WATER QUALITY AND THE SUMMER DISTRIBUTION OF COMMON LOON IN NEW YORK

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The Common Loon (*Gavia immer*) is dependent on water: it feeds in water, sleeps on water, vocalizes from water, and raises its chicks on water (Olson and Marshall 1952). It is so poorly adapted for terrestrial locomotion that its common name derives from the old English word, *lomme*, as in lummox (Thomson 1989). The Common Loon appears on land only to construct its nest and incubate its eggs on the shores of its summering lakes (Olson and Marshall 1952). In North America, it spends the breeding season on freshwater lakes across the northern United States and Canada. In winter, it can be found on coastal waters from Baja California to the Aleutian Islands in the West and from the Gulf of Mexico to Labrador in the East (Scott 1987, A.O.U. 1983).

In this study, I examined the connection between the quality of freshwater lakes and the summer distribution of Common Loons by analyzing 107 lakes in New York. I used information gathered by the New York State Department of Environmental Conservation (hereafter DEC) on the use of these lakes by loons and combined it with 37 lake- and water-quality parameters from each lake collected by the U.S. Environmental Protection Agency (hereafter EPA). My goals were to determine if certain lake- and water-quality parameters differed between lakes occupied and lakes not occupied by loons, and whether these parameters could be used to predict the presence of loons on these lakes.

Recent work on loons and water quality has centered around acid deposition and whether changes in lake acidity have affected loon populations. Parker (1988) found that the acidity of lakes in this same region, the Adirondacks, had no significant effect on loon reproductive success. He did find that lake acidity affected adult feeding behavior of chicks in that the adults fed chicks prey items that were smaller or larger than those normally preferred on neutral lakes. Alvo *et al* (1988) examined an area in Canada that was more severely acidified than those examined by Parker, and suggested that greater brood mortality on acidic lakes could be attributed to a shortage of food for the young. They also concluded that successful breeding was associated with large, clear, high-alkalinity lakes, while lack of breeding was associated with small, brown, low-alkalinity lakes. Both studies noted that loons continue to breed on marginal quality, critically acidified lakes rather than move to areas where food is readily available.

This study examines the link between Common Loon distribution and water quality by looking at 37 lake- and water-quality measurements. The procedure uses only those parameters that were available through the EPA study and does not involve all factors that may affect loon distribution in summer, including some that have already been shown to be important, such as shoreline development (*i.e.,* how convoluted the shoreline is, Dahmer 1986), availability of islands (Olson and Marshall 1952), and recreational pressure (Titus and VanDruff 1981). Though these factors were not considered, distinct patterns in loon distribution can still be delineated.

MATERIALS AND METHODS

I used logistic regression to examine the association between the Common Loon distribution information collected by the DEC and the lake- and water-quality information gathered by the EPA.

Loon Distribution: I obtained information on the summer distribution of loons from a report by the DEC (Parker *et al* 1986). I used all possible information provided by the report including the initial DEC survey from the summers of 1977-1979, surveys by DEC crews in the summers of 1984 and 1985, and surveys by Adirondack Loon Preservation Project Volunteers during the summers of 1983-1985. Generally, the surveyed lakes were larger than 10 ha. I classified all lakes on which loons had never been sighted as non-occupied lakes (n=49), lakes on which loons had been sighted at least once but had shown no evidence of breeding as having loons present (n=23), and lakes on which loons had shown breeding activity at least once, as evidenced by nests or chicks, as breeding lakes (n=35).

Water Quality: I gathered water quality information from the EPA sponsored Eastern Lakes Survey Phase I, which was part of the EPA's National Surface Water Survey and a contribution to the National Acid Precipitation Assessment Program (Linthurst *et aL* 1986). This survey, which was conducted in the fall of 1984, involved sampling over 1700 randomly selected lakes larger than four ha in surface area in the eastern United States. Physical parameters of the lake, such as elevation, lake area, and watershed area were determined from USGS topographic maps. Water quality characteristics were gathered by landing fixed-pontoon helicopters on the lakes at the apparently deepest part where most samples were taken from the helicopter, 1.5 m below the surface of the water.

The characteristics that were measured included acid neutralizing capacity, calcium, calculated conductance, the ratio of cations to anions, chloride ion, dissolved inorganic carbon, closed system pH, true color, dissolved organic carbon, elevation of the lake surface, air-equilibrated dissolved inorganic carbon, air-equilibrated pH, extractable aluminum, total dissolved fluoride, dissolved iron, bicarbonate ion, lake hydrologic type, dissolved potassium, lake surface area, measured conductance, dissolved magnesium, dissolved manganese, dissolved sodium, ammonium ion, nitrate ion, Secchi disk transparency (Secchi depth), dissolved silica, depth at sampling site (site depth), sulfate ion (SO_4),sum of anions, sum of cations, surface temperature, total aluminum, total phosphorous, turbidity, ratio of watershed area to lake area, and watershed area. For details concerning the methods used in sampling these characteristics, see Linthurst *et al* (1986).

Statistical Analysis: The combination of the Common Loon distribution information and the water-quality survey provided a sample size of 107 lakes: 35 lakes with evidence of breeding loons, 23 with loons present but having no indication of their breeding, and 49 not occupied by loons. This information was analyzed using logistic multiple regression provided by the MIDAS (Michigan Interactive Data Analysis System) statistical package at the University of Michigan. Logistic multiple regression differs from multiple linear regression in that it requires only two states for the response variable (loons or no loons) and that the restrictions concerning the normality of data are relaxed (Cox 1970, McCullagh 1980, Smith 1981). Logistic multiple regression allows prediction of the probability a lake of being in one group versus another, for example, whether a lake is occupied or not occupied by loons, based on the values of the independent variables in the equation. I assume that the probability of being in one group, for example, a lake not occupied by loons, is of the form $e^{xß}/(1+e^{xß})$, where xß is a linear combination of the predictors. The probability of being in the other group is then $1-[e^{xß}/(1+e^{xß})]=1/(1+e^{xß})$. In this form, xß is the logarithm of the probabilities of the two outcomes (loon-occupied, not loon-occupied) (cf. King *et al.* 1988). In this particular instance, xß is taken as a linear combination of lake- and water-quality parameters:

$$xß=a+ß_1x_1+ß_2x_2+....ß_ix_i$$

where a is some constant, x_i is the value of a specific lake- or water-quality parameter, and $ß_i$ is a coefficient.

The method of maximum likelihood was used to estimate a and the coefficients $ß_1...ß_i$ such that the likelihood (reconstructed probability) of the data as they were actually observed was a maximum. This reconstructed probability is the product of terms like $1/(1+e^{xß})$ for loon-occupied lakes and terms like $e^{xß}/(1+e^{xß})$ for unoccupied lakes. The method of maximum likelihood supplies approximate statistical significance tests for the logistic multiple regression as a whole (that is, the probability that the water quality parameters have nothing to do with loon presence or absence) as well as partial significance tests for each coefficient ß in the formula for the logs-odd x (King *et al* 1988). Problems with correlated variables may arise in multiple logistic regression models. In this case, variables with correlation coefficients of more than .50 were not used in the same model.

I compared lakes occupied by loons with breeding activity (n=35) to those where loons had only been spotted but had shown no evidence of breeding (n=23). A variable by variable comparison, using logistic regression, showed no substantial differences in these two sets of loon-occupied lakes and, consequently, I combined these two groups into one large group representing lakes where loons were present.

I compared lakes on which loons were present (n=58) to those where they had never been seen (n=49) using logistic regression on a variable by variable comparison. Few water quality factors proved to be different between these two groups of lakes, so factors that demonstrated a trend towards being different (indicated by $p<.1$) were flagged for use in developing a model of loon presence and absence. I used these water quality parameters in a multiple logistic regression model. To find the best model possible, I employed the Wald Test in which the variables that provided the least information to the model were deleted if the absolute value of the ratio of their estimated coefficient under the model and their asymptotic standard deviation was less than one (TenHave *pers. comm.*, Cox 1970, McCullagh 1980, Smith 1981).

Finally, this 'best model' was subjected to a validating jackknife procedure (TenHave *pers. comm.*). In this procedure, data from individual lakes were deleted from the data set one lake at a time, and the model was recalculated without the information concerning that particular lake. Then, a prediction was made as to whether loons would or would not occupy that lake based on the model derived from all the other lakes. This prediction was then compared to the actual observation as to whether loons actually did occupy the lake. Thus, I could determine whether the prediction from the model concerning the lake was correct and calculate a percentage of correctly classified lakes.

RESULTS

Differences between lakes where Common Loon breeds and does not breed: Lakes with breeding loons (n=35) had significantly lower levels of total dissolved fluoride than lakes with loons that showed no evidence of breeding (n=23) (x=2.997 μeq/l *vs.* x=3.991 μeq/l, p=.0134). Because this was the only discernible difference these two groups were combined into one group of loon-occupied lakes to increase sample size.

Differences between loon-occupied lakes and non-occupied lakes: In New York, most lake- or water-quality parameters did not differ between lakes that were occupied by loons (n=58) and lakes not occupied by loons (n=49). None of the following characteristics showed significant differences (p<.05) in levels between lakes occupied by loons and non-occupied by loons: elevation of the lake, watershed area, the ratio of watershed to lake surface area, surface temperature, depth of the sampling site, Secchi depth, turbidity, color, iron, sum of anions, sum of cations, the ratio of cations to anions, air-equilibrated pH, closed system pH, acid neutralizing capacity, measured conductance, calculated conductance, dissolved organic carbon, extractable aluminum, total aluminum, calcium, magnesium, sodium, potassium, ammonia, sulfate, bicarbonate, chloride ion, nitrate ion, total dissolved fluoride, total phosphorous, silica, and manganese.

The only characteristic that differed significantly at the 95 percent confidence level between lakes occupied by loons and not occupied by loons, was surface area: loons occupied lakes with significantly larger surface areas. Loons tended to occupy lakes with lower levels of measured conductance, calculated conductance and chloride ion. They also occupied lakes with higher levels of total dissolved fluoride and silica. Although these factors were only significantly different at the 90 percent level; they were combined with lake area in a multiple logistic regression model (Table 1).

The model for predicting Common Loon presence or absence: The backwards stepwise logistic multiple regression of the water quality characteristics indicated that the amount of total dissolved fluoride, the measured conductivity, the lake area, and the amount of silica were the best predictors, in that order, of loon presence or absence on a lake in New York (see Fig. 1). These four variables, when combined, explained 53 percent of the variance and were significantly related (p=.010) to lake use. For discrimination between loon-occupied lakes and non-occupied lakes, the best expression for log-linear modeling of odds ratios was obtained by:

$$P(\text{Loon Occupied}) = 1/(1 + e^{x\beta})$$

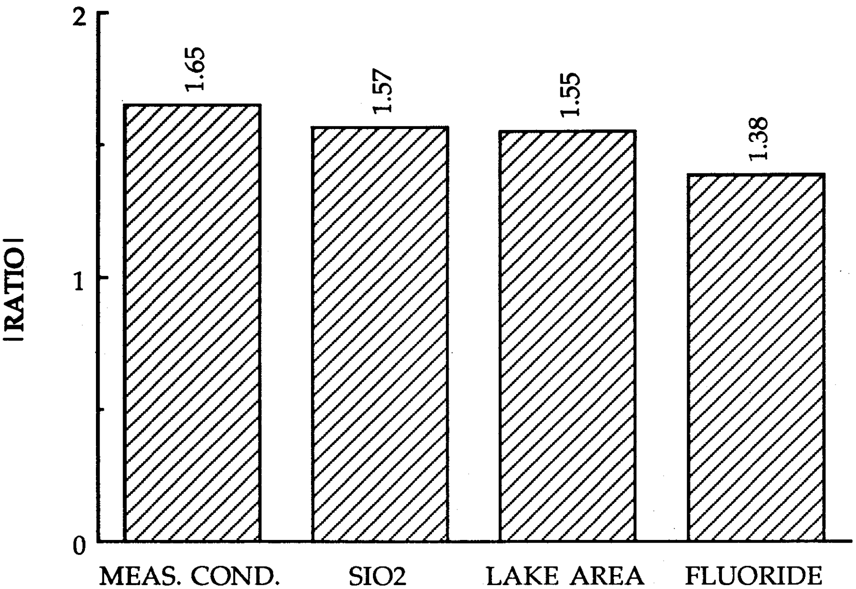

Figure 1. The relative value, as indicated by the absolute valuable under the model and its asymptotic standard deviation, of water quality parameters best predicting occupancy of lakes in New York by the Common Loon.

	n=58	n=49	
Parameter	**Loon Occupied ±s.e.**	**Not Occupied ±s.e.**	**p-value**
Surface Area	**141 ha ±36.7**	**56 ha ±13.9**	**.021**
Measured Conductivity	**29.2 µS/cm ±.24**	**36.2 µS/cm ±4.20**	**.086**
Calculated Conductivity	**29.5 uS/cm ±1.71**	**36.8 m ±4.33**	**.086**
Chloride Ion	**22.3 µeq/l ±5.28**	**43.9 ëq/l ±.13.06**	**.086**
Total Dissolved Fluoride	**3.4 µeq/l ±.20**	**2.9 µeq/l ±.19**	**.087**
Silica	**3.01 mg/l ±.282**	**2.33 mg/l ±.231**	**.067**

Table 1. Lake and water quality parameters with trends toward differences between lakes occupied and not occupied by Common Loon in New York.

where $x\beta$ =.3771 - .002946 [lake area (ha)] + .02627 [measured conductance (µS/cm)] -.20724 [total dissolved fluoride (µeq/l)] - .1750 [silica (mg/l)]

The validating jackknife procedure classified 57.9 percent of the lakes correctly.

DISCUSSION

In the Adirondack Mountains of New York, Common Loon generally uses lakes larger than 100 ha in area regardless of their water quality. The fact that loons are using larger lakes probably reflects their feeding requirements. Barr (1973) estimated that a pair of loons and a chick would eat 430 kg of fish, usually Yellow Perch, in a season. Their preference for lakes with large surface areas probably reflects the fact that larger bodies of water tend to produce greater fish yields than smaller ones (Youngs and Heimbuch 1982).

In developing a single multivariate model, the best predictors of loon use of a lake in New York were measured conductance, silica, lake area, and fluoride, in that order. Though surface area was the only factor that was significant at the 95 percent confidence level by itself, in this specific combination of factors it ranks as third in importance. These factors indicate that loon-occupied lakes tended to be larger with lower conductivities and higher levels of silica and fluoride. The inclusion of conductance in the model introduces a conglomeration of correlated factors. Conductance is a measure of the resistance of the water column to the flow of electricity. Consequently, it is related to the concentrations of the major ions in the water. In New York, conductance was correlated to bicarbonate, dissolved inorganic carbon, acid neutralizing capacity, magnesium, chloride ion, and potassium. It was inversely correlated to elevation and the level of manganese. This suite of factors may point to lower productivities on loon-occupied lakes, but the pattern is not clear, especially since many of these factors did not appear individually as significantly different between lakes occupied and not occupied by loons.

The lack of any other definitive differences between loon-occupied and non-occupied lakes probably reflects a uniformity of lakes in the region. In other states, I have found that factors such as lake productivity, lake depth, and water clarity differ between lakes occupied and not occupied by loons. This leads me to suspect that most lakes in thi region meet the criteria loons use to determine suitability and, conseq dispersed among these lakes.

Unfortunately, loons apparently have no ability to discriminate between the more subtle differences in lakes, including some human-induced changes in water quality. In the Adirondacks, the most important human-induced changes are those brought about by acid deposition. My findings support both Parker's (1988) and Alvo *et al.*'s (1988) contentions that loons attempt to breed and raise young on highly acidified lakes despite a lack of food. Evidence for this point of view is further enhanced by the fact that, for those lakes analyzed here, no substantial differences existed between lakes where loons displayed breeding activity and where they were merely reported as present. In other words, under today's conditions, those factors that I have identified as related to loon distribution are apparently not related to breeding success among those lakes.

Future work on the distribution of loons in the Adirondacks should focus on anthropogenic influences, including summer home development, public access, motorized boat use, and the effects of airborne pollutants.

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LITERATURE CITED

Alvo, R., D. J. T. Hussell and M. Berrill. 1988 The breeding success of common loons (*Gavia immer*) in relation to alkalinity and other lake characteristics in Ontario. *Can. J. Zool.* 66:746-752.

American Ornithologists Union. 1983. *Check-list of North American Birds.* 6th ed. Washington, DC: American Ornithologists Union.

Barr, J. F. 1973. Feeding biology of the common loon (*Gavia immer*) in oligotrophic lakes of the Canadian Shield. Ph.D. thesis, Univ. Guelph, Ontario.

Cox, D. R. 1970. *The Analysis of Binary Data.* Methuen:London.

Dahmer, P. A. 1986. Use of aerial photographs to predict lake selection and reproductive success of common loons in Michigan. Master's thesis, Univ. Mich., Ann Arbor. 41 pp.

King, C. Li, G. M. Glazer, L. E. Quint, I. R. Francis, A. M. Aisen, W. D. Ensminger, F. L. Bookstein. 1988. Distinction of hepatic cavernous hemangioma from hepatic metastases with MR imaging. *Radiology* 169:409-415.

Linthurst, R. A., D. H. Landers, J. M. Eilers, D. F. Brakke, W. S. Overton, E. P. Meier, and R. E. Crowe. 1986. Characteristics of lakes in the eastern United States. Volume 1. Population descriptions and physico-chemical relationships. EPA/600/4- 86/007 U.S. Environmental Protection Agency, Wash. DC, 136 pp.

McCullagh, P. 1980. Regression models for ordinal data (with discussion) *J. Roy. Stat. Soc. - Series B* 42:413-418.

Olson, S. T. and W. M. Marshall. 1952. The common loon in Minnesota. *Occas. Pap. Minn. Mus. Nat. Hist.* 5:1-77.

Parker, K. E. 1988. Common loon reproduction and chick feeding on acidified lakes in the Adirondack Park, New York. *Can. J. Zool.* 66:804-810.

Parker, K. E., R. L. Miller and S. E. Isil. 1986. Status of the Common Loon in New York State. N. Y. State Dept. Env. Cons., Div. Fish and Wildlife, Nongame Unit, Wildlife Resources Center, Delmar, N. Y. 73 pp.

Scott, S. L., ed. 1987. *Field Guide to the Birds of North America.* National Geographic Society: Washington, DC. 464 pp.

Smith, D. W. 1981. Properties of a Model for Ordered Categorical Dependent Variables. University Microfilms, Inc. Ann Arbor, MI.

Thomson, K. S. 1989. The common, but less frequent, loon. *Am. Scientist* 77:67-9.

Titus, J. R. and L. W. VanDruff. 1981. Response of the common loon to recreational pressure in the Boundary Waters Canoe Area, Northern Minnesota. *Wildl. Monogr.* 79:1-60.

Wetzel, R. G. 1983. *Limnology.* W. B. Saunders College Publishing, Philadelphia. 767 pp.

Youngs, W. D. and D. G. Heimbuch. 1982. Another consideration of the morphoedaphic index. *Trans. of the Am. Fisheries Soc.* 111:151-153.

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