

Adirondack Loons — Sentinels of Mercury Pollution In New York's Aquatic Ecosystems

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**ADIRONDACK LOONS — SENTINELS OF MERCURY POLLUTION
IN NEW YORK'S AQUATIC ECOSYSTEMS**

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Biodiversity Research Institute (BRI) is a 501(c) 3 nonprofit organization located in Gorham, Maine. Founded in 1998, BRI is dedicated toward supporting global health through collaborative ecological research, assessment of ecosystem health, improving environmental awareness, and informing science based decision making.

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About this report

Since 1998, Biodiversity Research Institute and its collaborators, including the Wildlife Conservation Society and the New York State Department of Environmental Conservation, have conducted research on the impacts of environmental mercury pollution to the Common Loon population of New York's Adirondack Park. This report distills the findings of this scientific study between 1998-2007 for use by decision makers and the public. To obtain a full version of the scientific BRI Report 2011-28 to the New York State Energy Research and Development Authority for NYSERDA EMEP Project #7608, please visit www.briloon.org/adkloon or www.nyserda.org.

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~Loons in the Light~
Sibling Rivalry

The first egg that is laid hatches a day or two before the second egg, and so the first chick is a bit bigger than its sibling. The chicks may fight initially, as the older chick attempts to establish dominance over the younger one.

The dominant chick will sometimes grow at a faster rate than the other one, as the dominant bird will get fed first and may also get fed more than the subordinate chick.



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2.0 Introduction

Each summer, the haunting and eerie call of the Common Loon (*Gavia immer*), resounds through New York's six million acre Adirondack Park, as the birds raise their families on the Park's lakes and ponds. This almost mystical icon of northern waters is a beautiful, highly charismatic bird – with striking black and white breeding plumage; strange tremolos, wails, and yodels; and endearing chicks riding on the parents' backs. Adirondack residents and visitors boating on one of the many lakes in the Park are thrilled by the sight of a loon, especially when it is caring for its chicks.

Loons are also excellent sentinels of threats impacting aquatic ecosystems (Evers 2006). They live more than 20 years, are at the top of the food web, and are very territorial, with the majority of birds coming back to the same area on the same lake each breeding season. Thus, environmental toxins that increase in concentration as they progress up the food web can accumulate to very high levels in Common Loons.

Mercury is one such environmental pollutant. This report summarizes the results of a long-term study to assess the effect of mercury contamination on wildlife and aquatic ecosystems in the Adirondack Park, using the Common Loon as an indicator species. More than 150 adult loons were uniquely color-banded in the Adirondack Park from 1998-2006, to determine annual productivity—as the average number of chicks fledged per territorial pair per year. Non-viable loon eggs were opportunistically collected from abandoned nests (after field staff confirmed the adult loons were no longer incubating them, or they were determined not to be viable). The mercury levels in loons were related to their long-term reproductive success to evaluate the effects of mercury contamination on the breeding population of loons in the Park, and to develop a mercury hazard profile. By evaluating the survival and reproductive success of Adirondack loons in relation to their mercury burden, this study details the impacts of mercury and acid deposition to a piscivorous (fish-eating) predator, and provides evidence for the need to stringently regulate mercury and acidic emissions on national and global scales.



3.0 A Brief Overview of Common Loon Natural History

3.1 The Family of Loons

The Common Loon, known as the “Great Northern Diver” in Europe, is one of five species in the family of birds called *Gaviidae*. The Yellow-billed Loon (*Gavia adamsii*) is a slightly larger bird with similar plumage, except for its striking yellow bill. The Arctic (*Gavia arctica*) and Pacific (*Gavia pacifica*) Loons are smaller birds with gray heads. During the breeding season, the backs of their necks are also gray, while the front is blackish with a greenish (arctic) or purplish (pacific) sheen. Vertical white stripes separate the gray back and dark front of their necks. The Red-throated Loon (*Gavia stellata*) is also smaller than the Common Loon, and when breeding, the front of its neck is a vibrant red, while the back is gray. The body of red-throated loons is gray and speckled with white. Arctic and Pacific Loons have a black back with white stripes, and white belly during the breeding season. During the winter, all five species are much more subdued in coloration, and become a dull gray. The eyes, which are a vivid red in a breeding bird, become gray-brown during the winter.

Loons reside in the Northern Hemisphere. They breed in freshwater lakes, ponds, and rivers in the northern United States and throughout Canada and Russia, as well as parts of Europe. Common loons migrate to the coasts of North America, Europe, and Russia and live in saltwater during the winter months.



3.2 Loon Specializations

Common Loons are large birds, weighing from six to more than 14 pounds, and everything about a loon’s body is designed for living in the aquatic environment. Unlike most birds, which have pneumatic (air-filled) bones, loons have dense, heavy bones. They can compress air out of their feathers, enabling them to dive underwater efficiently. Their streamlined bodies and extremely specialized, laterally flattened legs decrease resistance as the birds swim through the water. Additionally, their legs are placed far back on their body, the top part of their legs is enclosed within their body, and their lower legs are turned to the side (similar to a frog). These characteristics provide great power and propulsion when the birds kick against the water. However, because their legs are so specialized, loons are “terrestrially challenged,” and have great difficulty walking on land. Common loons are actually unable to get airborne from land, and must run on the water for several hundred feet to get into the air.

3.3 Loon Vocalizations

Loon “night choruses” echo across the water and mountains, filling the air and mesmerizing people boating or camping on Adirondack lakes and ponds. Loons use a variety of vocalizations, from soft hoots to screaming yodels, to communicate with each other about food, location, predators, and disturbance.

- **Wail:** Wails are long, drawn-out two or three note calls, similar to a wolf howl, which loons use to communicate with each other about their location. Loons will wail when another loon or eagle flies overhead, or, when two birds are fishing and one comes to the surface before the other, it may wail until it sees or hears the other loon.
- **Tremolo:** Loons use tremolos, a fluctuating high-frequency call, to express agitation or distress. The tremolo is also used as a “flight call”, and is occasionally heard if a loon is flying overhead. Two or more loons will “duet” with tremolos and wails, particularly if a predator is near or if they are disturbed by humans.
- **Yodel:** The yodel is an aggressive territorial call given only by male loons. It is a very loud, repetitive, screeching call, similar to a gull call, made to signal territorial defense. Yodels are heard when an intruding loon comes into a territory; when a predator, such as an eagle, approaches; or when a boater gets too close to loon chicks.

~Loons in the Light~ Yodeling Males

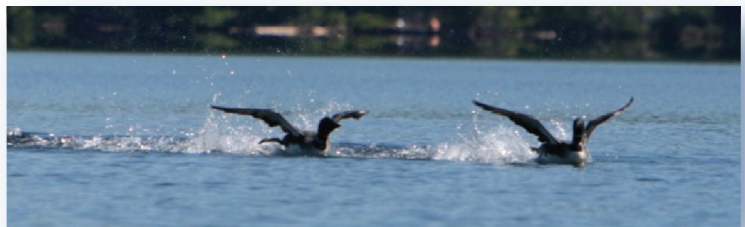
Male loons have unique individual yodels. If a male loon changes its territory, it also changes its tune! Its yodel changes pitch and frequency in a new territory (Walcott et al. 2006).



- **Hoot:** Hoots are very short, soft calls that loons use to communicate with each other. Members of a pair use hoots and soft “mew calls” as courtship calls or to call a chick to feed. When a group of loons is feeding together, they frequently hoot to each other.
- **Chick calls:** Loon chicks “peep” and whine almost endlessly to their parents, begging them persistently to bring food. If a chick is separated from its parents, it may give a high-pitched distress call—a repeated whiny vocalization. If a chick is in distress, it is also likely that the parents will be quite upset, and tremoloing, wailing, and yodeling to express their agitation. As a chick grows, it will practice making high-pitched wails and tremolos. Male chicks will also practice yodels, which deepen in frequency as the chick gets bigger.

3.4 Breeding Loons

During the breeding season, Common Loons have a checkered black and white back, white belly, greenish-black neck with vertical white stripes (a “necklace”), and vibrant red eyes. Male loons return from their wintering grounds to Adirondack lakes as soon as the ice lets out, usually in mid to late April. Females follow shortly after, and both members of a pair are usually back on their territory by mid-May. Loons have strong site fidelity, returning to the same territory on the same lake year after year. As they re-establish their territory (or establish a new territory), there can be much commotion when intruding loons test the ability of a pair to defend and maintain their territory. Loons utilize a variety of aggressive behaviors against intruding birds: they will chase another loon across the water, penguin dance, tremolo, yodel, and even fight by stabbing a bird in its chest with their beak. It is difficult to miss the defensive displays of a territorial loon, with its loud vocalizations, and splashing and spraying of water as the bird penguin dance or “wing rows” across the lake.



Adirondack loons usually begin nesting in early May to early June. Nests are typically

2–3 feet in diameter, consisting of a mound of vegetation or a scrape in the soil on the shore of an island, often in a bay or protected spot from the prevailing winds. Loons will also nest on logs, stumps, and rocks near the shoreline. Nest sites are usually placed along a gradual slope so the birds can readily clamber up into the nest, and with a minimum of a foot of water next to the site, enabling the loons to approach or leave the nest easily. Loons usually lay two large eggs, although occasionally they only lay one or, more rarely, three. Loon eggs are olive-green in color with dark brown spots, and are close to three inches long. They are well camouflaged in the nest, especially if it is a deep bowl of matted vegetation.

Both male and female loons incubate the eggs, with the female doing the majority of night-time incubation (Goodale et al. 2005). Most incubation shifts last 4-to-6 hours (with a range of <1 hour to 11 hours; Paruk 2000). Incubation



lasts almost a month, approximately 26–28 days. If a nest fails (e.g., due to predation or flooding), the loons will likely reneest.

In the Adirondacks, chicks hatch from early June through mid-August. The first egg that was laid hatches first, followed a day or two later by the second chick. Thus, the first chick is a bit bigger and often dominant over the second one; it gets fed first and grows faster and larger than the younger chick. After hatching, the family usually abandons the nest for the season, although, for a few days after hatching, a chick and parent may occasionally return to the nest to rest.

*~Loons in the Light~
Multiple Mates!*

Loons do not mate for life. Color-banding studies show that loons change mates when a new bird takes over the territory or one of the pair dies or does not return from migration. Some of banded Adirondack study birds have had multiple mates over the course of the study.

When they first hatch, chicks weigh almost a ¼ pound (approximately 100 grams) and are covered in soft black down on their backs and white down on their bellies. The parents move them to a “nursery” area of the lake, a shallow section that is protected from wind and waves. At this stage, the chicks spend most of the time riding on the back of one of their parents, which keeps them warm (the parents often cover the chick with a wing, and the under-wing of a Common Loon is covered in deep soft down) and safe from predators in the water.

At about two to three weeks of age, the black down is replaced by brown down. The chicks become more capable of diving and swimming as they grow. They are quite gangly at this stage, as their head and short wings seem very out of proportion to their body. By the time they are seven to eight weeks old, the chicks are too big to ride on the parents’ back and their down is being replaced by gray feathers, which gives them a disheveled appearance. By nine weeks of age, they are fully feathered and look very much like wintering adult birds. As juvenile loons approach three months of age, their flight feathers grow in and they become more independent, as their parents leave them for longer periods of time. By late fall, the juvenile loons remain on the lake, practicing flying, while their parents socialize with other birds or migrate to the coast.



3.5 Loon Migration and Winter Plumage

As summer wanes and fall approaches, loons often gather in large groups of 10, 20, or more birds. These social groups often perform a “circle dance” as they feed together. By late fall, adults molt their black and white body feathers and replace them with gray winter plumage. In October and November, they migrate to the coast in small numbers.

~Loons in the Light~ Migration and Body Size

Loons vary in size geographically. The loons that breed in the Midwest and northern Canada are smaller than the birds breeding in the Northeast. These smaller loons also migrate much further than Northeastern loons. Satellite telemetry studies have shown that Maine loons migrate directly to the Maine coast, while Midwestern and Canadian loons migrate hundreds to thousands of miles to the Gulf of Mexico for the winter.

Loons are extremely strong fliers—satellite telemetry studies have shown



that Adirondack loons migrate to the Atlantic coast (e.g., Cape Cod, Long Island, New Jersey) in one sustained flight, traveling 200 miles or more in less than 10 hours (Kenow et al. 2009). It is likely that loons migrate to the same area of the coast each winter.

Juveniles migrate after the adults, often staying on

Adirondack lakes until they absolutely have to leave as the lakes ice in, usually in mid to late November. Juveniles and subadults stay on the coast for two to three years. They may move up and down the coast during that time, going north in the summer months and south in the winter. After their second or third year, juveniles molt into the breeding black and white plumage, and begin returning each summer to the general area where they were born. Loons are usually five to seven years old before they are able to find a mate and establish a breeding territory of their own (Evers et al. 2010).

Migration and wintering on the coast are significant stresses for Common Loons. They travel extensive distances in a sustained flight to get to or from the coast. On the wintering grounds, their diet (fish, invertebrates, and crustaceans) changes from freshwater prey to saltwater prey, and they must excrete excess ingested salt through salt glands near their eyes. Additionally, although they usually venture no more than a mile from shore, they are exposed to strong winds and waves during winter coastal storms. In late winter, adult loons experience a full body molt, including a complete wing molt. Thus, much of the energy they take in is expended in growing new feathers, and they are incapable of flying for approximately a month until their flight feathers grow in.



3.6 Loons and Their Diet

Loons are opportunistic feeders, eating prey that is readily available and easiest to catch. They are visual hunters, and actively look for prey while diving under water or by peering into the water from above while floating on the surface. The average dive to catch food lasts about 45 seconds, and the maximum dive approximately two or three minutes. Adult loons catch a variety of fish and invertebrates, which they usually eat underwater. Adults require one to two pounds of food per day. They usually eat fish that are ¼-½ pound or less. However, large fish of a pound or more may occasionally be captured and eaten after much effort to subdue and kill the fish before swallowing it. Loons also ingest pea-sized stones which stay in their gizzards and aid in grinding up fish bones and shells from crustaceans.

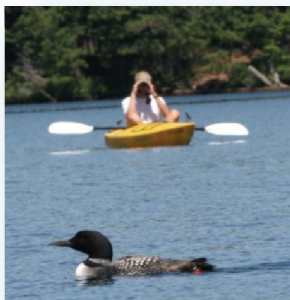


Loon chicks peer into the water and watch as the adults hunt for food. Adults feed young chicks small fish which are only an inch or two long, crayfish, and invertebrates such as leeches. As the chicks grow, adults release larger fish close to the chick, instead of directly transferring the fish from its bill to the chick's bill.

3.7 Threats to Loon Populations

Loon populations encounter a variety of threats, from human disturbance of nesting or parenting birds to the invisible, but insidious, impacts of airborne pollutants. The majority of conservation concerns are related to humans, and affect other wildlife in addition to loons.

- **Human disturbance:** Loons are fascinating birds to watch, and people often approach the birds to see them better or take a photograph. However, sometimes people inadvertently (or even intentionally) disturb nesting loons or loons raising chicks. A distraught incubating loon may show its distress by a lying in a “hangover” position, or by



leaving a nest very abruptly, potentially causing an egg to roll out of a nest. A loon protecting its chick will tremolo, wail, yodel (if a male), “penguin dance”, or constantly move away from the source of disturbance. All these signs of distress cause a bird to expend energy



and take time away from its parenting of the chicks. It is important for people sharing Adirondack lakes and ponds with loons to understand the behaviors and vocalizations of the birds, so they will know when a bird is tolerant of being approached, or if the bird is upset and the people should move away.

It is illegal to harass a Common Loon, and all migratory birds are protected by both state and federal laws. People caught disturbing loons, their nests, or eggs are likely to be fined.

- **Shoreline degradation/habitat alteration:** Shoreline degradation and alteration of shoreline habitat, particularly of islands, reduces the availability of suitable nest sites for Common Loons.

Loons prefer to nest along a shoreline that has surrounding vegetation to minimize disturbance and



visibility of the incubating bird or eggs. They also require a gradual slope to approach the nest, which is made difficult or impossible if shorelines are lined with rocks or a wall. If shorelines are maintained without natural vegetation or changed to make steep banks, a suitable nest site may not be available for a pair of loons, although the lake may have a sufficient prey base.

- **Water level fluctuation:** Loon nests are vulnerable to flooding or being left “high and dry,” if the water level on a lake varies more than a few inches during incubation. Intense storms, drought, or fluctuating water levels on a reservoir can all cause a loon nest to fail because the nest was flooded out or because the water had receded too far from the nest, rendering it inaccessible to the nesting pair.

- **Fishing line entanglement and lead poisoning from fishing tackle ingestion:** Loons can become entangled in fishing line or swallow lead fishing tackle when they eat a fish which is still attached to a line and/or tackle. Both of these circumstances can cause injury or a slow, debilitating death. Fishing line often wraps around a bird’s mouth, tongue, and neck, and occasionally around a wing or the body. A loon tangled in fishing line needs to be captured and freed from the line, or it will suffer from wounds that cut into its body, and potentially starve if it is unable to open its mouth. A loon that accidentally ingests lead fishing tackle will



experience gastrointestinal and neurologic signs, and a slow death due to lead poisoning, as the tackle degrades in the bird's stomach and the lead is absorbed into the bird's bloodstream.

~Loons in the Light~
Lead Poisoning in Loons

Lead poisoning due to accidental ingestion of lead fishing tackle is a major cause of mortality in adult loons in New York and the Northeast (Pokras and Chafel 1992, Stone and Okoniewski 2001). Anglers can easily help prevent lead poisoning in loons and other wildlife by using non-lead fishing tackle.

➤ **Predation:** Many animals prey on loon chicks and eggs, and occasionally on adult loons. Egg predators include eagles, who will take an egg directly from the nest, gulls, ravens, raccoons, otters, and mink, who have been documented rolling eggs out of a nest. Loon chicks are eaten by snapping turtles, eagles, and large fish such as pike and bass. Additionally, intruding loons may kill chicks in an attempt to take over a territory. Adult loons are harassed by eagles, especially if the loon is sick or debilitated. Loons also fight, and occasionally dramatically injure or kill another loon during a fight.

➤ **Catastrophic events:**

❖ **Botulism Type E:** Fish-eating birds migrating through the Great Lakes, particularly Lakes Erie and Ontario, are susceptible to exposure to Botulism Type E, which has killed thousands of loons and other species since 1999. The outbreak has been related to the introduction of two invasive species, Quagga mussels (*Dreissena rostriformis bugensis*), which harbor the toxin-producing bacteria *Clostridium botulinum*, and round gobies (*Neogobius melanostomus*), a predator of the mussels. As the migrating birds stop to rest on the lake, they eat the infected fish and become infected with the toxin, which is lethal (Roblee 2003, SeaGrant 2011, Canadian Cooperative Wildlife Health Centre 2011).

❖ **Oil spills:** An oil spill occurring on the coast during the winter or late spring, such as the 2003 Bouchard Barge 120 oil spill in Buzzard's Bay, Massachusetts, can affect loons and other waterbirds wintering on the coast. Loons are particularly susceptible to oil exposure during their flightless period in late winter. Exposure to oil causes both physical (lack of waterproofing) and physiological (e.g., anemia, inflammation) changes that can result in morbidity and mortality of affected birds.

➤ **Environmental pollutants:** Since loons are a long-lived predator at the top of the aquatic food web, they are susceptible to environmental contaminants such as mercury pollution. Contaminants in the diet can be sequestered in an animal's tissue (bioaccumulation), eventually producing concentrations of toxins much higher than the surrounding environment (bioconcentration).

Organisms at higher levels of the food web (top trophic levels) are particularly susceptible, as they ingest all of the accumulated toxins within multiple prey organisms.

Pollutants may produce synergistic effects, as in the case of acid deposition and higher mercury levels in biota (all organisms in a geographic region or time period) living on lakes. Bacteria thriving in the acidic environment convert elemental mercury to methylmercury at a higher rate than in non-acidic habitats.

*~Loons in the Light ~
Circle Dancing Loons!*

Groups of loons often feed together by doing a “circle dance”—they gather in a circle, peer under the water, then hoot and dive together. These social groups appear to be a time for loons to get acquainted with other birds in the area (Paruk 2006). They can also be observed feeding as a unit, with the whole group diving simultaneously. It is unknown if they have greater capture success this way than when they are feeding alone.



4.0 The Problem of Environmental Mercury Contamination

Environmental mercury, an invisible and often overlooked pollutant, affects aquatic ecosystems throughout the world. Atmospheric deposition of mercury from sources such as the burning of coal for electrical power has contaminated many watersheds in northern North America, including in New York's Adirondack Park. Although environmental mercury is a naturally occurring element, analyses of lake sediment cores indicate that the current rate of regional mercury deposition is 2–5 times greater than historical levels (pre-1940s; Swain et al. 1992). Scientists have traced this mercury increase to dry and wet atmospheric particulate fallout. Atmospheric mercury resulting from human actions primarily originates from coal burning power plants and incinerator emissions. Studies comparing fish mercury concentrations with rates of atmospheric deposition have found that these emission sources account for a major contribution to the aquatic system load (NESCAUM 1998).

Mercury is of especially high concern in acidic environments, as in many Adirondack lakes, where soils have low buffering capacity and sulfur-reducing bacteria convert elemental mercury to methylmercury, the toxic form that magnifies up the food web, at a higher rate. The current availability of methylmercury in aquatic ecosystems of northeastern North America is at levels that pose risks to human and ecological health. Concerns over human exposure have led to the issuance of fish consumption advisories throughout many regions of North America, including a blanket advisory for the Adirondack Park (New York State Dept. of Health, 2011).

Recent research on the impact of environmental mercury contamination to aquatic and terrestrial ecosystems in the northeastern North America confirmed five biological “hotspots,” including the Adirondacks, where high levels of mercury were found in several fish and wildlife species (Evers 2005, Driscoll et al. 2007b, Evers et al. 2007). Over the past two decades, the number of documented wildlife species with mercury levels of concern has increased substantially in the Great Lakes region and elsewhere in North America (Evers et al. 2011). Research has also found that the toxicological impacts of mercury pollution to fish and wildlife occur at lower mercury concentrations than previously thought (Evers et al. 2011). Although mercury contamination rarely causes mortality in wildlife, it does affect the nervous system, causing sublethal behavioral changes that detrimentally impact reproductive success and survival (Thompson 1996, Evers 2001, and Evers et al. 2008).

Anthropogenic inputs of mercury into the environment have resulted in an increasing gradient of mercury found in loons from west to east across North America (Evers et al. 1998). Methylmercury has been demonstrated to affect the reproduction, behavior, and survival of loons (Nocera and Taylor 1988, Meyer et al. 1998, Counard 2001, Evers 2001, Evers et al. 2008), and potentially other wildlife species (Thompson 1996). In loons, high levels of mercury result in lethargic behavior, failure to incubate eggs,

care for chicks, and defend territories (Scheuhammer and Blancher 1994, Meyer et al. 1995, 1998, Thompson 1996, Nocera and Taylor 1998, Counard 2001, Fevold et al. 2003, Evers et al. 2008). Studies throughout New York and the Northeast have shown that loons with high mercury levels have lower reproductive success than birds with low mercury levels, and that loons breeding on acidic lakes have extremely elevated blood mercury levels and significantly decreased reproductive success, potentially leading to a population impact if enough birds are affected (Schoch and Evers 2002, Burgess and Meyer 2008, Evers et al. 2008, Schoch et al. 2011).

Strict regulation of mercury emissions for coal-fired power plants has recently been implemented in the Northeast and New York, which will minimize impacts due to local point sources. However, national mercury emission regulations for coal-fired power plants have only recently been finalized, and have yet to be implemented (US EPA 2011). Although the United Nations Environment Programme (UNEP) Global Mercury Partnership is working to protect human and environmental health globally from mercury by minimizing and eventually eliminating mercury releases to the environment due to anthropogenic sources (UNEP 2011), a comprehensive global mercury pollution policy has not yet been initiated.

Since a primary source of environmental mercury and acidic contamination is airborne deposition, which does not recognize local or national boundaries, it is essential to regulate these emissions from all sources throughout North America, as well as globally. Persistent accumulation of mercury in the sediments of affected ecosystems is expected to make widespread recovery from the risks of mercury concentrating up the food web a long-term process, particularly in acidic environments (Driscoll et al., 2007a). Thus, it is all the more critical to regulate sources of mercury emissions and other pollutants, and to determine the impacts of environmental contaminants to wildlife and their habitats.



Mercury research in the Great Lakes region and elsewhere in North America underscores the benefits of policy advances, such as decreases in mercury emissions regionally and nationally. In general, trends indicate that controlling air emission sources should lower mercury concentrations in aquatic food webs, yielding multiple benefits to fish, wildlife, and people. These improvements will be roughly

proportional to declines in mercury deposition, which most closely track trends in regional and U.S. mercury air emissions (Evers et al. 2011). In addition, increasingly stringent regulations for atmospheric emissions of sulfur dioxide and nitrogen oxides will likely have the co-benefit of reducing biotic mercury levels because elevated mercury concentrations in aquatic biota are linked to acidic deposition (Driscoll et al. 2007a, Yu et al. 2011). We look forward to the day when the lingering call of the Common Loon will echo across Adirondack lakes unhindered by impacts from environmental pollutants such as mercury and acid deposition.

*~~Loons in the Light~
Juvenile vs. Adult Plumage*

Juvenile loons do not acquire the adult black and white plumage until they are at least 2–3 years old.

Thus, if you see a black and white bird, you know it is definitely an adult since it is at least 2 years old. Gray loons might be either an adult in winter plumage or a juvenile.



5.0 The Art of Studying Loons

To assess the impact of mercury pollution to Adirondack loons, the birds need to be captured to collect blood and feather samples and banded with a unique combination of color bands for subsequent identification. This is not an easy task for a bird that lives exclusively in the water, since they can easily swim and dive away from an approaching boat.



To address this problem, Dr. David Evers, Executive Director of Biodiversity Research Institute, developed a specialized technique utilizing nightlighting and playback tapes to enable loons to be successfully captured during the breeding season (Evers 2001). When nesting or raising chicks, loons are quite territorial, and thus, are very responsive to chick calls and hoots or territorial calls from other loons. They will readily approach people or tapes that mimic these calls. *(Note that if people were to do this on a regular basis, this would disrupt the ability of a loon pair to successfully nest or raise their chicks, and would be considered harassment of a protected species.)* Dr. Evers found that he could capture loons at night by combining playback tapes with shining a bright light in a loon's eyes so it could not see the boat moving towards it. Then, as the loon approached within a few inches of the boat, he would lower a large fishing net into the water, and the loon would swim into the net.

With special state and federal scientific collection and banding permits in hand, BRI biologists and their collaborators have since successfully used this technique for over two decades to capture thousands of loons throughout North America. A team of three people go out at night in a motorboat or a canoe—one person drives the boat, another shines the spotlight on the loon, and the third captures the bird with a net. The bird and net are lifted out of the water and into the boat. A towel is used to cover the bird's head to keep it calm as it is removed from the net.



One person then holds the bird, while another prepares the bands to fit the bird's legs and records the data. The third person collects a blood sample from the bird's leg and feather samples from its wings and tail, which are analyzed by a laboratory to determine the loon's body burden of mercury. Bill and leg measurements are recorded, as well as the bird's weight, gender, and age. A U.S. Fish and Wildlife Service (USFWS) band and a unique color combination of plastic bands are placed on the legs of adult loons and large juveniles. The loon is released shortly after capture—a little befuddled by the experience, no doubt—and it quickly resumes normal behavior and caring for its chicks.



Trained field staff paddle the capture lakes on a weekly basis during the capture year and in subsequent summers to assess the reproductive success of the banded loons. Binoculars are used to identify and observe the individual colored banded birds and determine what birds have mates, where territorial pairs nest, and what pairs successfully raise chicks to fledging age. The reproductive success of the banded birds can be followed over many years (even decades, since loons live so long), and related to their mercury levels to assess if mercury contamination has sublethal impacts to loons.



6.0 Study Objectives

To assess the impact of environmental mercury pollution to Adirondack aquatic ecosystems, we focused on three primary objectives:

1. **Characterize aquatic-based mercury in the Adirondack Park.** We determined mercury concentrations in different levels of the aquatic ecosystem (e.g., water, fish, loons), as this is the first step needed to set up a long-term mercury monitoring program and to quantify if any injury is occurring due to current environmental mercury contamination. We characterized mercury exposure in five ways:
 - a. **Individual lake mercury profiles.** We measured mercury levels in both the abiotic (water and sediment) and biotic (zooplankton, crayfish, fish, and loons) compartments of each lake. This baseline data is critical for future mercury monitoring programs in the Adirondack Park.
 - b. **Spatial distribution of mercury.** We looked at mercury levels across the Adirondack Park to determine if certain areas are at higher risk of mercury contamination, which is important for understanding how atmospheric deposition interacts with individual watershed characteristics.
 - c. **Bioconcentration factor for the Adirondack Park.** We explored the percentage of methylmercury between different compartments and also the ratio of mercury between different prey classes.
 - d. **Relationships between mercury at different levels in the food web.** We explored relationships between various compartments in the aquatic food chain web. Since mercury magnifies as it moves up the food chain, we wanted to test whether we could trace mercury levels back down the food chain from a top level predator (i.e., Common Loon) to the abiotic environment (i.e., water and sediment). Because of the difficulty associated with sampling Common Loons, this approach would be useful if other parts of the aquatic food web could be used as a proxy for loon samples.
 - e. **Relationship between lake acidity and mercury.** Since other studies have shown that Common Loon productivity is correlated with lake acidity, we also measured lake pH to understand if there could be synergistic relationships between lake acidity and mercury.
2. **Develop a mercury hazard profile for the Common Loon.** We used published estimates for mercury risk to Common Loons based on blood, feather, and egg values to determine what percentage of the Adirondack loon population is at risk for impairment to reproductive success.

3. **Assess the effect of mercury on the Adirondack Common Loon population.** We examined mercury concentrations in light of three criteria:
- a. ***Recommended water mercury level to protect the Adirondack Common Loon population.*** We assessed ecological risk using a U.S. Environmental Protection Agency (EPA)-based formula for a wildlife criterion value (WCV) that provides a water column mercury value that is protective of wildlife at the population level. The WCV estimates the viability of a wildlife population through measurement of contaminant stressors such as surface water mercury concentrations (Nichols et al. 1999). A loon-based WCV provides information needed by policy makers to better regulate mercury in aquatic systems.
 - b. ***Effect of mercury and lake acidity on loon reproductive success.*** We used our long-term dataset on Common Loon productivity in the Adirondack Park to determine if there were differences in reproductive success related to mercury exposure or lake acidity.
 - c. ***Model for long-term effect of mercury on the Adirondack loon population.*** We used the EPA Common Loon population model (Gear et al. 2009) to evaluate the relationship between methylmercury availability and the Park's loon population, and to assess if Adirondack loons are being detrimentally impacted on a population scale by mercury contamination of the aquatic ecosystem.

*~Loons in the Light~
Habituated Loons*

Just like people, loons have individual personalities. Some birds are very intolerant of even non-motorized boaters and potential predators. Other birds, however, are extremely habituated, successfully nesting and raising chicks on a well-developed lake in the midst of intense recreational boating activity.



7.0 Study Area

Our study area consisted of lakes in every watershed of the Adirondack Park (Figure 1), with characteristics ranging from acidic to non-acidic; high versus low mercury levels; developed versus non-developed; and reservoirs versus natural lakes. The original study lakes were selected to coordinate with ongoing or previous water quality research, such as that conducted by the Adirondack Lakes Survey Corporation, Adirondack Effects Assessment Program, and the EPA's Environmental Monitoring and Assessment Program, to complement existing datasets by other researchers in the Park. Study lakes have been added over time, as color-banded loons change territories or juveniles returning as adults established territories of their own.

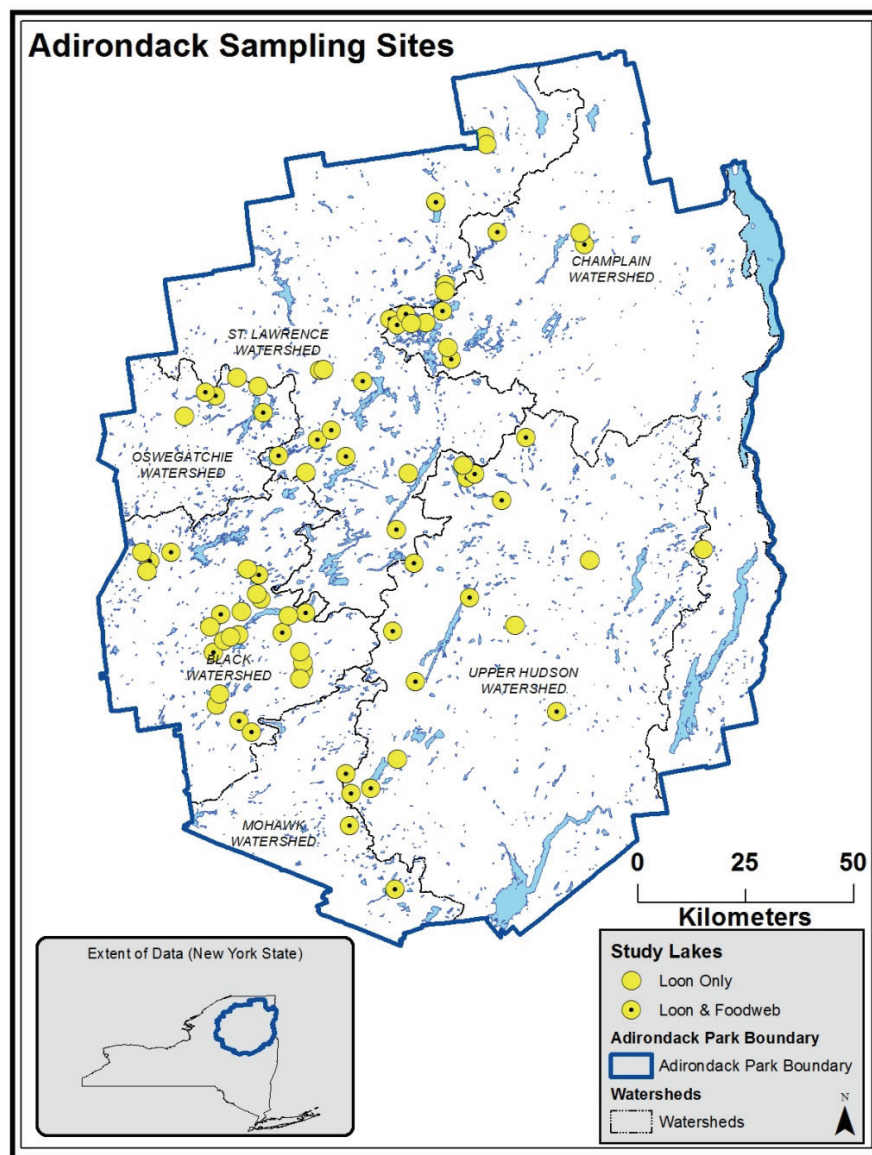


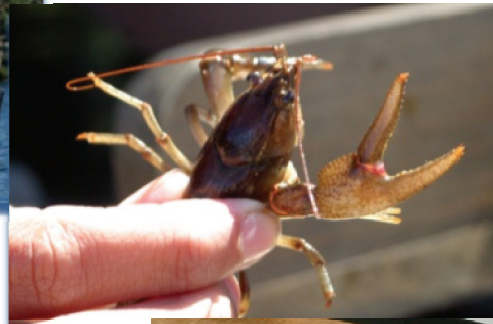
Figure 1. Loon and Food Web Study Lakes in New York's Adirondack Park, 1998–2007.

8.0 Sampling the Aquatic Food Web

We used mercury levels from abiotic (water column and sediment) and biotic (Common Loon blood, feathers, and eggs; prey fish; crayfish; and zooplankton) samples to develop a mercury exposure profile and to quantitatively assess the ecological risk that mercury deposition poses to Adirondack waterbodies. Biotic and abiotic samples were collected on 44 lakes within the Adirondack Park over a two-year period (2003 and 2004). Water and fish samples were collected from all 44 lakes, zooplankton from 43 lakes, crayfish samples from 26 lakes, and sediment samples from 32 lakes.



In the loon territory on each of the study lakes, we collected samples of sediment, water, zooplankton, crayfish, and prey fish to determine their mercury levels. Water chemistry samples were collected from the study lakes to evaluate the interactions between water chemistry (particularly pH, dissolved organic carbon, and aluminum) and mercury levels, and to enable us to interpret the water-fish-loon mercury relationships in more depth.



A composite of fish in each of four size-classes (small: 5–10 cm, medium: 10–15 cm, large: 15–20 cm, and extra large: 20–25 cm) was collected on each lake. Because mercury bioaccumulation can vary, based on fish species, we converted all fish captured into yellow perch equivalents (YPE) for ease of comparison (Evers et al. 2005, Simonin et al. 2008). Barr (1996) documented the loon's favored prey item was yellow perch, which is a relatively ubiquitous species in the Adirondack region of New York.



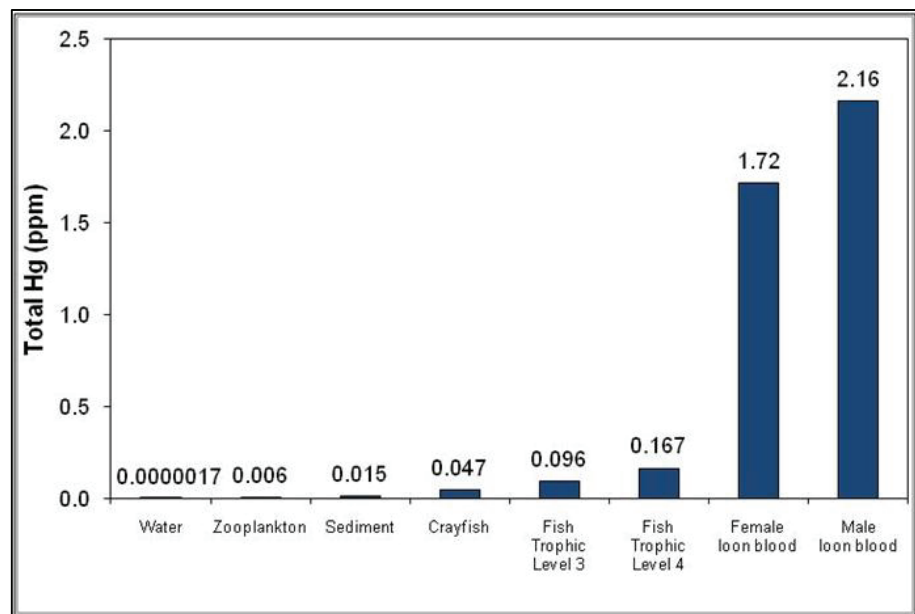
9.0 Mercury in Adirondack Aquatic Ecosystems

We characterized mercury within Adirondack aquatic ecosystems by examining individual lake profiles, the spatial distribution of mercury, and the relationships between mercury in different compartments of the aquatic food web. The important findings from this large-scale profile fall into three main categories: 1) the relationships between mercury in food web compartments are complex, 2) the southwestern portion of the Adirondack Park tends to have higher mercury levels, and 3) fish and loon mercury concentrations in many lakes exceed human and wildlife health criteria.

9.1 Mercury in the Aquatic Food Web

Because mercury is a contaminant that biomagnifies as it moves up the trophic levels (i.e., its concentration in plant and animal tissues increase by orders of magnitude as it moves from lower in the food chain to higher), we would expect that lower trophic levels (such as zooplankton) would have less mercury than high trophic levels (such as large fish and loons). Mean mercury concentrations within the food web in the sampled Adirondack lakes followed this expected pattern (Figure 2), with an increase in mercury by many orders of magnitude as it moved from lower in the food chain (water, zooplankton, and crayfish) to higher levels (small prey fish, predatory fish, and loons).

Figure 2. Average total mercury concentration for each level in the aquatic food web, used to calculate the bioconcentration factor.



Although zooplankton are low in the food chain, their ability to concentrate methylmercury is relatively high (Driscoll et al. 2007b), reflecting the importance of the lower food web in establishing the degree of mercury concentration at higher levels, and thus, affecting mercury exposure for wildlife and humans (Driscoll et al. 1994, Kamman et al. 2005).

Zooplankton mercury levels correlated with small and medium fish mercury levels, but not as strongly with large or extra-large fish mercury. Mercury levels in crayfish correlated to those in predatory large and extra-large fish, but not those in smaller prey fish, reflecting that crayfish are a prey item for larger fish, but smaller fish are more likely to eat items lower in the food web, such as insects or plant material. Mercury levels in fish reflect their diet. Fish mercury levels in our study increased with size class and fish length, with predatory large and extra large fish having higher mercury concentrations than small and medium fish that feed on insects or plants.

Loon mercury levels strongly correlated with mercury concentrations in large and extra-large fish as well as crayfish, all of which are common prey for these birds. The relationships between different stages of the food web were not as strong as expected, indicating that many factors come into play when determining how mercury accumulates in the food chain. For this reason, mercury monitoring programs designed to only sample loon prey (i.e., fish and crayfish) would likely overlook potential loon mercury hotspots. Thus, we recommend continuing to sample Common Loons as a part of any long-term mercury biomonitoring program.

9.2 Fish and Loon Mercury Concentrations

It is of concern that many lakes in our study had fish and loons with blood mercury levels exceeding criteria established for the protection of human and wildlife health. Mercury concentrations in 7% of all fish on our study lakes and 12% of the yellow-perch equivalent (YPE) samples were higher than the EPA threshold of 0.3 ppm (parts per million) for methylmercury in fish. Elevated mercury levels may also affect fish behavior and decrease their ability to evade predation (Webber and Haines 2003), resulting in piscivorous species, such as loons, disproportionately feeding on fish with reduced abilities to avoid predators (Evers et al. 2008).

Twenty-three percent of our Adirondack study lakes had at least one fish sample with mercury concentrations above the EPA 0.3 ppm threshold, and half of those lakes were not currently listed on the New York State fish consumption advisory (Yu et al. 2011). Sixty-four percent of the lakes had at least one fish with a mercury level higher than 0.16 ppm, which has been shown to significantly decrease loon reproduction (Evers et al. 2008); 48% of our study lakes had at least one fish mercury concentration greater than the 0.21 ppm threshold that Burgess and Meyer (2008) found to reduce loon productivity by 50%; and 9% of the lakes had one or more fish with a mercury level in excess of the 0.41 ppm mercury threshold value at which Barr (1986) and Burgess and Meyer (2008) predicted that loon reproduction would fail completely (Yu et al. 2011).

9.3 Mercury and Lake Acidity

Our results indicated that the acid-base status of a lake influences the accumulation of methylmercury in the aquatic food web. Mercury levels in biota, particularly fish and Common Loons, were negatively correlated with increasing lake pH (Figure 3) and acid neutralizing capacity (the buffering capability of the water), probably reflecting the increased methylation of mercury within acidic aquatic systems. Likewise, in the Canadian Maritimes and Wisconsin, Burgess and Meyer (2008) found a strong negative relationship between lake acidity and mercury concentrations in small fish and blood mercury levels in Common Loons over a wide range of pH (4.3–9.5).

A variety of factors contribute to the availability of mercury in Adirondack waterbodies, including numerous wetlands facilitating the movement of mercury to downstream lakes and the production of methylmercury (Selvendiran et al. 2008). Also included is the poor productivity of Adirondack lakes, which enhances concentration of mercury up the food web (Chen and Folt 2005). It is likely that these landscape characteristics (e.g., numerous wetlands, thin soils with poor buffering capacity) contribute to the sensitivity of Adirondack ecosystems to mercury inputs as well as ongoing effects of acidic deposition, resulting in the Adirondacks being classified as a biological mercury hotspot.

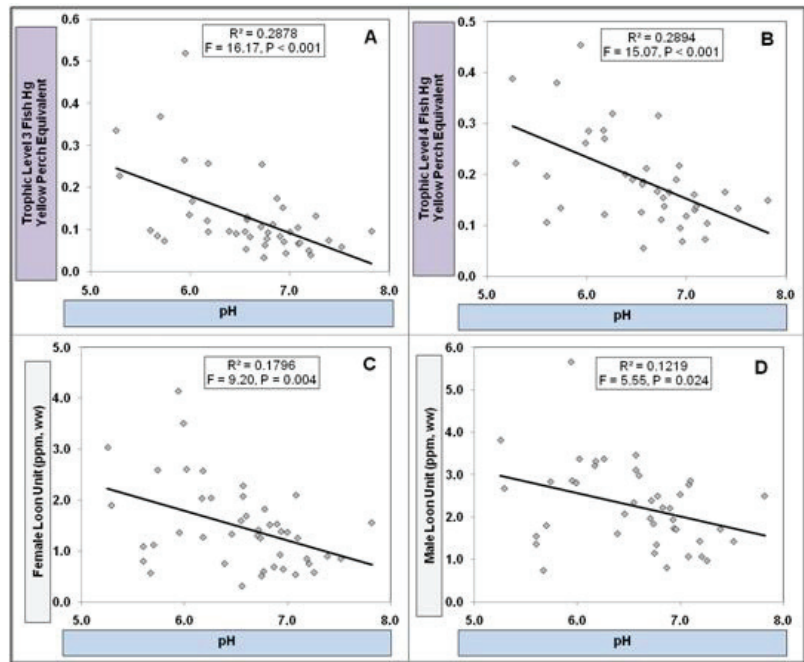


Figure 3. Correlation between lake pH and mercury for A) small fish, B) predatory large fish fish, C) female loon units and D) male loon units.

In addition, the increased availability of sulfate with “acid rain” promotes the methylation of mercury through an increase in sulfur-reducing bacteria that convert elemental mercury to methylmercury (Jeremiason et al. 2006). We observed the highest fish and loon mercury levels in Adirondack lakes that had low ability to neutralize acids, which are likely impacted by acid deposition (Driscoll et al. 2007a). It was notable that mercury concentrations in fish and loons decreased with slight increases in buffering capability, indicating probable interactions between acid deposition and mercury contamination of aquatic food webs (Yu et al. 2011).

9.4 Geographic Distribution of Mercury

Although no significant spatial trends in mercury availability within the Adirondacks were observed, the lakes in the southwestern Adirondacks had a tendency toward higher loon, fish, and zooplankton mercury levels, corresponding to increased acid deposition in that area of the Park (Figure 4). The highest loon blood mercury lake had five-fold higher mercury levels than the lowest lake, and was also considerably more acidic.

Lake pH correlated with loon mercury levels, indicating that mercury uptake in loons was driven, in part, by lake acidity. Loons that breed in mercury “hotspots,” such as the southwestern Adirondacks (Driscoll et al. 2007b, Evers et al. 2007), are likely to increase their mercury body burden annually due to the inability to sufficiently rid their bodies of the mercury they take in through their diet. Mercury hotspots have potential to cause age-related increases in mercury concentrations leading to a reduction in an individual’s lifetime reproductive success, and eventually skewing the age structure of the population toward younger individuals (Evers et al. 2008).

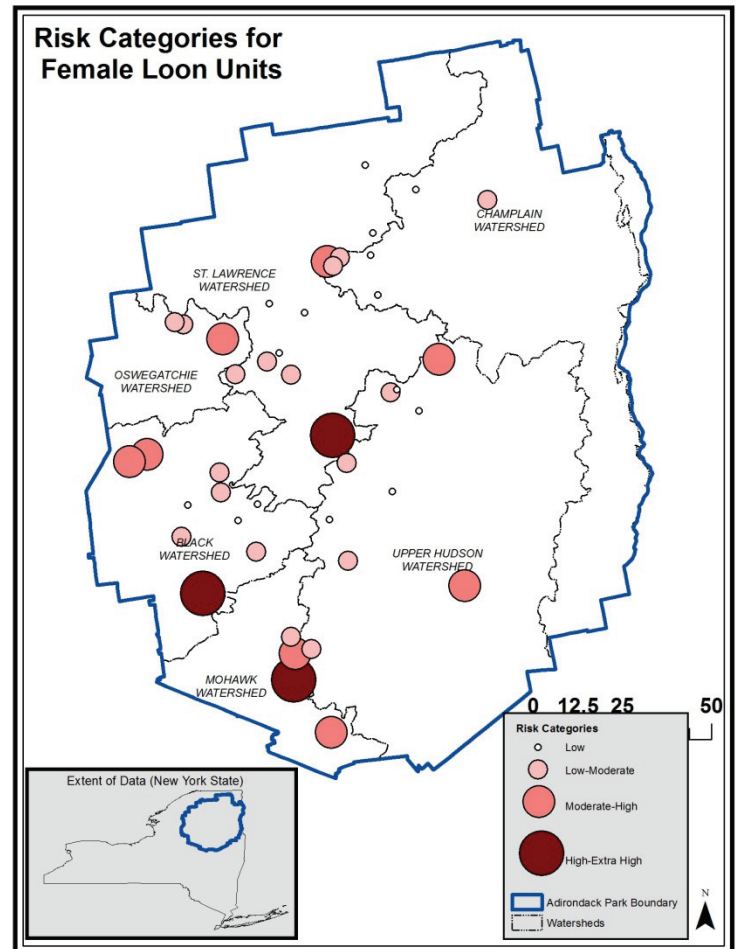


Figure 4. Spatial distribution of lakes with low, moderate, high and extra high female loon mercury levels. Low (0–1 ppm), moderate (1–2 ppm), high (2–3 ppm), and extra high (3+ ppm).

9.5 Mercury Hazard Profile for Adirondack Loons

Another objective of our study was to develop a mercury hazard profile using the Common Loon as an indicator species for Adirondack freshwater ecosystems. Loon blood mercury levels reflect recent dietary exposure (Evers et al. 2005a); strong evidence indicates that adult blood mercury levels reflect prey mercury levels in their breeding territory (Evers et al. 2005b, Burgess and Hobson 2006). In the Canadian Maritimes and Wisconsin, Burgess and Meyer (2008) found that loon blood mercury concentrations were increased in lakes with high fish mercury levels. Feather mercury provides insight into the lifetime mercury body burden of an individual loon, as muscle protein reservoirs are

remobilized when a bird molts its feathers (Evers et al. 2005a). Evers et al. (2008) found that loon feather mercury increased by an average of 8.4% per year.

The mean adult blood mercury level on our Adirondack study lakes was 1.97 ppm, with a wide range of variation across lakes (0.58–5.62 ppm). Females averaged lower blood and feather mercury loads than males, and juvenile loon blood mercury level was considerably lower than adults, averaging 0.24 ppm (range: 0.01 ppm–0.76 ppm). Adult feathers showed a large amount of variation in mercury levels, ranging from 3.940 ppm to 73.21 ppm. Nonviable eggs were collected at 29 study lakes, with total mercury concentrations ranged from 0.35 ppm to 2.15 ppm. As in other studies, male loon blood and feather mercury levels in the Adirondacks were greater than female blood and feather levels, due to the larger males consuming larger (and likely older) prey with higher mercury concentrations, and the ability of females to deposit mercury in the eggs they lay (Evers et al. 2005b). Adult loon blood mercury levels were significantly higher than chick blood mercury levels, reflecting their increasing mercury body burden over time, and the increased exposure of adults feeding on larger prey items that are higher in the food web.

Because Common Loon mercury data are from multiple tissues (i.e., adult male and female blood, juvenile blood, and loon eggs), we converted mercury concentrations to a single common unit to best evaluate data from various loon tissues, thus facilitating comparisons between locations and years. The female loon unit (FLU) represents the expected or observed blood mercury of adult females, and is the more universal unit because it includes egg and juvenile data. The male loon unit (MLU) predicts adult male exposure, which is often more severe given the larger size of males in an area; thus the MLU provides an indication of the potential for population-level adverse effects of mercury exposure (Evers et al. 2011). We found a negative correlation between productivity and mercury levels for both female and male loon units.

Loons were placed into low, moderate, high, and extra-high risk categories of mercury concentrations in their tissues, based on previous research for effects levels conducted by BRI and others (Thompson 1996, Evers et al. 2003, 2008, Burgess and Meyer 2008). Low risk indicates background mercury levels that are minimally impacted by anthropogenic inputs of mercury. Birds in the moderate risk category have elevated mercury levels but the impacts to individuals have not yet been determined. Loons in the high-risk category are exposed to toxic levels of environmental mercury that potentially can affect individual birds and the population as a whole. The extra high mercury category is based on known impacts to loons and other birds.

Adult loons with blood mercury concentrations higher than 3.0 ppm or feather mercury greater than 20 ppm, or loon eggs with mercury levels more than 1.3 ppm are at high risk for significant adverse

physiological, behavioral, and reproductive effects (Evers et al. 2008). Our results indicated that 21% of adult male and 8% of female Adirondack loons in our study were at high risk of behavioral and reproductive impacts based on their blood mercury exposure (Figure 5), and 37% of male and 7% of female study birds were at high risk based on their feather mercury exposure. When such a high proportion of the breeding population is in the high or extra-high risk category, mercury exposure is likely to result in population-level impacts (Evers et al. 2011).

Thirteen percent of the Adirondack loon eggs sampled were at high risk for mercury exposure, indicating that if the chicks hatched, their behaviors would be abnormal, and they would have a reduced likelihood of surviving to fledging. Several controlled studies have found that mercury exposure impairs egg development and hatchability at levels (i.e., 0.5–4.4 ppm) that were found in this study (Borg et al. 1969, Fimreite 1971, Gilbertson 1974, Heinz 1979, Spann et al. 1972).

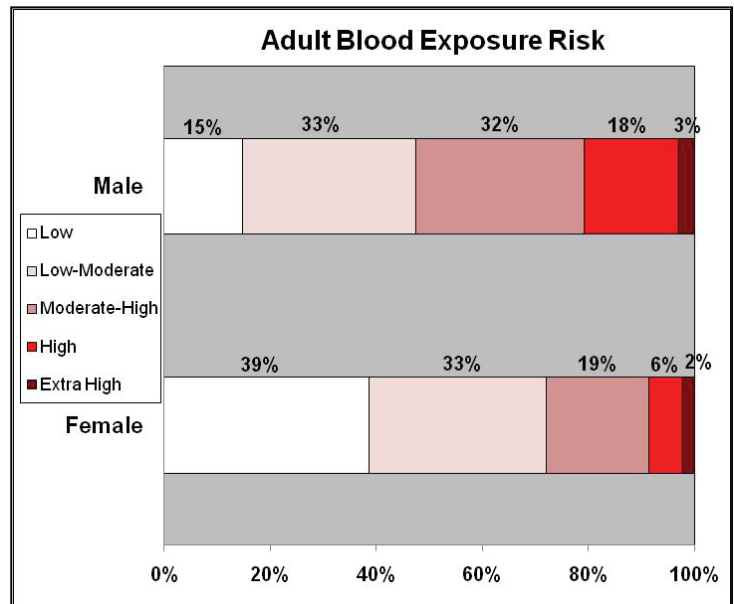


Figure 5. Risk ratios for mercury exposure based on adult blood mercury exposure groups: low (0–1 ppm), low-moderate (1–2 ppm), moderate-high (2–3 ppm), high (3–4 ppm) and extra high (>4 ppm).

9.6 Effect of Mercury on the Adirondack Common Loon Population

The evidence is compelling that loons with elevated mercury exposure experience numerous negative neurotoxic, physiologic, and reproductive impacts, including the production of smaller eggs (Evers et al. 2003), increased time spent in low-energy behaviors (Evers et al. 2005b, 2008), reduced diving frequency (Olsen et al. 2000), decreased time spent incubating eggs (Evers et al. 2005b, 2008), reduced chick feeding rates by adults (Counard 2000), and less back-riding by chicks (Nocera and Taylor 1998). Scheuhammer et al. (2008) also correlated brain mercury concentrations with changes in the nervous system of loons. Evers et al. (2008) found that loons with elevated blood mercury levels spent less time in high energy behavioral events, such as foraging for chicks and themselves, and incubating eggs, than birds with low mercury levels. These behavioral changes could contribute to decreased survival of eggs and chicks, providing insight into why there is reduced productivity in loons with increasing mercury body burden (Evers et al. 2008).

We used three separate analyses to explore the effect of mercury on Common Loons in the Adirondack

Park by: 1) developing a Wildlife Criterion Value to establish a water column mercury value that is protective of wildlife, 2) analyzing the effect of mercury and lake acidity on loon fecundity, and 3) applying a population model to assess the long-term impact of mercury on the Adirondack breeding loon population.

9.6.1 Recommended Water Mercury Level to Protect the Adirondack Common Loon Population

The Wildlife Criterion Value (WCV) uses measurement of contaminant stressors, such as surface water mercury concentrations, to estimate the viability of a wildlife population exposed to the stressors (Nichols et al. 1999). We modified the WCV formula by Nichols et al. (1999) with variables specific to the Adirondack Park, to develop a sensitive and appropriate New York-based WCV. We determined that a water mercury level equal to or less than 2.00 ng/L would protect male Adirondack Common Loons from having a mercury body burden that would cause reproductive and/or behavioral effects, while a water mercury concentration of 1.69 ng/L or less would protect female Common Loons at the population level.

9.6.2 Effect of Mercury and Lake Acidity on Loon Reproductive Success

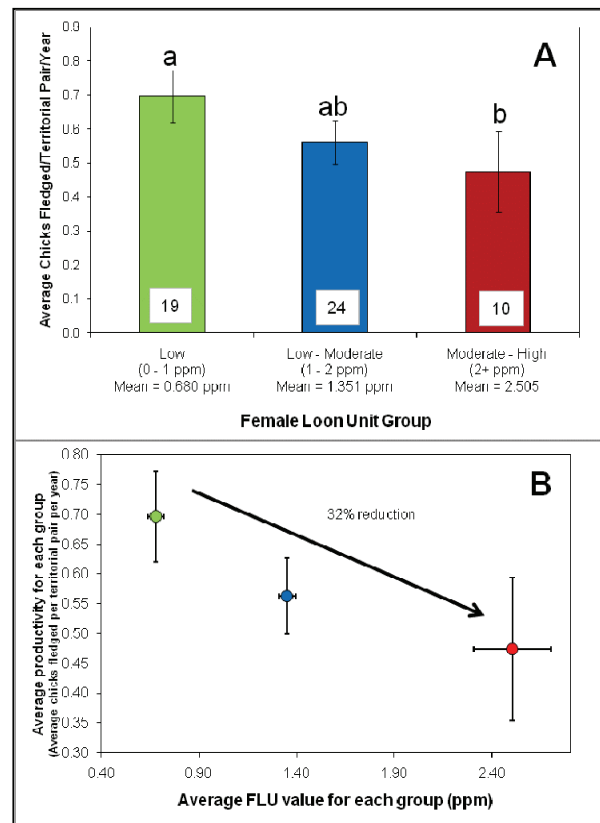
Other loon populations in the Northeast, with blood mercury levels greater than 3.0 ppm experience significant reproductive impacts—for example, breeding loons in Maine and Nova Scotia with high mercury concentrations fledged 40% fewer young than pairs with mercury levels below 1.0 ppm (Evers et al. 2005b). Our results indicated that the productivity of Adirondack loons decreased significantly with increasing mercury body burdens. High risk territorial pairs (>3.0 ppm mercury) fledged approximately 20% fewer chicks per pair than loons with lower mercury levels (<3 ppm), and female and male Adirondack loons in the highest mercury exposure category (2–4 ppm) showed a 32% (Figure 6) and 56% reduction in the number of chicks fledged per year, respectively, compared to birds in the lowest mercury exposure category (0–1 ppm). Similar patterns of lower productivity were found for other reproductive parameters.

Burgess and Meyer (2008) found that mercury exposure was associated with a linear upper limit on loon productivity, supporting the hypothesis that mercury exposure in Common Loons was a limiting factor on reproductive success. In the Adirondacks, our analysis indicated that the maximum Adirondack loon productivity would be ~1.0 chick/territorial pair if female or male loon mercury exposure was zero, and that productivity would be reduced by 50% when female blood mercury levels were 3.3 ppm or male blood mercury levels were 4.5 ppm. For both male and female loons, our analysis indicated that mercury likely regulates loon productivity (average chicks fledged per territorial pair; CF/TP) more dramatically in the segment of the Adirondack loon population with high and extra-high

mercury body burdens. Thus, mercury appears to be a primary anthropogenic stressor for the Adirondack Common Loon population, resulting in decreased productivity.

Figure 6. Comparison of annual productivity by female loon unit groups for A) three mercury risk groups and B) based on average mercury value within each group*.

* Numbers within bars indicate number of territories where productivity and female loon unit were both measured, letters indicate marginally significant differences between groups (Kruskal-Wallis $\chi^2 = 5.136$, $df = 2$, $p = 0.077$) and error bars indicate standard error.



Like Burgess and Meyer (2008), we also found that some loons with low mercury exposure also had low productivity, indicating stressors other than mercury are affecting their reproductive success, including intrinsic ones (e.g., species longevity, intraspecific interactions due to density), extrinsic (e.g., predation, weather), and/or anthropogenic factors (e.g., human disturbance, other contaminants). However, several studies have identified mercury as a cause of reduced loon productivity (Barr 1986, Burgess and Meyer 2008, Evers et al. 2008), and, as in Wisconsin, New Brunswick, and Nova Scotia (Burgess and Meyer 2008), we found that Adirondack loon productivity was never high when mercury exposure was high.

It is interesting that the average productivity (the number of chicks fledged per territorial pair) we observed for the overall Adirondack study population (0.59 CF/TP; Figure 7), was considerably lower than that determined in two earlier New York loon population surveys (Trivelpiece et al. (1979) observed 0.83 CF/TP, and Parker et al. (1986) observed 0.96 CF/TP). Differences in study methodology may potentially account for the difference in productivity results, as both previous surveys evaluated two years of loon productivity for a larger number of lakes with only two to four visits per lake annually,

while our study evaluated nine years of intensive (weekly) observations on a smaller number of loon territories and lakes.

In Wisconsin, loons occupying low pH (<6.3) lakes had significantly higher blood mercury levels than loons nesting on neutral pH lakes (Meyer et al. 1995). Burgess and Meyer (2008) concluded that the increased mercury exposure of loons living on acidic lakes is likely to be the cause of reduced fledging success.

Our study also examined relationships between lake acidity, mercury exposure, and loon productivity to assess potential impacts of acid deposition to aquatic

ecosystems. The results of our study support the conclusion that the elevated mercury body burden of loons breeding on acidic lakes detrimentally affects their productivity. We identified a positive trend between loon reproductive success and increasing lake pH; based on the results of our quantile regression, lake acidity was potentially a limiting factor on loon productivity, with maximum productivity attained at pH = 6.64 and a 50% reduction in productivity with lakes that had a pH of 5.16.

Alvo (1996; 2009) found no loon productivity on lakes with pH <4.4, significantly lower productivity on lakes with pH <5.8, and no impact on lakes with pH >6.6. Alvo (2009) attributed chick mortalities on lakes with very low pH to reduced growth after hatching due to inadequate food resources, and concluded that the critical lake pH for loon breeding success was 4.3, and a lake pH of approximately 6.0 was an important threshold for loon productivity. Although we evaluated loon productivity on territories with three or more years of observations based on lake acidity (pH<6.3 vs. pH>6.3), we did not observe a significant difference between the two groups. Parker (et al. 1986; 1988), in a two-year study of loons breeding on acidic and non-acidic Adirondack lakes with and without fish, concluded that the presence of loons and the incidence of breeding, hatching, and fledging success were not affected by the acidity of a lake.

Alvo (2009) and Parker (1988) attributed the low fledging success of loons breeding on acidic lakes to the decreased availability of food resources in those lakes. Parker (1988) felt that the impact of lake

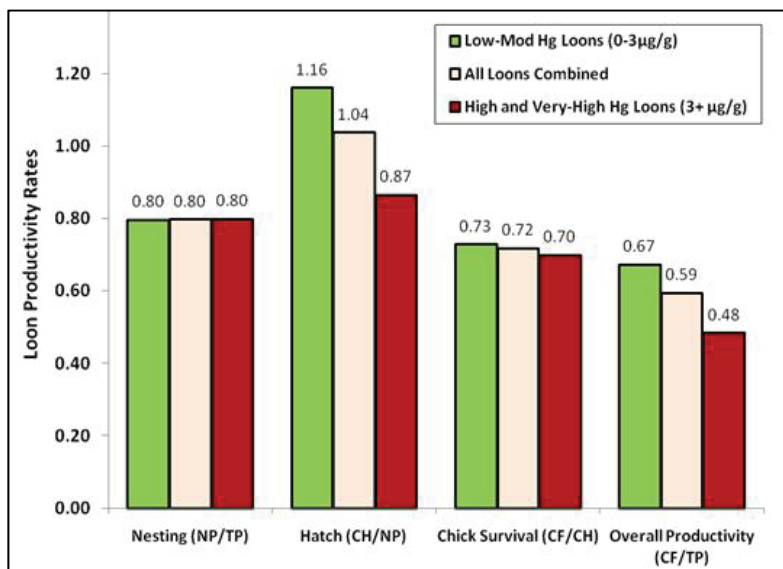


Figure 7. Summary of change in reproductive measures between low-moderate (<3.0 ppm blood Hg) and high/very-high (3.0+ ppm blood Hg) risk categories for Adirondack study loons, and all loons combined, 1999-2007.

acidification on loons would manifest as the insufficient availability of quality food for larger chicks who have increasing energetic demands, possibly weakening and predisposing them to other factors resulting in mortality. However, Alvo and Parker did not examine the potentially confounding factor of increased mercury exposure affecting loon productivity on acidic breeding lakes. In contrast, Burgess and Meyer (2008) found that, although fish species diversity decreased in acidic Maritime lakes, the biomass of small fish actually increased, confirming that decreased loon productivity on acidic lakes was not due to lower prey abundance. Burgess and Meyer (2008) also found that data from Parker (1988) indicated there was no relationship between lake acidity and prey biomass for 24 Adirondack lakes, including several of our study lakes.

9.6.3 Model for the Long-Term Effect of Mercury on the Adirondack Loon Population

To assess if the mercury body burden was affecting the population growth of Adirondack loons, we incorporated the productivity (CF/TP) of the study birds in three categories of mercury risk (low/moderate, all birds combined, and high/extra-high mercury) into Grear et al.'s (2009) loon population model. A population growth rate (λ) greater than 1.0 generally predicts that current vital rates (i.e., birth and survival rates) are sufficient to support a stable or growing population, but it is important to note the inherent error associated with models of this type. These projections are meant as estimates of overall population growth across many years; high variability within the population could cause yearly population growth to range below 1.0.

Our model results indicated that the portion of the Adirondack Common Loon population exposed to high and extra-high mercury levels has a considerably lower population growth rate (0.05 percent, just high enough for maintenance of a population) than the low mercury group (2.6 percent), suggesting that environmental mercury contamination has indeed affected the growth of a portion of the Adirondack loon population (Figure 8). The overall Adirondack loon population growth rate is estimated at 1.6%, a much lower rate than the 7% annual growth rate calculated in the 1980s (Parker et al. 1986).

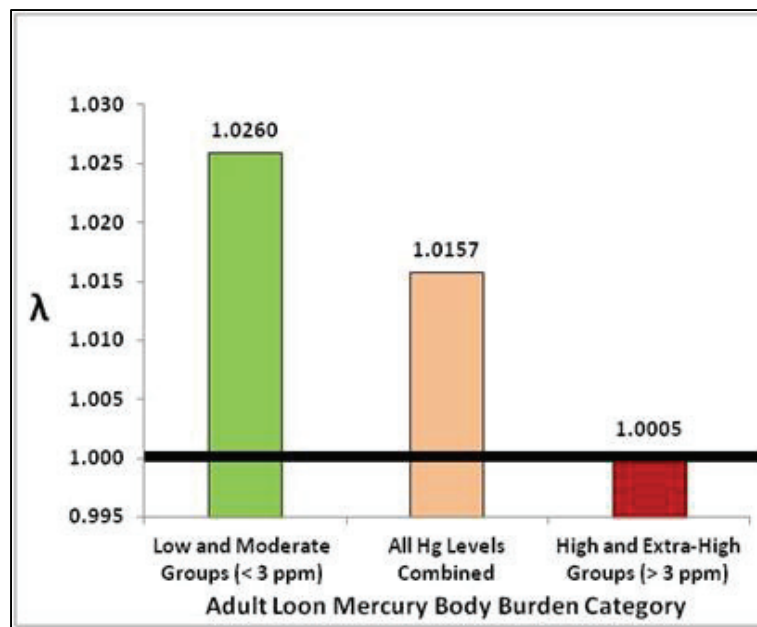


Figure 8. Adirondack adult loon population growth rate by mercury body burden category, based on Grear et al. (2009) loon population model. Black line shows $\lambda = 1.0$, or no change in population size.

The estimated population growth rates for the three mercury risk groups were all above 1.0, indicating that the current birth and survival rates of the Adirondack loon population are likely able to support a stable or increasing population. These results are also supported by numerous anecdotal observations from many Adirondack residents (Schoch, pers. comm.), and preliminary analysis of an annual New York loon count conducted since 2001 (Schoch and Sauer, unpubl. data), indicating a current adult population of 1,500–2,000 birds.

Grear et al.'s (2009) population matrix model indicates that loon breeding populations producing fewer than 0.48 chicks fledged per territorial pair are “population sinks” in which the population is decreasing (Evers et al. 2008). The Adirondack high/extra-high mercury loons are producing 0.483 CF/TP, and thus, are probably acting as a population sink. The remaining Adirondack loon population is likely acting as a “buffer” by filling unoccupied territories and producing enough chicks to maintain, and possibly even expand, the population as a whole.

To assess how the growth rates calculated from the population model would affect the Adirondack loon population over time, we conducted a projection of the adult loon population over 50 years, based on a starting point of 1,000 adult birds (estimated by Parker et al. (1986) from surveys conducted in the 1980s). Our mercury risk models indicated that not all loons in the Adirondack Park are exposed to mercury at levels high enough to affect reproduction, and that between 8% (based on female blood) and 37% (based on adult feathers) of the population is likely to fall within the high or extra high risk categories. Thus, we explored four different scenarios for population growth, starting with a hypothetical population of 1,000 birds, by modeling the effect when different percentages of the population are at risk of mercury impacts (Figure 9). The first scenario (S.1, Hypothetical No Hg Risk) projects the population growth for a hypothetical population with no mercury risk (all loons are in the low and moderate groups). The second scenario (S.2, Current Low Hg Risk) uses the mercury risk ratios for female loon blood in the Adirondack Park, where approximately 8% of the

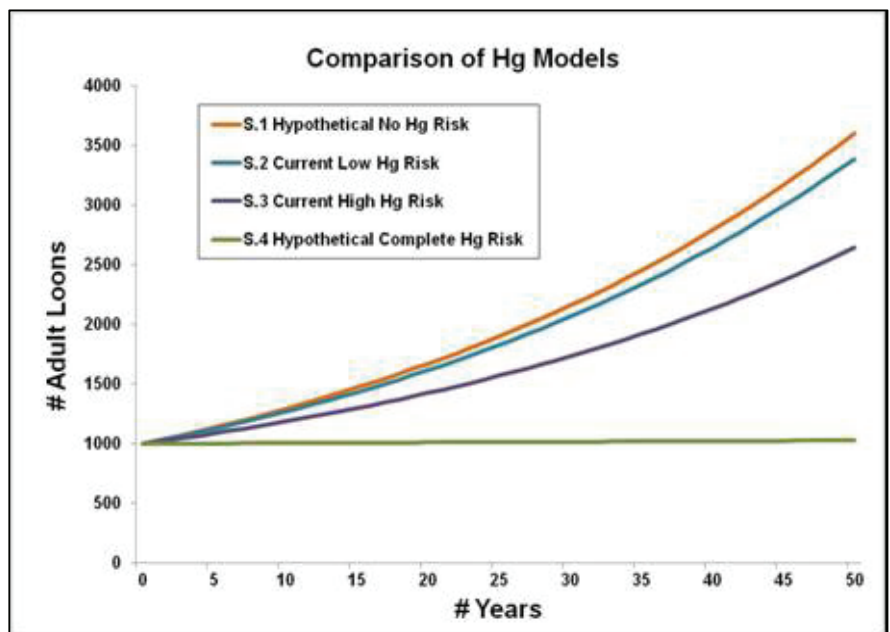


Figure 9. Comparison of overall Adirondack loon population growth in four different scenarios.

population is in the high and extra high risk groups. The third scenario (S.3, Current High Hg Risk) uses the mercury risk ratios for adult loon feather concentrations, in which approximately 37% of the population is at high or extra high risk. The fourth scenario (S.4, Hypothetical Complete Hg Risk) estimates population growth under a worst-case-scenario, where all the loons are in the high and extra-high risk groups.

Our 50-year projected population simulations for the different mercury burden scenarios graphically illustrate how the Adirondack loon population could be affected by mercury contamination. It is important to note that these scenarios represent hypothetical situations in which mercury is the only factor affecting differences in loon productivity and population growth, and do not include the effects of other potential limits to loon populations. In reality, loons experience numerous other stressors (e.g., predation, intraspecific competition, human disturbance, lakeshore development, nest failure, competition for limited breeding habitat, and disease), which can also influence their breeding success and population growth rates. Thus, it is expected that the actual population size over a given time period would be different than the hypothetical modeled size.

For example, some of our models predict a loon population of over 3,000 birds after 50 years, but it is unlikely that enough habitat exists in the Adirondack Park to support a population of this size. We did not set out to measure the carrying capacity of the area, however, so we included these density-independent projections as representations of what differences in the growth rate could mean for the population. A population living in a natural environment can experience yearly disruptions, as well as catastrophic events that limit population growth independent of mercury contamination, and these projections give us an estimate of how well the population would be able to recover from these setbacks. Similarly, we can use these projections to estimate how mercury exposure is likely to limit the growth of loon populations if other limitations or stressors (e.g., disease, human disturbance, and predation) could be removed through restoration or conservation.

The longevity, slow maturation, and low fecundity of this species mean that a population enduring annual and continual impacts from a stressor such as mercury contamination would result in erosion of the affected population over time (Evers et al. 2005b). We assume that the overall Adirondack loon population is equally exposed to other stressors present on the breeding grounds (Evers et al. 2008); thus, the results of our population modeling indicate that the risk imposed by environmental mercury contamination in the Adirondacks to the aquatic food web causes a long-term impact on the population growth and size of the segment of the Common Loon population breeding on acidic lakes in the Park.



~Loons in the Light~ The "Penguin Dance"

An upset loon will do a "penguin dance," which is a territorial defense display. The bird will spurt up out of the water in an upright posture, paddling furiously with its feet, calling with loud tremolos, and making a lot of commotion. The birds likely expend a lot of energy to do this display, as it is not easy for a loon to maintain a vertical position.

Although some people mistake the penguin dance for a mating/courtship behavior, it is actually done when a loon is defending its territory from another loon, a predator, or a boat encroaches into its territory.

10.0 Outcomes of Adirondack Loon Mercury Research

This project contributes to scientific knowledge as well as inspires the public and policy-makers to become more aware of and informed about conservation concerns affecting our environment. Our study provides additional support for the critical need to better regulate mercury emissions on national and local scales to protect biota living in aquatic ecosystems from the impacts of environmental mercury contamination and acid deposition. Our results provide valuable new information that:

1. ***Contributes to documenting the extent of mercury contamination and its effects on New York's aquatic ecosystems*** by increasing scientific understanding of the health and reproductive impacts of mercury pollution to Common Loons, a fish-eating predator at the top of the aquatic food web. Our work in the Adirondacks is also an integral component of BRI's larger regional study to evaluate mercury impacts on the Northeastern loon population as a whole, thus providing an improved assessment of the behavioral and health impacts of mercury exposure to wildlife (Evers et al. 2008).
2. ***Provides evidence for ecological damage to public resources***, based on the relationships between the body burden of mercury in Adirondack loons and the detrimental effect to their reproductive success, potentially resulting in long-term population impacts. Because of their position at the top of the food chain, Common Loons are indicators of the effects of mercury pollution to overall aquatic ecosystem health.
3. ***Establishes a baseline for detecting future changes in biotic impacts from atmospheric mercury deposition***, as stringent new state and regional mercury and acid emission regulations are implemented.
4. ***Provides science-based justification for, and increases public and policy-maker awareness of, the critical need to stringently regulate mercury and acidic emissions on all scales*** to minimize the ecological injury mercury pollution poses to wildlife and the environment.



Policy Implications

The results of this project will assist in the development of state and national policies and regulations, which reflect the ecological injury that mercury and other contaminants pose to freshwater ecosystems.

Long-term studies of biotic mercury levels, particularly those of top predators living in acidic or high mercury habitats, provide much information about the risks mercury and acidic deposition pose to wildlife and aquatic ecosystems. The results of our research are an important biotic component of the proposed Comprehensive National Mercury Monitoring Act (Mason et al., 2005). It is critical to develop such standardized state, regional, and national monitoring networks for both abiotic and biotic mercury contamination to inform federal and state mercury-related policies, provide data for predictive models, and characterize the biological effects in the United States of environmental mercury contamination from anthropogenic sources (Evers et al. 2011). The proposed mercury monitoring program would also ensure that recently implemented New York State and regional regulations, and recently finalized national regulations, are effective at preventing local biological mercury hotspots (Evers et al. 2007) and biotic impacts, such as the observed decreased reproductive success in a portion of the Adirondack Common Loon population.

Because elevated mercury concentrations in aquatic ecosystems are linked to acidic deposition, it is likely that increasingly strict regulations for atmospheric emissions of sulfur dioxide and nitrogen oxides (Driscoll et al. 2007a) will have the co-benefit of reducing biotic mercury levels (Yu et al. 2011). There are indications that the acidity of Adirondack lakes, and potentially elsewhere in North America, has been improving over time as sulfur emissions decrease with the implementation of the 1990 Clean Air Act Amendments, leading to biological recovery in some previously extremely acidic lakes (Driscoll et al. 2003, Driscoll et al. 2007a). In Ontario, Alvo (2009) also found that some very acidic lakes previously incapable of supporting loon reproduction could do so as the pH increased from the mid-1980s through the 1990s.

There are also encouraging indications that biological mercury levels decrease in response to declines in atmospheric deposition of acids and mercury. In northern Wisconsin, Hrabik and Watras (2002) found that fish mercury levels declined in conjunction with decreases in acidic and mercury deposition, and their results suggested that, over short time scales, small changes in acid rain or mercury deposition could affect the bioaccumulation of mercury. The Mercury Experiment to Assess Atmospheric Loading in Canada and the United States manipulated deposition rates of different mercury isotopes in an entire ecosystem and found that biotic mercury levels rapidly increased with mercury deposition on the lake surface, but that new inputs into the surrounding watershed filtered slowly over a long time period into the lake (Harris et al. 2007). The study predicted that initially, mercury concentrations in fish will

rapidly (within years) decrease in response to reduced atmospheric deposition of mercury and in direct relation to the decreased atmospheric input, followed by a more gradual (decades) decline over time with decreasing mercury inputs from the watershed. Additionally, the study concluded that lakes with small watersheds relative to their surface areas will respond most effectively to decreasing mercury deposition.

Our study provides additional evidence, based on the ecological injury mercury poses to wildlife living in freshwater ecosystems, for the need to stringently regulate mercury emissions on national and global scales. Since a primary source of environmental mercury contamination is airborne deposition, which does not recognize local or national boundaries, it is essential to regulate mercury emissions from all sources throughout North America as well as globally.

Strict mercury emission regulations for coal-fired power plants have recently been implemented in the Northeast and New York, which will minimize impacts due to local point sources. The Mercury and Air Toxics Standards Rule, which establishes national regulations for mercury emissions from coal-fired power plants, has recently been finalized, but has yet to be implemented (EPA 2011). The United Nations Environment Programme (UNEP) Global Mercury Partnership is working to protect human and environmental health globally from mercury by minimizing and eventually eliminating mercury releases to the environment due to anthropogenic sources (UNEP 2011), although a comprehensive global mercury pollution policy has not yet been instituted.

Despite new state and regional regulations, New York and the Northeast continue to receive mercury deposition, and Common Loons summering in the Adirondack Park will continue to be affected by mercury pollution until all sources of mercury emissions are greatly reduced or eliminated entirely. We look forward to the day when the unforgettable call of the Common Loon will resonate across the Adirondack Park unhindered by impacts from environmental pollutants such as mercury.

~Loons in the Light~
Loons Take Baths!

Just like most other birds, loons enjoy a good bath. They will roll over completely in the water, splashing and flapping their wings repeatedly. Baths can last for 45 minutes or more. These birds aren't sick...they are merely having a great bath!



11.0 Summary

In this project, we employed the Common Loon as an indicator species to assess the mercury exposure and risk in aquatic ecosystems in New York's Adirondack Park. We used abiotic and biotic mercury levels to characterize aquatic-based mercury and to quantitatively assess the ecological risk that mercury deposition poses to Adirondack freshwater habitats. Using Common Loon mercury levels, we developed a mercury hazard profile, and determined that, in the worst-case scenario, 37% of the Adirondack loon population is at risk of detrimental impacts due to mercury exposure. We showed that loon reproductive success is negatively affected by both increased mercury load and increased lake acidity; and the upper level of loon productivity is likely limited by both. At a population-level, our results indicate that the growth of the Adirondack Park loon population is limited by mercury exposure. Using the Wildlife Criterion Value developed by Nichols et al. (1999), we determined that a water mercury value of 2.00 ng/L and of 1.693 ng/L would protect male and female Adirondack Common Loons, respectively, from having a mercury body burden that would impair reproduction and/or alter behavior. This information is invaluable for policy makers seeking to make informed decisions about regulating environmental mercury contamination.

In summary, the results of our study indicate that:

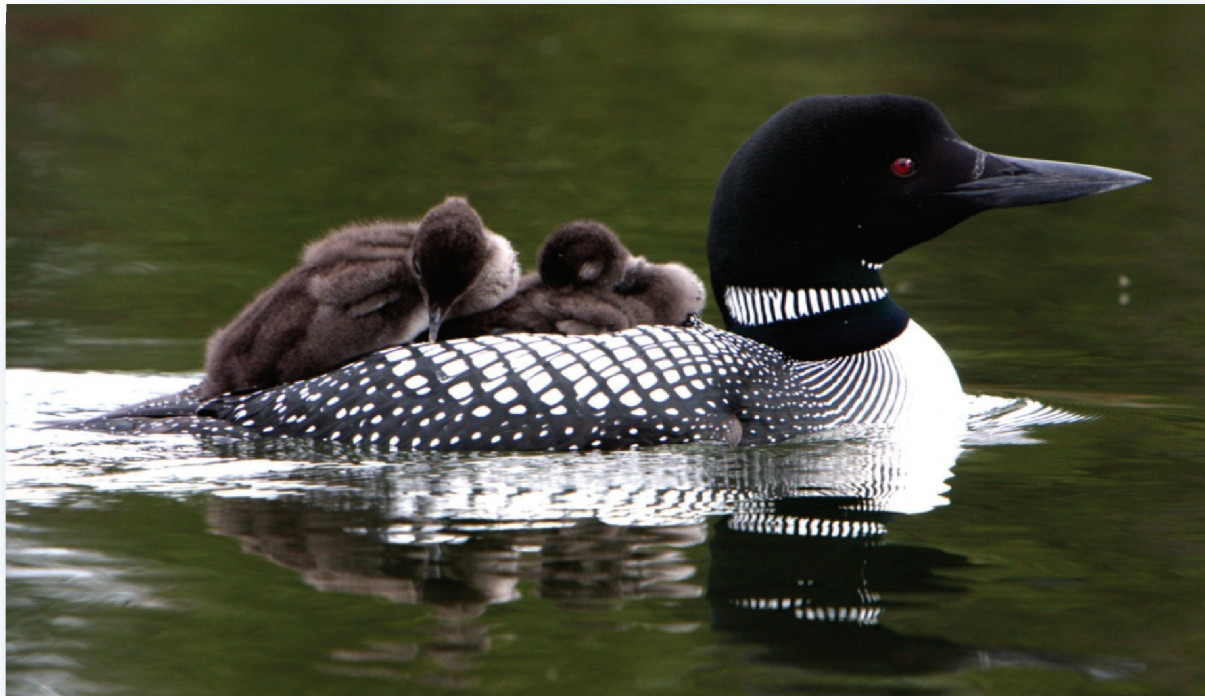
1. Mercury appears to be a primary anthropogenic stressor for the Adirondack Common Loon population, resulting in decreased productivity.
2. Increased mercury exposure of loons breeding on acidic lakes impairs their productivity.
3. The Adirondack loon population is apparently increasing, although at a much lower rate than the 7 % annual growth rate calculated in an Adirondack loon population survey conducted in the 1980s.
4. The risk imposed by mercury bioavailability in Adirondack aquatic ecosystems to predators at the top of the food web causes a long-term impact on the population growth and size of the segment of the Adirondack loon population breeding on acidic lakes in the Park.

Our results provide valuable new information that:

1. Contributes to documenting the extent of mercury contamination and its impacts to New York's aquatic ecosystems.
2. Provides evidence for ecological damage to public resources.

3. Establishes a baseline for detecting future changes in biotic impacts from atmospheric mercury deposition.
4. Provides science-based justification for policy-makers to stringently regulate mercury and acidic emissions on local, national and global scales.

Our study underscores the critical need to better regulate mercury emissions at local, national, and global levels to protect biota living in aquatic ecosystems from the impacts of environmental mercury contamination. Our research provides key scientific information for policy makers to make sound decisions about essential environmental protections, including monitoring and regulating emissions of anthropogenic pollutants, based on the health and reproductive impacts to the Common Loon, an iconic symbol of freshwater ecosystems in North America and New York's Adirondack Park.



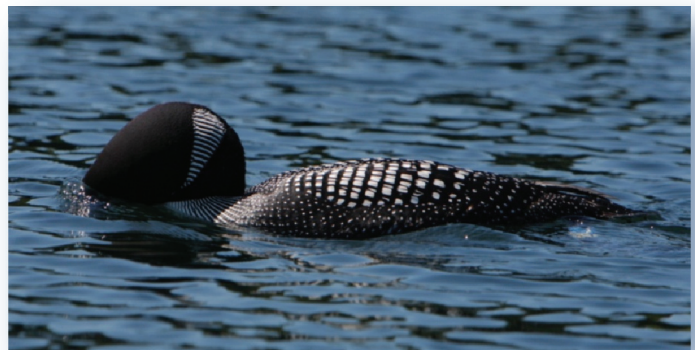
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Appendix A: Supplemental Loon Natural History Literature

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Appendix B: Supplemental Mercury and Acid Deposition Literature

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~Loons in the Light~
Male or Female Loon?

Superficially, male and female loons look alike. A few subtle cues can help tell males from females:

1. Males are larger than females; in the Adirondacks, males can weigh up to 14 pounds while females average 8 to 10 pounds.
2. Females lay eggs.
3. Males yodel, the territorial defense call, while females do not.

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Appendix C: Resources for Loon Monitoring and Research Organizations*

BioDiversity Research Institute

19 Flaggy Meadows Rd.
Gorham, ME 04038
(207) 839-7600
www.briloon.org

BRI's Adirondack Center for Loon Conservation

P.O. Box 195, Ray Brook, NY 12977
(888) 749-5666 x 145
www.briloon.org/adkloon

Canadian Lakes Loon Survey Bird Studies Canada

P.O. Box 160, Port Rowan, Ontario
Canada, N0E 1M0
(888) 448-2473
www.bsc-eoc.org/cllsmain.html

The Maine Loon Protection Project Maine Audubon Society

20 Gilsland Farm Road
Falmouth, ME 04105
(207) 781-2330
www.maineaudubon.org/consERVE/loon

Loon Lake Loon Association

P.O. Box 75, Loon Lake, WA 99148
(509) 233-2145
www.loons.org

Loon Preservation Committee

Audubon Society of New Hampshire
P.O. Box 604, Moultonborough, NH 03254
(603) 476-5666
www.loon.org

Loon Watch, Sigurd Olson Environmental Institute

Northland College, Ashland, WI 54806
(715) 682-1220
www.northland.edu/sigurd-olson-environmental-
institute-loon-watch.htm

Massachusetts Division of Fish and Wildlife, Natural Heritage & Endangered Species Program

One Rabbit Hill Rd., Westboro, MA 01581
(508) 389-6300
www.mass.gov/dfwele/dfw/nhESP/nhESP.htm

Michigan Loon Preservation Association

10181 Sheridan Rd.
Millington, MI 48746
www.michiganloons.org

Minnesota Loon Monitoring Program

500 Lafayette Road
St. Paul, MN 55155
888-646-6367
www.dnr.state.mn.us/eco/nongame/projects/ml
mp_state.html

Montana Loon Society

P.O. Box 1131
Seeley Lake, MT 59868
www.montanaloons.org

USFWS Migratory Bird Mgmt.

1011 E. Tudor Rd. MS 201
Anchorage, AK 99503
(907) 786-3517
http://alaska.fws.gov/mbSP/mbm/loons/loons.htm

USGS Upper Midwest Environmental Sciences Center – Loon Migration

2630 Fanta Reed Road
La Crosse, Wisconsin 54603
(608) 783-6451
www.umesc.usgs.gov/terrestrial/migratory_birds
/loons/migrations.html

Vermont Loon Recovery Project Vermont Center for Ecostudies

PO Box 22, Craftsbury, VT 05826
(802) 586-8064
www.vtecostudies.org/loons

*Information for Appendix C is adapted from: Schoch, Nina. 2002. *The Common Loon in the Adirondack Park: An Overview of Loon Natural History and Current Research*. WCS Working Paper No. 20.



Biodiversity Research Institute (BRI) is a 501(c)3 nonprofit organization located in Gorham, Maine. Founded in 1998, BRI is dedicated toward supporting global health through collaborative ecological research, assessment of ecosystem health, improving environmental awareness, and informing science based decision making. BRI's Adirondack Center for Loon Conservation is dedicated to improving the overall health of the environment, particularly the protection of air and water quality, through collaborative research and education efforts focusing on the natural history of the Common Loon and conservation issues affecting loon populations and their aquatic habitats.

To learn more about BRI and its Adirondack Center for Loon Conservation, visit www.briloon.org or www.briloon.org/adkloon

Biodiversity Research Institute	toll free: 1 (888) 749-5666 local: (207) 839-5666 fax: (207) 887-7164
652 Main Street Gorham, ME 04038	bri@briloon.org www.briloon.org

The Wildlife Conservation Society (WCS) saves wildlife and wild places worldwide through science, global conservation, education and the management of the world's largest system of urban wildlife parks, led by the flagship Bronx Zoo. WCS' Adirondack Program conservation efforts in New York's Adirondack Park take an interdisciplinary approach, linking wildlife, wilderness, and human well-being, through applied science and community-based conservation.

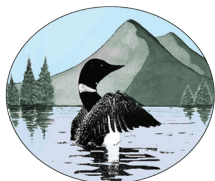
To learn more about WCS' Adirondack Program, visit www.wcsadirondacks.org

Wildlife Conservation Society (WCS) Adirondack Program	local: (518) 891-8872 fax: (518) 891-8875
7 Brandy Brook Ave #204 Saranac Lake, NY 12983	accp@wcs.org www.wcsadirondacks.org

New York State Energy Research and Development Authority (NYSERDA), a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise and funding to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce their reliance on fossil fuels. NYSERDA professionals work to protect our environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York since 1975.

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17 Columbia Circle Albany, New York 12203-6399	info@nyserda.ny.gov www.nyserda.ny.gov



BRI'S ADIRONDACK CENTER
FOR LOON CONSERVATION



Adirondack Loons— Sentinels of Mercury Pollution in New York's Aquatic Ecosystems

Final Report
February 2012

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