MeHg conc		15.6	—	—	15.6	15.6	15.6	—	—
			%MeHg		8.6	—	—	8.6	8.6	8.6	—	—
VOYA	Sand Point Lake	*Basiaeschna janata*	Length	4	34.6	0.8	0.4	34.3	34.0	35.7	3.5	1.8
			Moisture		77.9	1.6	0.8	77.4	76.7	80.2	2.8	1.7
			THg conc		188.0	32.7	16.4	189.9	153.8	218.2	-5.2	-0.1
			MeHg conc		129.4	18.8	9.4	131.5	104.7	150.0	1.3	-0.6
			%MeHg		71.4	20.5	10.3	73.2	49.0	90.3	-4.8	-0.2
VOYA	Sand Point Lake	*Didymops transversa*	Length	7	26.3	0.8	0.3	26.4	24.6	27.1	4.6	-1.9
			Moisture		75.4	2.8	1.1	75.8	71.6	78.6	-2.0	-0.2
			THg conc		234.3	42.9	16.2	226.4	169.1	282.6	-1.3	-0.4
			MeHg conc		218.7	32.0	12.1	232.7	167.9	254.5	-0.9	-0.7
			%MeHg		94.2	9.2	3.5	93.9	85.5	109.0	-0.9	0.7

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Sand Point Lake	*Dromogomphus spinosus*	Length	23	29.6	1.8	0.4	29.3	27.3	33.8	0.7	1.1
			Moisture		76.4	2.4	0.5	75.9	71.6	82.1	1.1	0.8
			THg conc		113.2	26.0	5.4	117.5	69.6	159.3	-0.9	0.2
			MeHg conc		87.6	22.7	4.7	90.3	32.4	131.7	0.7	-0.6
			%MeHg		78.3	18.7	3.9	74.7	40.6	123.1	1.2	0.7
VOYA	Sand Point Lake	*Epitheca cynosura*	Length	7	20.4	0.6	0.2	20.4	19.7	21.5	-0.1	0.7
			Moisture		77.1	2.4	0.8	77.6	73.7	81.0	-0.4	0.1
			THg conc		129.4	33.2	12.5	118.7	101.7	199.4	4.2	2.0
			MeHg conc		114.9	27.2	9.6	108.5	83.4	167.3	0.8	1.1
			%MeHg		86.4	6.8	2.6	85.5	77.8	99.4	2.0	1.1
VOYA	Sand Point Lake	*Epitheca princeps*	Length	12	26.5	0.7	0.2	26.5	25.7	28.0	0.2	0.7
			Moisture		74.8	2.3	0.6	74.3	72.6	78.9	-0.9	0.7
			THg conc		233.8	107.6	31.1	253.0	87.2	439.7	-0.5	0.3
			MeHg conc		215.3	106.0	30.6	222.9	76.1	422.6	-0.4	0.5
			%MeHg		91.4	7.9	2.3	89.6	83.2	113.4	5.9	2.1
VOYA	Sand Point Lake	*Epitheca spinigera*	Length	16	20.7	1.0	0.2	20.3	19.6	22.8	0.2	1.2
			Moisture		78.8	2.5	0.6	78.9	75.0	84.1	0.2	0.5
			THg conc		157.8	28.2	7.1	155.1	109.2	214.4	0.3	0.3
			MeHg conc		134.9	33.5	8.4	126.1	93.4	198.8	-1.0	0.6
			%MeHg		85.3	12.6	3.2	89.3	63.9	100.6	-1.4	-0.5

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Sand Point Lake	*Gomphus adelphus*	Length	31	33.3	2.4	0.4	34.5	27.7	36.1	-0.3	-0.8
			Moisture		79.7	4.1	0.7	79.8	71.0	87.4	-0.5	-0.2
			THg conc		128.0	29.8	5.3	129.2	43.4	174.4	1.4	-1.0
			MeHg conc		99.3	26.0	4.7	100.5	39.6	147.7	-0.3	-0.3
			%MeHg		78.6	14.2	2.6	79.0	48.4	108.4	0.0	0.2
VOYA	Sand Point Lake	*Gomphus exilis*	Length	19	26.1	1.7	0.4	26.7	21.3	28.2	2.3	-1.5
			Moisture		80.8	5.0	1.2	83.2	72.8	86.7	-1.3	-0.6
			THg conc		98.8	26.7	6.1	94.7	57.0	158.5	-0.2	0.6
			MeHg conc		63.2	30.2	6.9	58.3	16.5	133.3	0.0	0.5
			%MeHg		62.4	20.4	4.7	67.4	20.9	91.9	-0.2	-0.7
VOYA	Sand Point Lake	*Gomphus graslinellus*	Length	10	32.5	0.7	0.2	32.1	31.8	33.6	-1.3	0.8
			Moisture		77.4	2.5	0.8	77.1	73.1	82.7	1.7	0.6
			THg conc		94.7	14.2	4.5	95.8	68.7	116.4	-0.2	-0.3
			MeHg conc		76.6	17.2	5.4	72.1	53.6	103.9	-0.9	0.4
			%MeHg		82.0	18.0	5.7	83.3	46.0	102.7	0.5	-1.0
VOYA	Sand Point Lake	*Gomphus lividus*	Length	20	32.2	0.8	0.2	32.0	31.2	34.1	1.1	1.1
			Moisture		81.1	3.0	0.7	81.7	73.8	86.6	0.9	-0.6
			THg conc		114.6	23.5	5.3	108.9	70.4	156.8	-0.4	0.2
			MeHg conc		76.3	27.0	6.0	79.0	16.1	121.3	0.1	-0.5
			%MeHg		67.9	22.9	5.1	75.4	10.4	91.4	1.1	-1.4

Appendix H (continued). Summary statistics for total length (Length, mm), percent moisture (Moisture, %), concentrations of total mercury (THg conc, ng/g dry weight) and methylmercury (MeHg conc, ng/g dry weight), and percent of total mercury present as methylmercury (%MeHg) in whole larval dragonflies—listed by park unit, water body, and species—sampled during 2008–2012 from six park units in the Great Lakes Inventory and Monitoring Network (n = number of larvae analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value). Species with a superscript '1' are identified to a species-level taxonomic designation pending confirmation.

Park unit	Water body (site)	Species	Variable	n	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Sand Point Lake	*Gomphus rogersi* [1]	Length	11	34.9	0.6	0.2	34.8	34.3	36.1	0.1	0.9
			Moisture		79.2	2.6	0.8	79.9	74.4	82.5	-0.5	-0.6
			THg conc		96.1	18.4	5.6	99.1	71.7	127.4	-1.1	0.2
			MeHg conc		74.7	15.0	4.5	72.7	52.8	94.5	-1.4	0.0
			%MeHg		77.8	6.6	2.0	76.2	65.4	88.4	-0.1	-0.1
VOYA	Sand Point Lake	*Gomphus spicatus*	Length	19	30.6	2.1	0.5	30.9	26.4	33.2	-0.5	-0.6
			Moisture		78.6	3.7	0.9	78.3	71.1	84.9	-0.5	0.0
			THg conc		114.2	25.6	5.9	113.3	75.8	180.9	1.2	1.0
			MeHg conc		88.2	43.7	10.0	78.6	30.2	212.1	2.2	1.2
			%MeHg		76.9	33.0	7.6	74.1	21.4	179.4	4.6	1.5
VOYA	Sand Point Lake	*Hagenius brevistylus*	Length	3	18.9	2.7	1.6	19.2	16.0	21.5	—	-0.5
			Moisture		72.5	4.1	2.4	70.4	69.9	77.3	—	1.7
			THg conc		159.1	23.9	13.8	148.9	141.9	186.3	—	1.6
			MeHg conc		146.7	29.1	16.8	154.3	114.6	171.3	—	-1.1
			%MeHg		92.1	11.4	6.6	91.9	80.8	103.6	—	0.1
VOYA	Sand Point Lake	*Macromia illnoiensis*	Length	3	25.9	1.3	0.7	25.3	25.1	27.4	—	1.7
			Moisture		76.4	2.9	1.7	77.7	73.1	78.3	—	-1.7
			THg conc		176.6	25.9	14.9	185.4	147.5	196.9	—	-1.4
			MeHg conc		169.8	8.8	5.1	170.9	160.5	178.0	—	-0.6
			%MeHg		96.6	7.9	4.6	95.2	89.5	105.1	—	0.8

Appendix I. Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Grand Portage Creek	longnose dace	110	Length	77	11	1	76.5	49	107	1.18	0.11
				Weight	4.4	2.1	0.2	3.9	0.9	13.2	3.92	1.57
				Hg conc	58	43	4	47	21	355	21.58	3.94
				Hg burden	262	210	20	204	28	1013	2.58	1.69
GRPO	Grand Portage Creek	slimy sculpin	68	Length	59	10	1	58	41	83	-0.41	0.19
				Weight	2.9	1.5	0.2	2.7	0.8	7.9	1.22	1.02
				Hg conc	24	11	1	23.5	8	54	0.03	0.66
				Hg burden	74	55	7	56.5	9	253	0.8	1.15
GRPO	Poplar Creek	blacknose dace	43	Length	72	12	2	74	46	89	-0.87	-0.5
				Weight	4.7	2.3	0.4	5	1.1	8.6	-1.26	-0.06
				Hg conc	91	36	6	92	43	242	6.47	2
				Hg burden	469	365	56	358	77	1690	1.83	1.32
GRPO	Poplar Creek	brook stickleback	7	Length	48	4	1	47	44	55	2.79	1.51
				Weight	1.2	0.3	0.1	1.2	0.8	1.7	-0.04	0.68
				Hg conc	73	26	10	61	47	112	-1.52	0.58
				Hg burden	92	47	18	74	48	180	1.08	1.22
GRPO	Poplar Creek	creek chub	49	Length	80	15	2	78	56	105	-1.28	0.12
				Weight	6.1	3.6	0.5	5.2	1.5	14.3	-0.83	0.54
				Hg conc	49	20	3	45	29	118	3.09	1.8
				Hg burden	298	207	30	233	60	975	0.93	1.02

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Poplar Creek	central mudminnow	14	Length	50	12	3	47	32	77	0.58	0.93
				Weight	1.7	1.4	0.4	1.2	0.6	5.6	5.01	2.18
				Hg conc	67	21	6	69	37	123	2.79	1.09
				Hg burden	127	168	45	78	32	692	11.92	3.36
GRPO	Poplar Creek	longnose dace	15	Length	76	11	3	71	64	97	-0.94	0.68
				Weight	4.5	2.1	0.5	4.3	2.3	8.5	-0.52	0.72
				Hg conc	91	36	9	83.5	50	194	3.93	1.81
				Hg burden	465	401	100	370	121	1652	4.46	1.96
GRPO	Snow Creek	brook stickleback	8	Length	54	6	2	52.5	49	62	-1.44	0.63
				Weight	1.8	0.6	0.2	1.6	1.4	2.8	-0.39	1.19
				Hg conc	49	13	5	49.5	27	74	1.77	0.23
				Hg burden	92	37	13	92	37	141	-1.09	-0.02
GRPO	Snow Creek	creek chub	5	Length	114	25	11	102	90	144	-2.91	0.52
				Weight	18	13	6	9.4	7.5	33.5	-3.07	0.64
				Hg conc	51	6	3	51	43	60	1.54	0.66
				Hg burden	899	624	279	566	323	1615	-3.15	0.53
GRPO	Snow Creek	central mudminnow	123	Length	62	18	2	60	33	124	0.54	0.78
				Weight	3.1	2.9	0.3	2.2	0.3	19.5	10.17	2.61
				Hg conc	54	24	2	52	15	204	11.71	2.06
				Hg burden	200	349	31	95	9	3134	45.98	6.12
GRPO	Snow Creek	fathead minnow	11	Length	72	8	2	73	61	83	-1.16	-0.2
				Weight	4.7	1.6	0.5	4.4	2.6	7.6	-0.1	0.76
				Hg conc	53	15	5	57	29	75	-0.73	-0.51
				Hg burden	238	77	23	229	127	381	0.11	0.64

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Great Marsh 1	central mudminnow	61	Length	75	18	2	74	24	114	-0.06	-0.05
				Weight	6	4	1	5.5	0.1	17.4	0.56	0.95
				Hg conc	26	14	2	23	7	79	3.86	1.87
				Hg burden	164	136	17	145	4	701	3.55	1.65
INDU	Great Marsh 1	green sunfish	2	Length	47	6	4	47	43	51	.	.
				Weight	2.6	1.3	0.9	2.6	1.7	3.6	.	.
				Hg conc	34	11	8	34	26	42	.	.
				Hg burden	81	14	10	81	71	91	.	.
INDU	Great Marsh 2	central mudminnow	107	Length	71	17	2	69	20	123	0.37	0.28
				Weight	5.1	3.9	0.4	4	0.1	24.4	6.07	2.01
				Hg conc	38	15	2	35	11	84	0.78	0.98
				Hg burden	224	222	22	149	3	1056	2.81	1.73
INDU	Great Marsh 2	green sunfish	2	Length	42	3	2	42	40	44	.	.
				Weight	1.3	0.3	0.2	1.3	1.1	1.5	.	.
				Hg conc	63	2	2	62.5	61	64	.	.
				Hg burden	81	13	9	81	72	90	.	.
INDU	Great Marsh 3	central mudminnow	24	Length	68	16	3	72	21	96	2.38	-0.96
				Weight	4.9	2.8	0.6	4.6	0.1	12.3	1.42	0.91
				Hg conc	24	12	2	22	11	58	2.04	1.43
				Hg burden	136	122	25	106	2	462	1.27	1.36
INDU	Great Marsh 4	central mudminnow	59	Length	76	22	3	71	41	133	-0.31	0.6
				Weight	5.8	4.7	0.6	4.2	0.8	22.8	2.58	1.51
				Hg conc	59	29	4	52	17	134	0.72	1.14
				Hg burden	418	576	75	192	22	3052	10.35	3.04

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Long Lake	central mudminnow	82	Length	78	18	2	76	43	127	0.15	0.53
				Weight	6.4	4.9	0.5	5	0.8	23.5	3.35	1.8
				Hg conc	22	9	1	21	8	49	0.3	0.75
				Hg burden	163	193	21	100	7	1136	10.34	2.98
INDU	Long Lake	green sunfish	51	Length	37	5	1	37	30	54	3.32	1.49
				Weight	1	0	0	0.9	0.5	2.7	6.05	2.37
				Hg conc	23	9	1	21	10	44	-0.49	0.58
				Hg burden	22	14	2	20	6	72	2.96	1.59
INDU	Middle Lagoon	bluegill	14	Length	49	5	1	48.5	42	59	0.67	0.68
				Weight	1.7	0.4	0.1	1.6	1.0	2.6	0.83	0.69
				Hg conc	47	11	3	47.5	32	75	2.51	1.16
				Hg burden	78	28	8	69	48	152	3.04	1.84
INDU	Middle Lagoon	central mudminnow	29	Length	57	11	2	55	43	83	0.23	0.92
				Weight	2.4	1.4	0.3	2.1	0.9	6.8	2.57	1.62
				Hg conc	31	13	2	30	14	72	1.97	1.18
				Hg burden	84	87	16	45	21	396	5.64	2.3
INDU	Middle Lagoon	green sunfish	47	Length	54	19	3	46	22	114	2.14	1.55
				Weight	3.9	5	1	1.7	0.4	27.5	9.12	2.9
				Hg conc	25	8	1	24	13	60	6.27	1.98
				Hg burden	125	260	38	44	10	1637	25.76	4.73
INDU	Middle Lagoon	iowa darter	51	Length	45	5	1	44	37	59	0.22	0.79
				Weight	0.7	0.3	0.0	0.7	0.4	1.7	2.29	1.41
				Hg conc	27	11	2	24	12	82	12.75	2.94
				Hg burden	21	14	2	15	4	85	8.03	2.34

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Middle Lagoon	yellow perch	1	Length	69	.	.	69	69	69	.	.
				Weight	2.9	.	.	2.9	2.9	2.9	.	.
				Hg conc	13	.	.	13	13	13	.	.
				Hg burden	37	.	.	37	37	37	.	.
ISRO	Angleworm Lake	yellow perch	50	Length	70	16	2	69.5	47	102	-1.34	0.26
				Weight	3.8	2.4	0.3	3	0.9	11.6	0.62	0.99
				Hg conc	22	10	1	24	9	42	-1.4	0.08
				Hg burden	101	90	13	81.5	11	379	0.34	0.97
ISRO	Harvey Lake	fathead minnow	1	Length	86	.	.	86	86	86	.	.
				Weight	5.6	.	.	5.6	5.6	5.6	.	.
				Hg conc	96	.	.	96	96	96	.	.
				Hg burden	536	.	.	536	536	536	.	.
ISRO	Harvey Lake	yellow perch	116	Length	150	58	5	130	70	337	1.55	1.36
				Weight	49	69	6	20.4	2.9	334.5	6.52	2.6
				Hg conc	213	169	16	146.5	49	1094	7.76	2.47
				Hg burden	21060	51268	4760	2971.5	203	296968	14.94	3.78
ISRO	Richie Lake	yellow perch	78	Length	87	43	5	68	48	225	2.05	1.67
				Weight	15	28	3	2.9	1.1	145.6	10.07	3.11
				Hg conc	39	10	1	37.5	24	82	3.99	1.5
				Hg burden	659	1499	170	103	38	9607	19.06	4.07
ISRO	Sargent Lake	yellow perch	89	Length	68	19	2	60	51	144	4.7	2.22
				Weight	4	6	1	2.1	1.1	31.3	12.88	3.48
				Hg conc	39	9	1	38	19	72	1.25	0.51
				Hg burden	149	198	21	77	38	1258	16	3.7

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake	Iowa darter	40	Length	48	7	1	50	34	62	-0.38	-0.24
				Weight	1.0	0.4	0.1	1	0.3	1.9	-0.53	0.51
				Hg conc	58	26	4	60	20	111	-0.9	0.17
				Hg burden	59	40	6	54	7	145	-0.84	0.53
PIRO	Beaver Lake	johnny darter	41	Length	50	7	1	48	38	73	2.03	1.3
				Weight	1.1	0.5	0.1	1	0.4	2.9	4.26	1.86
				Hg conc	26	8	1	23	11	45	-0.29	0.63
				Hg burden	28	18	3	23	6	93	4.88	2.08
PIRO	Beaver Lake	mottled sculpin	56	Length	52	6	1	51	39	74	2.25	0.89
				Weight	1.7	0.6	0.1	1.6	0.8	3.5	0.61	0.94
				Hg conc	25	7	1	23	13	42	0.14	0.66
				Hg burden	42	17	2	37.5	19	94	1.05	1.14
PIRO	Beaver Lake	rock bass	4	Length	172	25	13	179.5	137	190	0.5	-1.21
				Weight	113	49	25	116.7	51.8	168.0	-0.1	-0.37
				Hg conc	98	15	7	94.5	86	118	0.31	1.12
				Hg burden	11385	6274	3137	10226	5180	19906	1.13	0.98
PIRO	Beaver Lake	yellow perch	83	Length	106	74	8	62	49	292	-0.68	1.02
				Weight	36	59	7	2.1	1.0	290.9	3.71	1.86
				Hg conc	76	61	7	49	20	263	0.44	1.24
				Hg burden	5997	11758	1291	110	22	60371	8.71	2.74
PIRO	Chapel Lake	central mudminnow	5	Length	60	5	2	60	53	66	-1.94	-0.15
				Weight	2	1	0	2	1.4	3.1	-3.03	0.33
				Hg conc	131	34	15	131	91	174	-1.8	0.11
				Hg burden	286	101	45	282	148	411	-0.46	-0.2

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Chapel Lake	iowa darter	46	Length	54	9	1	57	31	63	1.55	-1.47
				Weight	1.2	0.4	0.1	1.3	0.2	1.8	-0.02	-0.86
				Hg conc	88	45	7	75	36	187	-0.5	0.8
				Hg burden	107	71	10	90	9	291	-0.33	0.7
PIRO	Chapel Lake	johnny darter	28	Length	53	10	2	54	33	70	-1.01	-0.08
				Weight	1.3	0.7	0.1	1.2	0.2	2.7	-1.19	0.37
				Hg conc	61	18	3	58	23	106	0.82	0.46
				Hg burden	81	49	9	96	15	170	-1.46	0.04
PIRO	Chapel Lake	mottled sculpin	3	Length	50	6	3	49	45	56	.	0.78
				Weight	1.6	0.6	0.4	1.4	1.2	2.3	.	1.41
				Hg conc	18	1	1	18	17	19	.	0
				Hg burden	29	11	6	27	20	41	.	0.94
PIRO	Chapel Lake	rock bass	49	Length	147	33	5	147	42	192	1.75	-1.26
				Weight	71	39	6	62.5	1.3	152.0	-0.73	0.22
				Hg conc	244	154	22	225	42	841	3.46	1.41
				Hg burden	21316	20345	2906	14830	67	94803	2.5	1.5
PIRO	Chapel Lake	yellow perch	69	Length	141	37	4	131	69	285	2.86	1.31
				Weight	30	35	4	17.7	3.0	229.6	16.36	3.66
				Hg conc	276	160	19	261	62	872	3.2	1.41
				Hg burden	11498	21919	2639	4470	186	116652	12.95	3.56
PIRO	Grand Sable Lake	Iowa darter	51	Length	46	7	1	45	28	58	-0.51	-0.19
				Weight	0.8	0	0	0.7	0.2	1.4	-0.78	0.4
				Hg conc	54	17	2	51	16	100	0.33	0.43
				Hg burden	44	27	4	34	7	104	-0.85	0.63

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Grand Sable Lake	johnny darter	60	Length	43	5	1	42	35	57	0.54	0.96
				Weight	0.7	0.3	0.0	0.6	0.3	1.6	1.15	1.32
				Hg conc	42	13	2	41	7	76	0.97	0.25
				Hg burden	28	16	2	22.5	4	88	3.49	1.8
PIRO	Grand Sable Lake	mottled sculpin	42	Length	50	8	1	48.5	35	77	3.37	1.14
				Weight	1.7	1.0	0.1	1.5	0.5	6.0	8.74	2.4
				Hg conc	22	7	1	21	12	49	6.13	1.8
				Hg burden	38	29	4	30	9	157	9.21	2.91
PIRO	Grand Sable Lake	rock bass	4	Length	150	15	8	145.5	136	171	2.7	1.44
				Weight	74	30	15	67.6	45.9	116.2	2.33	1.26
				Hg conc	124	46	23	122.5	75	177	-2.79	0.15
				Hg burden	9211	5334	2667	7289	5249	17016	3.04	1.72
PIRO	Grand Sable Lake	yellow perch	68	Length	113	41	5	114	62	239	0.74	0.91
				Weight	20	27	3	13.4	2.3	151.3	9.27	2.87
				Hg conc	107	47	6	92.5	57	330	9.59	2.68
				Hg burden	3240	7489	908	1246.5	152	49943	26.05	4.84
PIRO	Legion Lake	central mudminnow	101	Length	81	17	2	81	52	124	-1	0.1
				Weight	5.9	3.5	0.3	5.3	1.4	15.8	-0.41	0.61
				Hg conc	121	46	5	118	43	289	1.56	0.93
				Hg burden	844	795	79	613	81	4011	4.23	1.87
PIRO	Miners Lake	mottled sculpin	25	Length	54	6	1	54	39	65	0.21	-0.39
				Weight	2.3	0.8	0.2	2.2	0.7	4.0	-0.73	0.12
				Hg conc	19	5	1	18	12	35	3.44	1.53
				Hg burden	45	20	4	40	19	90	-0.24	0.69

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Miners Lake	yellow perch	28	Length	231	40	8	248.5	134	293	-0.29	-0.68
				Weight	175	83	16	196.3	26.2	366.0	-0.38	0.17
				Hg conc	87	46	9	73.5	38	220	2.27	1.59
				Hg burden	17045	13058	2468	17056	1280	50938	0.66	0.97
SLBE	Bass Lake (Benzie)	bluegill	42	Length	37	6	1	36	29	54	1.38	1.22
				Weight	0.7	0.4	0.1	0.6	0.3	2.1	4.57	2.01
				Hg conc	82	36	6	80	24	157	-0.74	0.21
				Hg burden	56	39	6	45.5	11	203	4.69	2.05
SLBE	Bass Lake (Benzie)	central mudminnow	21	Length	62	9	2	63	38	88	4.31	0.17
				Weight	2.8	1.3	0.3	2.7	0.6	7.4	7.74	2.09
				Hg conc	29	14	3	27	14	72	3.95	1.58
				Hg burden	90	79	17	76	10	333	4.92	2.21
SLBE	Bass Lake (Benzie)	Iowa darter	40	Length	45	5	1	46	31	56	0.79	-0.4
				Weight	0.7	0.2	0.0	0.7	0.2	1.4	1.26	0.83
				Hg conc	82	42	7	70.5	43	284	12.81	3.08
				Hg burden	59	39	6	43	10	193	2.68	1.63
SLBE	Bass Lake (Benzie)	johnny darter	3	Length	54	7	4	54	48	61	.	0.23
				Weight	1.3	0.5	0.3	1.2	1.0	1.9	.	1.44
				Hg conc	24	14	8	21	11	39	.	0.82
				Hg burden	30	15	9	38	12	39	.	-1.72
SLBE	Bass Lake (Benzie)	rock bass	16	Length	200	37	9	213	115	243	1.03	-1.32
				Weight	187	84	21	200.7	30.7	337.7	-0.04	-0.43
				Hg conc	142	57	14	134	71	246	-0.68	0.58
				Hg burden	29738	22348	5587	28441	2904	83073	1.21	1.09

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Benzie)	yellow perch	24	Length	69	5	1	69	59	77	-0.92	-0.09
				Weight	3.3	0.8	0.2	3.2	2.1	4.8	-0.98	0.23
				Hg conc	60	21	4	59.5	30	107	-0.11	0.47
				Hg burden	206	96	20	211	69	376	-1.19	0.1
SLBE	Bass Lake (Leelanau)	rock bass	2	Length	205	16	11	205	194	216	.	.
				Weight	192	41	29	192	163.3	220.7	.	.
				Hg conc	92	49	35	91.5	57	126	.	.
				Hg burden	18547	13033	9216	18546.5	9331	27762	.	.
SLBE	Bass Lake (Leelanau)	yellow perch	83	Length	74	20	2	68	48	145	2.36	1.58
				Weight	5.1	5.7	0.6	3.1	1.1	36.5	12.65	3.21
				Hg conc	26	6	1	27	15	43	-0.51	0
				Hg burden	144	182	20	87	25	1112	11.12	3.06
SLBE	Lake Manitou	Iowa darter	73	Length	52	6	1	53	39	63	-1.05	-0.13
				Weight	1.0	0.4	0.0	1	0.5	2.0	-0.55	0.49
				Hg conc	30	7	1	30	16	48	0.19	0.36
				Hg burden	32	17	2	26	11	97	2.05	1.25
SLBE	Lake Manitou	yellow perch	68	Length	115	66	8	76	55	264	-0.57	1
				Weight	35	56	7	4.1	1.5	216.3	2.47	1.8
				Hg conc	49	28	3	38.5	18	139	1.3	1.43
				Hg burden	3043	5928	719	131.5	35	30081	8.07	2.7
SLBE	Round Lake	bluegill	61	Length	38	12	2	35	21	71	-0.03	0.83
				Weight	1.0	1.1	0.1	0.5	0.1	5.1	3.68	1.94
				Hg conc	32	12	2	31	10	74	1.35	0.83
				Hg burden	25	21	3	17	4	88	2.71	1.92

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Round Lake	central mudminnow	50	Length	59	8	1	59	44	78	-0.28	0.27
				Weight	2.4	1.1	0.1	2.3	0.9	5.3	0.88	0.94
				Hg conc	34	12	2	34.5	12	71	0.48	0.4
				Hg burden	88	59	8	84	14	279	2.23	1.27
SLBE	Round Lake	Iowa darter	10	Length	46	2	1	46	44	51	-0.14	0.78
				Weight	0.8	0.1	0.0	0.8	0.6	1.0	-0.48	0.29
				Hg conc	23	10	3	21.5	10	41	-0.15	0.65
				Hg burden	17	8	3	16	8	33	0.9	1.28
SLBE	Round Lake	johnny darter	25	Length	50	7	1	49	39	63	-1.26	0.22
				Weight	1.0	0.4	0.1	0.8	0.4	1.6	-1.19	0.45
				Hg conc	14	3	1	14	9	24	3.57	1.25
				Hg burden	13	4	1	12	6	25	0.92	0.85
SLBE	Round Lake	yellow perch	13	Length	218	112	31	290	74	319	-2.02	-0.53
				Weight	230	188	52	330	3.7	450	-1.97	-0.43
				Hg conc	39	17	5	42	10	64	-1.07	-0.41
				Hg burden	11272	9731	2699	13718	50	25080	-1.73	-0.14
VOYA	Brown Lake	yellow perch	115	Length	56	17	2	49	42	138	6.52	2.45
				Weight	2.2	3.0	0.3	1.1	0.7	20.3	15.08	3.57
				Hg conc	103	29	3	100	32	310	21.81	3.22
				Hg burden	260	627	58	112	58	6298	77.06	8.19
VOYA	Peary Lake	yellow perch	119	Length	49	12	1	47	37	106	9.94	2.93
				Weight	1.4	1.8	0.2	0.9	0.4	12.5	20.75	4.4
				Hg conc	37	10	1	36	15	84	3.26	1.12
				Hg burden	61	128	12	33	8	922	33.86	5.63

Appendix I (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), total mercury concentration (*Hg conc*, ng/g wet weight), and total mercury burden (*Hg burden*, ng/fish) in whole prey fish sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish analyzed, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Ryan Lake	Iowa darter	11	Length	48	7	2	47	40	60	-0.92	0.59
				Weight	0.8	0.4	0.1	0.7	0.4	1.5	-0.27	0.94
				Hg conc	131	46	14	128	57	224	0.84	0.7
				Hg burden	113	95	29	74	34	336	1.9	1.55
VOYA	Ryan Lake	yellow perch	102	Length	61	19	2	50	41	115	0.04	1.13
				Weight	2.8	3.0	0.3	1.3	0.5	15.7	3.81	1.93
				Hg conc	110	32	3	108	53	276	6.71	1.69
				Hg burden	358	552	55	132	65	4332	27.01	4.42
VOYA	Sand Point Lake	johnny darter	2	Length	44	10	7	44	37	51	.	.
				Weight	0.8	0.5	0.4	0.8	0.4	1.1	.	.
				Hg conc	52	0	0	52	52	52	.	.
				Hg burden	40	28	20	39.5	20	59	.	.
VOYA	Sand Point Lake	yellow perch	131	Length	60	11	1	57	47	121	9.74	2.92
				Weight	2.4	2.3	0.2	1.8	1.0	20.8	35.97	5.32
				Hg conc	104	33	3	101	48	196	-0.15	0.58
				Hg burden	272	332	29	188	52	2696	25.31	4.53
VOYA	Shoepack Lake	yellow perch	35	Length	81	9	2	79	69	101	-0.58	0.6
				Weight	4.6	1.9	0.3	4.1	2.0	9.5	0.47	1.07
				Hg conc	139	26	5	139	90	199	-0.17	0.29
				Hg burden	646	289	49	620	277	1568	1.67	1.2

Appendix J. Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
GRPO	Grand Portage Creek	rainbow trout	35	Length	117	41	7	111	75	308	13.60	3.17
			35	Weight	26	46	8	15.5	5	279	28.27	5.11
			0	Age	.	.	.	.	.	.	.	.
			35	Hg	40	10	2	38.4	23	69	1.81	1.18
GRPO	Hollow Rock Creek	rainbow trout	6	Length	122	6	3	124	113	129	-1.72	-0.54
			6	Weight	21	3	1	20.9	16	23	-1.86	-0.41
			0	Age	.	.	.	.	.	.	.	.
			6	Hg	19	2	1	18.9	15	22	1.46	-0.92
GRPO	Poplar Creek	creek chub	12	Length	130	22	6	129.5	99	168	-0.46	0.10
			12	Weight	26	13	4	23.6	10	48	-0.32	0.66
			0	Age	.	.	.	.	.	.	.	.
			12	Hg	91	38	11	76.3	54	168	0.08	1.20
GRPO	Reservation River	rainbow trout	6	Length	136	10	4	137	118	148	2.31	-1.18
			6	Weight	28	6	2	29.6	19	24	-0.02	-0.90
			0	Age								
			6	Hg	42	16	6	36.8	28	72	3.75	1.85
INDU	Great Marsh	grass pickerel	22	Length	142	27	6	139	112	214	0.68	1.01
			22	Weight	24	15	3	19.6	9	66	1.66	1.39
			18	Age	1.4	0.6	0.1	1	1	3	0.39	1.09
			22	Hg	128	59	13	124.4	39	272	0.99	0.98

Appendix J (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Long Lake	black bullhead	7	Length	192	10	3	191	176	203	-0.53	-0.36
			7	Weight	136	31	12	140	90	180	-0.81	-0.10
			0	Age	.	.	.	.	.	.	.	.
			7	Hg	43	9	3	40.1	28	56	-0.16	-0.11
INDU	Long Lake	common carp	12	Length	186	16	4	188	152	217	1.54	-0.24
			12	Weight	118	29	8	110	70	190	3.74	1.28
			0	Age	.	.	.	.	.	.	.	.
			12	Hg	13	2	1	12.1	10	16	-1.27	0.31
INDU	Middle Lagoon	bluegill	9	Length	123	18	6	122	89	153	1.32	-0.21
			9	Weight	62	17	6	70	30	90	0.78	-0.44
			0	Age	.	.	.	.	.	.	.	.
			9	Hg	29	6	2	28	22	43	5.10	1.96
INDU	Middle Lagoon	channel catfish	1	Length	485	.	.	485	485	485	.	.
			1	Weight	1240	.	.	1240	1240	1240	.	.
			0	Age	.	.	.	.	.	.	.	.
			1	Hg	221	.	.	222	222	222	.	.
INDU	Middle Lagoon	common carp	1	Length	165	.	.	165	165	165	.	.
			1	Weight	8	.	.	8	8	8	.	.
			0	Age	.	.	.	.	.	.	.	.
			1	Hg	15	.	.	15	15	15	.	.
INDU	Middle Lagoon	grass pickerel	12	Length	188	95	28	148	87	338	-1.39	0.72
			12	Weight	82	107	31	20.7	4	300	0.06	1.25
			11	Age	2.2	1.3	0.4	2	1	4	-1.63	0.54
			12	Hg	115	64	18	91.8	39	259	0.83	1.13

Appendix J (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
INDU	Middle Lagoon	gizzard shad	11	Length	334	12	4	333	310	352	0.78	-0.22
			11	Weight	406	47	14	400	310	470	0.56	-0.48
			0	Age	.	.	.	.	.	.	.	.
			11	Hg	29	9	3	26.8	19	42	-1	0
INDU	Middle Lagoon	largemouth bass	21	Length	363	57	12	355	239	494	1.19	0.28
			21	Weight	746	403	88	680	170	1920	2.85	1.49
			17	Age	5.9	1.6	0.4	6	4	10	1.55	1.09
			21	Hg	169	52	11	177	923	322	2.41	1.04
INDU	Middle Lagoon	yellow perch	1	Length	148	.	.	148	148	148	.	.
			1	Weight	33	.	.	33	33	33	.	.
			0	Age	.	.	.	.	.	.	.	.
			1	Hg	69	.	.	69	69	69	.	.
ISRO	Angleworm Lake	northern pike	57	Length	554	89	12	573	338	696	-0.27	-0.69
			57	Weight	1126	433	57	1170	290	1940	-0.65	-0.17
			50	Age	4.6	1	0.2	5	2	7	-0.20	-0.03
			57	Hg	240	163	22	193.8	59	843	4.10	1.87
ISRO	Lake Harvey	yellow perch	80	Length	240	66	7	243	128	347	-1.52	0.00
			80	Weight	164	122	14	147.9	19	437	-0.99	0.51
			8	Age	4	1	0.5	4	2	6	-0.70	0.00
			80	Hg	688	368	41	646.1	94	1453	-1.01	0.32
ISRO	Lake Richie	northern pike	64	Length	497	72	9	498.5	304	631	-0.55	-0.20
			64	Weight	824	301	38	820	350	1630	-0.24	0.49
			60	Age	3.6	0.8	0.1	4	2	6	0.12	0.37
			64	Hg	200	103	13	177.6	97	648	8.14	2.55

Appendix J (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
ISRO	Lake Richie	yellow perch	9	Length	187	24	8	184	161	225	-1.33	0.36
			9	Weight	81	38	13	74.6	41	146	-0.63	0.73
			0	Age	.	.	.	.	.	.	.	.
			9	Hg	76	18	6	67.5	51	111	0.81	0.80
ISRO	Sargent Lake	northern pike	55	Length	609	74	10	608	283	746	6.10	-1.49
			55	Weight	1464	473	64	1430	190	3030	2.22	0.62
			46	Age	5.2	1.3	0.2	5	2	9	1.74	0.49
			55	Hg	427	200	27	379	92	1379	9.08	2.36
PIRO	Beaver Lake	northern pike	64	Length	652	112	14	632.5	345	971	1.55	0.69
			64	Weight	2023	1249	156	1690	233	6400	4.68	2.11
			61	Age	4.7	1.7	0.2	4	2	11	2.32	1.28
			64	Hg	357	126	16	339.7	155	668	-0.36	0.60
PIRO	Beaver Lake	rock bass	4	Length	172	25	13	179.5	137	190	0.50	-1.21
			4	Weight	113	49	25	116.7	52	168	-0.10	-0.37
			0	Age	.	.	.	.	.	.	.	.
			4	Hg	153	23	14	150.5	129	183	-0.41	0.56
PIRO	Beaver Lake	smallmouth bass	5	Length	347	65	29	361	261	410	-1.97	-0.49
			5	Weight	806	335	150	850	460	1200	-2.58	-0.04
			1	Age	4	.	.	4	4	4	.	.
			5	Hg	263	103	46	250.8	119	402	1.02	-0.12
PIRO	Beaver Lake	walleye	33	Length	419	86	15	383	275	557	-1.43	0.02
			33	Weight	749	459	80	550	190	1840	-0.63	0.71
			28	Age	4.5	2	0.4	4	2	10	0.55	0.94
			33	Hg	425	232	40	292.6	194	1034	0.28	1.13

Appendix J (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Beaver Lake	yellow perch	33	Length	211	29	5	213	118	292	4.02	-0.15
			33	Weight	113	44	8	100.4	53	291	8.37	2.57
			0	Age	.	.	.	.	.	.	.	.
			33	Hg	256	65	11	242.3	156	436	0.99	1.02
PIRO	Chapel Lake	rock bass	70	Length	159	28	3	154.5	95	231	0.03	0.20
			70	Weight	89	51	6	68.5	16	272	2.66	1.34
			0	Age	.	.	.	.	.	.	.	.
			70	Hg	498	268	32	480.9	111	1500	2.33	1.26
PIRO	Chapel Lake	yellow perch	42	Length	180	35	5	169.5	132	285	2.20	1.50
			42	Weight	58	49	8	39.9	18	230	5.18	2.25
			0	Age	.	.	.	.	.	.	.	.
			42	Hg	604	263	41	655.2	178	1405	0.69	0.25
PIRO	Grand Sable Lake	northern pike	61	Length	617	98	13	615	356	928	1.18	0.14
			61	Weight	1738	839	107	1560	330	5390	4.65	1.50
			59	Age	4.3	1.2	0.2	4	2	8	0.54	0.49
			61	Hg	628	286	37	590.5	230	1693	2.33	1.31
PIRO	Grand Sable Lake	rock bass	4	Length	150	15	8	145.5	136	171	2.70	1.44
			4	Weight	74.3	30	15	67.6	46	116	2.33	1.26
			0	Age	.	.	.	.	.	.	.	.
			4	Hg	250	81	41	231.9	177	358	-0.41	0.94
PIRO	Grand Sable Lake	smallmouth bass	31	Length	331	65	12	325	234	456	-1.19	0.20
			31	Weight	601	341	61	540	180	1210	-1.09	0.53
			24	Age	5.7	1.4	0.3	6	3	8	-0.99	-0.06
			31	Hg	548	292	52	476	229	1497	2.82	1.59

Appendix J (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
PIRO	Grand Sable Lake	yellow perch	12	Length	185	25	7	178.5	154	239	0.81	1.05
			12	Weight	71	34	10	64.7	36	151	1.81	1.43
			0	Age	.	.	.	.	.	.	.	.
			12	Hg	275	141	41	220.4	140	561	1.05	1.45
PIRO	Miners Lake	northern pike	57	Length	509	81	11	506	370	805	1.97	0.83
			57	Weight	971	535	71	860	320	3570	8.80	2.25
			57	Age	3.8	1	0.1	4	2	6	-0.61	-0.13
			57	Hg	255	98	13	248.8	126	737	9.52	2.22
PIRO	Miners Lake	yellow perch	45	Length	230	34	5	234	134	293	0.14	-0.57
			45	Weight	170	72	11	172.5	26	366	0.04	0.35
			0	Age	.	.	.	.	.	.	.	.
			45	Hg	117	56	8	101.1	54	292	3.03	1.75
SLBE	Bass Lake (Benzie)	black crappie	15	Length	195	26	7	190	168	262	2.32	1.60
			15	Weight	150	65	17	140	78	340	4.81	2.01
			0	Age	.	.	.	.	.	.	.	.
			15	Hg	198	49	13	204	89	291	1.27	-0.58
SLBE	Bass Lake (Benzie)	largemouth bass	61	Length	327	46	6	330	219	414	-0.43	-0.29
			61	Weight	527	202	26	540	160	960	-0.85	0.21
			44	Age	5.9	1.4	0.2	6	2	9	0.56	-0.22
			61	Hg	543	179	23	582.9	234	912	-1.13	-0.02
SLBE	Bass Lake (Benzie)	northern pike	17	Length	500	106	26	492	366	833	5.93	2.04
			17	Weight	861	818	198	620	320	3850	12.69	3.43
			16	Age	3.8	1.4	0.3	3.5	2	8	5.31	1.96
			17	Hg	569	386	94	468.2	206	1762	5.05	1.95

Appendix J (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Bass Lake (Benzie)	rock bass	16	Length	200	37	9	213	115	243	1.03	-1.32
			16	Weight	187	84	21	200.7	31	338	-0.04	-0.43
			0	Age	.	.	.	.	.	.	.	.
			16	Hg	259	93	23	250.6	144	467	0.21	0.83
SLBE	Bass Lake (Leelanau)	largemouth bass	36	Length	337	63	11	333.5	230	462	-0.74	-0.05
			36	Weight	654	354	59	570	180	1570	-0.02	0.66
			24	Age	6	1.4	0.3	6	3	9	0.53	0.00
			36	Hg	274	143	24	232.4	113	708	1.20	1.22
SLBE	Bass Lake (Leelanau)	northern pike	45	Length	504	91	14	513	285	656	-0.29	-0.69
			45	Weight	887	415	62	860	155	1770	-0.82	0.05
			41	Age	3.2	1.1	0.2	3	1	5	-0.66	-0.26
			45	Hg	176	64	10	166	89	411	2.47	1.19
SLBE	Bass Lake (Leelanau)	rock bass	2	Length	205	16	11	205	194	216	.	.
			2	Weight	192	41	29	192.0	163	221	.	.
			0	Age	.	.	.	.	.	.	.	.
			2	Hg	141	79	56	140.6	85	196	.	.
SLBE	Lake Manitou	smallmouth bass	71	Length	380	41	5	383	247	477	1.03	-0.55
			71	Weight	799	223	26	790	210	1440	0.59	0.12
			56	Age	5.4	1.4	0.2	5	2	9	0.21	0.07
			71	Hg	369	186	22	309.9	109	916	0.45	1.07
SLBE	Lake Manitou	yellow perch	24	Length	211	32	7	209.5	154	264	-0.77	0.12
			24	Weight	108	52	11	101.6	39	216	-0.25	0.83
			0	Age	.	.	.	.	.	.	.	.
			24	Hg	133	54	11	124.2	79	296	3.85	1.90

Appendix J (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
SLBE	Round Lake	largemouth bass	56	Length	304	38	5	305	223	400	0.88	0.11
			56	Weight	384	155	21	362.5	140	920	3.54	1.53
			47	Age	5.3	1.8	0.3	6	2	9	-0.34	-0.05
			56	Hg	272	121	16	238.2	107	650	2.09	1.41
SLBE	Round Lake	smallmouth bass	1	Length	321	.	.	321	321	321	.	.
			1	Weight	520	.	.	520	520	520	.	.
			1	Age	5	.	.	5	5	5	.	.
			1	Hg	127	.	.	127	127	127	.	.
SLBE	Round Lake	yellow perch	8	Length	303	10	4	305	289	319	-0.02	0.00
			8	Weight	370	43	15	355	329	450	0.06	0.99
			0	Age	.	.	.	.	.	.	.	.
			8	Hg	84	16	6	79.6	58	106	-0.67	0.07
VOYA	Brown Lake	northern pike	50	Length	487	71	10	502.5	312	639	0.49	-0.53
			50	Weight	692	263	37	735	210	1430	1.04	0.40
			48	Age	3.9	1	0.1	4	2	6	-0.29	0.23
			50	Hg	860	490	69	774.4	336	3305	12.92	3.14
VOYA	Peary Lake	northern pike	70	Length	552	64	8	548	398	780	2.10	0.56
			70	Weight	997	368	44	915	430	2410	4.19	1.81
			65	Age	4.4	1	0.1	4	2	8	1.21	0.51
			70	Hg	506	219	26	455.4	180	1329	1.75	1.15
VOYA	Ryan Lake	northern pike	69	Length	485	52	6	490	358	589	0.59	-0.72
			69	Weight	629	162	20	650	280	990	0.04	-0.46
			66	Age	3.7	0.9	0.1	4	2	6	0.28	-0.02
			69	Hg	1071	440	53	1067.1	354	2193	-0.04	0.53

Appendix J (continued). Summary statistics for total length (*Length*, mm), wet weight (*Weight*, g), calendar age (*Age*, years) and mercury concentration (*Hg*, ng/g) in axial muscle tissue (skinless fillets) of adult fish of mostly upper trophic-level species sampled from six park units in the Great Lakes Inventory and Monitoring Network during 2008–2012 (n = number of fish, SD = standard deviation, SE = standard error, Min = minimum value, Max = maximum value).

Park unit	Water body	Species	n	Variable	Mean	SD	SE	Median	Min	Max	Kurtosis	Skewness
VOYA	Sand Point Lake	northern pike	59	Length	501	99	13	493	248	810	0.98	0.61
			59	Weight	795	504	66	650	140	2960	5.48	2.07
			55	Age	3.7	1.4	0.2	3	1	8	1.39	1.06
			59	Hg	774	478	62	610.9	217	2372	1.38	1.28
VOYA	Sand Point Lake	walleye	3	Length	409	25	14	410	384	433	.	-0.18
			3	Weight	627	102	59	670	510	700	.	-1.57
			2	Age	5	1.4	1.0	5	4	6	.	.
			3	Hg	1138	162	94	1130.6	980	1304	.	0.21

Appendix K. Inventories of fish samples from park units in the western Great Lakes region that were analyzed for selected organic contaminants and total lead.

Table K-1. Descriptive inventory of axial muscle samples of fish, which were sampled from five park units during 2008–2009 and analyzed for selected organic contaminants and total lead.

Park Unit	Water body	Species of fish	No. and size of fish in sample[1]			Sample identification code[2]	Axial muscle sample mass (g, wet weight)
			n	*Total length (mm)*	*Wet weight (g)*		
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	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
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	12.280
		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	624-728	1430-3030	2009-ISRO-SARG-NP-Comp2	12.040
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)	11.950
		northern pike	1	345	233	2008-PIRO-BEAV-NP-Ind2	11.586
		walleye	1	557	1500	2008-PIRO-BEAV-WE-Ind1	13.313

[1] For composite samples (more than 1 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 same composite sample.

Table K-1 (continued). Descriptive inventory of axial muscle samples of fish, which were sampled from five park units during 2008–2009 and analyzed for selected organic contaminants and total lead.

Park Unit	Water body	Species of fish	No. and size of fish in sample[1]			Sample identification code[2]	Axial muscle sample mass (g, wet weight)
			n	*Total length (mm)*	*Wet weight (g)*		
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
		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)	12.080
		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	13.010
		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	13.370
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

[1] For composite samples (more than 1 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 same composite sample.

Table K-1 (continued). Descriptive inventory of axial muscle samples of fish, which were sampled from five park units during 2008–2009 and analyzed for selected organic contaminants and total lead.

Park Unit	Water body	Species of fish	No. and size of fish in sample[1]			Sample identification code[2]	Axial muscle sample mass (g, wet weight)
			n	*Total length (mm)*	*Wet weight (g)*		
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
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	13.510
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 Point 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 (more than 1 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 same composite sample.

Table K-2. Descriptive inventory of whole-fish samples, which were sampled from six park units during 2010–2012 and analyzed for selected organic contaminants and total lead.

Park unit	Water body	Year	Species	No. and size of fish in sample [1]			Sample identification code
				n	*Total length (mm)*	*Wet weight (g)*	
GRPO	Grand Portage Creek	2011	rainbow trout	1	308	279	2011-GRPO-GRAN-RT-01
			rainbow trout	3	141-160	37-53	2011-GRPO-GRAN-RT-Comp1
		2012	rainbow trout	4	112-118	16-22	2012-GRPO-GRAN-RT-Comp1
			rainbow trout	2	151-166	39-61	2012-GRPO-GRAN-RT-Comp2
GRPO	Poplar Creek	2010	creek chub	4	114-138	16-26	2010-GRPO-POPL-CC-Comp1
			creek chub	4	109-115	12-15	2010-GRPO-POPL-CC-Comp2
		2011	creek chub	4	90-122	8-18	2011-GRPO-POPL-CC-Comp1
		2012	creek chub	4	128-155	23-45	2012-GRPO-POPL-CC-Comp1
			creek chub	4	99-127	10-22	2012-GRPO-POPL-CC-Comp2
INDU	Great Marsh	2010	grass pickerel	3	112-152	9-26	2010-INDU-GRMA4-GP-Comp1
			grass pickerel	3	143-168	25-41	2010-INDU-GRMA2-GP-Comp2
		2011	grass pickerel	4	166-214	28-66	2011-INDU-GRM4-GP-Comp1
		2012	grass pickerel	4	133-142	15-24	2012-INDU-GRM4-GP-Comp1
INDU	Long Lake	2010	black bullhead	3	191-203	140-160	2010-INDU-LONG-BLB-Comp1
			black bullhead	3	176-188	90-120	2010-INDU-LONG-BLB-Comp2
			common carp	4	171-217	100-190	2010-INDU-LONG-COC-Comp1
			common carp	4	184-191	110-120	2010-INDU-LONG-COC-Comp2
INDU	Middle Lagoon	2010	grass pickerel	2	320-338	190-300	2010-INDU-MILA-GP-Comp1
			gizzard shad	4	330-352	370-470	2010-INDU-MILA-GZS- Comp 1
			gizzard shad	4	327-352	390-470	2010-INDU-MILA-GZS- Comp 2
			largemouth bass	4	379-494	680-1920	2010-INDU-MILA-LB- Comp 1
			largemouth bass	4	282-373	290-730	2010-INDU-MILA-LB- Comp 2
		2011	largemouth bass	4	355-383	700-870	2011-INDU-MILA-LB- Comp 1
			largemouth bass	4	322-348	360-670	2011-INDU-MILA-LB- Comp 2

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

Table K-2 (continued). Descriptive inventory of whole-fish samples, which were sampled from six park units during 2010–2012 and analyzed for selected organic contaminants and total lead.

Park unit	Water body	Year	Species	No. and size of fish in sample [1]			Sample identification code
				n	*Total length (mm)*	*Wet weight (g)*	
INDU	Middle Lagoon	2012	largemouth bass	3	355-463	620-1500	2012-INDU-MILA-LB- Comp 1
ISRO	Angleworm Lake	2010	northern pike	4	409-466	430-740	2010-ISRO-ANGL-NP-Comp1
			northern pike	4	518-662	945-1455	2010-ISRO-ANGL-NP-Comp2
		2011	northern pike	4	499-594	8401400	2011-ISRO-ANGL-NP-Comp1
			northern pike	4	502-557	910-1040	2011-ISRO-ANGL-NP-Comp2
		2012	northern pike	3	606-696	1320-1940	2012-ISRO-ANGL-NP-Comp1
			northern pike	3	524-622	970-1530	2012-ISRO-ANGL-NP-Comp2
ISRO	Lake Harvey	2010	yellow perch	4	308-333	308-400	2010-ISRO-HARV-YP-Comp1
			yellow perch	4	244-262	152-219	2010-ISRO-HARV-YP-Comp2
		2011	yellow perch	4	279-297	184-260	2011-ISRO-HARV-YP-Comp1
			yellow perch	4	303-347	248-427	2011-ISRO-HARV-YP-Comp2
		2012	yellow perch	4	277-340	213-437	2012-ISRO-HARV-YP-Comp1
			yellow perch	3	263-292	199-255	2012-ISRO-HARV-YP-Comp2
ISRO	Lake Richie	2010	northern pike	4	437-579	590-1110	2010-ISRO-RICH-NP-Comp1
			northern pike	4	378-401	350-480	2010-ISRO-RICH-NP-Comp2
		2011	northern pike	4	408-494	500-800	2011-ISRO-RICH-NP-Comp1
			northern pike	4	435-499	550-840	2011-ISRO-RICH-NP-Comp2
		2012	northern pike	3	505-555	840-1020	2012-ISRO-RICH-NP-Comp1
			northern pike	3	515-627	820-1240	2012-ISRO-RICH-NP-Comp2
ISRO	Sargent Lake	2010	northern pike	4	501-613	790-1500	2010-ISRO-SARG-NP-Comp1
			northern pike	4	534-677	900-1710	2010-ISRO-SARG-NP-Comp2
		2011	northern pike	4	597-689	1370-1870	2011-ISRO-SARG-NP-Comp1
			northern pike	4	473-592	1250-1550	2011-ISRO-SARG-NP-Comp2
		2012	northern pike	3	640-746	1590-2670	2012-ISRO-SARG-NP-Comp1

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

Table K-2 (continued). Descriptive inventory of whole-fish samples, which were sampled from six park units during 2010–2012 and analyzed for selected organic contaminants and total lead.

Park unit	Water body	Year	Species	No. and size of fish in sample [1]			Sample identification code
				n	*Total length (mm)*	*Wet weight (g)*	
ISRO	Sargent Lake	2012	northern pike	3	586-669	1250-1740	2012-ISRO-SARG-NP-Comp2
PIRO	Beaver Lake	2010	northern pike	4	613-657	1560-2000	2010-PIRO-BEAV-NP-Comp1
			northern pike	4	636-689	1670-2430	2010-PIRO-BEAV-NP-Comp2
			walleye	4	509-535	1320-1550	2010-PIRO-BEAV-WE-Comp1
			walleye	3	479-501	820-1070	2010-PIRO-BEAV-WE-Comp2
PIRO	Beaver Lake	2011	northern pike	4	704-808	2510-3110	2011-PIRO-BEAV-NP-Comp1
			smallmouth bass	3	361-410	850-1200	2011-PIRO-BEAV-SB-Comp1
		2012	northern pike	4	588-727	1220-2740	2012-PIRO-BEAV-NP-Comp1
PIRO	Chapel Lake	2010	rock bass	5	175-197	111-149	2010-PIRO-CHAP-RB-Comp1
			rock bass	5	146-155	54-69	2010-PIRO-CHAP-RB-Comp2
		2011	rock bass	3	107-139	23-56	2011-PIRO-CHAP-RB-Comp1
		2012	rock bass	4	203-231	167-272	2012-PIRO-CHAP-RB-Comp1
			rock bass	4	184-189	127-143	2012-PIRO-CHAP-RB-Comp2
			yellow perch	3	222-285	113-224	2012-PIRO-CHAP-YP-Comp-1
PIRO	Grand Sable Lake	2010	northern pike	4	501-547	810-1120	2010-PIRO-GRSA-NP-Comp1
			northern pike	4	610-668	1380-1970	2010-PIRO-GRSA-NP-Comp2
			smallmouth bass	4	400-456	900-1210	2010-PIRO-GRSA-SB-Comp1
			smallmouth bass	4	293-376	360-710	2010-PIRO-GRSA-SB-Comp2
		2011	northern pike	4	677-762	2430-3040	2011-PIRO-GRSA-NP-Comp1
			smallmouth bass	4	376-413	880-1150	2011-PIRO-GRSA-SB-Comp1
		2012	northern pike	4	546-585	1100-1360	2012-PIRO-GRSA-NP-Comp1
PIRO	Miners Lake	2010	northern pike	4	549-603	1150-1420	2010-PIRO-MINE-NP-Comp1
			northern pike	4	485-532	840-1010	2010-PIRO-MINE-NP-Comp2
		2011	northern pike	4	543-653	1240-1930	2011-PIRO-MINE-NP-Comp1

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

Table K-2 (continued). Descriptive inventory of whole-fish samples, which were sampled from six park units during 2010–2012 and analyzed for selected organic contaminants and total lead.

Park unit	Water body	Year	Species	No. and size of fish in sample [1]			Sample identification code
				n	*Total length (mm)*	*Wet weight (g)*	
			northern pike	4	533-540	1020-1200	2011-PIRO-MINE-NP-Comp2
		2012	northern pike	4	521-627	980-1750	2012-PIRO-MINE-NP-Comp1
SLBE	Bass Lake (Benzie)	2010	largemouth bass	4	324-350	530-660	2010-SLBE-BABE-LB-Comp1
			largemouth bass	4	341-378	590-740	2010-SLBE-BABE-LB-Comp2
		2011	largemouth bass	4	348-363	580-710	2011-SLBE-BABE-LB-Comp1
			largemouth bass	4	379-399	750-880	2011-SLBE-BABE-LB-Comp2
		2012	largemouth bass	4	359-414	700-960	2012-SLBE-BABE-LB-Comp1
			northern pike	4	492-532	620-860	2012-SLBE-BABE-NP-Comp1
SLBE	Bass Lake (Leelanau)	2010	largemouth bass	4	384-435	865-1310	2010-SLBE-BALE-LB-Comp1
			largemouth bass	4	248-291	230-370	2010-SLBE-BALE-LB-Comp2
SLBE	Bass Lake (Leelanau)	2011	northern pike	4	567-610	1360-1520	2011-SLBE-BALE-NP-Comp1
			northern pike	4	516-580	900-1250	2011-SLBE-BALE-NP-Comp2
		2012	largemouth bass	4	362-374	710-8840	2012-SLBE-BALE-LB-Comp1
			northern pike	4	546-579	920-1050	2012-SLBE-BALE-NP-Comp1
			northern pike	4	570-656	1150-1770	2012-SLBE-BALE-NP-Comp2
SLBE	Lake Manitou	2010	smallmouth bass	4	397-412	860-1090	2010-SLBE-MANI-SB-Comp1
			smallmouth bass	4	328-385	450-730	2010-SLBE-MANI-SB-Comp2
		2011	smallmouth bass	4	436-477	1120-1440	2011-SLBE-MANI-SB-Comp1
			smallmouth bass	4	419-441	1020-1160	2011-SLBE-MANI-SB-Comp2
		2012	smallmouth bass	4	384-418	720-970	2012-SLBE-MANI-SB-Comp1
			smallmouth bass	4	325-390	560-780	2012-SLBE-MANI-SB-Comp2
SLBE	Round Lake	2010	largemouth bass	4	265-308	270-430	2010-SLBE-ROUN-LB-Comp1
			largemouth bass	4	289-303	330-350	2010-SLBE-ROUN-LB-Comp2
		2011	largemouth bass	4	337-400	520-870	2011-SLBE-ROUN-LB-Comp1

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

Table K-2 (continued). Descriptive inventory of whole-fish samples, which were sampled from six park units during 2010–2012 and analyzed for selected organic contaminants and total lead.

Park unit	Water body	Year	Species	No. and size of fish in sample [1]			Sample identification code
				n	*Total length (mm)*	*Wet weight (g)*	
SLBE	Round Lake	2011	largemouth bass	4	312-342	420-520	2011-SLBE-ROUN-LB-Comp2
		2012	largemouth bass	4	304-328	360-500	2012-SLBE-ROUN-LB-Comp1
VOYA	Brown Lake	2010	northern pike	4	451-529	440-800	2010-VOYA-BROW-NP-Comp1
		2011	northern pike	4	497-538	710-870	2011-VOYA-BROW-NP-Comp1
			northern pike	4	496-533	770-910	2011-VOYA-BROW-NP-Comp2
		2012	northern pike	3	418-538	420-950	2012-VOYA-BROW-NP-Comp1
			northern pike	3	561-639	840-1430	2012-VOYA-BROW-NP-Comp2
VOYA	Peary Lake	2010	northern pike	4	546-578	950-1020	2010-VOYA-PEAR-NP-Comp1
			northern pike	4	493-603	700-1260	2010-VOYA-PEAR-NP-Comp2
		2011	northern pike	4	547-592	920-1200	2011-VOYA-PEAR-NP-Comp1
			northern pike	4	522-586	840-1130	2011-VOYA-PEAR-NP-Comp2
		2012	northern pike	4	535-675	840-1890	2012-VOYA-PEAR-NP-Comp1
			northern pike	4	460-520	650-800	2012-VOYA-PEAR-NP-Comp2
VOYA	Ryan Lake	2010	northern pike	4	397-561	300-850	2010-VOYA-RYAN-NP-Comp1
			northern pike	4	474-513	645-740	2010-VOYA-RYAN-NP-Comp2
			northern pike	4	484-502	650-700	2011-VOYA-RYAN-NP-Comp2
		2012	northern pike	4	425-521	420-810	2012-VOYA-RYAN-NP-Comp1
			northern pike	4	471-514	560-780	2012-VOYA-RYAN-NP-Comp2
VOYA	Sand Point Lake	2010	northern pike	4	424-539	410-710	2010-VOYA-SAND-NP-Comp1
			northern pike	4	400-463	390-550	2010-VOYA-SAND-NP-Comp2
		2011	northern pike	4	426-502	470-780	2011-VOYA-SAND-NP-Comp1
			northern pike	4	393-411	380-460	2011-VOYA-SAND-NP-Comp2
		2012	northern pike	3	452-491	510-710	2012-VOYA-SAND-NP-Comp1
			northern pike	3	494-658	660-1180	2012-VOYA-SAND-NP-Comp2

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

Appendix L. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentrations of selected organic contaminants and total lead in samples of fish collected in 2008–2012 from six national park units in the Great Lakes Inventory and Monitoring Network. Samples of axial muscle (skinless fillets) were analyzed from fish collected in 2008 or 2009, whereas subsamples of whole fish were collected in 2010–2012. This appendix is composed of 11 tables:

Table	Park unit	Fish sample type	Year(s) of sample collection
L-1	GRPO	axial muscle	2009
L-2	GRPO	whole fish	2010–2012
L-3	INDU	whole fish	2010–2012
L-4	ISRO	axial muscle	2009
L-5	ISRO	whole fish	2010–2012
L-6	PIRO	axial muscle	2008
L-7	PIRO	whole fish	2010–2012
L-8	SLBE	axial muscle	2008
L-9	SLBE	whole fish	2010–2012
L-10	VOYA	axial muscle	2009
L-11	VOYA	whole fish	2010–2012

Table L-1. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in 4 composite samples of axial muscle from fish collected in 2009 from Grand Portage Creek and Poplar Creek at Grand Portage National Monument (ND = not detected; NA = not applicable).

	Analytes detected in axial muscle		LOD	Maximum concentration in axial muscle		
Analyte(s)	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	0	0	10	ND	NA	NA
p,p'-DDD[2]	0	0	10	ND	NA	NA
p,p'-DDE[3]	0	0	10	ND	NA	NA
Perfluoro-1-hexanesulfonate	0	0	NA	<0.50[6]	NA	NA
Perfluoro-1-octanesulfonate	4	2	NA	1.6	Grand Portage Creek	rainbow trout
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]	1	1	0.5-16	2.5	Grand Portage Creek	rainbow trout
Total Lead	4	2	9.04	13.8	Grand Portage Creek	rainbow trout

Table L-2. Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in individual and composite samples of whole fish collected during 2010–2012 from two streams in Grand Portage National Monument (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	2010 2012	6	2	0	0	10	ND	NA	NA
p,p'-DDD[2]	2010 2012	6	2	0	0	10	ND	NA	NA
p,p'-DDE[3]	2010 2012	6	2	0	0	10	ND	NA	NA
Perfluoro-1-butanesulfonate	2010 2011 2012	9	2	2	1	NA	0.22	Poplar Creek	creek chub
Perfluoro-1-decanesulfonate	2010 2011 2012	9	2	0	0	NA	<0.12[8]	NA	NA
Perfluoro-1-heptanesulfonate	2010 2011 2012	9	2	1	1	NA	0.2	Poplar Creek	creek chub
Perfluoro-1-hexanesulfonate	2010 2011 2012	9	2	4	2	NA	25	Poplar Creek	creek chub

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-2 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in individual and composite samples of whole fish collected during 2010–2012 from two streams in Grand Portage National Monument (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-1-octanesulfonate	2010 2011 2012	9	2	9	2	NA	6.4	Grand Portage Creek	rainbow trout
Perfluoro-n-butanoic acid	2010 2011 2012	9	2	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-decanoic acid	2010 2011 2012	9	2	7	2	NA	3.1	Poplar Creek	creek chub
Perfluoro-n-dodecanoic acid	2010 2011 2012	9	2	2	2	NA	0.52	Poplar Creek	creek chub
Perfluoro-n-heptanoic acid	2010 2011 2012	9	2	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-hexanoic acid	2010 2011 2012	9	2	0	0	NA	<0.12[8]	NA	NA

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-2 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in individual and composite samples of whole fish collected during 2010–2012 from two streams in Grand Portage National Monument (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-n-nonanoic acid	2010 2011 2012	9	2	4	2	NA	1.5	Grand Portage Creek	rainbow trout
Perfluoro-n-octanoic acid	2010 2011 2012	9	2	3	2	NA	0.96	Poplar Creek	creek chub
Perfluoro-n-pentanoic acid	2010 2011 2012	9	2	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-tetradecanoic acid	2010 2011 2012	9	2	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-tridecanoic acid	2010 2011 2012	9	2	1	1	NA	0.39	Grand Portage Creek	rainbow trout
Perfluoro-n-undecanoic acid	2010 2011 2012	9	2	3	2	NA	3.6	Poplar Creek	creek chub

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-2 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in individual and composite samples of whole fish collected during 2010–2012 from two streams in Grand Portage National Monument (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Total PBDEs[4,5]	2010	2	1	0	0	1.0-2.0	ND	NA	NA
	2012	3	2	2	1	NA[7]	1.3	Grand Portage Creek	rainbow trout
Total PCBs[6]	2010 2012	6	2	1	1	1.0-3.5	6.9	Grand Portage Creek	rainbow trout
Total Lead	2010	2	1	2	1	5.3	46.7	Poplar Creek	creek chub

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-3. Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010-2012 from four sites in Indiana Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	2010 2011 2012	16	4	0	0	10	ND	NA	NA
p,p'-DDD[2]	2010 2011 2012	16	4	5	1	10	160	Middle Lagoon	gizzard shad
p,p'-DDE[3]	2010 2011 2012	16	4	7	1	10	570	Middle Lagoon	gizzard shad
Perfluoro-1-butanesulfonate	2010 2011 2012	16	4	3	1	NA	0.13	Middle Lagoon	largemouth bass
Perfluoro-1-decanesulfonate	2010 2011 2012	16	4	7	1	NA	11	Middle Lagoon	largemouth bass
Perfluoro-1-heptanesulfonate	2010 2011 2012	16	4	2	2	NA	0.22	Great Marsh	grass pickerel

[1]2,2-bis (p-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (p-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (p-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-3 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010-2012 from four sites in Indiana Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-1-hexanesulfonate	2010 2011 2012	16	4	3	2	NA	1.5	Great Marsh	grass pickerel
Perfluoro-1-octanesulfonate	2010 2011 2012	16	4	15	4	NA	130	Middle Lagoon	largemouth bass
Perfluoro-n-butanoic acid	2010 2011 2012	16	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-decanoic acid	2010 2011 2012	16	4	13	4	NA	10	Middle Lagoon	largemouth bass
Perfluoro-n-dodecanoic acid	2010 2011 2012	16	4	12	3	NA	3.6	Middle Lagoon	largemouth bass
Perfluoro-n-heptanoic acid	2010 2011 2012	16	4	0	0	NA	<0.12[8]	NA	NA

[1]2,2-bis (p-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (p-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (p-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-3 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010-2012 from four sites in Indiana Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-n-nonanoic acid	2010 2011 2012	16	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-octanoic acid	2010 2011 2012	16	4	4	3	NA	0.46	Middle Lagoon	largemouth bass
Perfluoro-n-pentanoic acid	2010 2011 2012	16	4	2	1	NA	32	Middle Lagoon	gizzard shad
Perfluoro-n-tetradecanoic acid	2010 2011 2012	16	4	7	1	NA	0.94	Middle Lagoon	gizzard shad
Perfluoro-n-tridecanoic acid	2010 2011 2012	16	4	6	1	NA	1.6	Middle Lagoon	largemouth bass
Total PBDEs[4,5]	2010 2011 2012	11 5	4 2	4 2	1 1	1.0-2.0 NA[7]	21.6 12.8	Middle Lagoon Middle Lagoon	gizzard shad largemouth bass

[1]2,2-bis (p-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (p-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (p-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-3 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010-2012 from four sites in Indiana Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Total PCBs[6]	2010 2011 2012	16	4	7	1	1.0-3.5	446	Middle Lagoon	gizzard shad
Total Lead	2010	11	4	11	4	5.3	304	Middle Lagoon	gizzard shad

[1]2,2-bis (p-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (p-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (p-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-4. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in 10 composite samples of axial muscle from fish collected in 2009 from four lakes at Isle Royale National Park (ND = not detected; NA = not applicable).

	Analytes detected in axial muscle		LOD	Maximum concentration in axial muscle		
Analyte(s)	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	0	0	10	ND	NA	NA
p,p'-DDD[2]	0	0	10	ND	NA	NA
p,p'-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-undodecanoic 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

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

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

[5]Sum 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

[6]Less than the reporting limit

Table L-5. Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Isle Royale National Park (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	2010 2012	16	4	0	0	10	ND	NA	NA
p,p'-DDD[2]	2010 2012	16	4	0	0	10	ND	NA	NA
p,p'-DDE[3]	2010 2012	16	4	0	0	10	ND	NA	NA
Perfluoro-1-butanesulfonate	2010 2011 2012	24	4	4	3	NA	0.14	Lake Richie	northern pike
Perfluoro-1-decanesulfonate	2010 2011 2012	24	4	1	1	NA	0.12	Angleworm Lake	northern pike
Perfluoro-1-heptanesulfonate	2010 2011 2012	24	4	4	3	NA	0.17	Angleworm Lake	northern pike
Perfluoro-1-hexanesulfonate	2010 2011 2012	24	4	9	3	NA	1.4	Sargent Lake	northern pike

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-5 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Isle Royale National Park (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-1-octanesulfonate	2010 2011 2012	24	4	24	4	NA	5.1	Lake Harvey	yellow perch
Perfluoro-n-butanoic acid	2010 2011 2012	24	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-decanoic acid	2010 2011 2012	24	4	24	4	NA	2.7	Lake Harvey	yellow perch
Perfluoro-n-dodecanoic acid	2010 2011 2012	24	4	8	3	NA	0.64	Lake Harvey	yellow perch
Perfluoro-n-heptanoic acid	2010 2011 2012	24	4	2	1	NA	0.19	Angleworm Lake	northern pike
Perfluoro-n-hexanoic acid	2010 2011 2012	24	4	0	0	NA	<0.12[8]	NA	NA

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-5 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Isle Royale National Park (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-n-nonanoic acid	2010 2011 2012	24	4	10	4	NA	0.34	Angleworm Lake	northern pike
Perfluoro-n-octanoic acid	2010 2011 2012	24	4	10	4	NA	1.1	Lake Harvey	yellow perch
Perfluoro-n-pentanoic acid	2010 2011 2012	24	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-tetradecanoic acid	2010 2011 2012	24	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-tridecanoic acid	2010 2011 2012	24	4	3	2	NA	0.48	Lake Harvey	yellow perch
Total PBDEs[4,5]	2010 2012	8 8	4 4	1 0	1 0	1.0-2.0 NA[7]	1 ND	Lake Harvey NA	yellow perch NA

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-5 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Isle Royale National Park (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Total PCBs[6]	2010 2012	16	4	3	2	1.0-3.5	5.1	Sargent Lake	northern pike
Total Lead	2010	8	4	8	4	5.3	21.9	Lake Richie	northern pike

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-6. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in 15 individual and composite samples of axial muscle from fish collected in 2008 from three lakes at Pictured Rocks National Lakeshore (ND = not detected; NA = not applicable).

	Analytes detected in axial muscle		LOD	Maximum concentration in axial muscle		
Analyte(s)	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	0	0	10	ND	NA	NA
p,p'-DDD[2]	0	0	10	ND	NA	NA
p,p'-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

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

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

[5]Sum 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

[6]Less than the reporting limit

Table L-7. Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Picture Rocks National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	2010 2012	18	4	0	0	10	ND	NA	NA
p,p'-DDD[2]	2010 2012	18	4	0	0	10	ND	NA	NA
p,p'-DDE[3]	2010 2012	18	4	10	2	10	31	Grand Sable Lake	smallmouth bass
Perfluoro-1-butanesulfonate	2010 2011 2012	25	4	1	1	NA	0.13	Chapel Lake	rock bass
Perfluoro-1-decanesulfonate	2010 2011 2012	25	4	3	2	NA	0.20	Grand Sable Lake	northern pike
Perfluoro-1-heptanesulfonate	2010 2011 2012	25	4	2	2	NA	0.17	Beaver Lake and Miners Lake	northern pike
Perfluoro-1-hexanesulfonate	2010 2011 2012	25	4	8	4	NA	2.9	Chapel Lake	rock bass

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2011 and 2012 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-7 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Picture Rocks National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-1-octanesulfonate	2010 2011 2012	25	4	24	4	NA	6.5	Grand Sable Lake	smallmouth bass
Perfluoro-n-butanoic acid	2010 2011 2012	25	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-decanoic acid	2010 2011 2012	25	4	17	3	NA	1.7	Grand Sable Lake	smallmouth bass and northern pike
Perfluoro-n-dodecanoic acid	2010 2011 2012	25	4	10	4	NA	0.95	Grand Sable Lake	northern pike
Perfluoro-n-heptanoic acid	2010 2011 2012	25	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-hexanoic acid	2010 2011 2012	25	4	9	4	NA	2.9	Chapel Lake	rock bass

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2011 and 2012 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-7 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Picture Rocks National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-n-nonanoic acid	2010 2011 2012	25	4	5	2	NA	1.1	Grand Sable Lake	northern pike
Perfluoro-n-octanoic acid	2010 2011 2012	25	4	10	4	NA	0.9	Beaver Lake	walleye
Perfluoro-n-pentanoic acid	2010 2011 2012	25	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-tetradecanoic acid	2010 2011 2012	25	4	3	1	NA	0.36	Grand Sable Lake	northern pike
Perfluoro-n-tridecanoic acid	2010 2011 2012	25	4	8	3	NA	1.5	Grand Sable Lake	northern pike
Perfluoro-n-undecanoic acid	2010 2011 2012	25	4	17	4	NA	3.7	Grand Sable Lake	northern pike

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2011 and 2012 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-7 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Picture Rocks National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish		LOD	Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**(ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Total PBDEs[4,5]	2010	12	4	6	2	1.0-2.0	6.3	Grand Sable Lake	smallmouth bass
	2011	13	4	4	2	NA[7]	7.5	Grand Sable Lake	northern pike
	2012								
Total PCBs[6]	2010	25	4	10	2	1.0-3.5	61.2	Grand Sable Lake	northern pike
	2011								
	2012								
Total Lead	2010	12	4	11	4	5.3	47.4	Chapel Lake	rock bass

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2011 and 2012 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-8. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in 16 individual and composite samples of axial muscle from fish collected in 2008 from four lakes at Sleeping Bear Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Analytes detected in axial muscle		LOD	Maximum concentration in axial muscle		
Analyte(s)	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	0	0	10	ND	NA	NA
p,p'-DDD[2]	0	0	10	ND	NA	NA
p,p'-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

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

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

[5]Sum 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

[6]Less than the reporting limit

Table L-9. Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Sleeping Bear Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	2010 2012	16	4	0	0	10	ND	NA	NA
p,p'-DDD[2]	2010 2012	16	4	0	0	10	ND	NA	NA
p,p'-DDE[3]	2010 2012	16	4	7	4	10	28	Bass Lake (Leelanau)	largemouth bass
Perfluoro-1-butanesulfonate	2010 2011 2012	24	4	1	1	NA	0.14	Bass Lake (Benzie)	largemouth bass
Perfluoro-1-decanesulfonate	2010 2011 2012	24	4	1	1	NA	0.19	Bass Lake (Benzie)	largemouth bass
Perfluoro-1-heptanesulfonate	2010 2011 2012	24	4	1	1	NA	0.23	Lake Manitou	smallmouth bass
Perfluoro-1-hexanesulfonate	2010 2011 2012	24	4	5	3	NA	2.3	Lake Manitou	smallmouth bass

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2011 and 2012 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-9 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Sleeping Bear Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-1-octanesulfonate	2010 2011 2012	24	4	23	4	NA	6.5	Lake Manitou	smallmouth bass
Perfluoro-n-butanoic acid	2010 2011 2012	24	4	1	1	NA	2.0	Lake Manitou	smallmouth bass
Perfluoro-n-decanoic acid	2010 2011 2012	24	4	23	4	NA	2.1	Bass Lake (Benzie)	largemouth bass
Perfluoro-n-dodecanoic acid	2010 2011 2012	24	4	17	4	NA	0.62	Bass Lake (Leelanau)	largemouth bass
Perfluoro-n-heptanoic acid	2010 2011 2012	24	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-hexanoic acid	2010 2011 2012	24	4	7	4	NA	0.58	Bass Lake (Leelanau)	largemouth bass

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2011 and 2012 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-9 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Sleeping Bear Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-n-nonanoic acid	2010 2011 2012	24	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-octanoic acid	2010 2011 2012	24	4	8	4	NA	21	Bass Lake (Leelanau)	largemouth bass
Perfluoro-n-pentanoic acid	2010 2011 2012	24	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-tetradecanoic acid	2010 2011 2012	24	4	3	2	NA	0.71	Bass Lake (Leelanau)	largemouth bass
Perfluoro-n-tridecanoic acid	2010 2011 2012	24	4	9	4	NA	2.50	Bass Lake (Leelanau)	largemouth bass
Perfluoro-n-undecanoic acid	2010 2011 2012	24	4	23	4	NA	3.2	Round Lake	largemouth bass

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2011 and 2012 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-9 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Sleeping Bear Dunes National Lakeshore (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Total PBDEs[4,5]	2010 2011	8	4	6	4	1.0-2.0	10.3	Bass Lake (Leelanau)	largemouth bass
	2012	10	4	9	4	NA[7]	5.0	Bass Lake (Leelanau)	northern pike
Total PCBs[6]	2010 2011 2012	24	4	20	4	1.0-3.5	29.5	Round Lake	largemouth bass
Total Lead	2010	8	4	8	4	5.3	112	Lake Manitou	smallmouth bass

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2011 and 2012 sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-10. Occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in 10 composite samples of axial muscle from fish collected in 2009 from four lakes at Voyageurs National Park (ND = not detected; NA = not applicable).

	Analytes detected in axial muscle		LOD	Maximum concentration in axial muscle		
Analyte(s)	***No. of samples***	***No. of sites***	**(ng/g wet weight)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	0	0	10	ND	NA	NA
p,p'-DDD[2]	0	0	10	ND	NA	NA
p,p'-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-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]	0	0	0.5-16	ND	NA	NA
Total Lead	10	4	6.8	30.6	Peary Lake	northern pike

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

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

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

[5]Sum 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

[6]Less than the reporting limit

Table L-11. Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Voyageurs National Park (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
p,p'-DDT[1]	2010 2012	15	4	0	0	10	ND	NA	NA
p,p'-DDD[2]	2010 2012	15	4	0	0	10	ND	NA	NA
p,p'-DDE[3]	2010 2012	15	4	0	0	10	ND	NA	NA
Perfluoro-1-butanesulfonate	2010 2011 2012	23	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-1-decanesulfonate	2010 2011 2012	23	4	1	1	NA	0.14	Peary Lake	northern pike
Perfluoro-1-heptanesulfonate	2010 2011 2012	23	4	1	1	NA	0.14	Peary Lake	northern pike
Perfluoro-1-hexanesulfonate	2010 2011 2012	23	4	9	4	NA	1.8	Peary Lake	northern pike

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-11 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Voyageurs National Park (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-1-octanesulfonate	2010 2011 2012	23	4	22	4	NA	2.9	Sand Point Lake	northern pike
Perfluoro-n-butanoic acid	2010 2011 2012	23	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-decanoic acid	2010 2011 2012	23	4	23	4	NA	0.92	Sand Point Lake	northern pike
Perfluoro-n-dodecanoic acid	2010 2011 2012	23	4	11	3	NA	0.59	Brown Lake	northern pike
Perfluoro-n-heptanoic acid	2010 2011 2012	23	4	0	0	NA	<0.12[8]	NA	NA

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-11 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Voyageurs National Park (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-n-hexanoic acid	2010 2011 2012	23	4	8	4	NA	0.72	Sand Point Lake	northern pike
Perfluoro-n-nonanoic acid	2010 2011 2012	23	4	3	1	NA	0.34	Sand Point Lake	northern pike
Perfluoro-n-octanoic acid	2010 2011 2012	23	4	4	4	NA	1.8	Sand Point Lake	northern pike
Perfluoro-n-pentanoic acid	2010 2011 2012	23	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-tetradecanoic acid	2010 2011 2012	23	4	0	0	NA	<0.12[8]	NA	NA
Perfluoro-n-tridecanoic acid	2010 2011 2012	23	4	8	4	NA	0.70	Brown Lake	northern pike

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

Table L-11 (continued). Sample collection (year, number of samples and sites), occurrence (number of samples and sites), limits of detection (LOD), and maximum concentration of selected organic contaminants and total lead in composite samples of whole fish collected during 2010–2012 from four lakes at Voyageurs National Park (ND = not detected; NA = not applicable).

	Sample collection			Analytes detected in whole fish			Maximum concentration in whole fish		
Analyte(s)	***Year***	***No. of samples***	***No. of sites***	***No. of samples***	***No. of sites***	**LOD (ng/g wet wt.)**	***Concentration (ng/g wet wt.)***	***Location***	***Species***
Perfluoro-n-undecanoic acid	2010 2011 2012	23	4	23	4	NA	2.8	Peary Lake	northern pike
Total PBDEs[4,5]	2010	7	4	0	0	1.0-2.0	ND	NA	NA
	2012	8	4	2	2	NA[7]	3.0	Brown Lake	northern pike
Total PCBs[6]	2010 2012	15	4	0	0	1.0-3.5	ND	NA	NA
Total Lead	2010	7	4	7	4	5.3	17.9	Ryan Lake	northern pike

[1]2,2-bis (*p*-Chlorophenyl)-1,1,1-trichloroethane

[2]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethane

[3]2,2-bis (*p*-Chlorophenyl)-1,1-dichloroethylene

[4]In 2010, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 66, 85, 99, 100, 138, 153, 154

[5]In 2012, sum of polybrominated diphenyl ether (PBDE) numbers 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 156, 183, 196, 197, 206, 207, 209

[6]Sum 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

[7]Reporting limits ranged from 1 to 5 ng/g wet weight

[8]Less than the reporting limit

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 920/134144, September 2016

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

2016 National Park Service CENTENNIAL

EXPERIENCE YOUR AMERICA ™