Hydrobiologia (2006) 567:215–226
A.R. Hanson & J.J. Kerekes (eds), Limnology and Aquatic Birds
DOI 10.1007/s10750-006-0043-1

Factors influencing productivity of common loons (*Gavia immer*) breeding on circumneutral lakes in Nova Scotia, Canada

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Key words: acidity, common loon, dissolved organic carbon DOC, fledging success, *Gavia immer*, human disturbance, lake, pH, productivity, reproductive success, shoreline development

Abstract

Common loons (*Gavia immer*) are top predators that are sensitive to biotic and abiotic conditions associated with their breeding lakes, so factors such as lake chemistry and human activity or disturbance are thought to influence their seasonal and long-term reproductive success. We used two indices of loon productivity to evaluate (1) temporal patterns and (2) relationships with physical and chemical lake characteristics and human activities. Data collected from 1991 to 2000 by volunteers of the Canadian Lakes Loon Survey (CLLS) in Nova Scotia showed that loon productivity, as indexed by both the proportion of resident pairs that produced at least one large young (P_{s1}) and the proportion of successful pairs that produced two large young (P_{s2}), did not vary substantially from year to year and showed no linear trend from 1991 to 2000. Average estimates (1991–2000) for P_{s1} and P_{s2} were 0.49 ± 0.02 and 0.43 ± 0.03, respectively, and the mean number of chicks per residential pair over that time was 0.75 ± 0.04. We found that human disturbance and shoreline development did not influence loon productivity during the prefledging stage on lakes surveyed by CLLS volunteers. Proportion of resident pairs rearing at least one large young was independent of dissolved organic carbon (DOC) concentrations of breeding lakes, but there was a positive relationship between the proportion of successful pairs rearing two large young and DOC. Both indices of loon productivity tended to be negatively correlated with lake pH. These results were not consistent with other findings that loon productivity generally declines with lake acidity, but likely reflect the preponderance of circumneutral (pH 6.5–7.0) lakes surveyed by the CLLS volunteers in Nova Scotia.

Introduction

Common loons, *Gavia immer* (Brünnich) (hereafter loons), are often top predators in freshwater environments where they breed. Because of this, factors that influence this species' reproductive success have been studied in attempt to use loons as a bioindicator of lake health (Strong, 1990; Wayland & McNicol, 1990; McNicol et al., 1995). As such, many studies have identified a variety of biotic and abiotic factors that influence loon survival and reproductive success (see review by McIntyre & Barr, 1997), including predation (McIntyre, 1975, 1988a; Sutcliffe, 1980; Titus & VanDruff, 1981; Yonge, 1981; Belant & Anderson, 1991), weather (McIntyre & Barr, 1997), water-level fluctuations (Vermeer, 1973; Fair, 1979; Sutcliffe, 1980; Barr, 1986; McIntyre, 1988b; Belant & Anderson, 1991), anthropogenic influences (Vermeer, 1973; Sawyer, 1979; Robertson & Flood, 1980), and limnological parameters (Alvo et al., 1988; Wayland & McNicol, 1990; McNicol et al., 1995).

Breeding loons and humans often come into contact because both are attracted to the same lakes during summer. Construction of homes, boat docks, and retaining walls on lakes where loons prefer to nest can cause nesting habitat destruction and increased disturbance, both of which can reduce pair densities and chick production (Tate & Tate, 1970; Vermeer, 1973; McIntyre, 1975, 1988a). Typically, there is a positive correlation between intensity of shoreline development and recreational use and human disturbance rates of lakes (Heimberger et al., 1983). Human disturbance and watercraft use on lakes may lower nest attentiveness of adults and thus increase nest predation (Robertson & Flood, 1980; Titus & VanDruff, 1981; Heimberger et al., 1983; Ruggles, 1994). During the prefledging period, human activities can reduce feeding opportunities of chicks (and adults) and increase the possibility of loon/boat collisions or abandonment of young (McIntyre, 1988a; McIntyre & Barr, 1997; but see Titus & VanDruff, 1981; Belant & Anderson, 1991; Caron & Robinson, 1994; Ruggles, 1994), all of which may ultimately reduce loon productivity on lakes.

It has been known for decades that deposition of acid precipitation can lower pH in lakes and may result in reduced abundance and diversity of fish and other prey favoured by loons (Dillon et al., 1984; Schindler, 1988), which in turn can lower loon reproductive performance and chick survival (Alvo et al., 1988; Wayland & McNicol, 1990; McNicol et al., 1995; but see Parker, 1988). Acidification also tends to increase bioavailability of methyl-mercury in aquatic environments (Spry & Wiener, 1991; Wiener et al., 2002), and mercury concentrations in fish often are elevated in acidic lakes (Schuehammer & Blancher, 1994; Schuehammer & Graham, 1999; Carter et al., 2001). In turn, bioaccumulation of mercury by loons and other piscivorous birds may impair their behaviour, survival, or reproductive success (Burgess et al., 1998b; Meyer et al., 1995, 1998; Nocera & Taylor, 1998; Wiener et al., 2002).

Organic carbon concentrations (Dissolved Organic Carbon (DOC) and Total Organic Carbon (TOC)) in lakes can influence bioavailability of methyl-mercury, but their role in doing so is not entirely understood (Carter et al., 2001; Rencz et al., 2003). Large organic carbon concentrations in the water-column can facilitate mercury transport within watersheds (Mierle, 1990; O'Driscoll & Evans, 2000) and enhance bacterial production of methyl-mercury (Hecky et al., 1991; Miskimmin et al., 1992). Yet under some conditions DOC may act to reduce bioavailability of mercury to fish (Driscoll et al., 1995; Choi et al., 1998; Scheuhammer et al., 1998; Rencz et al., 2003), and thus top-level predators such as loons. Thus, investigating correlations between loon productivity and DOC concentrations within breeding lakes is interesting given the complex associations among DOC, methyl-mercury, and loon productivity (Burgess et al., 1998a, b).

The purpose of our study was to first describe temporal patterns of loon productivity from 1991 to 2000 using data collected by volunteers of the Canadian Lakes Loon Survey (CLLS) in Nova Scotia. Second, we evaluated the influence that chemical attributes of lakes (pH and DOC) and human activity (shoreline development and disturbance indices) had on loon productivity. We hypothesized that loon productivity would be (1) positively correlated with lake pH (i.e., higher on lakes that were less acidic) and (2) lower on lakes that had higher disturbance regimes and more highly developed shorelines. Given the complex associations among DOC, pH, methyl-mercury, and loon productivity, we had no clear expectation as to how DOC may affect loon productivity.

Methods

Reproductive performance

The CLLS is a long-term monitoring program that strives to maintain survey coverage of loon breeding lakes by the same volunteers for several consecutive years (see McNicol et al., 1995). Data included in this paper were collected on loon breeding lakes in Nova Scotia, Canada, from 1991 to 2000. Prior to their inaugural survey season, participants of the CLLS selected a lake (or sometimes part of very large lakes) at which they would survey and observe adult and young loons throughout the breeding season. From early June through mid-September volunteers recorded numbers of resident pairs (displaying breeding behaviour and/or territoriality; nesting period) and downy/small (<2/3 adult body length;

hatching period) young and large (≥2/3 adult body length; prefledging period) young. Volunteers were required to survey lakes (or their section of large lakes) at least three times during the breeding season (nesting [early June–mid-July], hatching [early–late July], and prefledging [mid-August–mid-September] periods) in an attempt to obtain the best estimate of maximum numbers of resident pairs and young on their survey areas; most volunteers, however, collected data more frequently (e.g., weekly, biweekly, etc.) than the minimum requirements. If no pairs or young were present on lakes, volunteers also reported that information each year the lake was surveyed. Data meeting eligibility and quality requirements were used to derive two indices of loon productivity:

$$P_{s1} = N_{s1}/N_{pr} \text{ and } P_{s2} = N_{s2}/N_{s1},$$

where P_{s1} is the proportion of resident pairs that reared at least one large young to pre-fledging age and P_{s2} is the proportion of successful pairs that produced at least two large young. N_{s1} and N_{s2} are the number of pairs observed with at least one large young and two large young, respectively, and N_{pr} is the total number of resident pairs on a lake. To better compare our productivity estimates to those of other studies, we also calculated annual and 10-year (1991–2000) averages for the number of large young per resident pair (McIntyre, 1988a; McIntyre & Barr, 1997).

Human disturbance & shoreline development

Each year, volunteers estimated the percentage of shoreline on lakes that was developed (e.g., cottages, houses, marinas). Lakes were assigned to one of five categories that each represented a 20% increase (i.e., 0–20%, 21–40%, 41–60%, 61–80%, 81–100%) in shoreline impacted by human development. Each month throughout the breeding season, volunteers assigned levels (1–8) of human activity and watercraft disturbance to lakes as follows: (1) no people, no boats; (2) people but no boats; (3) occasional use of boats/canoes without motors; (4) frequent use of boats/canoes without motors; (5) occasional use of boats with motors; (6) frequent use of boats with motors; (7) occasional water skiing and/or boat racing, and (8) frequent water skiing and/or boat racing. Although there was little variation in activity indices among summer months (CLLS, unpubl. data), we used the highest disturbance category recorded annually at each lake for analyses. For analyses, the original eight categories were combined into three broader ones, where categories 1–3, 4–6, and 7–8 became indices of low, moderate, and high disturbance, respectively.

Chemical and physical characteristics of lakes

Personnel of the Canadian Wildlife Service of Environment Canada collected the majority of the limnological data in this study (N. Burgess, pers. comm.). For some lakes, however, volunteers collected water samples using an established protocol; those samples were sent to an environmental water chemistry laboratory in Dorset, Ontario for determination of limnological values. In our analyses, mean pH and DOC values were used as explanatory variables in linear logistic regression models because (1) data for these chemical variables were not measured or available on an annual basis for each lake, (2) most lakes only had one pH or DOC measurement taken during the 1991–2000 study period, and (3) lake-specific pH showed little annual variation in Nova Scotia in general over the period of study (Clair et al., 2002). Lake surface areas (hectares) were obtained from the Gazetteer of Canada (Natural Resources Canada, 1997) and were log-transformed ($\log_e$) to normalize error distributions of those data.

Data available for statistical analyses

Loon productivity data (young per resident pairs) were available for 223 (497 annual volunteer reports) lakes in Nova Scotia, but that number varied from year to year depending on volunteer participation. In total, there were 59 (247 reports) and 47 (126 reports) lakes where pH and lake area and where DOC and lake area were available for analyses for P_{s1} and P_{s2}, respectively. There were 111 (321 reports) and 81 (167 reports) lakes where human disturbance/watercraft activity index and lake surface area data were available for analyses for P_{s1} and P_{s2}, respectively. In addition, there were 114 (322 reports) and 81 (162 reports) lakes where shoreline development index and lake surface area data were available for analyses for P_{s1} and P_{s2}, respectively.

Statistical analyses

Proportions reflecting breeding successes or failures of loons on lakes (i.e., P_{s1} and P_{s2}) approximated a binomial distribution and were treated as events/trials in all analyses. Generalized Linear Models (PROC GENMOD; SAS Institute Inc., 2001), which assumed a binomial error distribution and a linear logistic response probability distribution (i.e., logit link function: log [mean/1−mean]), were used to evaluate effects of pH (continuous), DOC (continuous), human activity/watercraft disturbance (categorical index), and shoreline development (categorical index), while controlling for year (categorical) and lake area (continuous), on each of the two indices of loon productivity (P_{s1} and P_{s2}). Lakes were treated as repeated clusters (*n*) in analyses to account for within-lake correlations in productivity (because pairs often return to the same lake each year to breed (McIntyre & Barr, 1997)) by using Generalized Estimating Equations (GEE). Evaluation of degrees of freedom and deviance indicated overdispersion in both P_{s1} and P_{s2} (Collett, 1991), so we used the DSCALE option in PROC GENMOD (SAS Institute Inc., 2001) to account for overdispersion. Standardized residuals were plotted against continuous variables of interest to evaluate fit of linear logistic models (Collett, 1991); doing so showed that all models specified adequately fit these data. Only main effects models were evaluated and statistical significance ($p \leq 0.05$) of those effects were assessed using score statistics from Type III GEE analyses. Temporal trends (year: continuous variable) and annual variation (year: class variable) in (1) numbers of resident pairs that raised at least one large young to prefledging age and (2) numbers of successful pairs that reared two large young to prefledging age were examined using Generalized Linear Models (PROC GENMOD; SAS Institute Inc., 2001) that assumed a Poisson error distribution and where lakes were treated as repeated clusters. As stated above, over-dispersion was accounted for and statistical effects were deemed significant at $p \leq 0.05$. Unless otherwise stated, means and parameter estimates are reported to ±1 SE.

Results

Temporal variation in adult loon productivity

Linear logistic regression analysis using the entire CLLS Nova Scotia data set (i.e., not constrained to include only lakes with matching pH, DOC, and lake area data) consisting of 283 lakes for P_{s1} and 180 lakes for P_{s2} showed that the proportion of resident pairs that reared at least one large young to prefledging age and proportion of successful pairs that reared two large young to prefledging age was stable (year linear effect, $p > 0.10$ for P_{s1} and P_{s2}) through time and did not vary annually (year class effect, $p > 0.10$ for P_{s1} and P_{s2}) (Fig. 1a, b). Over the 10-year period, the average proportion of resident pairs that reared at least one large young was 0.49 ± 0.02 and proportion of pairs that reared two large young was 0.43 ± 0.03 (Fig. 1a, b). Given these estimates, about 28% of resident pairs raised one large young and 21% of resident pairs, on average, raised at least two large young to prefledging age. There were, on average, 0.75 ± 0.04 chicks per resident pair (Fig. 1c); annual average estimates ranged from a low of 0.50 ± 0.13 chicks per resident pair in 1997 to a high of 1.19 ± 0.17 chicks per resident pair in 1998 (Fig. 1c).

Lake physical and chemical parameters

The majority (78%) of lakes in this study were between 20 and 400 ha in size (Fig. 2c). Further, most lakes surveyed (70%) were circumneutral for pH (6.5–7.5) and few lakes (<10%) had pH of ≤ 5.5 (Fig. 2a). The range and distribution of pH values for CLLS lakes were identical to those reported by Clair et al. (2002) for a larger sub-sample of Nova Scotia lakes, except that the range of values reported by Clair et al. (2002) included more lakes with $\mathrm{pH} < 5.0$. In our sample of Nova Scotia lakes, there was a negative correlation between pH and DOC (Fig. 3). Because of this inter-correlation, we performed four separate statistical analyses to investigate the possible influence that each of these chemical parameters had on each measure of loon productivity. On the subset of lakes where both pH and lake area data were available, both measures of productivity (i.e., P_{s1} and P_{s2}) varied by year, but neither was

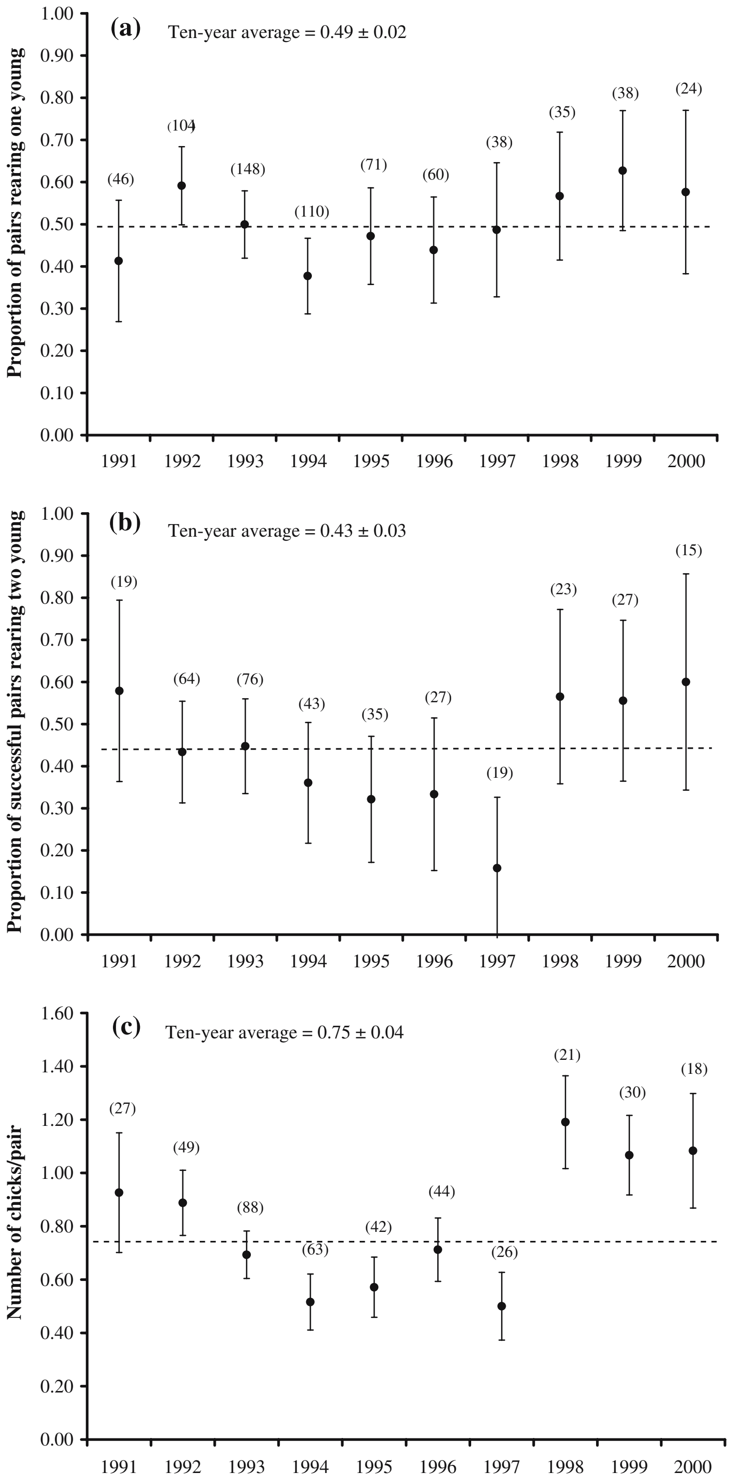

Figure 1. Temporal patterns in proportion of (a) resident pairs of common loons (*Gavia immer*) that raised at least one large chick to prefledging age, (b) successful resident pairs that raised two large chicks to prefledging age, and (c) number of chicks per resident pair on lakes. Sample sizes are shown in parentheses above bars and 95% confidence intervals. The dashed lines represent 10-year average values.

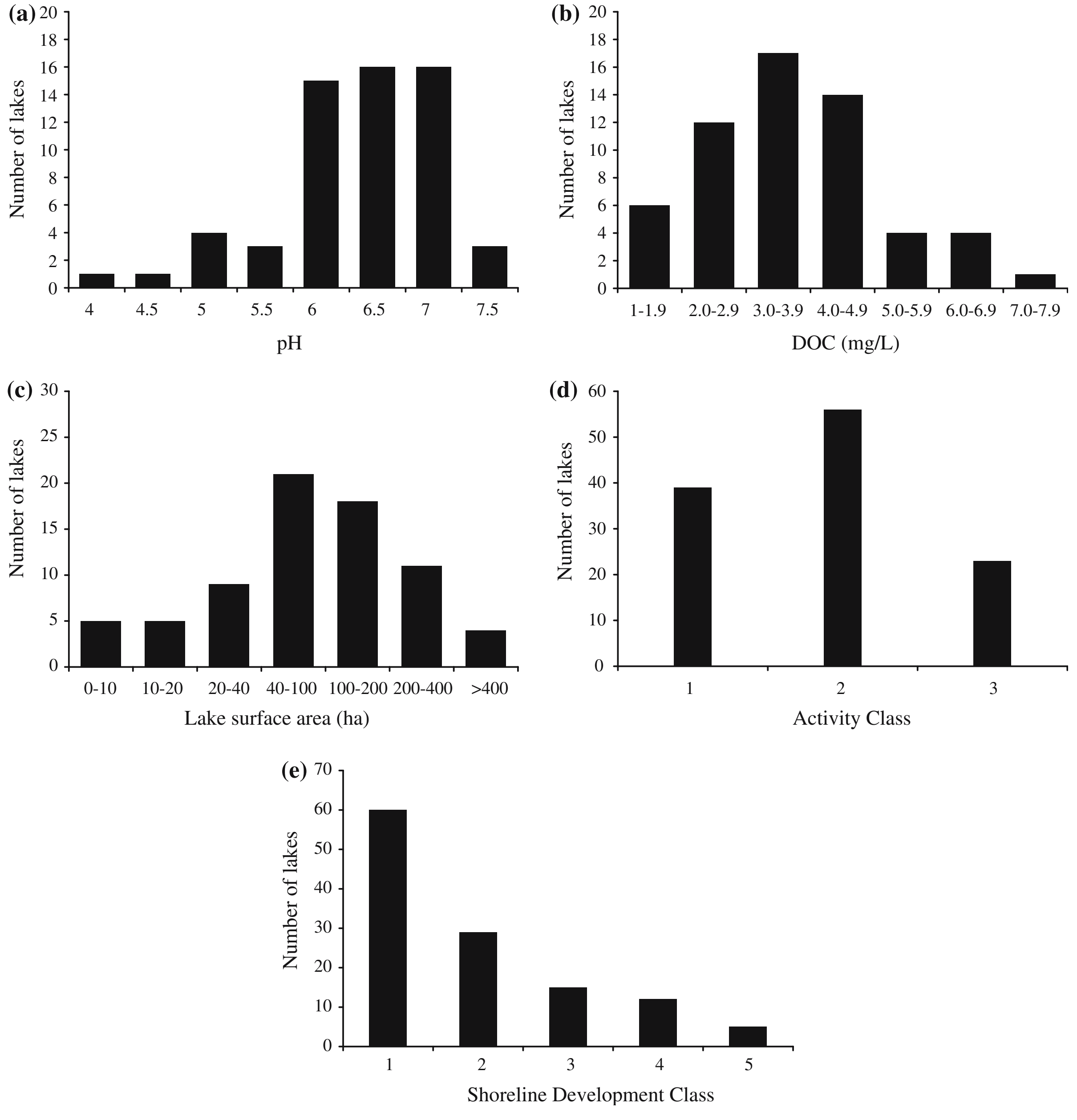

Figure 2. Frequency distributions for (a) lake acidity (pH), (b) dissolved organic carbon (DOC) concentration (mg/L), (c) lake surface area, (d) over-water human activity classes, and (e) relative shoreline development classes of lakes surveyed by the Canadian Lakes Loon Survey during 1991–2000 in Nova Scotia, Canada.

strongly correlated with lake area (Table 1). The probabilities of resident pairs rearing at least one large young, and successful pairs rearing two large young, tended to be lower on lakes of higher pH (Table 1).

DOC concentrations on CLLS lakes ranged from 1.6–7.9 mg/l (Fig. 2b). DOC concentrations of CLLS lakes had a similar, but truncated, frequency distribution as compared to that shown for a larger sample of lakes in Nova Scotia (see Clair et al., 2002). For lakes where both DOC and lake area data were available, both measures of loon productivity tended not to vary by year or lake area (Table 1). When controlling for year and

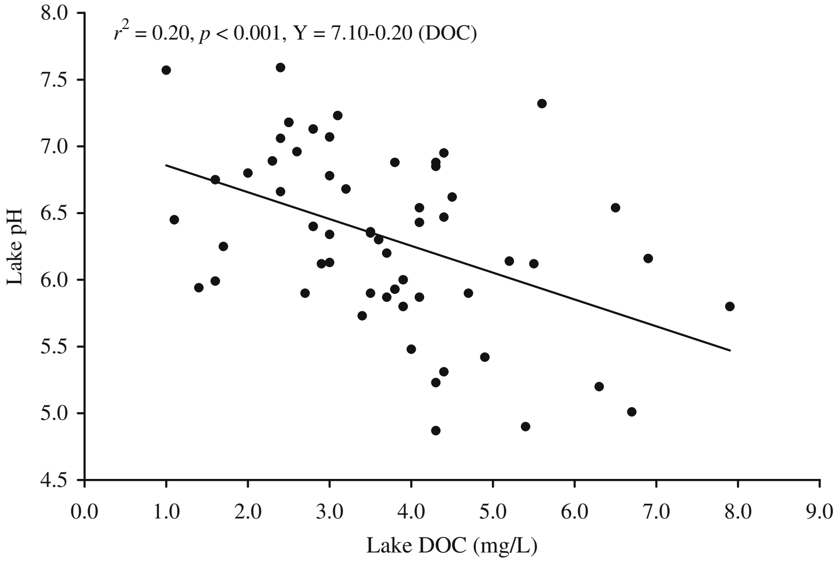

Figure 3. The relationship between lake acidity (pH) and dissolved organic carbon (DOC) data collected from 59 lakes surveyed by the Canadian Lakes Loon Survey in Nova Scotia from 1991 to 2000.

Table 1. Relationships between lake chemical and physical parameters and two indices of common loon (*Gavia immer*) productivity (P_{s1} and P_{s2}) on lakes during 1991–2000 in Nova Scotia, Canada

Response variable[a]	Explanatory variables	$\beta \pm$ SE[b]	*n*	*df*	χ^2	p[c]
P_{s1}	Year	–	59	9	19.11	0.02
	Lake area (ln)	−0.10 ± 0.21		1	0.20	0.66
	pH	−0.59 ± 0.21		1	4.87	0.03
P_{s2}	Year	–	47	9	15.89	0.08
	Lake area (ln)	+0.19 ± 0.18		1	1.04	0.31
	pH	−0.37 ± 0.26		1	2.18	0.14
P_{s1}	Year	–	41	9	12.95	0.16
	Lake area (ln)	−0.01 ± 0.25		1	0.00	0.97
	DOC	+0.36 ± 0.26		1	1.69	0.19
P_{s2}	Year	–	30	8	14.12	0.08
	Lake area (ln)	+0.33 ± 0.23		1	1.47	0.23
	DOC	+0.89 ± 0.34		1	4.70	0.03

[a] P_{s1} = proportion of resident pairs rearing at least one large young; P_{s2} = proportion of successful pairs rearing two large young.
[b] Parameter estimates from Generalized Estimating Equations (GEE) shown as logit-transformed values. Year effects are not presented, as they were included only to account for annual variation.
[c] Based on score statistics from Type III GEE analysis.

lake-area, we found the probability of resident pairs raising at least one large young was independent of DOC concentrations of lakes (Table 1). However, the probability that successful pairs reared two large young was positively correlated with DOC concentrations (Table 1).

Human activity/disturbance and shoreline development

The majority of CLLS lakes where chick success was monitored tended to have low to moderate levels of water-based human activity (as indexed by water-based disturbance/boating) and relatively little shoreline development (0–20%) (Fig. 2d, e). Given this, our analyses showed that human activity on lakes had no measurable/detectable impact on either measure of loon productivity (Table 2). Two separate analyses where pH and DOC were included as additional explanatory variables also showed that probability of resident pairs rearing at least one young did not differ among lakes with differing activity classes (sample sizes were too low to evaluate effects on P_{s2}). Further, after accounting for both year and lake area, we found that probability of resident pairs rearing at least one large young and successful pairs rearing two large young did not differ among the five classes of shoreline development (Table 2). Again, we entered pH and DOC separately into models (which also included year and lake area) and found no measurable difference in the probability of resident pairs rearing at least one large young on lakes with different levels of shoreline development.

Discussion

Productivity was relatively high for adult loons breeding on lakes surveyed by the CLLS in Nova Scotia from 1991–2000. For example, we found that about 49% of pairs were accompanied by at least one large young during late August and 43% of those pairs were able to raise two large young to prefledging age. McIntyre (1994) has suggested that 0.50 chicks/territorial pair is needed to maintain common loon populations, which has been more recently supported by a value of 0.48 chicks/territorial pair derived from a loon population model developed by Evers (2004). Our 10-year (1991–2000) average estimate of 0.75 chicks/resident pair was consistent with loon populations being relatively stable on lakes surveyed by the CLLS. The range of annual productivity estimates we report for Nova Scotia lakes (0.50–1.19 chicks/resident pair) also were well within the range of values (0.07–1.40) reported in several other loon studies conducted in eastern North America (see McIntyre, 1988a; Clay & Clay, 1997; McIntyre & Barr, 1997), but were much higher than the 0.33 and 0.29 chicks per resident pair reported for several lakes in Kejimkujik National Park in Nova Scotia (see Kerekes et al., 1993, 1995). Estimates of chicks per residential pair are dependent on our volunteer's ability to detect all resident pairs and those with large young on lakes. If the detection of resident pairs is lower than that of pairs with large young,

Table 2. Relationships between human activity and shoreline development and two indices of common loon (*Gavia immer*) productivity (P_{s1} and P_{s2}) on lakes during 1991–2000 in Nova Scotia, Canada

Response variable[a]	Explanatory variables	$\beta \pm$ SE[b]	*n*	*df*	χ^2	*p*[c]
P_{s1}	Year	–	111	9	19.20	0.02
	Lake area (ln)	+0.04 ± 0.11		1	0.12	0.73
	Activity index	–		2	3.31	0.19
P_{s2}	Year	–	81	9	17.15	0.05
	Lake area (ln)	+0.1 ± 0.15		1	0.67	0.41
	Activity index	–		2	0.81	0.67
P_{s1}	Year	–	114	9	18.71	0.03
	Lake area (ln)	+0.14 ± 0.13		1	1.30	0.25
	Development	–		4	6.12	0.19
P_{s2}	Year	–	81	9	16.76	0.05
	Lake area (ln)	+0.08 ± 0.15		1	0.23	0.63
	Development	–		4	4.00	0.41

[a] P_{s1} = proportion of resident pairs rearing at least one large young; P_{s2} = proportion of successful pairs rearing two large young.
[b] Parameter estimates from Generalized Estimating Equations (GEE) shown as logit-transformed values; year effects are not shown, as they were included only to account for annual variation.
[c] Based on score statistics from Type III GEE analysis.

our productivity estimates would be biased high. This may occur at some of the very large lakes that volunteers surveyed in Nova Scotia and could be one reason why our productivity estimates were higher than those of other more intensive studies.

The lack of agreement between our productivity values and those reported by Kerekes et al. (1993, 1995) for lakes in Kejimkujik National Park may be due to the broader geographic representation of the CLLS. Monitoring productivity over a larger area naturally includes lakes with a much wider range of abiotic and biotic attributes that can influence loon productivity (Barr, 1986; McNicol et al., 1995; Scheuhammer et al., 1998; McNicol, 2002). The majority of the lakes in this study were circumneutral (see Fig. 2a), compared to the more acidic lakes in the Kejimkujik Park, which may partly explain our higher productivity estimates. Productivity estimates from each of these two subsets of Nova Scotia lakes (CLLS and Kejimkujik lakes) at least collectively show how variable loon productivity is within the province.

Despite some documented negative effects on loons associated with human induced disturbance/habitat alteration (McIntyre & Barr, 1997), our results showed no meaningful patterns in loon productivity attributable to intensity of human water-based disturbance or shoreline development (see also McIntyre, 1975; Titus & VanDruff, 1981; Caron & Robinson, 1994). It is possible that loons on CLLS lakes in Nova Scotia have habituated to human activities and habitat modifications or simply avoid areas on lakes that humans frequent (McIntyre, 1988a; Caron & Robinson, 1994). Our study did encompass a sizeable number of lakes that were surveyed over a relatively long period of time, but relatively few of them had “high” levels of disturbance and many had relatively undeveloped shorelines, which could have reduced our ability to detect differences in productivity among lakes with different activity and shoreline development indices. It is also possible that measures of human activity recorded by volunteers (e.g., documenting boat traffic in general on lakes) might not adequately quantify levels of disturbance (or capture important one-time events) close to nests during incubation and early brood rearing, two periods that are critical in determining loon productivity (McIntyre, 1988a). Human disturbance likely has the greatest effect on loon productivity before young hatch from eggs (Robertson & Flood, 1980; Heimberger et al., 1983), but the CLLS currently does not intensively monitor fate of loon nests, only of hatched young.

Loons on some lakes may be at risk from human induced disturbance or habitat loss (Vermeer, 1973; Ream, 1976), but effects of environmental contaminants, including lake acidification and the associated uptake and bioaccumulation of methyl-mercury extend much farther into loon’s breeding range (McIntyre, 1988a; McIntyre & Barr, 1997). Loon pairs typically return to the same lakes to breed each year and require large quantities of prey to feed their young (Barr, 1996; McIntyre & Barr, 1997), so reductions or changes in the forage base due to lake acidification can affect loon productivity (Alvo et al., 1988; Wayland & McNicol, 1990; McNicol et al., 1995).

In regional studies of loons in Ontario, productivity was lower on acidic lakes ($\mathrm{pH} < 6.5$) as compared to lakes that were circumneutral (pH 6.5–7.5) or more alkaline ($\mathrm{pH} > 7.5$) (Alvo et al., 1988; Wayland & McNicol, 1990; McNicol et al., 1995). Within our subset of Nova Scotia lakes, however, productivity of loons breeding on the more acidic lakes was not reduced as compared to those breeding on less acidic lakes (see also Parker, 1988). In fact, resident pairs had a higher probability of rearing at least one large young to age of fledging on lakes with relatively low pH; there also was a tendency for higher probability of success for rearing two large young on lakes of lower acidity. It must be noted that the majority of lakes surveyed by the CLLS volunteers in Nova Scotia were not highly acidic (e.g., <10% had $\mathrm{pH} < 5.5$, mean $\mathrm{pH} = 6.2$, see Fig. 2a) and tended to be ones that were accessible, popular for fishing or boating, and had permanent or seasonal residences. Such lakes also tend to have relatively clear water, near neutral pH, and likely healthy fish populations. Further, our findings regarding lake pH and loon productivity also may reflect (1) the relatively small number of lakes where loon productivity and pH were monitored; (2) our inability to control for other correlated or confounding variables that affect productivity (e.g., fish abundance, loon predation rates, other lake chemistry variables, etc.); and (3) other potential weaknesses/biases of volunteer surveys (e.g., non-random sampling, sampling frequency, and ability to detect pairs and young, etc.) (McNicol et al., 1995). Thus, productivity patterns captured by CLLS are most representative of loons breeding on "recreational" lakes and are not necessarily representative of loon productivity, or its relation to environmental factors, over the entire range of these parameters for all lakes in Nova Scotia (e.g., lakes in Kejimkujik National Park).

Mercury content in lakes throughout Nova Scotia and other northeastern provinces and states are among the highest recorded in North America (Burgess et al., 1998a, b; Evers et al., 1998). Loon chicks exposed to relatively high levels of mercury may develop anomalous behavioural patterns that reduce time available for foraging, which ultimately affects fledging success (Nocera & Taylor, 1998). Relatively high concentrations of DOC, especially on acidic lakes, can reduce availability of mercury to fish, and thus to loons, by binding with mercury on a molecular level (Driscoll et al., 1995; Choi et al., 1998; Rencz et al., 2003). The increased productivity (i.e., two fledged chicks) we observed for loons on lakes with relatively high DOC was at least consistent with the possibility that DOC reduced the incorporation of mercury into these food webs and thus reduced maladaptive behaviour in chicks and enhanced their survival.

In summary, lakes in Nova Scotia monitored by the CLLS generally had relatively high loon productivity and no reductions attributable to human activities, or increased acidity of breeding lakes. Our results, however, should not be interpreted to mean lake acidification (and its facilitative effect on mercury uptake) does not currently threaten loons in Nova Scotia because some lakes in this province have some of the lowest surface water pH values measured in North America (Kerekes et al., 1982). Several of the areas that contain some of the more acidic lakes in Nova Scotia are also of concern for mercury contamination (Evers et al., 1998) and show little recovery from effects of reduced sulphur dioxide deposition (Clair et al., 2002). Monitoring loon productivity, abundance, and distribution and its relation to pH, DOC, and other important limnological factors should continue as part of longer-term, loon/lake monitoring programs aimed at evaluating recovery of acidified lakes. Efforts need to be made to encourage volunteers to consistently survey lakes annually and include more lakes in the lower pH range throughout the province, possibly by employing a stratification strategy for sampling. Doing so will improve long-term monitoring of loon productivity and provide a more sensitive biomonitoring tool for lakes in Nova Scotia and other regions of Canada.

Acknowledgements

Funding for this study was provided by the Canadian Wildlife Service (CWS) of Environment Canada – Atlantic Region. Over the years, additional financial support for the CLLS was provided by CWS – Ontario Region, Mountain Equipment Co-op, Northern Reflections, Shell Foundation, and CLLS volunteers. We would like to recognize the tireless efforts of the many volunteers of the Canadian Lakes Loon Survey in Nova Scotia for collecting data reported in this paper. J. Paquet of CWS collected most of the lakewater samples, which were analyzed at the Environment Canada laboratory in Moncton, New Brunswick. N. Burgess and R. Elliot of CWS provided help and critical comments during the analysis/writing phase and throughout this study. We thank N. Burgess, S. Earnst, A. Hanson, J. McCracken, C. Paszkowski, and R. Zimmerling for their critical reviews of various versions of the manuscript.

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