1997 Project Abstract
For the period ending June 30, 2000
This project was supported by MN Environment and Natural Resources Trust Fund

Title: Loons: Indicators of Mercury in the Environment
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Legal Citation: ML 1997, Ch. 216, Sec. 15, Subd. 14 f.
Appropriation Amount: $230,000

Results located at web address: http://www.consbio.umn.edu/loon

Statement of Objectives

Mercury can bioaccumulate in the aquatic food chain to the level that consumption of fish is hazardous to wildlife and humans. The goals of this study were to (1) determine mercury levels in adult and juvenile Common Loons captured at Minnesota lakes (2) investigate relationships between mercury levels in loons and prey-sized fish (3) examine relationships between mercury levels in loons and loon chick behavior and (4) build a spatial database integrating our data with other appropriate state databases that contain information pertinent to mercury reduction in Minnesota's aquatic ecosystems.

Overall Project Results

Adult (93) and juvenile (64) loons were captured and banded at lakes in Minnesota and Wisconsin. Blood and feather samples were collected for analysis of total mercury content. Approximately 7% of adult loons and 1% of juvenile loons captured in Minnesota had blood and/or feather mercury concentrations exceeding threshold levels associated with reproductive, behavioral or physiological effects reported in other studies. Strong linear relationships were found between mercury measured in prey-sized fish and in blood of adult loons and chicks. We observed loon chick behavior at 20 study lakes in Minnesota and Wisconsin for approximately 355 hours. Common Loon chicks were most susceptible to variation in behavior related to elevated mercury exposure within the first 12 days after hatching and when they were > 40 days old. Databases were compiled and GIS applications created to show distributions of Common Loon presence and reproduction, mercury levels in blood and feathers of Common Loons, mercury levels in game fish, and physical and chemical lake characteristics.

Project Results and Dissemination

Data were presented at several professional and public meetings, compiled on a CD and are available for viewing and printing (of maps) at http://www.consbio.umn.edu/loon. Two papers will be submitted for publication to peer reviewed journals. A thesis (M.S.) written by C. J. Counard will be published by the University of Minnesota.

Date of Report: July 1, 2000

LCMR Final Work Program Report

Book Copy

I. PROJECT TITLE: Loons: Indicators of Mercury in the Environment

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Total Biennial Project Budget: $230,000

$ LCMR: $230,000

-LCMR Amount Spent: $230,000

= $LCMR Balance: $0

A. Legal Citation: ML 1997, Chapt. 216, Sec. 15, Subd. 14 f.

Carryforward: ML 1998, (The availability of the appropriations for the following projects is extended to June 30, 2000: Laws 1997, chapter 216, section 15, subdivision 14, paragraph (f), Loons: Indicators of Mercury in the Environment

Appropriation Language: This appropriation is from the trust fund to the University of Minnesota to analyze loon exposure to mercury and its effects on loon health and reproduction in the wild.

II. PROJECT SUMMARY AND RESULTS: Mercury bioaccumulates in the aquatic food chain to the point that consumption of fish is hazardous to wildlife and humans. Previous research has shown that Common Loons (*Gavia immer*) are exceptionally sensitive to elevated concentrations of mercury and are excellent indicators of environmental quality. Loons are ideal early warning indicators of mercury contamination because they bioaccumulate methylmercury, are obligate fish-eaters, live 2-3 decades, and are easily captured and recaptured. This study determined mercury levels in 71 adult and 46 juvenile loons captured on experimentally paired and historically studied lakes in Minnesota. Blood and feather samples were collected and analyzed to determine mercury levels in individual birds. Mercury levels were measured in potential prey species (e.g. perch) at selected lakes where loons were sampled. Relationships between Hg concentrations in loon chick blood and chick behavior were investigated. A GIS spatial database was developed that integrates data collected on mercury levels in loons and prey with other appropriate databases (e.g. MPCA data on fish mercury levels, lake sediment mercury, water quality). GIS applications facilitated design of some aspects of this study, and allowed us to

examine geographic patterns of mercury bioaccumulation in loons. Results include: (1) mercury levels in feather and blood of Minnesota loons, (2) mercury levels in prey species (fish), (3) relationships between loon blood mercury levels and loon chick behavior and (4) a spatial database integrating our data with other appropriate state databases containing information pertinent to reducing mercury in Minnesota's aquatic ecosystems.

III. PROGRESS SUMMARY:

1 July 2000

Results 1 and 2: Feather and blood mercury (Hg) levels in adult and juvenile loons; relationships between Hg concentrations in blood and feathers of paired male and female loons and in blood of adults and their offspring; and relationships between loon blood and feather Hg concentrations and both Hg in prey sized fish and lake water chemistry parameters.

Adult (n = 162) and juvenile (n = 96) Common Loons (*Gavia immer*) were captured at 38 lakes in northeastern Minnesota for determination of total Hg content in their blood and feathers. Male loons had significantly higher Hg in blood ($p < 0.001$) and feathers ($p < 0.001$) compared to their female mates. Positive relationships between Hg in adult blood and medium (10 to 20 cm) fish ($p = 0.011$, $R^2 = 0.63$) and between Hg in chick blood and small (5 to 10 cm) fish ($p < 0.001$, $R^2 = 0.78$) demonstrated that blood Hg levels in both adults and chicks are most likely caused by dietary Hg exposure at the breeding lakes. Blood Hg concentrations in adults and their offspring were significantly related ($p < 0.001$, $R^2 = 0.32$) but Hg levels in adults averaged 16x higher than in their offspring. Negative relationships were found between both adult and juvenile blood Hg concentrations and lake pH levels ($R^2 = 0.41$ and $R^2 = 0.51$, respectively) but loon blood Hg was not related to lake water DOC or color. Blood Hg concentrations in adult Minnesota loons averaged lower than blood Hg concentrations in loons caught in Wisconsin, Ontario, New England and Canadian Maritimes but feather Hg concentrations were similar among regions. Approximately 7% of adult loons and 1% of juvenile loons captured in Minnesota during this study had blood and/or feather Hg concentrations exceeding threshold levels associated with reproductive, behavioral or physiological effects in other studies.

Result 3: Relationships between mercury levels and loon chick behavior

Previous studies investigating relationships between loon blood Hg concentrations and alterations in loon behavior are contradictory, demonstrating a need for further investigation. We used multiple linear regression to evaluate the influence of Hg in combination with other external factors (e.g. human disturbance), on loon chick behavior during 3 growth stages at breeding lakes in Wisconsin and Minnesota. This is the first study to present results from behavior observations of loon chicks greater than 40 days old. Common Loon chicks are most susceptible to variation in behavior related to elevated Hg exposure within the first 12 days after hatching (downy young) and during the large young (> 40 days old) growth stage. Chick blood Hg was a significant predictor in multiple regression models for both preening and back riding during downy young

and for swimming, diving, peering, begging and wing flapping during large young. Duration of time downy young loon chicks spent preening increased ($p < 0.001$) and time spent back riding decreased ($p = 0.009$) as chick blood Hg concentrations increased. During the large young growth stage, positive relationships were found between chick blood Hg and swimming ($p = 0.009$), peering ($p < 0.001$) and begging ($p = 0.026$). Negative relationships were observed between chick blood Hg and both diving ($p = 0.007$) and wing flapping ($p = 0.016$). Alterations in behaviors of large young chicks may affect survival because all are elements of feeding/foraging behavior except wing flapping. However, interpretations of relationships between chick blood Hg and large young behaviors are complicated by linear relationships between chick blood Hg and lake pH ($p < 0.001$, $R^2 = 0.84$), adult blood Hg ($p < 0.001$, $R^2 = 0.85$) and the Near/Off (duration of time one adult was < 25 m from the chick while other adult was off the lake) adult proximity predictor ($p < 0.001$, $R^2 = 0.75$) for large young. Further research is needed to determine which factor or combinations of factors are responsible for alterations in chick behavior and survival.

Result 4: Spatial analysis (GIS) of project data and related databases

Compiled project data and related databases from MPCA and MNDNR. Created GIS applications showing distributions of the following:

~ Common Loon presence and reproduction
~ Hg levels in blood and feathers of Common Loons
~ Hg levels in game fish
~ Lake Characteristics and water chemistry parameters

Developed an interface to serve GIS data on the World Wide Web. Loon web site (http://www.consbio.umn.edu/loon) now contains interactive GIS maps served through Mapserver at real time. Data can be viewed and distribution maps printed.

IV. OUTLINE OF PROJECT RESULTS:

Result 1: Feather and blood mercury levels for adult and juvenile loons; relationships between Hg concentrations in blood and feathers of paired male and female loons and in blood of adults and their offspring; and relationships between loon blood and feather Hg concentrations and lake water chemistry parameters.

LCMR Budget: $100,000 Balance: $0
Match: $0 Match Balance: $0
Completion Date: March 1999

Sampling Effort

- Ninety-three adult and 64 juvenile loons were captured to obtain blood and feather samples for Hg analysis during the 1997/1998 breeding seasons. Seventy-one adults and 46 juveniles were captured from 50 territories on 34 lakes in Minnesota. Twenty-two adults and 18 juveniles were captured on 17 single territory lakes in Wisconsin. All 93 adults and 64 juveniles were banded with individually numbered aluminum leg bands and unique color

combinations of plastic bands. Ninety-six feather and 94 blood samples from adult loons and 8 feather and 69 blood samples from juvenile loons were collected during capture for determination of total Hg content using cold-vapor atomic absorption spectroscopy. The following results include data collected in Minnesota from 1997 to 1998 as well as Hg levels measured in additional 91 adult and 50 juvenile Minnesota loons captured by Evers *et al.* (1998) from 1992 to 1996. Detailed methods can be found in Appendix 1 pages 4-10.

Hg in Loon Blood and Feathers

- A mean Hg concentration (± SD) of 11.80 ± 4.82 ppm was measured in adult feathers (n = 160) and 1.25 ± 0.58 ppm in adult blood (n = 158). Hg levels measured in chick blood (n = 72) averaged 0.098 ± 0.052 ppm. Frequency distributions of adult feather and blood Hg concentrations and chick blood Hg concentrations are presented in Appendix 1 pages 31-33, Figs. 2-4. Ranges of Hg levels measured in loon blood and feathers as well as mean Hg concentrations in blood and feathers of adult male and female loons are presented in Appendix 1 page 27, Table 1.

Hg in Adult Male and Female Loons

- A significant positive relationship ($p < 0.001$, $R^2 = 0.45$; Appendix 1 page 34, Fig. 5) was found between blood Hg concentrations of paired male and female loons but their feather Hg concentrations were not related ($p = 0.837$, $R^2 = 0.001$) (Appendix 1 page 11). The positive relationship between blood Hg concentrations from paired male and female loons suggests that both adults were feeding at the same lakes during the breeding season. The lack of relationship between feather Hg concentrations in male and female loons from the same pair provides evidence that paired adults had different food sources during winter when feathers were formed.

- Male loons had 54% greater Hg levels in blood ($t = 6.403$, $df = 50$, $p < 0.001$) and 35% greater Hg in feathers ($t = 3.679$, $df = 49$, $p < 0.001$) compared to their female mates (Appendix 1 page 11). Similar relationships have been documented in other regions of North America and attributed to maternal transfer of Hg to eggs and to prey partitioning between sexes resulting from sexual dimorphism (Scheuhammer *et al.* 1998 and 1987, Evers *et al.* 1998, Meyer *et al.* 1995 and 1998). Male loons are larger than females, suggesting an ability to catch and ingest larger prey that generally have higher Hg content. Male loons averaged 19% larger than their female mates in Minnesota.

Hg Accumulation in Feathers of Recaptured Adults

- Twenty one adult loons were captured in consecutive years, 4 of which were recaptured multiple times. Combining the total number of recaptures yields 27 potential Hg accumulation-years. While feather Hg concentrations increased an average 4.6% between consecutive years, less than half (13) of loons sampled had an increase in feather Hg levels from one year to the next. Of 11 female loon recaptures, 5 (45%) had increases in feather Hg in consecutive years but there was an average decrease of 2.1%. Seven of 13 (54%) male loon recaptures had an annual increase in feather Hg with an average increase of 10.8%. (Appendix 1 page 11)

Hg in Adult Loons and their Offspring

- Adult blood Hg levels were significantly related to chick blood Hg ($p < 0.001$, $R^2 = 0.41$), with a stronger relationship found between females and their offspring ($p < 0.001$, $R^2 = 0.55$) than males and their offspring ($p < 0.001$, $R^2 = 0.32$) (Appendix 1 page 37, Fig. 8). The relationship between blood Hg in adults and their offspring provides evidence that adults are feeding primarily on the breeding lake because chicks eat solely at the breeding lake. The stronger relationship between blood Hg in female loons and their offspring compared to males and their offspring may be because the size of prey ingested by female loons overlaps with chick prey while male loons are eating larger fish.

Hg in Loons and Lake Water Chemistry

- Measures of lake pH, alkalinity, conductivity and calcium were highly correlated (Appendix 1 page 29, Table 3), therefore, only pH, dissolved organic carbon (DOC) and color were included in multiple regression analyses of loon blood and feather Hg concentrations. Significant negative relationships were found between lake pH and both log chick blood Hg ($p = 0.001$, $R^2 = 0.51$; Appendix 1 page 40, Fig. 11) and log adult blood Hg ($p = 0.004$, $R^2 = 0.41$; Appendix 1 page 41, Fig. 12). DOC and color were not significant predictors in either multiple regression model including lake pH. (Appendix 1 page 13) Lake pH appears to be the best water chemistry parameter for indicating where loons are at risk to elevated Hg exposure but this does not imply a direct causative relationship. More likely a suite of variables affects the bioavailability of MeHg to loons in the aquatic system (Richman *et al.* 1988, Sorensen *et al.* 1990).

Geographic Comparisons

- Evers *et al.* (1998) documented a west to east trend of increasing mean Hg concentrations measured in blood of Common Loons captured in 5 regions of North America (Alaska, northwestern United States, Upper Great Lakes, New England and Canadian Maritimes). Mean blood Hg concentrations in Minnesota loons captured during this study fit within this west to east trend of increasing loon blood Hg. Atmospheric mercury deposition, lake pH levels and loon size may contribute to variation in loon blood Hg among breeding regions (Appendix 1 page 14). Feather Hg concentrations in Minnesota loons were similar to Hg levels measured in feathers of loons captured in other regions of the Upper Great Lakes and Northeast, providing evidence that loons breeding in these regions are exposed to similar Hg concentrations in ocean fish during the winter molt (Appendix 1 page 14).

Risk to Minnesota Common Loons from Sublethal Effects of Hg Exposure

- Approximately 7% of adult loons and 1% of juvenile loons from this study had blood and/or feather Hg concentrations exceeding threshold levels associated with reproductive, behavioral or physiological effects in other studies (Evers *et al.* 2000, Scheuhammer 1991, Meyer *et al.* 1998). One chick (total $n = 96$) had a blood Hg concentration of 0.3 ppm, the threshold level above which fewer loon chicks hatched or fledged to 8 weeks in Wisconsin (Meyer *et al.* 1998). Two adult male loons (total $n = 162$) had blood Hg concentrations exceeding 3 ppm, within the range associated with reproductive impairment and increased circulating corticosterone levels, suggesting immunosuppression, in New England loons (Evers *et al.*

2000). Scheuhammer (1991) suggested that Hg levels exceeding 20 ppm in feathers should be indicative of habitat where piscivorous birds are at risk to reproductive impairment. Nine (11%) male and 2 (3%) female adult loons had feather Hg concentrations greater than 20 ppm, with a maximum level of 30 ppm. Based on these risk threshold levels, Hg poses a greater threat to male than female loons. (Appendix 1 page 19)

Recommendations

- Long term monitoring of Hg in blood and feathers of individual loons would aid in understanding the effects of age on accumulation of Hg body burdens. Because monitoring started in 1992, Minnesota is an ideal location for continued efforts. Particular attention should be paid to 2 known aged adult loons (banded as juveniles) on territories in Voyageurs National Park.

Result 2: Mercury levels in loon prey sized fish from lakes where loons were captured

LCMR Budget: $10,000 Balance: $0
Match: $0 Match Balance: $0
Completion Date: March 1999

Sampling Effort

- Loon prey sized fish were sampled from 12 northeast Minnesota lakes in late August through early September. Yellow perch (*Perca flavescens*), bluegill (*Lepomis macrochirus*), and minnows (*Cyprinidae spp.*) were collected using trap nets, minnow traps and angling. Yellow perch was the primary target species but bluegill and minnow species were collected where yellow perch were unavailable, or uncommon. All fish collected were between 5 to 20 cm in length and weighed < 70g. Each fish was analyzed for total Hg content using cold vapor atomic absorption spectroscopy. Average fish Hg content was calculated for two size classes based on fish length, small (5 to 10 cm) and medium (10 to 20 cm). A more detailed description of methods can be found in Appendix 1 page 8.

Hg in Whole Fish

- We collected 256 fish ranging in size from 5 to 17.5 cm (1.27 to 61.46 g) with an average Hg concentration of 0.051 ± 0.033 ppm wet weight (Appendix 1 page 12). Mean Hg concentrations in whole fish and sample sizes for each fish group (yellow perch, bluegill, and minnows) are presented by lake in Appendix 1 page 28, Table 2.

Hg in Loons and Prey Sized Fish

- A strong linear relationship ($p < 0.001$, $R^2 = 0.78$; Appendix 1 page 38, Fig. 9) was found between Hg concentrations measured in loon chick blood and small (5 to 10 cm) fish. Adult blood Hg concentrations were also significantly related to Hg concentrations in small fish ($p = 0.011$, $R^2 = 0.53$), however, Hg levels in medium fish explained 10% more variation in adult blood Hg ($p = 0.011$; Appendix 1 page 39, Fig. 10) than the variation explained by small fish Hg. Medium fish Hg explained 24% less variation in chick blood Hg ($p = 0.025$, $R^2 = 0.54$)

among study lakes than the variation explained by small fish Hg. (Appendix 1 page 12) Relationships found between Hg measured in adult and juvenile loon blood and prey sized fish provide evidence that both adult and juvenile loons feed primarily at the breeding lakes. Chick blood Hg was more strongly related to small fish Hg and adult blood Hg to medium fish Hg, which demonstrates adults are feeding on bigger fish than chicks. Furthermore, adult blood Hg averaged 16x higher than blood Hg levels measured in their offspring.

- No relationships were found between adult feather Hg concentrations and either small fish Hg ($p = 0.259$, $R^2 = 0.14$) or medium fish Hg ($p = 0.651$, $R^2 = 0.03$) (Appendix 1 page 12).

Recommendations

- Hg in loon blood and feathers should be measured at lakes where MPCA is studying the dynamics of Hg in the aquatic system to better understand the links between Hg in water, sediments, fish and top predators such as the Common Loon.

Result 3: Relationship between mercury levels and loon biology

LCMR Budget: $75,000 Balance: $0
Match: $0 Match Balance: $0
Completion Date: March 1999

Egg Exchange Experiments

- Egg exchange experiments were conducted in 1997 to fulfill two main objectives: To determine if a relationship exists between Hg levels in loons and adult incubation behavior and to determine if mercury deposited in eggs from the female affects hatchability. Although exchange of loon eggs was experimental and used for the first time in this study, a method for successfully switching eggs was developed. Two egg exchanges were completed during summer 1997. One exchange was a control in which eggs from two low Hg lakes were switched and placed in the nests. The second exchange was between 2 eggs from a high mercury lake and two from a low Hg lake. Exchange nests were monitored for hatching success. In the control exchange, one pair successfully hatched two young and eggs from the second nest were depredated. In the second exchange, eggs from the high mercury lake placed in the nest at the low mercury lake were depredated. Eggs from the low mercury lake placed in the nest at the high mercury lake were incubated for almost the entire incubation period then abandoned. The abandoned eggs were collected for analysis of mercury content. We determined in 1997 that egg exchange experiments with Common Loons are difficult and time consuming because of distance between nesting sites, the challenge of locating synchronously nesting pairs at high and low Hg sites, and the high incidence of nest abandonment, flooding, and predation (approximately 70% of the known nests monitored in 1997 failed). Therefore, in 1998 we refocused the Hg and loon biology portion of the study to investigate the effects of Hg on loon chick behavior.

Sampling Effort

- The behavior study was conducted in Minnesota and Wisconsin to obtain the widest possible spectrum of mercury levels. Effort in Minnesota was concentrated in St. Louis and Lake counties where a relatively wide range of mercury levels was found in loon blood and feathers during the 1997 season (Appendix 1 page 85, Fig. 1). Twenty-four loon pairs were monitored in MN during the pre-nesting and incubation periods, of which 8 pairs successfully produced young. Loon behavioral observations were collected after the chicks hatched on the 8 territories. Twenty-four loon pairs were also monitored during the pre-nesting and incubation periods in Oneida and Vilas counties in Wisconsin (Appendix 1 page 86, Fig. 2). Behavioral observations were collected from twelve of the territories where loon chicks successfully hatched. All juvenile loons and 26 adults on the 20 study lakes were captured to determine blood and feather Hg levels.

Methods

- Loon chicks were observed from one day old until fledging or the age reached by 31 August. Each loon territory was visited approximately once every 4 to 6 days with a maximum of 8 days between observations for a total of 359 observations. Target duration for each observation was 60 minutes of in sight time. Time-activity budgets were recorded using continuous (Tacha *et al.* 1985), focal animal sampling (Martin and Bateson 1986, Altmann 1974, Nocera and Taylor 1998) with a single juvenile loon per territory as the focal animal. At territories with sibling loons, one chick was randomly chosen at the beginning of each observation (Altmann 1974). Observations for each chick were divided into the following age categories; downy young (<13 days), small young (13 to 40 days) and large young (>40 days) (Nocera and Taylor 1998). During each observation we recorded duration of state behaviors (lasting > 5 seconds) and frequency of event behaviors (lasting < 5 seconds) (Nocera and Taylor 1998, Altmann 1974). State behaviors include swimming, drifting, diving, preening, back riding and bill tuck. Event behaviors recorded include peering, begging, foot waggle, wing flap, snaking, alert posture, and eating food. See Appendix 1 page 99 for detailed descriptions of behaviors.

- We performed multiple linear regression analyses to investigate the potential role of mercury in combination with other external factors in influencing chick behavior. Best Subset Regressions (Analytical Software 1996) was used to identify the best combinations of independent variables based on Mallow's Cp criterion for each behavioral state and event per growth period as the response variable. Independent variables used in the analyses included; pH, lake area, lake depth, total time observed by growth period (time observed), chick blood Hg, adult blood Hg and the frequency of eagles, intruder loons and boats (human) in sight of the loons per hour observed. Adult proximity predictors for the particular growth period; no adults near (<25 m) the chick (0Near); one adult near while other adult was far (> 25 m) from the chick but on the lake (Near/Far); one adult near while other adult was known off the lake (Near/Off); both adults near (2Near) and both adults off the lake (2Off), were also included in analyses (Appendix 1 page 81, Table 1). Models with greater than four predictors were not considered due to sample size. We present only multiple regression results for those behaviors in which chick blood Hg was a significant predictor in the "best" models. A detailed description of methods can be found in Appendix 1 pages 52-59.

Blood Hg Concentrations

- Mean blood Hg concentration found in loon chicks on the 20 study lakes was 0.198 ± 0.185 ppm, ranging from 0.035 to 0.570 ppm. Adult blood Hg levels ranged from 0.59 to 4.10 ppm with a mean of 1.66 ± 0.95 ppm. Five of the 20 study lakes had chicks with blood Hg levels > 0.3 ppm, the range in which fewer loon chicks hatched or survived to 8 weeks in a previous Wisconsin study (Meyer *et al.* 1998). All five of these lakes were located in the Wisconsin study area. Chick blood Hg concentrations exceeding those in this study have been measured only in the Canadian Maritimes, New England and Ontario, Canada (Evers *et al.* 1998, Nocera and Taylor 1998).

Downy Young (< 13 days old) Behavior and Hg

- Results of multiple regression analyses demonstrated that chicks spent more time preening and less time back riding during the downy young growth stage as chick blood Hg concentrations increased (Appendix 1 page 60). Nocera and Taylor (1998) found the same results for downy young chicks in Nova Scotia and New Brunswick. The positive relationship observed between preening and chick blood Hg was counter to what we expected because maintenance behaviors tend to be energy intensive. However, increases in preening during the downy young stage were also associated with increased presence of both eagles and intruder loons, indicating that preening may be a behavior engaged in when chicks are exposed to danger. Therefore, increases in preening associated with elevated chick blood Hg may result from an increased response to fright stimulus similar to that found in ducklings of Mallards dosed with methylmercury (Heinz 1979). Decreased back riding associated with elevated levels of chick blood Hg may increase exposure of chicks to environmental stress and underwater predators (McIntyre 1988).

Small Young (13 to 40 days old) Behavior and Hg

- Results from multiple regression analyses of small young behaviors revealed that chick blood Hg was a significant predictor in only one model, log (begging), but the relationship was not strong. See Appendix 1 page 61 for details.

Large Young (>40 days old) Behavior and Hg

- This is the first study to measure relationships between chick blood Hg and behavioral endpoints in loon chicks greater than 6 weeks of age and I found the strongest relationships between chick blood Hg and behavior in large young growth stage. In multiple regression models without adult proximity predictors, I observed increases in swimming, peering and begging and decreases in diving and the frequency of wing flaps as chick blood Hg concentrations increased (Appendix 1 page 62). Diving is considered an energy intensive behavior and Hg is associated with decreased activity levels and increased lethargy (Bouton *et al* 1999, Thompson 1996, Heinz 1996). Wing flapping is also an energy intensive maintenance behavior for straightening wing feathers after preening and for shaking water off feathers after diving (McIntyre 1988). The decrease in frequency of wing flaps associated with increases in chick blood Hg may be due to lower energy levels in mercury exposed chicks. (Appendix 1 page 70)

- Relationships observed between chick blood Hg and swimming, diving, peering and begging may be critical for chick survival because all are elements of foraging/feeding behavior. Common loons are visual predators, searching for food while swimming and peering on the surface and while diving underwater (McIntyre 1988). Chicks can often induce adults to feed them with begging behavior (Barr 1996). (Appendix 1 page 70)

Lake pH confounds Interpretations of Large Young Behaviors

- A strong negative linear relationship ($p < 0.001$, $R^2 = 0.85$) was observed between log (chick blood Hg) and lake pH at the 20 study lakes (Appendix 1 page 88, Fig. 4). Lake pH has been associated with decreased fish abundance and diversity in other studies which could partially explain the changes in behavior associated with chick blood Hg. Chicks may spend more time swimming, peering and begging as they follow adults in their more frequent but less successful foraging bouts on lakes with higher Hg prey and lower pH levels. With less abundant food, chicks would have less energy for active behaviors such as diving and performance of wing flaps. Although this explanation is plausible, lake pH levels were not significantly related to swimming, diving, peering or begging in place of chick blood Hg in the multiple regression models. (Appendix 1 page72)

Near/Off as an Indicator of Natal Lake Quality

- With adult proximity predictors included in the multiple regression analyses, Near/Off (the duration of time one adult was near the chick while the other adult was off the lake) during large young stage, replaced chick blood Hg in the "best" models for diving, swimming, begging and wing flapping (Appendix 1 page 64, Table 4). I suggest that Near/Off is not merely a measurement of adult proximity during the large young growth period but it may also be an indicator of natal lake quality. Adults nesting on small, low pH lakes associated with lower fish abundance and fish diversity (Henriksen *et al.* 1989, Schindler *et al.* 1985, Almer *et al.* 1974) tend to leave the nesting lake regularly (Barr 1996, Alvo *et al.* 1988, Parker *et al.* 1986, Piper *et al.* 1997). Barr (1996) proposed that adult loons establish feeding territories on other lakes as one of several strategies to raise chicks on lakes with low fish abundance. Near/Off was positively related to both chick and adult blood Hg (Appendix 1 page 98, Fig. 14) and negatively related to pH and lake area (Appendix 1 page 65). Chick blood Hg alone explained 75% of the variation in duration of time adults spent in the Near/Off proximity category between study lakes. This relationship does not imply causation, however, we cannot eliminate chick blood Hg as a factor potentially influencing chick behavior.

- Near/Off could be used to identify lakes where chicks are exposed to multiple environmental stresses that together may affect survival. Adults at Swanson, Wharton, McGrath, Nineweb, and Shallow Lakes spent the longest duration of time in the Near/Off proximity category (100%, 100%, 86%, 78%, and 44% respectively). Each loon pair at the five lakes hatched two chicks and all except one lost a chick during the season. The loon pair at Little Bearskin Lake was the only other pair in the study to lose a chick. (Appendix 1 page 73)

Recommendations

- We identified alterations in chick behavior associated with chick blood Hg but were unable to separate influences of chick blood Hg, lake pH and Near/Off because of the strong linear relationships between these variables. Further research is needed to determine which factor or combinations of factors are responsible for alterations in chick behavior and survival. Results from this study can help focus future research questions and guide research design.

Result 4: Spatial analysis (GIS) of project data and related databases

LCMR Budget: $45,000 Balance: $0
Match: $0 Match Balance: $0
Completion Date: June 1999

People contacted to obtain data

I. Minnesota Pollution Control Agency
1. Edward Swain.
2. Gretchen Rohweder.
3. Linda Nelson.
4. Peter Torken
5. Mike M. Mondloch
6. Anne M. Jackson

II. Minnesota Department of Natural Resources
1. Richard Baker
2. Pam Perry
3. Kevin Woizeschke
4. Les Maki
5. Tim Loctsch

III. Fornet Program, University of Minnesota
1. Steve Lime
2. Perry Nacionales

IV. Judy McIntyre, Utica College of Syracus University.

VI. Susanne Maeder, LIMIC

Data Collection and Analysis

- Loon distribution data from Loon Monitoring project, Minnesota Department of Natural Resources

Obtained loon distribution data from R. Baker which was compiled by the Loon Monitoring Project of MNDNR through Voluntary Surveys. The data contained information on the number of adult and juvenile loons at 380 lakes, of which 360 lakes were surveyed for a 6-year period (1994-99). Arc/Info (GIS) point coverages were built to map distributions of adult and juvenile

loons. The Arcview GIS application built to show distribution of loons in relation to mercury concentrations contains 5 GIS layers:

1. Lakes with adult loons
2. Distribution of juvenile loons
3. Fish mercury concentrations (Northern pike equivalents from MPCA)
4. Roads
5. State boundary

Distributions of adult loons and fish mercury concentrations are represented by different colored dots. By clicking on any dot one can obtain detailed information on each theme. A tool can be used to zoom-in to an area of interest, making more information available (e.g. number of loons present in particular lake or amount of mercury concentration along with name of lake).

- Loon distribution data from Nongame section of the Department of Natural Resources, Brainerd, Minnesota

Nongame section of Minnesota DNR at Brainerd compiled loon data from 1979-97 which were collected by volunteers (independent of data from Rich Baker). This database contains information regarding presence of adults, nesting pairs, and chicks at 1051 lakes. 75% of the lakes (793), however, had data for only 1-3 years. Individual databases linked to each lake were created for adults, nesting pairs, and chicks. For spatial analysis Arc/Info (GIS) point coverages were built for presence of adults, nesting pairs, and chicks. The Arcview application developed to map the distribution of loons based on these data has 6 layers:

1. Distribution of adults in different lakes
2. Distribution of nesting pairs
3. Distribution of chicks
4. Towns (as landmarks)
5. Roads
6. State boundaries.

By clicking on any dot one can obtain detailed information on name of the lake, number of times a particular lake was visited in the 18-year time period, and number of adults, nesting pairs or chicks seen in a given year.

- Mercury and water chemistry data from Minnesota Pollution Control Agency

  To analyze relationships between mercury concentration and loon reproduction mercury concentration data was requested from MPCA for all the lakes that had information on loons for at least 4 years (513 lakes). Mercury data was available for 35 lakes (Table 1) and water chemistry (temp, pH, conductivity, color, aluminum, and total suspended solids) data was available for 103 lakes. An arcview application was developed to compare distribution of adults, nesting pairs, and chicks present in 1979-1997 with water chemistry parameters for 103 lakes.

- Loon blood and feather mercury concentrations collected between 1992-98

  A GIS map was developed with average blood and feather mercury levels for adult and juvenile loons at each lake where they were captured during this study and previous studies done by Evers and Cuthbert. Arcview applications were developed to compare Hg levels

measured in loons with other reproductive history, e.g. number of nesting pairs, chicks produced, and water chemistry parameters.

Research results on World Wide Web

- Developed an interface to serve GIS data on the World Wide Web. Loon web site (http://www.consbio.umn.edu/loon) now contains interactive GIS maps served through Mapserver at real time. Anyone with an Internet connection can access this database and query information or print the following distribution maps.
  b) Loon distribution and alkalinity in Minnesota lakes
  c) Blood and feather mercury distribution in lakes monitored from 1992-98
  d) Distributions of lakes with information on loon reproduction, fish mercury concentrations, and water chemistry.

Appendix 2 contains database names and detailed descriptions of their content

V. DISSEMINATION AND PEER REVIEW:

A. Publications

2000 Counard, C. J. Mercury Exposure and Effects on Behavior of Common Loons (Gavia *immer*) in the Upper Midwestern United States. M.Sc. thesis, University of Minnesota, St. Paul.

The thesis has been successfully defended and final revisions will be completed by September 2000. Defense committee included Dr. Francesca Cuthbert (Fisheries and Wildlife Department, U of MN), Dr. Frank McKinney (Ecology Evolution and Behavior, U of MN), Dr. Edward Swain (MPCA) and Dr. Michael Meyer (WIDNR). Both chapters of the thesis will be submitted for publication in peer reviewed journals by October 2000.

B. Presentations at professional meetings

Sept 1999 Counard, C. J., F. J. Cuthbert, D. C. Evers, W. E. Braselton. "Minnesota Common Loons and Mercury: A North American Context." At the 1999 Mercury in the Environment Conference in St. Paul, MN.

Apr 1998 Counard, C. J., P. S. Reaman, D. C. Evers, J. D. Kaplan, F. J. Cuthbert, W. E. Braselton, B. Davis, J. Hines. "Mercury exposure of Common Loons in Minnesota." At the 1998 North American Ornithological Conference in St. Louis, Missouri.

C. Presentations to public

Feb 1999 Conservation Biology graduate student seminar, University of Minnesota, Twin Cities.

Mar 1999	Roseville Bird Club, St. Paul, MN.
May 1999	Biological Conservation: An ecosystem approach (undergraduate class), University of Minnesota, Twin Cities.
May 1999	Citizen Advisory Committee to the Legislative Commission on Minnesota Resources
Jun 1999	LoonWatch volunteers, Manitowish Waters, WI.
Mar 2000	Conservation Biology (undergraduate class), University of Minnesota, St. Thomas.
Jun 2000	Thesis defense seminar, University of Minnesota, Twin Cities.

D. Compilation of GIS data on CD

CD distributed to MPCA and MNDNR and will be available upon request. Ed Swain and Jeff Jeremiason from MPCA have reviewed GIS data. We have made initial contacts with the Science Museum about the possibility of displaying GIS output at a kiosk in the museum.

E. Internet site

http://www.consbio.umn.edu/loon

VI. CONTEXT:

A. Significance: Previous work by MPCA (Enser et al. 1992) documented mercury in feather and liver tissue of living and dead loons. More than 20% of livers analyzed had mercury levels high enough to cause reproductive impairment in loons in a Canadian study. Our study built on the MPCA report by (1) using a more accurate method to measure breeding season mercury levels (sampling blood), (2) relating loon mercury levels to levels in prey (fish) and to water chemistry, (3) strengthening sampling methods (using both historic sites and experimentally paired lakes characterized by high and low mercury levels, (4) attempting to determine if high mercury levels affect behavior and (5) using GIS to provide spatial analysis of data to interested state and public agencies. This information is needed by MPCA as part of their effort to reduce mercury levels in Minnesota aquatic ecosystems.

B. Time: not applicable

C. Budget Context: Background field work has been conducted by Evers and Cuthbert on Common Loon biology and mercury levels at 2 sites (Voyageurs National Park and Grand Rapids area) in Minnesota since 1992. Funding was provided by U.S. Forest Service, MPCA and MDNR. Logistic support (housing, boat and fuel) was provided by Voyageurs National Park.

	July 95-96 Prior Expend	July 97-99 Expend	July 99-01 Future Expend
1. LCMR	$0	$230,000	$0
2. MPCA	$20,000	$0	$0
MDNR	2,000	$0	$0
3. US Forest Service	$20,000	$0	$0

LOONS: INDICATORS OF MERCURY IN THE ENVIRONMENT (J-9)

Project Manager: Francesca J. Cuthbert
Affiliation: University of Minnesota

Budget Overview:	1997-98	98-99	Total
Personnel:	135,732	66268	202,000
Equipment:			
Computer & Printer	5000		5000
Field Supplies	1000	1000	3000
Transportation			
Airfare	1500	1500	3000
Mileage	4750	4750	9500
Communications	1000	1000	2000
Lab analyses	3750	2750	6500
Total:	$152,732	$77,268	$230,000

VII. COOPERATION: The following organizations are cooperators for various aspects of project implementation including study design, field operations, GIS development

~ University of Minnesota-David Evers, Ph.D. graduate student, project supervisor and co-principal investigator; Dr. David Smith, GIS consultant (1% time, no costs associated)

~ MPCA-Dr. Ed Swain (2% time, occasional consulting, no costs associated)

~ MDNR-Richard Baker (1% time; occasional consulting, no costs associated)

VIII. LOCATION: Appendix 1 page 30, Fig. 1 and pages 85-86, Figs. 1-2

IX: Reporting Requirements: Periodic workprogram progress reports will be submitted by 1 October 1997, 1 April 1998 and 1 October 1998. A final workprogram report and associated products will be submitted by June 30 1999.

X. Research projects: see attached.

SCHEDULE:

Result 1: Feather and blood Hg levels for loons
July -Sept. 1997 and May-Sept. 1998 (capture adult and juvenile loons)
Sept-Nov 1997 and 1998 (analyze feather, blood and egg samples)

Result 2: Hg levels of potential prey
June-Sept. 1998 (collect fish)
Apr-Jun 1999 (prepare and analyze fish samples)

Result 3: Relationship of Hg levels and loon biology
July-Aug 1997 and Jan-May 1998 (identify study lakes)
July-Aug 1997 (monitor study lakes, conduct egg experiments)
Apr-Sept 1998 (behavior study)
Jan-Apr 1998 and Jan-Apr 1999 (analyze and interpret loon-prey Hg relationships)
Jun 1999-May 2000 (enter, analyze and interpret behavior data)

Result 4: Spatial analysis of databases
July-Dec 1997 and Jan Dec 1998 (contact agencies, centralize data, initiate GIS development and project data input)
April 1998-May 1999 (develop GIS output)