STATUS REPORT ON THE EFFECTS OF ACID PRECIPITATION ON COMMON LOON REPRODUCTION IN ONTARIO: THE ONTARIO LAKES LOON SURVEY

Mark Wayland
Donald McNicol

Technical Report Series No. 92
Ontario Region 1990
Canadian Wildlife Service

This series may be cited as:

Wayland, M.; McNicol, D. 1990. Status Report on the Effects of Acid Precipitation on Common Loon Reproduction in Ontario: The Ontario Lakes Loon Survey. Technical Report Series No. 92. Canadian Wildlife Service, Ontario Region.

Published by Authority of the
Minister of Environment
Canadian Wildlife Service

Catalogue No. CW69-5/92E
ISBN 0-662-17533-6
ISSN 0831 - 6481

Copies may be obtained from:

Donald K. McNicol
Canadian Wildlife Service
Ontario Region
49 Camelot Drive
Nepean, Ontario
K1A 0H3

ABSTRACT

As part of the Canadian Wildlife Service Long Range Transport of Airborne Pollutants (LRTAP) Biomonitoring Program, a volunteer-based project known as the Ontario Lakes Loon Survey (OLLS) was expanded in 1987 to study the effects of lake acidification on Common Loon (Gavia immer) reproduction in Ontario. Data were collected on 491 and 458 lakes in 1987 and 1988 respectively. After combining lakes surveyed in 1988 with those that were surveyed only in 1987, there were 387 lakes with reliable data on loon reproductive success. More than 80% of these lakes were within the populated southern and eastern parts of the province. Although most of this area is sensitive to acidification and receives relatively high loadings of acid deposition, only 54 acidic or extremely sensitive lakes (alkalinity < 40 ueq/L) were surveyed. Overall, lakes without breeding attempts were on average smaller ($\bar{x}$ = 37 ha) than those with unsuccessful attempts ($\bar{x}$ = 68 ha), moderately successful attempts ($\bar{x}$ = 83 ha), or highly successful attempts ($\bar{x}$ = 95 ha). Neither pH nor alkalinity was able to discriminate among lakes differing in these four levels of production. However, when survival of downy or small chicks (DS; < 6 weeks old) to the large young stage (LY; > 6 weeks old) was considered, lake area failed to discriminate significantly between lakes with high survival (LY/DS > 0.5) and those with low survival (LY/DS $\leq$ 0.5), while both pH and alkalinity provided significant discrimination between these two categories of lakes. Lakes where survival of DS chicks to the LY stage was high tended to be less acidic (pH: $\bar{x}$ = 6.65; alkalinity: $\bar{x}$ = 109 ueq/L) than those where survival was low (pH: $\bar{x}$ = 6.28; alkalinity: $\bar{x}$ = 54 ueq/L). This was primarily because broods with two DS chicks suffered mortality proportionately more often on acidic, low alkalinity lakes than those on non-acidic, high alkalinity lakes. Mechanisms that may contribute to this response are discussed and some recommendations to improve the OLLS are delineated.

RÉSUMÉ

Dans le cadre du volet contrôle biologique du Programme de transport à distance des polluants atmosphériques (TADPA) du Service canadien de la faune, un projet entrepris par des bénévoles, le projet Ontario Lakes Loon Survey (OLLS) a été développé en 1987 pour étudier les effets de l'acidification des lacs sur la reproduction des Huarts à collier (Gavia immer) en Ontario. Les données ont été recueillies dans 491 lacs en 1987 et dans 458 lacs en 1988. Après avoir combiné les lacs échantillonnés en 1988 avec ceux qui ont été échantillonnés en 1987 seulement, il y avait 387 lacs avec des données fiables sur le succès de la reproduction des Huarts. Plus de 80% de ces lacs se trouvaient dans les parties habitées du sud et de l'est de la province. Bien que la plus grande partie de cette région soit sensible à l'acidification et reçoive une charge relativement élevée de dépôts acides, seulement 54 lacs acidifiés ou extrêmement sensibles (taux d'alcalinité < 40 ueq/l) ont été échantillonnés. Dans l'ensemble, les lacs sans tentatives de reproduction étaient en moyenne plus petits ($\bar{x}$ = 37 ha) que les lacs où il y a eu des tentatives infructueuses ($\bar{x}$ = 68 ha), tentatives modérément fructueuses ($\bar{x}$ = 83 ha), ou des tentatives très fructueuses ($\bar{x}$ = 95 ha). Le pH et le taux d'alcalinité n'ont pas été déterminants dans le cas des lacs qui accusent ces quatre différents niveaux de production. Toutefois, quand on a tenu compte de la survie des oisillons ou des petits poussins (poussins = < 6 semaines) jusqu'au stade de jeunes plus développés (jeunes = > 6 semaines), la superficie des lacs n'a pu établir une distinction significative entre les lacs où il y a un taux de survie élevé (poussins/jeunes > 0.5) et ceux où il y a un faible taux de survie (poussins/jeunes $\leq$ 0.5), tandis que le pH et le taux d'alcalinité ont donné lieu à une distinction significative entre ces deux catégories de lacs. Les lacs où la survie des poussins etait elevée avaient tendance à être moins acides (pH: $\bar{x}$ = 6,65; taux d'alcalinité: $\bar{x}$ = 109 ueq/l) que ceux où le taux de survie était bas (pH: $\bar{x}$ = 6,28; taux d'alcalinité: $\bar{x}$ = 54 ueq/l). La raison principale nous vient du fait que les nichées comptant deux poussins ont un taux de mortalité proportionnellement plus élevé dans les lacs acides. On discute des méchanismes pouvant contribuer à cette tendance et on présente quelques recommandations pour améliorer le projet OLLS.

TABLE OF CONTENTS

1. INTRODUCTION

Acid precipitation has been implicated in recent changes to aquatic ecosystems in acid-sensitive areas in eastern North America and Europe (Haines 1981, Dillon et al. 1984, Cook et al. 1988, Schindler 1988). Aquatic and semi-aquatic species of birds have been affected by acid precipitation, mainly through the impacts of acidification on the abundance and quality of potential prey items (Ormerod and Tyler 1987, McAuley and Longcore 1988, Blancher and McNicol 1988; also see Blancher and McAuley 1987 and McNicol et al. 1987 for review).

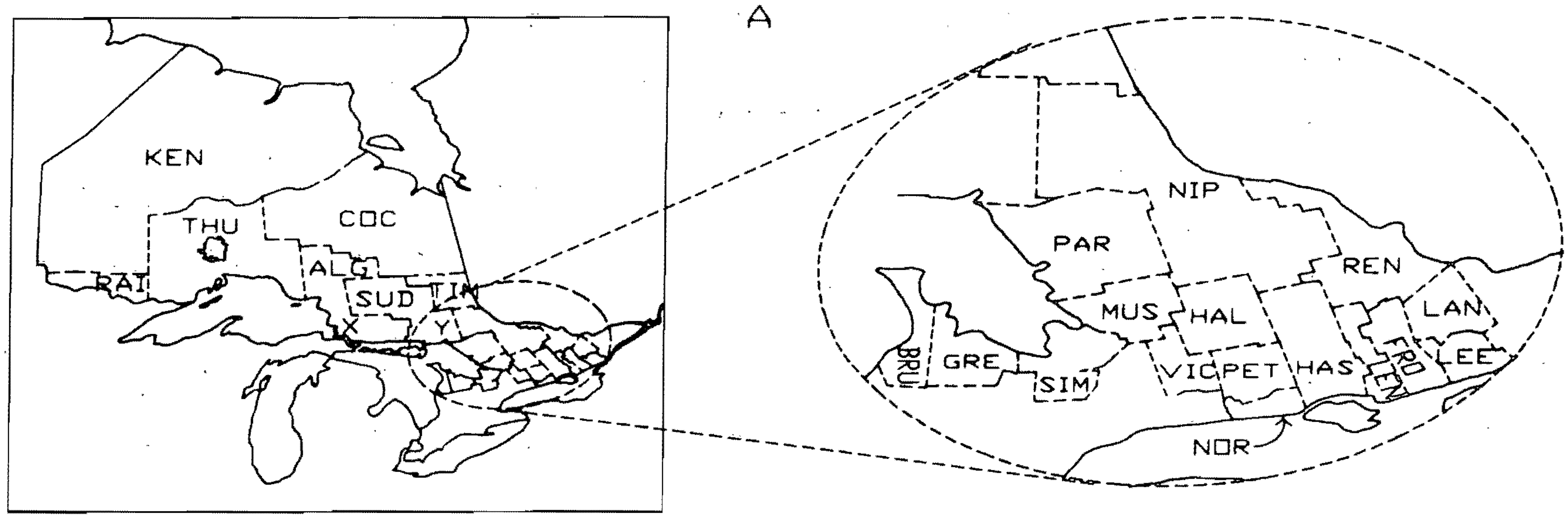
Common Loons (Gavia immer) are mainly piscivorous birds which breed in acid-sensitive areas of northern North America (Longcore et al. 1987). Of the estimated 211,000 pairs of loons in northeastern North America, approximately 17,000 (8%) breed within areas which are considered sensitive to acidification (acid neutralizing capacity of surface waters < 200 ueq/L alkalinity) (Longcore et al. 1987). With regards to the effects of lake acidification on the reproductive success of loons, at least three possible scenarios have been proposed or can be inferred from other studies. The first is one of decreasing reproductive success as a result of the loss of fish prey (Alvo et al. 1988, Parker 1988, McIntrye 1989) that is known to occur as lakes acidify (Harvey 1982). The second scenario also predicts impaired loon reproduction on acidic lakes. In this case, however, the impairment is thought to stem from the toxic effects of mercury on loons (Barr 1986) coupled with the well-documented positive correlation between lake acidity and mercury concentrations in fish (Wren and MacCrimmon 1983, Suns et al. 1987). The third scenario, inferred from Eriksson (1985, 1986), paints a neutral effect of acidification. It is based partly on his 1986 study of the mainly piscivorous Black-throated Diver (Gavia arctica), a species closely-related to the Common Loon, which showed that in acidic lakes, increased insect abundance (a secondary food source) combined with decreased abundance of fish predators such as pike (Esox lucius) may have offset partially the negative effects of acidification on fish prey. Moreover, his 1985 study on 'pursuit-divers' including the Black-throated Diver suggested that the increased water transparency normally associated with acidification may have improved their capacity to visually detect prey, thus offsetting further any acidification-induced reduction in fish prey.

Recent surveys have shown that loons use acidic lakes proportionately less often than non-acidic lakes in southern Quebec (DesGranges and Darveau 1985), while in northeastern Ontario, the ratio of the number of broods observed to the number of breeding pairs was lower in an acid-stressed area near Sudbury, Ontario compared to a more moderately stressed area near Sault Ste. Marie, Ontario (McNicol et al. 1987b). Furthermore, Jones and Wedeles (1989) found that broods and breeding pairs of a group of piscivorous birds consisting of Common Mergansers (Mergus merganser) and Common Loons were more common on high pH lakes (>6.0) than on those of lower pH (<6.0). McNicol et al. (1987) speculated that reduced food abundance on acidic lakes explained the apparently lower rates of reproductive success observed in the Sudbury area. This contention was supported by Alvo et al. (1988) who found that the breeding effort and success of loons on 68 lakes within a 135 km radius of Sudbury were higher on high alkalinity than on low alkalinity lakes, a phenomenon they attributed to a reduced density of fish on low alkalinity (< 40 ueq/L) lakes. However, Parker (1988) was unable to detect any effect of either pH or alkalinity on loon reproductive effort or success on 24 lakes in Upper New York State despite the large differences in fish biomass found on acidic and non-acidic lakes in his study area.

Because of the conflicting nature of the results of the two latter-mentioned studies, as well as their relatively small study areas and small sample sizes of lakes, further research on the effects of lake acidification on the reproductive success of individual pairs of Common Loons was warranted. Therefore, in 1987, the Canadian Wildlife Service (CWS) and the Long Point Bird Observatory (LPBO) initiated a project to expand the Ontario Lakes Loon Survey (OLLS) in an effort to determine the relationship between the reproductive success of Common Loons and lake chemistry across a large area of eastern, central and northern Ontario. Since the project examines long-term reproductive success of loons in Ontario, it could form an integral part of the biological monitoring programme being developed by the Canadian Wildlife Service for eastern Canada (see McNicol et al. 1987 for review). Administered by the LPBO, the OLLS consists of a series of surveys conducted by CWS staff and a network of volunteers. In this paper, we review some of the major results from surveys done in 1987 and 1988, discuss the value of the OLLS as a tool for monitoring loon production in relation to acid rain in Ontario, and identify areas which must be improved prior to incorporation into the overall CWS Biomonitoring program.

2. STUDY AREA

The study area spanned the breadth of the province from the county of Lanark in southeastern Ontario to Kenora in northwestern Ontario. A large proportion of the surveys were done on lakes in central and northeastern Ontario in the districts of Haliburton, Nipissing, Parry Sound, Peterborough, Muskoka, Sudbury and Algoma (Fig. 1). These core areas are characterized, in general, by mixed hardwood or boreal forest underlain by Precambrian granitic bedrock, calcareous bedrock, non-calcareous sedimentary, igneous and metamorphic rock, or carbonate-rich bedrock (Shilts 1981). Localized patterns of glacial drift have created a heterogeneous situation with respect to the acid-neutralizing capacity of the bedrock and surficial till throughout most of the core area (Shilts 1981). In general, however, the scarcity of carbonate-rich bedrock and the predominance of coarse-textured, shallow soils in these areas make them highly sensitive to acid precipitation (IWD 1988) (Fig 2a). These core areas account for most of the estimated 34% of Ontario's land which is considered to have a low potential to buffer acid deposition (IWD 1988).



ALG - Algoma
BRU - Bruce
COC - Cochrane
FRO - Frontenac
GRE - Grey
HAL - Haliburton
HAS - Hastings
KEN - Kenora

X - Ranger Lake

LAN - Lanark
LEE - Leeds & Grenville
LEN - Lennox & Addington
MUS - Muskoka
NIP - Nipissing
NOR - Northumberland
PAR - Parry Sound
PET - Peterborough

RAI - Rainy River
REN - Renfrew
SIM - Simcoe
SUD - Sudbury
TIM - Timiskaming
THU - Thunder Bay
VIC - Victoria

Y - Wanapitei

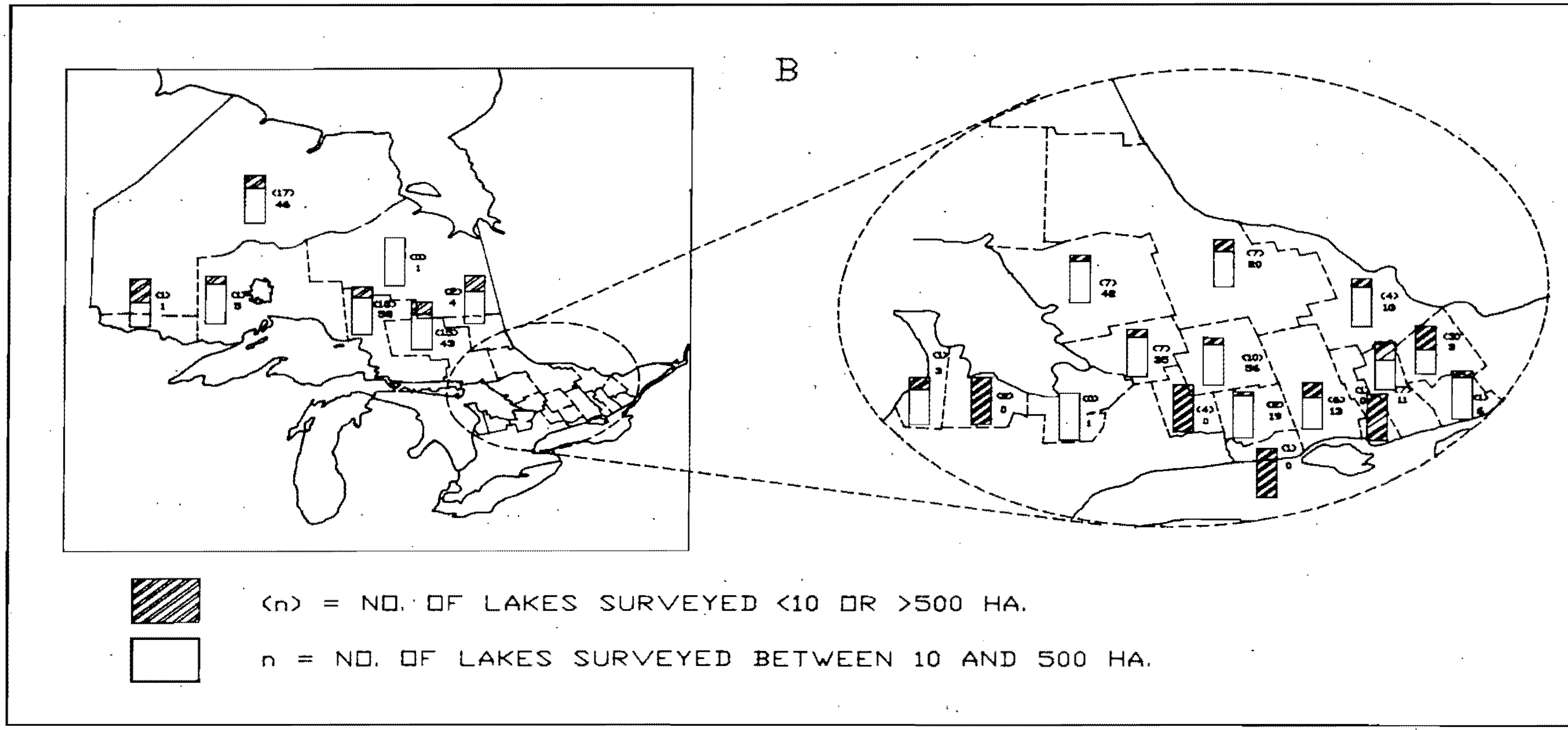


Fig. 1. Names and locations of counties and administrative districts within which lakes were surveyed (A) and the distribution of the survey effort according to counry or district (B).

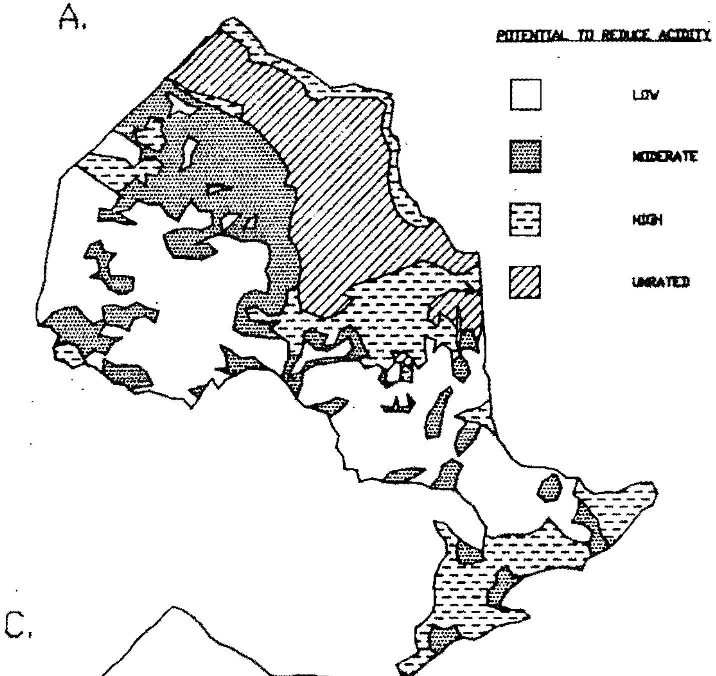
The pattern of sulphate deposition shows a marked increase from west to east across Ontario with a low of 10 kg SO_4/ha in northwestern Ontario compared to 30-35 kg deposited in southern Ontario (Fig. 2b) (Ro et al. 1989). This pattern of deposition coincides with the dramatic decrease in the mean annual pH of precipitation (increased acidity) from northwestern Ontario (pH 5.0-4.8) to central and southern Ontario (pH 4.4-4.2) (Fig. 2c). In the major area of interest in central and northeastern Ontario, sulphate deposition ranges from 20-30 kg SO_4/ha, with a corresponding pH of precipitation averaging below 4.4 on an annual basis. Nearly 350,000 km^2 of the exposed Precambrian Shield of Ontario annually receive in excess of 10 kg SO_4/ha.

Recently, it has been estimated that approximately 97,000 pairs of Common Loons breed in Ontario. Densities are highest on the Precambrian Shield (Fig. 3), where approximately 80,000 pairs reside. Of these, 29,000 (36%) breed in acid-sensitive areas where the annual wet SO_4 deposition exceeds 10 kg/ha (McNicol et al. 1990). Thus, it is clear that a sizeable proportion of Ontario's breeding loons are at risk from acid precipitation. Yet, it remains uncertain whether, or to what extent, loon populations in this area have been affected by the deterioration of water quality and fish stocks known to have occurred as a result of acid rain in past decades (Kelso et al. 1986).

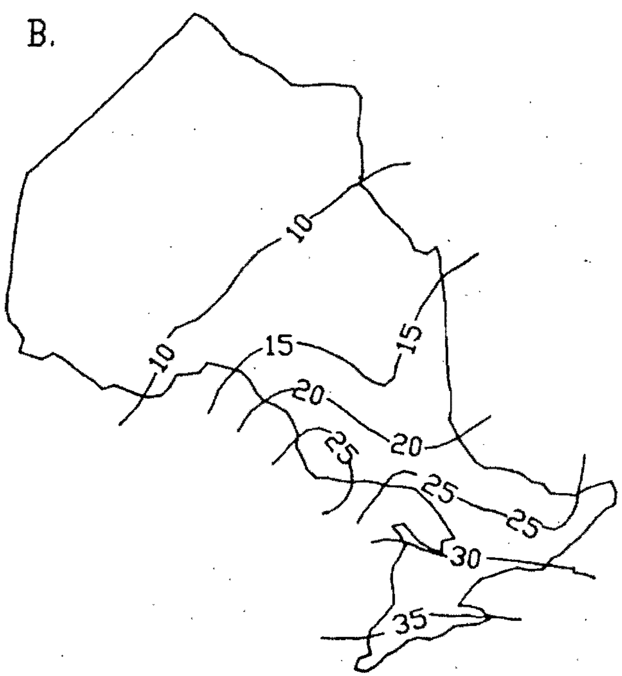
In the present study, alkalinities ranged from 0 to 3346 ueq/L (median = 78.8, n = 218), pH values from 4.3 to 8.8 (median = 6.5, n = 224) and lake area from 10 to 486 ha (median = 68, n = 281) on lakes for which useful data on reproductive success were obtained. Approximately 40% of these lakes were fairly well buffered (alkalinity > 100 ueq/L), more than 50% had pH values greater than 6.3, and were thus capable of supporting diverse fish populations (Weiner et al. 1984). More than 75% of these lakes were larger than 30 ha in size (Fig. 4).

Fig. 2. (A) The potential of soils and bedrock to reduce acid precipitation in Ontario. (Adapted from IWD 1988). (B) Distribution of mean wet annual sulphate deposition (kg/ha) (1982-86) (adapted from Ro et al. 1989). (C) Distribution of mean annual pH of precipitation (1982-86) (adapted from Ro et al. 1989).

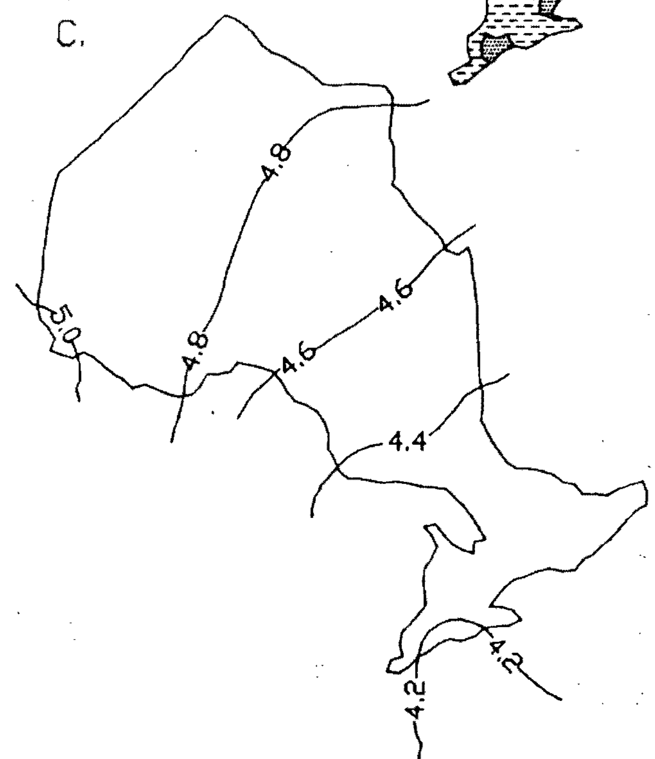
A.



B.



C.



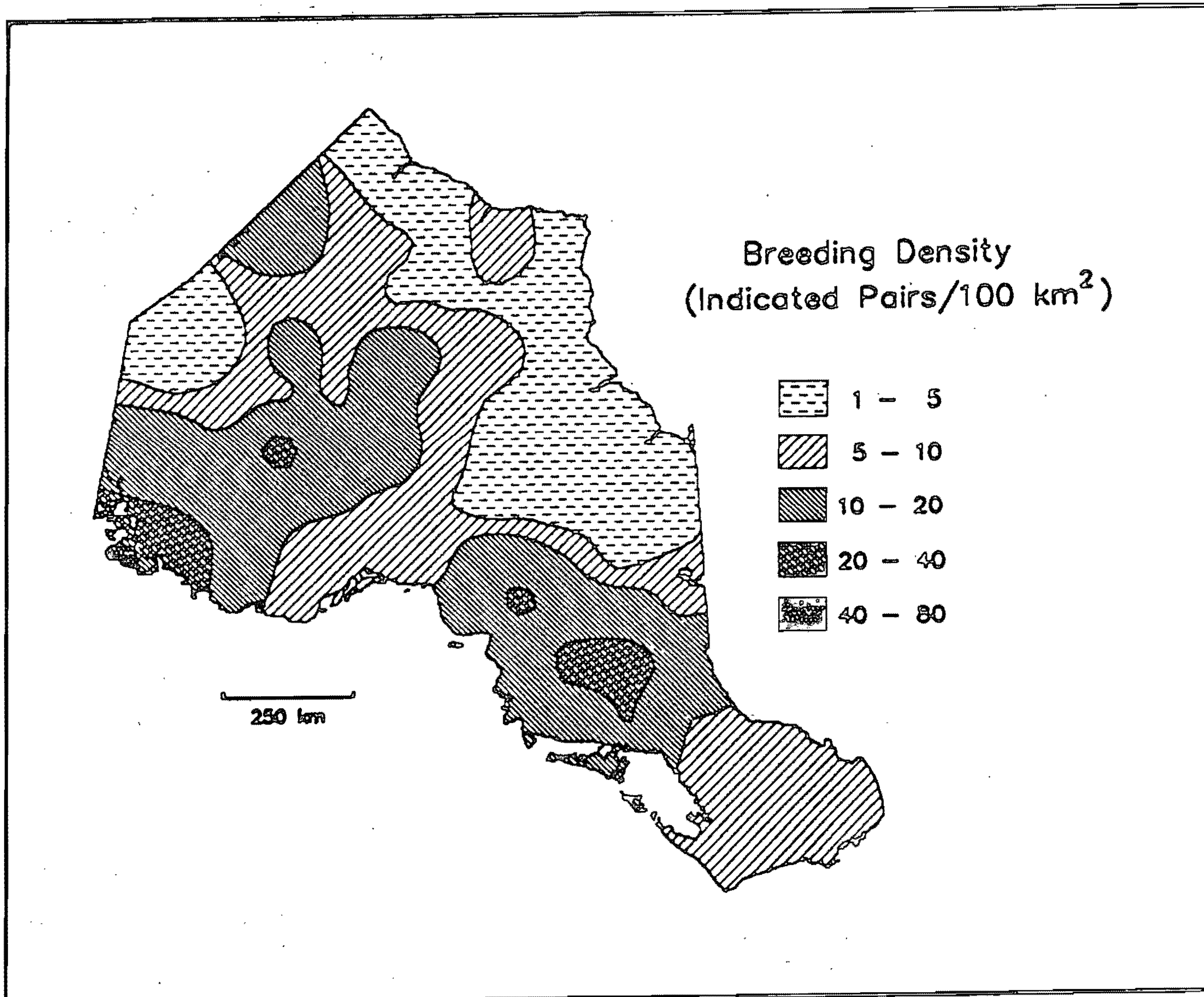
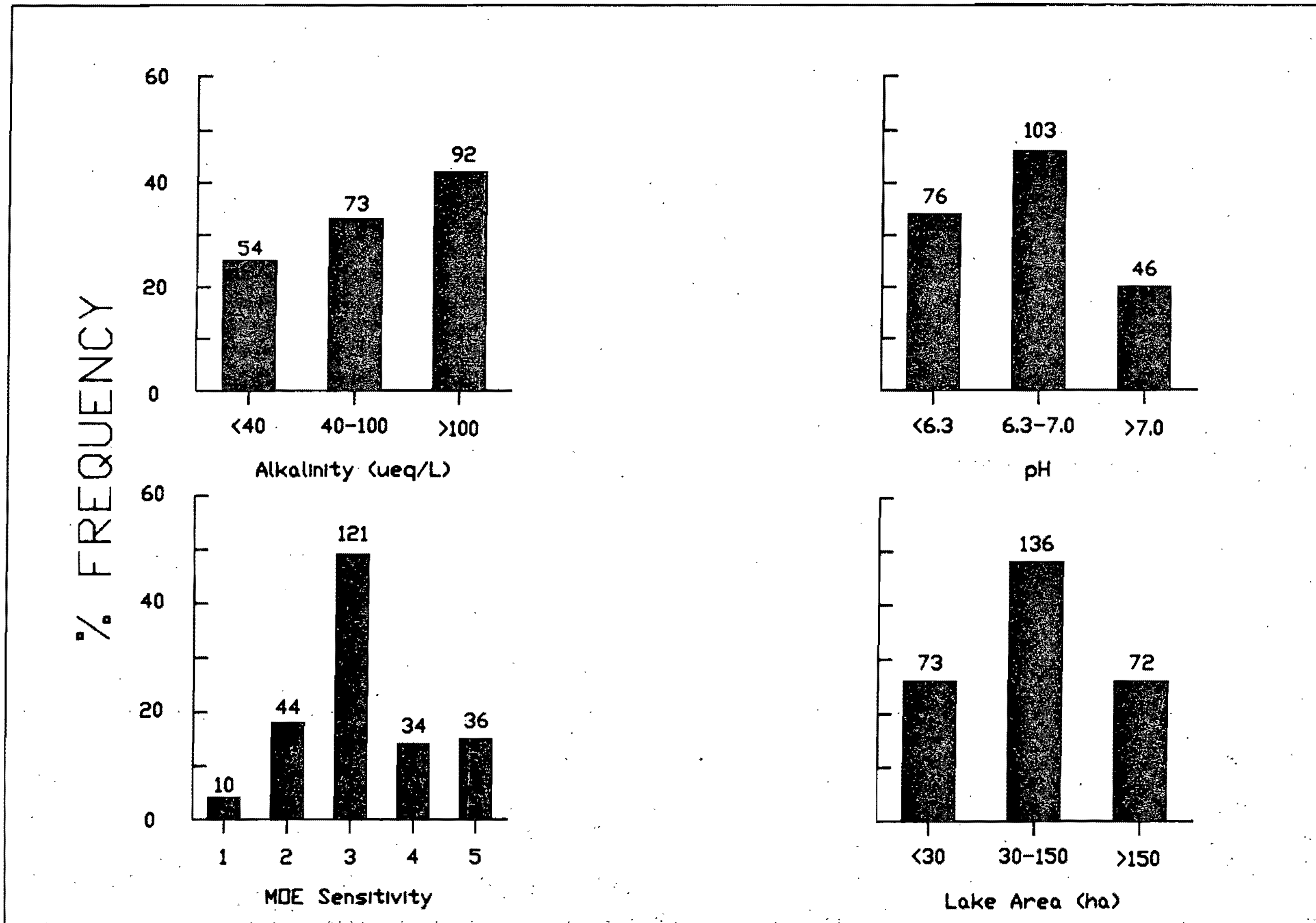


Fig. 3. Distribution of breeding loons in Ontario according to their density (No. indicated pairs/100 km^2).

Fig. 4. Of the lakes between 10-500 ha and for which the level of loon reproductive effort and success were known, their % frequency of occurrence within the indicated categories of pH, alkalinity, MOE Sensitivity and lake area are shown. Numbers above bars are sample sizes.



3. METHODS

The methods employed in co-ordinating the OLLS have been described in detail by McCracken (1988) and Ashenden (1989). Briefly, LPBO solicited volunteers from naturalist clubs and cottagers' associations. When possible, volunteers were assigned to specific lakes which met three criteria: 1) high acid sensitivity, 2) easily accessible, and 3) less than 75 ha (i.e. lakes which would have, at most, one pair of breeding loons). It was felt that small, one-pair lakes would be easier to survey completely, resulting in more reliable data; moreover, interpretative problems associated with density-dependent survival of young on large, multiple-pair lakes would be minimized by concentrating on single-pair lakes. Otherwise, volunteers independently selected lakes which they wished to survey. Data sheets were sent to volunteers in the spring of each year so that the collection of data would be as systematic as possible. Volunteers were asked to record the number of breeding pairs (BP) they observed, the number of downy or small young (DS) estimated to be less than 6 weeks old, and the number of large young (LY)(> 6 weeks old), the number of times each lake was surveyed in a season and the proportion of each lake surveyed. The accuracy of volunteer data was evaluated by a separate study conducted in 1987 in which volunteer data were compared with data collected by LPBO staff on 16 lakes in the Muskoka-Haliburton area (McCracken 1988).

In addition to volunteer surveys, CWS staff surveyed a series of lakes near Ranger Lake in the Algoma District and near Lake Wanapitei in the Sudbury District (Fig. 1a) (see McNicol et al. 1987 for detailed description of study area). Three sets of surveys were conducted in both 1987 and 1988; the first set in late June, the second set in late July and the third set in late August (1987) or early September (1988). In 1987, 77 lakes were surveyed by two people paddling a canoe around the perimeter of each lake while in 1988, 60 lakes were surveyed by paddling or, on a small number of lakes, by using an outboard motor (2HP). During the first survey in each year, likely nesting locations, such as islands and points, were checked for nests. During each survey, the number of paired and unpaired loons, downy chicks (< 3 weeks old), small chicks (3-6 weeks old) and large young (> 6 weeks old) were recorded.

Lakes that were surveyed by CWS staff and those surveyed by volunteers were combined in the final data set. Lakes meeting the following criteria were included in subsequent analyses: 1) loon data (BP, DS and LY) and/or lake chemistry/area data which were necessary for a given analysis were not missing, 2) the survey covered 100% of the lake surface area, and 3) lake area was between 10-500 ha. This final criterion was inserted because small lakes less than 10 ha are usually not used by loons (Alvo et al. 1988, McNicol et al. 1987) and may not contain sufficient fish biomass to sustain a pair of loons and their chick(s) through to successful fledging (Kelso 1985, Parker 1988, Kerekes et al. 1988). Because large lakes are difficult to survey accurately, and because volunteers usually survey large lakes only partially without accurately delineating the location or size of the portion they surveyed, we eliminated lakes larger than 500 ha from the analysis.

Total inflection point alkalinity (ueq/L), pH, and lake area data were extracted from the following sources: the Ontario Ministry of the Environment (OMOE) Extensive Lake Survey Data Base (B. Neary, OMOE, pers. comm.), the Sudbury Environmental Study (SES) data base for lakes in the greater Sudbury area (OMOE 1978) or the CWS (ONT)-LRTAP data base. MOE Sensitivity Indices (MOESI) were obtained from the ongoing Acidic Precipitation in Ontario Study (APIOS) (OMOE 1987). Under this system, lakes with alkalinities $\leq$ 0 ueq/L are considered to be acidic, those with alkalinities in the range of 0.01-39.99 ueq/L are considered to be extremely sensitive to acid precipitation, those with alkalinities between 40-199.9 ueq/L are moderately sensitive, alkalinities in the range of 200-499.9 ueq/L are rated as having a low sensitivity, and those > 500 ueq/L are rated as not sensitive to acid precipitation. When lake area data were missing, a Hi-State Digitizer (Gentian Electronics Ltd.) was used to calculate areas from 1:50,000 or 1:100,000 scale topographic maps.

In the analysis, lakes were characterized according to four levels of loon production: 1) lakes where no breeding attempts were made, 2) lakes where attempts were made but where no large young were produced (defined as unsuccessful), 3) lakes where the LY:BP ratio was > 0 but $\leq$ 1.0, (low production), and 4) lakes where the LY:BP ratio was > 1.0 (high production). Lakes were also characterized according to two levels of chick survival: 1) lakes where the LY:DS ratio was $\leq$ 0.50 (low chick survival), and 2) lakes where the ratio was > 0.50 (i.e. 1.0 on lakes with only one BP) (high chick survival). Stepwise discriminant anlysis (SAS 1988) was used to identify which, if any, of the measured lake variables discriminated significantly among 1) the levels of loon production, and 2) the levels of chick survival. The probability level for entry into or removal from the model was set at 0.15. Alkalinity and lake area data were normalized as follows:

1) transformed alkalinity = $(\text{alkalinity (ueq/L)} + 0.5)^{0.15}$
2) transformed area = $\log_{10}$ (area).

All mean alkalinities and areas reported in this paper are backtransformed means of transformed variables.

G-tests of independence were used to determine whether survival of one - and two - chick broods was independent of lake chemistry. In all cases, G-test values were adjusted using William's correction (Sokal and Rohlf 1981).

4. RESULTS

4.1 Volunteer Participation, Regional Coverage and Data Quality

In 1987, volunteers returned 494 records on 414 lakes, while CWS staff returned 77 records on 77 lakes for a total of 491 lakes surveyed; in 1988, volunteers returned 484 records on 398 lakes, while CWS staff returned 60 records on 60 lakes for a total of 458 lakes surveyed. Of the CWS and volunteer-surveyed lakes which were surveyed in 1987, and which were between 10-500 ha, 123 were surveyed again in 1988. These lakes provided the basis for comparing loon production and chick survival between years. Neither production nor survival was significantly different (production: $\chi^2 = 2.25$, 3 df, $P = 0.52$; survival: $\chi^2 = 0.40$, 1 df, $P = 0.53$) between years (Table 1), suggesting that 1987 and 1988 were not different in their effects on the overall breeding performances of loons. Therefore, in order to increase the sample size while retaining the independence of the observations, 1988 data on all lakes were combined with 1987 data on lakes which were surveyed only in 1987. After eliminating lakes which were < 10 or > 500 ha, this data set consisted of 387 lakes, 321 of which had information on breeding status, and 281 of which had data on overall reproductive success. Figure 1b shows the survey effort by administrative district or county across the portion of Ontario which was surveyed.

Two hundred and eighteen lakes (including 53 CWS-surveyed lakes) had data on loon reproductive success, lake area and lake chemistry, while 111 lakes (including 23 CWS-surveyed lakes) had data on survival between the DS and LY stages, as well as on the lake variables. Data from these lakes were used to examine the effects of lake area and water chemistry on loon production and chick survival.

4.2 Common Loon Productivity and Chick Survival

Two hundred and ninety-four pairs of Common Loons were seen on 254 of the 321 lakes (79%) with known breeding status. Breeding loons were observed on 215 of the 281 lakes for which the level of reproductive success was known. Parents were successful in rearing at least one chick to the LY stage on 163 of the 215 (76%) lakes. BP produced an average of 1.26 DS and 1.04 LY. Survival between the DS stage and the LY stage was 0.88 based on those lakes for which data were available on both stages (n = 142 lakes).

Only lake area discriminated significantly ($F = 12.21$, 3,214 df, $P < 0.0001$, $R^2 = 0.15$) among the four designated levels of loon production; thus, this analysis was analagous to a one-way ANOVA. The mean area of lakes where breeding was not attempted ($\overline{x} = 37$ ha) was significantly different ($P < 0.05$, Newman-Keuls test) from the mean areas of lakes representing the other levels of production (unsuccessful: $\overline{x} = 68$ ha; low: $\overline{x} = 83$ ha; high: $\overline{x} = 95$ ha); the mean areas of these latter groups of lakes were not significantly different ($P > 0.05$, Newman-Keuls test) from one another (Table 2).

Table 1. Between-year comparison of the number (%) of lakes having given levels of loon production and survival of chicks, for 123 lakes sampled in both years[a].

Loon Variable	Level	YEAR 1987	YEAR 1988	Total
Production	No attempt[b]	13 (16)	20 (24)	3 (20)
	Unsuccessful[c]	17 (21)	13 (16)	30 (18)
	Low[d]	31 (38)	31 (38)	62 (38)
	High[e]	21 (26)	18 (22)	39 (24)
Chick Survival	Low[f]	7 (18)	5 (13)	12 (16)
	High[g]	31 (82)	33 (87)	64 (84)

a - Only lakes with known levels of production or survival in both years were used in analysis.
b - Lakes where no breeding attempts were made
c - Lakes where breeding was attempted but where no large young were produced
d - Lakes where the number of large young per breeding attempt was greater than 0 but less than or equal to 1.0 ($0<LY/BP\leq 1.0$)
e - Lakes where the number of large young per breeding attempt was greater than 1.0 ($LY/BP>1.0$)
f - Lakes where the ratio of the number of large young to the number of downy (small) young was less than or equal to 0.5 ($LY:DS\leq 0.5$)
g - Lakes where the ratio of the number of large young to the number of downy (small) young was greater than 0.5 ($LY:DS>0.5$).

Table 2. Mean values of chemical and morphometric variables associated with four levels of production in loons[a].

Lake Variable	n	No attempt	Unsuccessful	Low	High
		Production Category			
pH	224	6.50	6.52	6.56	6.57
Alkalinity	218	77.4	82.9	95.0	98.3
Area	281	37.0	68.0	83.0	95.0

a – Values with common underlines are not significantly different (P > 0.05 according to Newman-Keuls tests).

Table 3 Number (%) of lakes by MOE Sensitivity ratings having a given level of loon production or chick survival.

Loon Variable	Category	MOE Sensitivity Index[a] 1 & 2	3	4 & 5	P > ^{2}
Production	No attempt	15 (28)	28 (23)	17 (24)	
	Unsuccessful	12 (22)	21 (17)	13 (19)	0.95
	Low	17 (31)	44 (36)	23 (33)	
	High	10 (19)	29 (24)	17 (24)	
Chick Survival	Low	9 (38)	16 (23)	2 (6)	0.02
	High	15 (63)	54 (77)	31 (94)	

a – Classes 1 & 2: alkalinity < 40 ueq/L
Class 3: alkalinity 40 - 199.99 ueq/L
Classes 4 & 5: alkalinity ≥ 200 ueq/L

The MOESI variable provided significant discrimination ($F = 5.96$, 1,108 df, $P = 0.016$, $R^2 = 0.05$) between lakes where survival between the DS and LY stages was low (≤ 0.5) and those where it was high (> 0.5). Low survival ratios occurred more frequently ($\chi^2 = 8.4$, 2 df, $P = 0.02$) on acidic and extremely sensitive lakes than on those which were moderately sensitive or not sensitive (Table 3). Because the MOESI is a categorical variable based on measurements of alkalinity, this variable was excluded from subsequent models and stepwise discriminant analysis was repeated using lake area and alkalinity in one model and lake area and pH in the other. In the former model, alkalinity alone provided significant discrimination ($F = 4.8$, 1,109 df, $P = 0.03$) between the two levels of chick survival, while in the latter model, pH alone provided significant discrimination ($F = 6.34$, 1,111 df, $P = 0.01$) making these analyses analagous to one-way ANOVAS. The similar results for the two models are not surprising in view of the highly significant correlation co-efficient ($r = 0.86$, $n=303$) between these two variables. Mean alkalinity and pH of lakes where survival was low (alkalinity: $\bar{x} = 54.2$ ueq/L, ; pH: $\bar{x} = 6.28$) were significantly lower than those of lakes where survival was high (alkalinity: $\bar{x} = 108.6$; pH: $\bar{x} = 6.65$). There was no significant difference in mean lake area between the two levels of survival ($P = 0.48$) (Table 4).

The absence of any significant effect of water chemistry on overall loon productivity coupled with its significant effect on chick survival raises the possibility that the increased mortality on low alkalinity - low pH lakes resulted from initially larger broods being seen there. In other words, the proportion of lakes where deaths of young chicks went undetected may have been higher on high alkalinity - high pH lakes. Although there appeared to be a slight tendency for this to be true, the relationship between the number of DS chicks in a brood and lake chemistry was never significant. The frequency of occurrence of broods with two versus one DS chick was independent of alkalinity ($G_{adj} = 0.51$, 2 df, $P > 0.75$), pH ($G_{adj} = 2.40$, 2 df, $P > 0.25$) and MOESI ($G_{adj} = 3.35$, 2 df, $P > 0.10$) (Fig. 5). Therefore, it was apparent that survival between the DS and LY stages was affected by lake chemistry but not to the extent where overall production was significantly lowered.

For broods with only one DS chick, the low frequency of lakes with 0% survival to the LY stage within all categories of alkalinity, pH and MOESI precluded the use of statistical tests to examine the effects of lake chemistry on survival. However, the high level of survival to the LY stage at every level of alkalinity, pH and MOESI ($\geq 86\%$ in all cases) (Fig. 6) suggests that survival of chicks in broods with only one DS chick was independent of lake chemistry. This contrasts with the situation in two-chick broods which experienced significantly higher mortality (alkalinity: $G_{adj} = 8.39$, 2 df, $P < 0.025$; pH: $G_{adj} = 7.26$, 2 df, $P < 0.05$; MOESI: $G_{adj} = 6.65$, 2 df, $P < 0.05$) on poorly-buffered/low pH lakes than on those with higher alkalinity or high pH (Fig. 7).

Table 4. Mean values of chemical and morphometric variables associated with two levels of chick survival between the downy (small) young stage and the large young stage.

Lake Variable	n	Chick Survival Category[a]		
		Low	High	P > F
pH	113	6.28	6.65	0.01
Alkalinity	111	54.2	108.6	0.04
Area	143	83	95	0.48

a See Table 1 for explanation of low and high chick survival

Fig. 5. Percent frequency of occurrence of either one (solid bars) or two (open bars) downy or small chick broods according to water chemistry.

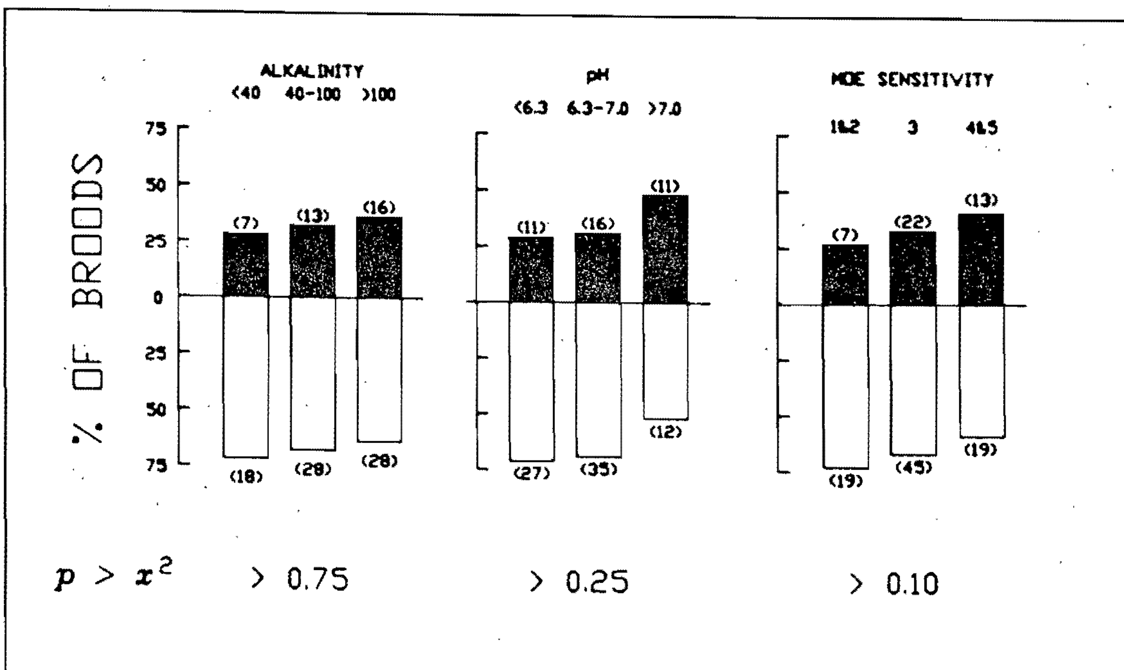


Fig. 6. Of the broods with only one DS chick, the percentage (n) in which the chick survived to the LY stage (open bars) or died before reaching that stage (solid bars) are shown according to the chemistry of the lakes where they were raised. Exact survival could not be determined for one brood.

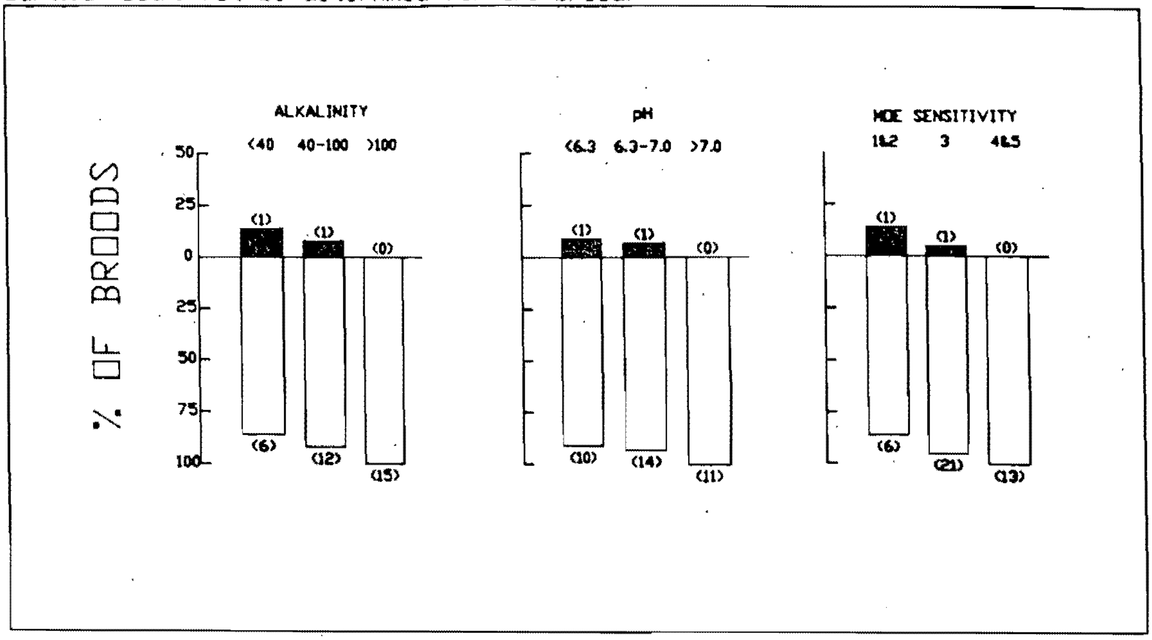
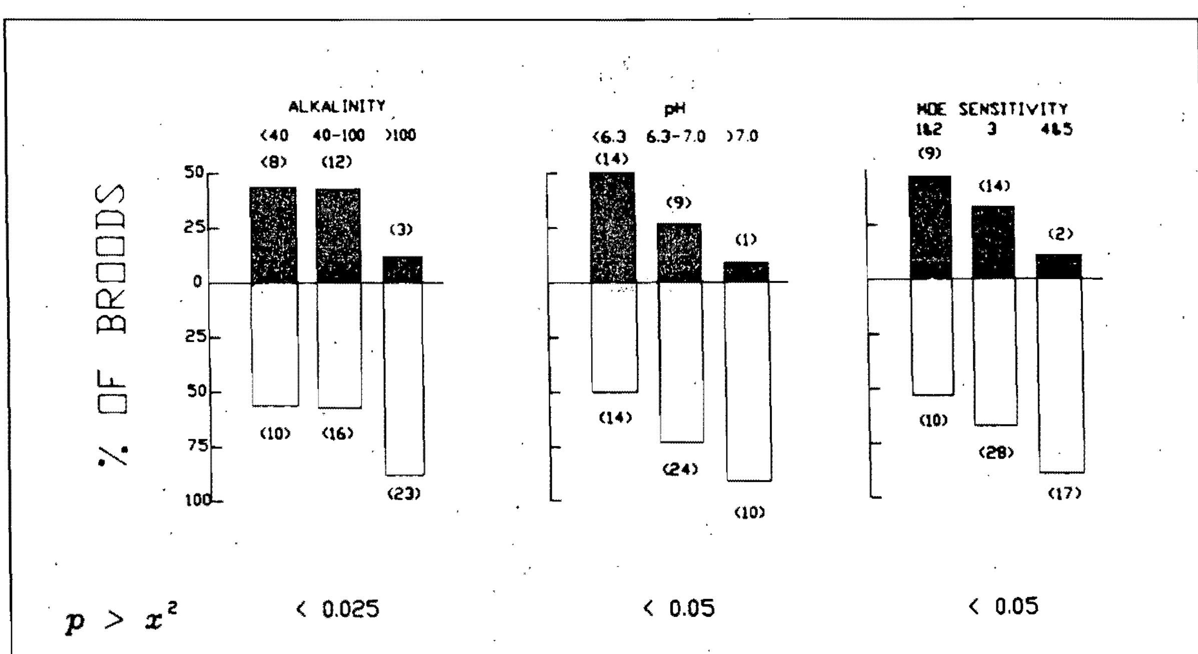


Fig. 7. Of the broods with two DS chicks, the percentage (n) in which survival to the LY stage was either 100% (open bars) or less than 100% (solid bars) are shown according to the chemistry of the lakes where they were raised. Exact survival could not be determined for two broods in the alkalinity and pH histograms and for three broods in the MOE Sensitivity histogram and therefore were not included in the analyses.



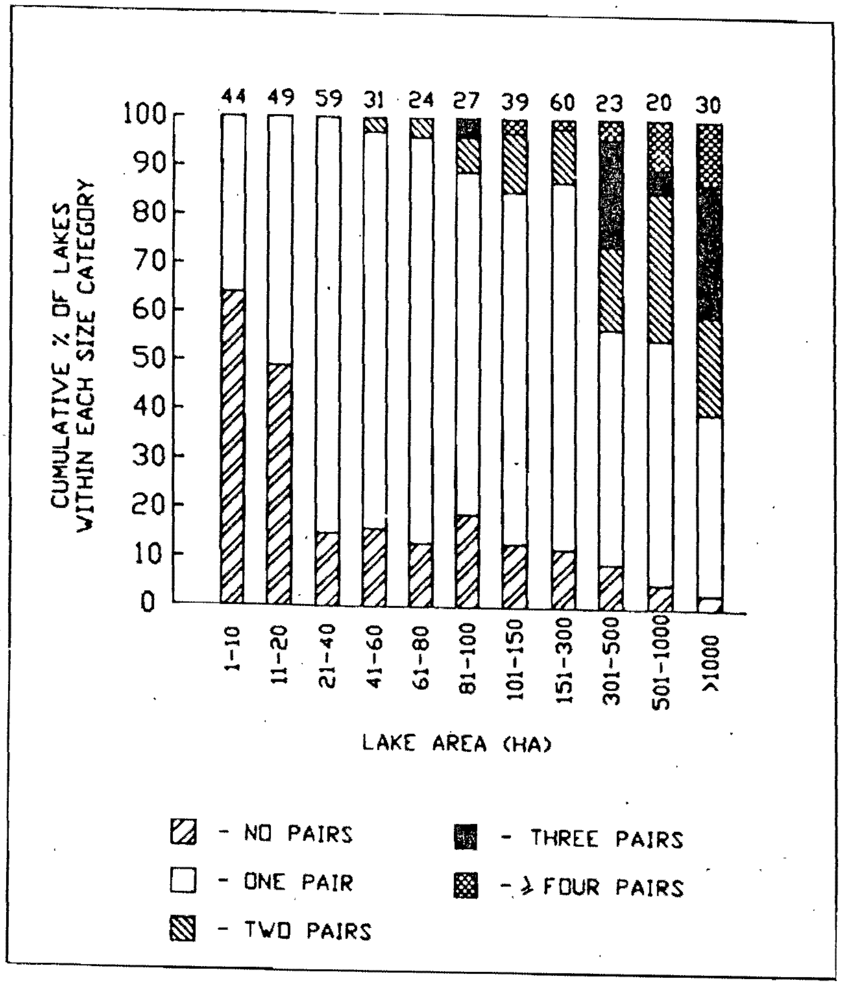
5. DISCUSSION

5.1 Common Loon Productivity and Chick Survival

The overall fledging rate in the OLLS was 1.04 LY/BP. This is comparable to the 0.88 large young (6-8 weeks old) per breeding pair in Upper New York State (calculated from Parker 1988), but somewhat higher than the 0.74 large young per breeding attempt found near Sudbury (calculated from Alvo 1985), the 0.72 fledged chicks per territorial pair in an uncontaminated watershed in northwestern Ontario (Barr 1986), and the 0.38 fledged chicks per breeding pair in an acid-sensitive area of Nova Scotia (Kerekes et al. 1988). The difference between the findings of this study and those of Alvo (1985), Barr (1986) and Kerekes et al. (1988) may be attributed partially to inter-year and/or survey lake differences, and therefore may represent real differences in overall production. On the other hand, the relatively lower production rates found in their studies may have resulted from the high frequency and intensity of their surveys, increasing the likelihood of detecting failed nesting attempts. The approach used by OLLS volunteers did not include nest searches or a rigorous schedule of lake visits. Moreover, there may have been a systematic bias towards underreporting instances where nesting attempts were known to have failed despite efforts to encourage volunteers to submit such observations.

The results of the 1987 and 1988 surveys indicated that lake selection by a pair of breeding loons was significantly related to lake area (Table 2); in general, breeding pairs avoided small lakes. This finding is consistent with those of Barr (1986) who found that the average territory size of breeding loons was 75 ha and Alvo et al. (1988) who found that lake area discriminated between lakes with or without breeding attempts. When lakes of all sizes were considered in the OLLS, breeding pairs were absent from about 60% of lakes $\leq$ 20 ha and were present on more than 80% of lakes > 20 ha (Fig. 8). Moreover, multiple pairs occurred occasionally on lakes in the range of 40-300 ha and frequently on lakes > 300 ha. Small lakes may be avoided by loons because of their low annual fish biomass production (Kerekes et al. 1988). Parker (1988) has estimated that a single loon chick requires approximately 62 kg of food during its first 16 weeks of life, the approximate residency time on its natal lake. Kelso (1985) found that fish production (not including cyprinids) in three small, oligotrophic central Ontario lakes ranged from 1.2-6.6 kg/ha/yr. Therefore, to sustain a level of fledging of one loon chick/lake/yr, the minimum size of lake required by a pair of loons would be in the range of 10-52 ha, a pattern of lake size selection consistent with that found in this study (Fig. 8). This estimate assumes that the parents would feed on another lake, and that the size-specific food requirements of the chicks which prevents them from consuming the proportion of production attributable to fish > 200 g (Barr 1986), would offset the additional production that cyprinids may provide. In contrast to these projected minimum size requirements, loons were observed to successfully raise young on lakes as small as 3 ha. Moreover, of the nine breeding attempts with known outcomes on lakes < 10 ha, six were successful. This suggests that the

Fig. 8. For a given category of lake size, the cumulative percentage of lakes (n) with the indicated number of breeding pairs.



rates of fish production documented by Kelso (1985) may be low compared to some lakes in central Ontario, that alternative prey may be sufficiently abundant to warrant breeding on small lakes, or that loons may be capable of augmenting the food supply by bringing fish from neighbouring lakes. Parker (1988) observed loons carrying fish from one lake to another, but concluded that such a strategy is used only rarely. Alvo et al. (1988) did not observe food-carrying behaviour, and concluded that this strategy was not adopted by loons rearing young on lakes with depauperate fish populations. Insects and crayfish are common foods for loon chicks (Barr 1986, Alvo et al. 1988, Parker 1988); however, Barr (1986) concluded that, given a choice, loons would avoid lakes where the availability of fish was low, while Alvo et al. (1988) concluded that, when compared to fish, alternate prey would be less likely to sustain growing loons through to fledging. The total fish production in a small, oligotrophic shield lake near North Bay, Ontario was estimated to be 30.8 kg/ha/yr (Chadwick 1976), a rate substantially higher than those reported above by Kelso (1985). Less than 1% of this production was attributable to fish larger than the maximum size that can be consumed by loon chicks (200 g according to Barr 1986). Based on this rate, the minimum lake size required to raise a chick would be only 2 ha. If this level of production is typical of at least some lakes on the Precambian Shield in Ontario, it may explain, partially, the decision by loons to attempt to breed on almost 40% of the surveyed lakes $\leq$ 10 ha (Fig. 8).

Contrary to the results of Alvo et al. (1988) which showed fewer successful breeding attempts by loons on highly sensitive lakes (< 40 ueq/L) than on those which were only moderately or non-sensitive ($\geq$ 40 ueq/l), this study did not show any significant effects of lake sensitivity or lake acidity on overall loon production (Tables 2 & 3). This difference occurred despite the similar ranges of alkalinities in the two studies. Our results support to some extent Parker's (1988) findings which showed that loons were capable of rearing at least one chick to fledging on some acidic lakes in upper New York State. However, the results should be viewed with caution since there was a definite trend towards lower production on low pH, acid-sensitive lakes when compared with high pH, non-sensitive ones. The mean LY:BP ratios were 0.97, 1.01, and 1.10 on lakes with pH values < 6.3, between 6.3-7.0, and > 7.0, respectively. When lake alkalinity was considered, these ratios were 0.92, 1.01, and 1.10 on lakes < 40, between 40-100, and > 100 ueq/L, respectively. On acidic or highly-sensitive lakes, the relatively low rate of production was associated with a low level of survival between the DS and LY stages. LY:DS ratios were 0.75, 0.82, and 0.96 on lakes < 40, 40-100, and > 100 ueq/L respectively. Since loons usually lay two eggs and hatch two chicks, the relatively large number of broods with only one DS chick (Fig. 5) suggests that the deaths of some very young chicks went undetected. Therefore, the above ratios probably overestimate overall chick survival rates. Nevertheless, since observations of complete broods (i.e. those with two DS chicks) versus those that possibly had suffered some undetected mortality (i.e. broods with only one DS chick) were independent of lake chemistry variables (especially alkalinity - Fig. 5), failure to detect some deaths of young chicks should not have biased unduly the results on the significant relationship between survival and lake chemistry.

The slightly lower rates of production and survival on acidic or highly sensitive lakes was likely the result of poorer survival of broods with two DS chicks on these lakes when compared to circumneutral and non-sensitive lakes (Fig. 7). The relatively high rate of survival of both chicks in two-chick broods on lakes ≥ 6.3 is consistent with Alvo's (1985) results which showed that both chicks survived in 15 of 18 (83%) two-chick broods on lakes of a similar pH category. Unfortunately, Alvo (1985) had data on only four lakes with pH < 6.3 where two-chick broods occurred. Both chicks survived on only two of these four lakes (50%), a pattern matching that of the OLLS data (Fig. 7). Also, Parker et al. (1986) monitored loon production in upper New York State and found that broods with two fledged chicks occurred proportionately more often on lakes ≥ pH 5.0 (57%, n=14 lakes) than on lakes < pH 5.0 (0%, n=6 lakes). The survival of two chick broods may be influenced to some extent by the food supply. Fish species richness (Harvey 1982, Weiner et al. 1984, McNicol et al. 1987a, Matuszek and Beggs 1988) and biomass (Frenette et al. 1986, McNicol et al. 1987a) decrease with pH especially below pH 6.0. Moreover, lake acidification is also known to be detrimental to crayfish (Schindler et al. 1985), which were found to be important in the diets of loons (Barr 1986). Alvo et al. (1988) found that the foraging efficiency of loon parents was reduced on acidic lakes and suggested that depletion of potential prey was the main cause for this reduction. Parker (1988) showed that loons can't always obtain optimum-sized fish for their young on acidified lakes. Therefore, it is probable that loons would experience difficulty in successfully rearing both chicks in a two-chick brood when faced with food shortages on an acid lake. Under such conditions, it is possible that the larger sibling would dominate the parent's attention and obtain a disproportionate share of the scare food supply.

5.2 OLLS Volunteer Participation

Volunteer participation in the OLLS was high in 1987 and 1988 with nearly 500 records returned each year (excluding CWS surveys). Moreover, McCracken (1988) compared volunteer and LPBO staff surveys on a subsample of sixteen lakes in the Muskoka-Haliburton area and concluded that multiple volunteer surveys on those lakes produced higher quality data on loon reproductive success than single surveys conducted by LPBO staff. She further showed that when volunteers visited lakes several times a season, preferably in late June, in mid-July and in late August, the degree of loon breeding success was accurately ascertained. Thus, it is evident that a volunteer-based project can be an effective means of monitoring the long-term reproductive success of loons on a large number of lakes in eastern, central and northern Ontario, especially if volunteers continue to show the same level of interest in the OLLS as was evident in 1987 and 1988.

However, several shortcomings were also evident in this study. Chief among them was the large-scale elimination of records for any one of the following reasons: 17 and 18% of the records returned in 1987 and 1988 respectively were redundant (i.e. records from one volunteer duplicated records from other volunteers on the same lake); a further 32%

of 1987 records and 30% of 1988 records were eliminated because the data were judged to be of poor quality (McCracken 1988), or the lakes were not completely surveyed; after data from the two years were combined, 118 of the 505 lakes (23%) were eliminated because they did not fall within the size range of lakes considered acceptable for analysis (10-500 ha); the degree of reproductive success could not be determined on 106 of the 387 remaining lakes (27%); and, finally, lake alkalinity and pH data were not available on another 63 and 57 lakes, respectively.

In addition, data on both breeding status and status of large young were obtained on only 54 lakes (including 18 CWS-surveyed lakes) which were classified as either acidic or highly sensitive (< 40 ueq/L). Thus, despite the large number of lakes that were surveyed, data on loon reproductive success were available on only a relatively small number of lakes which were of specific interest in the development of a long-term biomonitoring program in Ontario; specifically, those lakes currently suffering the biological effects of acid precipitation (i.e. increased acidification) and those lakes whose acid neutralizing capacity may be insufficient to buffer continued inputs of acid deposition in the future (i.e. extremely sensitive).

Another important consideration is that surveyors probably failed to detect deaths of very young chicks in some cases. In this study, it was fortuitous that the proportional occurrence of one and two-DS chick broods was distributed approximately evenly across alkalinity, pH, and MOE sensitivity categories. However, analysis of survival data could lead to wrong conclusions if the failure to detect deaths is not distributed evenly across categories of lake chemistry. In the future, it will be necessary for volunteers to schedule their surveys so that one is done within a few days of hatching, particularly in those cases when the number of eggs laid and hatched is unknown.

Finally, the analysis of loon reproductive success or chick survival depended on a small number of explanatory variables, a situation which seriously inhibits the investigators' ability to predict reproductive effort and success rates of loons on individual lakes. For example, while lake area discriminated significantly among the different levels of breeding success, only 14% of its total variation was explained by these levels. There can be little doubt that other morphometric, chemical and biotic variables would provide additional discriminatory power. For example, turbidity affected patterns of habitat selection by Common Loons in northwestern Ontario (Barr 1986), while potential nest sites were considered an important determinant of reproductive effort in northern Alberta (Vermeer 1973). The availability of undisturbed, shallow-water areas close to shore was felt to be a requisite for rearing chicks on large lakes in Maine (Strong and Bissonette 1989). In Ontario, McNicol et al. (1987b) found that piscivorous waterbirds, and the Common Loon in particular, nested and raised their young on large lakes with irregular shorelines often draining substantial areas. Breeding lakes were also characterized by their dilute, oligotrophic (low nutrient and low dissolved organic carbon) nature and capacity to support viable fish populations.

To rectify some of the above-mentioned problems, volunteers must be strongly encouraged to survey the entire lake (100% coverage) sufficient times in a season to permit the evaluation of relative reproductive success. Partial surveys of large lakes should be avoided where possible since it is often difficult for staff members to determine the area of the portion of the lake surveyed by volunteers; moreover, if breeding loons are encountered, some uncertainty may exist as to whether their territories were surveyed completely during each survey. Finally, on large, multiple-pair lakes, surveyors may have difficulty distinguishing among different pairs or broods on successive surveys, thus increasing the possibility of errors in the assessment of individual reproductive success. Moreover, further steps must be taken to target particular lakes that are within the acceptable size limits and for which water chemistry data are available. Ashenden (1989) has discussed the general resistance of volunteers to being assigned to specific lakes. Clearly, other steps must be investigated to increase the sample size of targeted lakes. Finally, if the OLLS is to continue as part of a long-term monitoring program, consideration must be given to methods that will permit the collection of data on a wider variety of variables on key lakes that are surveyed year after year. This additional information would provide a more precise explanation of patterns of reproductive success and chick survival.

5.3. Recommendations

If the OLLS is to become a tool for monitoring Common Loon production in relation to acid precipitation in Ontario, we recommend the following steps be taken to improve the project in the future:

1) improve the quality of data collected by volunteers; specifically, reduce the number of lakes that were incompletely surveyed or were surveyed too infrequently to determine overall loon breeding success and schedule surveys so that brood survival can be assessed from a few days after hatch until the chicks are six to eight weeks old;

2) increase the number of targeted lakes which are surveyed; specifically, increase the sample size of acid-sensitive lakes (< 40 ueq/L alkalinity);

3) gather data on other, pertinent lake variables (which may be important in assessing loon reproductive success) on key lakes including mean lake depth, turbidity, shoreline development and the number of potential nest sites (i.e. number of small islands and/or extent of boggy shoreline).

6. ACKNOWLEDGEMENTS

We thank the volunteers who participated in the OLLS and encourage them to continue their efforts. We would especially like to thank Jane Ashenden, coordinator for the Ontario Lakes Loon Survey, for her hard work in administering the OLLS project and compiling the volunteer data. We thank D. Hussell and P. Strong for reviewing the manuscript. Helpful comments also were provided by J. Ashenden, P. Blancher, and K. Ross. We thank P. Blancher, M. Mallory, B. Matsuda, D. Morgan, J. Perkins, M. Porter and V. St. Louis for their assistance in field work conducted by the CWS. Technical advice for the OLLS project was provided by D. Hussell, V. Glooschenko, E. Dunn, M. McNicholl, P. Carson, M. Cadman and S. Gibson. B. Neary of the Ontario Ministry of the Environment and D. Dodge and D. Wales of the Ontario Ministry of Natural Resources provided lake area and chemistry data from the Ontario Extensive Lakes Survey Data Base. D. Morgan and R. Chow produced the figures and S. Bradford & W. Hayes typed the manuscript. OLLS is a joint project of the Canadian Wildlife Service (Ontario Region) and the Long Point Bird Observatory, and is largely funded by the federal Long Range Transport of Airborne Pollutants program.

7. LITERATURE CITED

Alvo, R. 1985. The breeding success of Common Loons (Gavia immer) in relation to lake alkalinity, M.Sc. Thesis, Trent University, Peterborough, Ont. 122 pp.

Alvo, R., D.J.T. Hussell, and M. Berrill. 1988. The breeding success of Common Loons in relation to alkalinity and other lake characteristics in Ontario. Can. J. Zool. 66: 746-752.

Ashenden, J.E. 1989. Ontario Lakes Loon Survey: Progress Report No. 6: 1988. Long Point Bird Observatory, Port Rowan, Ont. 34 pp.

Barr, J.F. 1986. Population dynamics of the Common Loon (Gavia immer) associated with mercury-contaminated waters in northwestern Ontario. Occasional Paper No. 56. Canadian Wildlife Service. 25 pp.

Blancher, P.J., and D.G. McAuley. 1987. Influence of wetland acidity on avian breeding success. Trans. N.A. Wildl. and Nat. Res. Conf. 52: 628-635.

Blancher, P.J., and D.K. McNicol. 1988. Breeding biology of tree swallows in relation to wetland acidity. Can. J. Zool. 66: 842-849.

Chadwick, E.M. 1976. Ecological fish production in a small Precambrian lake. Env. Biol. Fish. 1: 13-60.

Cook, R.B., M.L. Jones, D.R. Marmorek, J.W. Elwood, J.L. Malanchuk, R.S. Turner, and J.P. Smol. 1988. The effects of acidic deposition on aquatic resources in Canada: an analysis of past, present and future effects. Publ. No. 2894, Environmental Sciences Division, Oak Ridge National Laboratory.

DesGranges, J.-L., and M. Darveau. 1985. Effect of lake acidity and morphometry on the distribution of aquatic birds in southern Quebec. Hol. Ecol. 8: 181-190.

Dillon, P.J., N.D. Yan, and H.H. Harvey. 1984. Acidic deposition: effects on aquatic ecosystems. CRC Critical Reviews in Environmental Control 13: 167-194.

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

Eriksson, M.O.G. 1986. Reproduction of Black-throated Diver, Gavia arctica in relation to fish density in oligotrophic lakes in southwestern Sweden. Ornis Scand. 17: 245-248.

Frenette, J.-J., Y. Richard, and G. Moreau. 1986. Fish responses to acidity in Quebec lakes: a review. Water, Air, and Soil Pollution 30: 461-475.

Haines, T.A. 1981. Acidic precipitation and its consequences for aquatic ecosystems: a review. Trans. Am. Fish. Soc. 110: 669-707.

Harvey, H.H. 1982. Population responses of fishes in acidified waters. pp 227-242. In: Acid Rain/Fisheries: Proceedings of an International Symposium on Acidic Precipitation and Fishery Impacts in Northeastern North America (R.A. Johnson, ed.) Am. Fish. Soc. Bethesda, Maryland.

IWD. 1988. Acid Rain: a national sensitivity assessment. Inland Waters Directorate. Environment Canada: Environmental Fact Sheet 88-1. 6 pp.

Jones, M.L., and C. Wedeles. 1989. Developing a regional model of acidification effects on waterfowl. ESSA unpubl. report 51 pp.

Kelso, J.R.M. 1985. Standing stock and production of fish in a cascading lake system on the Canadian Shield. Can. J. Fish. Aquat. Sci. 42: 1315-1320.

Kelso, J.R.M., C.K. Minns, J.E. Gray, and M.L. Jones. 1986. Acidification of surface waters in eastern Canada and its relationship to aquatic biota. Can. Spec. Publ. Fish. Aquat. Sci. 87. 42pp.

Kerekes, J., D. Sears, and R. Tordon. 1988. Loon population survey in Kejimkujik National Park. Abstract from paper given at Kejimkujik '88 Conference held at Wolfville, N.S., Canada, Oct. 25-27, 1988.

Longcore, J.R., R.K. Ross and K.L. Fisher. 1987. Wildlife resources at risk through acidification of wetlands. Trans. N. A. Wildl. and Nat. Res. Conf. 52: 608-618.

Matuszek, J.E., and G.L. Beggs. 1988. Fish species richness in relation to lake area, pH, and other abiotic factors in Ontario lakes. Can. J. Fish. Aquat. Sci. 45: 1931-1941.

McAuley, D.G., and J.R. Longcore. 1988. Survival of juvenile ring-necked ducks on wetlands of different pH. J. Wildl. Manage. 52: 169-176.

McCracken, J.E. 1988. The Ontario Lakes Loon Survey: Progress Report No. 5: 1987. Long Point Bird Observatory, Port Rowan, Ont. 73 pp.

McIntyre, J. 1989. The Common Loon cries for help. National Geographic. April: 510-524.

McNicol, D.K., B.E. Bendell, and D.G. McAuley. 1987a. Avian trophic relationships and wetland acidity. Trans. N.A. Wildl. and Nat. Res. Conf. 52: 619-627.

McNicol, D.K., B.E. Bendell, and R.K. Ross. 1987b. Studies of the effects of acidification on aquatic wildlife in Canada: waterfowl and trophic relationships in small lakes in northern Ontario. Occasional Paper No. 62. Canadian Wildlife Service. 76 pp.

McNicol, D.K., R.K. Ross, and P.J. Blancher. 1990. Waterfowl as indicators of acidification in Ontario Canada. Trans. Int. Union of Game Biologists. Congress No. 19. Trondheim, Norway. Sept. 8-13, 1989.

OMOE. 1978. Extensive monitoring of lakes in the Greater Sudbury area 1974 - 1976. Sudbury Environmental Study Report. Water Resources Assessment, Northeastern Region, Ontario Ministry of the Environment. 40 pp. and appendices.

OMOE. 1987. Acid sensitivity of lakes in Ontario. Ontario Ministry of the Environment. Toronto, Ont. 26 pp.

Ormerod, S.J., and S.J. Tyler. 1987. Dippers (<u>Cinclus cinclus</u>) and grey wagtails (<u>Motacilla cinerea</u>) as indicators of stream acidity in upland Wales. pp 191-208. <u>In</u>: The Value of Birds (A.W. Diamond and F.L. Filion, eds.), ICBP Tech. Publ. No. 6. Cambridge, U.K.

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

Parker, K.E., R.L. Miller, and S. Isil. 1986. Status of the Common Loon in New York State. Unpubl. Report, New York State Dep't. of Env. Cons. Delmar, N.Y. 73 pp.

Ro, C.U., W. Sukloff, & R.J. Vet. 1989. NATCHEM: CFS Project. Unpublished. Report. Environment Canada. Atmospheric Environment Services. 6pp. + 5 maps.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 edition. Cary, NC: SAS Institute Inc., 1988. 1028 pp.

Schindler, D.W. 1988. Effects of acid rain on freshwater ecosystems. Science 239: 149-157.

Schindler, D.W., K.H. Mills, D.F. Malley, D.L. Findlay, J.A. Shearer, I.J. Davies, M.A. Turner, G.A. Linsey, and D.R. Cruickshank. 1985. Long-term ecosystem stress: the effects of years of experimental acidification on a small lake. Science 228: 1395-1401.

Shilts, W.W. 1981. Sensitivity of bedrock to acid precipitation: modification by glacial processes. Geological Survey of Canada. Paper 81-14. 7 pp and maps.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry 2nd edition. W.H. Freeman and Co. San Francisco, CA. 859 pp.

Strong, P.I.V., and J.A. Bissonette. 1989. Feeding and chick-rearing areas of common loons. J. Wildl. Manage. 53: 72-76.

Suns, K., G. Hitchin, B. Loescher, E. Pastorek, and R. Pearce. 1987. Metal accumulations in fishes from Muskoka-Haliburton lakes in Ontario. Unpubl. Report. Ontario Ministry of the Environment. Water Resources Branch. 38 pp.

Vermeer, K. 1973. Some aspects of the nesting requirements of Common Loons in Alberta. Wilson Bull. 85: 429-435.

Weiner, J.G., P.J. Rago, and J.M. Eilers. 1984. Species composition of fish communities in northern Wisconsin lakes: relation to pH. pp 133-146. In: Early Biotic Responses to Advancing Lake Acidification (G.R. Hendrey, ed.), Butterworth Publishers, Woburn, MA.

Wren, C.E., and H.R. MacCrimmon. 1983. Mercury levels in the sunfish, Lepomis gibbosus relative to pH and other environmental variables of precambrian shield lakes. Can. J. Fish. Aquat. Sci. 40: 1737-1744.