
Assessing the potential impacts of methylmercury on the Common Loon in southern New Hampshire

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Executive Summary

The atmospheric deposition of mercury on New Hampshire's landscape impacts wildlife. The information presented in this report describes impacts on the Common Loon and its unusually high risk to mercury (Hg) in southern New Hampshire.

Past models generated by the U.S. Environmental Protection Agency predict particularly high levels of Hg deposition in the southern part of New Hampshire. Beginning in 1994, a collaborative effort by members of the Northeast Loon Study Working Group, including BioDiversity Research Institute, the Loon Preservation Committee, and the U.S. Fish and Wildlife Service responded to the model-generated outputs by non-lethally collecting eggs from abandoned nests and blood samples from live loons.

Between 1994 and 2000, 375 egg and adult blood samples were collected in New Hampshire, including 266 samples south of the White Mountains. These samples represent 65 loon territories and 47 southern New Hampshire lakes. Laboratory analysis shows that statewide mean Hg levels in New Hampshire eggs and blood are some of the highest in the nation. Although mean egg and blood Hg levels between northern and southern New Hampshire were not significantly different, those levels from nine loon territories on six lakes in southeastern New Hampshire were significantly higher than other regions of the state.

A risk assessment for New Hampshire's breeding loons indicates at least 19% of the population (i.e., individuals higher than the lowest observed adverse effect level) is at risk to physiological, behavioral, or reproductive impact. Loon individuals at risk to high Hg levels have been shown to produce 37% fewer fledged young. Consistent with how environmental Hg levels vary according to hydrological and biogeochemical factors, loon territories at high risk are found throughout New Hampshire. However, a grouping of loon territories at high risk in southeastern New Hampshire indicates greater than average methylmercury bioavailability. Two of these lakes, Swain's and Mendums, have loon egg and blood Hg levels higher than any other egg or breeding loon in the United States (based on 571 egg and 2,279 blood samples). This translates to a risk for southern New Hampshire populations of at least 32%, while in the southeastern study area the risk is 89%.

Based on the 266 southern New Hampshire samples, ArcView 8.1 spatial analyst extension was used to model the potential extent of Hg risk to loons and relate the distribution of this exposure to major sources of Hg emissions in southern New Hampshire. Results from this coarse approach agree with earlier U.S. Environmental Protection Agency predictions and current weight of evidence strongly indicates that local, major emission sources in southern New Hampshire are related to high Hg levels in loons and are thereby enhancing Hg bioavailability in some areas of south-central and southeastern New Hampshire, as well as southern Maine. Further sampling efforts will provide higher resolution data, and ongoing efforts to link the relationship of Hg to population level impacts will provide the information needed to monetize the overall injury to loons and potentially other wildlife.



Introduction

The elevated levels of mercury (Hg) in the Northeast are well known. U.S. Environmental Protection Agency (USEPA) models predict Hg deposition in this area to be the highest in the country (NESCAUM 1998). Recently, biotic validation of these models has been established with the Common Loon (*Gavia immer*) (Evers et al. 1998a). The results from various state and federally funded programs, including the USEPA's Regional Environmental Monitoring and Assessment Program (REMAP) study continue to emphasize this serious environmental problem and now provide a better understanding of the distribution of methylmercury (MeHg) bioavailability and relationships within this landscape's hydrology and aquatic biogeochemistry. Compilations of fish Hg data convincingly show human health advisories for fish consumption are warranted (NESCAUM 1998). Current research on the ecological health and integrity of freshwater aquatic environments also show population level impacts of some species of piscivorous wildlife, such as the Common Loon (Evers et al. 2001).

Emphasis from policy makers and researchers has been on higher trophic level piscivorous wildlife since they are most at risk due to mercury's ability to bioaccumulate and biomagnify (Scheuhammer 1991, Thompson 1996). This interest has facilitated new initiatives by the USEPA-Office of Research and Development's NHEERL program, U.S. Department of Agriculture's Northeastern Ecosystem Research Cooperative, and the Maine Department of Environmental Protection to investigate stressors (such as Hg) using a focal species (such as the loon) to provide geographically relevant empirical information for science-based policy.

Using Birds as Bioindicators of MeHg Availability

The use of piscivorous birds as indicators of MeHg availability is common (e.g., Thompson 1996, Evers et al. 1998a,b, Wolfe et al. 1998, Wolfe and Norman 1998). Piscivorous birds are also useful as general ecological indicators of aquatic ecosystem integrity and of the presence and effects of environmental stressors.

Mercury deposition and MeHg availability is now sufficiently elevated in the Northeast region to cause impacts on wildlife (Welch 1994, Burgess et al. 1998, Nocera and Taylor 1998, Evers et al. 2001). Based on the USEPA probability-based sampling efforts in the USEPA's Region 1 and 2, Yearley et al. (1998) predicted that 98% of New England's lakes contained fish with MeHg levels exceeding critical values for piscivorous birds. In corroboration, Evers et al. (1998a) found Common Loons breeding in New England had the highest mean blood Hg levels in the United States, while juvenile loon blood Hg levels were four times those of the designated reference site in Alaska. Further studies on a suite of five piscivorous birds in Maine indicated over 70% of lakes have the capacity to produce MeHg at levels above designated risk categories (Evers et al. 1998b). These studies demonstrate that extensive Hg contamination and MeHg availability exists in New England.

Yearley et al. (1998) found from analyzing 11 metals in fish throughout the U.S. that, "MeHg was determined to be the elemental contaminant of regional concern to fish consumers." This study therefore focused on assessing the ecological risk of Hg to a piscivorous bird—the Common Loon. The loon selected as a bioindicator because of the vast literature available on its demographics (e.g., Piper et al. 1997a, b, Evers et al. 2000, Evers 2001), behavioral ecology (e.g., Evers 1994, Gostomski and Evers 1998, Nocera and Taylor 1998, Paruk 1999), feeding biology



(Barr 1996), toxicology (e.g., Evers et al. 1998a, b, Meyer et al. 1998, Scheuhammer et al. 1998a, b), and local breeding population status (Taylor and Vogel 2000, Evers et al. 2001).

Mercury Risk to Loons

A state-by-state analysis shows an estimated 10-30% of the New England Common Loon breeding population has Hg levels that exceed wildlife safety thresholds designated by other studies (e.g., Barr 1986, Scheuhammer 1991, Thompson 1996, Burgess et al. 1998, Meyer et al. 1998, Evers et al. 2001). In New Hampshire, at least 19% of the breeding loon population is at risk to physiological, behavioral, or reproductive impacts from Hg (Evers et al. 2001). Additionally, over 60% of abandoned loon eggs collected in New England (n=305) have Hg levels considered elevated (i.e., 0.5 ppm) by laboratory studies (Fimreite 1971, Heinz 1979) and 5% have lethal levels (i.e., 2.0 ppm) (Thompson 1996).

Because of the loon's limited ability to disperse and colonize (Evers 2001), recruitment into areas that are impacted by local stressors can take time. This demographic character combined with lowed reproductive output contributes to models predicting likely population-level impacts (Evers et al. 2001). This study was initiated to determine the extent of actual exposure and impacts on breeding loons in southern New Hampshire lakes and eventually will provide the foundation for determining spatially-explicit projections of population-level impacts.

Methods

Collecting and handling samples for toxicological analysis:

Blood was drawn from the metatarsal vein through a leur adapter directly into 5-10 cc vacutainers with sodium heparin (green tops) and placed immediately on ice in a cooler. Vacutainers were opened once, 10-14 hours later, to add 10% buffered formalin (1:20 formalin-blood ratio) using USFWS protocols (Stafford and Stickel 1981, Wiemeyer et al. 1984). Each time, formalin was drawn from a sealed container with a new one cc syringe with a measurement precision of 0.02 cc. The vacutainer with blood preserved with formalin was then placed in a refrigerator and not opened until reaching the lab. Whole blood from samples less than one cc was immediately frozen and vacutainers not opened until analysis. Feathers were clipped at the calamus and placed in a polyethylene bag. Methylmercury is locked in the keratin proteins in the feather and is not subject to degradation (Thompson 1996). Feathers were clipped again at a standard location at the the superior umbilicus and cleaned in the lab to remove external contaminants.

When possible, biologists from the Loon Preservation Committee and BioDiversity Research Institute collected whole eggs from nests that had been abandoned, predated or flooded. Eggs were only removed from a site when the adults were no longer incubating them, or when they were determined inviable (i.e., strong odor, or indications that eggs were not turned). Eggs were placed in a polyethylene bag and labeled with lake and territory name, date, and collector while in the field. Eggs were then frozen as soon as possible. Later, eggs were measured for length, weight, and volume. Egg volume was measured by water displacement and weighed on an electronic balance to the nearest 0.01g. Egg weight was also measured to the nearest 0.01g. The egg length and width were measured with calipers to the nearest 0.01 mm. Eggs were cut open with a scalpel and the contents were placed into sterile I-Chem® jars (including as much of the egg membrane as possible). The contents were then categorized into one of the developmental stages.



All samples were labeled in the field within a standard protocol including date, species, age, sex, band or identification number, lake and specific locale, and state. In the field lab, samples were listed on a form and another label was made based on the field form, compared with the field label, and added to the sample (therefore all samples were double labeled). A catalog was developed in the field and a proofed copy accompanied the samples when sent to the analytical lab and again were proofed before preparation for analysis-creating a secure chain of custody of samples.

Analytical methods for blood and feather follow those of Evers et al. (1998a) and meet requirements used by the United States Fish and Wildlife Service and USEPA. All blood and feather samples were analyzed using cold-vapor atomic absorption (CVAA) spectroscopy at the University of Pennsylvania's toxicology lab and for eggs at Texas A&M University Trace Element Research Lab. Analysis of bird blood, feather, and eggs was for total Hg because MeHg comprises 95% or more of the total Hg (Thompson 1996, BRI Unpubl. data). Preparation and analysis of egg contents and fish for Hg concentrations were similar to those used for blood homogenizing and digestion. All eggs were adjusted for moisture loss by dividing the total egg weight by the egg volume (Stickel et al. 1973).

Analyzer Performance evaluation:

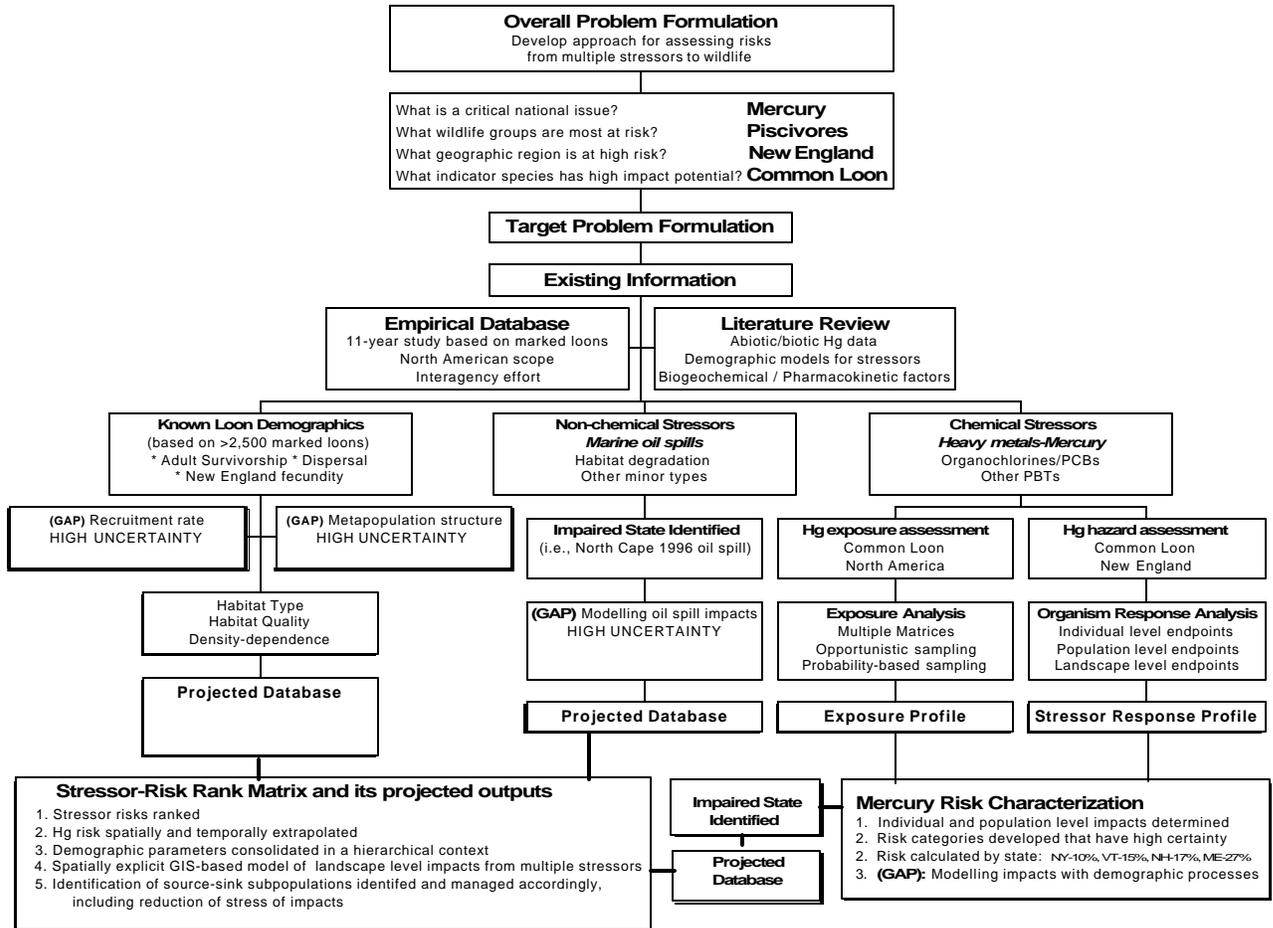
Analysis of loon egg, blood, and feather tissues was conducted at the Texas A&M University Trace Element Research Lab, College Station, Texas and at the University of Pennsylvania's Animal Health Diagnostics Laboratory, New Bolton, Pennsylvania. Instrument performance was evaluated through use of control charts. Analytical precision of total mercury was calculated as the RSD for three or more replicate analyses. The precision objective was $\pm 10\%$ for total mercury. Accuracy for total mercury was assessed by recovery of matrix spikes and standard reference materials (DORM 2, NRC, Canada). The accuracy objective was $100 \pm 10\%$ for spikes that are at least 10x the unspiked sample concentration. Data quality indicators were calculated as described in "Preparing Perfect Project Plans", EPA/600/9-89/087, October 1989. For mercury analyses, 10% of samples were split into laboratory duplicates. Random field blanks were included in each analytical run. During each day's operation, at least 5% of the samples analyzed were distilled water blanks, matrix spikes, or known standards. The analytical detection limit for total mercury in whole blood, feathers and eggs was 25 ppb. Instrument performance was permanently recorded in instrument log books, which include a control chart for tracking instrument performance.

Results and Discussions

The overarching goal of this long-term, international ecological risk assessment is designed to (1) assemble the wealth of existing toxicological and demographic information into an integrated format, (2) fill in data gaps identified through demographic models and evaluation of current inadequate sample sizes, (3) improve resolution of spatially-explicit toxicological and demographic information through analysis of genetic population structure of the Northeast metapopulation, and (4) organize the existing and newly collected databases into a stressor-risk rank matrix that will provide a basis for spatially-explicit models of landscape level impacts from critical environmental stressors such as MeHg availability and marine oil spills (Figure 1).



Figure 1. Conceptual framework for overall bioassessment model of multiple stressors of the Common Loon.

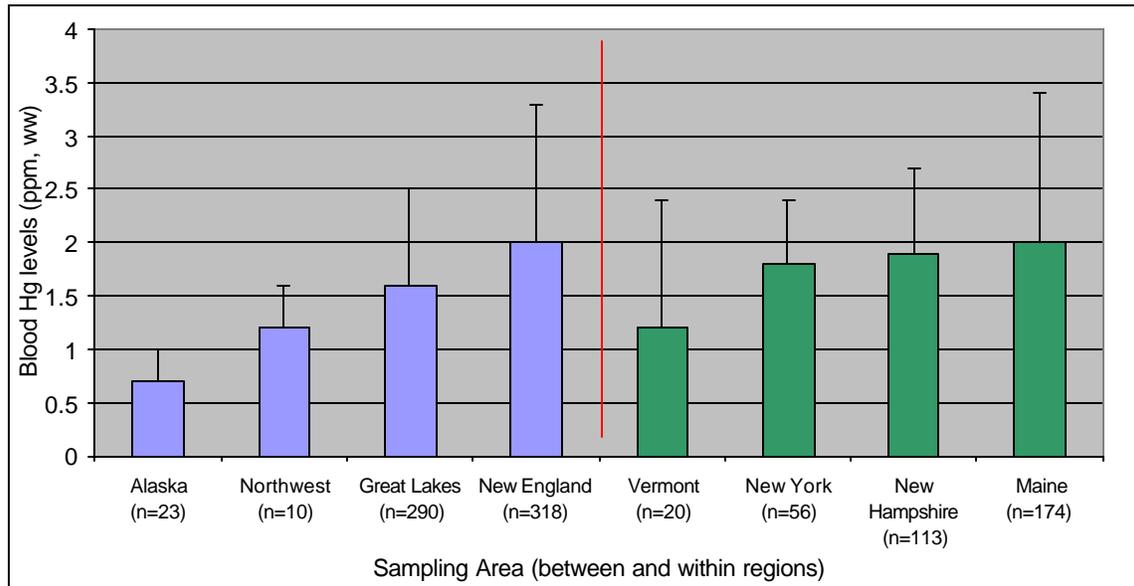


1. National Context for Loon Hg Levels

In recognition of widespread environmental contaminants, the USEPA uses the Environmental Monitoring and Assessment Program (EMAP) as a long-term tool for monitoring and assessing ecological condition (e.g., effectiveness of the Clean Air Act). The monitoring of surface waters using EMAP's probability-based surveys for ecological indicators provides a statistically valid technique for making regional and eventually national extrapolations of the exposure and effects of various environmental stressors (e.g., Whittier et al. 1997, Yeardley et al. 1998). The complementary regional program, REMAP, has also proven effective in this same regard (e.g., Stafford and Haines 1997, Mower et al. 1997, N. Kamman, pers. com.). EMAP and REMAP efforts within New England and elsewhere are designed to provide a method for evaluating and prioritizing the threat of environmental stressors to lacustrine habitats. One issue that has surfaced from these studies is the widespread and elevated levels of Hg in sediments, water column, fish tissue, and piscivorous wildlife.



Figure 2. Mercury levels measured in loon blood in four U.S. regions and within four New England states, 1991-2000.



Although the sampling of loons and other biota from 1992-2001 indicates geographic differences in MeHg availability has a west to east trend across North America, with New England having the highest levels (Figure 2) (Evers et al. 1998a), within-region differences are primarily related to hydrological and biogeochemical factors (Evers and Reaman 1998, Evers et al. 2001). Within-region loon blood Hg levels appears to be similar in Maine, New Hampshire, and New York and tend to be lower in Vermont. Particularly high levels of MeHg bioavailability are in the western Adirondack Mountains of New York, in southeastern New Hampshire, and in several areas of Maine (Figure 3). Because of these factors and potential point sources, a geographic risk assessment using EMAP/REMAP protocols needs to incorporate and characterize sampling areas in a probability-based strategy.

2. Description of established risk categories

Samples collected from lakes in other New England states, the Great Lakes region, and the Canadian Maritimes, were used in regional comparisons and for measuring Hg effect endpoints. Loon territories were categorized on single and multi-territorial lakes according to known exposure to MeHg (indicated by blood or eggs). The four risk categories were based on literature and *in situ* studies by the author and his collaborators (Table 1). Low risk indicates background Hg levels that have no known impact on wildlife. Loon territories that are in the moderate risk category have elevated MeHg levels but their impact levels on individuals remains unknown. Loons that are in the high-risk category are exposed to toxic levels of environmental Hg that statistically show physiological, behavioral, and reproductive impacts. The extra high Hg category is based on in-field observable impacts on loons and other birds.



Table 1. Risk categories for Hg (ppm) availability in the Common Loon.

Matrix	Type ⁴	Low	Moderate	High	X High	Reference Base
Egg	ww	0-0.5	0.5-1.0	1.0-2.0	>2.0	Barr 1986
Blood-Adult	ww	0-1.0	1.0-3.0	3.0-4.0	>4.0	BRI ¹ , inferred by Barr 1986 ²
Blood-Juv.	ww	0-0.1	0.1-0.3	0.3-0.4	>0.4	Meyer et al. 1998 ³
Feather	fw	0-9	9-20	20-35	>35	Thompson 1996, BRI ¹
Prey Fish	ww	0-0.1	0.1-0.3	0.3-0.4	>0.4	Barr 1986, Evers & Reaman 1998

¹ BRI refers to unpublished data by BioDiversity Research Institute

² Adult blood Hg levels are generally 10x higher than prey Hg levels (Evers and Reaman 1998) and Barr 1986 found lower reproduction of loons with prey Hg levels of 0.3 ppm and no reproduction at 0.4 ppm.

³ Applies to 3-5 week-old juveniles, only.

⁴ Matrix numbers refer to wet weight (ww) and fresh weight (fw).

3. Common Loon Risk Profile

The following exposure assessment is partly based on risk categories from literature reviews (Table 1) but primarily follows Evers et al. (2001) hazard assessment. There is high confidence in adult blood categories based on findings with corticosterone levels and their step-wise and significant relationship with blood Hg levels. Adult and juvenile blood Hg categories also agreed with associated prey fish Hg levels and compared well to levels found in study areas by Barr (1986) and Meyer et al. (1998). Feather and egg Hg categories are based on extensive literature reviews summarized by Thompson (1996).

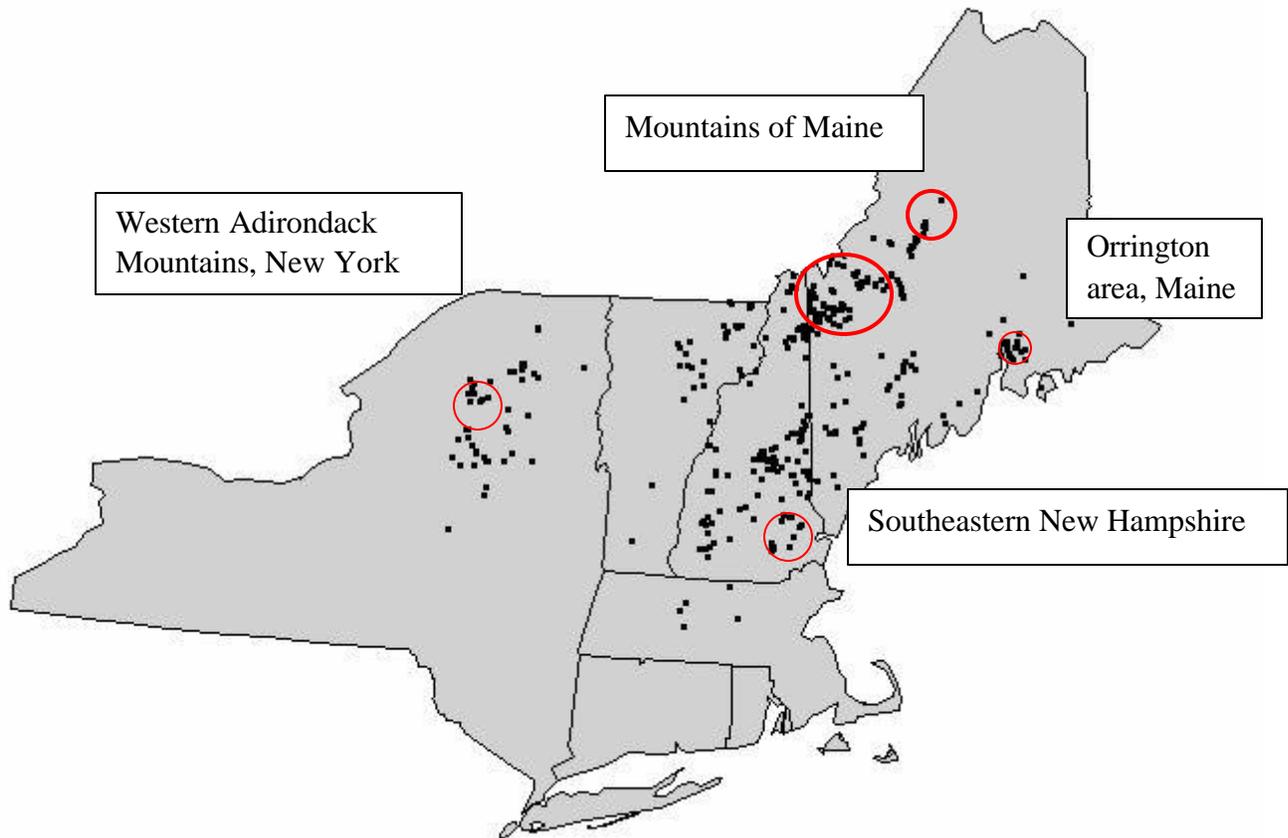
While this “bright line” or point estimate approach to risk does not integrate the actual mechanisms of how Hg impacts wildlife, they do provide an initial approach to understanding the extent of risk. The category limitations should be viewed as mean levels of potential impact. For now, the upper limit of the low risk category is the no observed adverse effect level (NOAEL) and the lower limit of the high risk category is the lowest observed adverse effect level (LOAEL). Future analysis will incorporate more statistically robust approaches that investigate the probability of the risk to the target population (i.e., Rumbold et al. 1999, Sample and Suter 1999).

In New England states, adult male loons (36%) have greater risks to MeHg availability in their prey than female loons (19%). Other geographic areas outside New England also have significant differences between gender Hg levels (Evers et al. 1998a). Male loons are at greater risk than females because of their tendency to eat larger fish with higher levels of Hg and the female’s ability to depurate some of her Hg body burden through eggs.

According to risk levels set by several studies on loons and other species, nearly 60% of the eggs laid by New Hampshire loons are at high risk to Hg toxicity. Although some species of birds can apparently tolerate much higher levels of Hg in the eggs without impact (e.g., Herring Gull, *Larus argentatus*) (Vemeer et al. 1973), the loon is likely far more sensitive to Hg levels in its eggs. The extra high risk category of greater than two ppm is widely accepted as showing high mortality in many bird species (Thompson 1996). The high-risk category is based on Barr (1986). He found eggs were not hatching when they exceeded one ppm. Other bird species are known to be impacted at egg Hg levels of 0.5 ppm (Thompson 1996).



Figure 3. Distribution of MeHg bioavailability in New England based on loon blood Hg levels with hotspots identified by red circles.

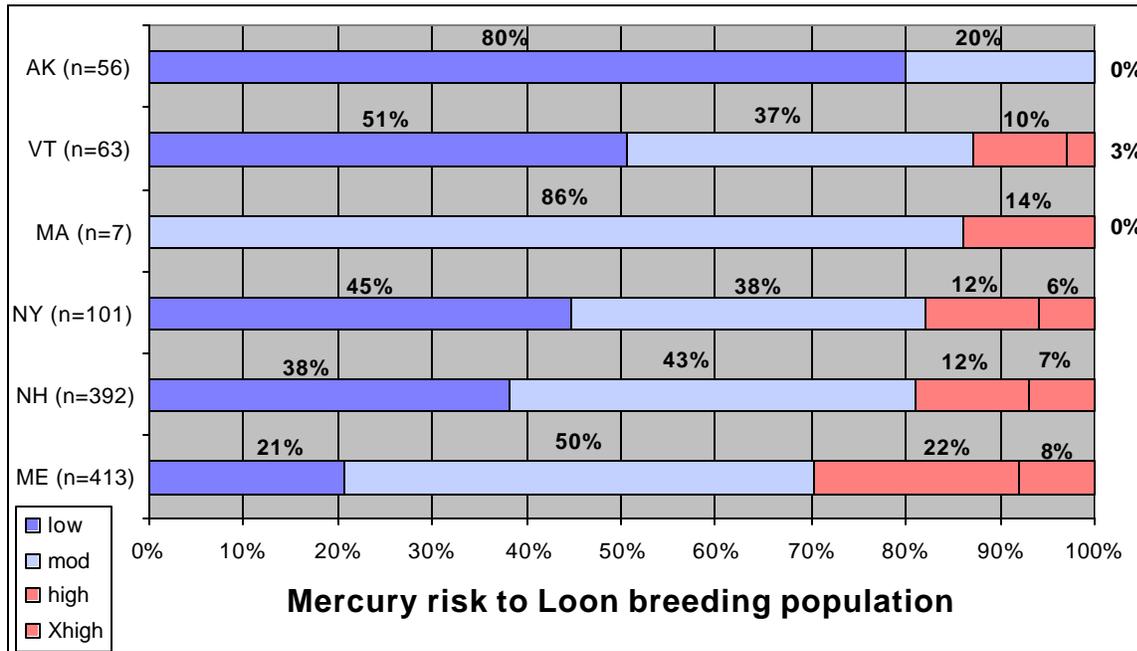


The cumulative risk level of Hg for loons is based on the premise that individual impacts of Hg can be determined through blood and egg measurements (Figure 4). The combination of these two matrices provides a comprehensive picture of Hg exposure that can be related to the breeding lakes. The few eggs laid by females that had blood drawn were not included here to avoid statistical problems of repeated measures. Egg Hg levels do correlate with female blood Hg levels and are therefore representative measures of the MeHg bioavailability on the breeding lake. Repetitive measures of blood Hg levels for individuals were averaged to provide one value. Feather Hg levels were not included in the cumulative risk assessment.

Loons in the extra high and high risk categories show a decline in their reproductive success of 37%. A model showing how this impacts loons at the population level is being developed in collaboration with the USEPA-Office of Research and Development in Narragansett, Rhode Island to determine how the risk of Hg impacts New Hampshire's breeding loon population. Using stage-classified matrix models, a deterministic model (Caswell 2001) will be developed to better understand the impacts of stressors such as Hg on the loon's breeding population.



Figure 4. Distribution of the cumulative risks of Hg impacts for the Common Loon in two matrices (adult and juvenile blood and egg) in New England, New York, and Alaska, 1994-00.



4. Hg exposure and risk for breeding Common Loons in New Hampshire

Until REMAP-based data that were gathered between 1998-2001 can be analyzed, I have used an iterative, opportunistic sampling approach for the past eight years. Biologists from BioDiversity Research Institute and the Loon Preservation Committee collected 251 abandoned eggs and 124 adult blood samples across New Hampshire from 1993 to 2000. From this effort, 266 egg and blood samples collected from southern New Hampshire were analyzed representing 65 territories on 47 lakes (Appendix 1). Sampling efforts in 2001 further contribute toward greater sample sizes and confidence. These samples are yet to be analyzed, however the 21 samples from 2001 collections will add 11 new territories on 7 new lakes.

Mean egg and blood Hg levels for southern New Hampshire (south of the White Mountains) were not significantly different than the northern part of the state ($p > 0.05$). This is not surprising, because the Hg bioavailability to aquatic wildlife is generally more related to the hydrological and biogeochemical factors of the particular lake rather than varying levels of atmospherically deposited Hg. However, an important distinction is the amount of atmospherically deposited Hg related to local versus long-range transport from regional or global sources (i.e., hotspots happen).

Six lakes with loon territories were targeted in the area that USEPA models indicated as high Hg deposition. Those lakes include Ayers, Massabesic, Mendums, Pawtuckaway, Swain's and Tower Hill (Onway Lake was sampled in 2001). The mean blood Hg level for males was 5.32 ± 2.32 ($n=6$) and for females was 3.65 ± 2.48 ($n=7$) (Table 1). These levels are significantly higher than mean levels for southern New Hampshire ($p < 0.01$) and statewide ($p < 0.01$). In particular, two lakes repeatedly contained loon egg and blood Hg levels (i.e., multiple years of sampling) that were higher than any other egg or loon in the United States ($n=571$ eggs, $n=2,279$ blood samples).



The mercury exposure found in New Hampshire loons was linked with established risk levels (Table 2). A cumulative assessment of New Hampshire's breeding loon population shows that at least 19% of the breeding population is at high risk to Hg poisoning by impacting overall reproductive success, behavior, and survival (Figure 4). The risk for breeding loons in southern New Hampshire is at least 32%, while in the southeastern study area the risk is 89%.

Table 2. Mercury levels in Common Loon egg and blood (mean +/- standard deviation) for New Hampshire, 1993-2000.

Matrix	Statewide Mean +/- sd	Southern NH Mean +/- sd	Southeastern NH Mean +/- sd
Abandoned Egg (Sample size: # eggs, # territories)	0.66 +/- 0.47 (n=251, 122)	0.67 +/- 0.51 (n=194, 93)	1.83 +/- 0.94 (n=17, 6)
Adult Male Blood (Sample size: # blood samples, # territories)	2.11 +/- 1.40 (n=69, 64)	2.24 +/- 1.78 (n=38, 37)	5.32 +/- 2.32 (n=6, 6)
Adult Female Blood (Sample size: # blood samples, # territories)	1.64 +/- 1.46 (n=55, 55)	2.01 +/- 1.73 (n=34, 34)	3.65 +/- 2.48 (n=7, 7)

5. How do southern New Hampshire loon Hg levels relate to local emissions?

Within the area of concern (see Appendix 2), there are five major emission sources in the southern New Hampshire area; they include two municipal waste combustors, a coal-fired power plant, and two medical waste incinerators. Other major sources are known in northeastern Massachusetts and elsewhere and their influence on southern New Hampshire is critical for fully understanding the Hg deposition fluxes of the region and their contribution when related to the long-range transport of Hg.

Because the amount of atmospherically deposited Hg is a sufficient source to create a risk to wildlife throughout New England, the factors that amplify this risk are crucial to understand. Evers and Reaman (1998) list and describe these factors as they relate to aquatic wildlife. Some of the more important factors are dissolved organic carbon levels, acid neutralizing capacity, shoreline and watershed wetland and coniferous vegetation acreage, and summer fluctuating water levels.

How these factors contribute to the higher risk of Hg to loons in southern New Hampshire, and particularly southeastern New Hampshire, are unknown and remain to be quantified. Needed is an exhaustive relational analysis of regional Hg emissions that incorporates variables related to emissions (e.g., forms of Hg), dispersal patterns, the aforementioned hydrology and biogeochemical factors, and Hg bioavailability. However, current weight of evidence strongly indicates that local major emission sources in southern New Hampshire are related to breeding Common Loon Hg levels and are thereby enhancing Hg bioavailability in some areas of south-central and southeastern New Hampshire (Appendix 2), as well as southern Maine. This relationship and the associated model, created by the Environmental Systems Research Institute's ArcView 8.1 spatial analyst extension, will increase in resolution as more data are collected and integrated into this analysis.



6. Can potential injuries to loons be monetized?

Should an acceptable link be made between local Hg emissions and loon risks, this injury can be monetized. Precedent-setting mitigation of >4,000 loon-years loss from a Rhode Island oil spill now provides a means for repairing degraded ecosystems (NOAA 1999). This is possible because of the (1) exhaustive information on Hg exposure and impacts for the loon across North America, (2) local, 25-year standardized database on their productivity, (3) well known demographics for the loon that are based on color-marked individuals, and (4) current investigations into modeling population dynamics.

Recommendations

The results from this study and future work will enable governmental agencies to meet potential strategy goals by (1) documenting the extent of Hg contamination to the state's lakes, (2) using as evidence for ecological damage to public resources and for setting appropriate science-based policy (e.g., mitigation), (3) providing regional and national policy makers with science-based reasons for regulating Hg emissions, and (4) serving as a reference for detecting future changes in Hg emissions. In association with my collaborators, particularly the Loon Preservation Committee, I recommend further studies to continue using the Common Loon as the primary ecological indicator of aquatic integrity for multiple geographic and ecological scales in southern New Hampshire. Specific task for 2002 could include:

- 1) Continue the population-level analysis of Hg impacts on various reproductive measures by targeting 20-30 territories of each risk category. Analyze these data to determine spatially-explicit reproductive damage;
- 2) Continue with the established REMAP sampling strategy that will provide a probability-based risk assessment for New Hampshire;
- 3) Further investigate the extremely high MeHg bioavailability for lakes in southeastern New Hampshire by determining a bioaccumulation factor for each lake. This will provide insight on the mechanisms driving the loon's Hg risk;
- 4) Construct a statewide, stressor-risk matrix in a spatially-explicit way that is based on genetic distinction of subpopulations; and
- 5) Continue to improve the spatial model of potential Hg bioavailability in southern New Hampshire by linking Hg emissions, attributes related to emissions and their dispersal, and bioavailability within aquatic ecosystems.

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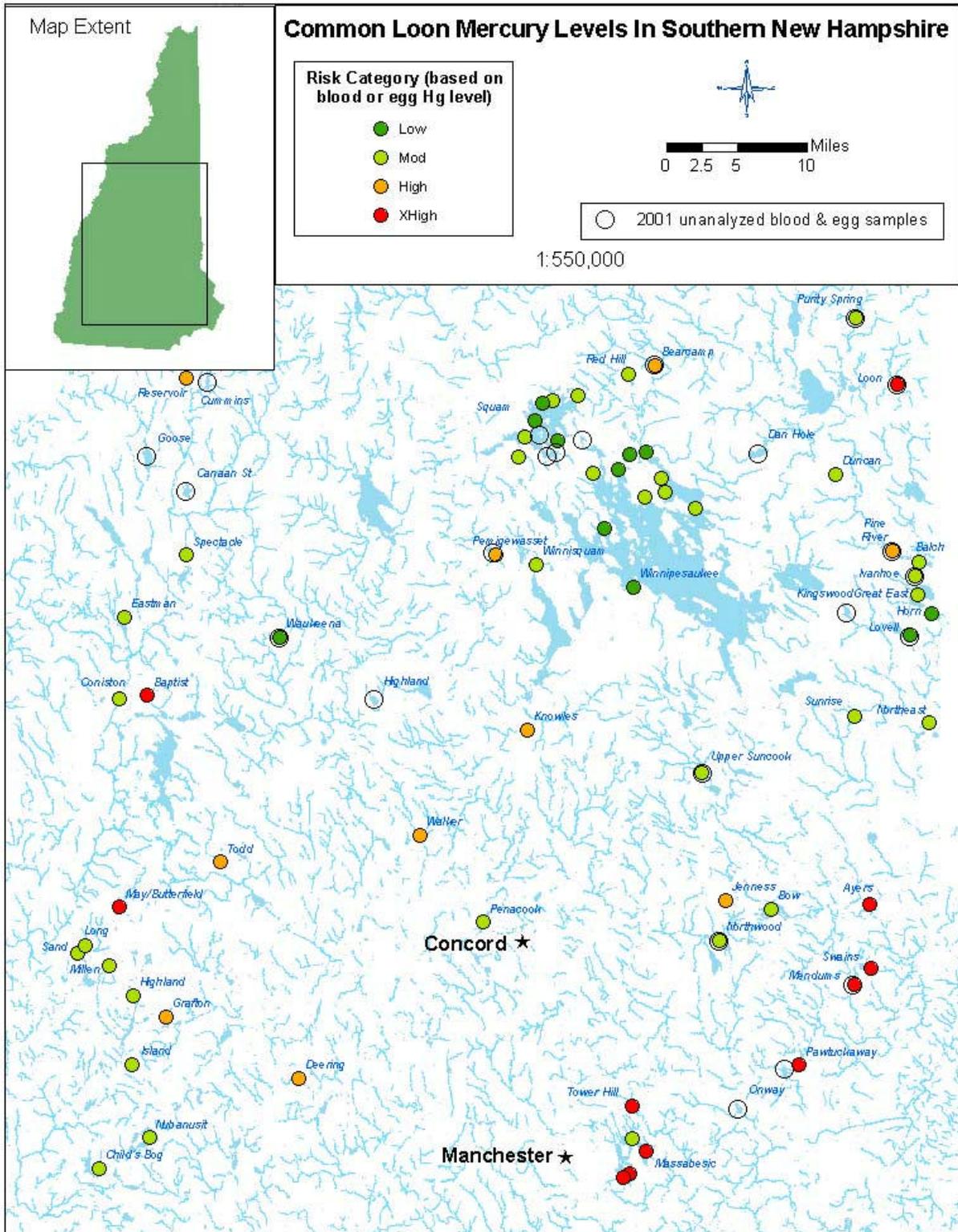
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Appendix 1. Map of sampling locations of Common Loons in southern New Hampshire



Appendix 2. Map of Hg risk to breeding Common Loons in southern NH as indicated by exposure.

