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## LAKE FEATURES, WATER QUALITY AND THE SUMMER DISTRIBUTION OF COMMON LOONS IN NEW HAMPSHIRE

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Abstract.—Logistic regression was used to analyze the association between 37 lake- and water-quality characteristics and the summer presence or absence of Common Loons (*Gavia immer*) on 87 lakes in New Hampshire. The goal was to determine whether these characteristics differed between lakes occupied and not occupied by loons, and whether these characteristics could be used to predict the occurrence of loons on lakes. The results indicate that, in contrast to non-occupied lakes, loons frequented lakes that had significantly larger surface areas and sampling site depths. Also, these lakes were clearer, warmer and less productive. The individual best predictors of loon use of a lake, in decreasing order of importance, were lake area, iron, surface temperature and sampling-site depth.

**ATRIBUTOS DE LAGOS, CALIDAD DEL AGUA, Y DISTRIBUCIÓN DE *GAVIA IMMER* DURANTE EL VERANO EN NEW HAMPSHIRE.**

Sinopsis.—Se utilizó regresión logística para analizar la asociación entre 37 lagos-y las características de la calidad del agua, y la presencia o ausencia de *Gavia immer* durante el verano, en 87 lagos de New Hampshire. La meta fue determinar si estas características diferían entre lagos ocupados y no-ocupados por los somormujos, y si las mismas podían ser utilizadas para predecir la presencia de estas aves en dichos cuerpos de agua. Las aves frecuentaron lagos que tenían significativamente una mayor área superficial y mayor profundidad en los lugares de muestreo, en contraste con los lagos no-ocupados. Además los lagos utilizados resultaron ser menos productivos, más templados y con aguas más claras. Los mejores factores de pronóstico en el uso de lagos por parte de los somormujos en orden decreciente resultaron ser, área, cantidad de hierro disuelto, temperatura superficial y profundidad en el área de muestreo.

Common Loons (*Gavia immer*) are always on water except when they are copulating, incubating or flying. They spend the breeding season on freshwater lakes where they sleep, care for young, maintain territories, and feed (Olson and Marshall 1952). Consequently, the topographical

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features of lakes and the quality of lake waters should play an important role in the summer distribution of Common Loons.

In this study, I examined the connection between various measures of the quality of freshwater lakes and the summer distribution of Common Loons by analyzing 87 lakes in New Hampshire. I used information gathered by the Loon Preservation Committee in New Hampshire on the use of these lakes by loons, and combined it with 37 lake- and water-quality characteristics on each lake collected by the U.S. Environmental Protection Agency (EPA). My goal was to determine if certain lake- and water-quality characteristics were associated with occupancy by loons and whether these characteristics could 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. One study, which looked at the presence and absence of loons on lakes in southern Quebec, concluded that loons tend to be found on larger lakes at lower altitudes with lower levels of acidity, though loons were sometimes found on lakes with moderate levels of lake acidity (DesGranges and Darveau 1985). Parker (1988) found that the acidity of Adirondack lakes 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. Alvo et al. (1988) examined an area in Canada that was more severely acidified, 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 Parker (1988) and Alvo et al. (1988) noted that loons continue to breed on marginal quality, critically acidified lakes rather than moving to areas where food is readily available.

This study analyzes only those lake- and water-quality measurements that were available through the EPA study, and does not involve all factors that may affect the summer distribution of Common Loons, 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), cottage development (Heimberger et al. 1983), and recreational pressure (Titus and VanDruff 1981).

## METHODS

I combined loon distribution information collected by the Loon Preservation Committee of New Hampshire with lake- and water-quality information gathered from the U.S. EPA, and examined it for trends using logistic regression.

*Loon distribution.*—The information provided by the Loon Preservation Committee of New Hampshire addressed loon distribution information for all of the lakes in the EPA survey for the years 1984–1988 (Loon

Preservation Committee 1984, 1985, 1986, 1987, 1988). I classified all lakes on which loons had not been seen in all five years as not occupied ($n = 61$), lakes on which adult loons had been sighted but with no evidence of breeding over the 5-yr period as lakes with loons present but no breeding ($n = 11$), and lakes on which loons had attempted to breed at least once during the 5-yr period as breeding lakes ($n = 15$).

*Water quality.*—I obtained the water quality information from the U.S. EPA-sponsored Eastern Lakes Survey-Phase I, which was part of EPA's National Surface Water Survey and a contribution to the National Acid Precipitation Assessment Program (Linthurst et al. 1986). This survey was conducted in the fall of 1984 and involved sampling over 1700 lakes randomly selected in the eastern United States that were larger than 4 ha in surface area. Physical parameters of each lake, such as elevation, lake area and watershed area, were determined from U.S. Geological Survey topographic maps. Water quality characteristics were gathered by landing fixed-pontoon helicopters on the lake at the apparently deepest part and taking most samples 1.5 m below the surface.

The characteristics 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, lake hydrologic type, dissolved potassium, lake surface area, latitude, longitude, conductance, dissolved magnesium, dissolved manganese, dissolved sodium, ammonium ion, nitrate ion, Secchi disk transparency, silica, depth at sampling site, sulfate ion, sum of anions, sum of cations, surface temperature, total aluminum, total phosphorus, 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 loon distribution information and the water quality survey provided a sample size of 87 lakes: 15 lakes with evidence of breeding by loons, 11 lakes occupied by loons but showing no evidence of breeding and 61 not occupied by loons.

This information was analyzed using multiple logistic regression. Multiple logistic regression is different 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). Multiple logistic regression allows prediction of the probability of being in one group versus another based on the values of the independent variables in the equation. I assumed that the probability of being in one group, for example a lake not occupied by loons, is of the form $e^{x\beta}/(1 + e^{x\beta})$, where $x\beta$ is a linear combination of the predictors. The probability of being in the other group is then $1 - [e^{x\beta}/(1 + e^{x\beta})] = 1/(1 + e^{x\beta})$. In this form, $x\beta$ is the logarithm of the probabilities of the two outcomes (loon-occupied, not loon-occupied) (cf. King et al. 1988). In this particular instance, $x\beta$ is taken as a linear combination of lake- and water-quality parameters: $x\beta = a + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_i x_i$ where a is some constant, $x_i$ is the value of a specific lake- or water-quality parameter and $\beta_i$ is a coefficient.

The method of maximum likelihood was used where a and the coefficients $\beta_1 \ldots \beta_i$ were computed so 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 $1/(1 + e^{x\beta})$ for loon-occupied lakes and terms like $e^{x\beta}/(1 + e^{x\beta})$ 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) and partial significant tests for each coefficient $\beta$ 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 0.5 were not used in the same model.

First, I compared lakes occupied by loons with breeding activity ($n$ = 15) to those where loons had only been spotted but had shown no evidence of breeding ($n$ = 11). Next, I combined these two groups into one large group representing lakes where loons were present ($n$ = 26) and compared them to those where they had never been seen ($n$ = 61) using logistic regression on a variable-by-variable comparison. Several water-quality factors proved to be different between these two groups of lakes.

I used the significant water-quality parameters in a multiple logistic regression model. To find the best model possible, the variable that provided the least information in the model, as shown by the ratio of its estimated coefficient under the model and its asymptotic standard deviation, was deleted. This procedure was repeated until the deletion of a variable indicated a significant change in the model as indicated by a significant increase in the difference between the two likelihoods for the models using the likelihood-ratio test statistic (Cox 1970, McCullagh 1980, Smith 1981). As a procedure, this is roughly analogous to the parametric backwards, stepwise, multiple linear regression.

Finally, this best model was subjected to a validating jacknife procedure (Gong 1986). In this procedure, data from one lake were deleted from the data set and the model was recalculated without information concerning that particular lake. Then, for that lake, a prediction was made as to whether loons would occupy that lake or not, based on the model for all the other lakes. This model-based prediction was then compared to whether loons actually did occupy the lake. Consequently, 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 on which loons breed and do not breed.*—The comparison of single water quality parameters between lakes on which loons were reported to have shown breeding activity ($n$ = 15) to those lakes on which loons had been merely seen but did not display any evidence of breeding ($n = 11$) resulted in no significant differences between these two groups in any lake- or water-quality parameter.

*Differences between loon-occupied lakes and non-occupied lakes.*—Many lake- or water-quality parameters did not differ between lakes in New Hampshire that were occupied by loons ($n = 26$), and lakes not occupied by loons ($n = 61$). None of the following showed significant differences ($P > 0.05$): elevation of the lake, watershed area, the ratio of watershed to lake surface area, turbidity, 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, sodium, sulfate, chloride ion, nitrate ion, total dissolved fluoride and silica.

Several physical measures were significantly different between lakes occupied by loons and not occupied by loons (Table 1). Loons frequented lakes with relatively large surface areas and depths at the sampling site, which was at the apparently deepest part of the lake as viewed from the helicopter; higher surface water temperatures as measured shortly after fall turnover; deeper Secchi depths; lighter-colored waters; and lower levels of air-equilibrated dissolved inorganic carbon, closed-sample dissolved inorganic carbon, bicarbonate, ammonia, total phosphorus, potassium, iron, magnesium and manganese.

*The model for predicting loon presence or absence.*—The stepwise logistic multiple regression of the water quality parameters indicated that lake area, the level of dissolved iron, the depth of the lake at the sampling site and the surface temperature of the lake were the best predictors, in that order, of loon presence or absence on lakes in New Hampshire (see Fig. 1). These four variables, when combined, explained 73% of the variance and were significantly ($P < 0.00005$) related 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:

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

where $x\beta = -6.0174 - 0.0433$ [lake area (ha)] + 0.033606 [dissolved iron ($\mu$g/l)] + 0.1571 [site depth (m)] + 0.574 [surface temperature (°C)]. The validating jacknife procedure classified 81.5% of the lakes correctly.

## DISCUSSION

*Lake size and food: area, depth, surface temperature.*—The results of this analysis show that three of the four best predictors for loon use of a lake are physical qualities of the lake. Loons are using larger, deeper and warmer lakes in New Hampshire. The combination of a large surface area and a deep lake implies these lakes have a larger volume and a larger fishery (Youngs and Heimbuch 1982). Loons require large amounts of food in the breeding season. Barr (1973) estimated that a pair of loons and two chicks consume 430 kg of fish in a season. The need for a large lake by loons is confirmed by Alvo et al. (1988) who concluded that

TABLE 1. Lake- and water-quality characteristics (mean ± SE) with significant differences between lakes occupied and not occupied by loons in New Hampshire.

| Parameter | Loon Occupied $n = 26$ | Not Occupied ($n = 61$) | $P$-value |
|---|---|---|---|
| Surface area | 275 ± 109.6 ha | 33 ± 4.7 ha | <0.00005 |
| Sampling site depth | 8.1 ± 1.1 m | 5.5 ± 0.5 m | 0.006 |
| Surface temperature | 12.4 ± 0.24°C | 11.8 ± 0.16°C | 0.045 |
| Secchi depth | 4.4 ± 0.39 m | 3.0 ± 0.22 m | 0.002 |
| Color | 19 ± 2.8 PCU | 34 ± 3.6 PCU | 0.002 |
| Ammonia | 1.2 ± 0.13 μeq/l | 2.4 ± 0.43 μeq/l | 0.002 |
| Total phosphorus | 6.2 ± 0.82828 μeq/l | 10.1 ± 1.0320 μeq/l | 0.003 |
| Potassium | 11.6 ± 1.5332 μeq/l | 18.0 ± 1.342 μeq/l | 0.012 |
| Eq. dissolved inorganic carbon | 0.94 ± 0.117 mg/l | 1.68 ± 0.325 mg/l | 0.044 |
| Closed dissolved inorganic carbon | 1.19 ± 0.129 mg/l | 2.27 ± 0.367 mg/l | 0.004 |
| Bicarbonate | 72.5 ± 9.9292 μeq/l | 137.6 ± 30.813 μeq/l | 0.047 |
| Dissolved iron | 32.7 ± 6.6909 μg/l | 103.7 ± 18.527 μg/l | <0.00005 |
| Magnesium | 40.4 ± 4.03 μeq/l | 61.7 ± 7.65 μeq/l | 0.021 |
| Manganese | 13.3 ± 3.25 μeq/l | 29.7 ± 5.43 μeq/l | 0.020 |

breeding success of loons was connected to both the depth and surface of a lake.

The surface temperature of the lake may be related to the presence of yellow perch (*Perca flavescens*) which are the primary food of loons (Barr 1973). Perch are traditionally known as cool water fish, as opposed to the cold water rainbow trout (*Oncorhyncus mykiss*), and tend to occupy areas only a few degrees warmer than trout (Magnuson et al. 1979). Barr (1973) concluded that loons prefer trout to perch, but the burst speed of trout is too quick and too straight for loons to make efficient captures in most instances (McIntyre 1988).

*Clarity: Secchi depth, color.*—The second most significant factor is that loons are occupying lighter, clearer lakes as indicated by Secchi depth and water color. The birds may be selecting lakes where their hunting can be more successful because they pursue their prey, mainly fish, by sight (Barr 1973, Eriksson 1985).

*Productivity: $NH_4$, P, K, $CO_2$, $HCO_3$, metals (Fe, Mg, Mn).*—The last significant trend apparent in these data, as indicated by a combination of factors, is productivity. Loons occupied lakes with lower levels of ammonia and phosphorus, both of which imply lower primary productivity. Ammonia is the most significant source of nitrogen for plankton, while phosphorus is generally correlated to lake productivity and is most often the limiting factor in a lake's primary productivity (Wetzel 1983). Both of these are factors that are likely to affect the metabolism, and clarity, of the lake.

Loons also occupied lakes with lower amounts of dissolved inorganic carbon and bicarbonate. Algae and macrophytes need free inorganic car-

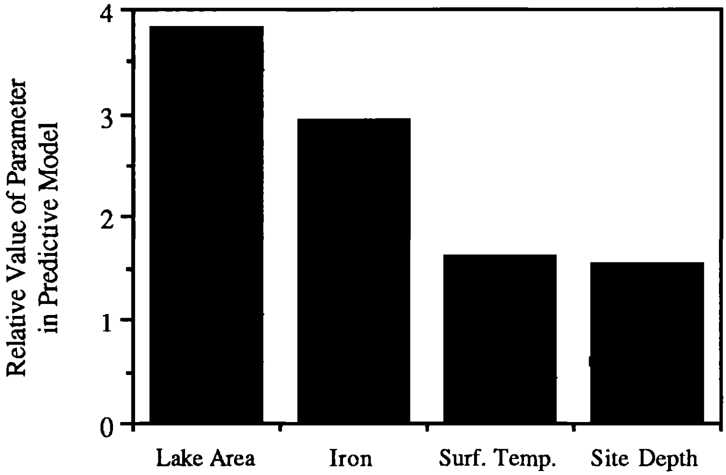


FIGURE 1. The relative value (the absolute value of the ratio of the estimated coefficient for the variable under the model and its asymptotic standard deviation) of water quality parameters best predicting occupancy of lakes in New Hampshire by Common Loons.

bon to grow in a lake but usually phosphorus or nitrogen are the limiting factors to their growth, not carbon dioxide (Wetzel 1983). Consequently, though these factors point to a lake's productivity, they may not be controlling it.

Loons occupied lakes with lower levels of potassium, iron, manganese and magnesium, all of which may affect primary productivity. Iron may be a micronutrient and limit algal production (Wetzel 1983). Similarly, magnesium is a micronutrient required by the enzymes used in photosynthesis, but in most lakes the demand for magnesium is much less than the amount available (Wetzel 1983).

Loons are thus occupying lakes with lower productivities. This tendency may be another indication of loons' preference for clearer lakes because more productive lakes tend to be less clear with their abundant growth of algae and other phytoplankton.

Loons apparently are occupying lakes with differing characteristics that may be at odds with one another. The distribution of loons represents a distinct compromise in that loons are occupying large lakes with their inherently larger fisheries but are also occupying clearer, less productive lakes so that they can be more successful in their hunting. These are not opposing standards; loons need a large fishery in lakes that are clear as well.

The tendency for loons to occupy clearer lakes may also be complicated by the fact that highly-acidified lakes are often strikingly clear, which would be good for hunting, except that they can also be devoid of fish. Thus, acid deposition in these watersheds may prove harmful to loon populations in the future.

*Loon distribution in New Hampshire.*—The information gained from this analysis must be considered in light of the current distribution of loons in New Hampshire. The loon population is sparse and occupies a fraction of its former range. This suggests that the loons may select the lakes they occupy, and in that way they may indicate a preference for different lake and water-quality characteristics. On the other hand, many small New Hampshire lakes are subject to strong human recreational pressure. Few, or no, suitable nesting sites may be available on these lakes and, consequently, loons may be absent from them. From this view, factors other than those analyzed may be affecting the distribution of loons in the state. This dichotomy, choice due to a small population vs. lack of choice due to human recreational pressure, only confirms that the qualities that appear as significantly different in this analysis are factors that are significant regardless of other factors, like human recreational pressure, which were not analyzed.

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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.

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

COX, D. R. 1970. The analysis of binary data. Methuen, London, United Kingdom.

DAHMER, P. A. 1986. Use of aerial photographs to predict lake selection and reproductive success of common loons in Michigan. M.S. thesis. Univ. Michigan, Ann Arbor, Michigan.

DESGRANGES, J. L., AND M. DARVEAU. 1985. Effect of lake acidity and morphometry on the distribution of aquatic birds in southern Quebec. Holarctic Eco. 8:181–190.

ERIKSSON, M. O. G. 1985. Prey detectability for fish-eating birds in relation to fish density and water transparency. Ornis. Scand. 16:1–7.

GONG, G. 1986. Cross-validation, the jacknife, and the bootstrap: excess error estimation in forward logistic regression. J. Amer. Stat. Assoc. 81:108–113.

HEIMBERGER, M., D. EULER, AND J. BARR. 1983. The impact of cottage development on common loon reproductive success in central Ontario. Wilson Bull. 95:431–439.

KING, C. L., G. M. GLAZER, L. E. QUINT, I. R. FRANCIS, A. M. AISEN, W. D. ENSMINGER, AND 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. Vol. 1. Population descriptions and physico-chemical relationships. EPA/600/4-86/007 U.S. Environmental Protection Agency, Washington D.C. 136 pp.

LOON PRESERVATION COMMITTEE. 1984. Annual report 1984. Meredith, New Hampshire. 7 pp.

———. 1985. Annual report 1985. Meredith, New Hampshire. 6 pp.

———. 1986. Annual report 1986. Meredith, New Hampshire. 5 pp.

———. 1987. Annual report 1987. Meredith, New Hampshire. 8 pp.

———. 1988. Annual report 1988. Meredith, New Hampshire. 8 pp.

MAGNUSON, J. J., L. B. CROWDER, AND P. A. MEDVICK. 1979. Temperature as an ecological resource. Amer. Zool. 19:331–343.

McCULLAGH, P. 1980. Regression models for ordinal data (with discussion) J. Royal Stat. Soc. Series B 42:413–418.

McINTYRE, J. W. 1988. The common loon: spirit of northern lakes. Univ. Minnesota Press, Minneapolis, Minnesota. 229 pp.

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.

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

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 Publ., Philadelphia, Pennsylvania. 767 pp.

YOUNGS, W. D., AND D. G. HEIMBUCH. 1982. Another consideration of the morphoedaphic index. Trans. Amer. Fisheries Soc. 111:151–153.

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