

BEHAVIOURAL TOXICOLOGY OF COMMON LOONS (*GAVIA IMMER*)  
IN THE CANADIAN MARITIMES

by

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## ABSTRACT

Mercury is a global pollutant that negatively impacts visual function, breeding behaviour, and development of animals. Common loons (*Gavia immer*) are high trophic level, visually oriented predators suggested to be sensitive to mercury (Hg) contamination. Previous studies have shown that exposure to Hg in prey is associated with changes in pre-nesting adult loon behaviour. Loons in Kejimikujik National Park (Nova Scotia, Canada) have the highest blood Hg concentrations of any loon population tested. I monitored the summer behaviour of loons in Kejimikujik and the Lepreau watershed (New Brunswick, Canada) to test the hypothesis that high Hg levels in Kejimikujik are associated with negative behavioural impacts. The amount of time that chicks spend brooding (by back-riding) decreases as Hg levels in their blood rise and preening increases. The concomitant increase in energy expenditure is not compensated with increases in feeding rates or begging. More frequent back-riding is associated with improved fledging success. Adult behaviour and hunting patterns appeared to be affected by Hg, but not significantly so. I also show that time activity budgets of very young chicks indicate effects of Hg concentrations in their blood. However, the behaviour of breeding and non-breeding adults is not a sensitive indicator of *in situ* contamination levels. I confirm the hypothesis that loons and other upper-trophic level predators could be at risk from elevated levels of bioavailable Hg. This may help explain the chronically low productivity of contaminated sites such as Kejimikujik, and allow for more focused management initiatives.

## LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
AST	Atlantic Standard Time
CPC	Chemistry Principle Component
CWS	Canadian Wildlife Service
DY	“Downy young” stage of chick development (1 - 12 d old)
Hg	chemical symbol for mercury
LY	“Large young” stage of chick development (41 - 70 d old)
MANOVA	Multivariate Analysis of Variance
MeHg	chemical symbol for methylmercury
MPC	Morphometric Principal Component
PC	Principle Component
PCA	Principal Components Analysis
PCB	Polychlorinated biphenyls
SO <sub>4</sub> <sup>2-</sup>	chemical suffix symbol for sulfides
SY	“Small young” stage of chick development (13 - 40 d old)
TABs	Time-activity Budgets
USEPA	United States Environmental Protection Agency



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## General Introduction

In 1988, the Canadian Wildlife Service (CWS) began monitoring Common Loon (*Gavia immer*) reproductive success in Kejimikujik National Park (Nova Scotia, Canada; Figure 1). This investigation indicated that Kejimikujik loons exhibited an average reproductive rate of 0.29 chicks per residential pair (Kerekes et al. 1995). Other North American populations showed a much higher reproductive success: approximately 0.5 chicks/residential pair in Eastern Canada (Heimberger et al. 1983), Saskatchewan (Titus 1978), and in the north-eastern United States (summarised in McIntyre 1994). Furthermore, such a level is barely half the suggested productivity (0.5 chicks per residential pair) necessary to maintain Common Loon populations (McIntyre 1994).

Kejimikujik is a 365 km<sup>2</sup> protected wilderness area with numerous “pristine” lakes. These lakes are typical of preferred loon habitat (McIntyre 1983, Belant and Anderson 1991, Kerekes et al. 1994): deep, cool oligotrophic lakes, with an abundance of fish (especially yellow perch (*Perca flavescens*)), and a low level of human disturbance and predators. There are many isolated nesting islands on most lakes in Kejimikujik and water fluctuation is minimal in most years (Kerekes and Schwinghammer 1973). Therefore, the low reproductive success of Kejimikujik loons was enigmatic.

CWS established a loon capture and banding program in Kejimikujik in 1995, to mark individuals for future identification and to screen their blood for potential contaminants. Blood was assayed for several toxic chemicals (e.g. polychlorinated biphenyls (PCBs), organochlorines, etc.). Mercury (Hg) was the only contaminant

present in unduly high levels, and is the highest of any loon population tested in the continent (Evers et al. 1998).

Mercury is a neuropoison known to cause aberrant behaviour, physiological defects, and mortality in many animal species (e.g., Tejning 1967, Heinz 1976, 1979, Barr 1986, Scheuhammer and Blancher 1994). However, the potential effects of mercury on Kejimikujik's loons, and the cause of their low reproductive success, had yet to be identified.

Concurrently, CWS began the same banding program on lakes within the Lepreau River watershed of south-western New Brunswick, Canada (Figure 1). Loon presence and absence had been historically documented on these lakes (G. Parker, unpub. data) and reproductive success was monitored in 1995 (N. Benjamin unpub. data). This research showed that reproductive success there was typically higher (0.46 chicks/residential pair) and that loons had lower levels of blood Hg than in Kejimikujik (Beauchamp et al. 1997).

It is unknown from where Hg in Kejimikujik loons originates; however, Hg has high mobility in the environment, and can be transmitted over long distances in the atmosphere. Recent increases in anthropogenic environmental mercury contamination in North America (US EPA 1997) are largely a byproduct of fossil fuel combustion, waste incineration, and other industrial operations (Swain et al. 1992, Carpi 1997).

Regardless of the source of Hg, the ultimate causation of Hg poisoning in animals is a swelling of the myelin sheath insulating nerves, that prevents signals from being "correctly" sent along axons (Fimreite and Karstad 1971). This pathological change may translate into behavioural abnormalities. Loons are appropriate study species to monitor

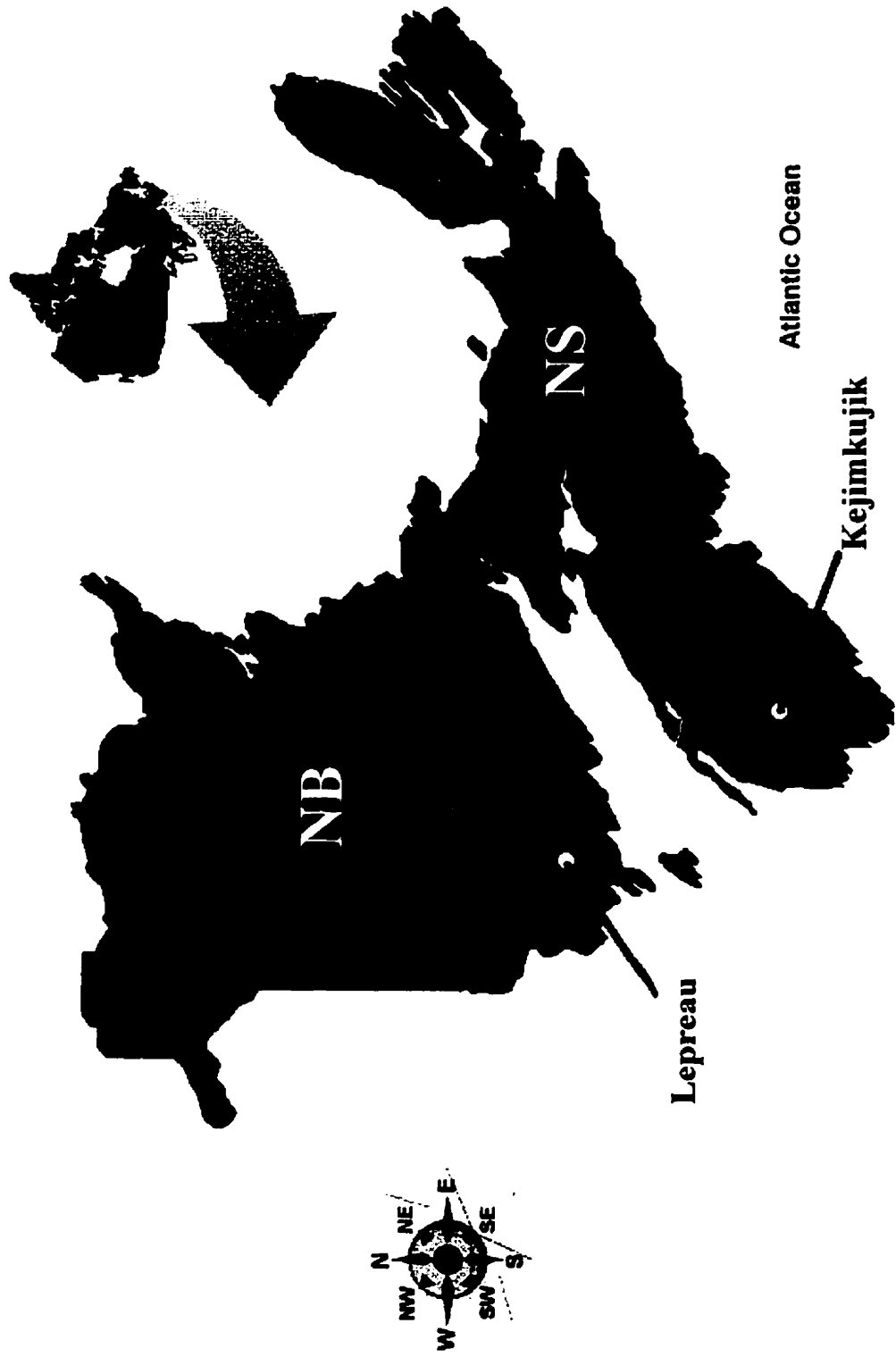


Figure 1. Map of New Brunswick (NB) and Nova Scotia (NS) denoting research site locations (inset = Canada).

the effects of such toxicants as mercury, because they are at severe risk to its effects, since they are high trophic level obligate piscivores with K-selected life history traits (Strong 1990). Their trophic level leaves them susceptible to biomagnification and their long life span permits toxic chemicals to bioaccumulate (Strong 1990). Their breeding behaviour has been well documented (e.g. Sjölander and Ågren 1972, McIntyre 1975, Evers 1994), which offers a template for comparison across geographic ranges, seasons, and lake characteristics. Unfortunately, behaviour of non-breeding and failed breeding loons has not been studied during the breeding season.

If loons in Kejimikujik are suffering negative impacts from exposure to elevated levels of Hg, behavioural effects should be detectable. I tested this hypothesis through a comparative, cross-generational investigation of breeding and non-breeding loon behaviour. I used a range of lakes in Kejimikujik and the Lepreau watershed that exhibit variation in morphometry, chemistry, and biological characteristics.

This study presented me with the opportunity to describe behavioural changes that might be associated with Hg. I was also able to capitalise upon availability of marked birds and known territorial histories to describe other facets of loon behavioural ecology unrelated to contamination, such as the behaviour of failed and non-breeding loons in the summer breeding season. No other study has examined *in situ* behavioural abnormalities of contaminated birds.

## Forward Note on Methods Used in this Thesis

To elucidate potential relationships between behaviour and contamination in this thesis, I employ the collection of time-activity budgets (TABs), which is a widely used technique in behavioural studies (described in detail by Altmann (1974)). Essentially, TABs represent the proportion (percentage) of time that an animal spends performing various state behaviours during the course of observation. States are behavioural patterns that have a prolonged duration (> 5 seconds in this study), such as swimming, foraging, and others outlined first on page 13. The duration (mean, total, or proportion time spent) in a state is its defining feature (Martin and Bateson 1993).

I also quantify the frequency of event behaviours, which are behavioural patterns of short duration (< 5 seconds in this study), defined first on page 13. Events are viewed as behavioural occurrences that “can be approximated as points in time” (Martin and Bateson 1993).

*Sampling Units.* Defining the sampling units for behavioural observation and for deriving reproductive success estimates is controversial (J.J. Kerekes pers. comm.). The sampling unit may be described as the lake, pair, or territory. Therein, these units are reclassified through *residential* versus *territorial* pairs. To ameliorate this problem, I define reproductive success as the number of chicks to fledge (surviving to 70 days) per residential pair. I limit the discussion of residential pairs in this thesis to any two loons obviously occupying a distinct lake surface area. I also define territorial pairs as only those loon pairs obviously occupying a distinct area of the lake surface that exhibit

territorial behaviour (see Sjölander and Ågren 1972), which is usually exhibited only by breeding loons.

*Statistical Treatments.* Prior to any statistical analyses in this thesis, all percentage data from TABs are arcsine squareroot transformed. This angular transformation is done to prevent the problem of the *variation* acting as a function of the *mean*, a common dependency problem encountered with percentage and proportion data (Sokal and Rohlf 1995).

Two statistical techniques are used widely in this study: Principal Components Analysis (PCA) and Multivariate Analysis of Variance (MANOVA). The decision to use MANOVA for the behavioural analyses is rooted in the hypothesis that all behavioural states are inherently correlated. MANOVA applies the technique of ANOVA to multiple responses, the collection of which is viewed as one multivariate observation (MathSoft 1995). To use multiple ANOVAs would be repetitive and less informative. Secondly, models estimated by MANOVA are far more conservative.

PCA is used to reduce the complexity of the suite of predictive variables, in this study, used in the MANOVA analyses. This method offers a means to describe the greatest variation in a cloud of points in three-dimensional space through a smaller number of linear combinations of those variables (MathSoft 1995).



The following three chapters show the proper use of the techniques mentioned above, and represent the culmination of the past three years of research.

#### **Data Holdings**

All behavioural data collected during this study is located in, and available from, the library holdings of:

- The Atlantic Cooperative Wildlife Ecology Research Network (available from Dr. Philip Taylor, Biology Department, Acadia University, Wolfville, NS B0P 1X0)
- The Canadian Wildlife Service (available from Neil Burgess, CWS - Atlantic Region, Environment Canada, PO Box 6227 (17 Waterfowl Lane), Sackville, NB E4L 1G6)
- Parks Canada (available from Sally O'Grady, Kejimikujik National Park, PO Pox 131, Maitland Bridge, NS B0T 1B0).

Explicit written permission must be granted from Joseph J. Nocera or Dr. Philip D. Taylor for use of these data. Some predictive variables used for analysis in this study were provided by the Canadian Wildlife Service (Neil Burgess) and may be made available upon request.

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## Chapter 1.

### ***In situ* Behavioral Response of Common Loons Associated with Elevated Mercury (Hg) Exposure<sup>1</sup>**

**Keywords.** - behavioral toxicology, common loon behavior, *Gavia immer*, Kejimikujik National Park (Nova Scotia, Canada), mercury, neurotoxicity, southwestern New Brunswick, sub-lethal exposure, time-activity budgets

**Abstract.-** Common loons (*Gavia immer*) in Nova Scotia, Canada have the highest blood mercury (Hg) concentrations of any loon population in North America. Previous studies have shown that exposure to varying levels of Hg in prey is associated with changes in pre-nesting adult behavior. We report here the first association of sub-lethal blood Hg contamination with changes in behavior of common loon young. The amount of time that chicks spend brooding (by back-riding) decreases as Hg levels in their blood rise ( $p = 0.004$ ) and preening increases ( $p = 0.003$ ). The sum increase in energy expenditure is not being compensated for with expected increases in feeding rates or begging. We suggest that such altered time-activity budgets may disrupt the energetic balance of young. Our results show that variation in time spent back-riding is associated with changes in fledging rates. Adult behavior did not significantly vary with Hg, but

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<sup>1</sup> This Chapter published as : Nocera, J.J. and P.D. Taylor. 1998. *In situ* behavioral response of common loons associated with elevated mercury (Hg) exposure. Conservation Ecology [online] 2(2):10. Available from the internet - URL: <http://www.consecol.org/Journal/vol2/iss2/art10>. Copyright © 1998 by the Ecological Society of America.

results are suggestive that an association may exist. We also show that monitoring the time-activity budgets of very young chicks can serve to indicate the effects of Hg concentrations in their blood. We confirm the hypothesis that loons and other upper-trophic level predators could be at risk from elevated levels of bioavailable Hg. This may help explain the chronically low productivity of such contaminated sites as Kejimikujik and allow for more focused management initiatives.

## **INTRODUCTION**

Mercury is a volatile toxicant because of its persistence and high mobility in the environment. It can be transmitted over long ranges in the atmosphere and deposited far from its source. It can be biologically transformed into methylmercury (a highly toxic compound) and bioaccumulates in top predators, including humans. Human activities that release mercury into the environment can therefore pose significant dangers to both human health and wildlife.

A large contribution of environmental mercury is made through anthropogenic deposition as a byproduct of fossil fuel combustion, municipal waste incineration, and other industrial processes (Swain et al. 1992, Carpi 1997). Ubiquitous contaminants that artificially enter ecosystems put all wildlife at risk, particularly those that are upper-trophic level predators such as loons. Monitoring the behavior of such animals can provide an indication of the sub-lethal effects of toxic substances on an organism and is a practical means of assessing the ecological impact of certain toxicants (Døving 1991, Cohn and MacPhail 1996).

Common loon (*Gavia immer*) blood mercury (Hg) levels in the northeastern United States and Atlantic Canada, particularly Kejimikujik National Park (Nova Scotia, Canada), are the highest known among tested loon populations in North America (Burger 1994, Beauchamp et al. 1997, Evers et al. 1998). Kejimikujik has one of the most easterly North American loon populations and blood Hg levels have shown a trend of easterly increase (Evers et al. 1998). Increases in atmospheric deposition of mercury during the past century have been documented (Swain et al. 1992) and it is known that mobilization of mercury currently exceeds that which occurs naturally (U.S. EPA 1997, Vitousek et al. 1997).

Loon reproductive success at Kejimikujik (Kerekes et al. 1994, N. Burgess unpub. data) is low compared with other North American populations, most notably among those in Eastern Canada (Scheuhammer et al. 1998). Mercury is a known neurotoxin that has been observed to affect avian behavior and cause aberrant breeding responses (Heinz 1976, 1979) when consumed in prey or forage. It may result in reduced productivity through lack of a nesting attempt (Barr 1986, Scheuhammer and Blancher 1994), lower nest attentiveness (Barr 1986) or lower nest site fidelity (Tejning 1967). However, no previous studies have assessed the effects of Hg contamination on the *in situ* behavior of loons or on potential population effects of any behavioral changes. Such information is relevant to the management of viable populations by identifying and indicating potential impacts of contaminants, such as mercury exposure.

Because common loons are long-lived piscivores, and are a K-selected species, impacts of low productivity on a population may not be seen for many years. Given its

low productivity (Kerekes et al. 1994, N. Burgess unpub. data), Kejimikujik may act as a sink for common loon reproduction even though requisite nesting habitat is found in abundance (namely, large (<40 ha) fish-containing, oligotrophic lakes with island nesting areas that are relatively free from predators and human disturbance (McIntyre 1983, Belant and Anderson 1991, Kerekes et al. 1994)). The implications of a sink population in Kejimikujik may be that this site drains regional populations of potentially successful breeding loons; adding yet another stress point to a species whose range is progressively decreasing (Sutcliffe 1978a, Blair 1992). Reasons for low reproductive success at this site have yet to be identified.

In contrast, loon populations in southwestern New Brunswick have higher productivity and much lower blood Hg levels than in Kejimikujik (Beauchamp et al. 1997). A strong correlation of blood Hg within families suggests it is being accumulated on these summer territories (Beauchamp et al. 1997). Therefore, Hg should exert the strongest effects during the breeding season, with potential negative consequences for overall productivity. We tested the hypothesis that any such effects might reveal themselves through subtle, altered behaviors of adults or chicks. We address this question through a comparative, cross-generational, investigation of breeding, non-breeding, and failed breeding loon behavior across a range of lakes that exhibit variation in lake morphometry, lake chemistry and biological characteristics in Kejimikujik and the Lepreau Crown Lands (southwestern New Brunswick).

## **METHODS**

*Response variable compilation.* We collected time-activity budgets (TABs) (Altmann 1974, Tacha et al. 1985) and event behavior (Martin and Bateson 1993) quantifications to catalog pre / post hatch and pre / post nesting behavioral states (Martin and Bateson 1993) of 12 breeding pairs (24 adults and 16 chicks) of common loons in Kejimikujik National Park, Nova Scotia, Canada (44° 20' N, 65° 20' W), and the Lepreau watershed, New Brunswick, Canada (45° 20' N, 66° 35' W), that resided on 11 territories of varying chemistry, morphometry, loon blood and yellow perch Hg levels (one breeding pair was sampled in both years). We collected the same data for 14 pairs of non-breeding and 4 pairs of failed breeding loons that resided on 15 lakes at the same sites.

We observed common loon behavior on both study areas for 264 hours (n = 295 observations, mean observation time = 53.7 min per bout) from May to September of 1996 and 1997. Behavioral observations were made with 8x42 binoculars or a 20-60x spotting scope from a concealed location (Bradley 1985) from shore (with a good view of the nest, brood, resident pair or individual). Diurnal observation times were divided into three h maximum slots ranging from 0600-0900 to 1800-2100 AST in 1996 and one h maximum slots ranging from 0600-0700 to 2000-2100 AST in 1997. At least two behavioral observations were done per day allowing for every lake to be covered at least once every 9 days. All individuals were randomly chosen for each observation and concurrent observations were made when individuals could be positively identified. Observations conducted during the development stages of chicks were divided among 3

age classes: downy young (DY) (<13 d old), small young (SY) (13 to 40 d old) and large young (LY) (>40 d old) stages.

Previously described loon behaviors (Sjölander and Ågren 1972, McIntyre 1975, Evers 1994) were documented by dictating observations into a microcassette recorder along with times recorded using a 1/100s stopwatch. Behaviors that lasted longer than five s were deemed states; behaviors that lasted less than five s were considered events. We quantified the following states : swimming (all active and passive locomotory behaviors (e.g. swimming, drifting and flying)), incubation, preening, diving, brooding, territorial encountering and bathing (both were combined to form the category “other”). We quantified the following behavioral events: foot waggle, stretching, vulture posturing, splash diving, peering, yawning, vocalizing (wails, tremolos, hoots, yodels and mews) penguin dancing and begging.

Our observed behavioral states did not include time spent in observation with the birds out of sight. “Out of sight” is a category that has sometimes been included in TABs (e.g. Evers 1994), but was not included in this study as it was felt that the information gained from quantifying “out-of-sight” times would be minimal, if not detrimental, by biasing towards a category that is not a behavior, but a ramification of observer location. There was no reason to believe that particular discrete behaviors were occurring during “out of sight” times, which is an acknowledged danger (Martin and Bateson 1993) regarding secretive behaviors of select animals (such as cats (*Felis domestica*) procuring prey and taking it elsewhere to eat). Therefore, we removed out-of-sight times and reduced the sampling period accordingly (as did Gese et al. 1996).

To help avoid the potential problem of individual observer bias and misinterpretation of behaviors (Martin and Bateson 1993), all field assistants were trained by us for 5-7 days (watching a loon simultaneously to define behaviors) to establish a consistent protocol before they proceeded to collect data independently (as did Gese et al. 1996). Because common loons are not sexually dimorphic and many of our study subjects were unbanded, we were unable to investigate gender differences in behavior. However, Mager (1995) demonstrated that male and female loons exhibit minimal difference in behavior.

We chose to use continuous observations and focal animal sampling (Altmann 1974, Martin and Bateson 1993) since they are the only reliable means to calculate actual activity patterns (Winchell and Kunz 1993). These measures offer a more complete and descriptive data set than instantaneous and/or non-focal animal sampling (Martin and Bateson 1993). Behaviors that are infrequent can often be missed during scan and instantaneous sampling and can only be accurately quantified with focal continuous observation (Winchell and Kunz 1993).

*Independent variable compilation.* We first categorized lakes using Principal Components Analyses (PCA)(Mathsoft 1995). These were conducted for both the morphometric and chemical variables (Table 1) to limit the analysis against behavior to a smaller number of linear combinations of those variables. All principal components with composite eigenvalues below the eigen mean (= 1) were excluded from the analyses (MathSoft 1995). Chick blood was sampled and Hg concentrations determined (N. Burgess unpub. data) for 6 of our 11 territories sampled for behavior and adult blood



<b>Lake Chemistry</b>	<b>Lake Morphometry</b>	<b>Biological Characteristics</b>
alkalinity	surface area	interspecific competition
conductivity	island area	intraspecific competition
color	basin area	human disturbance
pH	shore length	predator presence
chlorides	maximum depth	Hg burdens in blood
SO <sub>4</sub> <sup>2-</sup>	mean depth	breeding history
nitrogen	maximum effective length	breeding stage
sodium	maximum effective width	
potassium	volume	
calcium	Length/Area	
total organic carbon	basin permanence	
total phosphorus	shoreline development	
	maximum length	
	maximum width	
	flushing	

**TABLE 1.** List of independent variables used to test for variation with loon behavior on respective lakes. [These data were collected by the Canadian Wildlife Service (N. Burgess unpublished), Parks Canada (Beauchamp et al. 1997), or were extracted from Kerekes and Schwinghammer (1973) and from McNicol et al. (1996).

for 7 of 11 territories. On one of our territories, no chick or adult blood was sampled, so this territory was eliminated from all further analysis. Hg concentrations in chick blood for the missing 4 of the remaining 10 territories was estimated by fitting a linear regression of Hg in chick blood on Hg in adult blood using an extended dataset with measures from 19 adults with 14 chicks in 13 territories on lakes throughout the two study areas (N. Burgess unpub. data). The 3 missing samples of Hg in adult blood were likewise predicted. Such an approach is justified since chicks theoretically have Hg levels that are related to their parents because adults depurate Hg to the embryo (Heinz 1987); empirically the relationship between Hg in adults and chicks bears this out.

All blood samples were also screened for organochlorines, lead, and polychlorinated biphenyls (N. Burgess unpub. data). These samples showed normal levels of these contaminants with only Hg being irregularly high. We therefore only used Hg in our analyses. Observations of the presence of predators, humans, inter- and intraspecifics were also quantified for each lake on an individual observed per unit time (100 min.) basis.

*Statistical Analysis.* All percentage data from the TABs were arcsine squareroot transformed. Then, we tested for effects of the predictors (independent variables) on the response (loon behavior as TABs and events) using MANOVA (Mathsoft 1995) to elucidate any potential effects. We chose Pillai's criterion (Hair et al. 1987), which considers all characteristic roots, for significance testing in MANOVA. To further elucidate which (if any) discrete behavioral state(s) or event(s) were affected by these predictors, multiple univariate ANOVAs were performed as the final step. For these

analyses, significant correlation probability values were assumed at a level of confidence below or equal to 0.01 (Bonferroni correction (Sokal and Rohlf 1995)).

To examine the influence of behavioral patterns on reproductive success, we used any significantly modified behaviors as predictive variables in a linear regression with reproductive success estimates.

## **RESULTS**

The first PCA reduced the 15 lake morphometry variables (Table 1) to three components that explained 89.7% of the original variation in those variables. The first morphometrical principal component (MPC1) was loaded heavily by all morphometric variables, the second (MPC2) was loaded heavily by volumetric parameters such as flushing (flow rate) and basin area, and the third (MPC3) was loaded primarily by variables describing shoreline length and complexity and area.

A second PCA reduced 12 lake chemistry variables (Table 1) to three components that explained 76.7% of the original variation in those variables. The first chemical principal component (CPC1) was loaded heavily by pH,  $\text{SO}_4^{2-}$ , and chlorides, the second (CPC2) was heavily loaded by all chemical variables but was influenced most by conductivity, phosphorus, and calcium. The third component (CPC3) was loaded primarily by variables describing water clarity (e.g. color and total organic carbon) and nitrogen.

Using MANOVA, we then separately tested how each of the 3 chemical and 3

lake morphometry principle components and 7 other biological variables influenced TABs and event behaviors of adult loons. These analyses revealed that event behaviors of pre-nesting, non-incubating and post-hatch adults were influenced by the presence of interspecifics in territories (Pillai trace = 0.979,  $p = 0.042$ ). Secondly, TABs of breeding adults seemed to be marginally associated with blood Hg (Pillai trace = 0.847,  $p = 0.087$ ). The TABs of non-breeding adults were not significantly associated with any predictor. However, event behaviors were significantly related to predator threat and intraspecific competition (Pillai trace = 0.989,  $p = 0.04$  and Pillai trace = 0.999,  $p = 0.002$ , respectively).

Further multiple univariate ANOVA showed the only event behavior of breeding adults modified by interspecific presence was the hooting vocalization ( $p = 0.03$ ). Predators correlated with the occurrence of non-breeder stretching events ( $p = 0.02$ ). The relationship of stretching events with predator presence was driven by two outliers (the only two non-zero points). When these outliers were removed from the analysis the significant relationship was lost ( $p = 0.4$ ). Lastly, intraspecific competition correlated significantly with yodeling events ( $p = <0.01$ ). Again, the significant effect was lost when a single outlier (the only non-zero point) was removed from the analysis ( $p = 0.5$ ).

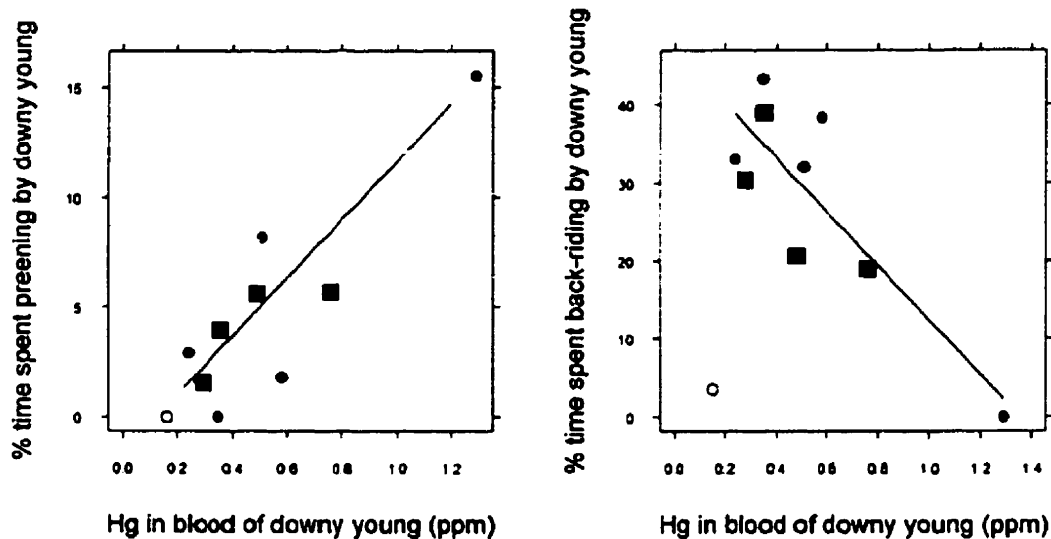
A second set of analyses on TABs of chicks at all developmental stages (Table 2) revealed a relationship between Hg burdens in chick blood (0.15 - 1.29 ppm) and TABs patterns of downy young (<12 d old)( $p = 0.044$ ). Additional analyses (Table 3) show this was manifest as a significant negative effect of chick blood Hg burden on time spent by

<b>Predictive Variable</b>	<b>Pillai Trace</b>	<b>P</b>
CPC1	0.815	0.123
CPC2	0.548	0.527
CPC3	0.738	0.226
Predators	0.294	0.821
Interspecifics	0.428	0.622
Intraspecifics	0.175	0.943
Human Disturbance	0.161	0.953
Adult loon blood Hg	0.847	0.087
Chick blood Hg	0.894	0.044

**TABLE 2.** Results of MANOVA on time-activity budgets of downy young (>12 d old) common loon chicks. Predictive variables were compiled separately for each lake. CPC1-3 are the first three principal components of lake chemistry. Time-activity budgets quantify the proportion of time spent in various behavioral states. Pillai's Trace criterion for significance testing in MANOVA was used. Maximum probability (type-I) error was set at 0.05.

<b>Response</b>	<b>Inclusion of outlier*</b>		<b>Exclusion of outlier*</b>	
	<b>F - value</b>	<b>P</b>	<b>F - value</b>	<b>P</b>
swimming	0.033	0.861	3.246	0.115
diving	1.908	0.205	1.344	0.284
back-riding	2.312	0.167	17.751	<b>0.004</b>
preening	26.008	<b>0.0009</b>	19.955	<b>0.003</b>

**TABLE 3.** Multiple univariate ANOVA exploration of significant interaction between time-activity budgets of downy young chicks and Hg burdens in their blood. (\* = pre and post-removal of a single outlier with high influence and leverage).



**FIGURE 1.** Least squares regression line trends in percent time spent preening and back riding by downy young (>12 d old) common loon chicks as a function of Hg concentration (ppm) of in their blood. Filled circles are actual values, squares are predicted values and the open circle in each graph is an outlying lake. Removal of the rightmost point in each graph show that the observation had some leverage and influence on the analyses, but did not significantly change the parameter estimates for both back-riding (Inclusion:  $\beta = -34.8 \pm 8.26$ ,  $t = -4.21$ ; Exclusion:  $\beta = -25.9 \pm 17.35$ ,  $t = -1.49$ ) and preening (Inclusion:  $\beta = 12.3 \pm 2.76$ ,  $t = 4.47$ ; Exclusion:  $\beta = 7.41 \pm 5.50$ ,  $t = 1.35$ ).

chicks back-riding (i.e. brooding by riding on a parent's back (McIntyre 1975)) ( $p = 0.004$ ) and a positive effect on time spent preening ( $p = 0.003$ ) (Figure 1). One observation had very high influence and leverage and was removed from this analysis (Table 3) and all further discussion. The chicks in this territory had very low mercury burdens yet spent little time back-riding (Figure 1). This territory had no secluded nursery areas and three large boat launches were present that created an inordinate amount of human disturbance. A second observation, with the lowest estimate of back-riding and highest of preening, had moderate leverage and influence, but was not removed from the analysis as excluding this point did not change the magnitude and direction of the regression coefficients (Figure 1). The point's leverage is owing to a lack of behavioral data from chicks with similarly high blood Hg.

We then tested for any relationship between modified behaviors and reproductive success estimates (Kerekes et al. 1994, N. Burgess unpub. data) from the same set of lakes. A marginal positive relationship ( $B=0.024$ ) of back-riding with the ratio of fledged chicks per hatched nest was revealed ( $F=3.79$ ,  $p=0.087$ ). Fledging rates (range: 0 - 1.67 fledged chicks/hatched nest) differed by ca. 1 chick per nest over the range of back-riding time observed (0 to 43%).

## DISCUSSION

Previous laboratory studies have shown that parent/offspring interactive behaviors are modified by *in vivo* mercury levels through decreases in responsiveness to parental vocalizations (Heinz 1979). Our results, which show that back-riding time decreases



as blood Hg increases, add to this argument as we believe that back-riding is a similar composite interactive behavior. Increases in preening may function either as a random displacement activity or result from increased exposure to wave action as time spent back-riding declines. However, a lack of correlation between back-riding and preening times, suggests that random displacement is more plausible.

We were unable to indubitably specify that Hg affects only chick behavior as the relationship between adult TABs and blood Hg approached significance. Future investigations might move toward developing a more sensitive assay for these behaviors to describe if chicks are soliciting rides less or the instances of adults offering them decreases as Hg increases.

Regardless, we suggest that these results support the hypothesis that loons are affected from exposure to elevated levels of bioavailable Hg (Meyer et al. 1995) through behavioral modifications. Brooding young by back-riding protects chicks from underwater predators, facilitates thermoregulation and serves as an energy-saving strategy (McIntyre 1975). Any reduction in the frequency of this behavior exposes young to increased predatory threat and increased energy expenditure. Increases in preening time also draw from the energetic supply of young. Concomitant increases in feeding or begging rates that would compensate for any increased energy expenditure were not observed. The marginal relationship between modified chick behaviors and reproductive success estimates adds further evidence that decreases in back-riding times may be affecting chick survival by any combination of these factors. We propose that this

relationship between back-riding times and fledging rate indicates a biologically significant effect that warrants further study.

Altered behaviors of chicks may serve as an indicator of sub-lethal Hg exposure on natal lakes and we now have indirect evidence that they serve as an indicator of survivorship. In addition, Barr (1986) found that Hg exposure from prey has a negative relationship with the occurrence of nesting. Without nesting, no chicks will be produced to serve as sub-lethal Hg exposure indicators. There is likely a critical threshold of Hg burden and altered loon behaviors (which serve as an indicator of sub-lethal exposure) and a higher threshold at which there is zero productivity. Loon chicks in this study with the highest Hg exposure of 1.29 ppm in blood, spent no time being brooded by parents (Figure 1). We suggest that exposure of this magnitude (1.25 - 1.50 ppm) is at, or near, a critical behavioral and/or lethal effect level for chicks.

Monitoring the behavior of animals can provide a sensitive indicator of the effects of toxins on an organism (Pfister et al. 1992). We propose that quantitative *in situ* observational methodology, such as we used, could be used in other taxa as indicators of environmental stress by toxicants. Behavioral studies of this sort do not preempt physiological investigations of organismal toxicity. Use of both methods in conjunction in laboratory or field studies can provide a means to accurately portray the full influence of animal intoxication (Cohn and MacPhail 1996).

## SPECULATION

We did not detect a response to Hg by adults, however the marginal relationship that was revealed may indicate an association. Perhaps chicks are back-riding less due to fewer solicitations or parents are decreasing the rate they offer rides, or perhaps it is a combination. However, we are certain that back-riding is affected and that chicks preen more often as Hg increases. How Hg elicits these responses is unknown to us. One plausible pathway is through endocrine dysfunction, which has been associated with Hg contamination in wildlife (Facemire et al. 1995, Hontela et al. 1995), especially in developing organisms, and subsequent lack of reproductive success. Future research should examine if endocrine dysfunction in loons with high Hg burdens is an issue and whether subsequent behavioral modifications of adults and/or chicks is primary or secondary to that dysfunction.

Recently described anthropogenic increases in environmental mercury contamination (U.S. EPA 1997) are likely associated with the high levels of Hg in the blood of loons in Kejimikujik and elsewhere, and surely extends to other top-end predators. Our demonstration of sub-lethal Hg-associated behavioral changes does not implicate any particular source of environmental Hg. However, we suggest that further control of mercury emissions from industrial sources would be a move towards prevention of further environmental degradation and adverse effects on wildlife. This research should provide an impetus for future investigation of *in situ* animal behavioral toxicology and the identification of the major Hg pollution sources in North America.

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## Chapter 2.

### **Behavior of post-nest failure and non-breeding Common Loons, *Gavia immer*, during the breeding season<sup>1</sup>**

**Abstract.-** Common Loon (*Gavia immer*) breeding, pre-migratory and wintering behavior has been well described, but no previous studies have characterized failed and non-breeding loon behavior during the summer breeding season. We quantified the behavior of non-breeding and failed breeding summering loons across 15 lakes in Kejimikujik National Park (Nova Scotia, Canada) and the Lepreau watershed (New Brunswick, Canada). Time-activity budgets and event quantifications were used to describe behavioral state and event patterns. The time of day that observations were made had no effect on states or events. Seasonal progression positively influenced the time spent swimming and the rate of peering events and we propose that such circannual changes indicate a move towards pre-migratory behavior. Non-breeders foot-waggled more than failed breeders, while splash-diving events were only exhibited by failed breeders (which may demonstrate a reduced form of territoriality). The behavior of failed and non-breeders in summer is remarkably similar to that described for pre-nesting, pre-migratory and wintering loons with foraging as the predominant behavioral state and peering the predominant event. We propose that allotted circannual foraging times are temporally fixed.

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<sup>1</sup> This chapter citable as : Nocera, J.J. and P.D. Taylor. *Submitted*. Behavior of post-nest failure and non-breeding Common Loons, *Gavia immer*, during the breeding season. Wilson Bulletin, March 1999.

## INTRODUCTION

Common Loon (*Gavia immer*) breeding behavior has been well described (Sjölander and Ågren 1972, McIntyre 1975, Evers 1994), as has the behavior of pre-migratory (McIntyre and Barr 1983) and wintering loons (McIntyre 1978, Daub 1989, Ford and Gieg 1995). However, no previous studies have quantified the behavior of failed or non-breeding loons during the summer breeding season. The paucity of such data was acknowledged by Evers (1994) when he posed the question "what is the distribution of time spent by loon pairs without nesting and chick rearing duties?". Evers (1994) compared his pre-nesting behavioral catalogues to the fall and winter catalogues described in previous studies (e.g. McIntyre 1978, McIntyre and Barr 1983) and stated that "time spent foraging is consistently between 50 to 60%. Would this hold true during the nesting and post-nesting periods for non-breeding loons..."? As part of a larger study, we examined the summer behavior of non-breeding and failed breeding loons at two selected sites in Atlantic Canada (Kejimikujik National Park, Nova Scotia, and the Lepreau watershed, southern New Brunswick) to test the hypothesis that behavior of non-breeding loons is similar to that of breeding loons at various concurrent breeding stages.

Common Loons in Kejimikujik have lately been the subject of intensive investigation (Kerekes et al. 1994, Evers et al. 1998, Nocera and Taylor 1998) as they have the highest blood mercury levels of any loon population tested to date in North America (Beauchamp et al. 1997). Behavioral variation in breeding loons exposed to high mercury levels in Kejimikujik and Lepreau have been described, but no relationship was found between the behavior of failed or non-breeding loons and any predictive

variable addressed by Nocera and Taylor (1998). Therefore, behavioral variation among failed and non-breeders may not be due to such extrinsic factors, but may be related to observational methodology, recent breeding history, or individual dissimilarities between the study subjects.

We tested these hypotheses through a comparative behavioral investigation of failed and non-breeding loons across a range of lakes in Kejimikujik and Lepreau. The results allow for a more complete description of circannual behavior for non-breeders and for those that have lost their nest, and broad comparisons with other lifecycle stages.

#### **STUDY AREA AND METHODS**

We catalogued behavioral states (Martin and Bateson 1993) (any behavior typically lasting longer than 5 s) of non breeding and failed breeding loons in Kejimikujik National Park, Nova Scotia, Canada (44° 20' N, 65° 20' W), and the Lepreau watershed, south-western New Brunswick, Canada (45° 20' N, 66° 35') using the time-activity budgeting (TABs) technique outlined by Altmann (1974) as used by Evers (1994) and Nocera and Taylor (1998). We quantified event behaviors (Martin and Bateson 1993) (any behavior typically lasting less than 5 s) to take into account subtler behaviors that are often overlooked in TABs.

Between 1996 and 1997, 47 pairs of resident Common Loons were selected during the spring pre-nesting season (in the course of a larger study). We had no way of *a priori* selecting lakes or pairs that would, or would not, breed. Twenty-one pairs did not subsequently breed, and we continued monitoring 14 of those pairs for the duration

of the summer. Six pairs bred but failed early in incubation, and we continued monitoring 4 of those pairs for the duration of the summer. The 14 non-breeding and 4 failed breeding pairs that we continued to monitor resided on 15 lakes with varied chemistry, morphometry, and descriptive biological characteristics.

All observations were made from a concealed location with 8x42 binoculars and/or a 20-60x spotting scope, between May and September of 1996 and 1997, with a total of 75 h of continuous observation (n = 108 observations, mean observation time = 41.7 min per bout). The majority of our study lakes were small (<100 ha) single-pair territories, with only 3 lakes having more than one pair.

To construct TABs, we quantified the following behavioral states: swimming (all active and passive locomotory behaviors such as swimming and drifting), preening, and diving. Territorial encountering, bill tuck and bathing were summed as "other". We declared swimming a conjugate category of swimming and drifting; we did not feel that we could accurately differentiate these activities into discrete states during field observation. Secondly, we quantified the following behavioral events: foot-waggle, stretching, vulture-posturing, splash-diving, peering, yawning, vocalizing (wails, tremolos, hoots, yodels and mews), penguin-dancing and rushing (Sjölander and Ågren 1972, McIntyre 1975).

Five predictive variables were used to test for effects of modified structure of TABs and event behavior catalogues: total time observed, time of day (as three categories (0600-1100, 1100-1600, and 1600-2100)), Julian date, territory, and recent breeding history. Julian date can be viewed as a substitute for concurrent breeding stage of

breeding loons on the same lakes. Individuals were only identified to within known residential pairs or "territories", as many of the study subjects were unbanded and identification of unmarked individuals was often impossible. Recent breeding history was described categorically as having not bred or as having failed.

We used MANOVA (MathSoft 1998) to test for associations between TABs and event behavior observations and the suite of predictive variables for each lake (total time observed, time of day, Julian date, territory, and recent breeding history). The total time observed was included as a predictive variable in the MANOVA, thereby weighting the analysis for differences between times observed. Pillai's criterion (Hair et al. 1987), which accounts for all characteristic roots, was used for significance testing in MANOVA with a Type-I error rate of 0.05 (Sokal and Rohlf 1995). Multiple univariate ANOVA (MathSoft 1998) was then used to elucidate which discrete behaviors (if any) were manifest as statistically significant effects in the MANOVA.

We also compared and contrasted our study to other studies of loons in winter (McIntyre 1978, Daub 1989, Ford and Gieg 1995), spring (Evers 1994) and fall (McIntyre and Barr 1983). All reported values were taken directly from the literature, except in cases where the authors' behavioral designations were not analogous to ours. Therefore, wherever possible, we summed certain categories of those authors to match our designations of behaviors.



## RESULTS

Non-breeding and post-failure loons at both sites spent their time foraging (56%), swimming (30%), preening (10%), and other (4%). All event behaviors occurred at least once; the predominant event was peering (19.2 events per h), followed by the tremolo vocalization (4.2 per h); stretching and foot waggling were equally common (3.0 per h). All other event behaviors were relatively rare (<1.0 event per hour).

We detected few differences between behavioral catalogues of failed and non-breeders, or among published catalogues of pre-nesting, post-nesting pre-migratory, and wintering loons (Fig. 1). The time-activity budget hierarchy we observed was similar to that described by McIntyre (pers. comm., 1978) for wintering loons (foraging > preening > swimming > other). McIntyre and Barr (1983) did not report complete TABs for loons on autumnal staging grounds, but they did note foraging as the predominant behavioral state. Spring TABs were described by Evers (1994) and his behavioral hierarchy observations are analogous to ours. Ford and Gieg (1995) reported that wintering loons spent most of their time foraging (followed by swimming, preening and other) which again resembles failed and non-breeding loon behavioral patterns in summer. However, Daub's (1989) report of swimming and drifting as the predominant wintering state differs from our results.

MANOVA revealed that, as expected, individual (i.e. "territorial") variation significantly influenced all states (Pillai = 2.07,  $p = 0.001$ ) and events (Pillai = 4.1,  $p = 0.001$ ). Total time observed influenced states (Pillai = 0.99,  $p = <0.001$ ) and events (Pillai = 0.51,  $p = <0.001$ ). Time of day that observations were made had no

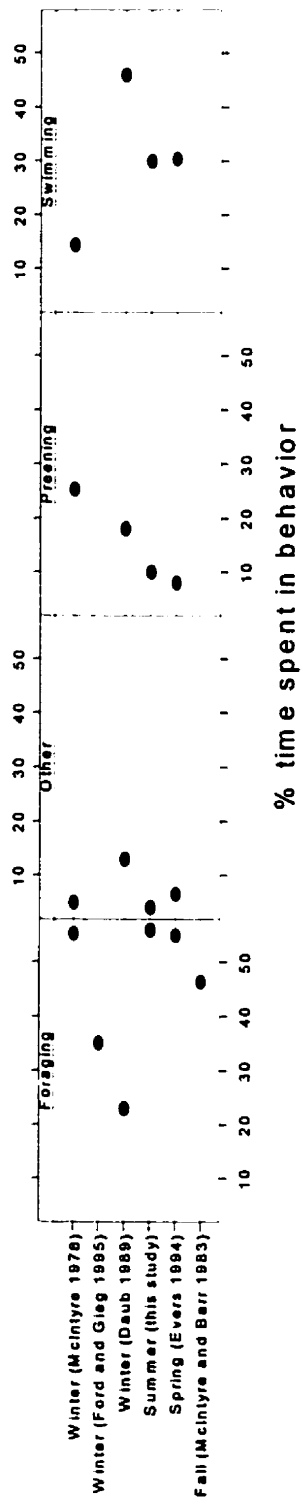


Figure 1. Comparisons of seasonal behavior descriptions for Common Loons (*Gavia immer*).

statistically significant effect on behavioral states (Pillai = 0.10,  $p = 0.16$ ) or events (Pillai = 0.11,  $p = 0.38$ ). Julian date significantly affected states (Pillai = 0.21,  $p = 0.01$ ) and events (Pillai = 0.36,  $p = 0.01$ ). Recent breeding history had a significant effect on events (Pillai = 0.43,  $p = 0.001$ ) but not on states (Pillai = 0.09,  $p = 0.33$ ). Further multiple univariate ANOVA of all significant MANOVA interactions revealed that individuals swam more as the season progressed ( $p = 0.003$ ) and the number of peering events increased ( $p = 0.007$ ). Non-breeders foot-waggled more often than failed breeders ( $p = 0.002$ ); failed breeders were the only ones to exhibit splash-diving ( $p = <0.001$ ).

## DISCUSSION

Breeding loons in our study sites exhibited aberrant behavioral patterns associated with increased mercury exposure (Nocera and Taylor 1998). However, behavior of failed and non-breeders was not sensitive to mercury exposure, lake chemistry, lake morphometry, or other measured biological characteristics of a territory (Nocera and Taylor 1998). This may be due to the freedom of non-breeders from performing parental duties, which require a complex suite of interactive behaviors (between individuals such as parent and chick). Most behaviors performed by non-breeders do not require as many complex additive components as parental functions (such as peering and swimming while a chick is on a parents back) .

We detected significant variation in TABs and events that was related to the individual pairs themselves. This was expected as it shows that apart from any extrinsic

effects, variation is intrinsic within individuals of a population (Martin and Bateson 1993). Time of day showed no effect on states or events.

Evers (1994) found that pre-nesting loons spent 53-57% of their time foraging, 29-32% swimming (sum of resting and locomotion), 8% preening and 4-5% other. Those results are very similar to the TABs we present of failed and non-breeders (56%, 30%, 10%, and 4% respectively) (Fig. 1).

We detected an increase in the amount of time spent swimming and drifting as the season progressed. We propose that this increase, combined with an increase in peering events (used often in social aggregations later in the breeding season (McIntyre 1988)), indicates a move towards pre-migratory behavior (where swimming may be a more sedentary behavior that allows an individual to interact more often with others).

Our results not only answer Evers' (1994) question regarding foraging time distribution of non-breeders, but go further in demonstrating that all behaviors, with the exception of swimming and drifting, remain evenly performed through equivalent breeding stages. Therefore, failed and non-breeding loons slightly modify their time-activity budgets during the nesting period by increasing the time spent resting. However, this increase may indicate an instinctive behavioral change timed with the onset of incubation in the concurrent breeding season.

The hierarchy of behavioral states we observed (foraging > swimming > preening > other) agrees with those discovered for wintering loons (McIntyre 1978, Ford and Gieg 1995), pre-migratory loons (McIntyre pers. comm., McIntyre and Barr 1983) and pre-nesting loons (Evers 1994) to the degree described by the respective authors (some did

not present complete time-activity budgets) (see Fig. 1). However, our results are very different from the wintering behavioral patterns described by Daub (1989) who found that drifting (equivalent to our designation of swimming) was the predominant behavior with less time devoted to foraging. One source of discrepancy may be that Daub (1989) used scan sampling (as did Ford and Gieg (1995)), whereas we used a continuous sampling scheme. Scan sampling does not usually offer the sensitivity necessary to describe actual activity patterns of animals (Winchell and Kunz 1993).

The strong similarities between the TABs of wintering, pre-migratory, pre-nesting, failed and non-breeding loons seem initially counter-intuitive. Evers' (1994) study site at Seney National Wildlife Refuge in Michigan consisted of shallow, eutrophic pools with few shoreline irregularities (D. Evers pers. comm.), while the wintering studies occurred at sea under highly variable conditions. Lakes in our Atlantic Canada study tend to be deep and oligotrophic with a high degree of shoreline complexity (Kerekes and Schwinghammer 1973). Additionally, there may be a difference in fish availability between these study sites which may affect the amount of time spent foraging. Also, differences in behavior of a species may vary between geographic regions (e.g. Zink 1989, Ely and Takekawa 1996). We propose that loons without parental responsibilities may be limited to a specific amount of time devoted to foraging each day, but may be able to vary the intensity of foraging by modifying the time spent submerged.

Splash-diving events were performed only by failed breeding loons, providing evidence that they may exhibit some reduced form of territoriality as has been

hypothesized by Rummel and Goetzinger (1975) and Belant (1992) for non-breeders. No territorial battles occurred with failed breeders, so the occurrence of splash-diving may act as the forerunner of aggressive displays that precludes actually engaging in them. That the majority of lakes in the study were single-pair lakes (where the probability of intruder visits is low) implies that this relationship may be more pronounced in an expanded survey of multi-pair lakes where confrontations are more likely.

One theorized advantage of intraspecific territoriality is protection of a territory's prey resource (Belant 1991). The subdued territoriality of non-breeders may be an artefact of their increased ability to forage elsewhere and lessened necessity to protect a home resource. It may also serve to "carry over" territory ownership and affinity during non-breeding years while a temporary pair bond is maintained.

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## Chapter 3.

### **Foraging efficiency of Common Loons, *Gavia immer*, exposed to elevated levels of mercury**

**Abstract.**-- Mercury is a global pollutant that negatively impacts visual function, breeding behavior, and development of animals. Common Loons (*Gavia immer*) are high trophic level, visually oriented predators sensitive to mercury (Hg) contamination. We tested the hypothesis that loons exposed to mercury alter foraging behavior to compensate for reduced visual acuity. We report that the dive duration and dive-pause components of the loon dive cycle are not modified to account for variation in Hg exposure, lake acidity, water color, fish abundance, or lake morphometry. Secondly, diving patterns were not significantly different among breeding categories. We propose that loons might otherwise alter their underwater hunting strategies to account for compromises in foraging ability, but they do not seem to alter their diving time budgets.

**Key words.**-- Common Loon; diving cycle; fish abundance; foraging efficiency; *Gavia immer*; Kejimikujik National Park; mercury exposure; visual acuity.

#### **INTRODUCTION**

Common Loons (*Gavia immer*) are upper trophic level piscivores known to be sensitive to environmental contaminants, especially mercury (Hg; Barr 1986,

Scheuhammer and Blancher 1994, Nocera and Taylor 1998). Variation in overall behavioral patterns of adult loons is not associated with Hg in their blood (Nocera and Taylor 1998), but exposure to increased Hg in prey is related to aberrant nesting behavior and low reproductive success (Barr 1986).

Exposure to high levels of Hg has a negative impact on the visual acuity of animals (Fox and Sillman 1979, Rice and Gilbert 1982). It has been suggested that such an effect should manifest itself by compromising the foraging efficiency of visual predators such as loons (McIntyre 1994). Hence, a compensatory change in foraging patterns should be observed, yet Nocera and Taylor (1998) found no association between Hg intoxication and the amount of time spent foraging by adult loons. Also, no change was seen in feeding rates to chicks that would suggest a change in adult foraging efficiency as Hg exposure increases.

Foraging patterns (dive cycles) of diving animals can be divided into two components: dive duration and the dive-pause (period between dives; as in Walton et al. 1998). The timing of these components may be modified to account for varying environmental conditions. Such compensation has been seen in diving waterfowl that exhibit longer dive durations with increasing water depth (Carbone et al. 1996). Alvo and Berrill (1992) found that breeding adults increase dive duration as prey becomes increasingly difficult to capture. Decreases in prey detectability are related to declines in fish abundance which have been associated with increased acidity of waterbodies (e.g. references in Eriksson 1985, Rees and Ribbens 1995, Hubert and Chamberlain 1996) and subsequent increases in water clarity (Dickson 1978). Prey detectability has not been



associated with negative impacts on Arctic Loon (*G. arctica*) reproduction (Eriksson 1985, 1986) but the effect on loon foraging patterns is unknown.

The time that loons devote to foraging is remarkably constant throughout the year (Nocera and Taylor *submitted*), suggesting that foraging is fixed temporally within and among seasons, with an inflexible minimum time apportioned to it. Therefore, quantifying the total time spent foraging may not provide a sensitive indicator of the relative stressors affecting an individual or their toxicant burden.

If loons experience a compromise in visual acuity from Hg intoxication, but are not varying the amount of time they spend foraging, an adaptation to such stressors may exist through increased dive duration and decreased dive-pauses. This study was initiated for the purpose of describing the foraging patterns of Common Loons residing on, or visiting, lakes with varying chemistry, morphometry, and physical characteristics in Kejimikujik National Park (Nova Scotia, Canada) and south-western New Brunswick (Canada). Our objectives were to describe (1) the effect of Hg on loon foraging patterns (2) what other variables best predict loon foraging patterns (3) the relationships between dive pattern parameters, and (4) the effect of breeding stage on the dive cycle.

## **METHODS**

As part of a larger study, we collected dive cycle data during foraging rounds (as defined in Strong and Bissonette 1989) of adult Common Loons and chicks in Kejimikujik National Park, Nova Scotia, Canada (44°20' N, 65°20' W), and the Lepreau

watershed, south-western New Brunswick, Canada (45°20' N, 66°35') between May and September of 1996 and 1997.

Between these two seasons, 40 known Common Loon territories (Kerekes et al. 1994) were selected in early May (prior to the nesting season). On those territories, 15 territorial pairs bred and hatched chicks, 15 pairs did not breed, 6 pairs bred but failed during incubation, and 4 small (>15 ha) lakes had no residential pairs but were regularly visited by foraging loons. Many of our study subjects were unbanded, rendering individuals within a pair unidentifiable. Dive cycles were not monitored if both adult members of a pair were foraging.

We employed continuous (Martin and Bateson 1993) diurnal observations, using a 20-60x spotting scope and/or 8x42 binoculars, from a covert lakeshore location, to collect a total of 1,656 dive durations and 1,505 dive pause times (N = 78 observational periods, mean foraging bout with timed dive cycles = 37.0 min). Dive cycles for adults with chicks were monitored only during the 40 d following hatch (1-12 d = downy young (DY), 13-40 d = small young (SY)). Observations were made of foraging adults at all other breeding and non-breeding stages: pre-nesting, foraging non-incubators (nesting), failed breeding, non-breeding, and foraging visitors. We were unable to collect sufficient data on chick diving patterns.

Water samples were collected from each lake in the late spring and fall of 1995 and 1996 to be analyzed for chemistry at Environment Canada's Environmental Quality Lab (Moncton, NB, Canada). We used the spring sampling values as they best described the lake composition at the onset of breeding and the concurrent trophic community.

In Kejimikujik (June and July 1997), 10 unbaited minnow traps were set between 1-5 m in each territory for 24 h. All fish captured were identified to species, measured (fork length) and classified to one of three size classes. We then calculated the mass of each fish from a standard estimate for each class and species. All mass calculations were then summed and indexed to obtain fish biomass estimates for each loon territory. Lepreau fish samples (June - August 1997) were likewise obtained (E. Barry and R.A. Curry unpub. data). All data were standardized on a catch-per-unit-effort basis.

We first assessed any potential relationship between dive duration and dive-pause with ANOVA (MathSoft 1998). We then used linear regression (MathSoft 1998) to model the variables of mean dive duration and dive-pause, counts (weighted by total time observed), variance, and variance:mean ratio for each with the terms of total time observed, time of day, shoreline complexity index and lake surface area (log) (both from Kerekes and Schwinghammer 1973), water color, pH, fish biomass, mercury in adult blood (sampled as in Evers et al. 1998), and parental responsibility categories (breeding stage / non-breeding / failed). These models were graphically diagnosed for fit (MathSoft 1998). Our small sample size did not allow the freedom to include breeding code (defined categorically in Table 1) in the saturated model. Therefore, all significant terms from any of the initial models were subsequently used in a restricted model, that also included breeding code, to define which term(s) best described the dive cycle. For all analyses, we set the maximum probability of a type-I error at 0.05 (Sokal and Rohlf 1995).

## RESULTS

The mean dive duration, dive-pause, and ratios for each breeding category of adults observed diving are shown in Table 1. No significant interaction was seen between mean dive duration and mean dive-pause (ANOVA;  $F = 0.17$ ,  $P = 0.68$ ).

*Saturated Models.* (Tables 2a and 2b; these models included all predictive variables except breeding code) Dive duration was not related to dive-pause or any other variable. Mean dive-pause was significantly associated with (log) surface area. pH was the best fitting term for both the counts of dives and dive-pause but was only marginally significant ( $P = 0.09$  and  $0.05$  respectively). Variance in dive duration was not significantly modeled by any term in the saturated model. However, the variance in dive-pause was significantly associated with (log) surface area. The [variance:mean dive duration] and the [variance:mean dive-pause] ratios were not significantly associated with any term in the saturated model.

*Restricted Models.* (Table 3; these models included all significant terms from the saturated models and breeding code) No diving variable was associated with breeding category or lake surface area (log). Total time observed showed an expected strong effect on the counts of dives and dive-pauses, whereas pH had only a marginally significant effect on both.

## DISCUSSION

No predictive variable we addressed was directly associated with dive pattern variation. Therefore, we did not detect any evidence to support the hypothesis that

Breeding Category	Mean Dive Duration (s) $\pm$ SE	Mean Dive Pause (s) $\pm$ SE	Dive:Dive-Pause
Pre-nesting adults	39.3 $\pm$ 2.4	17.1 $\pm$ 4.0	2.3 : 1
Non-incubating adults	42.6 $\pm$ 5.2	10.5 $\pm$ 1.0	4.1 : 1
Failed breeding adults	38.4 $\pm$ 2.6	11.0 $\pm$ 1.3	3.5 : 1
Non-breeding adults	34.3 $\pm$ 3.1	18.9 $\pm$ 4.9	1.8 : 1
Visiting foragers	49.6 $\pm$ 5.5	9.5 $\pm$ 1.3	5.2 : 1
$\Sigma$ Adults without chicks	39.1 $\pm$ 1.8	14.9 $\pm$ 2.1	2.6 : 1
Adults with DY	29.8 $\pm$ 6.9	14.1 $\pm$ 2.0	2.1 : 1
Adults with SY	61.2 $\pm$ 22.0	20.4 $\pm$ 0.9	3.0 : 1
$\Sigma$ Adults with chicks	43.3 $\pm$ 39.7	34.3 $\pm$ 6.0	1.3 : 1

**TABLE 1.** Mean dive duration, dive-pause, and their ratio for each breeding category of Common Loons observed diving.

Factor	Mean dive duration		Mean dive-pause		Dive counts / Total		Dive-pause counts /	
	F	p	F	p	F	p	F	p
Total time observed	0.34	0.57	3.06	0.12	NA	NA	NA	NA
Time of Day	0.36	0.56	0.28	0.61	0.76	0.4	0	0.99
Lake surface area (log)	0.4	0.54	<b>9.2</b>	<b>0.02</b>	0.11	0.75	0.09	0.76
Water color	0.18	0.68	0.24	0.64	0.65	0.44	1.6	0.23
pH	0.25	0.63	4.26	0.08	3.24	0.09	<b>4.22</b>	<b>0.05</b>
Fish biomass	0	0.98	2.77	0.14	0.73	0.41	3.1	0.1
Parental responsibility	0.01	0.94	1.92	0.21	1.57	0.23	0.95	0.35
Hg in adult blood	1.25	0.28	0.63	0.45	0	0.97	0.1	0.75
Hg in blood: parental responsibility	3.03	0.11	0.2	0.67	0.06	0.81	0.01	0.93

**TABLE 2A. F-values and associated probabilities for the saturated linear model with all diving variable means and counts (ANOVA).**

Factor	Variance of dive duration		Variance of dive-pause		Variance:Mean		Variance:Mean		Variance:Mean	
	F	p	F	p	F	p	F	p	F	p
Total time observed	0.15	0.71	0.01	0.92	0.05	0.84	0.53	0.49	0.53	0.49
Time of Day	1.9	0.2	0.6	0.46	0.79	0.39	1.26	0.3	1.26	0.3
Lake surface area (log)	0.22	0.65	<b>6.47</b>	<b>0.04</b>	0.13	0.72	5.08	0.06	5.08	0.06
Water color	0.36	0.56	1.17	0.32	0.21	0.65	2.21	0.18	2.21	0.18
pH	0.32	0.58	2.37	0.17	2.58	0.14	3.05	0.12	3.05	0.12
Fish biomass	0.53	0.48	0.09	0.77	2.03	0.18	0.03	0.87	0.03	0.87
Parental responsibility	0.12	0.74	0.44	0.53	0.45	0.52	0.87	0.38	0.87	0.38
Hg in adult blood	2.17	0.17	0.13	0.73	0.28	0.61	0.01	0.93	0.01	0.93
Hg in blood: parental responsibility	0.3	0.6	0.56	0.48	2.12	0.17	0.35	0.57	0.35	0.57

**TABLE 2B.** F-values and associated probabilities for the saturated linear model with variance estimates of all diving variables (ANOVA).

Response	Total Time			(log) surface area			pH			Breeding Code		
	F	p		F	p		F	p		F	p	
Mean dive duration	0.20	0.66	0.42	2.89	0.52	0.10	1.90	0.10	0.10	1.90	0.10	0.10
Mean dive-pause	0.75	0.39	1.05	0.00	0.31	0.98	1.79	0.13	0.13	1.79	0.13	0.13
Dive counts / Total time observed	<b>32.33</b>	<b>0.00</b>	<b>0.00</b>	<b>4.40</b>	<b>0.99</b>	<b>0.07</b>	<b>0.76</b>	<b>0.60</b>	<b>0.60</b>	<b>0.76</b>	<b>0.60</b>	<b>0.60</b>
Dive-pause counts / Total time observed	<b>18.79</b>	<b>0.00</b>	<b>0.35</b>	<b>4.30</b>	<b>0.56</b>	<b>0.06</b>	<b>0.80</b>	<b>0.58</b>	<b>0.58</b>	<b>0.80</b>	<b>0.58</b>	<b>0.58</b>
Variance of dive duration	1.01	0.32	0.05	1.75	0.82	0.19	0.19	0.98	0.98	0.19	0.98	0.98
Variance of dive-pause	0.00	0.96	1.74	0.01	0.20	0.94	1.08	0.39	0.39	1.08	0.39	0.39
Variance:Mean Ratio of dive duration	0.36	0.55	0.01	0.10	0.92	0.75	0.35	0.91	0.91	0.35	0.91	0.91
Variance:Mean Ratio of dive-pause	0.10	0.75	1.37	0.37	0.25	0.54	0.85	0.54	0.54	0.85	0.54	0.54

**TABLE 3.** F-values and associated probabilities for a linear model of diving variables restricted to total time observed, lake surface area, pH, and breeding code (ANOVA).



mercury burden may cause an adjustment in foraging patterns. Nor do our results support the suggestion of Alvo and Berrill (1992) that dive duration increases as prey becomes more difficult to capture because fish biomass was not a significant predictor in any of our models. Hence, the biomass of fish available to loons may alter the detectability of prey (as suggested by Eriksson 1985), but it is not associated with diving time budget changes. Loons may alter their underwater hunting strategies (such as switching to invertebrates) to account for decreased availability or detectability of fish. This supports Eriksson's (1986) reasoning for decreased prey detectability positively affecting Arctic Loon reproduction. We propose that (1) Alvo and Berrill (1992) observed an artefact of strategy change as chicks aged, shown by the increase in adult foraging time associated with older chicks, that is unrelated to available fish biomass; or (2) we had an insufficient sample size to detect differences in loon diving patterns across breeding categories.

It was usually impossible to distinguish between successful or unsuccessful dives and subsequent diving variables for loons without parental responsibilities, as they rarely surfaced with food items (most prey is swallowed underwater (Barr 1996)). However, Grant (1996) was able to quantify successful foraging at sea based on the theory that loons brought most food items to the surface that were too large to swallow underwater. However, this likely enormously underestimated his estimate of successful dives.

Stewart (1967) reported a dive:dive-pause ratio of 2.1:1 for loons at sea in winter and Dickson (1980) reported a mean dive duration of 46.6 s for post-breeding loons. These estimates closely resemble the means of our observations (Table 1). These similarities support the hypothesis of Nocera and Taylor (*submitted*) that overall foraging time is

circannually fixed, and suggests that the amount of time devoted to underwater foraging, and above water recesses, are likewise fixed for adult loons.

Nocera and Taylor (1998) found a significant effect of mercury burden on the overall behavior of young chicks. We did not collect sufficient data on chick diving, so we may have overlooked a potential effect of visual acuity compromise in chicks. Further studies should address the question of foraging efficiency and its relationship to toxicant exposure for chicks.

## General Discussion

Common Loon chicks decrease brooding time, and increase preening, as their exposure to Hg increases. This decline in brooding time is associated with a decrease in fledging success. As they spend less time on a parents' back, and more time on the lake surface (under their own power), they are exposed to predators such as Great Black-backed Gulls (*Larus marinus*) and Snapping Turtles (*Chelydra serpentina*) for longer periods. Secondly, they are not receiving greater thermal benefits of extended brooding, and expend more of their own energy. This increase in energy expenditure is not compensated for with increases in feeding or begging rates. Therefore, Hg exposure is compromising the health of these chicks at a very early, crucial stage in their development.

Adults do not seem to be adversely affected by Hg at the levels we observed. Breeding adults showed no behavioural sign of mercury intoxication. Non-breeding and failed breeding adults were likewise visibly unaffected. This is perplexing, as mercury in high doses is thought to prohibit nesting (Barr 1986, Scheuhammer and Blancher 1994), and birds that have not bred, or failed, are the most likely to have high blood Hg burdens. However, the sampling method used to capture loons (described in Evers et al. 1998) biases towards breeding adults and their young; non-breeding loons are unresponsive. If an improved capture method is developed, future studies could address the hypothesis that non-breeding adults should have the highest mercury burden within a population.

The hypothesis that mercury burdens negatively affect visual acuity was not supported in this study. I found no correlation between loon foraging patterns and

mercury exposure. Likewise, foraging patterns were not related to any other predictive variable addressed. Fish biomass variation may have altered the detectability of prey, but did not affect foraging.

Therefore, chicks at early developmental stages are a more sensitive indicator of Hg contamination than adults. This relationship is supported by laboratory research results (see review in Wren et al. 1995). I propose that Hg contamination in Kejimikujik has a negative impact on Common Loon chicks through a compromise in behavioural patterns and survivability. This trend may be immediately reversible if mercury contamination is derived through anthropogenic deposition where control of industrial output can be exerted.

#### Present Problems from a Historical Perspective

Gaviids have shown little morphological evolution since the Paleocene epoch (65 million years ago (Johnsgard 1987)). Therefore, it can be supposed that loon populations were able to adapt to most existing stressors and persist. However, loon populations in this century have been exposed to a multitude of novel anthropogenic insults, such as pesticide exposure (Sutcliffe 1978b), lakeside developments creating a loss of nesting habitat (Heimberger et al. 1983), lake impoundments with unpredictable water level fluctuations (Fair 1978), and numerous other abuses outlined by Vitousek et al. (1997).

The geographic range of Common Loons has decreased substantially continent-wide in recent decades (McIntyre 1994). This is presumably owing to the new suite of stressors impairing present populations, including lake acidification (Alvo et al. 1988),

human disturbance (Caron and Robinson 1994), and mercury poisoning (Barr 1986). A combination of stressors may be adversely affecting populations to a degree that may not have been encountered in their 65 million year history.

Loon populations are not currently classified as threatened, endangered, or a species of concern in Canada, but they are in some states (e.g. Michigan (Caron and Robinson 1994)). Therefore, this study, and companion studies (Evers et al. 1998, C.J. Counard pers comm.), have assumed a proactive direction while loon populations are still stable enough to potentially counteract any detrimental influences. This is rare, as research of anthropogenically afflicted wildlife tends to be reactive, as in the case of the Piping Plover (*Charadrius melodus*) and Leatherback Turtle (*Dermochelys coriacea*).

I have shown that mercury negatively impacts the survivability and behaviour of young loons in Nova Scotia. These changes may be evident in other areas where Hg burdens are considered high (e.g. Wisconsin; Meyer et al. 1995). Other top-end predators, such as eagles, otters, and some freshwater fish are likely at equal risk to mercury contamination (Wolfe et al. 1998).

Such information was in demand when the U.S. Environmental Protection Agency (1997) collated the best available science on mercury contamination in a report to Congress, proposing the limitation of industrial mercury output in the continental U.S.. A similar action was taken in Canada with the signing of legislation by the New England Governors and Eastern Canadian Premiers Task Force on Mercury (Hamilton et al. 1998), where Hg outputs in the participating provinces and states will be cut by 50% before the year 2003. Such limitation of mercury deposition is certainly a positive move for

wildlife conservation. However, more information must be collected before the most appropriate management decisions can be made.

### Future Directions

*Focused future studies.* Despite the small sample sizes and the high number of predictive variables used in this thesis, I was able to elucidate certain statistically significant relationships between loon behaviour and contamination, averting a Type II error in these cases only. However, no comprehensive power analysis (Sokal and Rohlf 1995) of my data was performed and Type II error may have occurred in analyses where a statistically significant result was not obtained. However, given that I have shown a significant interaction between mercury and certain aspects of behaviour, future work can now test explicit hypotheses on mercury and loon behaviour which should entail *a priori* power analyses.

*Mercury.* Loons in the Kejimikujik ecosystem have the highest blood Hg levels in the continent. Yet, the toxicant's origin is unknown. Leaching of bedrock-bound mercury can occur over time, drawn by the acidic water washing over it (Plouffe 1995). However, Hg in Kejimikujik could also, and likely does, originate via industrial anthropogenic sources. Future studies should address the source of mercury for contaminated sites such as Kejimikujik.

Chicks exhibit behavioural effects of Hg at an early stage in their development. This finding answers Meyer's (1998) challenge "...a chronic exposure...controlled field study to develop a MeHg dose-response curve for a fish-eating avian species would

provide a relevant avian test dose". However, I was unable to determine if the ultimate cause of decreased brooding by chicks was a decreased desire to back-ride, or the adults offering more infrequently. A more sensitive behavioural assay needs to be done to describe the mechanism leading to decreased brooding times and ultimate productivity declines.

*Geographic variation.* Future investigators may want to secure the opportunity to compare behaviour across large geographic regions. I did not assess the possibility of geographic variation (including each study site as a geographic covariate in analyses) as the distance between the two sites (< 150 linear km) did not present an appropriate condition for such. Secondly, Hg levels between the two sites differed greatly, and to a degree, categorised those sites. Geographic clines in loon behaviour have never been noted, and were they to be, would likely be manifest only in a broader geographic region where the location is not confounded within other predictive variables such as Hg.

*Lake acidification, water chemistry, and fish abundance.* Lake acidity effects on territory choice, breeding and productivity have been well studied (e.g. Eriksson 1984, Parker 1988, Alvo et al. 1988). These studies have shown that pH is tightly correlated with water colour, fish abundance, and Hg (Wren et al. 1995). Yet, I found no resulting behavioural effects of any of these variables on adult loons. It is counter-intuitive that behaviour does not vary according to fish abundance. Twenty-nine lakes in Kejimikujik harbour 13 species of fish (Kerekes 1983). Yellow perch (*Perca flavescens*) and American eels (*Anguilla rostrata*) are found in all lakes (Kerekes 1983). However, brook trout (*Salvelinus fontinalis*) and white perch (*Morone americana*) are found in no

fewer than 19 of these lakes (Kerekes 1983), yet our fish biomass sampling failed to catch these species. Therefore, either these species have been extirpated from all the lakes we sampled, or (more likely) the sampling scheme was biased towards yellow perch.

Yellow perch is a favoured loon prey item (Barr 1996). However, loons will opportunistically prey upon salmonids, or other fish species, if readily available (Barr 1996). Lakes that are the most acidic in Kejimkujik harbour only yellow perch and eels, both acid-tolerant species (Kerekes 1983). On more alkaline lakes, there may be fewer yellow perch because of competition with other species. Therefore, the actual fish biomass of each lake in Kejimkujik may be quite similar, yet our results “show” a difference. Future studies might want to assess a combination of fish biomass and fish species diversity to calculate an index more applicable to applied behavioural questions that might reflect the effect of fish availability more accurately.

Furthermore, Eriksson (1986) suggested that loon prey detectability is related to water colour and fish abundance. pH is negatively correlated to water colour and positively correlated to fish species diversity (Kerekes 1983, Alvo et al. 1988). Secondly, pH is a mitigating factor for the relative toxicity of bioavailable mercury (Wren et al. 1995). This combination of factors should decrease the relative detectability of prey for loons. However, neither Eriksson (1985, 1986) or myself have been able to find any negative impacts associated with relative estimates of prey detectability. This may be due to, as Eriksson (1986) suggests, a change in foraging strategies where loons may switch to other primary prey species such as invertebrates. For loons, this hypothesis has never been tested, and such a dietary change has never been empirically observed.



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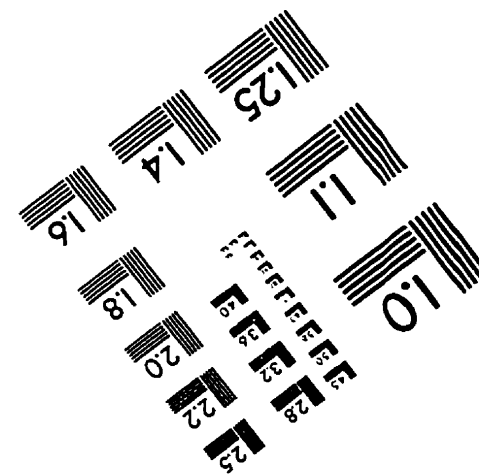
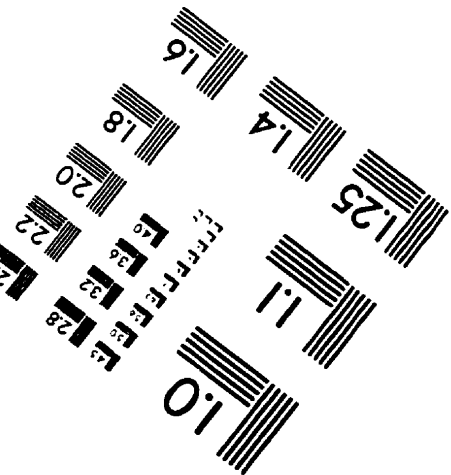
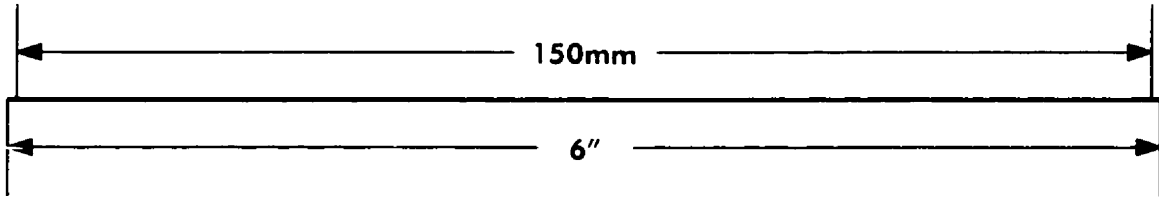
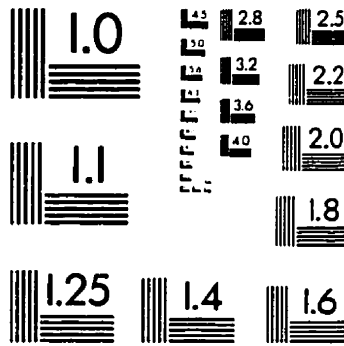
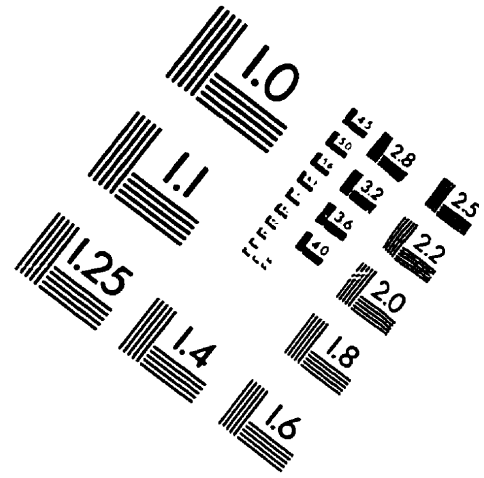
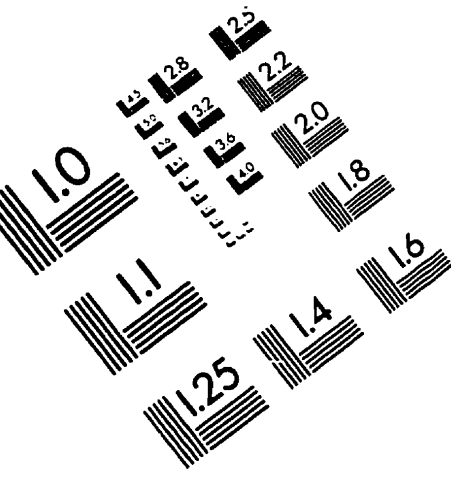


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