

**Investigations of Mercury in the Food Web of
Isle Royale National Park, Michigan:**

**A Summary of Research Projects
Completed Under a Grant From Canon USA**

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Background

The Lake Superior Lakewide Management Plan (Lake Superior Binational Program 2000) identifies mercury (Hg) as one of the nine major chemicals of concern in the Lake Superior basin. A naturally occurring metal found in bedrock and in soils with high organic carbon (Cannon and Woodruff 1999, 2000), mercury is used in many commercial products, including thermometers and batteries. It is also a by-product of fossil fuel combustion and industrial processes such as ore processing (Lake Superior Binational Program 2000). In its elemental form, mercury is easily transported by rain and wind and deposited on the landscape by atmospheric processes. Once it is deposited, bacterial action causes elemental mercury to transform into methylmercury (MeHg), which can bioaccumulate in plants and animals. Using lake sediment core samples collected from Wisconsin and Minnesota, Swain *et al.* (1992) reported that there has been a three-to-four-fold increase in mercury deposition into the Lake Superior region since 1850.

Following his three-year (1995-1997) survey of fish communities on 32 of Isle Royale's inland lakes, Kallemeyn (2000) was the first to report on the current status of mercury in the aquatic food chain on Isle Royale. His work, along with other studies that showed the potential negative effects of mercury in Lake Superior, prompted Isle Royale Resource Management to apply for funding from Canon USA to be used in support of research that would:

1. Determine atmospheric mercury inputs into the Isle Royale ecosystem and assess the contribution of the park geology for mercury inputs.
2. Determine mercury levels in the island's abiotic and biotic environment by examining sediments, water, plankton, and fish in Sargent Lake; blood, feathers, and egg shell fragments of Common Loons (*Gavia immer*) on Sargent Lake and other inland lakes; deer mice within and outside the Sargent Lake watershed; and moose molars on Isle Royale and human baby teeth from the Upper Peninsula.
3. Compile all the information into an integrated analysis of mercury presence and impacts to the Isle Royale ecosystem.
4. Broadly disseminate information and results of the project to park visitors, major media, the research community, volunteers, and agencies and stakeholders involved in the Lake Superior Binational Program.

The grant was awarded in 1998, and this report has been prepared to help in meeting the fourth objective. By compiling and summarizing the results of all the projects into one brief document, the information becomes more easily accessible to park interpreters and management. This, in turn, will hopefully raise awareness and support for eliminating mercury and other contaminants from the Lake Superior basin in general and Isle Royale in particular.

Project Summaries

Seven projects were conducted between 1995 and 2002, and a detailed final report was submitted to Isle Royale Resource Management for each of them. Those seven reports are summarized below and include the following:

1. Description of project objectives
2. General summary of methods
3. Data and analyses
4. Management implications or options
5. Concluding remarks

Though Kallemeyn's fish survey was completed before the Canon USA grant was received, it is included here among the six projects that did receive grant support because it was the springboard for the other studies and played a role in successfully securing the funds from Canon USA. For the same reason, it appears first despite its 2000 publication date. The rest of the reports appear in order of their publication dates.

Copies of the original reports can be obtained by contacting Isle Royale National Park, Natural Resource Management, 800 East Lakeshore Dr., Houghton, Michigan 49931. Copies of Kallemeyn's fish survey report can also be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (Phone: 800-553-6847 or 703-487-4650). See the Literature Cited section of this report for full citation information.

Locations of lakes and other sites mentioned in this report are identified in Figure 1. My thanks to Mark Romanski, Isle Royale Resource Management, for creating the map from the park's Geographic Information System data.

A Comparison of Fish Communities from 32 Inland Lakes in Isle Royale National Park, 1929 and 1995-1997

By L.W. Kallemeyn (2000)

The first and only comprehensive survey of Isle Royale's inland lakes was conducted in 1929 when 38 lakes were described with detailed observations of shoreline and substrate types, aquatic vegetation, surrounding landforms and terrestrial vegetation, and more than 3,600 measurements of water depths. Fish samples revealed 30 species in the inland lakes, with subspecies for five of them (Koelz 1929). Studies of the lakes since that time have been limited, so this study was designed to assess long-term changes in the fish communities of the inland lakes by comparing present distributions to the results of previous surveys.

Thirty-two of the island's 42 named inland lakes were sampled between June and September, 1995 and 1996. In 1997, sampling for four water chemistry parameters was repeated on all 32 lakes. Nine lakes were re-visited in 1997 to collect fish species previously reported by Hubbs and Lagler (1949), but not found in 1995 or 1996. Fish were sampled by standard fish sampling methods: unbaited Gee minnow traps, a beach seine, and multifilament nylon experimental gill nets. Fish were sampled in 30 lakes with gill nets. Total length, weight, and sex were recorded, and scale samples were taken for age determination along with cleithra from northern pike (*Esox lucius*), pectoral fin rays from white sucker (*Catostomus commersoni*), and otoliths from burbot (*Lota lota*). Environmental data that could be used to better define the major lake types and to explore relations with the observed fish distributions were also collected. Fish collected from gill net catches or angling, especially northern pike, were used to assess mercury contamination. Northern pike from 25 lakes, walleye (*Stizostedion vitreum*) from two lakes, and lake trout (*Salvelinus namaycush*), yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), and white suckers from one lake each were analyzed for total mercury. Limnological data were collected at one station per lake near the location identified by Koelz (1929) as the deepest point in each lake. Depth, water temperature, dissolved oxygen, water transparency, pH, conductivity, total dissolved solids, and alkalinity were determined on-site or later on Mott Island (the location of the summer headquarters in the park). Other chemical analyses were conducted by staff of the Natural Resources Research Institute at the University of Minnesota - Duluth. A voluntary creel card survey was conducted in 1997 to identify which inland lakes were fished the most, what species were being caught, and what species were being harvested. Though the scope of Kallemeyn's study was far broader than just determining mercury levels, this summary will focus primarily on the results that are germane to mercury levels in Isle Royale fish.

Mercury concentrations ranged from 30 to 1,720 nanograms per gram (ng/g). Mercury concentrations in 32 of the 179 fish examined (17.9%) exceeded 500 ng/g, which is typically the threshold criterion for fish consumption advisories. Mercury ranges in northern pike, walleye, and lake trout (all piscivores, or fish eaters) were similar and were higher than those of lake whitefish and white sucker (both benthivores, or bottom feeders). The highest mercury concentrations were in yellow perch taken from Lake Harvey. This was unexpected, as perch are commonly regarded as omnivores, and so are expected to have intermediate levels of mercury. However, stomach content analysis revealed that larger, older perch in Lake Harvey were functioning as piscivores. Mercury levels in pike ranged from 39 to 1,002 ng/g. Kallemeyn

found that mercury concentrations generally increased with length of fish, and an average concentration in a standard-sized (550 mm, or 22 inch) pike was 304 ng/g. Average mercury level in a legal-sized (610 mm, or 24 inch) pike was 414 ng/g. Legal-sized pike from five of the 25 lakes sampled had a mercury level above the 500 ng/g fish advisory threshold. For Isle Royale lakes, pH was the only water quality variable that was significantly correlated with mercury concentrations in standard-sized pike. Among the 32 lakes that were sampled, the pH ranged from 7.3 to 8.9 (average = 7.6). The six lakes with the highest mercury concentrations in pike all lie along a 4.8 km-long line running north to south from Lake Eva to Angleworm Lake. The author speculated on possible reasons for this trend, including geologic sources, but he cited Cannon and Woodruff's (1999) recent geochemical survey (see their summary below) in refuting this possibility. Kallemeyn notes that mercury pollution has been identified as an issue in Thunder Bay, Ontario, which lies 56 km north-northwest of Isle Royale. Monitoring of atmospheric deposition of mercury at a number of sites on Isle Royale is suggested as a means of determining whether deposition rates are uniform or are focused in particular areas of the island. In addition, further monitoring of limnological attributes and other biological components of the aquatic communities is suggested as a means to refine or develop a new classification system for the island's inland lakes. Depending on project or management objectives, states Kallemeyn, data from such monitoring could also be used in selecting lakes for assessment of larger issues such as atmospheric contamination.

Mercury Distribution in Bedrock, Native Copper Ore, and Soils – Isle Royale National Park, Michigan

By W.F. Cannon and L.G. Woodruff (1999)

Though airborne deposition via precipitation has been a suspected source of mercury to Isle Royale, a study of mercury in Michigan walleyes (*Stizostedion vitreum vitreum*) during the 1970s suggested that higher mercury levels in Isle Royale fish was a result of the Keweenaw basalt, conglomerate, sandstone, and associated copper deposits having greater mercury concentrations than the glacial drift found on the Michigan mainland (Kelly *et al.* 1975). When Kallemeyn's (2000) fish survey revealed that the highest mercury concentrations in pike on Isle Royale came from a cluster of six lakes (Sargent, Linklater, Wagejo, Angleworm, Shesheeb, and Eva) that lie along a north-south line in the north-central part of the island, speculation turned to a third possibility: that mercury comes from the waste dumps at abandoned copper mines and their associated processing operations that were located along this line of lakes. Before addressing this question, though, the authors had to first discount the findings of Kelly *et al.* (1975).

Collecting samples of island bedrock and analyzing them at a minimum detection level of 5 parts per billion (ppb), the authors found no mercury in any of their samples. Island bedrock, it turned out, is an unlikely source because it contains too little mercury to have any affect. With only two possibilities remaining (mining or airborne deposition), the authors set their sights on copper deposits.

Sixty-five soil samples were collected from around the Minong mine and within the drainage basins of Sargent Lake and Lake Wagejo. The Minong mine was the longest running and most productive mining operation on Isle Royale, lasting nine years and yielding 498,650 pounds of refined copper (Harmon 1992). Conversely, there are no known copper deposits within the basins of either Lake Wagejo or Sargent Lake, but it is possible that deposits are located deep beneath the surface and are concealed beneath extensive glacial deposits. Samples were taken from the A soil horizon (a dark, organic mineral soil located 1 to 6 inches below the surface) and from the BC-horizon (reddish, sandy glacial till or till slightly modified by soil-forming processes located about 2 feet below the surface).

Mercury was commonly found near copper deposits around the Minong mine, especially in the BC-horizon, where it amounted to an average of 44 parts per billion (ppb). Mercury averaged 70 ppb in the A-horizon, and the highest amount of mercury in the Minong mine soils was 110 ppb. In the Lake Wagejo and Sargent Lake watersheds, copper deposits were nearly five times smaller than those around the Minong mine, yet mercury levels averaged 133 ppb in the A-horizon and the maximum value of all the samples in this area was 370 ppb. Average mercury level in the BC-horizon of Lake Wagejo and Sargent Lake was 38 ppb.

The authors concluded that mercury could not be coming from mining waste dumps because soils near Lake Wagejo and Sargent Lake, neither of which are near historic mine sites, showed higher mercury levels than the soils taken from around the Minong mine. When these data are coupled with the fact that the island bedrock is very low in mercury content, the most viable possible source for mercury becomes airborne deposition via precipitation.

Some Factors that Control the Distribution of Mercury in the Near-Surface Environment of Isle Royale National Park, Michigan – Earth, Wind, and Fire

By W.F. Cannon and L.G. Woodruff (2000)

If, as their 1999 study showed, precipitation is the most likely source of mercury to Isle Royale, then why are soil mercury concentrations so variable across the island? This is the question the authors attempted to answer with their second set of analyses in which they used the same samples collected from around the Minong mine and the Lake Wagejo and Sargent Lake area (Cannon and Woodruff 1999) and compared them to additional samples collected from near Lake Richie. They found a very high correlation between the level of organic carbon in the soil and the level of mercury. It appears, they concluded, that factors controlling the isolation of carbon in terrestrial environments also control the isolation of mercury.

One of the processes that influences carbon levels is fire. During a fire, carbon is burned up, which causes mercury attached to it to be released into the air. After a fire, the amount of carbon and subsequently mercury in the burned area is low and takes many years to re-build. Perhaps by coincidence, some of the sites that Cannon and Woodruff sampled for their 1999 study were within an area of Isle Royale that burned in 1936. In their analyses, they found that soil samples collected from within the 1936 burn area invariably had low carbon and mercury content, and all were below the mean mercury concentration for the island. Some samples outside the 1936 burn area had similarly low mercury levels, but most were significantly higher.

They also used their data to suggest that terrestrial inputs of mercury to lakes may have a greater influence on mercury levels in fish than has been previously understood. They point to their results in stating that there are much higher mercury concentrations in soils of the Sargent Lake watershed (where there is high mercury in fish) than in soils of the Lake Richie watershed (where fish mercury levels are low), so it is possible that mercury levels in the terrestrial environment are a controlling factor in the mercury levels found in fish.

Mercury Exposure in the Common Loon (*Gavia immer*) at Isle Royale National Park, Michigan

By J.D. Kaplan and K.B. Tischler (2000)

Though toxicological studies of banded, nesting Common Loons (*Gavia immer*) have been conducted on Isle Royale since 1991, they focused only on those pairs nesting along the island's eastern Lake Superior shoreline (Evers *et al.* 1996). In 1998, the study was expanded to include five of the interior lakes that had shown the highest mercury levels in Kallemeyn's (2000) fish survey (Angleworm, Eva, Sargent, Shesheeb, and Wagejo), plus one (Siskiwit Lake) in which the Michigan Department of Natural Resources (MIDNR) reported finding elevated mercury levels in lake trout (MIDNR 1997).

From May through September, the authors surveyed the six interior focal lakes along with protected Lake Superior shoreline areas along the east end of the island to determine loon territory occupancy, nest site locations, and productivity (hatching and fledging). Between July and September, loons were captured on Lake Superior and on Sargent Lake, and blood and feather samples were collected for mercury analysis. Feather samples were not collected from juvenile loons captured prior to complete feather development (approx. eight weeks of age). Birds that were unbanded were fitted with an aluminum U.S. Fish and Wildlife Service band and one-to-three colored leg bands to aid in subsequent field identification.

Twenty-five loon territories were identified on Lake Superior, with 12 producing fledging-aged chicks. Twelve territorial loon pairs were found on the six interior lakes, but only three fledging-aged chicks were produced and they all came from Sargent Lake. Consequently, only Sargent Lake loons were caught and sampled for mercury among the interior lakes because adults can only be captured if they are with chicks. Ten percent of adults on Isle Royale had feather mercury concentrations at or above 20 ug/g (micrograms per gram), which is the level that Scheuhammer and Bond (1991) suggested is the risk threshold for toxic effects in loons. Blood and feather mercury levels in adult loons were similar for both Lake Superior and Sargent Lake, but 82% of the Lake Superior adults that were recaptured in successive years showed an increase in feather mercury. The average annual increase was 3%. Males on Lake Superior had significantly higher blood and feather mercury than females, while there was no significant difference between Sargent Lake males and females. Average blood mercury level (1991-1998) for 4-to-7-week-old chicks on Lake Superior was 0.06 ug/g, while Sargent Lake juveniles of the same age class in 1998 alone averaged 0.11 ug/g. Blood and feather mercury levels of fully-developed juveniles on Sargent Lake were significantly higher than those on Lake Superior.

The authors concluded that the flight feathers of fledging-aged juveniles are the most reliable indicator of mercury exposure in a specific water body because complete growth and development of juvenile flight feathers occurs on natal territories, thus the mercury concentration in those feathers reflects that of the territory. They also noted that discrepancies in the number of territorial pairs observed during their survey in early summer indicated that many territories may be failing before the annual loon survey conducted by Resource Management staff begins in late summer. As a result, loon productivity as previously calculated by Resource Management may be inaccurate. → overestimating.

Mercury Concentrations in Deer Mouse (*Peromyscus maniculatus*) Tissues From Isle Royale National Park

By L.M. and J.A. Vucetich (2000)

Similar to Cannon and Woodruff (2000) above, Vucetich and Vucetich state that less is known about mercury in the terrestrial environment than in aquatic systems, despite the literature showing that small mammals are known to accumulate heavy metals. They argue that deer mice (*Peromyscus maniculatus*) in particular are important indicators of heavy metal pollution in the terrestrial environment because (1) they are predators of insects and other invertebrates, so are more likely to accumulate environmental toxins than terrestrial herbivores; (2) they have relatively small home ranges (approx. 0.2 – 2.5 hectares), so they provide a fine-scale resolution of the distribution of heavy metals in terrestrial environments; and (3) they are the only small mammal (<150 g) inhabiting Isle Royale, thus an important food source for mid-level predators and an important link in the transport of heavy metals through the terrestrial system.

To determine the validity of Kallemeyn's (2000) suggestion that the Sargent Lake watershed may contain higher mercury concentrations than other areas of Isle Royale, the authors live-trapped three adult deer mice from each of five locations inside the Sargent Lake watershed and five locations outside the watershed. The mice were sacrificed by cervical dislocation, and tissue samples were taken from the liver and kidneys of each. Livers and kidneys were analyzed separately, and tissues from each location were pooled and analyzed as a single composite sample.

Kidneys had significantly higher mercury concentrations than livers both inside and outside the Sargent Lake watershed, though sites outside the watershed had significantly higher liver mercury concentrations than those inside the watershed. Kidney mercury concentrations between the two sites did not differ significantly (see figure below). Mercury concentrations in both kidneys and livers did not vary based on body weight or sex.

<u>Inside the Sargent Lk. Watershed</u>	<u>Outside the Sargent Lk. Watershed</u>
Kidney > Liver	Kidney > Liver
	Liver < Liver
	Kidney = Kidney

The island ecosystem may exhibit a different pattern of mercury concentration across its trophic levels. Citing Cannon and Woodruff (1999) who found total mercury concentrations of 0.133 ppm in soil samples from the A-horizon near Sargent Lake, the authors noted that deer mice from inside the Sargent Lake watershed had dry weight (all tissue moisture removed) mercury concentrations of 0.035 ppm in their livers, which was lower than the soil concentrations. In contrast, dry weight concentration of mercury in their kidneys was 0.361 ppm, which was higher than the soil concentrations. Further study could illuminate how this discrepancy is manifested in higher levels of the food web. The authors concluded that, while mercury in Isle Royale deer mice is not alarmingly high, additional studies with larger sample sizes and a broader geographic representation could provide fine scale details on mercury distribution within the island's deer mouse population.

An Investigation of Mercury Levels in the Food Web of Isle Royale National Park, Michigan: Report for the Aquatic Subproject – Sargent and Richie Lakes, Summer 1998 – Summer 1999

By P.R. Gorski, L.B. Cleckner, J.P. Hurley, D.E. Armstrong, P.J. Garrison, M.E. Sierszen, and D.R. Engstrom (2002)

Focusing on mercury in the lower food web, water, and sediments (each perhaps influencing mercury concentrations in fish), the authors proposed to identify the factors affecting mercury bioaccumulation in Isle Royale lakes, with a particular focus on Sargent Lake. Though Siskiwit, Anglemore are closest to Sargent's size and also have fish mercury advisories by the State of Michigan, Lake Richie served as a comparison to Sargent because of its similar surface area, watershed area, perimeter, and elevation.

Samples of water, zooplankton, littoral zone invertebrates (insects and mussels), fish (perch, *Perca flavescens*; and northern pike, *Esox lucius*), and sediments (taken from the center of each lake) were collected between June and August, 1998, and February, May, July, and August, 1999. They were then analyzed for concentrations of total mercury (Hg_T) and methylmercury (MeHg).

In June 1998, concentrations of both Hg_T and MeHg in water from Sargent and Richie were similar. MeHg levels were low in both lakes, but increased in August, with the highest concentrations found eight meters below the surface. The hypolimnetic water from Lake Richie had the highest proportion of Hg_T present as MeHg (about 20%). Streams that flowed into Sargent and Richie were sampled and found to have significantly higher MeHg levels than the lakes they flowed into, but the authors believe the feeder streams are relatively unimportant in transporting MeHg because they typically exhibit little or no continuous flow. Zooplankton samples show important differences in mercury concentrations between lakes and may enhance bioaccumulation in Sargent Lake. Individual zooplankton from Sargent Lake were generally higher in both Hg_T and MeHg than zooplankton from Lake Richie. Averaging all individuals together by lake for the entire year (1998), Sargent Lake zooplankton had more than double the amount of Hg_T and MeHg, but plankton from both lakes had about 40% of their Hg_T available as MeHg. Bulk zooplankton generally had mercury concentrations similar to individual zooplankton. When individual and bulk data were combined for both years (1998 and 1999) and compared between lakes, Sargent zooplankton had significantly higher Hg_T concentrations, whereas both lakes had statistically similar MeHg concentrations. Species diversity of littoral invertebrates was low but consistent throughout the study. All taxa of insects had higher concentrations of Hg_T and MeHg in Sargent Lake in June 1998 except for one species of mayfly (*Hexagenia*). This relationship held for most measurements in August 1998, but in 1999, Richie insects often had mercury values similar to or higher than Sargent insects. Although average values for Sargent were higher than Richie, the data sets for Richie and Sargent in both years showed no significant difference between lakes for either Hg_T or MeHg. Caddisflies generally exhibited significantly lower Hg_T than other insects, while dragonflies generally had significantly higher MeHg than other insects. Other studies have suggested that mercury accumulation among insects occurs through ingestion during feeding, and the Isle Royale data are consistent with this concept. Overall, though, insects are probably not the main route for increased mercury in fish. Mussels (Family: Unionidae) contained similar mercury concentrations between lakes. Overall, fish length and age were significant predictors of Hg_T

concentration, as both yellow perch and northern pike displayed an increase in total mercury concentration as they grew and aged. Sargent Lake contained older and longer pike than Richie, and Sargent Lake pike had a statistically higher Hg_T level than pike in Lake Richie. Two pike taken from Sargent Lake were above the state advisory limit (>500 nanograms/gram; ng/g), while none taken from Richie were above the limit. Northern pike taken from Sargent Lake for this study have similar but lower mercury concentrations than those taken by Kallemeyn (2000). Conversely, pike taken from Lake Richie had higher mercury concentrations than previously reported by Kallemeyn (2000). **Sediment** cores showed an increase in Hg_T concentration from bottom to top. Lowest concentrations were found between 70 and 40 cm, with average concentrations for this region being 143 and 173 ng/g for Sargent and Richie, respectively. MeHg concentrations increased exponentially up the core, with the highest concentration in the top 1 cm. The sediment-water interface is a possible source of MeHg to aquatic biota, but mining on the island is probably not a source to the sediments because mining ceased in 1879, and most Hg_T increases in the cores appear to have occurred after 1890. The sediment cores from both Sargent and Richie reveal the most likely source of increasing mercury concentrations in both lakes is atmospherically derived from other anthropogenic sources.

The authors concluded:

1. Mercury measurements taken on Isle Royale from water and various biota are within the range of ambient mercury concentrations found in other lakes in the upper Midwest and are much lower than sites in systems recovering from direct industrial contamination. No localized source of mercury unique to Sargent Lake was evident.
2. Concentrations of Hg_T and MeHg in the water columns of Sargent and Richie are similar, although the two lakes differ in ancillary water characteristics such as concentrations of dissolved organic carbon, suspended particulate matter, and chlorophyll *a*. Furthermore, pigment signatures revealed that epilimnetic algae in Sargent Lake are more edible to zooplankton than those in Lake Richie.
3. Zooplankton mercury concentrations from Sargent Lake were elevated relative to Lake Richie. The lower concentrations of ancillary water characteristics in Sargent may result in higher bioavailability and bioaccumulation of MeHg by Sargent zooplankton. The differences in zooplankton can be biomagnified through the food chain to produce greater differences among predatory fish between lakes.
4. Concentrations of Hg_T in pike and adult perch in the two lakes were significantly different. Northern pike samples from Kallemeyn (2000) and this study suggest differences in bioaccumulation at the pike level between Sargent Lake and Lake Richie, with Sargent exhibiting higher Hg levels in pike than those in Richie. Other factors, such as growth differences and efficiencies, diet, and age/length structure could exist between the lakes' pike populations that could result in differential bioaccumulation.
5. Trophic level differences between the pike from the two lakes are not apparent as measured by stable carbon and nitrogen isotope analyses. Based on the Carbon-13 analysis, Sargent Lake appears to have a pelagic (open water)-based food web, while Lake Richie's food web is benthic (bottom)-based. A pelagic-based food web has been shown to enhance bioaccumulation of organochlorines (Campbell *et al.* 2000). It is possible that the same is true for MeHg and other contaminants, and this deserves further study.

6. Sediment profiles suggest that atmospheric inputs are most likely the source of mercury to both lake systems and have been increasing similarly through time. No discernable increases were observed during periods of increased mining activities on the island. Sedimentation rates were higher at the Lake Richie core site. Present-day water samples confirm that Lake Richie is more productive than Sargent Lake.

Differential fishing pressure on off-trail versus canoe or trail-accessible lakes likely influences the population structure of fish and consequently its mercury load, as the age structure of Sargent and Richie have shown. Sargent (the off-trail lake) has the larger, older fish, and older fish populations tend to have higher mercury levels.

Other studies have shown that factors influencing mercury accumulation in food chains and top predators are flooding, food chain length, and water chemistry. Recent flooding of Isle Royale lakes has not occurred, and food chain length appears similar between the lakes. Therefore, water chemistry seems most likely to be the key in mercury accumulation of Isle Royale's interior lakes. Basic water chemistry between Richie and Sargent appears to be similar, with the exception of dissolved organic carbon, suspended particulate matter, chlorophyll *a* and the pigment zeaxanthin, so these parameters warrant further investigation in connection with enhanced mercury accumulation in pike. Additionally, better information on bioenergetics for pike in Sargent Lake and Lake Richie would enhance our understanding of mercury accumulation. The authors caution that their findings for Sargent Lake and Lake Richie may not hold true for other lakes on Isle Royale. Therefore, sampling many lakes with a similar approach to this study may yield a much clearer understanding of the complex process of mercury accumulation on the island's interior lakes.

Mercury Deposition in Teeth from Moose and Humans in the Vicinity of Isle Royale National Park

By R.O. Peterson, R. Eide, and A. Hinsenkamp (2002)

In 1997, Rune Eide and Rolf Peterson reported that the mercury content of molars collected from Isle Royale moose (*Alces alces*) had increased between 1945 and 1980, which was consistent with continental and regional trends (Eide and Peterson 1997). Following up on that earlier work, the authors used Canon USA grant funds to: (1) examine moose teeth collected from Isle Royale in or after 1980, compare them to the teeth from 1945-1980, and determine if pollution control measures have affected mercury levels in them; and (2) to evaluate human exposure to mercury using baby teeth collected from Upper Peninsula of Michigan (U.P.) residents. To do this, they analyzed teeth that had been previously collected from male and female Isle Royale moose in the 1980s along with teeth from young moose (one year and over) collected in the 1990s. Human teeth were collected from school-age children in each of the 15 counties of Michigan's Upper Peninsula by soliciting volunteers through U.P. dentists and K-2 schoolteachers. All of the child volunteers were between the ages of five and seven years old, had been born in the U.P. after 1990, and lived in a single location for at least the first two years of their life. One tooth per child was used in the final analysis.

The study found that mercury levels in moose born in or after 1980 had declined dramatically from those levels found in moose born between 1945 and 1979. Prior to 1980, the average mercury content in moose teeth was 181 nanograms (ng) of mercury (Hg) per gram (g) of tooth substance. Between 1980 and 1997, the average mercury content was 79 ng Hg/g. Mercury levels in human teeth were uniformly low, averaging 10 ng Hg/g. Even the human tooth with the highest mercury content (81 ng Hg/g) was only slightly higher than the average for moose teeth between 1980 and 1997. These results held even when compared by location and by fish consumption and maternal factors. Overall, moose teeth contained relatively higher levels of mercury than human teeth.

The authors believe this is the first study to provide definitive evidence that biological uptake of mercury in terrestrial food chains has begun to decline. This, like their previous study's results, is consistent with a regional trend, as mercury emissions in the Great Lakes region have declined since 1970 when air pollution control measures were strengthened. The source of mercury to the island environment is less understood. It has been suggested that the by-products of historic mining activity may have contributed some of the contamination, but the results of this study suggest that the source is most likely atmospheric deposition.

Though the authors do not present any management implications as a result of their study, they point out that Isle Royale moose provide an isolated biomonitor of mercury uptake by a largely terrestrial food chain that probably reflects long-term regional patterns of atmospheric mercury deposition. For this reason, continued collection of teeth from dead moose on the island can provide a unique resource for monitoring mercury in the terrestrial environment of Isle Royale.

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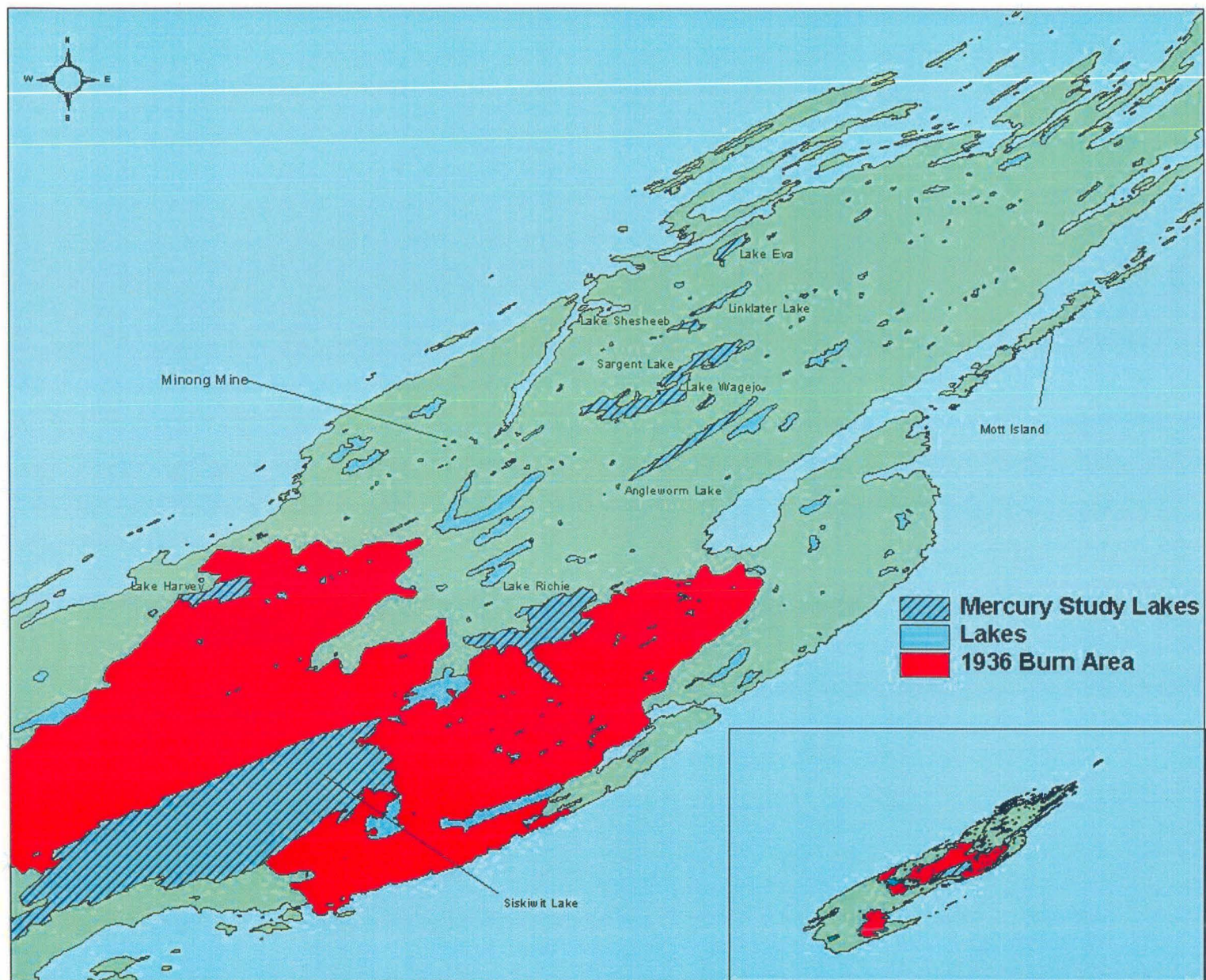


Figure 1: Map of Isle Royale National Park (Keweenaw Co., Michigan) showing the locations of lakes and sites identified in this report. Inset shows the extent of the 1936 fire across the entire island. Map provided courtesy of Isle Royale Resource Management.