Edited by
Jean-Luc DesGranges

Studies of the effects of acidification on aquatic wildlife in Canada: Lacustrine birds and their habitats in Quebec

Occasional Paper
Number 67
Canadian Wildlife Service

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Edited by
Jean-Luc DesGranges*

Studies of the effects of acidification on aquatic wildlife in Canada: Lacustrine birds and their habitats in Quebec

Occasional Paper
Number 67
Canadian Wildlife Service

Disponible également en français

*CWS (Quebec Region)
1141 Route de l'Église
Sainte-Foy, Quebec G1V 4H5

Published by Authority of the
Minister of Environment
Canadian Wildlife Service

Catalogue No. CW69-1/67E
ISBN 0-662-16845-3
ISSN 0576-6370

Design: Rolf Harder & Assoc.

Canadian Cataloguing in Publication Data

Main entry under title:

Studies of the effects of acidification on aquatic wildlife in Canada: lacustrine birds and their habitats in Quebec

(Occasional paper/Canadian Wildlife Service; no. 67)
Issued also in French under title: Étude des effets de l'acidification sur la faune aquatique au Canada.
Includes bibliographical references.
ISBN 0-662-16845-3
DSS cat. no. CW69-1/67E

1. Water-birds — Quebec (Province) — Ecology. 2. Wetland conservation — Quebec (Province). 3. Birds, Protection of — Quebec (Province). 4. Acidification — Environmental aspects — Quebec (Province). 5. Acid rain — Environmental aspects — Quebec (Province). I. DesGranges, Jean-Luc. II. Canadian Wildlife Service. Quebec Region. III. Title. IV. Title: Lacustrine birds and their habitats in Quebec. V. Series: Occasional paper (Canadian Wildlife Service); no. 67.

QH545.A17D4713 1989 598.29'24 C89-097058-0

Contents

List of figures

List of appendices

Acknowledgements

We wish to acknowledge and thank all our co-workers for their admirable work: principal technician for the study Rhéal Anger; ornithologists Jacques Boisvert, Pierre Brousseau, Marcel Darveau, André Desrochers, Thérèse Dupuis, Gilles Falardeau, Peter Lane, André Nadeau, and Yves Turcotte; limnologists Gérard Croteau, Dario Lemelin, Daniel Richard, and Aline Sylvestre; and the technicians who carried out the soil analyses (Magella Gauthier) and plant identification (Jean-Louis Lethiecq), both from Laurentian Forestry Centre.

We also wish to thank Yves Grimard, Paul Potvin, and Jean Rodrigue, limnologists of the Water Quality Service of the Quebec Department of the Environment, and Dr. Antonio Gonzalez, chemist with the Laurentian Forestry Centre, for their invaluable contribution.

We are grateful to Suzelle Giroux and Louise Trudel, who processed the statistical data; Lynne Grégoire, who keyed in the manuscript; and Lise Villeneuve and Peter Lane, who prepared the figures. Many colleagues, notably Brian Collins, Joe Kerekes, Don K. McNicol, and Kathy L. Fischer, all from CWS, and Pierre Grondin and Michel Melançon, made helpful comments on parts of the preliminary version of this paper. Jean-Dominique Lebreton, of the Centre national de la recherche scientifique in France, graciously reviewed the entire manuscript and made many valuable suggestions.

Our project received financial assistance under the federal program for research into the long-range transport of airborne pollutants (LRTAP).

Foreword

This report contains the results of research carried out under the auspices of the Long Range Transport of Air Pollutants program, an interdepartmental research initiative of the federal government involving Agriculture Canada, Fisheries and Oceans Canada, Energy, Mines and Resources Canada, Health and Welfare Canada, and Environment Canada. Within Environment Canada, research into various aspects of long-range transport of air pollutants is being carried out by the Atmospheric Environment Service, Inland Waters/Lands, and the Canadian Wildlife Service (CWS).

The CWS research program was started in 1980 to assess the impacts of acid deposition on wildlife and wildlife habitats in eastern Canada. The results of the first phase of the program are contained in this and other volumes in the Occasional Papers series.

A major objective of the CWS research was to compare avian breeding and feeding ecology data collected from sensitive headwater habitats receiving different rates of acid loading. The first paper describes the work on waterfowl and their food chains in Ontario, while this second one describes the results of surveys of freshwater bird communities in Quebec, as well as phyto-ecological studies of their associated habitats, in relation to acidification.

Other important areas of interest are the influence of long-range deposition and acidification on metal uptake by wildlife prey organisms and the toxicity of low-level metal exposure to aquatic birds. Long-range transport of airborne pollutants can affect the availability of heavy metals to biota both by direct transport and by the mobilization of metals from soils and sediments as acidity increases. A forthcoming Occasional Paper will include preliminary results of research at the National Wildlife Research Centre on the fate of heavy metals in waterfowl food chains, as well as laboratory studies of the effects of dietary heavy metals on the reproductive output of birds under controlled conditions.

Together these volumes will provide a summary of the first phase of the CWS LRTAP program. The objective of this phase was to determine which species and habitats might be most at risk from acidification. Current studies are designed to establish a more definite cause-and-effect relationship between acidification and biological changes, chiefly in bird communities; to provide the basis for a biomonitoring program which will track the changes expected to occur as emissions are reduced to the target loading (i.e., 50% of 1980 levels by 1994); and to evaluate the adequacy of that target loading for protecting aquatic biota.

Interdisciplinary studies of calibrated basins form an important aspect of the LRTAP program. CWS has played a major role in one of these, the Kejimkujik Calibrated Catchment program, studying nutrient release in and limnological characteristics of acidified waters in Kejimkujik in Atlantic Canada. Results of these and other related CWS studies on acidification are included in the *Final report of Impact Assessment Work Group 1 of the U.S.–Canada Memorandum of Intent* (1983); the two-volume proceedings of the International Symposium on Acidic Precipitation held at Muskoka, Ontario, in 1985, edited by H. Martin and published as Vol. 30 of *Water, Air and Soil Pollution* (1986); and the proceedings of an International Workshop on Birds as Bio-indicators held in Kingston, Ontario, in 1986 and published in *The value of birds*, edited by A.W. Diamond and F.L. Filion, a Technical Publication of the International Council for Bird Preservation (Cambridge, U.K., 1987).

D.B. Peakall
Scientific Advisor, LRTAP Program
Canadian Wildlife Service

A.W. Diamond
Coordinator, LRTAP Program
Canadian Wildlife Service

Effects of acidity and other environmental parameters on the distribution of lacustrine birds in Quebec

Jean-Luc DesGranges and Benoît Houde[a]

CWS, Sainte-Foy, Quebec
G1V 4H5

1. Abstract

This study examines the potential impact of acid precipitation on lacustrine birds in Quebec. We determined the composition of bird communities at lakes in regions with various levels of deposition and sensitivity. This made it possible to evaluate the sensitivity to acidity of a large number of species found in the wetlands of the Canadian Shield and helped identify species that could be affected by the acidification of nesting habitats.

We made several visits to a total of 146 lakes located in the most important Quebec biomes in order to count the birds and describe the morphometry, the water quality, several biological factors, the riparian soils, and the aquatic and riparian vegetation. As a result, we are now in a position to assess the relative importance of each of these environmental features in the selection of wetland habitats by lacustrine birds.

The lakes located in the Laurentians were found to support a dozen lacustrine species on average whether they were acidic (pH between 4.4 and 5.5) or not. In the taiga, on the other hand, highly acidic lakes (pH < 4, geological in origin) had only half as many species as neutral or alkaline lakes. At acidic lakes it is primarily the aquatic species that are missing. While about 10 aquatic species are common at non-acidic lakes in the taiga, at acidic lakes only two species of waterfowl were found (Canada Goose *Branta canadensis* and Red-breasted Merganser *Mergus serrator*), along with occasional shorebirds.

The statistical technique of correspondence analysis made it possible to examine simultaneously the effects of the main morphological, physical-chemical, and biological features of the lakes so that the relative role of each of these in the birds' selection of a lake could be assessed. The results show that productivity (as estimated by chlorophyll "a" levels in the lakes) and degree of "reticulation" (in the sense of Darveau *et al.*, this publication; i.e., the nature of the interface between riparian vegetation and water) are the two most important factors in the division of available habitats among the aquatic species. Some species — mainly waders (e.g., American Bittern *Botaurus lentiginosus* and dabbling ducks (e.g., American Black Duck *Anas rubripes* and Green-winged Teal *A. crecca*) — prefer productive lakes, generally with well-developed riparian vegetation. This type of lake tends to have a large, shallow littoral zone that allows light to reach the bottom of the lake in several locations. This, along with the generally near-neutral pH, fosters the growth of aquatic plants and allows the development of an abundant aquatic fauna.

Other species — notably diving ducks — prefer lakes with low productivity and water that is often acidic. In this group were Common Goldeneye *Bucephala clangula* and Red-breasted Merganser, found chiefly at lakes with undeveloped riparian vegetation, and Ring-necked Duck *Aythia collaris* and Hooded Merganser *Lophodytes cucullatus*, seen mainly at lakes with a wide and well-reticulated belt of vegetation. Although aquatic invertebrates are often less numerous in acidic lakes, there are also few or no fish. Acidic lakes are therefore suitable for nesting, because the ducks do not have to compete with a large number of fish for food. However, while the lack of fish may be good for certain diving ducks, it poses an obstacle to species whose diet consists entirely of fish, such as the Common Loon *Gavia immer*, which is found almost exclusively at lakes with large fish populations.

Water colour is also an important factor in lake selection by aquatic species. The Common Loon, Red-breasted Merganser, and Hooded Merganser were found to prefer lakes with clear water, probably because these species spot most of their prey by swimming with their eyes open underwater.

In the two regions covered in this study, a similar variety of riparian species was found regardless of the degree of soil mineralization and acidity (i.e., peatlands, swamps, marshes, riparian woodlands). While there is a regular relationship between species present and vegetation structure, it does not appear that any family of birds is better represented on any specific soil type. Shorebirds (Charadriidae and Scolopacidae), flycatchers (Tyrannidae), warblers, blackbirds, and sparrows (Emberizidae) — the major families — are found on most wetlands, whatever their degree of soil mineralization and acidity. The heterogeneity of the habitats and their high level of productivity during the summer probably explain the cohabitation of a large number of species and families in these ecosystems, which, after all, occupy only a rather small area of the lakes and of the continent as a whole.

2. Introduction

To date, most biological studies on acid precipitation have been concerned with the effects of lake acidification on the composition of communities of aquatic organisms (Almer *et al.* 1978; Haines 1981; Memorandum of Intent 1983). There are far fewer studies about the harmful effects on birds. This is probably because birds

[a]Current address: 1178 des Muguets, Saint-Rédempteur, Quebec G0S 3B0.

have coverings that protect them from the ambient environment and hence from the direct effects of acidity (Mercer 1966). They are not, however, protected from ecosystem transformations, and these may be substantial. It is known that acid deposition can reduce soil fertility and that it damages vegetation and causes significant decreases in the populations of many groups of invertebrates, fish, and amphibians. It also increases the solubility in runoff of several toxic metals (e.g., cadmium, mercury, lead, selenium), whose concentrations in living organisms may then increase (Memorandum of Intent 1983). Thus the effects of acid precipitation on birds are indirect. The vegetation structure of the birds' habitats could change to the point where some species would no longer be able to find the plants they need for food and cover during nesting (Clark and Fischer 1981; Haines and Hunter 1982; Schreiber and Fischer 1983). Food resources are threatened as well: insects, benthic organisms, fish, and amphibians are often less numerous and no longer meet the birds' needs (Eriksson 1984; Ormerod *et al.* 1985; DesGranges and Hunter 1987). Finally, accumulations of heavy metals in the flesh of their prey may impair reproduction in some bird species (Nyholm and Myhrberg 1977; Nyholm 1981).

Aquatic environments are particularly susceptible to a rapid drop in pH because they act as reservoirs for acid-laden runoff. In regions where the bedrock and soil consist of carbonate-poor minerals and are thus unable to neutralize the acidity of the water traversing them, runoff contains proportionately more hydrogen ions (Shilts 1981). This is true of most lakes in Quebec. Their buffering capacity is very low and in some instances non-existent, with the result that the pH of a large number of lakes is decreasing rapidly because they are located along the major trajectories of acid rain and snow (Bobée *et al.* 1982, 1983; Lachance *et al.* 1985).

In Quebec, over 50 bird species nest in the wetlands of the Canadian Shield. Some of them feed on fish, amphibians, and benthic organisms that they find in the lakes. According to the most recent estimates by the Canadian Wildlife Service, this group includes some 50 000 Common Loons[b] (DesGranges and Laporte 1979), nearly 1 million Canada Geese, and over 2 million ducks of various species (Reed 1978). In addition there are the even more numerous populations of riparian species, including the waders that feed on small fish and amphibians in shallow pools and bays, the shorebirds that search mud flats and bogs for small invertebrates, and a wide range of perching birds that nest close to the water and feed on insects emerging from the aquatic larval phase. The populations of all these species could be considerably reduced by the acidification of their environment.

Because of the absence of physical-chemical and ornithological data on the state of Quebec lakes in earlier times, the effects of lake acidification on lacustrine birds up to the present cannot be determined. To establish any cause-and-effect relationships, biomonitoring of a large number of lakes undergoing acidification would have to be carried out, ideally for 25 years at least. Given the lack of time and money, however, the typological approach was used. Categorizing the lacustrine bird groups on the basis of the acidity of the various environments should quickly show which species are most sensitive to wetland acidification. This, in turn, will give some idea of the transformations that the bird communities might undergo if the acidification of their environment were to continue, though no causal links would be demonstrated.

In southern Quebec, a region that receives a great deal of acid precipitation and is very sensitive to it, the birds of several small, shallow lakes surrounded by suitable habitats were selected for study (see DesGranges and Darveau 1985). Acidification usually occurs fairly rapidly in such lakes, which are frequently found in the mountains and at the heads of small drainage basins. Although the lakes selected are all physically similar, each has a distinct level of acidity and alkalinity. It should therefore be possible to estimate the threshold of tolerance for most of the wetland species.

Lakes were also selected for study in northern Quebec, a region which is very sensitive to acid precipitation but has not yet received a great deal of it. This was important because the vast majority of shorebirds and over 75% of all Quebec waterfowl nest in this region (Reed 1978). The idea was to assess how lacustrine birds might react to increased acidity in their nesting habitat before acidification became a major problem.

Each lake was visited several times to take bird counts and describe the morphometry, water quality, several biological factors, riparian soils, and aquatic and riparian vegetation. As a result, we are now in a position to assess the relative importance of each of these environmental features in the selection of the wetland habitats most used by lacustrine birds.

3. Study areas

3.1. Selection of lakes

The geographical areas to be included in the study were selected on the basis of existing information about the acidity and sensitivity to acidification of Quebec lakes (Shilts 1981; Gilbert *et al.* 1985). Many of the lakes selected are in the Laurentians between the La Vérendrye and Laurentides reserves, because this is where most of the acidic lakes in Quebec are found. However, since there are few neutral or alkaline lakes here, a number of lakes were selected in the Appalachians south of Quebec City, where neutral and alkaline lakes are much more common. In northern Quebec, the study area lies between the Labrador Trough to the west and George River to the east, and between the 55th and 57th parallels. This area, located northeast of Schefferville, is divided in two by the tree line. Its geological and lithological features are highly varied and have produced a wide range of physical-chemical conditions in the lakes.

Once the geographical framework had been established, the study lakes in each of the two regions had to be chosen. The objective was to find lakes undisturbed or minimally disturbed by humans, having different levels of acidity, and surrounded as much as possible by riparian habitats suitable for nesting by lacustrine birds. For consistency, only lakes with a surface area of approximately 5–35 ha were selected.

Aerial photographs were used to identify all the undisturbed lakes with the desired surface area as well as the appropriate riparian vegetation. The next step was to select lakes with a variety of acidity levels. In southern Quebec, the most promising ones were visited during the winter and sampled. Once the pH and alkalinity of the water were known, it was easy to select lakes possessing a variety of physical-chemical characteristics. In the north, lakes were selected on the basis of their sensitivity to acidification, given the ecological districts in which they are located (Gilbert *et al.* 1985). Some lakes were selected in ecological districts considered highly sensitive to acidification, others in districts of low sensitivity. Sampling carried out during the fall prior to the bird observations confirmed that the lakes had varying levels of acidity and revealed one area where the lakes are highly acidic. A number of lakes were selected from this area.

Logistic and financial considerations were also important. Wherever possible, groups of lakes near each other were to be selected, and lakes were to be less than 200 km from the base of operations so as to keep helicopter travel to a minimum.

Figure 1 shows the regions of Quebec covered by the study. The exact position of the 146 selected lakes may be determined by consulting Potvin and Grimard (1983) and Rodrigue and DesGranges (1989). Figures 2, 3, and 4 show the general features of the lakes and riparian soils. Analytical methods are described in Appendix 1.

3.2. Environmental features

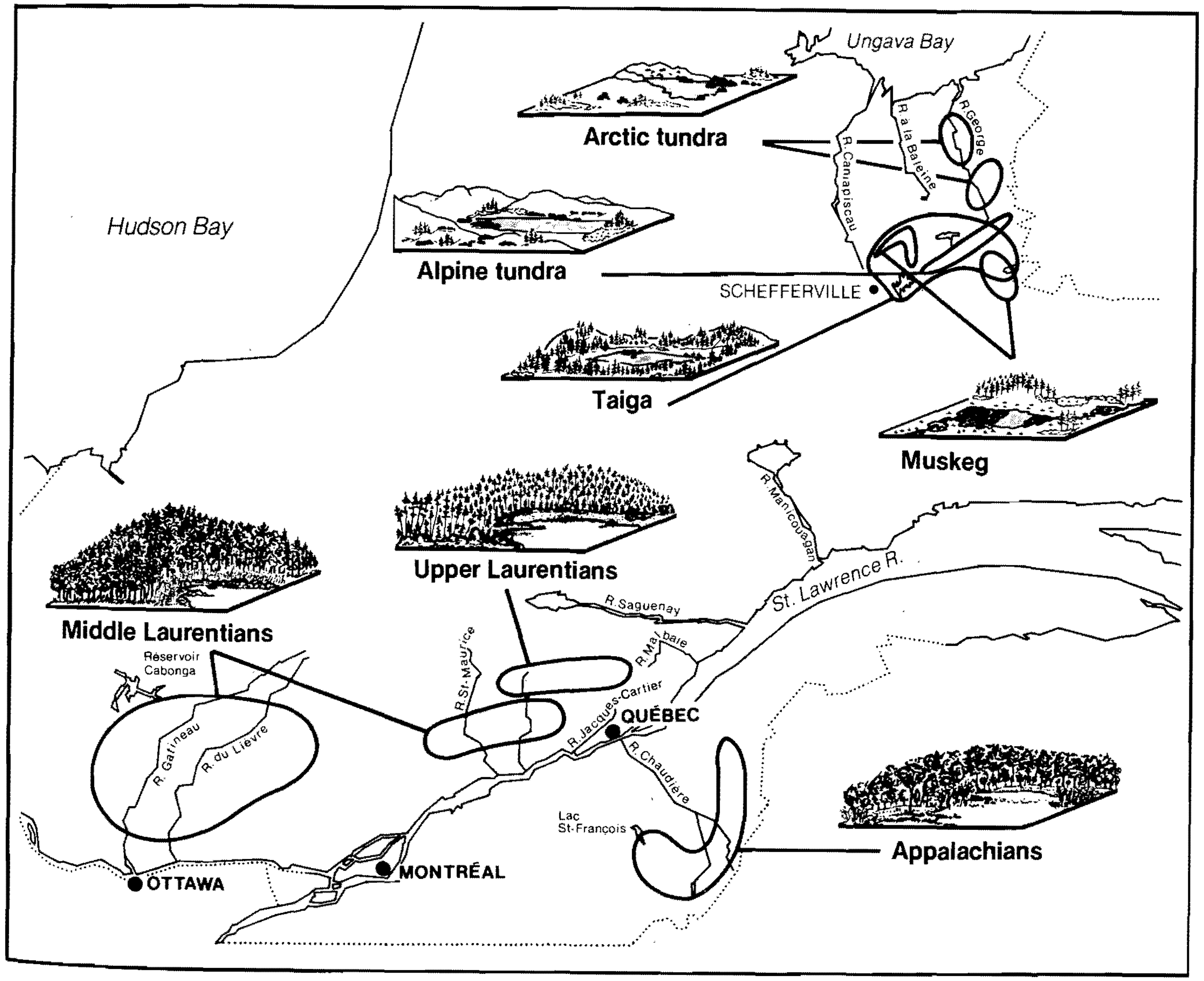
Several visits were made to each lake in order to describe its general environment as well as the morphometry, water quality, several biological factors, riparian soils, and aquatic and riparian vegetation. These data have been analyzed in detail in other publications (listed in the references), so in what follows we simply give the main conclusions.

3.2.1. Natural districts

The concept of a "natural district" is based on the ecological classifications of Jurdant *et al.* (1977) and Gilbert *et al.* (1985), according to whom the study areas may be divided into 11 ecological regions (geographical regions characterized by a distinctive climate expressed in its vegetation) with nine ecological landscapes (areas characterized by a distinctive physical geography and geology). These we reduced to seven functional groups, which we call natural districts: the Appalachians, Middle Laurentians, and Upper Laurentians in the south, which are subject to a cool-temperate climate; and the taiga, muskeg, alpine tundra, and arctic tundra in the north, which are subject to a tundra climate (Darveau *et al.*, this publication) (Fig. 1).

The Appalachians district is mountainous. Lakes cover barely 3% of the area and bogs less than 1%. The

Figure 1
Geographical regions and natural districts covered in the study



[b]The scientific and common names of all bird species mentioned in the text are given in the alphabetical listing on page 67.

well-drained slopes of the hills are dominated by forests of sugar maple *Acer saccharum* and yellow birch *Betula alleghaniensis*. Eastern white cedar *Thuya occidentalis* and tamarack *Larix laricina* populate the low-lying areas. The peatlands take the form of small bogs containing ericaceous vegetation, sphagnum, and black spruce *Picea mariana*. About 20% of the area of lake bottoms is covered with vegetation, primarily associations of *Nuphar variegatum* and *Sparganium* sp. as well as *Sparganium fluctuans* and *Potamogeton oakesianus* (Darveau *et al.*, this publication).

The Middle Laurentians district consists of undulating highlands, 10% of whose surface area is lakes and 5% peatlands. The forests on the slopes are dominated by sugar maple and yellow birch, with black spruce in the low-lying areas. The peatlands are small, uniform bogs along with a few fens, and they are dominated by sedges *Carex* spp. About 20% of the area of lake bottoms is covered with vegetation, often including associations of *Nuphar variegatum* and *Sparganium* sp., as well as patchworks of *Eleocharis smallii* and *Brasenia schreberi*.

Figure 2
General characteristics of lakes by natural district. For continuous variables, a box plot gives the median, quartile deviations, and extreme values. For class variables, a histogram gives the distribution of values as a percentage of the sample. Crosshatching toward the right means value 1 of the variable; vertical lines, value 2; and crosshatching toward the left, value 3.

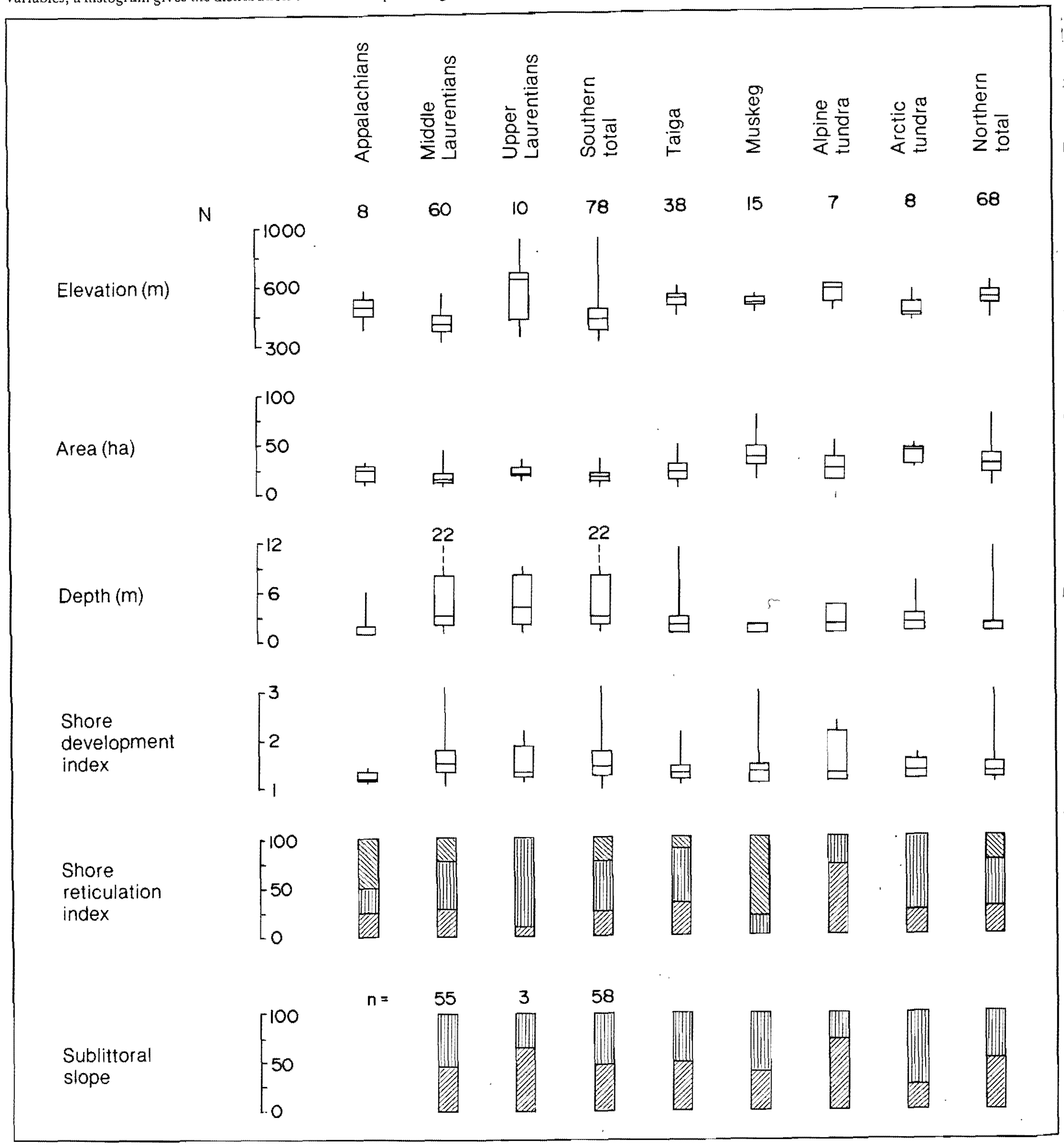


Figure 3
Lake water quality by natural district

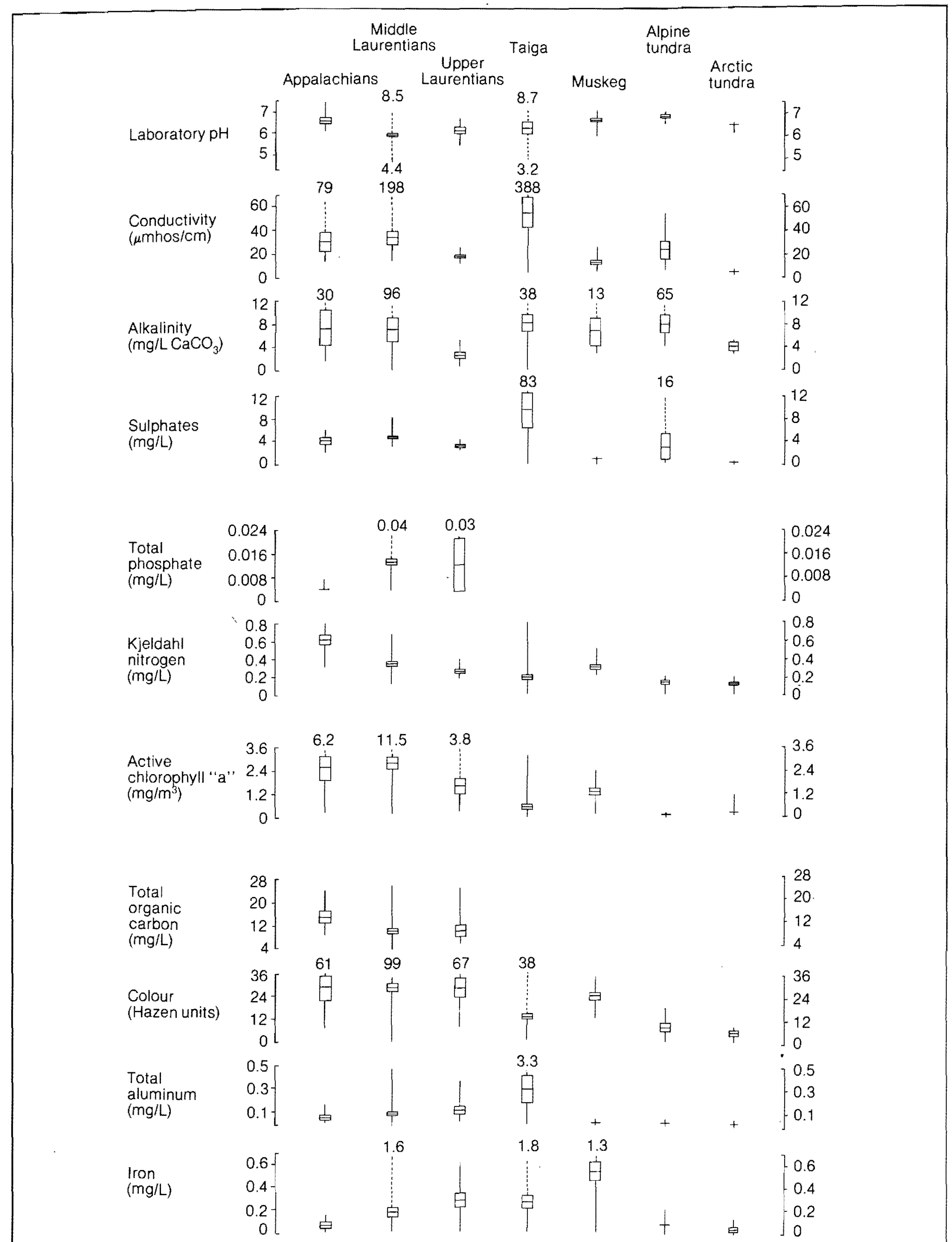
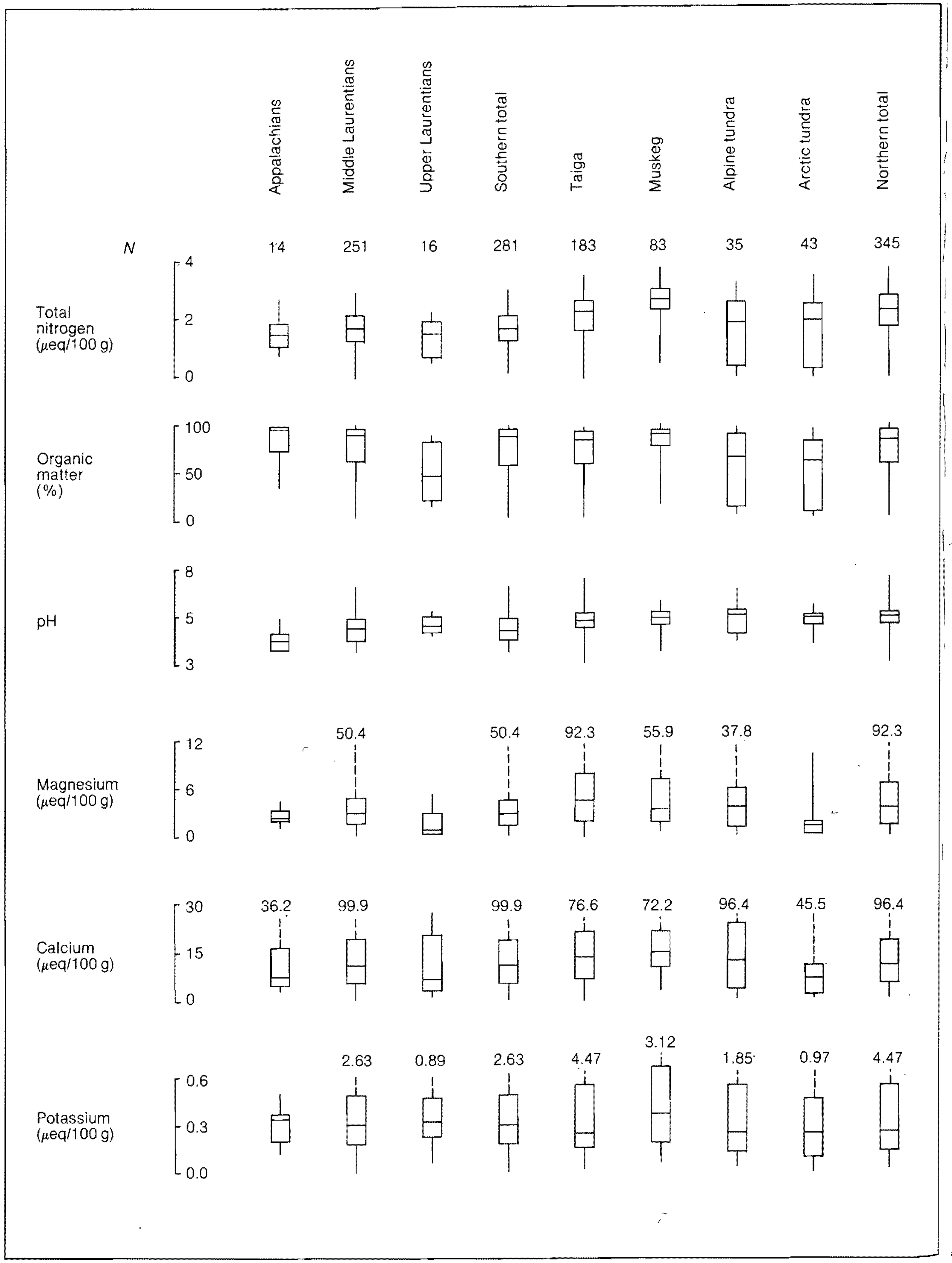


Figure 4
Riparian soil quality at lakes, by natural district



The Upper Laurentians district features more rugged terrain than the Middle Laurentians, has fewer lakes and peatlands, and a more boreal vegetation. On the slopes, maple and birch give way to balsam fir *Abies balsamea* and white spruce *Picea glauca*. The lake vegetation is similar to that found in the Appalachians district.

In the northern study area, the rolling or undulating hills and highland plateaus create a patchwork of subarctic taiga vegetation and arctic tundra vegetation. The taiga district consists of sparse black spruce forests over beds of sphagnum or lichens. Sedges and tamarack are found around the shores of the lakes. The lakes themselves support very little vegetation: less than 10% of the bottom area is covered, most often with *Scorpidium scorpioides*, *Menyanthes trifoliata*, and *Potamogeton filiformis*.

The muskeg district — *muskeg* is an Algonquian word meaning *peatland* — consists of relatively flat areas dotted with lakes and covered with extensive palsa bogs featuring sedges and tamarack. The lake vegetation is similar to that of the taiga district.

The alpine tundra district consists of highland plateaus and hilltops within the taiga district. Lichens grow on the bedrock; sedges and scrub birch *Betula glandulosa* grow along the edges of the lakes, which support virtually nothing by way of bottom vegetation except some *Scorpidium scorpioides*.

The arctic tundra district, which is farther north than the others, is at the southern limit of the arctic proper. The landscape consists of a smooth carpet of lichens, its flatness unbroken as a result of low shrubs growing in depressions and other sheltered areas. The vegetation at the edges of the lakes resembles that of the alpine tundra district, but lake bottoms also have *Drepanocladus exannulatus* and *Potamogeton filiformis*.

3.2.2. General description of lakes

3.2.2.1. Water quality

Table 1 shows the values of the physical-chemical parameters of the study lakes by natural district. The chief limnological characteristics of the lakes within each district are summarized in Table 2. Because the relationships among water quality parameters have been considered in other publications, here we show only a single matrix of Spearman correlation coefficients (Table 3).

The acidic lakes (pH ≤ 5.5) in southern Quebec are all located in the Middle Laurentians, particularly in the Outaouais region (Rodrigue and DesGranges 1989). The pH of the lakes in the Appalachians and Upper Laurentians ranges from 5.6 to 6.5 during the summer. The least productive lakes (oligotrophic and oligo-mesotrophic, in the sense of Rodrigue and DesGranges 1989) are mostly located on the Canadian Shield in the Portneuf forest region to the northwest of Quebec City. The most productive lakes, mainly meso-eutrophic, are in the Appalachians district.

In northern Quebec, there are considerable differences in a number of physical-chemical parameters between the various groups of lakes (Potvin and Grimard 1983). Although the neutral lakes in both the arctic tundra and alpine tundra districts have very little colour, they differ significantly when it comes to mineral content and type of sediment. In contrast, the neutral lakes of the muskeg and taiga districts do not appear to be very different from one another except in iron, of which there is a higher concentration in the muskeg lakes.

While neutral lakes are found in each of the four northern natural districts, only in the taiga are there both acidic lakes and alkaline lakes with significant differences in the majority of parameters. The main source of acidification for the very acidic lakes is apparently the sulphides and in particular the pyrite in the bedrock around the lakes. The pyrite oxidizes in the presence of water and air to release H^+ ions into the environment.

Generally speaking, the neutral tundra lakes are very obviously oligotrophic, if not ultra-oligotrophic, while the neutral muskeg and taiga lakes are typically more productive. The acidic and alkaline taiga lakes differ greatly in productivity: the latter are much more productive, probably because the very acidic lakes (pH < 4.2) have high levels of toxic heavy metals that definitely hinder biological production.

3.2.2.2. Food chains

A subgroup of the study lakes (14 in the Middle Laurentians near Maniwaki and 13 in the taiga near Schefferville) was examined in detail as part of a descriptive study of the trophic links among 50 lakes that are fairly representative of the range of acidity conditions found in Quebec lakes (IEC Beak 1985). The Maniwaki region receives a fairly high level of atmospheric sulphates, and it is believed that some of the study lakes selected are undergoing acidification by acid rain. In the Schefferville region,

Table 1
Means and standard errors ($S\bar{x}$) for principal physical-chemical acidification-related parameters by natural district[a]

Physical-chemical parameters	Natural districts: Appalachians (n = 8)	Middle Laurentians (n = 60)	Upper Laurentians (n = 10)	Taiga (n = 38)	Muskeg (n = 15)	Alpine tundra (n = 7)	Arctic tundra (n = 8)
pH (laboratory)	6.7 ± 0.2	6.0 ± 0.1	6.2 ± 0.1	6.4 ± 0.2	6.7 ± 0.1	6.9 ± 0.1	6.5 ± 0.1
Conductivity (µS/cm)	30.6 ± 7.4	33.8 ± 4.2	18.3 ± 1.6	54.4 ± 13.7	12.4 ± 1.5	23.3 ± 6.3	6.5 ± 0.7
Alkalinity (mg/L $CaCO_3$)	7.6 ± 3.3	7.0 ± 2.1	2.6 ± 0.5	8.1 ± 1.4	6.8 ± 0.7	7.9 ± 1.7	4.0 ± 0.3
Sulphates (mg/L)	4.3 ± 0.5	5.3 ± 0.1	3.3 ± 0.2	9.9 ± 3.2	1.3 ± 0.1	3.3 ± 2.2	0.3 ± 0.1
Total phosphorus (mg/L)	0.004 ± 0.001	0.001 ± 0.001	0.012 ± 0.009	—	—	—	—
Kjeldahl nitrogen (mg/L)	0.63 ± 0.05	0.34 ± 0.02	0.27 ± 0.02	0.19 ± 0.02	0.31 ± 0.02	0.14 ± 0.02	0.12 ± 0.01
Active chlorophyll "a" (mg/L)	2.7 ± 0.7	2.8 ± 0.3	1.6 ± 0.4	0.5 ± 0.1	1.3 ± 0.2	0.1 ± 0.1	0.3 ± 0.1
Total organic carbon (mg/L)	15.4 ± 2.0	10.8 ± 0.5	10.4 ± 1.8	—	—	—	—
Colour (Hazen units)	29.4 ± 6.5	29.1 ± 2.6	29.1 ± 5.5	14.5 ± 1.5	25.3 ± 1.8	9.4 ± 2.1	6.0 ± 1.0
Total aluminum (mg/L)	0.07 ± 0.02	0.11 ± 0.01	0.13 ± 0.03	0.31 ± 0.11	0.04 ± 0.01	0.03 ± 0.01	0.03 ± 0.01
Iron (mg/L)	0.08 ± 0.02	0.19 ± 0.03	0.31 ± 0.06	0.29 ± 0.06	0.57 ± 0.08	0.09 ± 0.03	0.06 ± 0.02

[a]According to Potvin and Grimard (1984) and Rodrigue and DesGranges (1989).

the acidic lakes lie over mineral deposits rich in sulphides, which would explain why the lakes' acidity levels are extremely high. Also examined were lakes in the Sept-Îles and Gagnon regions that are coloured by humic acid from bogs. In each region, the sample includes both neutral and alkaline lakes. Many of them are biogeographically isolated headwater lakes that may be impossible for fish to colonize, and many of them are small and shallow and may periodically be subject to winter anoxia, which would severely affect the structure of aquatic communities.

The study brought out some interesting variations in species composition and abundance for populations of fish, zooplankton, and zoobenthos, along an acidity gradient of Canadian Shield lakes in Quebec.

Only 2 of 16 lakes with a pH below 5.5 contain fish but, with the exception of the lakes in the Schefferville region (where the acidification is geological in origin), the absence of fish is attributable primarily to biogeographical isolation or limiting factors in the habitat. This conclusion is corroborated by the discovery that a number of neutral high-altitude lakes with a pH above 6.0 have limited fish communities. These neutral lakes generally contain populations characteristic of cold waters: salmonids, catostomids, and cyprinids. In the study regions this type of population is the one most threatened by the acidification of headwater lakes.

In all of the study lakes, the diet of the dominant fish species is diverse and includes nearly all the main groups of invertebrates. The groups considered sensitive to acidity, such as molluscs and amphipods, are a key source of food in some neutral lakes with a small buffering capacity. Ephemeras, odonates, and trichopterans were an important food source in every lake found to contain fish.

Examination of the benthos indicated that only molluscs, amphipods, ephemeras, and pelagic cladocerans are rare in moderately acidic lakes (pH 5.3–4.6), while

Table 2
Summary of lake characteristics for each natural district in terms of acidity[a]

Natural district	Lake acidity[b]	Main characteristics
Arctic tundra	Neutral	Very clear, slightly acidic water with low mineral content; environment highly sensitive to acidification; mineral sediments.
Alpine tundra	Neutral	Clear water, much higher mineral content than in arctic tundra lakes; organic sediments; environment sensitive to acidification.
Muskeg	Neutral	Slightly brownish water, low mineral content, higher tannin, lignin, and iron content; environment sensitive to acidification; organic sediments.
Taiga	Acidic	Very clear water; very high mineral content; high level of acidity resulting from iron pyrite in watershed; high toxicity for aquatic life; abundant magnesium.
	Neutral	Slightly coloured water, low mineral content; higher aluminum concentration than in the other neutral lakes; significant tannin and lignin content; very similar to muskeg lakes.
	Alkaline	Clear water, fairly high mineral content; high magnesium content; organic sediments; well-buffered environment.
Upper Laurentians	Neutral	Oligo-mesotrophic and moderately dystrophic; environment sensitive to acidification.
Middle Laurentians	Acidic	Mesotrophic and moderately dystrophic; environment sensitive to acidification.
	Neutral	Oligotrophic to mesotrophic; moderately to highly dystrophic; environment generally sensitive to acidification.
Appalachians	Neutral	Meso-eutrophic and moderately dystrophic; environment moderately sensitive to acidification; shallow lakes.

[a]According to Potvin and Grimard (1983) and Rodrigue and DesGranges (1989).
[b]Alkaline lake: pH ≥ 7.0; neutral lake: pH 5.6–6.9; acidic lake: pH ≤ 5.5.

Table 3
Spearman correlation coefficients (r_s) for comparison of the principal water quality and morphometry parameters at study lakes in southern Quebec and northern Quebec: acidity (pH), conductivity (CD), alkalinity (AC), sulphates (SF), calcium (Ca), total phosphorus (PT), Kjeldahl nitrogen (NK), chlorophyll "a" (YA), total organic carbon (CT), colour (CO), total aluminum (Al), iron (Fe), area (SU), maximum depth (PX), and elevation (AT)

NORTHERN QUEBEC[b] (above diagonal); SOUTHERN QUEBEC[a] (below diagonal)

pH	0.25	0.85	—	0.37	?	—	—	?	—	–0.43	–0.31	—	–0.33	—
0.38	**CD**	0.34	0.71	0.91	?	–0.27	—	?	–0.28	0.24	—	–0.35	—	0.42
0.67	—	**AC**	—	0.48	?	0.30	—	?	0.31	–0.45	–0.27	—	–0.26	—
—	0.46	—	**SF**	0.61	?	—	—	?	—	0.51	0.28	–0.33	—	0.27
0.81	0.62	0.54	0.37	**Ca**	?	–0.24	—	?	–0.30	—	—	–0.28	—	0.42
—	—	–0.28	—	—	**PT**	?	?	?	?	?	?	?	?	?
0.41	0.23	–0.28	—	0.41	—	**NK**	0.76	?	0.83	—	0.26	—	–0.57	–0.35
—	0.23	—	—	0.28	0.38	0.37	**YA**	?	0.55	—	—	—	–0.38	—
0.27	0.34	0.29	—	0.39	—	0.57	0.49	**CT**	?	?	?	?	?	?
—	—	—	—	—	0.33	0.28	0.41	0.47	**CO**	—	0.24	—	–0.45	–0.36
–0.79	–0.31	–0.45	—	–0.65	—	–0.28	—	—	0.42	**Al**	0.32	–0.34	—	—
–0.30	—	—	–0.27	–0.26	0.29	—	—	—	0.65	0.46	**Fe**	—	—	—
0.23	—	0.30	—	—	—	—	—	—	—	—	—	**SU**	—	–0.25
–0.29	—	—	—	—	–0.28	–0.65	—	–0.30	—	—	—	–0.46	**PX**	0.26
—	–0.46	—	–0.31	–0.36	—	—	–0.33	—	—	0.32	0.26	—	—	**AT**

[a]Southern Quebec: $n = 78$, $d.f. = 76$ $p = 0.01$, $r_s = 0.29$; $p = 0.05$, $r_s = 0.22$

[b]Northern Quebec: $n = 68$, $d.f. = 66$ $p = 0.01$, $r_s = 0.31$; $p = 0.05$, $r_s = 0.24$

many other large groups survive. At a pH of 4.2–3.0, several groups, including chironomids, could be an important source of food for fish.

Because biogeographical isolation and habitat limitations restrict fish communities in headwaters (which are more sensitive to acidification), the food chains are often relatively simple. They usually consist of an omnivorous fish and the main benthic species on which it preys. Plankton does not appear to play an important role in the food chains of the adult fish, with the possible exception of the few cyprinids found in these lakes.

The constraints involved in benthic sampling limited the collection of quantitative data on many important groups of free-swimming predatory insects: hemipterans, odonates, and coleopterans. For this reason, it is difficult to say whether an increase in benthic populations actually occurs in fishless lakes. Assignment of a semi-quantitative abundance rating does indicate that benthic groups tend to be more numerous in such lakes, but there are significantly more benthic cladocerans in fishless lakes that are moderately acidic than in neutral or alkaline lakes. The plankton study showed high densities of predatory insects (*Chaoborus, Acilius*, and *Buenoa*) in a few of the fishless lakes. With only a few exceptions, the zooplankton communities in the moderately acidic study lakes resembled communities affected by acidification rather than communities free of predation by fish.

4. Bird counts

The listening post method was used to count the lacustrine birds at the study lakes during the nesting season. This method is fairly rapid, so that a large number of lakes could be visited each summer. The procedure used was similar in principle to the one described by Blondel *et al.* (1970), except that instead of remaining immobile for 20 min, we used the time to explore on foot the habitats within 60 m of the central point of the post. Each resulting bird find was located as accurately as possible on a sketch of the post that was drawn at the site during the minutes just prior to the count. This small departure from the conventional technique was motivated by our goal of measuring the relative abundance of each species not just for each post, but also for each type of habitat.

All the listening posts were located in habitats that were primarily riparian. Each was visited by an ornithologist during the nesting period (i.e., between early June in southern Quebec and mid-July in northern Quebec). All counts were done in the morning, between dawn and 07:00 (EST), on days when there was no rain and no significant wind. These are the conditions under which birds are most active and more likely to make territorial displays (Robbins 1981*a*, *b*). Since the nesting period is relatively short in northern regions, and most species normally nest at the same time, a single visit to each post was sufficient to give a reasonably accurate idea of the number of nesting birds.

Every morning, when weather conditions were favourable, an A-Star 350 D helicopter took off with three ornithologists, each of whom did a count at the four or five lakes visited. Before they disembarked, the helicopter circled the lake slowly at low altitude to allow them to count the aquatic birds and decide on the location for the listening posts.

5. Results

5.1. Ordination of habitats and birds

5.1.1. Three principal bird communities

On the basis of over 7000 sightings of 102 different species, the birds were broken down into five main groups (the list of species in each group is given in Appendix 2). The breakdown was achieved using correspondence analysis (CORANA) (Benzécri 1973; Hill 1974), an ordination method that is being increasingly used in studies of bird-habitat relationships (Beaver *et al.* 1980; Prodon and Lebreton 1981; DesGranges and Darveau 1985) (see Section 5.2.1. for further details). The "proximities" of the species to each physiognomically defined habitat, in the plane of the first two factor axes F_1–F_2, are shown semi-schematically on Figures 5 and 6 for southern and northern Quebec, respectively. For clarity, the exact positions of the habitats and species are not shown, because several positions coincide; instead, ovals are used to show the groups of species that were regularly present in the various environments.

A large number of bird species are found on the lakes and riparian habitats of the forest regions of southern Quebec. Figure 5 breaks these down into three main groups. The typically aquatic species are seen to be clearly distinct from the terrestrial species, and the statistical ordination divides the latter into two main groups — riparian species and forest species. Some species have more ubiquist habits and thus are clustered near the origin of the factor axes. Although they are frequently present in transitional habitats it was decided to associate them with the habitat in which they are found most frequently, in order to facilitate the statistical analysis. The botanical formations (i.e., taxonomically defined habitats) frequented by these species were sometimes taken into account in order to ensure the accuracy of the classification.

There are far fewer bird species present near lakes in northern Quebec than there are in southern Quebec, mainly because there are no deciduous forests in the north, and thus few forest birds.

In the following sections, we shall consider only lacustrine species (i.e., aquatic and riparian species), because these are the only ones for which detailed data on the physical, chemical, and botanical features of their habitats were collected.

5.1.2. Composition and structure of lacustrine bird communities by natural district

Table 4 gives the percent occurrence (percentage of lakes frequented) and relative abundance (average number of individuals sighted at each lake) for each lacustrine species at the study lakes in each of the natural districts. The most abundant and widely occurring species are shown in boldface. Judgement must be used in examining the data because some species and individuals were probably not sighted during visits to the lakes. Still, in our view, the figures constitute very acceptable estimates of relative abundance and occurrence and provide a satisfactory picture of the ecological preferences of the most frequently sighted lacustrine species.

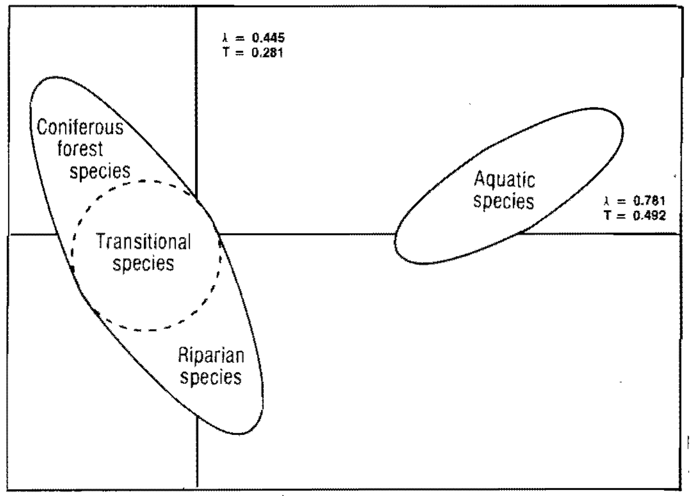
As Table 5 shows, in general a wider variety of lacustrine bird species is found in the natural districts of southern Quebec than in the north, where only the muskeg district has a species richness (average number of species per lake) comparable with what is found in the south. Also, the species pool (number of species found at at least 10% of the lakes in a natural district) is approximately 30 in the south, 25 in the taiga and muskeg, 20 in the alpine tundra, and 15 in the arctic tundra. The muskeg district has a species richness comparable with that of southern districts, despite its species pool being smaller, because it has a large number of regular species (ones occurring at 75% or more of the lakes), which is not the case for the other natural districts in the north.

Bird life at the lakes of the Middle Laurentians district is significantly less varied than in the other southern districts (one-way analysis of variance (ANOVA): $F(2.75) = 34.07; p < 0.0001$; Duncan's multiple range test (Duncan 1975): $p \leq 0.05$), because it consists primarily of occasional species — ones occurring at 25% or fewer of the lakes. This is why in the south the Shannon diversity index is lowest in the Middle Laurentians district (ANOVA: $F(2.75) = 15.27; p < 0.0001$; Duncan: $p \leq 0.05$) and why in the north it is highest in the muskeg district (ANOVA: $F(3.64) = 7.62; p < 0.0002$; Duncan: $p \leq 0.05$). The notable feature of the Appalachians district is the low equitability index (ANOVA: $F(2.75) = 4.40; p < 0.016$; Duncan: $p \leq 0.05$), resulting from the fact that three species (Red-winged Blackbird, Common Yellowthroat, and Swamp Sparrow) account for over half the lacustrine birds observed there, whereas elsewhere the distribution of individuals among species is more equitable.

Aquatic species account for slightly over 40% of lacustrine species in most of the natural districts. The arctic tundra district appears to be the exception: aquatic species represent only 25% of lacustrine species, though it may be that the sample was too small.

The three southern districts have a very similar lacustrine bird life. A correspondence analysis (not shown here) of the relative abundances of Table 4 places the districts very close to one another in a two-dimensional space, though an examination of Table 4 does show a number of differences worth noting: the American Bittern, Ring-necked Duck, and Song Sparrow prefer the Appalachian lakes while the Common Loon, Black Duck, Osprey,

Figure 6
Semi-schematic diagram showing the distribution of bird species among the principal types of environment in northern Quebec. The list of species in each group is given in Appendix 2.



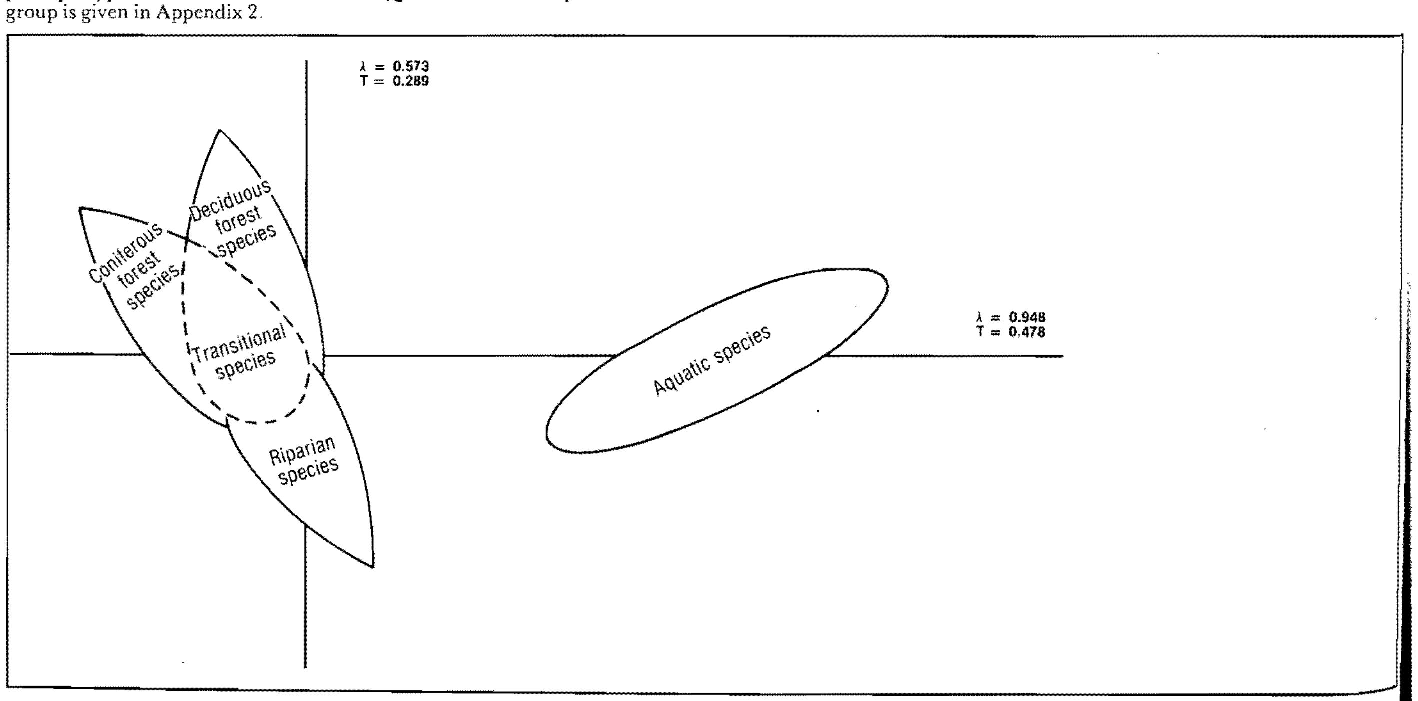
Spotted Sandpiper, Wilson's Warbler, and Rusty Blackbird were seen most frequently near the Upper Laurentian lakes.

The northern districts do not show such a great degree of similarity. The muskeg, taiga, and alpine tundra lakes share a single species pool, while the arctic tundra lakes have a more distinctive pool. Table 4 also shows that the Green-winged Teal, Common Snipe, Least Sandpiper, and Short-billed Dowitcher are much more attracted to the muskeg district than the other northern districts, and that the abundant Lapland Longspur is found only around arctic tundra lakes.

5.1.3. Composition and structure of lacustrine bird communities by lake acidity

Table 6 gives the percent occurrence and relative abundance of lacustrine bird species at the acidic and non-acidic study lakes in the Laurentian and taiga districts.

Figure 5
Semi-schematic diagram showing the distribution of bird species among the principal types of environment in southern Quebec. The list of species in each group is given in Appendix 2.



The analysis is limited to these districts because they are the only ones where both types of lake were encountered. Once again, boldface is used for the most abundant and widely occurring species.

Both acidic and non-acidic lakes in the two Laurentian districts support an average of about a dozen lacustrine species (Table 7), and these belong to a pool of 32 species, half aquatic and half riparian. Acidic and non-acidic lakes also show no significant difference in the Shannon diversity index or in the equitability index (ANOVA: $F(1.68) \leq 0.70; p \geq 0.41$).

The acidic lakes in the taiga district, however, are very different from the neutral and alkaline lakes. As Table 7 shows, they had only half the number of lacustrine species found at the neutral and alkaline lakes (ANOVA: $F(1.36) = 17.99; p < 0.0001$; Duncan: $p \leq 0.05$). The neutral and alkaline lakes supported an average of 10 species, which is almost as high as the dozen or so found at the Laurentian lakes. The species missing from the pool at the acidic lakes are primarily aquatic. While about 10 aquatic species were typically found at the non-acidic lakes, at the acidic lakes there were only 2 — the Canada Goose at 43% of these lakes and the Red-breasted Merganser at 14%, along with shorebirds in a few cases. The Shannon diversity index is also significantly lower for the acidic lakes (ANOVA: $F(1.36) = 16.84; p < 0.0002$; Duncan: $p \leq 0.05$), though the equitability index is approximately the same (ANOVA: $F(1.36) = 2.57; p < 0.12$). Thus only at the highly acidic taiga lakes was the structure of the bird community very different from the structure at the Laurentian and taiga lakes taken together.

Table 6 shows that in the Laurentians, three species appear to prefer the acidic lakes: the Ring-necked Duck, the Common Goldeneye, and Lincoln's Sparrow.

Table 4
Occurrence and relative abundance of lacustrine bird species commonly found in the major natural districts of Quebec

		Natural districts						
Species	Code	Appalachians ($n = 8$)	Middle Laurentians ($n = 60$)	Upper Laurentians ($n = 10$)	Taiga ($n = 38$)	Muskeg ($n = 15$)	Alpine tundra ($n = 7$)	Arctic tundra ($n = 8$)
Common Loon	HUA	38% (2.7)	33% (1.4)	60% (2.2)	P[a]	P	P	P
American Bittern	BUT	63% (2.8)	15% (1.3)	10% (2.0)				
Canada Goose	BCN				61% (3.4)	73% **(10.9)**	57% (3.0)	50% **(5.3)**
Black Duck	CN	63% (2.0)	33% (1.7)	**90%**[b] (1.9)	11% (1.0)	53% (4.3)	14% (1.0)	
Green-winged Teal	SAV	38% (2.0)	3% (2.0)	50% (2.2)	11% (1.0)	40% **(6.2)**	14% (2.0)	
Ring-necked Duck	MOC	**75%** (3.2)	48% (3.2)	30% (2.0)				
Greater Scaup	GMO				18% (2.9)	40% (5.8)		
Common Goldeneye	GAC	13% (2.0)	42% (2.0)	50% (2.8)	P		P	
Black Scoter	MAJ				16% (1.8)	20% (3.0)	14% (2.0)	
Hooded Merganser	BSC		23% (1.9)	30% (1.3)				
Common Merganser	GRB		15% (1.6)	20% (1.5)	8% (4.7)		14% (4.0)	25% (2.5)
Red-breasted Merganser	BSR				16% (2.7)	13% (3.5)	43% (1.3)	38% (2.7)
Osprey	PEC	13% (1.0)	3% (1.0)	60% (1.5)	P			
Semipalmated Plover	COL				5% (2.5)	40% (2.0)	14% (2.0)	13% (2.0)
Killdeer	KIL	25% (1.5)	1% (1.2)	20% (4.5)				
Solitary Sandpiper	VAL		3% (1.0)	40% (2.8)	P	P		
Spotted Sandpiper	MBQ	38% (1.7)	37% (2.2)	**80% (7.1)**	24% (2.4)	27% (1.8)	29% (3.0)	
Least Sandpiper	BEM				42% (2.3)	**93% (6.6)**	43% (1.3)	**88%** (3.4)
Short-billed Dowitcher	BER				18% (4.4)	67% **(5.2)**		
Common Snipe	BO	50% (3.0)	3% (2.5)	20% (3.0)	39% (2.5)	**100%** (4.3)	14% (2.0)	38% (1.3)
Red-necked Phalarope	PHA				5% (1.5)	73% **(8.2)**	14% (1.0)	25% (4.0)
Herring Gull	ARG	P	P	P	50% (2.4)	73% (2.2)	57% (2.8)	**88%** (3.1)
Arctic Tern	STA				34% (2.9)	**87%** (3.2)	71% (3.0)	25% **(5.0)**
Chimney Swift	RAM	38% (1.3)	25% (2.4)	30% (2.3)				
Ruby-throated Hummingbird	CGR	38% (1.3)	15% (1.3)	40% (1.3)				
Belted Kingfisher	MP	38% (1.0)	1% (1.0)	20% (1.0)				
Olive-sided Flycatcher	MOL	**75%** (2.7)	63% (2.2)	**80%** (2.5)				
Alder Flycatcher	MAU	38% **(5.3)**	17% (1.8)	30% **(5.7)**				
Eastern Kingbird	TYR	63% (2.2)	42% (2.1)	20% (4.0)				
Horned Lark	ALO						P	50% (3.3)
Tree Swallow	HB	**88% (8.3)**	63% (2.7)	**100% (13.3)**	21% (2.0)	27% (3.0)		
Barn Swallow	HG	63% (2.0)	3% (3.0)	60% (2.7)				
American Robin	M	**100% (7.8)**	38% (2.3)	**100% (8.2)**	61% (1.9)	73% (2.5)	71% (2.8)	P
Water Pipit	PIP				5% (1.0)	P	29% (3.5)	50% (2.8)
Palm Warbler	ROU				13% (2.0)			
Northern Waterthrush	RUI	63% (4.0)	25% (1.8)	**80% (7.9)**	68% (2.7)	73% (1.7)	29% (2.0)	
Common Yellowthroat	MAS	**100% (14.0)**	**100% (7.5)**	**90% (12.9)**				
Wilson's Warbler	CAL	25% (5.5)	15% (1.4)	**100%** (4.7)	P			
American Tree Sparrow	HUD				**100% (6.7)**	**100% (7.9)**	**100% (7.1)**	**75% (5.5)**
Savannah Sparrow	PRE			P	24% (1.7)	**93% (5.4)**		75% (3.3)
Song Sparrow	PCT	**88%** (3.9)	18% (2.0)	30% **(9.7)**				
Lincoln's Sparrow	LIN	**75%** (1.7)	40% (2.0)	**90% (8.6)**	29% (2.0)	47% (1.7)		
Swamp Sparrow	MAR	**88% (12.0)**	**92% (6.2)**	**90% (11.6)**		P		
White-crowned Sparrow	COB				**89%** (2.9)	**80%** (3.3)	**86%** (3.2)	50% (1.8)
Lapland Longspur	BRU							**88% (8.4)**
Red-winged Blackbird	CAR	**100% (29.3)**	65% **(6.3)**	90% (6.0)				
Rusty Blackbird	MRO	38% (1.0)	23% (1.9)	**90% (6.7)**	61% (3.7)	**100% (7.1)**		
Common Grackle	MAI	**100%** (4.5)	45% (2.7)	**90%** (3.1)				
Common Redpoll	SIZ				39% (1.5)	27% (2.5)	43% (3.0)	50% (2.5)
Pine Siskin	CHA	**75%** (1.8)	18% (3.1)	**90% (14.7)**				

[a]P means the species is present.
[b]Boldface indicates the most abundant and most widely occurring species in each natural district.

Table 5
Characteristics of lacustrine bird communities in the seven natural districts

	Number of lakes visited	Species richness	Shannon diversity index	Equitability index	Regular species (≥ 75% of the lakes)	Occasional species (≤ 25% of the lakes)	Species pool	Aquatic species pool	Riparian species pool
Appalachians	8	16.3	3.28	0.82[a]	11	4	29	12	17
Middle Laurentians	60	10.0[a]	2.80[a]	0.87	2	14	32	15	17
Upper Laurentians	10	18.8	3.62	0.86	14	6	32	15	17
Taiga	38	8.6	2.66	0.89	2	12	26	10	16
Muskeg	15	14.2[b]	3.36[b]	0.88	7	5	23	9	14
Alpine tundra	7	7.6	2.57	0.88	2	10	19	8	11
Arctic tundra	8	8.3	2.66	0.88	3	4	16	4	12

[a]In southern Quebec, equitability is significantly lower in the Appalachians district; species richness and diversity are significantly lower in the Middle Laurentians.
[b]In northern Quebec, species richness and diversity are significantly greater in the muskeg district.

5.2. Selection of lakes by aquatic birds

5.2.1. Description of lakes

The original data matrices for the 146 lakes in the sample take the form of contingency tables showing, for each of the principal lacustrine species (i.e., those present on at least 10 lakes in a study area), the number of birds observed at lakes having certain environmental features. The features are regional, morphometric, physical-chemical, biological, and pedological-botanical variables that take the form of metric and non-metric ordinated descriptors, or unordinated descriptors, each of which is divided into a number of classes. The limits of the classes were selected to follow as closely as possible the classifications established by other Quebec researchers and at the same time reflect the most important thresholds found in the data. An attempt was also made to distribute the species observations within the classes as equitably as possible. The species and descriptors are given in Appendices 3 and 4. Since the number of lakes in each class is not the same, absolute numbers were converted into percentages, which means that each entry in the contingency tables indicates the percentage of lakes in a class at which a given species was observed. While this makes the tables much easier to use, absolute numbers were used in the actual statistical analyses in order to take into account the "weights" of the different classes; the weights reflect the size of the sample for each species/class situation.

Given the diversity of the descriptors, it was decided to use correspondence analysis to relate the species to the ecological variables. This method of ordination, developed for analyzing contingency tables (i.e., class variables), has the advantage of taking into consideration the availability and frequency of use of the various types of lake. It is particularly well suited to a biological context in which the variables are not always linear (Benzécri 1973; Hill 1974).

An initial series of correspondence analyses carried out (using absolute numbers) on each of the divisions in the two tables made it possible to eliminate several descriptors and to reduce the number of classes considerably. Descriptors were eliminated if they had only a low correlation with the first three axes, and two classes were combined if the heads of the vectors representing them on the graph of the factorial axes F_1–F_2 were close to each other, this being taken as an indication that the birds probably do not distinguish between the two. This initial data consolidation yielded the tables that were used as the source matrices for the correspondence analyses discussed in detail below. The advantage of the simplified tables is that they include only those lake characteristics that have the greatest effect on the most frequently encountered species. Restricting the number of attribute states gave stronger classes that more accurately reflect the reliability of the data.

The correspondence analyses must be seen as essentially descriptive (hence the absence of statistical probability thresholds). This kind of analysis brings out the correspondences between the classifiers used in the rows and columns of a contingency table. The statistics software that was used provides not only a graph of the correspondences, but also numerical results that help in interpreting the data. The three most useful interpretation aids are the percentage of total variance explained by a factor (axis); the absolute contribution, which indicates the percentage of the factor's variance explained by each of the environmental variables; and the relative contribution, which indicates the percentage of variance in species distribution explained by the factor. The aids to interpreting the correspondence analyses discussed in this paper are given in Appendices 8 and 9. Because of the large number of analyses carried out and the complexity of the graphs they generate, it was decided to publish only two three-dimensional representations — those relating to the summarizing analyses (Figs. 7 and 9). The interpretation aids of Appendices 8 and 9 suffice to give a clear idea of the strongest relationships revealed by each of the analyses.

5.2.2. Effect of the lakes' general appearance

The distribution of aquatic birds among the lakes was first examined with reference to the lakes' overall appearance. The first three axes of the correspondence analysis for the southern lakes explain all the variance (Appendix 8). The first axis reflects the nature of the interface between riparian vegetation and water (the "reticulation," in the sense of Table 2 of Darveau *et al.*, this publication). It explains 57% of the total variance. The second axis reflects lake morphometry and explains an additional 35% of the variance.

The Common Loon was found primarily at lakes where the belt of riparian vegetation is undeveloped but dense and difficult to penetrate; it was observed most often at relatively large, fairly deep lakes (*cf.* Silieff and Hussell 1982). The American Bittern, Black Duck, and Ring-necked Duck, on the other hand, are more attracted by lakes with well-developed and well-reticulated riparian vegetation, as reported by Ringelman and Longcore (1982) and Ringelman *et al.* (1982) for the Black Duck. These lakes are generally small (especially those used by the Ring-necked Duck) and shallow (especially those used by the Black Duck). The Common Goldeneye and Hooded Merganser were encountered most frequently at deep and poorly reticulated lakes, while the Spotted Sandpiper and

Table 6
Occurrence and relative abundance of lacustrine bird species commonly found around acidic and non-acidic lakes

		Natural districts			
		Middle and Upper Laurentians		Taiga	
Species	Code	Acidic[a] (n = 20)	Non-acidic (n = 50)	Acidic (n = 7)	Non-acidic (n = 31)
Common Loon	HUA	35% (1.1)	38% (1.7)		P[b]
American Bittern	BUT	5% (1.0)	18% (1.4)		
Canada Goose	BCN			43% (3.0)	65% (3.5)
Black Duck	CN	40% (1.8)	42% (1.7)	0% (0.0)	13% (1.0)
Green-winged Teal	SAV	10% (2.0)	10% (2.2)	0% (0.0)	13% (1.0)
Ring-necked Duck	MOC	70% (3.6)	36% (2.7)		
Greater Scaup	GMO			0% (0.0)	23% (2.9)
Common Goldeneye	GAC	**75%**[c] (2.4)	30% (1.9)		P
Black Scoter	MAJ			0% (0.0)	19% (1.8)
Hooded Merganser	BSC	35% (1.9)	20% (1.7)		
Common Merganser	GRB	15% (1.7)	16% (1.5)	0% (0.0)	10% (4.7)
Red-breasted Merganser	BSR			14% (1.0)	16% (3.0)
Osprey	PEC	15% (1.0)	10% (1.6)	P	P
Semipalmated Plover	COL			14% (1.0)	3% (4.0)
Killdeer	KIL	20% (1.0)	8% (3.0)		
Solitary Sandpiper	VAL	0% (0.0)	12% (2.2)		P
Spotted Sandpiper	MBQ	35% (2.1)	46% (3.7)	14% (1.0)	26% (2.6)
Least Sandpiper	BEM			14% (3.0)	48% (2.3)
Short-billed Dowitcher	BER			0% (0.0)	23% (4.4)
Common Snipe	BO	5% (4.0)	6% (2.3)	14% (2.0)	45% (2.6)
Red-necked Phalarope	PHA			0% (0.0)	6% (1.5)
Herring Gull	ARG	P	P	0% (0.0)	61% (2.4)
Arctic Tern	STA			0% (0.0)	42% (2.9)
Chimney Swift	RAM	15% (2.3)	30% (2.4)		
Ruby-throated Hummingbird	CGR	15% (1.3)	20% (1.3)		
Belted Kingfisher	MP	10% (1.0)	12% (1.0)		
Olive-sided Flycatcher	MOL	65% (2.2)	66% (2.2)		
Alder Flycatcher	MAU	15% (1.3)	20% (3.1)		
Eastern Kingbird	TYR	15% (4.7)	48% (1.9)		
Horned Lark	ALO				
Tree Swallow	HB	70% **(5.1)**	68% (4.9)	0% (0.0)	26% (2.0)
Barn Swallow	HG	15% (2.7)	10% (2.8)		
American Robin	M	35% (3.3)	52% (4.3)	43% (3.0)	65% (1.8)
Water Pipit	PIP			0% (0.0)	6% (1.0)
Palm Warbler	ROU			43% (2.0)	6% (2.0)
Northern Waterthrush	RUI	35% (1.9)	32% (4.8)	29% (1.0)	**77%** (2.9)
Common Yellowthroat	MAS	**100%** **(9.2)**	**98%** **(7.8)**		
Wilson's Warbler	CAL	25% (1.4)	28% (3.8)	P	P
American Tree Sparrow	HUD	P		**100%** (4.1)	**100%** **(7.2)**
Savannah Sparrow	PRE	P		0% (0.0)	29% (1.7)
Song Sparrow	PCT	20% (2.0)	20% (4.3)		
Lincoln's Sparrow	LIN	70% (2.9)	38% (4.4)	14% (5.0)	32% (1.7)
Swamp Sparrow	MAR	**95%** **(6.4)**	**90%** **(7.1)**	**95%** **(6.4)**	**90%** **(7.1)**
White-crowned Sparrow	COB			**86%** (4.2)	**90%** (2.6)
Red-winged Blackbird	CAR	75% (7.6)	66% **(5.6)**		
Rusty Blackbird	MRO	50% (2.3)	26% (4.9)	14% (1.0)	71% (3.8)
Common Grackle	MAI	55% (3.5)	50% (2.5)		
Common Redpoll	SIZ			71% (1.8)	32% (1.3)
Pine Siskin	CHA	30% (3.2)	28% **(10.5)**		

[a]Acidic lake ≤ pH 5.5 < non-acidic lake.
[b]P means the species is present.
[c]Boldface indicates the most abundant and most widely occurring species.

Table 7
Characteristics of lacustrine bird communities at acidic and non-acidic lakes

	Number of lakes visited	Species richness	Shannon diversity index	Equitability index	Regular species (≥ 75% of the lakes)	Occasional species (≤ 25% of the lakes)	Species pool	Aquatic species pool	Riparian species pool
Laurentians									
Acidic[a] lakes	20	11.7	3.01	0.87	3	14	32	15	17
Non-acidic lakes	50	10.9	2.89	0.87	2	13	32	15	17
Taiga									
Acidic lakes	7	4.7[b]	1.96[b]	0.92	3	7	15	2	13
Non-acidic lakes	31	9.4	2.82	0.88	4	11	27	10	17

[a]Acidic lake ≤ pH 5.5 < non-acidic lake.
[b]The species richness and diversity of acidic lakes are lower only in the taiga district.

Tree Swallow were found in the greatest numbers around the lakes that were largest and had undeveloped riparian vegetation.

The first three axes likewise explain all the variance in the correspondence analysis for the northern lakes (Appendix 8). The first axis again reflects reticulation. The lakes with undeveloped and poorly reticulated riparian vegetation were also the deepest. The first axis explains 69% of the total variance and the second an additional 23%, indicating that the smaller lakes (< 15 ha) are generally shunned by aquatic birds.

Thus, we are dealing with three groups of aquatic species. The first group is found primarily at lakes with well-developed and well-reticulated riparian vegetation. It includes the Short-billed Dowitcher, Black Duck, Black Scoter (already noted by Haapanen and Nilsson 1979), Green-winged Teal, Greater Scaup, and Red-necked Phalarope. At the opposite end of the scale are species that concentrate on lakes that have an undeveloped belt of riparian vegetation: the Herring Gull, Canada Goose, Spotted Sandpiper, and Red-breasted Merganser. The third group includes species that do not respond to the appearance of the shoreline and are therefore encountered at lakes with varying degrees of reticulation: the Arctic Tern, Least Sandpiper, Common Snipe, and Tree Swallow.

5.2.3. Effect of the lakes' physical-chemical features

A second pair of correspondence analyses relates the distribution of aquatic birds to the physical-chemical quality of the water in the lakes. For the southern lakes, the first three axes explain 94% of the total variance (Appendix 8). The first axis reflects the acidity and buffering capacity of the lakes and accounts for 66% of the variance. The second axis reflects the aluminum content of the water and serves mainly to explain the avoidance by some species of the more acidic lakes. It explains an additional 18% of the variance. The three species of diving ducks — Ring-necked Duck, Hooded Merganser, and in particular Common Goldeneye (as noted in Danell and Sjoberg 1978; DesGranges and Darveau 1985) — occurred most frequently at highly acidic, poorly buffered lakes with high aluminum content. The remaining species chose lakes with a higher buffering capacity, which are therefore less acidic. The American Bittern, Tree Swallow, and Common Loon were found at lakes whose alkalinity was generally higher and whose aluminum content was lower than lakes used by the Spotted Sandpiper and Black Duck. Water colour was not a distinguishing factor, probably because high aluminum content in the study lakes is associated more with high acidity ($r = -0.79$, $p < 0.0001$) than with dark water colour ($r = 0.42$, $p < 0.0002$) (Table 3; Rodrigue and DesGranges 1989).

The situation is more complex at the northern lakes. Although the first three axes of the correspondence analysis explain 90% of the total variance (Appendix 8), the very low pH (< 4; geological in origin) of the acidic lakes makes interpretation difficult. There is no doubt that low pH is very important, because aquatic birds almost totally avoided the very acidic lakes. The high toxic heavy metal content may also be playing a role at these lakes. To understand the distribution of birds among the neutral and alkaline lakes, it is necessary to look at physical-chemical features with a little less discriminating capacity: on the first axis (57% of variance), water colour; on the second axis (18% of variance), aluminum content (as at the southern lakes). The Spotted Sandpiper and Red-breasted Merganser were present at clear-water lakes, whereas Green-winged Teal, Black Scoter, Short-billed Dowitcher, and Red-necked Phalarope occurred most often at coloured lakes. The other species react more to the aluminum content of the water than to its colour. The Canada Goose, Tree Swallow, and Greater Scaup occurred most frequently at lakes with a fairly high aluminum content, whereas the Herring Gull, Arctic Tern, Least Sandpiper, and Black Duck preferred lakes whose water was low in aluminum. The Common Snipe was found at all the alkaline lakes; it did not react to the water colour or aluminum content.

5.2.4. Effect of lake biological features

The role of biological features in lake selection was also examined. At the southern lakes the first three axes of the correspondence analysis account for 88% of the total variance (Appendix 8). The first axis (55% of variance) reflects primary productivity as estimated by the chlorophyll "a" concentration in the water. The second axis (an additional 20%) represents the botanical characteristics of lakes with abundant emergent vegetation, as well as lakes surrounded by herb meadows but having few aquatic plants. The third axis (explaining a further 12%) reflects the importance of aquatic vertebrates, estimated qualitatively (IEC Beak 1985). The birds distinguish lakes with fish from fishless lakes containing an abundance of amphibians. Common Goldeneyes and Hooded Mergansers both occur at unproductive lakes, but the merganser prefers lakes with fish that have many herb meadows in its riparian belt, while the goldeneye generally seeks fishless lakes with few herb meadows in the surrounding belt of vegetation. The American Bittern is found almost exclusively at the edges of productive lakes that have numerous patches of floating-leaved plants as well as herb meadows around a good portion of the perimeter; bitterns also tend to select lakes abounding in amphibians. Black Duck are most frequently found at lakes with extensive emergent vegetation and few herb meadows around the shore; such lakes were most often productive and supported fish. Common Loons pay little attention to botanical features, as long as the lakes contain fish and are productive. Tree Swallows select lakes having an abundant emergent vegetation and often lacking in fish. Ring-necked Duck and Spotted Sandpipers are generalist species that showed no preference for any particular biological characteristics.

In northern Quebec, the first three axes of the correspondence analysis account for 93% of the total variance (Appendix 8). The first axis alone accounts for 72%. It distinguishes unproductive lakes with few herb meadows around the shore from productive lakes surrounded by large herb meadows with pools. The second axis (accounting for a further 14%) reflects the type of aquatic plants that dominate the lake. The birds distinguish lakes where vascular plants are abundant from those where non-vascular plants (mosses and sphagnums) predominate. The productive lakes, surrounded by herb meadows with pools, are used by Green-winged Teal, Black Duck, Short-billed Dowitchers, Red-necked Phalaropes, Common Snipe, and Tree Swallows. The unproductive lakes, which are skirted by a fair area of herb meadows (but without pools), support Canada Geese and Herring Gulls, while Hooded Mergansers and Spotted Sandpipers are generally found at unproductive lakes with few or no herb meadows around them. Greater Scaups and Black Scoters occur at lakes having large areas of vascular aquatic plants (the Greater Scaup primarily at productive lakes), whereas Least Sandpipers and Arctic Terns occur frequently at lakes where non-vascular aquatic plants are abundant.

5.2.5. Effect of aquatic plant species

Darveau *et al.* (this publication) describe the major aquatic plant mosaics found at the study lakes. Correspondence analysis was used to determine whether aquatic birds select lakes that have a specific form of aquatic vegetation. The initial matrices are given in Appendix 5. For the southern lakes, the first three axes explain 86% of the total variance (Appendix 8). The first axis (49% of variance) separates lakes containing *Eleocharis smallii* and *Brasenia schreberi* from those where *Sagittaria latifolia* dominates. The American Bittern uses the former; the Ring-necked Duck prefers the latter. The second axis (explaining an additional 21%) identifies lakes containing *Utricularia vulgaris* and *Eriocaulon septangulare*, which are generally preferred by the Common Goldeneye. The third axis (a further 16%) identifies lakes containing *Dulichium arundinaceum*, *Potamogeton epihydrus*, and *Sparganium eurycarpum*, which are especially attractive to Tree Swallows. Hooded Mergansers and Black Duck are found at the lakes with *Eleocharis smallii* and *Brasenia schreberi* and also at the lakes with *Eriocaulon septangulare*. The Common Loon does not appear to have a preference for any particular type of aquatic vegetation.

At the northern lakes, the first three axes explain 96% of the total variance (Appendix 8). One type of lake, with *Hippuris vulgaris*, is mainly used by Black Duck and Common Snipe. Another type, with *Scorpidium scorpioides*, is generally used by the Least Sandpiper, Arctic Tern, and Red-necked Phalarope, although Greater Scaup and Black Scoters are also sometimes found. The other species of water bird are less selective. They are found on lakes containing *Menyanthes trifolia* (particularly the Black Scoter, Canada Goose, and Red-necked Phalarope), *Potamogeton filiformis* (particularly Herring Gulls, Greater Scaup, Black Scoters, Tree Swallows, and Canada Geese), or *Drepanocladus exannulatus* (particularly the Tree Swallow, Canada Goose, and Herring Gull).

5.2.6. Effect of acidity

The preceding sections were concerned with the importance of individual kinds of environmental parameters in lake selection by aquatic birds. We shall now consider the joint effect of the main morphological, physical-chemical, and biological features of the lakes, in order to determine their relative importance in the selection of lakes by aquatic birds. Because the specific goal is to assess the role of acidity, only the Laurentian and taiga lakes will be considered, because they are the two natural districts in which all the acidic study lakes are located. Reducing the number of lakes included in the statistical analyses meant that the number of bird species and environmental variables had to be reduced as well, leaving only those regularly encountered in these two natural districts.

Figure 7 deals with the lakes in the Laurentian districts. The first three axes explain 92% of the total variance (Appendix 8). The first axis (58%) reflects primary productivity and acidity. Aquatic birds occur either at unproductive, acidic lakes (probably because they are unbuffered and have few nutrients as a result of being located geologically in an area of granitic plutons), or else at productive alkaline or neutral lakes. The second axis (22%) reflects the development and reticulation of the riparian vegetation, and the third axis (12%) reflects the role of water colour. Figure 8 shows semi-schematically how the birds are distributed among the lakes in terms of the two main gradients resulting from the analysis. The American Bittern actively seeks productive alkaline or neutral lakes with well-developed, well-reticulated riparian vegetation. The Common Loon prefers productive, non-acidic lakes, usually with clear water. The Common Goldeneye is primarily found at unproductive, acidic lakes with poorly developed riparian vegetation. The Hooded Merganser and Ring-necked Duck are generally found at acidic lakes, but differ from the Common Goldeneye in that they prefer lakes with well-developed and well-reticulated riparian vegetation. The Ring-necked Duck occurs primarily at lakes with brown water, while the Hooded Merganser is more attracted by lakes with clear water. The Black Duck is encountered at many types of lakes, but concentrates on those with dark water and a pH higher than that of normal rainwater. Water quality is of little importance to the Spotted Sandpiper as long as the riparian vegetation is poorly developed. The Tree Swallow is found at all types of lake, perhaps with a preference for those in which the water is clear.

For the taiga lakes, the first three axes explain 92% of the total variance (Fig. 9, Appendix 8). The unusually low pH (< 4) of the acidic lakes in this part of the province makes it difficult to interpret Figure 9. The low pH is a very important feature, since the great majority of aquatic birds avoided the highly acidic taiga lakes. Other, less distinguishing, features must be examined in order to understand how these birds are distributed among the non-acidic lakes in the district. The first axis (51% of variance) represents primary productivity and water colour. The second axis (29%) represents the development of riparian vegetation. Figure 10 shows semi-schematically how the birds are distributed among the lakes in terms of the two main gradients resulting from the analysis. The Green-winged Teal, Black Duck, and Black Scoter occur at productive taiga lakes with coloured water. The Red-necked Phalarope and Tree Swallow, on the other hand, are found at productive lakes with clear water. The other species are found mainly at unproductive lakes. The Spotted Sandpiper, Red-breasted Merganser, Arctic Tern, Herring Gull, and Common Snipe select lakes with clear water and poorly developed riparian vegetation, while the Canada Goose and Least Sandpiper prefer unproductive lakes with well-developed and well-reticulated riparian vegetation. While the species favouring unproductive lakes were on rare occasions observed at acidic lakes, the Greater Scaup avoided them completely. According to Haapanen and Nilsson (1979), this diving duck is more abundant in those parts of Sweden in which the lakes overlie a basic bedrock.

5.3. Selection of wetlands by riparian birds

5.3.1. Effect of soil and vegetation

As in the preceding section, the initial matrices for the statistical processing take the form of contingency tables indicating the number of individuals of each of the principal riparian species (those sighted at least 10 times in one of the two study areas) found in the various habitats (as defined by soil and botanical features) (Appendices 6 and 7). The relationships between edaphic features, habitat physiognomy, and plant associations are examined in detail elsewhere (Darveau *et al.*, this publication). Although we performed separate correspondence analyses to reveal how the edaphic features, habitat physiognomy, and plant associations each affect the distribution of riparian birds, only figures combining all these factors will

Figure 7
Correspondence analysis (CORANA) showing how acidity, biological productivity, and reticulation of riparian vegetation affect habitat selection by aquatic birds in southern Quebec. Eigenvalues (λ) indicate the strength of the correlation between the axes; T is the percentage of the total variance that is explained by each axis.

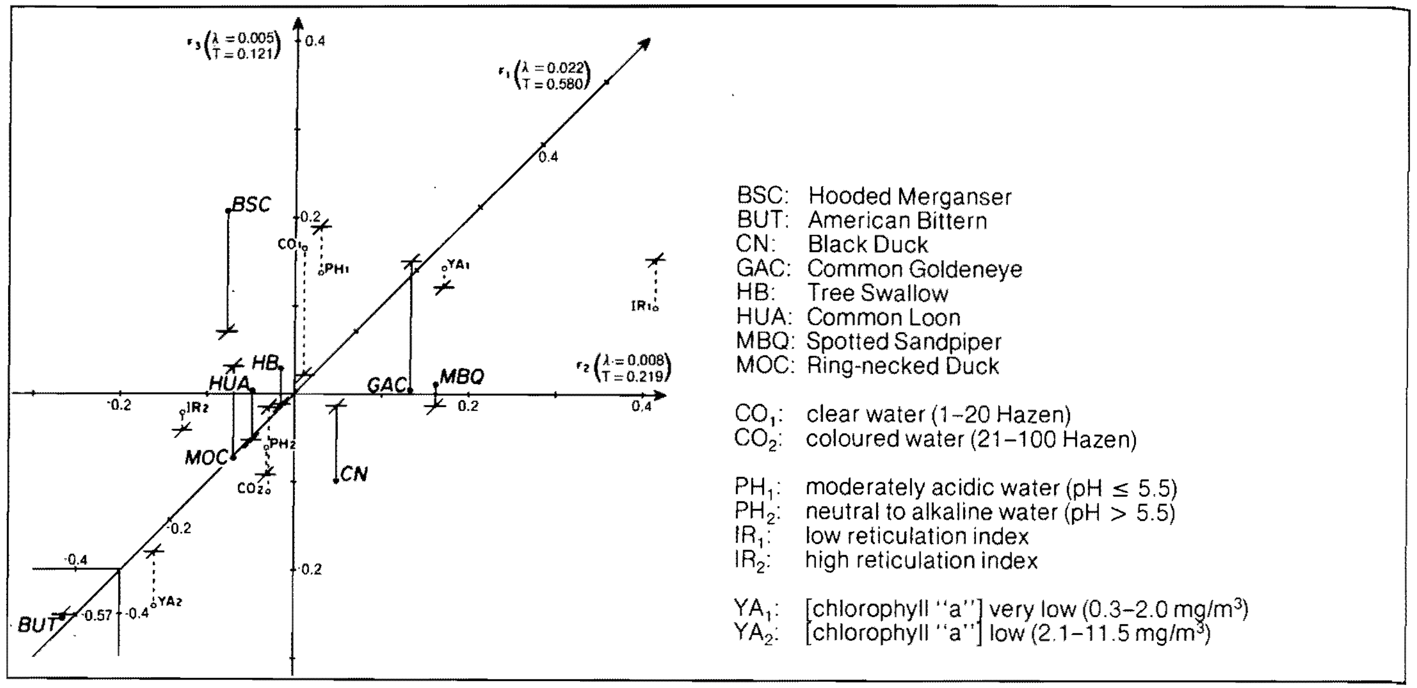


Figure 8
Semi-schematic diagram showing how acidity, biological productivity, and reticulation of riparian vegetation affect habitat selection by aquatic birds in southern Quebec

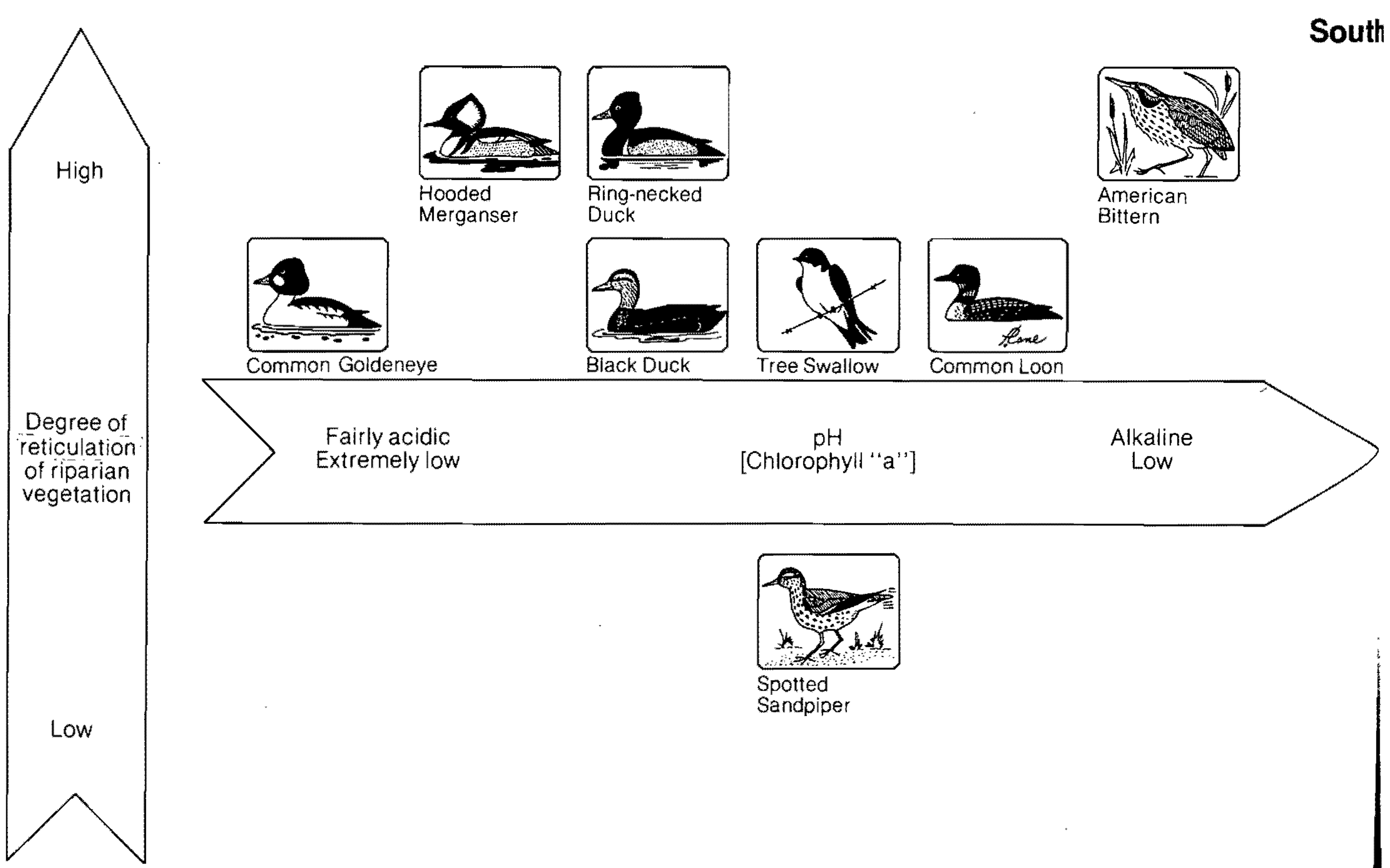


Figure 9
Correspondence analysis (CORANA) showing how acidity, biological productivity, and reticulation of riparian vegetation affect habitat selection by aquatic birds in northern Quebec

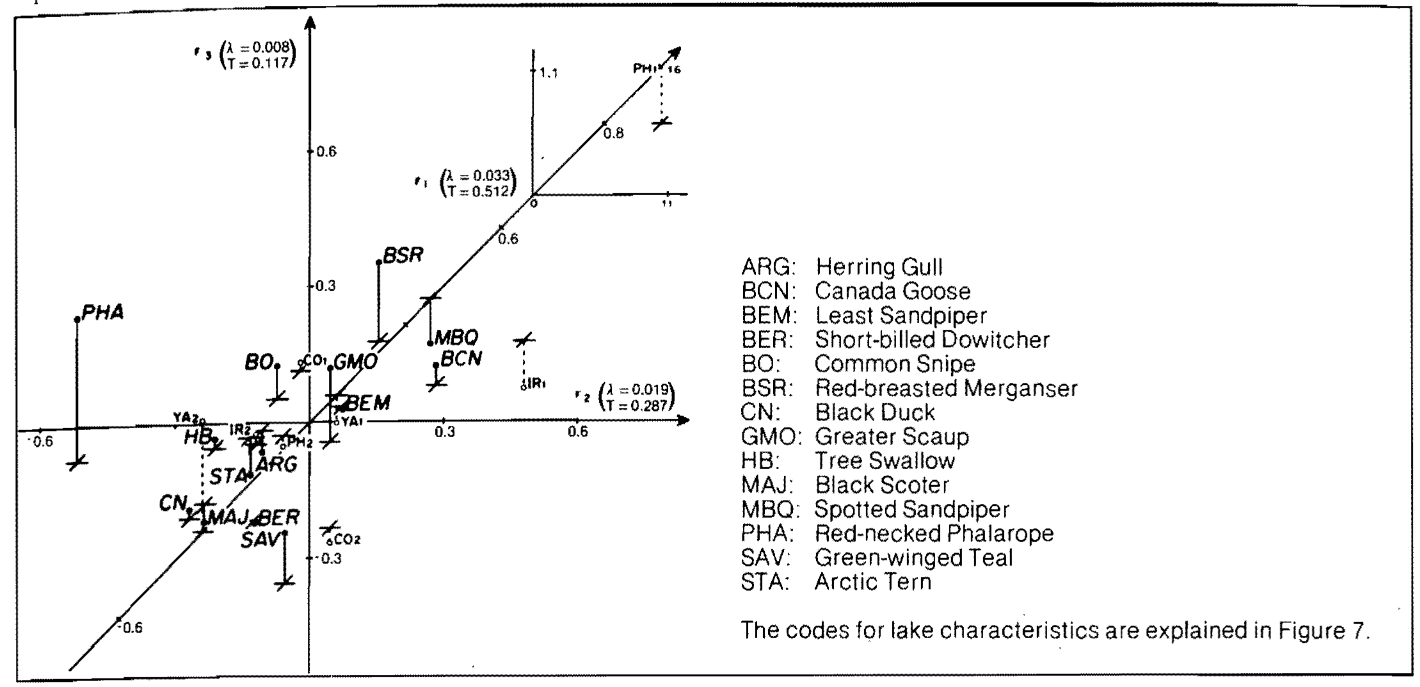
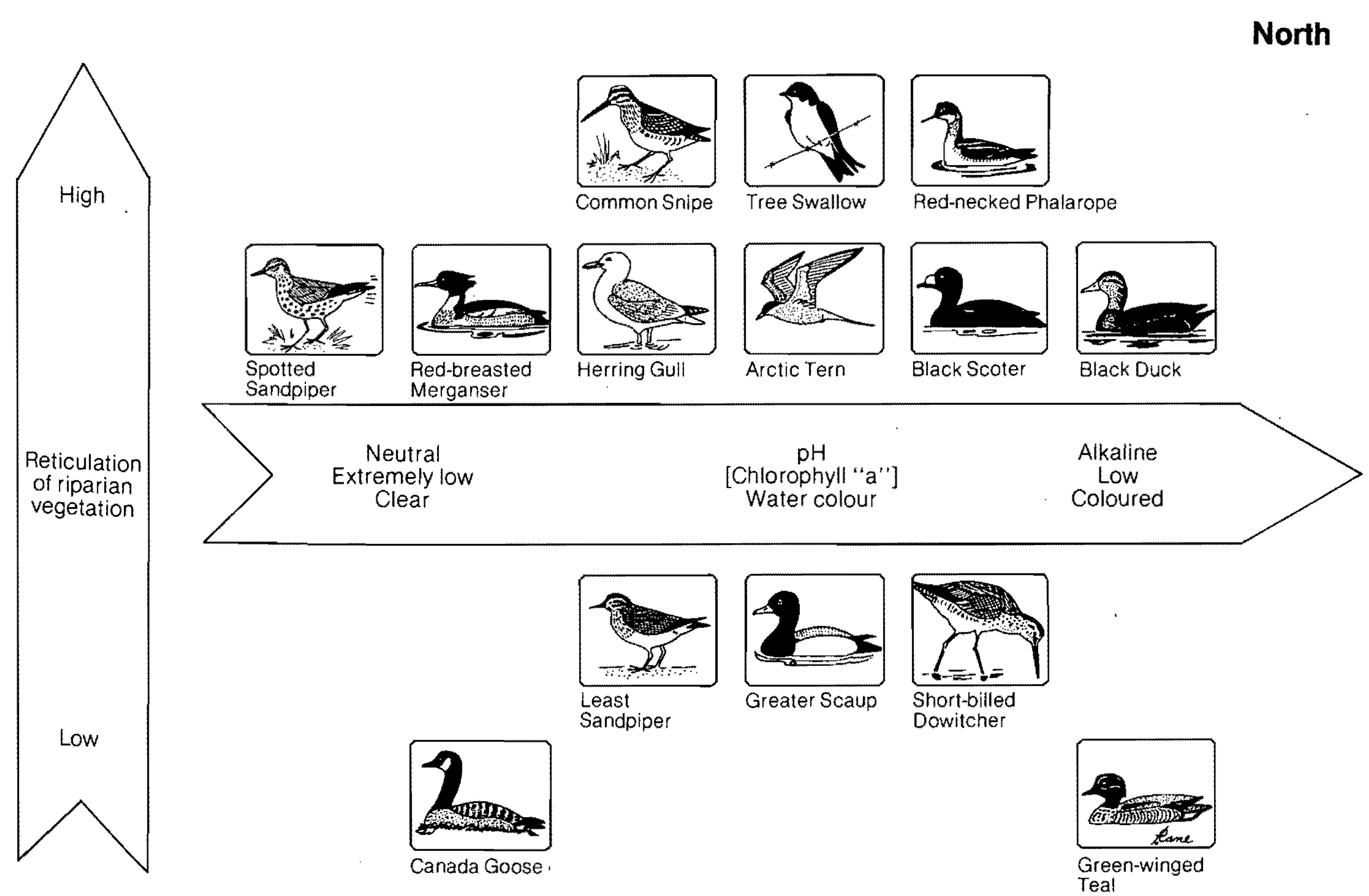


Figure 10
Semi-schematic diagram showing how acidity, biological productivity, water colour, and reticulation of riparian vegetation affect habitat selection by aquatic birds in northern Quebec



be given here (Figs. 11 and 12). This is because many of the relationships identified in the analyses stem from the close links between soils and preferred habitats — links discussed at length in the other article.

Soil mineralization and acidity are the major influences on the riparian botany. In southern Quebec (Fig. 11), organic soils that are acidic and fairly well mineralized are generally forest-covered, whereas less acidic sites support alder stands. Organic soils that are fairly well mineralized and of medium acidity (although this sometimes varies) support herb meadows. Organic soils with a low mineral content usually have patchy shrubs if they are highly acidic, and a fuller shrub cover if they are less acidic.

Figure 11 also shows the most common birds of riparian habitats in southern Quebec. The Eastern Kingbird, Alder Flycatcher, Wilson's Warbler, and Song Sparrow preferred the shrubs growing on neutral soils with a high mineral content. The Northern Waterthrush, Pine Siskin, American Robin, and Common Grackle preferred the trees (especially mixed forests close to shrubs) growing on acidic organic soils with a high mineral content. Killdeer and Spotted Sandpipers selected gravel beaches and sedge meadows without pools on mineralized and moderately acidic organic soil. Other species use habitats associated with highly organic soils. Swamp Sparrows, Common Yellowthroats, and Red-winged Blackbirds were sighted most frequently among low shrubs (sometimes bordered by cattails) growing on moderately acidic organic soil; Lincoln's Sparrows, Rusty Blackbirds, and Olive-sided Flycatchers preferred a patchy ericaceous cover or else treed areas dominated by conifers on highly acidic organic soil. These results agree fairly well with those of Erskine (1977).

The species that occur in the riparian habitats of northern Quebec are shown in Figure 12. The Horned Lark, Water Pipit, Lapland Longspur, Spotted Sandpiper, and Semipalmated Plover prefer lichen heaths and herb meadows with pools on moderately mineralized and moderately acidic organic soil. The Palm Warbler, Common Redpoll, White-crowned Sparrow, and American Tree Sparrow were sighted mainly in areas with shrubs or patchy tamarack and spruce, on moderately acidic soil with a fairly high mineral content. Other species prefer habitats associated with highly organic soils. The Savannah Sparrow, Red-necked Phalarope, Short-billed Dowitcher, Common Snipe, and Rusty Blackbird were observed most frequently in sedge meadows with pools, on neutral organic soil, whereas the Northern Waterthrush and Least Sandpiper were usually found in scattered shrubs on acidic organic soil. The American Robin and Lincoln's Sparrow preferred patchy spruce on moderately acidic organic soils.

5.3.2. Effect of acidity

A number of studies have shown that the species composition of vegetation acts through plant physiognomy to influence the composition of bird communities (e.g., Karr and Roth 1971; Wiens 1973; Rov 1975; Nilsson 1979; DesGranges 1980). This has mainly been noted for land habitats, but it also applies to wetlands, as the results of this study show. Riparian birds seek a specific type of physiognomic habitat, whose presence at a given location depends on both the mineral content and acidity of the soil. Correspondence analyses for the effects of shore soil features on the distribution of riparian birds yielded the following results. In southern Quebec, the first axis reflects soil acidity and explains 56% of the total variance, while the second axis shows the effect of soil mineralization and explains an additional 33% (Appendix 9). In northern Quebec, the first axis reflects soil mineralization and explains 86% of the total variance, while the second axis represents soil acidity and explains an additional 11% (Appendix 9).

The pH of wetlands is usually acidic (< 5.0) as a result of the presence of organic acids, which do not appear to have any great effect on the majority of the riparian species. Some species, however, did demonstrate a preference for habitats typical of neutral soils, frequently avoiding habitats with a suitable plant physiognomy but soil that was very acidic. These species were the Common Yellowthroat in southern Quebec and the Palm Warbler and Common Snipe in northern Quebec (Appendix 9).

6. Discussion

6.1. Community structures

This study has revealed a decline in species richness of lacustrine bird communities with latitude, from the small swampy lakes of the Appalachians to the wetlands of the arctic tundra. Such a gradient has already been noted for terrestrial species (Tramer 1974; Short 1979; McLaren and McLaren 1981), but has never been clearly established for lacustrine species. This is probably because the gradient is less pronounced for lacustrine birds, which occur in environments that are among the most heterogeneous and productive of the boreal regions.

It is worth noting that few "generalist" species are capable of living in all of the natural districts. No species was sighted regularly in all of them, and the only species playing an important role in lacustrine communities of both the north and the south were the Black Duck, Green-winged Teal, Common Snipe, Spotted Sandpiper, American Robin, Northern Waterthrush, Rusty Blackbird, and Lincoln's Sparrow. Few species change their habitat preferences so as to adjust to the different availability of the various types of wetland environment in each of the natural districts, and this suggests that these environments, which are both rich and relatively stable during the summer, must have allowed a large number of habitat-specialized species to pack the lacustrine communities (Levins 1968; Cody 1974; Rotenberry 1978). In the course of its evolution, each species developed a distinctive morphology and feeding pattern that allowed it to specialize in certain types of prey in a few specific habitats; this sheltered it from competition with other species occurring in similar environments in other natural districts (Terborgh 1971; Able and Noon 1976; Noon *et al.* 1980).

6.2. Selection of lakes by aquatic birds

Using correspondence analysis, several ordinations were made of the species, in terms of the most important environmental factors likely to affect their selection of a nesting habitat. The results show that production (as estimated by chlorophyll "a" levels in the lakes) and "reticulation" (in the sense of Table 2 of Darveau *et al.*, this publication; i.e., the nature of the interface between the riparian vegetation and the water) are the two most important factors in the distribution of available habitats among the aquatic species. Some species — mainly waders (e.g., American Bittern) and dabbling ducks (e.g., Black Duck, Green-winged Teal) — prefer productive lakes, generally with well-developed riparian vegetation. This type of lake usually has a large, shallow littoral zone that allows light

Figure 11
Semi-schematic diagram showing how the mineral content and acidity of soils affect the physiognomy of riparian habitats and indirectly affect habitat selection by riparian birds in southern Quebec

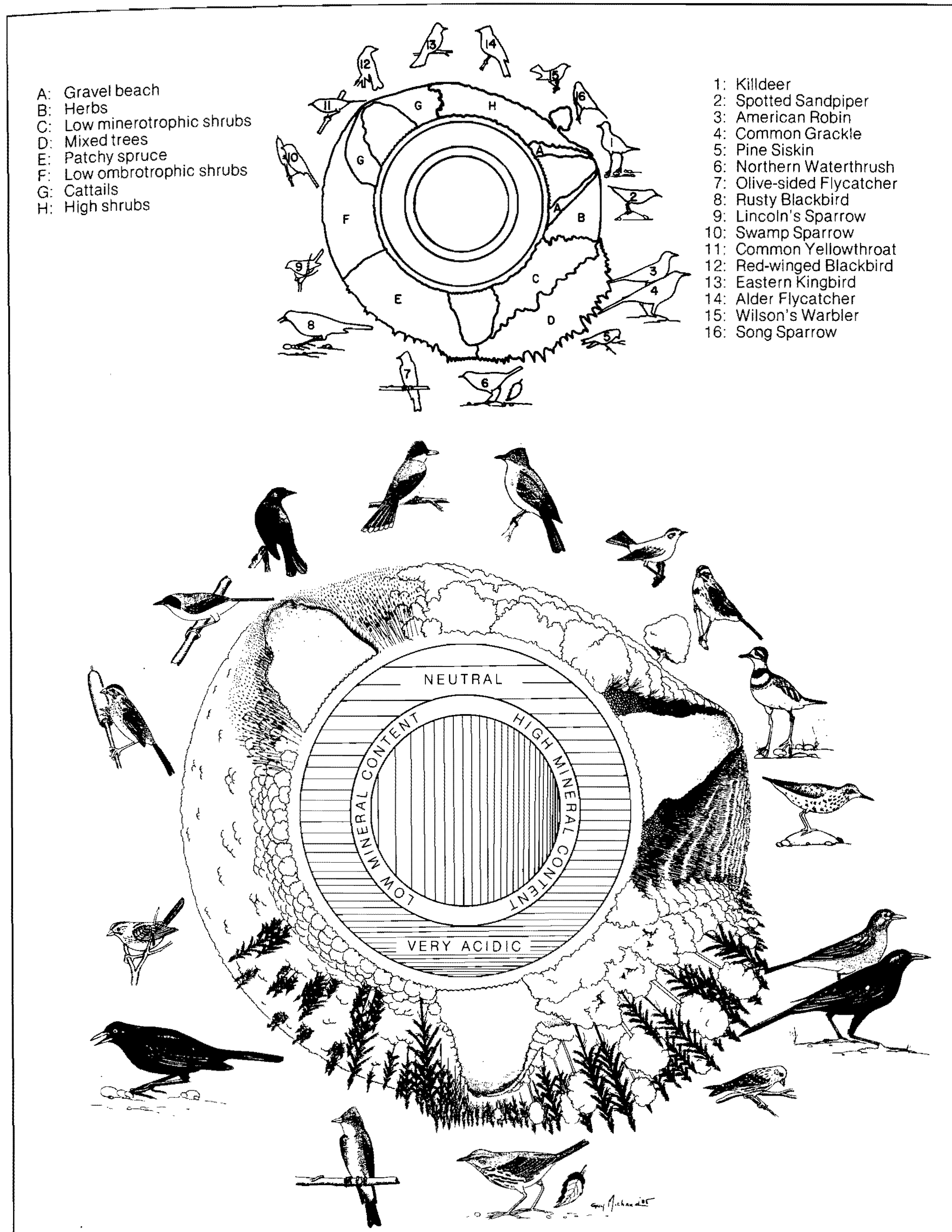
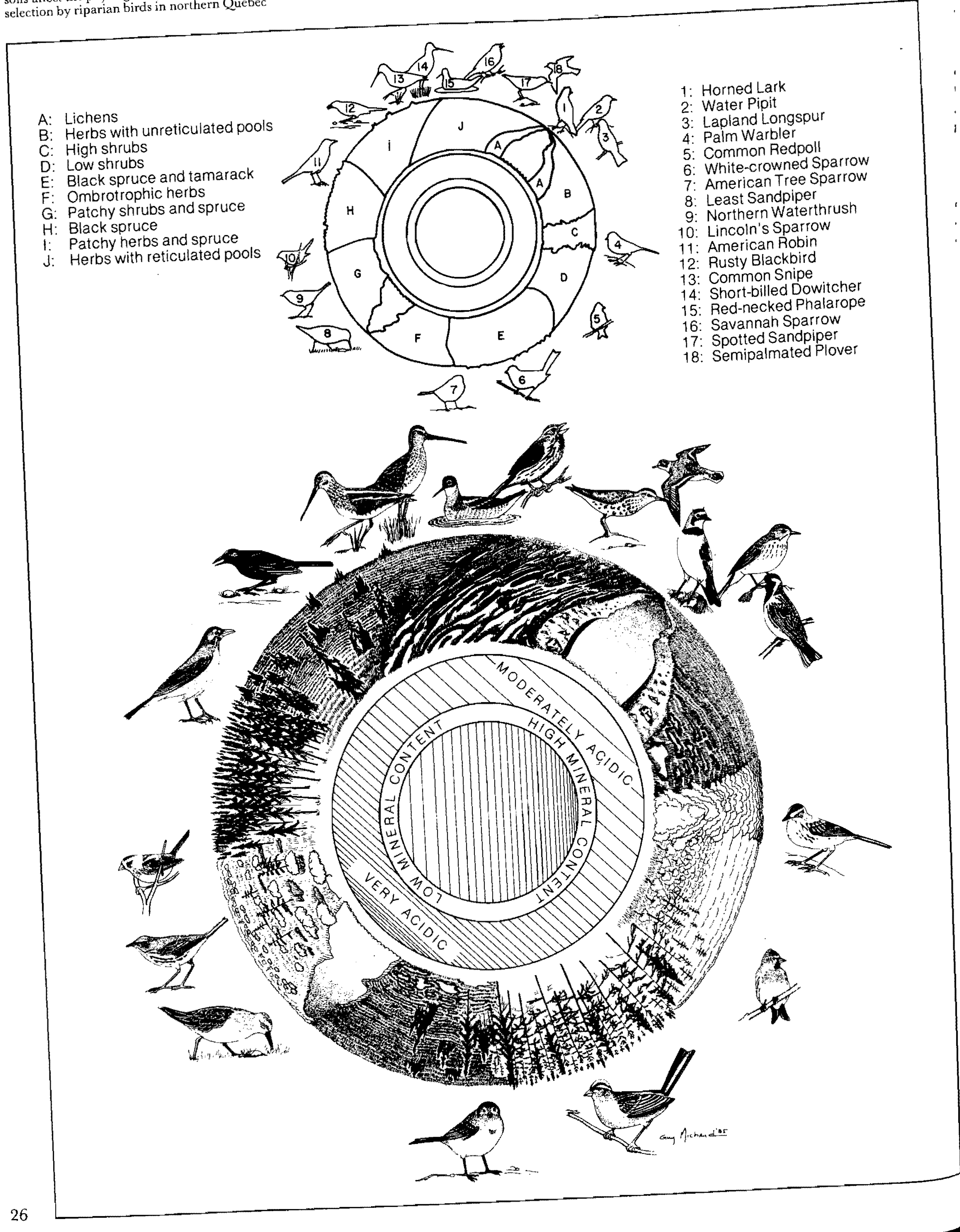


Figure 12
Semi-schematic diagram showing how the mineral content and acidity of soils affect the physiognomy of riparian habitats and indirectly affect habitat selection by riparian birds in northern Quebec



to reach the bottom of the lake in several locations. This, along with the generally near-neutral pH, fosters the growth of aquatic plants and allows the development of an abundant aquatic fauna (Moyle 1961; Patterson 1976; Joyner 1980). In these well-buffered lakes, emergent insects metamorphose more easily (Bell 1971), and the abundance of reproductive adults nearby maintains large populations of aquatic insect larvae, despite predation by fish in many cases (Moyle 1961; DesGranges and Brodeur 1985). We note, however, like other researchers, that the generally high pH of these lakes is not a characteristic the birds require. Sometimes a high level of a fertilizing element such as phosphorus in a shallow acidic lake contributes to an increase in the occurrence of dabbling ducks (Nilsson and Nilsson 1978; Kerekes *et al.* 1984; Murphy *et al.* 1984), thus demonstrating that biological productivity (see also Hilden 1964 and DesGranges and Hunter 1987) and food availability (see also Danell and Sjoberg 1978) are much more important than pH in lake selection by this group of birds.

Other species — notably diving ducks — are often found on lakes where productivity is low. These lakes are usually highly acidic, and as a result the decomposition of organic matter and the recycling of nutrients by bacteria take place less quickly (Haines 1981). The Common Goldeneye and the Red-breasted Merganser were found chiefly at lakes with undeveloped riparian vegetation, whereas the Ring-necked Duck and Hooded Merganser were sighted mainly at lakes with a wide and well-reticulated belt of vegetation. Although aquatic invertebrates are often less numerous in acidic lakes (Raddum 1980; Collins *et al.* 1981), there are also often few or no fish (IEC Beak 1985; Frenette 1986; McNicol *et al.* 1987). Acidic lakes are therefore suitable for nesting because the ducks do not have to compete with a large number of fish for food (Pehrsson 1974, 1979, 1984; Eriksson 1979, 1983; Eadie and Keast 1982; DesGranges and Darveau 1985; DesGranges and Brodeur 1985; DesGranges and Rodrigue 1986; Hunter *et al.* 1986; DesGranges and Hunter 1987; McNicol *et al.* 1987). However, while the lack of fish may be good for certain diving ducks, it poses an obstacle to species whose diet consists entirely of fish, such as the Common Loon, which is found almost exclusively at lakes with large fish populations (Silieff and Hussell 1982; Eriksson 1985; McNicol *et al.* 1987; this paper).

Water colour is also an important factor in lake selection by aquatic species (Hilden 1964). The Common Loon, Red-breasted Merganser, and Hooded Merganser preferred lakes with clear water, probably because these species spot most of their prey by swimming with their eyes open underwater (a view shared by Eriksson 1985). The Herring Gull, Arctic Tern, and Tree Swallow also preferred clear-water lakes, probably because they spot their prey while flying, before diving to capture it on or just beneath the water surface. A finding which lends support to the model of Eriksson (1985) is that species which swim underwater were relatively uninfluenced by lake acidity, while those which dive from high in the air generally avoided acidic lakes. The greater transparency of some acidic lakes apparently allows swimming birds to pursue their prey to greater depths, which compensates for the lower concentration of aquatic organisms (especially fish) in these lakes. Diving birds, however, cannot significantly increase the depth to which they dive, and thus derive no benefit from the greater transparency of the water in some acidic lakes.

6.3. Selection of wetlands by riparian birds

As with forest birds, the composition of riparian bird communities depends primarily on the plant physiognomy of the habitats (Stauffer and Best 1980; Ewert 1982; Rice *et al.* 1983; Swift *et al.* 1984; this paper). In some cases, certain plant species appear to exert a significant influence, probably because they have a distinctive appearance that gives the habitat a characteristic structure. The presence at a given location of a specific type of riparian habitat depends primarily on the soil's mineral content, acidity, and water regime (the last of which is not considered in this paper) (Jeglum 1973). Because there are a number of classifications of Canadian wetlands (Zoltai *et al.* 1975; Grondin and Ouzilleau 1980; Tarnocai 1980) and because it was often difficult to classify the areas within which birds were being counted, we decided to measure the most important distinguishing parameters directly, and, through statistical analysis, let the birds, so to speak, establish their own division of the wetlands.

In the two regions covered in this study, a similar variety of riparian species was found regardless of the degree of soil mineralization and acidity (bogs, swamps, marshes, riparian woodlands), except that the lack of trees on poorly mineralized organic soils in southern Quebec was reflected in a slightly lower species richness (see Fig. 11 and Erskine 1977). Although there is a regular change over time, dependent on the vegetation structure, in the species present, it did not appear that any family of birds is better represented on any specific soil type. Shorebirds (Charadriidae and Scolopacidae), flycatchers (Tyrannidae), warblers, blackbirds, and sparrows (Emberizidae) — the major families — were found on most wetlands, whatever their degree of soil mineralization and acidity. The heterogeneity of the habitats and their high level of productivity in summer probably explain the cohabitation of a large number of species and families in these ecosystems, which, after all, occupy only a rather small area of the lakes and of the continent as a whole.

6.4. Probable consequences of acid precipitation

There is no longer any doubt that wetland acidification causes great changes in lake biocenoses. Whether the acidity is of natural origin or stems from acid precipitation, the results are virtually the same (IEC Beak 1985). Lake acidification hinders reproduction in many fish species, including speckled trout *Salvelinus fontinalis*, which is the principal and sometimes only fish present in the lakes (Moreau *et al.* 1984; Richard 1985). Acidification also causes numerous changes in aquatic organisms generally, changes which are sometimes the result of the toxic effects of acidity such as the release of toxic heavy metals (Wright *et al.* 1976). This would appear to be what has happened to several species of plankton, gastropods, and ephemerids, and to numerous species of fish (IEC Beak 1985). More often still, the changes are the result of the gradual elimination of fish predators, which sets in motion a major transformation of the food chain (IEC Beak 1985). The most spectacular manifestation of this is the increase in populations of active swimming insects and emergent insects (DesGranges 1985; IEC Beak 1985). By changing the availability of food (fish and aquatic invertebrates), acid rain can lead to significant changes in the distribution of aquatic bird populations.

The decrease in the number of small fish in acidic lakes (Frenette 1986; McNicol *et al.* 1987) contributes to making these lakes less attractive to fish-eating birds such as the Common Loon, Common Merganser, Red-breasted Merganser, and waders (Silieff and Hussel 1982; DesGranges and Darveau 1985; McNicol *et al.* 1987; this paper). In the month following hatching, the adults need to be able to find enough fish to feed their young and meet their own needs as well. It is easy to see why these birds would find it difficult to nest on acidic lakes: most of the fish species they feed on are experiencing difficulty reproducing and eventually disappear when the water becomes too acidic.

Lake acidification (at least as low as pH 5) would also appear to contribute to slowing down the decomposition of organic matter and the recycling of nutrients by bacteria (Haines 1981). This slowdown would make the lakes less productive and cause the fish in these lakes to depend to a much greater extent on aquatic insect populations (DesGranges 1985). This in turn would deprive several species of ducks of their food sources, since they consume virtually the same prey as the fish (Hunter *et al.* 1986). However, because the fish have trouble reproducing in acidic lakes, they disappear once a high level of acidity is reached (IEC Beak 1985), and when this happens, certain diving ducks (Common Goldeneye, Hooded Merganser, and Ring-necked Duck) can take advantage of the situation (Eriksson 1984; Pehrsson 1984; DesGranges and Darveau 1985; DesGranges and Brodeur 1985; DesGranges and Rodrigue 1986; Hunter *et al.* 1986; DesGranges and Hunter 1987; McNicol *et al.* 1987) until the acidity reduces the biomass of aquatic insects too drastically. In fact, most of the lakes that have undergone acidification as a result of acid rain are already showing signs of declining fish populations, though the fish have not yet disappeared (Moreau *et al.* 1984; Richard 1985). These lakes are suitable for neither ducks nor fish (DesGranges and Hunter 1987), which demonstrates the extent to which acid precipitation can damage the whole structure of life forms in lakes of the Canadian Shield.

The effects of acid precipitation on wetlands are not yet understood. Recently, researchers have found that acid precipitation can change the structure of certain swampy habitats (Gorham *et al.* 1984). This would likely affect the wildlife of these environments. Research in this field has only just begun. With respect to birds, our study of the relationship between the acidity of wetlands and the distribution of riparian birds is a first. It shows that the majority of riparian species do not appear to be affected by the customary high acidity of such environments (pH < 5, of organic origin). For most of the species, habitat physiognomy is much more important than the acidity of the soil. However, if these environments were to undergo further acidification as a result of atmospheric acid deposits, that might affect species with a preference for habitats associated with neutral soils.

Appendices

Appendix 1
Analytical methods used to determine quality of water and riparian soil at study lakes

Water quality	
Parameters	Analytical methods
pH	Electrometry
Conductivity	Radiometer-type conductivity meter
Transparency	Secchi disk
Turbidity	Nephelometry
Alkalinity	Gran titration
Strong acids, Cl	Conductometric filtration
Ca, Fe, Mn, Cu, Zn, Cd, Pb, K, Na, Mg, Al	Atomic absorption
SO_4, F, SiO_2, NH_4, NO_3 + NO_2, Kjeldahl nitrogen, C/N, total phosphorus, tannins and lignins, true colour	Colorimetry
Total carbon, inorganic carbon	Combustion and infrared
Temperature, O_2	Hydrolab
Filterable residues	Computation
Chlorophyll "a"	Spectrophotometry
Seston	Filtration, drying, weighing
Quality of riparian soils	
Parameters	Analytical methods
pH	Electrometry (in water 1:2)
Organic carbon	Combustion
Kjeldahl nitrogen	Colorimetry
Ca, K, Mg	Atomic absorption

Note: All samples were collected between mid-July and late August in 1980, 1981, and 1982.

Appendix 2
List[a] of bird species considered in this study. Also shown is the main type of environment in which each species occurs.

Code	Species	Principal habitat[b]	Code	Species	Principal habitat[b]
ALO	Horned Lark	R	MAI	Common Grackle	R
ARG	Herring Gull	A	MAJ	Black Scoter	A
BAI	Bay-breasted Warbler	C	MAR	Swamp Sparrow	R
BCN	Canada Goose	A	MAS	Common Yellowthroat	R
BEM	Least Sandpiper	R	MAU	Alder Flycatcher	R
BER	Short-billed Dowitcher	R	MBQ	Spotted Sandpiper	R
BGN	Black-throated Blue Warbler	F	MOC	Ring-necked Duck	A
BO	Common Snipe	R	MOL	Olive-sided Flycatcher	R
BOI	Wood Thrush	F	MOU	Great Crested Flycatcher	F
BRU	Lapland Longspur	R	MP	Belted Kingfisher	A
BSC	Hooded Merganser	A	MRO	Rusty Blackbird	R
BSR	Red-breasted Merganser	A	MTB	Boreal Chickadee	E
BUT	American Bittern	A	MTN	Black-capped Chickadee	E
CAL	Wilson's Warbler	R	MVJ	Yellow-bellied Flycatcher	E
CAN	Canada Warbler	E	NB	Black-and-White Warbler	F
CAR	Red-winged Blackbird	R	OBS	Tennessee Warbler	C
CEN	Magnolia Warbler	E	OLI	Swainson's Thrush	E
CGR	Ruby-throated Hummingbird	R	ORA	Blackburnian Warbler	E
CHA	Pine Siskin	R	PAR	Northern Parula	E
CHE	Hairy Woodpecker	E	PCT	Song Sparrow	R
CN	Black Duck	A	PEC	Osprey	A
COB	White-crowned Sparrow	R	PHA	Red-necked Phalarope	R
COL	Semipalmated Plover	R	PI	Eastern Wood-Pewee	F
COU	Ovenbird	F	PIC	Pileated Woodpecker	E
CRO	Yellow-rumped Warbler	E	PIP	Water Pipit	R
DOR	Northern Flicker	E	POU	Purple Finch	E
FA	Fox Sparrow	C	PRE	Savannah Sparrow	R
FAU	Veery	F	RAM	Chimney Swift	A
FLA	American Redstart	E	RAY	Blackpoll Warbler	C
FM	Chestnut-sided Warbler	E	ROD	Golden-crowned Kinglet	C
GAC	Common Goldeneye	A	ROU	Palm Warbler	R
GB	Blue Jay	E	RUB	Ruby-crowned Kinglet	E
GBP	Pine Grosbeak	E	RUI	Northern Waterthrush	R
GEL	Ruffed Grouse	E	SAV	Green-winged Teal	A
GER	Evening Grosbeak	E	SIZ	Common Redpoll	R
GG	Gray Jay	E	SOL	Hermit Thrush	E
GMO	Greater Scaup	A	SPR	Red-breasted Nuthatch	E
GOB	White-throated Sparrow	E	STA	Arctic Tern	A
GPR	Rose-breasted Grosbeak	F	TAN	Scarlet Tanager	F
GRB	Common Merganser	A	TCH	Least Flycatcher	F
HB	Tree Swallow	A	TFO	Winter Wren	E
HG	Barn Swallow	A	TIG	Cape May Warbler	E
HUA	Common Loon	A	TRI	Mourning Warbler	F
HUD	American Tree Sparrow	R	TYR	Eastern Kingbird	R
JAU	Yellow Warbler	F	VAL	Solitary Sandpiper	R
JC	Cedar Waxwing	E	VB	Solitary Vireo	E
JOG	Gray-cheeked Thrush	C	VGN	Black-throated Green Warbler	E
JOU	Nashville Warbler	E	VP	Philadelphia Vireo	E
JUN	Dark-eyed Junco	E	VR	Red-eyed Vireo	E
KIL	Killdeer	R			
LIN	Lincoln's Sparrow	R			
M	American Robin	M			
MAC	Yellow-bellied Sapsucker	E			

[a]In alphabetical order of the code names used to identify the birds in figures and tables.
[b]Correspondence analysis yielded five major groups of birds corresponding to the following environments: aquatic (A), riparian (R), deciduous forest (F), coniferous forest (C), and transitional (E).

Appendix 3
Percentage of southern Quebec study lakes selected by aquatic birds

Variables	Number of lakes visited (n = 78)	Code before consolidation	Species BO	BSC	BUT	CN	GAC	GRB	HB	HG	HUA	KIL	MBQ	MOC	MP	PEC	RAM	SAV	VAL	Code after consolidation
Regional variables																				
Ecological zone																				
Boreal	11	ZEa	18	27	18	82	45	18	99	63	55	27	73	27	27	55	27	45	36	
Cool temperate	67	ZEb	9	21	19	36	37	13	63	9	34	10	36	49	12	4	27	7	3	
Subzone																				
Boreal	11	SZd	18	27	18	82	45	18	99	64	55	27	73	27	27	55	27	45	36	
Transitional wet	16	SZe	0	13	13	31	38	19	50	0	25	13	44	56	6	0	13	0	6	
Mid wet	23	SZf	0	26	17	39	52	17	70	9	35	9	30	52	17	4	30	0	4	
Low mid wet	7	SZg	57	0	57	71	14	0	86	57	43	14	43	86	29	14	43	43	0	
Low wet	21	SZh	10	29	14	24	29	10	57	0	38	10	33	29	5	5	29	10	0	
Ecoregion																				
Upper Laurentians	10	ERc	20	30	10	90	50	20	99	60	60	20	80	30	20	60	30	50	40	
Baskatong	16	ERd	0	13	13	31	38	19	50	0	25	13	44	56	6	0	13	0	6	
Middle Laurentians	23	ERe	0	26	17	39	52	17	70	9	35	9	30	52	17	4	30	0	4	
Appalachians	8	ERf	50	0	63	63	13	0	88	63	38	25	38	75	38	13	38	38	0	
Outaouais	21	ERg	10	29	14	24	29	10	57	0	38	10	33	29	5	5	29	10	0	
Ecological landscape																				
Coniferous forest	30	PEe	17	23	17	53	37	7	60	27	40	10	57	53	13	23	23	23	17	
Conifers ringing lake, deciduous forest behind	20	PEf	10	15	25	40	35	20	90	15	55	0	25	40	10	5	35	0	5	
Mixed forest	21	PEg	5	29	10	33	52	24	62	10	24	33	43	48	24	5	14	10	0	
Deciduous forest	7	PEh	0	14	43	29	14	0	57	0	14	0	14	29	0	0	57	14	0	
Elevation (m)																				
Average (200–450)	59	ATa	7	24	20	39	39	15	63	12	37	14	36	47	10	7	32	7	2	
High (451–900)	19	ATb	21	16	16	53	37	11	84	32	37	11	58	42	26	26	11	32	26	
Sensitivity to acidification[a]																				
Medium	17	SAa	29	12	41	41	12	0	76	29	47	12	35	53	24	6	47	12	0	
High	61	SAb	5	25	13	43	46	18	66	13	34	13	43	44	11	13	21	13	10	
Morphometric variables																				
Area (ha)																				
Very small (5–15)	42	SUa	7	21	24	40	38	10	55	14	29	10	31	55	10	2	24	10	5	SU1
Small (16–40)	36	SUb	14	22	14	44	39	19	83	19	47	17	53	36	19	22	31	17	11	SU2
Maximum depth (m)																				
Very shallow (≤ 2)	33	PXa	12	12	24	45	27	12	70	24	27	15	42	45	15	9	30	12	0	PX1
Shallow to medium (3–22)	45	PXb	9	29	16	40	47	16	67	11	44	11	40	47	13	13	24	13	13	PX2
Sublittoral slope																				
Gentle	28	BNa	4	18	14	39	43	14	61	7	25	14	46	43	7	4	29	0	4	
Moderate	30	BNb	3	23	17	30	37	20	57	7	33	10	37	37	13	3	17	7	3	
Small islands																				
Yes	62	ILa	13	24	21	44	35	16	73	21	44	15	39	45	11	15	29	15	8	
No	16	ILb	0	13	13	38	50	6	50	0	13	6	50	50	25	0	19	6	6	
Shoreline development index																				
Circular (1.0–1.3)	23	IDa	22	9	22	39	17	0	65	30	52	13	49	43	17	22	22	22	17	
Semi-circular (1.4–3.0)	55	IDb	5	27	18	44	47	20	69	11	31	13	38	47	13	7	29	9	4	
Shoreline reticulation index																				
Low	20	IRa	5	5	5	35	50	20	55	15	30	10	55	35	15	0	20	0	0	IR1
Medium	40	IRb	8	49	23	38	40	15	80	20	40	13	38	45	15	20	30	13	15	IR1
High	18	IRc	22	22	28	61	22	6	56	11	39	17	33	61	11	6	28	28	0	IR2

Appendix 3 (continued)
Percentage of southern Quebec study lakes selected by aquatic birds

Variables	Number of lakes visited (n = 78)	Code before consolidation	Species BO	BSC	BUT	CN	GAC	GRB	HB	HG	HUA	KIL	MBQ	MOC	MP	PEC	RAM	SAV	VAL	Code after consolidation
Physical-chemical variables																				
Colour (Hazen units)																				
Clear water (1–20)	31	COa	3	26	19	32	48	19	77	6	42	16	45	42	19	10	29	13	3	CO1
Coloured water (21–40)	30	COb	17	20	17	57	33	13	67	27	37	3	33	43	10	10	33	13	13	CO2
Dark water (41–100)	17	COc	12	18	24	35	29	6	53	18	29	24	47	59	12	18	12	12	6	CO2
Turbidity (Jackson units)																				
Low (< 1.0)	30	TUa	13	33	10	53	50	20	77	17	47	13	57	47	13	23	10	20	13	
Moderate (1.0–1.9)	39	TUb	5	15	28	31	28	10	64	13	36	8	26	46	13	3	38	5	5	
High (2.0–3.3)	9	TUc	22	11	11	56	44	11	56	33	11	33	56	44	22	11	33	22	0	
Summer pH																				
Fairly acidic (4.4–5.0)	10	PHa	0	20	0	60	60	10	60	10	20	10	10	60	0	0	10	0	10	PH1
Moderately acidic (5.1–5.5)	10	PHb	10	50	10	10	80	30	80	20	50	40	60	70	30	30	30	20	0	PH1
Neutral (5.6–6.9)	47	PHc	11	19	23	47	34	15	66	17	38	9	47	40	15	11	21	13	11	PH2
Alkaline (7.0–8.5)	11	PHd	18	9	27	36	0	0	73	18	36	9	27	36	9	9	64	18	0	PH2
Alkalinity (mg $CaCO_3$/L)																				
Very poorly buffered (0–3)	38	ACa	3	18	11	34	50	21	50	3	29	13	39	47	8	3	13	3	5	AC1
Poorly buffered (4–10)	15	ACb	13	13	13	40	27	0	80	20	40	7	60	33	13	13	13	27	13	AC1
Well buffered (11–35)	14	ACc	21	36	29	50	29	14	79	36	43	14	29	50	14	36	36	21	7	AC2
Very well buffered (36–95)	11	ACd	18	27	45	64	27	9	99	36	55	18	36	55	36	9	82	18	9	AC3
Conductivity (µS/cm)																				
Low (8–25)	47	CDa	13	21	17	40	45	17	66	19	36	15	47	51	13	13	17	15	11	
Moderate to high (26–200)	37	CDb	6	23	23	45	29	10	71	13	39	10	32	39	16	10	42	10	3	
Calcium saturation index																				
Very well buffered (0–3.0)	19	ISa	21	16	42	42	11	5	79	32	37	16	32	42	26	11	58	16	5	
Moderately buffered (3.1–5.1)	37	ISb	8	27	14	41	41	14	73	16	43	5	49	38	8	16	22	16	11	
Poorly buffered (5.2–6.6)	22	ISc	5	18	9	45	59	23	22	5	27	23	36	64	14	5	9	5	5	
Tannins and lignins (mg/L)																				
Low to moderate (0.2–1.0)	29	TLa	0	21	17	28	45	17	79	7	45	14	45	41	21	10	34	7	3	
Moderate to high (1.1–3.6)	49	TLb	16	22	20	51	35	12	61	22	33	12	39	49	10	12	22	16	10	
Sulphates (mg SO_4/L)																				
Low (2.0–3.5)	14	SFb	29	21	36	71	36	7	86	36	50	7	50	57	14	36	21	36	21	SF1
High (3.5–8.0)	64	SFc	6	22	16	36	39	16	64	13	34	14	39	44	14	6	28	8	5	SF2
Aluminum (mg/L)																				
Low (0.02–0.05)	25	ALa	8	20	32	24	16	4	68	8	36	4	32	40	12	8	44	8	4	AL1
Moderate (0.06–0.10)	28	ALb	11	21	18	57	43	25	68	18	43	14	50	36	18	7	21	11	4	AL2
High (0.11–0.5)	25	ALc	12	24	8	44	56	12	68	24	32	20	40	64	12	20	16	2	16	AL3
C/N ratio (organic)																				
Very low (8.0–30.0)	28	CNa	11	14	21	43	36	14	68	21	36	11	39	43	18	11	25	18	4	
Low (30.1–39.9)	24	CNb	13	29	25	46	29	8	63	13	38	17	33	50	8	8	29	13	4	
Moderate to high (40.0–135.0)	26	CNc	8	23	12	38	50	19	73	15	38	12	50	46	15	15	27	8	15	

Appendix 3 (continued)
Percentage of southern Quebec study lakes selected by aquatic birds

Variables	Number of lakes visited (n = 78)	Code before consolidation	BO	BSC	BUT	CN	GAC	GRB	HB	HG	HUA	KIL	MBQ	MOC	MP	PEC	RAM	SAV	VAL	Code after consolidation
Biological variables																				
Chlorophyll "a" (mg/m^3)																				
Extremely low (0.3–1.0)	12	YAa	17	33	8	58	42	25	99	33	58	42	67	33	25	50	8	42	25	YA1
Very low (1.1–2.0)	25	YAb	4	24	8	44	56	20	72	12	20	8	40	56	12	4	16	8	8	YA1
Low (2.1–11.5)	37	YAc	14	11	30	38	24	8	57	14	35	8	41	41	14	3	32	8	3	YA2
Seston dry weight (mg/m^3)																				
Oligotrophic (7–50)	32	SEa	9	25	13	41	44	22	72	9	38	13	41	47	16	13	16	13	16	SE1
Mesotrophic (51–175)	11	SEb	9	27	9	45	27	9	55	18	27	0	36	18	0	9	18	9	9	SE2
Eutrophic (176–1400)	15	SEc	7	7	40	60	33	7	60	13	40	7	47	67	0	7	33	13	0	SE2
Total phosphorus (mg/L)																				
Oligotrophic (0.005–0.01)	32	PTa	19	19	22	50	44	19	84	25	47	19	41	50	22	19	34	16	6	
Meso-eutrophic (0.011–0.04)	46	PTb	4	24	17	37	35	11	57	11	30	9	41	43	9	7	22	11	9	
Winter anoxia																				
Absent	24	AHa	8	25	13	38	42	17	75	13	50	8	33	38	17	21	33	13	17	
Possible	14	AHb	0	29	14	36	43	7	71	0	29	0	36	50	0	0	36	0	7	
Oxygen curves																				
Unstratified	44	OXa	14	18	23	39	32	14	66	23	30	14	39	50	14	9	32	14	2	OX1
Moderately clinograde	14	OXb	7	29	14	64	57	7	86	14	57	14	36	43	14	29	36	21	21	OX1
Strongly clinograde	20	OXc	5	25	15	35	40	20	60	5	40	10	50	40	15	5	10	5	10	OX2
Calcium (mg/L)																				
Very low (1.0–1.4)	13	CEa	15	23	0	62	69	8	69	23	38	23	31	69	0	15	8	31	15	
Low (1.5–2.9)	46	CEb	7	24	20	39	46	20	67	15	37	11	52	46	17	13	24	4	9	
Medium to high (3.0–30.0)	19	CEc	16	16	32	37	0	5	68	16	37	11	21	32	16	5	47	21	0	
Toxicity																				
No problem	58	TXa	10	17	22	41	33	9	67	17	41	9	38	45	14	10	28	14	7	
Possible problems	20	TXb	10	35	10	45	55	30	70	15	25	25	50	50	15	15	25	10	10	
Fish																				
Fishless	7	POa	0	14	29	14	43	0	57	14	43	0	43	43	0	14	14	14	0	PO1
Detrivorous	12	POb	8	25	17	33	42	25	75	8	25	25	58	42	25	0	17	17	0	—
Carnivorous	34	POc	12	24	21	56	35	9	74	21	47	6	44	50	12	21	35	15	12	PO2
Amphibians																				
Fairly large numbers	12	AMa	0	25	42	17	33	0	42	0	25	17	33	42	8	0	17	0	0	—
Large numbers	10	AMb	10	40	10	30	50	30	70	0	20	20	50	40	10	10	0	20	0	AM1

Appendix 3 (continued)
Percentage of southern Quebec study lakes selected by aquatic birds

Variables	Number of lakes visited (n = 78)	Code before consolidation	BO	BSC	BUT	CN	GAC	GRB	HB	HG	HUA	KIL	MBQ	MOC	MP	PEC	RAM	SAV	VAL	Code after consolidation
Pedological and botanical variables																				
Trophic structure of banks																				
Organic deficiency	12	RTa	8	17	8	58	33	25	83	33	50	8	42	67	8	17	33	17	8	
Mineral deficiency	36	RTb	17	22	22	36	28	17	72	17	36	25	50	42	14	14	19	22	11	
No deficiency	30	RTc	3	23	20	43	57	7	63	10	33	0	33	47	17	7	33	0	3	
Organic sediments																				
Few (≤ 33% of shore)	10	SOa	10	20	20	30	50	50	80	30	20	20	80	20	20	10	40	10	0	
Fairly large amounts (33–100% of shore)	48	SOb	2	21	15	35	40	10	58	2	31	10	35	46	8	2	19	2	4	
Helophytic plants																				
Few (< 2% of lake surface)	61	PPa	11	23	20	43	38	13	69	16	39	15	43	49	11	10	31	11	7	
Fair number (2–8% of lake surface)	17	PPb	6	18	18	41	47	18	76	18	29	6	41	41	24	18	12	18	12	
Limnophytic plants																				
Few (≤ 10% of lake surface)	46	PIa	4	24	17	41	41	17	67	9	35	11	46	43	11	7	24	9	9	
Fair number (11–80% of lake surface)	32	PIb	19	19	22	44	38	9	75	28	41	16	38	53	19	19	31	19	6	
Submersed plants																				
Few (≤ 10% of lake bottom)	65	PSa	11	23	22	45	38	15	71	20	38	11	42	49	14	14	29	15	9	—
Medium to large number (11–50% of lake bottom)	13	PSb	8	15	8	31	46	8	69	0	31	23	46	38	15	0	15	0	0	PS2
Floating-leaved plants																				
Few (≤ 6% of lake surface)	64	PFa	9	25	14	41	44	16	72	13	34	13	44	45	16	9	27	9	8	—
Medium to large number (6–50% of lake surface)	14	PFb	14	7	43	50	21	7	64	36	50	14	36	57	7	21	29	29	7	PF2
Emergent plants																				
Very few (≤ 3.5% of lake surface)	60	PMa	12	27	18	42	43	15	68	15	42	12	43	50	12	10	30	10	7	—
Few (3.6–14% of lake surface)	18	PMb	6	6	22	44	28	11	78	22	22	17	39	39	22	17	17	22	11	PM2
Total aquatic vegetation																				
Little (≤ 11% of lake surface)	46	TPa	4	24	17	41	41	17	67	9	35	11	46	43	11	7	24	9	9	TP1
Fairly large amount (12–84% of lake surface)	32	TPb	19	19	22	44	38	9	75	28	41	16	38	53	19	19	31	19	6	TP2
Composition of riparian belt																				
Few herb meadows (≤ 25% of shore)	63	BRa	10	17	21	44	43	13	73	19	37	11	40	46	17	11	30	11	8	BR1
Many herb meadows (26–50% of shore)	15	BRb	13	40	13	33	27	20	60	7	40	20	53	53	0	13	13	20	7	BR2

[a]According to Shilts (1981).

Appendix 4
Percentage of northern Quebec study lakes selected by aquatic birds

Variables	Number of lakes visited (n = 68)	Code before consoli-dation	ARG	BCN	BEM	BER	BO	BSR	CN	COL	GMO	HB	MAJ	MBQ	PHA	SAV	STA	Code after consoli-dation
Regional variables																		
Subzone																		
High semi-arctic	8	SZa	75	50	75	0	38	50	0	25	0	0	13	13	25	0	50	
Mountainous semi-arctic	56	SZb	61	64	57	29	54	18	21	14	21	21	16	25	23	18	48	
Low semi-arctic	4	SZc	25	50	50	25	25	0	25	0	25	0	0	0	25	25	50	
Ecoregion																		
George River area	11	ERa	82	36	82	0	27	36	0	18	0	0	9	9	27	0	45	
de Pas River area	57	ERb	56	67	54	30	54	18	23	14	23	21	16	25	23	19	49	
Ecological landscape																		
Arctic tundra	8	PEa	88	50	88	0	38	38	0	13	0	0	0	0	25	0	25	
Alpine tundra	7	PEb	57	57	43	0	14	43	14	14	0	0	14	29	14	14	71	
Muskeg	15	PEc	73	73	93	67	99	13	53	40	40	27	20	27	73	40	87	
Taiga	38	PEd	50	61	42	18	39	16	11	5	18	21	16	24	5	11	34	
Elevation (m)																		
Average (350–450)	18	ATa	61	61	72	22	61	28	11	6	28	22	28	6	22	11	50	
High (451–600)	50	ATb	60	62	54	26	46	18	22	18	16	16	10	28	24	18	48	
Sensitivity to acidification[a]																		
Average	47	SAa	53	57	53	27	47	15	21	21	17	13	13	21	23	19	53	
High	21	SAb	76	71	71	19	57	33	14	0	24	29	19	24	24	10	38	
Morphometric variables																		
Area (ha)																		
Very small (3–15)	17	SUa	41	47	24	12	24	6	12	6	0	12	12	24	0	18	29	SU1
Small (16–75)	51	SUb	67	67	71	29	59	25	22	18	25	20	16	22	31	16	55	SU2
Maximum depth (m)																		
Very shallow (≤ 2)	51	PXa	65	63	65	33	57	22	24	14	25	22	20	24	29	22	53	PX1
Shallow (3–11)	17	PXb	47	59	41	0	29	18	6	18	0	6	0	18	6	0	35	PX2
Sublittoral slope																		
Gentle	35	BNa	54	66	54	23	43	26	20	9	11	9	11	20	26	23	51	
Moderate	33	BNb	67	58	64	27	58	15	18	21	27	27	18	24	21	9	45	
Small islands																		
Yes	35	ILa	49	63	51	26	51	17	23	17	23	23	6	20	20	14	49	
No	33	ILb	73	61	67	24	48	24	15	12	15	12	24	24	27	18	48	
Shoreline development index																		
Circular (1.0–1.3)	36	IDa	64	64	53	31	44	17	22	19	22	19	14	17	22	22	47	
Semi-circular (1.4–3.0)	32	IDb	56	59	66	19	56	25	16	9	16	16	16	28	25	9	50	
Shoreline reticulation index																		
Low	20	IRa	40	60	35	5	20	15	5	15	10	5	0	15	5	5	35	IR1
Medium	32	IRb	66	53	53	19	47	31	16	6	16	19	16	25	19	9	34	IR1
High	16	IRc	75	81	99	63	94	6	44	31	38	31	31	25	56	44	94	IR2

Appendix 4 (continued)
Percentage of northern Quebec study lakes selected by aquatic birds

Variables	Number of lakes visited (n = 68)	Code before consoli-dation	ARG	BCN	BEM	BER	BO	BSR	CN	COL	GMO	HB	MAJ	MBQ	PHA	SAV	STA	Code after consoli-dation
Physical and chemical variables																		
Colour (Hazen units)																		
Clear water (1–20)	49	COa	61	53	53	14	43	27	12	12	12	16	10	29	16	6	41	CO1
Coloured water (21–40)	18	COb	56	89	72	50	67	6	33	17	33	17	28	6	39	39	67	CO2
Turbidity (Jackson units)																		
Low (< 1.0)	19	TUa	47	58	47	5	37	37	11	5	11	5	5	32	5	5	37	
Moderate (1.0–1.9)	32	TUb	59	56	50	16	34	16	9	19	19	22	16	16	16	9	34	
High (2.0–8.0)	17	TUc	76	76	88	65	94	12	47	18	29	24	24	24	59	41	88	
Summer pH																		
Very acidic (3.0–4.5)	7	PHa	0	43	14	0	14	14	0	14	0	0	0	14	0	0	0	PH1
Neutral (5.6–6.9)	47	PHc	66	64	64	28	53	19	21	17	21	21	19	19	30	19	57	PH2
Alkaline (7.0–8.6)	14	PHd	71	64	64	29	57	29	21	7	21	14	7	36	14	14	43	PH2
Alkalinity (mg $CaCO_3$/L)																		
Very poorly buffered (0–3)	11	ACa	36	45	36	0	18	18	0	18	9	9	0	18	9	0	27	AC1
Poorly buffered (4–10)	45	ACb	67	69	64	31	58	20	24	16	22	22	22	18	29	22	58	AC1
Well buffered (11–35)	12	ACc	58	50	58	25	50	25	17	8	17	8	0	42	17	8	33	AC2
Conductivity (μS/cm)																		
Low (3–25)	49	CDa	69	65	65	29	57	18	18	14	20	20	20	18	29	18	55	
Moderate to high (26–40)	18	CDb	33	56	39	11	28	28	17	11	11	6	0	33	6	6	28	
Calcium saturation index																		
Very well buffered (0.5–3.0)	13	ISa	62	54	62	31	54	31	23	8	23	15	8	38	15	15	38	
Moderately buffered (3.1–5.1)	47	ISb	68	68	64	26	53	19	19	15	19	19	19	19	28	17	57	
Tannins and lignins (mg/L)																		
Low to moderate (0.1–1.0)	54	TLa	61	59	59	22	46	26	19	13	17	17	15	26	19	17	46	
Moderate to high (1.1–1.5)	13	TLb	54	77	54	31	62	0	15	15	23	15	15	8	38	8	54	
Sulphates (mg SO_4/L)																		
Very low (0.3–1.5)	42	SFa	69	60	67	24	57	26	19	14	21	21	24	24	26	14	55	SF1
Low (1.6–3.5)	16	SFb	63	81	63	38	50	6	19	13	19	13	0	19	25	25	50	SF1
Moderate to high (3.5–83.0)	9	SFc	11	44	11	0	11	22	11	11	0	0	0	22	0	0	11	SF2
Aluminum (mg/L)																		
Low (0.03–0.05)	38	ALa	71	58	74	26	53	26	24	16	16	11	18	21	29	18	61	AL1
Moderate (0.06–0.10)	18	ALb	56	83	39	22	44	11	11	6	22	22	6	33	17	11	33	AL2
High (0.11–3.35)	11	ALc	27	45	36	18	45	18	9	18	18	27	18	9	9	9	27	AL3
Biological variables																		
Chlorophyll "a" (mg/m³)																		
Extremely low (0.1–1.0)	30	YAa	47	50	50	10	40	20	10	10	10	10	3	23	10	3	43	YA1
Very low (1.1–2.0)	19	YAb	79	79	58	21	37	32	11	11	21	21	32	26	21	16	47	YA1
Low (2.1–3.1; 33)	19	YAc	63	63	74	53	79	11	42	26	32	26	16	16	47	37	58	YA2
Seston dry weight (mg/m³)																		
Oligotrophic (0–50)	30	SEa	60	53	47	7	33	30	10	10	0	7	10	23	10	3	33	SE1
Mesotrophic (51–175)	25	SEb	60	68	60	32	56	12	24	16	32	28	20	16	24	28	56	SE2
Eutrophic (176–500; 866)	12	SEc	58	75	92	58	75	17	33	25	42	25	17	33	50	25	75	SE2
Natural fertility potential (mg/L)																		
Oligotrophic (0.0–0.9)	36	FNa	53	56	56	17	44	19	11	17	11	14	19	25	19	14	47	
Mesotrophic (0.1–0.6)	22	FNb	73	73	59	23	50	23	14	14	27	14	9	23	23	14	32	
Eutrophic (0.7–3.2; 8.9)	10	FNc	60	60	70	30	70	20	60	10	30	40	10	10	40	30	90	
Calcium (mg/L)																		
Very low (0.4–1.4)	38	CEa	71	66	71	32	58	21	21	18	21	24	24	21	34	18	61	
Low (1.5–2.9)	18	CEb	50	56	44	22	39	17	6	6	11	6	6	11	11	17	33	
Medium to high (3.0–10.0)	11	CEc	36	64	36	0	36	27	27	9	18	9	0	45	0	0	27	
Toxicity																		
No problem	56	TXa	68	63	63	28	50	23	21	14	21	21	14	25	21	16	52	
Possible problems	6	TXb	50	83	67	50	83	17	17	17	17	0	33	17	67	33	67	
Serious problems	6	TXc	0	33	17	0	17	0	0	17	0	0	0	0	0	0	0	
Fish																		
Fishless	6	POa	0	33	17	0	17	0	0	17	0	0	0	0	0	0	0	
Carnivorous	14	POb	71	86	79	29	57	43	14	7	21	36	29	36	21	14	43	PO2
Fish probably present	40	POc	60	60	60	33	55	18	28	18	20	13	10	23	30	23	60	

Appendix 4 (continued)
Percentage of northern Quebec study lakes selected by aquatic birds

Variables	Number of lakes visited (n = 68)	Code before consolidation	Species: ARG	BCN	BEM	BER	BO	BSR	CN	COL	GMO	HB	MAJ	MBQ	PHA	SAV	STA	Code after consolidation
Pedological and botanical variables																		
Trophic structure of banks																		
Organic deficiency	13	RTa	54	54	31	0	23	23	0	8	0	15	0	23	0	0	31	
Mineral deficiency	13	RTb	69	46	85	46	85	8	46	31	46	31	8	23	62	46	77	
No deficiency	42	RTc	60	69	60	26	48	24	17	12	17	14	21	21	19	12	45	
Organic sediments																		
Few (≤ 33% of shore)	47	SOa	66	64	60	26	49	21	15	17	17	15	9	23	23	11	43	
Fair amounts (33–80% of shore)	21	SOb	48	57	57	24	52	19	29	10	24	24	29	19	24	29	62	
Helophytic plants																		
Few (< 2% of lake surface)	52	PPa	58	63	63	29	54	23	23	19	19	13	13	21	29	19	50	
Fair number (2–18% of lake surface)	13	PPb	69	54	46	15	38	15	8	0	23	38	23	31	8	8	46	
Limnophytic plants																		
Few (< 20% of lake surface)	52	PIa	65	65	63	33	56	23	23	15	23	21	19	23	29	21	56	
Fair number (20–80% of lake surface)	13	PIb	38	46	46	0	31	15	8	15	8	8	0	23	8	0	23	
Total aquatic vegetation																		
Little (< 12% of lake surface)	45	TPa	64	69	67	38	60	22	27	18	22	22	16	18	33	24	56	TP1
Fair amount (12–80% of lake surface)	20	TPb	50	45	45	0	30	20	5	10	15	10	15	35	5	0	35	TP2
Composition of riparian belt																		
Few herb meadows (≤ 10% of shore)	12	BRa	33	33	25	0	8	17	0	8	8	0	8	25	0	0	25	BR1
Many herb meadows without pools (≥ 25% of shore)	19	BRb	74	58	63	16	53	37	26	5	21	21	21	26	11	16	42	BR2
Many herb meadows with pools (≥ 25% of shore)	19	BRc	63	74	95	58	84	11	37	32	26	26	21	21	58	32	79	BR3
Types of aquatic plants																		
No aquatic plants	34	VSa	65	74	68	41	62	26	26	18	24	24	18	26	29	29	53	—
Mainly vascular plants	11	VSb	73	64	36	9	55	9	18	9	36	18	27	18	9	9	45	VS1
Mainly non-vascular plants	20	VSc	45	40	60	10	30	20	10	15	5	10	5	20	25	0	45	VS2

[a]According to Gilbert *et al.* (1985).

Appendix 5
Percentage of lakes with given aquatic vegetation that are selected by aquatic birds in southern Quebec and in northern Quebec

Plant associations (southern Quebec)	Number of lakes visited	Codes	Species: BSC	BUT	CN	GAC	HB	HUA	MOC
Dulichium arundinaceum and algae	26	DUaALg	8	8	12	8	38	19	8
Eleocharis smallii and *Brasenia schreberi*	36	ELsBRs	6	17	11	8	11	8	0
Eriocaulon septangulare	31	ERs	13	3	16	16	6	13	3
Nuphar variegatum and *Sparganium* sp.	43	NUvSPA	7	12	16	14	28	23	30
Sagittaria latifolia	7	SAGI	0	0	14	0	43	57	71
Sparganium angustifolium and *Eleocharis uniglumis*	15	SPAaELu	7	13	33	13	53	40	7
Sparganium eurycarpum and *Potamogeton epihydrus*	17	SPAePOe	12	0	12	18	53	18	24
Sparganium fluctuans and *Potamogeton oakesianus*	12	SPAfPOo	0	0	0	25	25	17	25
Utricularia vulgaris	19	UTv	5	0	26	21	21	16	32

Plant associations (northern Quebec)	Number of lakes visited	Codes	Species: ARG	BCN	BEM	BO	CN	GMO	HB	MAJ	PHA	STA
Drepanocladus exannulatus	4	DRe	50	75	75	25	0	0	25	0	25	50
Hippuris vulgaris	3	HIv	67	67	67	100	100	33	33	0	0	67
Menyanthes trifoliata	5	MEt	60	80	40	20	0	20	20	40	20	40
Potamogeton filiformis	4	POf	50	50	25	50	0	25	25	25	0	50
Scorpidium scorpioides	7	SCs	29	29	57	14	14	14	14	14	29	71

Appendix 6
Number of individuals of the principal riparian species sighted at typical habitats of southern Quebec

Variables	Number of units identified	Code	Species: CAL	CAR	CGR	CHA	KIL	LIN	M	MAI	MAR	MAS	MAU	MBQ	MOL	MRO	PCT	RUI	TYR
Edaphic variables																			
Soil pH																			
Very acidic (3.5–4.5)	87	PL_1	3	104	2	11	4	31	15	27	153	194	10	9	25	9	8	6	18
Moderately acidic (4.6–6.2)	62	PL_2	3	13	3	0	1	3	1	3	47	57	5	11	7	1	1	0	6
Total nitrogen (%)																			
Low (0.03–1.5)	112	NT_1	2	7	2	0	1	7	1	1	28	54	2	7	0	3	2	0	1
Average to high (1.6–3)	219	NT_2	1	22	1	0	0	12	0	3	84	93	6	6	9	2	0	0	8
Organic matter (%)																			
Moderate (1–60)	76	MO_1	3	7	2	0	0	1	1	2	17	34	5	8	1	1	2	0	4
High (61–100)	255	MO_2	0	22	1	0	1	18	0	2	95	113	3	5	8	7	0	0	5
Physiognomy of habitats																			
Herbs and gravel beach	59	H_1	0	9	—	0	3	4	0	3	11	1	0	9	0	0	0	0	1
Patchy shrubs and cattails	199	$TTYAM_1$	0	28	—	0	0	0	0	5	11	9	0	0	1	0	1	1	2
Patchy shrubs and conifers	61	$TAMCO_1$	1	9	—	0	0	10	0	2	29	33	1	0	3	2	1	1	3
Low minerotrophic shrubs	276	AM_1	1	58	—	4	2	17	1	5	147	168	1	9	7	3	4	0	13
Low ombrotrophic shrubs	53	AM_2	0	3	—	0	0	4	0	0	23	41	0	0	5	1	2	0	1
High shrubs	59	AH_1	4	4	—	0	0	2	0	3	15	23	15	0	0	1	2	0	5
Deciduous trees	74	FFE_0	0	7	—	0	0	1	0	0	0	5	0	0	2	0	0	1	0
Coniferous trees	117	FCO_0	0	14	—	5	0	3	5	7	7	10	0	0	10	4	1	2	4
Mixed trees	123	$FMIX_0$	2	5	—	2	0	2	9	11	4	13	0	0	11	0	1	3	3
Taxonomy of habitats																			
Cattails	33	TY	0	21	—	0	—	0	0	1	3	4	0	0	0	0	0	0	1
Sedges	751	C	4	165	—	9	—	32	27	3	164	146	2	38	5	0	21	8	16
Myrica	53	MY	0	14	—	0	—	1	0	1	15	14	1	1	1	0	0	0	1
Myrica with leatherleaf	277	MYCH	8	30	—	24	—	9	6	0	55	70	0	2	5	2	8	2	4
Leatherleaf with myrica	446	CHMY	0	144	—	0	—	9	12	0	76	102	2	5	6	1	12	2	13
Leatherleaf	109	CH	1	5	—	0	—	12	0	0	22	42	1	0	2	1	1	0	2
Tamarack with leatherleaf and myrica	110	MECHMY	0	15	—	0	—	5	2	0	25	26	0	0	3	0	1	0	1
Black spruce with leatherleaf	22	PNCH	0	2	—	0	—	5	0	0	3	5	0	0	0	1	0	0	0
Riparian white birch	42	BOB	0	2	—	0	—	0	0	0	2	24	4	0	2	0	0	2	2
Alders with myrica	100	ALMY	8	7	—	12	—	0	0	0	3	9	12	0	4	0	2	4	1
Alders with sedge	347	ALC	13	13	—	17	—	21	8	2	26	37	16	2	2	1	8	18	5

Appendix 7
Number of individuals of the principal riparian species sighted at typical habitats of northern Quebec

Variables	Number of units identified	Code	ALO	BEM	BER	BO	BRU	COB	COL	HUD	LIN	M	MBQ	MRO	PHA	PIP	PRE	ROU	RUI	SIZ
Edaphic variables																				
Soil pH																				
Very acidic (2.9–4.5)	76	PL_1	2	10	2	4	5	16	4	38	2	3	3	20	1	0	8	1	7	3
Moderately acidic (4.6–6.6)	269	PL_2	6	31	25	23	23	47	5	128	11	21	8	54	21	7	62	4	27	15
Total nitrogen																				
Low (0.01–1.5%)	83	NT_1	2	9	3	2	18	21	3	45	3	6	2	23	0	4	8	3	6	10
Average to high (1.6–3.7%)	262	NT_2	6	40	30	25	10	47	6	126	10	18	9	52	38	3	69	2	28	8
Organic matter																				
Moderate (1–60%)	94	MO_1	2	12	3	7	18	21	3	47	3	5	2	23	0	4	12	3	7	9
High (61–98%)	251	MO_2	6	37	30	20	10	47	6	124	10	19	9	52	38	3	65	2	27	9
Physiognomy of habitats																				
Lichens	27	Lo	3	1	0	0	4	5	1	6	0	2	2	0	0	4	0	0	0	0
Herbs without pools	61	$HSMN_1$	0	6	3	5	6	0	0	6	0	0	5	2	0	0	6	0	1	1
Herbs with pools	132	HM_1	4	54	37	18	25	20	8	38	2	12	5	45	42	4	74	0	8	4
Low shrubs without streams	7	ABos	2	1	0	0	3	0	0	5	0	0	0	0	0	1	1	0	0	1
Low shrubs with streams	12	ABo	0	1	0	0	0	4	0	10	0	0	0	0	0	0	3	0	0	0
Minerotrophic low shrubs	36	AB_1	0	0	0	3	0	8	0	22	2	0	0	4	0	0	1	0	9	6
Patchy herbs and spruce	129	$THPN_2$	0	7	6	5	0	30	1	112	9	18	2	27	4	0	7	1	17	3
Black spruce and tamarack	217	PNME	0	1	0	1	0	42	0	81	7	14	0	22	0	0	1	4	28	8
Black spruce	22	FPNo	0	0	0	0	0	3	0	4	0	3	1	0	0	0	0	0	1	3
Patchy shrubs and spruce	12	TABPo	0	0	0	0	0	10	0	6	0	4	0	0	0	0	0	0	0	0
High shrubs	10	AH_1	0	0	0	0	0	5	0	7	0	1	0	0	0	0	0	3	2	2
Taxonomy of habitats																				
Lichens	27	LI	3	1	0	0	3	4	1	5	0	2	0	0	0	4	0	0	0	1
Sedges	245	C	3	21	22	17	21	6	6	16	1	3	6	26	19	6	34	0	8	1
Sedges with scrub birch	88	CBG	4	6	1	4	17	3	0	14	2	0	1	5	9	1	10	0	0	2
Sedges with tamarack	258	CME	0	27	11	14	0	12	6	67	6	16	2	39	16	1	35	3	4	5
Sedges with black spruce	155	CPN	0	4	5	2	0	15	0	48	2	5	3	15	0	0	4	0	8	2
Black spruce with sphagnums	80	PNSP	0	0	0	0	0	3	1	20	2	0	0	8	0	0	0	0	5	3
Tamarack with black spruce	28	MEPNSP	0	0	0	0	0	2	0	11	0	2	0	1	0	0	0	0	1	0
Tamarack with scrub birch	114	MEBG	0	7	0	2	0	10	0	33	5	7	0	6	4	0	0	0	10	1
Scrub birch with spruce	30	BGEP	0	0	0	0	0	8	0	4	0	3	0	0	0	0	0	0	0	1
Scrub birch	25	BG	2	1	0	0	3	3	0	13	0	0	0	0	0	0	1	0	0	3
Willow	48	SA	0	0	1	2	0	6	0	14	2	0	0	11	0	0	0	0	9	3

Appendix 8
Aids to interpreting correspondence analyses for aquatic birds

Subject of analysis, dimensions[a] of matrix, total variance of multi-dimensional cluster, percentage of total variance explained by principal factors	Environmental variables contributing most to variance of the first three factors (percent absolute contribution to factor)[b]	Aquatic species whose distribution is most affected by the first three factors (percent relative contribution of factor)[c]
General appearance of lakes		
Southern Quebec (8 species and 3 variables with 6 values; total variance = 0.025)		
First factor (57%)	SU_2 (22%) / IR_2 (−27%), SU_1 (−20%)[d]	HUA (67%) / BUT (−95%), MOC (−76%), CN (−68%)
Second factor (35%)	PX_1 (35%), SU_2 (20%) / PX_2 (−22%), SU_1 (−21%)	MBQ (75%), HB (71%) / BSC (−66%), GAC (−56%)
Third factor (7%)	IR_2 (16%) / IR_1 (−17%)	HUA (32%), CN (18%)
Northern Quebec (14 species and 3 variables with 6 values; total variance = 0.049)		
First factor (69%)	PX_2 (36%), IR_1 (22%) / IR_2 (−32%)	ARG (97%), BCN (90%), BSR (64%), MBQ (61%) / BER (−99%), PHA (−69%), MAJ (−63%), CN (−59%), GMO (−56%), SAV (−55%)
Second factor (23%)	SU_1 (80%)	SAV (44%) / BEM (−61%)
Third factor (8%)	PX_2 (48%), IR_2 (26%)	STA (87%), BO (42%), BEM (35%)
Physical-chemical features of lakes		
Southern Quebec (8 species and 5 variables with 12 values; total variance = 0.037)		
First factor (66%)	PH_1 (29%), AL_3 (17%) / AL_1 (−15%), AC_3 (−12%), PH_2 (−12%)	GAC (98%), BSC (37%), MOC (30%) / BUT (−93%), HUA (−74%), HB (−67%)
Second factor (18%)	AL_2 (33%) / AL_1 (−27%)	MBQ (66%) / MOC (−33%)
Third factor (10%)	CO_1 (38%) / CO_2 (−27%)	HUA (20%), BSC (19%) / CN (−33%), MOC (−27%)
Northern Quebec (14 species and 5 variables with 12 values; total variance = 0.016)		
First factor (57%)	SF_2 (24%), CO_1 (17%), PH_1 (16%) / CO_2 (−27%)	MBQ (93%), BSR (75%), BCN (30%) / SAV (−84%), PHA (−79%), BER (−75%), MAJ (−66%), GMO (−45%), STA (−45%)
Second factor (18%)	AL_2 (26%), CO_2 (17%), PH_1 (16%) / AL_1 (−18%)	BCN (62%), GMO (25%) / BEM (−64%), ARG (−62%), STA (−40%)
Third factor (12%)	AL_3 (18%) / SF_2 (−22%), AL_1 (−17%)	HB (82%) / CN (−51%)
Biological features of lakes		
Southern Quebec (8 species and 8 variables with 16 values; total variance = 0.029)		
First factor (55%)	YA_1 (16%) / PF_2 (−26%), YA_2 (−19%)	BSC (71%), GAC (61%) / BUT (−80%)
Second factor (20%)	YA_1 (10%), PM_2 (8%) / AM_1 (−29%), BR_2 (−21%), PO_1 (−8%)	CN (65%), HB (42%) / BSC (−23%)
Third factor (12%)	BR_2 (23%), PO_2 (13%) / AM_1 (−24%), PM_2 (−13%), PO_1 (−12%)	HUA (58%) / HB (−29%), GAC (−22%)
Northern Quebec (14 species and 8 variables with 16 values; total variance = 0.074)		
First factor (72%)	SE_1 (18%), TP_2 (15%), BR_1 (12%) / YA_2 (−15%), BR_3 (−12%)	ARG (88%), MBQ (84%), BSR (82%), BCN (72%) / BER (−94%), SAV (−88%), CN (−77%), PHA (−69%), BO (−61%), HB (−55%)
Second factor (14%)	US_2 (24%) / US_1 (−38%)	BEM (55%) / MAJ (−73%), GMO (−71%)
Third factor (7%)	US_2 (18%), TP_2 (14%) / BR_2 (−27%), SE_1 (−15%)	STA (72%)
Types of aquatic vegetation		
Southern Quebec (7 species and 9 variables with 9 values; total variance = 0.292)		
First factor (49%)	ELsBRs (45%) / SAGI (−21%)	BUT (67%), BSC (39%) / MOC (−83%)
Second factor (21%)	− / ERs (−54%), UTv (−15%)	HB (39%) / GAC (−65%), BSC (−33%)
Third factor (16%)	SPAePOe (24%) DUaAIg (21%) / NUvSPA (−19%), ELsBRs (−15%)	HB (50%)
Northern Quebec (10 species and 5 variables with 5 values; total variance = 0.283)		
First factor (55%)	MEt (17% / HIv (−74%)	PHA (42%), MAJ (39%), BCN (30%) / CN (−93%), BO (−65%)
Second factor (27%)	SCs (38%) DRe (11%) / POf (−34%), MEt (−18%)	BEM (85%), PHA (53%), STA (45%) / ARG (−62%), GMO (−42%)
Third factor (12%)	DRe (65%) / SCs (−32%)	HB (43%), BCN (40%) / GMO (−48%)

Appendix 8 (continued)
Aids to interpreting correspondence analyses for aquatic birds

Subject of analysis, dimensions[a] of matrix, total variance of multi-dimensional cluster, percentage of total variance explained by principal factors	Environmental variables contributing most to variance of the first three factors (percent absolute contribution to factor)[b]	Aquatic species whose distribution is most affected by the first three factors (percent relative contribution of factor)[c]
Effect of lake acidity		
Laurentians (8 species and 4 variables with 8 values; total variance = 0.038)		
First factor (58%)	PH_1 (27%), YA_1 (18%), IR_1 (12%) / YA_2 (−27%), PH_2 (−13%)	GAC (86%), BSC (19%) / BUT (−94%), HUA (−59%)
Second factor (22%)	IR_1 (45%) / PH_1 (−25%), IR_2 (−18%)	MBQ (92%), CN (21%) / MOC (−45%), BSC (−42%)
Third factor (12%)	CO_1 (47%) / CO_2 (−30%)	HB (42%), BSC (36%), HUA (32%) / MOC (−45%), CN (−41%)
Taiga (14 species and 4 variables with 8 values; total variance = 0.064)		
First factor (51%)	PH_1 (27%), CO_1 (13%) / CO_2 (−26%), YA_2 (−17%)	MBQ (93%), BSR (60%), BEM (48%) / BER (−91%), CN (−76%), SAV (−67%), MAJ (−55%)
Second factor (29%)	CO_2 (33%), IR_1 (25%), PH_1 (19%) / CO_1 (−16%)	BCN (74%), BEM (31%) / HB (−77%), BO (−58%), PHA (−56%)
Third factor (12%)	YA_2 (39%), PH_1 (38%)	BSR (32%), PHA (30%) / GMO (−67%), STA (−39%)

[a]The values of the environmental variables are described in Appendices 3, 4, and 5.
[b]This is the percentage of variance of the factor explained by each of the environmental variables.
[c]This is the percentage of variance in the species distribution that is explained by the factor.
[d]"+" and "−" indicate whether the correlation with the factor is positive or negative.

Appendix 9
Aids to interpreting correspondence analyses for riparian birds

Subject of analysis, dimensions[a] of matrix, total variance of multi-dimensional cluster, percentage of total variance explained by principal factors	Environmental variables contributing most to variance of the first three factors (percent absolute contribution to factor)[b]	Aquatic species whose distribution is most affected by the first three factors (percent relative contribution of factor)[c]
Edaphic features of banks		
Southern Quebec (17 species and 3 variables with 6 values; total variance = 0.128)		
First factor (56%)	− / PL_1 (−55%)[d]	MAS (75%), MBQ (56%), CGR (50%) / CAR (−95%), RUI (−94%), CHA (−94%), MAI (−79%), M (−71%), MOL (−59%)
Second factor (33%)	MO_1 (37%) / MO_2 (−35%)	PCT (76%), CAL (72%), MAU (48%), CGR (47%), MBQ (43%) / MAR (−73%), LIN (−61%)
Third factor (9%)	NT_2 (20%) / NT_1 (−63%)	TYR (72%) / MRO (−96%), KIL (−35%)
Northern Quebec (18 species and 3 variables with 6 values; total variance = 0.081)		
First factor (86%)	NT_1 (38%), MO_1 (28%) / NT_2 (−17%), MO_2 (−14%)	ROU (97%), BRU (95%), SIZ (93%), COB (79%), MRO (66%), PIP (66%), HUD (54%) / PHA (−94%), BER (−90%), PRE (−10%), RUI (−78%), BO (−52%)
Second factor (11%)	PL_2 (13%) / PL_1 (−84%)	M (53%), LIN (42%) / ALO (−85%), COL (−70%), MBQ (−59%), HUD (−43%)
Third factor (2%)	PL_2 (35%) / NT_1 (−34%), MO_2 (−23%)	BO (36%)
Physiognomy of riparian vegetation		
Southern Quebec (16 species and 9 variables with 9 values; total variance = 0.791)		
First factor (35%)	AM_1 (11%) / $FMIX_0$ (−50%), FCO_0 (−29%)	MAR (75%), MAS (35%) / M (−88%), MOL (−87%), RUI (−82%), MAI (−78%), CHA (58%)
Second factor (27%)	H_1 (22%) / AH_1 (−70%)	MBQ (30%), KIL (28%), CAR (19%) / MAU (−77%), CAL (−77%), PCT (−55%), TYR (−47%)
Third factor (19%)	H_1 (64%) / AH_1 (−17%)	KIL (62%), MBQ (58%), MAU (17%) / MAS (−49%)
Fourth factor (11%)	− / $TTYAM_1$ (−66%)	LIN (21%) / CAR (−74%)
Northern Quebec (18 species and 11 variables with 11 values; total variance = 0.844)		
First factor (53%)	HM_1 (47%) / PNME (−23%)	BEM (96%), PRE (88%), BER (87%), PHA (74%), COL (68%), BRU (62%) / HUD (−83%), RUI (−66%), LIN (−61%), COB (−63%)
Second factor (19%)	− / L_0 (−68%), ABos (−23%)	MRO (45%) / PIP (−82%), ALO (−80%)
Third factor (8%)	$HSMN_1$ (55%)	MBQ (39%), SIZ (34%), BO (31%)
Fourth factor (7%)	$THPN_2$ (17%) / AH_1 (−62%)	− / ROU (−59%)
Types of riparian vegetation		
Southern Quebec (15 species and 11 variables with 11 values; total variance = 0.459)		
First factor (54%)	ALMY (40%), ALC (34%)	CAL (93%), MAU (82%), CHA (75%), RUI (70%) / CAR (−50%), MAR (−45%)
Second factor (16%)	TY (15%), ALMY (14%) / CH (−32%), PNCH (−15%)	CAR (42%) / LIN (−53%), MAS (−45%), MRO (−40%)
Third factor (11%)	C (23%), ALC (14%) / BOB (−33%)	M (60%), PCT (41%), MBQ (40%) / MOL (−52%), MAS (−44%)
Fourth factor (8%)	MYCH (60%) / ALC (−18%)	CHA (22%) / TYR (−25%)
Northern Quebec (18 species and 11 variables with 11 values; total variance = 0.658)		
First factor (44%)	− / C (−36%)	HUD (78%), COB (46%) / PRE (−75%), PHA (−75%), BO (−67%), BRU (−54%), BER (−46%)
Second factor (23%)	CME (18%) / LI (−43%), BG (−15%)	MRO (57%) / ALO (−77%)
Third factor (10%)	SA (22%) / CME (−26%), BGEP (−23%)	RUI (38%) / M (−61%), ROU (−37%)
Fourth factor (8%)	LI (28%) / CBG (−33%)	PIP (35%)

[a]The values of the environmental variables are described in Appendices 3, 4, and 5.
[b]This is the percentage of variance of the factor explained by each of the environmental variables.
[c]This is the percentage of variance in the species distribution that is explained by the factor.
[d]"+" and "−" indicate whether the correlation with the factor is positive or negative.

Phyto-ecology of lacustrine bird habitats in Quebec

Marcel Darveau[a], Benoît Houde[b], and Jean-Luc DesGranges

CWS, Sainte-Foy, Quebec
G1V 4H5

1. Abstract

The work reported on here is part of a research program being conducted by Environment Canada's Canadian Wildlife Service on the potential impact of acid precipitation on lacustrine birds in Quebec. The purpose is to describe the lake habitats, and the potential effects of acidification on these habitats, in two biogeographical zones of Quebec — the temperate zone and the semi-arctic zone. The aquatic and riparian vegetation of 78 lakes in southern Quebec and 68 lakes in northern Quebec are briefly described and related to the regional characteristics of the environments in which they occur, the morphometry and water quality of the lakes, and features of the riparian soils.

At the southern lakes — which typically have 20% of their area covered by vegetation — nine associations of aquatic plants are described, in terms of their dominant species. At the northern lakes, the typical coverage is 10% and there are five associations. The associations in each zone are correlated with the five variables that best expressed the morphometry, physical-chemical characteristics, and biological productivity of the lakes. In the south, the associations are distributed along a gradient from neutral, shallow lakes to acidic, deep lakes and, to a degree, along gradients of water calcium level and shoreline "reticulation" (the latter being given by an index reflecting the indentation of the banks, the area subject to flooding, and the number and morphology of streams). In the north, except for the acidic lakes containing none of the five recognized associations, calcium levels and reticulation explain the distribution of the associations.

For riparian vegetation, 11 associations belonging to 6 morphological (physiognomic) units were identified at the southern lakes, and 11 associations corresponding to 10 morphological units at the northern lakes. In the south, the distribution of the associations followed a gradient ranging from highly acidic soils rich in organic matter to soils with the opposite characteristics. In the north, the roles of the various pedological variables are more difficult to determine; the nitrogen and organic matter contents of the soils proved to be the main pedological variables explaining the distribution of the associations. The effect of soil acidification is discussed in the context of sphagnum ecology and the accumulation of organic matter.

[a]Current address: Biology Department, Université Laval, Cité universitaire, Sainte-Foy, Quebec G1K 7P4.
[b]Current address: 1178 des Muguets, Saint-Rédempteur, Quebec G0S 3B0.

2. Introduction

It is well known that acid deposits are very harmful to the environment; they decrease soil fertility, damage vegetation, and reduce populations of aquatic invertebrates, fish, and amphibians (Memorandum of Intent 1983). Compared with the number of studies on these topics, there are relatively few studies on the effects of acid precipitation on birds, because they are not affected directly, but indirectly, via contamination of their habitats with heavy metals and alteration of food chains. The Canadian Wildlife Service decided to examine the potential impact of acid precipitation on lacustrine birds in two regions of Quebec that are particularly rich in bird life: the temperate region and the semi-arctic region (as defined in Rousseau 1952). The results of this work are presented in three reports, one for each of three trophic levels: water quality, vegetation, and bird life. The present report concerns vegetation; the report by Rodrigue and DesGranges (1989) deals with water; and the report by DesGranges and Houde (this publication) covers bird life.

There are virtually no studies on lacustrine vegetation in Quebec, but the literature on vegetation along the St. Lawrence River, and in the peatlands of southern Quebec and the James Bay area, provides indirect information on lake plant associations (Couillard and Grondin 1986). A number of works have been published on the lake plants of Ontario (Crowder *et al.* 1977; Vitt and Bayley 1984) and of the northeastern United States (Hunter *et al.* 1985). The effects of acid deposits on lake plants have been studied by Ferguson *et al.* (1978), who demonstrated that the growth and chlorophyll content of sphagnums is affected, and by Cowling (1978), who found that lesions can occur on plant leaves when the pH of rain falls below 3.4. Acidification also affects plant successions: Hultberg and Grahn (1976) and Grahn (1977) found a negative correlation between pH and the spread of sphagnum associations. Hendry and Vertucci (in Haines 1981) note that sphagnums accelerate the acidification of the environments in which they occur, while Gorham *et al.* (1984) point out that acidification decreases the number of sphagnum species. Wile *et al.* (1985) studied the aquatic macrophytes in three Ontario lakes and found that the most acidic lake contained the fewest species but also the largest biomass. Hunter *et al.* (1985), in a study of the interactions among waterfowl, fish, invertebrates, and macrophytes in four Maine lakes, corroborated the results of Wile *et al.* (1985), except that one of their two alkaline lakes had practically no vegetation.

Because we have little information about the flora and the physical-chemical conditions of Quebec lakes before they were subjected to acid precipitation, it is impossible to determine the previous impact of such precipitation, or to predict with certainty what effect acid precipitation will have in the coming years. Nevertheless, since there are different levels of acidity in Quebec's lakes, we may assume that these levels correspond to stages of acidification and use them to describe probable plant successions.

To sum up, the study describes the riparian and aquatic vegetation at 146 lakes and attempts to relate the distribution and abundance of plants to the regional characteristics of the environments in which they grow, to the morphometry and water quality of the lakes, and to the features of the riparian soils, all with a view to determining the role of acidity in explaining the distribution of plants.

3. Study areas

3.1. Lake selection

In the temperate zone of southern Quebec, 68 lakes were selected in a quadrilateral lying between 69° and 77° West longitude and 46° and 47° North latitude (Fig. 1). This area contains lakes with various degrees of sensitivity to acidification (Shilts 1981), and the precipitation here has an average pH of 4.4 — 16 times the acidity of normal rain (pH 5.6) (Rubec 1981). In the semi-arctic zone of northern Quebec, the study area lies between 65° and 69° West longitude and 55° and 57° North latitude. The precipitation in this area is less acidic (pH about 5.3, twice as acidic as normal rain), but the area does contain acidic lakes and lakes that are sensitive to acidification in varying degrees (Dugas 1970; Potvin and Grimard 1983).

Topographical maps and aerial photographs were used to identify lakes meeting the following conditions: 1) no man-made structures, 2) developed riparian habitats, and 3) for consistency, an area of approximately 20 ha. The lakes were then classified by pH (see DesGranges and Houde, this publication, for details of the pH measurements) and by sensitivity to acidification (the capacity of the soils and bedrock in a lake's watershed to reduce the acidity caused by rain and snow) (Gilbert *et al.* 1985). The final selection of lakes was based on the logistical constraint of ensuring that they were within range of helicopter bases. Figure 1 shows the study areas that were eventually selected. The exact position of the lakes in these areas is described in the reports of Rodrigue and DesGranges (1989) for southern Quebec and Potvin and Grimard (1983) for northern Quebec.

3.2. Description of environments

3.2.1. Biological zones

The study lakes fall into two biological zones. In the south they are in the temperate zone, which is characterized by dense forests and a rich vegetation of herbs and shrubs. The forests range from deciduous to coniferous depending on latitude. In the north, the study lakes are in the semi-arctic zone, which is characterized by taiga-type parcels in sheltered areas and tundra-type parcels in exposed areas. The vegetation is not intermediate between taiga (parkland with scattered trees) and tundra (grassland), but rather a mosaic of the two, with each section of the patchwork retaining its distinctive characteristics (Rousseau 1952).

The southern zone has seven ecoregions (geographical regions each having a distinctive climate as expressed in its vegetation) and five ecological landscapes (areas having a distinctive physiography and geology) (Jurdant *et al.* 1977; Gilbert *et al.* 1985). For the purposes of the study, these divisions were reduced to three functional groups, which we call natural districts: 1) the Appalachians, a young mountain massif with few lakes or peatlands and mainly deciduous forests; 2) the Middle Laurentians, a part of the Canadian Shield that is rather hilly, with a fair number of lakes and peatlands and mixed forests; and 3) the Upper Laurentians, which are more rugged than the Middle Laurentians and have a harsher climate and mainly coniferous forests.

The northern zone has four ecoregions and four ecological landscapes. In view of the patchwork structure of the ecosystems in this study area, the four ecological landscapes are used as natural districts. These natural districts are not at the same level of ecological classification as those selected for southern Quebec, but we believe that in each zone we have selected the most functional groupings. The taiga, muskeg (peatland), and alpine tundra districts appear in a patchwork structure in the area immediately to the northeast of Schefferville, while the arctic tundra district appears more to the north, along the George River.

3.2.2. Climate

Table 1 gives an overview of the climate in the study areas, based on the climatic normals obtained from weather stations in each of the natural districts. In the south, the climate is of the Koeppen wet cool-temperate type (Trewartha 1968). The mean annual temperature in the Upper Laurentians is nearly 4°C lower than in the other southern districts, and there is 40% more precipitation. As a result of the temperature difference, there are also differences in the number of growing degree-days and the portion of precipitation that falls as snow. The pH of the precipitation varies from 4.33 in the Appalachians to 4.41 in the Upper Laurentians.

In the north, the climate is of the Koeppen tundra type, with permafrost. The arctic tundra district, which is farther north than the others, has slightly lower temperatures, but far fewer growing degree-days and much less total annual precipitation. The average pH of precipitation was 4.85 in 1982–83 in the Schefferville area (Table 1), as compared with 5.3 in the late 1970s (Environment Canada 1979, in Rubec 1981).

3.2.3. Physiography

The lakes sampled in southern Quebec belong to two major physiographical regions separated by the St. Lawrence River: the Appalachians and the Laurentians (Fig. 1 and Table 1). The former are rather hilly within the study area and contain few lakes and almost no peatlands, while the latter are primarily undulating highland plateaus with more lakes and peatlands than the Appalachians (Couillard and Grondin 1986). The Upper Laurentian ecological region differs from the Middle Laurentians in having very few wetlands. The whole of the southern study area is covered with till, carbonated in the Appalachians but not in the Laurentians, which are therefore more sensitive to acidification (Shilts 1981).

The northern Quebec study area belongs to the Davis physiographical region. In general, the relief is not very pronounced — rolling or undulating near Schefferville, while farther north there are major rivers that divide the land into valleys and highland plateaus (Couillard and

Figure 1
Areas covered by the study

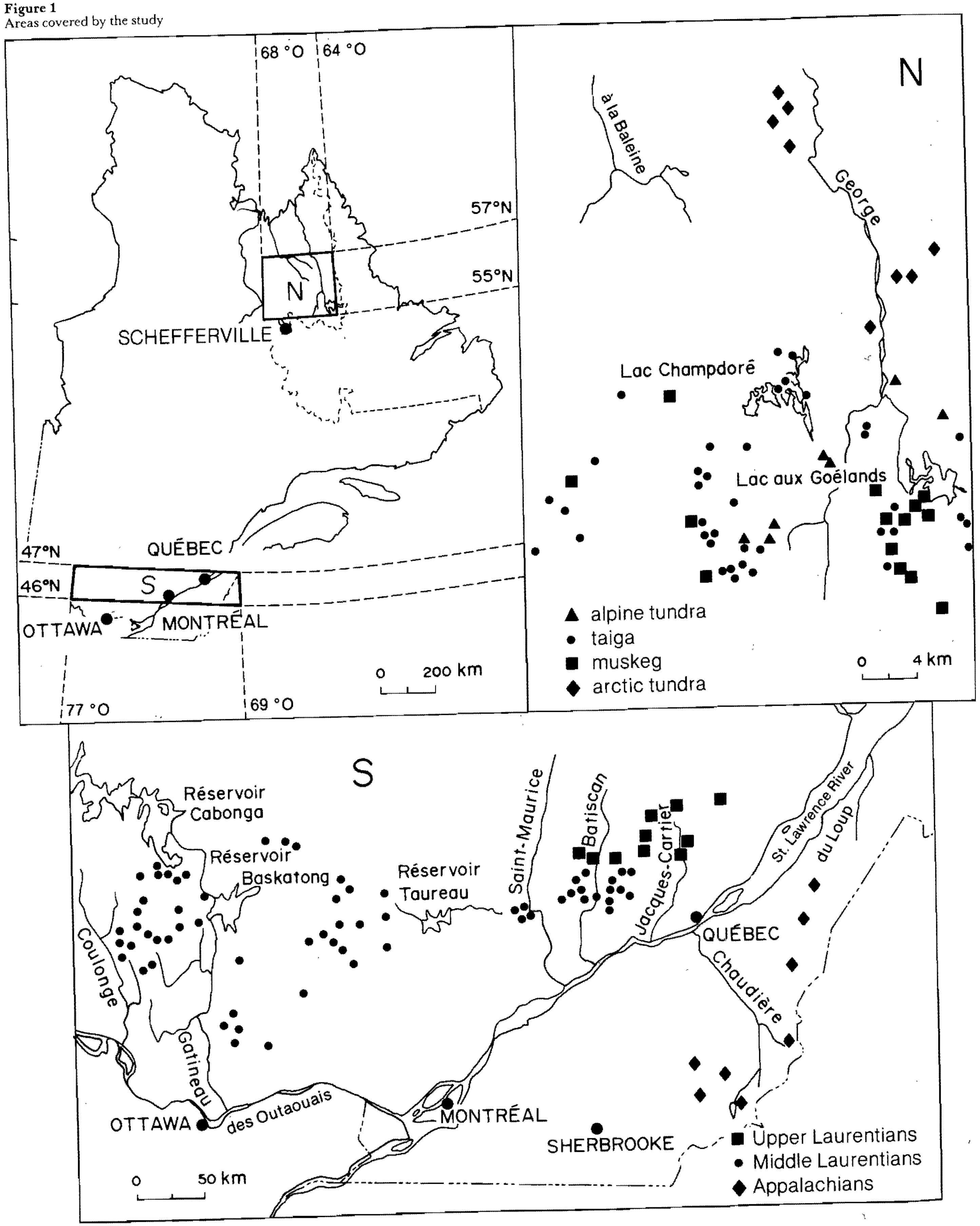


Table 1
Physical characteristics of natural districts

Variable	Appalachians[a]	Middle Laurentians	Upper Laurentians	Taiga	Muskeg	Alpine tundra	Arctic tundra
Mean ann. temp. (°C)[b]	3.8	3.5	−0.4	−4.8	−4.8	−4.8	−5.4
Total precipitation (mm)[b]	916	1050	1433	769	769	769	594
Fraction of precipitation falling as snow (%)[b]	25	26	37	50	50	50	41
Mean pH of precipitation[c]	4.33	4.40	4.41	4.85	4.85	4.85	—
Growing degree-days (> 5°C)[b]	1579	1626	939	614	614	614	524
Physiographic region[d]	Appalachians	Laurentians	Laurentians	Davis	Davis	Davis	Davis
Water area (%)[e]	3	10	3	9	9	9	9
Relief[f]	Mountainous	Undulating highlands	Undulating highlands	Rolling	Flat	Highland plateaus	Valleys and plateaus
Soil[f]	Brunisols and podzols	Brunisols and podzols	Podzols	Cryosols	Cryosols	Cryosols	Cryosols

[a]See description of natural districts in Section 3.2.1.
[b]Meteorological stations: St-Théophile (Appalachians); Mont-Laurier (Middle Laurentians); Jacques-Cartier Lake (Upper Laurentians); Schefferville (taiga, muskeg, and alpine tundra); Indian House Lake (arctic tundra) (Environment Canada 1982).
[c]Means (1982–83) from Grimard (1984). No data for arctic tundra.
[d]According to Bostock (1967) in Fremlin (1974).
[e]According to Fremlin (1974).
[f]According to Rowe (1972).

Grondin 1986). The western portion of the study area lies in the Labrador Trough, with its topography of north-south folds.

3.2.4. Soils

The soils on the fertile and well-drained slopes of the Appalachians and Middle Laurentians belong to the Dystric Brunisol and Humo-Ferric Podzol great groups, while the Upper Laurentian soils are Ferro-Humic and Humo-Ferric Podzols. The rocky ridges support Regosols, while the low-lying areas have organic soils (Rowe 1972).

The northern soils, which are characterized nearly everywhere by permafrost, belong to the Cryosolic order. They are unstable and poorly drained soils because of the continuous ice barrier less than 1 m below the surface.

3.2.5. Vegetation

The forest vegetation around the southern lakes is described by Rowe (1972). The Appalachians district is in the Eastern Townships forest region, where the fertile slopes are dominated by sugar maple *Acer saccharum* and yellow birch *Betula alleghaniensis*. Low-lying areas and lake environs are dominated by eastern white cedar *Thuya occidentalis* and tamarack *Larix laricina*. The Middle Laurentians, which fall within the Laurentian and Algonquin-Pontiac forest regions, are also dominated by sugar maple and yellow birch, but the low-lying areas are populated primarily by black spruce *Picea mariana*. The Upper Laurentians, located within the Laurentian-Onatchiway region, are much more boreal in character: balsam fir *Abies balsamea* and white spruce *Picea glauca* dominate the hillsides, while black spruce populates the low areas (Rowe 1972).

Peatlands cover less than 1% of the area of the Appalachians district; they take the form of small uniform bogs with ericaceae, sphagnums, and black spruce. In the Laurentian districts, uniform bogs, or sometimes fens, occupy some 5% of the area (Couillard and Grondin 1986). There are very few descriptions of riparian systems, which differ from peatlands in that they are periodically flooded when water levels rise. Their vegetation is often different from peatland vegetation, especially when it is growing on Gleysols or Regosols.

Northern Quebec vegetation is a patchwork of subarctic taiga and arctic tundra. The taiga areas are open forests with stunted black spruce over beds of lichens or sphagnums, depending on whether the soil is dry or wet. The tundra areas are grasslands with no trees or coniferous shrubs. They are found at dry, elevated sites and consist essentially of a lichen carpet combined with a few mosses, shrubs, and phanerogams (Rousseau 1952). The peatlands in the northern study area fall into two regions, according to Couillard and Grondin (1986). The New Quebec Plateau and George River region east of the Baleine River has few — primarily palsa — peatlands, covering less than 5% of the area, though there is a concentration of fens with pools around Lac aux Goélands. The Labrador Hills region west of the Baleine River has 6–10% peatlands, primarily fens with various physiognomies (Couillard and Grondin 1986).

3.2.6. Water quality

The water quality of the southern study lakes has been studied by Rodrigue and DesGranges (1989), and that of the northern lakes by Potvin and Grimard (1983) (see Fig. 2, DesGranges and Houde, this publication). At the southern lakes, water acidity and sensitivity to acid precipitation increase from east to west. Lakes with a pH below 5.5 are found in the Middle Laurentians; in the other districts, the pH ranges from 5.6 to 6.5. The oligotrophic and oligo-mesotrophic lakes, i.e., the less productive lakes, are located northwest of Quebec City. The meso-eutrophic, or more productive lakes, are found in the Appalachians. Most of the lakes are moderately dystrophic.

In northern Quebec, acidic lakes (n = 7, pH 3.2–4.5) and alkaline lakes (n = 8, pH 7.8–8.7) are found only in the taiga district. Neutral lakes (n = 54) are found in all four districts. The neutral lakes of the tundra district are the least productive, while those in the muskeg and taiga districts are the most productive. The acidic lakes and the alkaline lakes are very productive.

4. Methods

In what follows, the terms *aquatic* and *limnophytic* are used indiscriminately to refer to vegetation that is permanently covered with water; "permanently" means covered for more than 50% of the growing season, a figure proposed by Gauthier (1979, in Couillard and Grondin 1986). The terms *riparian* and *helophytic* refer to vegetation that is temporarily covered. The nomenclature used for vascular plants is that of Marie-Victorin (1964), while the nomenclature of Crum *et al.* (1973) is used for bryophytes.

4.1. General description of lakes

Much information was obtained from documents: lake elevations were found on 1:50 000 topographical maps; area, shoreline development (in the sense of Joyner 1980), and "reticulation" (Table 2) were calculated from 1:15 000 aerial photographs. The sublittoral slope, defined as the average slope of the zone extending from the low water line to the line where the water is 6 m deep, was estimated using the ordinal scale of Jurdant *et al.* (1977). Maximum lake depth was measured by Rodrigue and DesGranges (1989) and Potvin and Grimard (1983).

4.2. Water quality

Rodrigue and DesGranges (1989) and Potvin and Grimard (1983) provide a complete description of the lake water quality studies carried out in co-operation with the Quebec environment ministry. Their results are used here to relate water quality to vegetation.

4.3. Aquatic vegetation

Samples were taken from 26 May to 22 June 1980 and from 26 May to 28 June 1982 at the southern lakes, and from 18 June to 12 July 1981 at the northern lakes. This was a little early in the season, considering the phenology of aquatic plants, but logistical constraints forced us to carry out the plant inventories concurrently with the bird inventories.

The plant inventories for each lake were carried out as follows. Areas of at least 50 m^2 covered with plants were located by flying over the lake in a helicopter. A boat was then used to take samples by the Braun-Blanquet (1932) method, moving along transects perpendicular to the shore. Zones where no areas covered with water plants had been observed in the first instance were then traversed, and the lake bottom was examined with an aquascope. A telemeter was used to map the vegetative cover. Only dominant species, accounting for at least 5% of any given area of vegetation, were considered. Most areas were found to have only a single species or else two species. In all, 224 areas were sampled at the southern lakes and 103 at the northern lakes.

Also calculated were percent coverage for five functional groups of species, in order to correlate these with the birds present. The groupings were helophytes as a whole, limnophytes as a whole, emergent limnophytes, submersed limnophytes, and floating-leaved limnophytes.

4.4. Riparian vegetation

Two sampling methods were used, corresponding to two types of bird survey. In 1980, observers used rowboats to move about the lakes and count all individuals on the riparian belt. The corresponding vegetation study consisted of an ecological mapping of the belt. First, morphologically defined vegetation units were marked off on a large-scale aerial photograph, using a classification based on Grondin and Ouzilleau (1980). Then physiognomic and floral profiles of a 16-m^2 sample area in the centre of each unit were prepared in the field. For the physiognomic profile, it was simply a matter of identifying the morphological unit and noting the abundance of dead tree stumps, which in southern Quebec remain standing in riparian areas and are used by birds for perching and nesting. The floral profile was developed by listing taxons having at least 5% coverage and assigning to them Braun-Blanquet (1932) abundance-dominance ratings. Floral data were assembled on a phytosociological table, which served for the identification of associations by the Braun-Blanquet

Table 2
Definition of reticulation index[a]

Variable	State	Points
1. Shoreline configuration	a. rectilinear	1
	b. jagged	2
	c. indented, floating islands present	3
2. Potential flood areas	a. few	1
	b. many	2
3. Streams	a. few, rectilinear, narrow	1
	b. few, winding, little branching	2
	c. many (≥ 3), winding, much branching	3

[a]Reticulation index (I) = sum of points ÷ 3, with I rounded off to the nearest whole number. Values of I are described qualitatively as follows: 1 = low, 2 = average, and 3 = high.

method. Over 30 associations were obtained in each study area. In view of this large number, and the rarity of some of them, a new set of associations was established on the basis of bird communities, giving a final count of about a dozen.

In 1981 and 1982, the bird survey method was modified to increase the number of lakes visited. Three circular areas with a 100-m radius were surveyed on the riparian belt of each lake. The vegetation study was then limited to the morphological units in these areas. Those portions of the bird survey areas that extended into the forest beyond the riparian belt were not mapped.

4.5. Riparian soils

In each plant sampling area, a soil sample was taken from the rhizosphere at a depth of 20–40 cm. The minimum thickness of organic matter was measured to a depth of 1 m. The soil samples were frozen for shipping to the laboratory, where they were dried by exposure to the ambient air and then put through a mixer.

The pH was measured in a mixture of one part soil to two parts water. The percentage of organic carbon was calculated from the percentage of organic matter, measured by controlled combustion. The total nitrogen content was measured using the macro-Kjeldahl method. Exchangeable cations (Ca^{2+}, K^+, and Mg^{2+}), extracted by elution with ammonium sulphate, were measured with an absorption spectrometer.

4.6. Data analysis

Three data matrices were set up for the northern lakes and three for the southern lakes, covering lake biophysics, aquatic vegetation, and riparian vegetation. The biophysical matrices for the 78 southern and 68 northern lakes contain 26 variables, 6 of which are ecological-geographical, 5 morphometric, 10 physical-chemical, 4 biological (related to water quality), and 1 pedological (Appendices 1 and 2). The aquatic vegetation matrices for the southern and northern lakes contain 63 and 43 taxons respectively. The matrices for the 1025 riparian vegetation sites in the south and the 932 sites in the north contain 14 variables, including the trophic type and the morphological unit (in the sense of Grondin and Ouzilleau 1980), the taxonomic association, the area of the site, presence/absence of streams, and nine soil descriptors (Appendices 3 and 4).

Because there was such a variety and such a large number of descriptors, the data needed to be condensed. The first step was to reduce all the descriptors to a common type. Thus, if an analysis was to simultaneously include qualitative variables (e.g., presence of a species), semi-quantitative ordered variables (e.g., Braun-Blanquet abundance classes), and quantitative variables (e.g., elevation), classes were set up for the variables of each kind. The classification was based on the sample structure, the distribution of the variables, and our knowledge of natural biological thresholds.

The second step was to correlate the variables within each set, in order to determine how informative each was and to identify any redundancies. This was done using correspondence analysis (CORANA), an ordination method initially developed to analyze contingency tables (i.e., class variables) (Benzécri 1973; Hill 1974). CORANA makes it possible to simultaneously represent proximities between species and environmental variables. It is extremely well suited to a biological context, in which variables are not always linear (Austin 1976; Fasham 1977; Gauch *et al.* 1977). CORANA led to the elimination of poorly distributed variables, together with a number of variables that were correlated to other more informative ones. In general, the variables that remained were the same for the south and the north. Appendices 1 to 4 give the initial matrices used for the analyses, but it should be noted that the analyses were based on the raw data (numbers of lakes with given features), whereas the appendices display the data in terms of percentages of lakes.

Aquatic plant associations were analyzed by complete-linkage hierarchical clustering. The Jaccard similarity coefficient (1900, in Legendre and Legendre 1979) was applied to the logarithms of the coverage percentages for species or taxons present in at least five lakes. Species that occurred in less than five lakes were eliminated.

5. Results

5.1. General lake characteristics

The southern lakes vary widely in elevation, from 213 to 914 m (median (Me) = 360 m, see Fig. 3). The Appalachian and Upper Laurentian lakes generally have a higher elevation than those in the Middle Laurentians. The median area for all the lakes is 14 ha, but the Appalachian and Upper Laurentian lakes are generally larger than those in the Middle Laurentians (Me = 23 and 17 ha as opposed to 12 ha). The depth and the shoreline development index are consistently lower in the Appalachians than in the Laurentians. The shorelines at the southern lakes have "average" reticulation, but in the Appalachians, half of them are highly reticulated. The sublittoral slope values are the same in each of the three districts: half the lakes have a gentle slope and the other half a moderate slope. The pH in the southern lakes varies from 4.4 to 8.5, with a median of 6.2. The pH in the Appalachian lakes is generally higher than in the Laurentian lakes: 75% of the former have a pH higher than 6.4, but only 25% of the latter do.

The elevation of the northern lakes varies from 351 to 580 m (Me = 480). The arctic tundra lakes are lower than the lakes in the other three districts, with a median elevation of 381 m and a 3rd quartile elevation of 464 m. The lake areas vary from 3 to 76 ha, but 50% have areas between 15 and 35 ha, the distribution being approximately the same in all four districts. The lakes are generally shallow, with 75% of them no more than 2 m deep; the exceptions are in the taiga and arctic tundra districts. The shoreline development index varies from 1.05 to 2.94 (Me = 1.28), and the medians for the four districts are similar (1.27–1.32). The reticulation index is less constant: high for muskeg lakes, moderate for taiga and arctic tundra lakes, and low for alpine tundra lakes. The sublittoral slope is either gentle (50% of the lakes) or moderate. The pH varies from 3.0 to 8.6 (Me = 6.4) in the taiga lakes, but lies between 6.1 and 7.4 in the other districts.

5.2. Aquatic vegetation

Because the distribution of aquatic vegetation is the result of a number of interrelated factors, it is relatively difficult to measure the impact of acidity on the basis of field observations. The procedure in the present study was to identify four sets of variables governing the distribution of aquatic vegetation associations: ecological-geographical, morphometric, physical-chemical, and biological (related to lake productivity) (see Appendices 1 and 2). Four correspondence analyses were then carried out in order to find the variables of greatest explanatory value in each set, followed by a "consolidated" CORANA to relate these variables jointly to acidity. The following sections first describe the aquatic vegetation associations in the two study zones, then present the results of the CORANA relating them to the ecological-geographical variables, and finally give the results of the consolidated CORANA. The results of the correspondence analyses correlating plant associations with the morphometric, physical-chemical, and biological variables are not given in this paper because the most informative variables in each of these sets are included in the consolidated CORANA.

5.2.1. Composition of associations

Nine associations were identified for the south and five for the north, on the basis of the similarity thresholds closest to the visual separation of the associations on dendrograms (Laven 1982; Darveau and Bellefleur 1984). Two of the southern lakes and 20 of the northern lakes appeared to be devoid of vegetation.

The most frequently found association in the south is dominated by *Nuphar variegatum* and *Sparganium eurycarpum*. This association was present at 43 of the 78 lakes and accounted for 19% of the water-plant coverage; it generally appears in scattered form and often includes expanses of *Nuphar rubrodiscum*, *Potamogeton* sp., and *Sparganium* sp. *Typha latifolia* sometimes occurs at the edge of the riparian zone. The second largest association (36 lakes, 16% coverage) is a patchwork of *Eleocharis smallii* and *Brasenia schreberi*. The main accompanying species are *Sparganium americanum, Nuphar microphyllum, Potamogeton natans*, and *Dulichium arundinaceum*. The third association (31 lakes, 14% coverage) is dominated by *Eriocaulon septangulare*, accompanied by *Utricularia vulgaris, Isoetes braunii*, and *Sparganium* sp. (which carpets the shallows), and by scatterings of large-leafed, floating macrophytes of the genera *Brasenia, Nuphar*, and *Nymphaea*. The fourth association (26 lakes, 12% coverage) is *Dulichium arundinaceum* and algae, accompanied here and there by *Sparganium* sp. and *Carex* sp. at the edge of the helophytic zone.

Four other *Sparganium* associations are less frequent: *Sparganium eurycarpum* and *Potamogeton epihydrus* (17 lakes, 8% coverage), *Sparganium fluctuans* and *Potamogeton oakesianus* (12 lakes, 5% coverage), *Sparganium angustifolium* and *Eleocharis uniglumis* (15 lakes, 7% coverage), and *Sagittaria latifolia* occasionally accompanied by *Sparganium* sp. (7 lakes, 3% coverage). The ninth and final association in the south consists of pure, very dense populations of *Utricularia vulgaris* (19 lakes, 8% coverage).

The five northern associations occur as nearly pure populations and are found at only a small number of lakes. The first two are associations of mosses: *Drepanocladus exannulatus* accompanied by *Cladopodiella fluitans* (4 lakes), and *Scorpidium scorpioides* (7 lakes). The other three are associations of vascular plants: *Hippuris vulgaris* (3 lakes), *Menyanthes trifoliata* (5 lakes), and *Potamogeton filiformis* Pers. (4 lakes). Other species were found only once, each forming a significant population at a particular lake and not relatable to the five associations. These were *Potamogeton alpinus* (30% coverage), *Sphagnum lindbergii* (39% coverage), and an alga of the genus *Nitella* (36% coverage).

In addition to the taxonomic associations, functional groupings of aquatic plants were established, based on physiognomy and accessibility to waterfowl, and the percent coverage with submersed, floating-leaved, and emergent plants was measured. The typical southern lake may be described as follows: lake bottom 20% covered in vegetation, 42% of which is submersed, 27% floating-leaved, and 31% emergent. The typical northern lake has only half as much aquatic vegetation (i.e., 10% coverage). The percentages for the three functional groupings were not determined for the northern lakes.

5.2.2. Correlation of associations with regional features

The nine southern Quebec taxonomic associations were correlated via correspondence analysis with nine variables describing the ecoregion, the elevation, and the sensitivity of bedrock to acidification. The first three axes explain 97% of the variance — a very good fit between the variables and the vegetation associations (Appendix 5).

The first axis (explaining 60% of the variance) represents primarily high elevation and the Upper Laurentians and Appalachian ecoregions (positively correlated), as well as the average elevation of the Outaouais ecoregion (negatively correlated). The second axis (31% of variance) separates the Appalachian ecoregion from the Upper Laurentians. Sensitivity to acidification explains nothing. Associations of *Sparganium fluctuans–Potamogeton oakesianus* and *Sparganium angustifolium–Eleocharis uniglumis*, correlated positively with the first axis, are connected with high elevation and the Upper Laurentian and Appalachian ecoregions. Associations of *Eleocharis smallii–Brasenia schreberi*, *Dulichium arundinaceum*–algae, and *Eriocaulon septangulare*, correlated negatively with the first axis, are connected with the Outaouais ecoregion. The *Sparganium eurycarpum–Potamogeton epihydrus* association, correlated positively with the second axis, is common in the Appalachian ecoregion and absent in the Upper Laurentian ecoregion, while associations of *Utricularia vulgaris* and *Sagittaria latifolia*, correlated negatively, are common in the Upper Laurentians and absent in the Appalachians. The *Nuphar variegatum–Sparganium eurycarpum* association is ubiquist.

The five northern Quebec associations were correlated with regional variables describing the subzone and ecoregion, the elevation, and the sensitivity of the bedrock to acidification (Appendix 5). The first three axes explain 97% of the variance. The first axis (57% of variance) distinguishes the mountainous subzone (positively correlated) from the high and low subzones (correlated negatively). The George River ecoregion, associated with these two subzones, also contributes to the first axis. The second axis (29% of variance) represents primarily sensitivity to acidification, while the third (11% of variance) reflects elevation. Over 75% of the variance for three of the associations is explained by the first axis: *Menyanthes trifoliata* and *Hippuris vulgaris* associations, correlated positively, are found only in the mountainous subzone, while *Scorpidium scorpioides*, correlated negatively, is virtually absent. *Potamogeton filiformis* and *Drepanocladus exannulatus* associations tend to appear in zones that are highly sensitive to acidification.

5.2.3. Effect of acidity

The consolidated CORANA for southern Quebec compares the nine above-described associations with five variables: lake depth, shoreline reticulation, pH, calcium, and chlorophyll "a." The first three axes explain 88% of total variance (Appendix 5). The first axis (52% of variance) orders the associations along a gradient from very shallow, neutral lakes to deep, acidic lakes. The second axis (26% of variance) primarily reflects a calcium gradient, and the third axis distinguishes shallow, reticulated lakes from deep, unreticulated lakes. Of the nine associations, seven react strongly to the shallow/neutral versus deep/acidic factor: *Sagittaria*, *Eleocharis–Brasenia*, and *Sparganium–Eleocharis*, correlated positively, populate the least acidic and shallowest lakes, whereas *Utricularia*, *Sparganium eurycarpum–Potamogeton epihydrus*, *Dulichium*-algae, and *Eriocaulon* are associated with deeper, more acidic lakes (Appendix 5). Calcium content affects three of the associations: *Sparganium–Eleocharis* populates lakes whose calcium content is low, while *Sparganium fluctuans–Potamogeton oakesianus* and *Nuphar–Sparganium* react in the opposite fashion. The latter two associations are distinguished by the third factor (reticulation and depth).

In the CORANA for the aquatic associations of northern Quebec, all the variance is explained by the first three axes, but none of these reflects a significant contribution by acidity (Appendix 5). This is because none of the five associations selected for analysis (i.e., those present at five lakes or more) occurred at acidic lakes, so that the attribute state PH1 had to be removed from the analysis. The first two axes of the analysis (explaining 67% and 29% of variance) reflect calcium content and reticulation, while the third reflects chlorophyll "a." Associations of *Drepanocladus*, *Hippuris*, and *Menyanthes* are correlated with lakes whose calcium content is low and whose shoreline is reticulated, while associations of *Scorpidium* and *Potamogeton* are found on lakes with high calcium content and unreticulated shoreline.

5.3. Riparian vegetation

5.3.1. Composition of associations

Six morphological (physiognomic) riparian vegetation units were identified in southern Quebec (see Grondin and Ouzilleau 1980). They consist of 11 taxonomic associations. Table 3 provides a brief description of the associations and their morphological correlates. The relationship between these associations and the ones described in the literature is discussed in Section 6.

For the riparian vegetation in northern Quebec, 11 morphological units consisting of 11 taxonomic associations were identified. These are described in Table 4.

5.3.2. Correlation of associations with regional features

The 11 taxonomic associations from southern Quebec were related to the following variables: ecoregion, ecological landscape, elevation, and sensitivity of bedrock to acidification (Appendix 6). The first three axes of the CORANA explain 85% of the total variance. The first axis (43% of variance) reflects, along its positive portion, the Baskatong ecoregion and the coniferous forest ecological landscape and, along its negative portion, the deciduous forest landscape, the Outaouais ecoregion, and average sensitivity to acidification. The second axis (29% of variance) separates the Baskatong and the Outaouais from the high-elevation Appalachian and Upper Laurentian ecoregions. The third axis (13% of variance) distinguishes the Upper Laurentian ecoregion from the Appalachians.

Cattails are one of the rarest and least well-distributed associations, primarily found in Appalachian deciduous forests and, to a lesser extent, in the Middle Laurentians and the Outaouais. Sedge, leatherleaf with myrica, and myrica with leatherleaf are the most abundant and best distributed associations. Leatherleaf with myrica occurs at half the sites in the Appalachians. The first axis reflects a gradient from leatherleaf to myrica associations. Both types of association occur quite frequently, but are not found in the Appalachians; in the other four ecoregions, they appear to be correlated with ecological landscapes: leatherleaf is most common in coniferous environments, myrica in deciduous. Tamarack with leatherleaf and myrica is not found in the Upper Laurentians, but is common in the Appalachians. This is a common element of the landscapes described as "conifers ringing lake, deciduous forest behind." Alder with myrica is a rare association found primarily in Appalachian deciduous forests. Alder with sedge, black spruce with leatherleaf, and riparian white birch are found in the high-elevation areas of the Appalachians and Upper Laurentians.

Table 3
Taxonomic associations of riparian vegetation in southern Quebec

Taxonomic association	Occurrence (%, n = 1025)	Morphology and trophic conditions[a]	Dominant and subdominant species
Cattails	3	Patchy shrubs and cattails (M)	*Typha latifolia* *Carex* sp. *Myrica gale* *Alnus rugosa*
Sedges	25	Uniform herb meadow (M)	*Carex rostrata* *Carex stricta* *Carex* sp.
Myrica	6	Medium shrubs (M)	*Myrica gale* *Spiraea latifolia* Borkh. *Cornus stolonifera* *Carex* sp. *Sphagnum* sp.
Myrica with leatherleaf	13	Medium shrubs (M)	*Myrica gale* *Chamaedaphne calyculata* *Kalmia polifolia* *Carex* sp. *Sphagnum* sp.
Leatherleaf with myrica	15	Medium shrubs (O)	*Chamaedaphne calyculata* *Myrica gale* *Kalmia polifolia* *Carex* sp. *Sphagnum* sp.
Leatherleaf	10	Medium shrubs (O)	*Chamaedaphne calyculata* *Sphagnum* sp. *Kalmia polifolia* *Andromeda glaucophylla* *Carex* sp.
Tamarack with leatherleaf and myrica	9	Patchy shrubs and conifers (M)	*Larix laricina* *Chamaedaphne calyculata* *Myrica gale* *Kalmia polifolia* *Carex* sp. *Sphagnum* sp.
Black spruce with leatherleaf	2	Patchy shrubs and conifers (M)	*Chamaedaphne calyculata* *Picea mariana* *Sphagnum* sp. *Kalmia polifolia* *Andromeda glaucophylla* *Ledum groenlandicum* *Carex* sp.
Riparian white birch	3	High shrubs (M)	*Betula papyrifera* *Chamaedaphne calyculata* *Myrica gale* *Carex* sp. *Sphagnum* sp. *Kalmia polifolia*
Alder with myrica	4	High shrubs (M)	*Alnus rugosa* *Myrica gale* *Carex* sp. *Spiraea latifolia* *Sphagnum* sp.
Alder with sedge	10	High shrubs (M)	*Alnus rugosa* *Carex* sp. *Calamagrostis canadensis* *Thalictrum pubescens*

[a]Trophic conditions: M = minerotrophic, O = ombrotrophic.

Table 4
Taxonomic associations of riparian vegetation in northern Quebec

Taxonomic association	Occurrence (%, n = 932)	Morphology and trophic conditions[a]	Dominant and subdominant species
Lichens	2	Lichen meadows (M)	Lichens *Betula glandulosa* *Larix laricina* *Salix sp.*
Sedge	23	Herb meadows with or without pools (HO)	*Carex* sp. *Betula pumila* *Salix* sp. *Myrica gale*
Sedge with scrub birch	8	Herb meadows with or without pools (HO)	*Carex* sp. *Betula glandulosa* *Vaccinium uliginosum*
Sedge with tamarack	24	Herb meadows with or without pools, or patchy herbs and conifers (HO)	*Carex* sp. *Larix laricina* *Picea mariana* *Betula pumila* *Sphagnum* sp.
Sedge with black spruce	14	Herb meadows with or without pools, or patchy herbs and conifers (LO)	*Carex* sp. *Picea mariana* *Larix laricina* *Sphagnum* sp.
Black spruce with sphagnum	7	Spruce and tamarack (HO, LO)	*Picea mariana* *Sphagnum* sp. *Larix laricina*
Tamarack with black spruce	3	Spruce and tamarack (HO)	*Larix laricina* *Picea mariana* *Sphagnum* sp.
Tamarack with scrub birch	10	Spruce and tamarack, or patchy shrubs (HO)	*Larix laricina* *Betula glandulosa* *Sphagnum* sp.
Scrub birch with spruce	3	Patchy shrubs and spruce (M)	*Betula glandulosa* *Picea glauca* *Picea mariana*
Scrub birch	2	Low shrubs (M)	*Betula glandulosa*
Willow	4	Low or high shrubs (HO)	*Salix* sp. *Betula glandulosa* *Betula pumila* *Carex* sp.

[a]Trophic conditions: M = mineral, HO = high organic, LO = low organic.

The CORANA relating taxonomic associations and regional variables in northern Quebec explains 95% of the total variance (Appendix 6). The first axis (72% of variance) essentially reflects the features of tundra ecological landscapes. The second axis (18% of variance) reflects alpine tundra and muskeg landscapes, elevation, and sensitivity to acidification. The third axis explains only 5% of variance. Thus, the analysis divides the associations into three categories: exclusively tundra associations, exclusively taiga and muskeg associations, and other associations found everywhere. Lichens and scrub birch are typical of tundra, while willow, tamarack with black spruce and sphagnums, and tamarack with scrub birch are typical of muskeg and taiga. Pure sedge is ubiquist, but of the three mixed sedge associations, sedge with scrub birch shows a preference for tundra, while sedge with tamarack or with black spruce is characteristic of the taiga and muskeg.

5.3.3. Relationship of vegetation to soils

The general characteristics of riparian soils are given by natural district in Figure 4 of DesGranges and Houde (this publication). The southern districts have soils that are relatively alike in terms of total nitrogen, pH and exchangeable cations. The percentage of organic matter appears to be more variable in the Upper Laurentians, with a quartile deviation of 68%, as compared with 25% and 34% in the other districts. The northern districts also have fairly similar soils, except that nitrogen and organic matter are variable in the tundra district but high in the taiga and muskeg. Magnesium and calcium are relatively low in arctic tundra soils.

The CORANA correlating southern Quebec associations with pedological variables explains 94% of the total variance (Appendix 6). The first axis (77% of variance) clearly reflects a gradient from highly acidic soils with a high organic content to soils with the opposite characteristics. The second axis (11% of variance) separates soils by calcium and magnesium content. The third axis (6% of variance) separates soils by nitrogen content. Four associations populate acidic and organically rich riparian soils: leatherleaf with myrica, pure leatherleaf, tamarack with leatherleaf and myrica, and black spruce with leatherleaf. Two associations are ubiquist: pure myrica and myrica with leatherleaf, with the latter preferring soils rich in calcium and magnesium. Sedge, and alder with sedge, are associated with neutral soils having lower organic content. Our analysis failed to elucidate the distribution of the cattails, a rare association which may prefer acidic soils with a high nitrogen, calcium, and magnesium content.

The CORANA for the associations and soils of northern Quebec (Appendix 6) explains 94% of the total variance, but the plant-soil relationships are less evident than in the south. The first axis (66% of variance) reflects a gradient from soils of low nitrogen, calcium, and organic content to soils with a high nitrogen content. The second

axis (20% of variance) primarily reflects the organic content of soils and, to a degree, a very low pH. The third axis (8% of variance) reflects a magnesium gradient. Five associations are typical of soils with low nitrogen, organic matter, and calcium: scrub birch, lichens, scrub birch with spruce, tamarack with black spruce and sphagnums, and sedge with scrub birch. Three associations are found in soils rich in nitrogen and organic matter: willow, pure sedge, and sedge with tamarack. The pH at sites with these last three associations tends to be low, whereas at sites with the first five it is not so low (note that pH does not contribute much to the principal factors). Tamarack with scrub birch appears to be relatively unrelated to the variables that were measured. Soils that support black spruce with sphagnum, and sedge with black spruce, are mainly characterized by a high organic matter content.

6. Discussion

The type of lake considered in this study — remote, average area of about 20 ha, with developed riparian vegetation — is much sought after by waterfowl during the nesting season. Because the study aimed to describe the effects of acidification, lakes with differing pH levels had to be sampled, and so it was necessary to have study areas in regions differing significantly in climate, physiography, and geology. This may be considered either an advantage or a disadvantage depending on whether the intent is to identify the principal factors governing vegetation distribution or to identify the effects of acidification.

6.1. Aquatic vegetation

Nine aquatic vegetation associations were identified at southern Quebec lakes and five at northern lakes. Though not based on exhaustive surveys, they may nevertheless be compared with or related to other associations described in the literature. Two in the south correspond reasonably well with associations described by Vincent and Bergeron (1983) at Lac des Deux-Montagnes. These authors describe an association dominated by *Sagittaria latifolia* accompanied primarily by *Sparganium eurycarpum*, which corresponds very closely with one of our own associations; they also describe an association of *Nuphar variegatum* accompanied primarily by *Elodea canadensis*, *Potamogeton richardsonii*, and *Vallisneria americana*. The absence of *Elodea* and *Vallisneria* from the corresponding association in the present study may be explained by the fact that these are species more usually associated with the St. Lawrence River and its immediate tributaries.

Three associations display species correspondences with the results of Hunter *et al.* (1985) concerning the macrophyte biomass in four Maine lakes: one of their lakes combined the dominant species of our *Sparganium angustifolium–Eleocharis uniglumis*, *Utricularia vulgaris*, and *Eriocaulon septangulare* associations. This last species also dominated three Ontario lakes studied by Wile *et al.* (1985). The dominant species in two of our associations — *Eleocharis smallii*, *Brasenia schreberi*, *Sparganium eurycarpum*, and *Potamogeton epihydrus* — were found in separate associations by Vincent and Bergeron (1983), Wile *et al.* (1985), and Crowder *et al.* (1977). The dominant species in the *Sparganium fluctuans–Potamogeton oakesianus* association are not mentioned in any of the above studies; this is surprising in the case of *Sparganium fluctuans*, which is widely distributed, according to Marie-Victorin (1964). One last point worth noting is that the *Dulichium arundinaceum* and algae association is linked more closely to basin mires than to lakes, according to Vitt and Bayley (1984).

The northern associations, *Drepanocladus exannulatus* and *Cladopodiella fluitans*, are found at a lake near Sudbury, Ontario (Wile *et al.* 1985) and on the fringes of peatlands in the James Bay area (Grondin and Ouzilleau 1980). The latter also describe an association of *Menyanthes trifoliata* accompanied, among other species, by *Scorpidium scorpioides* in the pools of minerotrophic peatlands. *Hippuris vulgaris* and *Potamogeton filiformis*, two associations that appear at the northern lakes and are found throughout Quebec (Marie-Victorin 1964), were not identified in the above-mentioned studies.

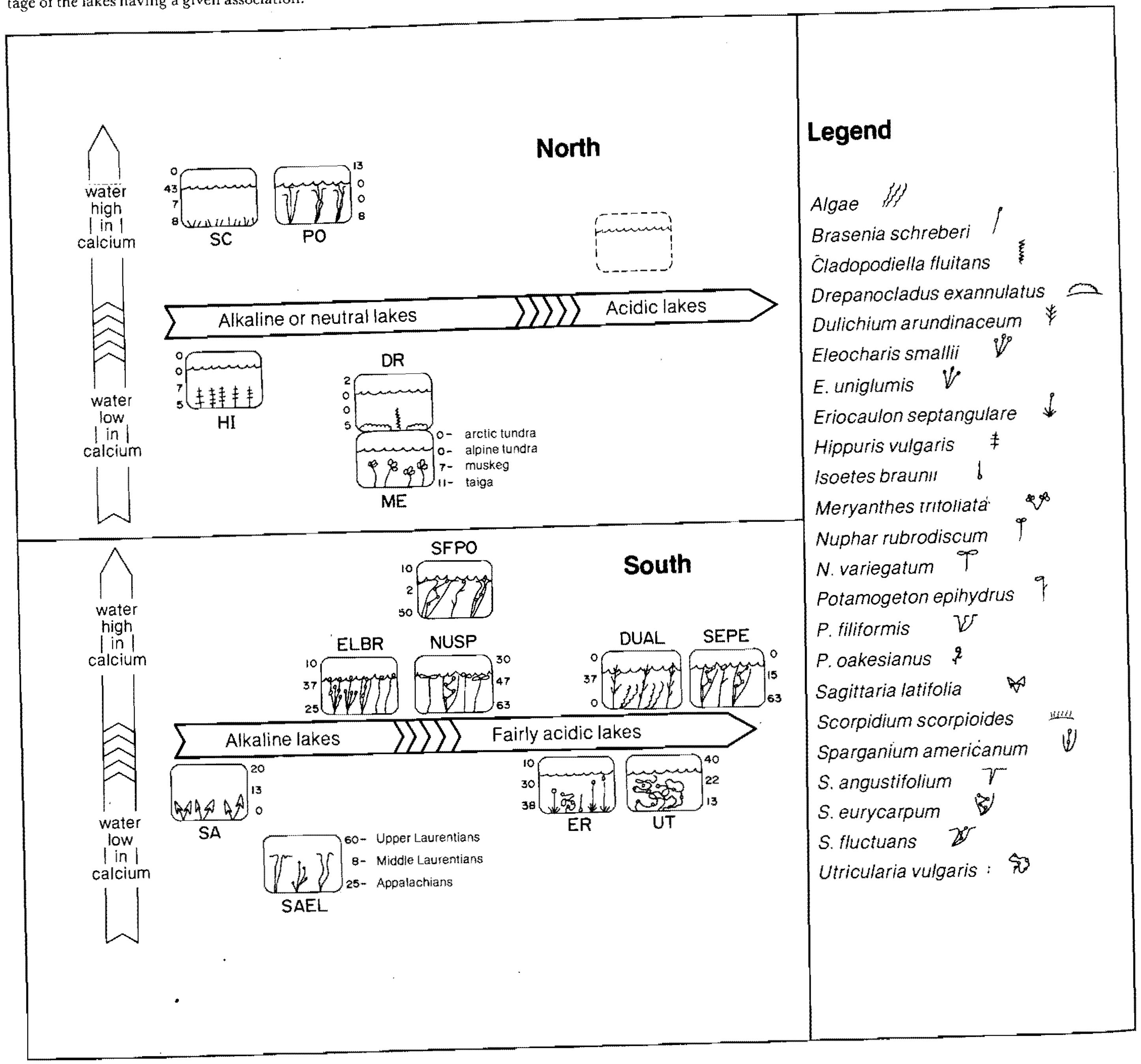
The work on correlations of vegetation with regional characteristics (*cf.* Sections 5.2.2. and 5.3.2.) is a first approximation for temperate and semi-arctic lacustrine environments in Quebec. It is noteworthy that none of the dominant species was found in both southern and northern Quebec, which suggests that there are special features in the environments preferred by each species. In the present study, the aim was to identify which of a series of regional (climatic, physiographic, and geological), morphometric, physical-chemical, and productivity-related variables provide the best explanation for aquatic plant distribution. In analyzing the results, it is important to remember that several significant variables could not be taken into consideration, notably fluctuations in the water level, the nature of the substrate, and the site exposure (Vincent and Bergeron 1983; Couillard and Grondin 1986). The results of the analyses identified water pH as the variable that was most highly correlated with the distribution of aquatic plant associations in the two study areas, followed by calcium content and lake depth. Given that in the case at hand pH is the best indicator of the set of physical-chemical properties and calcium best reflects the set of biological productivity features, we may conclude that among the variables measured for this study, those related to physical-chemical properties and biological productivity are the ones that best explain the distribution of aquatic vegetation. Lake depth, which reflects the set of morphometric variables, has explanatory force in the southern study area. Figure 2, which locates the associations of aquatic plants along a schematic acidity gradient, brings out the effect of calcium content (i.e., of lake biological productivity). Clearly this gradient does not explain any plant succession, but it does bring out the fact that some associations are adapted to acidic environments while others are adapted to alkaline environments.

If lake acidification continues, we may expect plant associations that do not tolerate acidity well to be replaced by others that are more tolerant. This would mean a decrease in the species richness and macrophyte biomass of the lakes. Wile *et al.* (1985) measured such decreases in Ontario lakes. The acidification of the study lakes could also lead to an invasion by sphagnums, as has happened in some Swedish lakes (Grahn 1977). In either event, there would be a major impact on bird life (DesGranges and Houde, this publication).

6.2. Riparian vegetation

Since the associations of riparian vegetation were — like those of the aquatic vegetation — identified from an analysis of the common and widely occurring species, we may relate them, without providing an exhaustive description, to associations of peatland plants described elsewhere

Figure 2
Schematic diagram showing the distribution of aquatic vegetation in terms of water acidity and calcium content. Dominant and subdominant species of each association are illustrated. The figures in the margins give the percentage of the lakes having a given association.



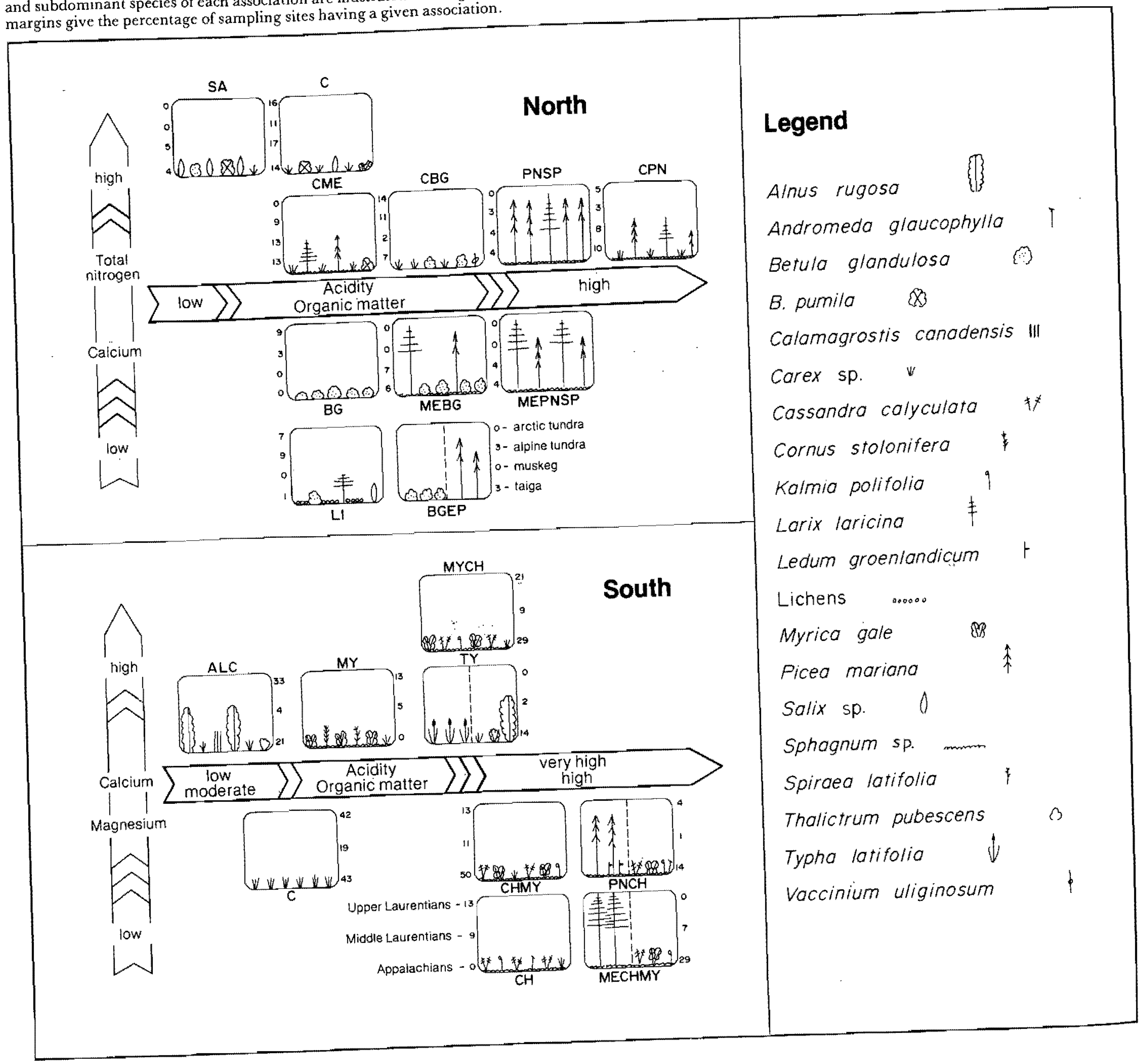
in the literature. In southern Quebec, myrica and myrica with leatherleaf are comparable with associations of these plants found by Dansereau and Segadas-Vianna (1952) and Gaudreau (1979). Leatherleaf with myrica corresponds to the myrica with leatherleaf s-ass. leatherleaf found by Millette and Fontaine (1975). Leatherleaf, tamarack with leatherleaf and myrica, and black spruce with leatherleaf resemble respectively the leatherleaf with sphagnums identified by Grandtner (1960), the tamarack with sphagnums and myrica identified by Millette and Fontaine (1975), and the sphagnum with black spruce found by Gauthier (1980). Alder with myrica probably corresponds to the similar association found by Gérardin *et al.* (1984, in Couillard and Grondin 1986), whereas alder with sedges corresponds to the speckled alder with sphagnums s-ass. sedges identified by Damman (1964). The sedge-dominated associations of the present study cannot be related to associations described in the literature because the species of the sedges are not identified. Our cattail and white birch associations appear to be new ones, not mentioned elsewhere.

The riparian associations at the northern study lakes have certain affinities with those described by Zarnovican and Bélair (1979) and Grondin and Ouzilleau (1980) at peatlands in the James Bay area, but no correspondence can be identified solely on the basis of dominant and subdominant species. The difference between riparian and peatland environments appears to be more important in the north than in the south.

The CORANA correlating the riparian vegetation of the south and north to regional variables suggests that the distribution of vegetation is better explained by natural district than by elevation or by the sensitivity of the bedrock to acidification. The southern ecoregions display a fairly uniform level of association richness, whereas in the north, the arctic tundra is far less rich.

The southern soils are fairly homogeneous despite the large area covered by the study. This is not the case in the north, where the arctic tundra soils are less developed. Relating the vegetation to the different soils brings out the effect of acidity more in the south than in the north, which suggests that the southern vegetation would display a greater reaction to acidification. In the north, the most active variables are nitrogen and organic matter, which has more to do with soil trophic conditions. If we look at the aids to interpretation (Appendix 6) in the light of the trophic conditions of the associations (Table 4), we see that the first axis separates the three associations growing on mineral soils (LI, BGEP, and BG) from those growing on organic soils. This does not tally with the results of Ducruc and Zarnovican (1976), who demonstrated that pH was the variable that best explained the distribution of tamarack and black spruce along the southern edge of Ungava Bay. According to Gorham *et al.* (1984), acidification, which fosters the development of certain species of sphagnum, probably underlies the transformation of (minerotrophic) fens into (ombrotrophic) bogs. This hypothesis is partly based on the fact that the bog/fen ratio is higher in Europe, where acidification resulting from human activity has been under way longer than in North America. Given that sphagnums decrease pH and encourage the accumulation of organic matter, we may assume that northern vegetation will react as much to acidification as southern vegetation if acid precipitation continues to increase in the northern part of Quebec. It is interesting that sphagnums are among the dominant species in associations found on acidic soils in both the southern and northern study areas (Fig. 3).

Figure 3
Schematic diagram showing the distribution of aquatic vegetation in terms of water acidity and calcium, nitrogen, and organic matter content. Dominant and subdominant species of each association are illustrated. The figures in the margins give the percentage of sampling sites having a given association.



Appendices

Appendix 1
Percentage of southern Quebec study lakes having a given association of aquatic plants

Variables	Number of lakes (n = 78)	Code[a]	Aquatic association ELBR[b]	ER	DUAL	UT	NUSP	SAEL	SEPE	SFPO	SA
Eco-geographical variables											
Ecological zone[c]											
Boreal	11	ZE2	9	9	0	36	36	55	9	9	18
Cool temperate	67	ZE3	36	31	33	21	48	11	19	8	12
Subzone[b]											
Boreal	11	SZ4	9	9	0	36	36	55	9	9	18
Transitional wet	16	SZ5	31	19	19	19	38	25	13	0	13
Mid wet	23	SZ6	39	30	30	22	48	0	17	4	13
Low mid wet	7	SZ7	29	43	0	14	57	29	57	57	0
Low wet	21	SZ8	38	38	57	24	52	5	14	0	14
Ecoregion[c]											
Upper Laurentians	10	ER3	10	10	0	40	30	60	0	10	20
Baskatong	16	ER4	31	19	19	19	38	25	13	0	13
Middle Laurentians	23	ER5	39	30	30	22	48	0	17	4	13
Appalachians	8	ER6	25	38	0	13	63	25	63	50	0
Outaouais	21	ER7	38	38	57	24	52	5	14	0	14
Ecological landscape[c]											
Coniferous forest	30	PE5	30	20	13	30	40	27	17	7	10
Ring of coniferous and deciduous	20	PE6	35	45	35	10	55	20	30	15	15
Mixed forest	21	PE7	29	33	43	29	38	5	14	0	14
Deciduous forest	7	PE8	43	0	29	14	71	0	0	14	14
Elevation (m)											
Average (200–450 m)	59	AT1	36	32	31	24	51	8	16	3	17
High (451–900 m)	19	AT2	21	16	21	21	32	42	26	21	0
Sensitivity to acidification[d]											
Medium	17	SA1	29	29	29	24	71	18	35	18	6
High	61	SA2	33	28	28	23	39	16	13	5	15

Appendix 1 (continued)
Percentage of southern Quebec study lakes having a given association of aquatic plants

Variables	Number of lakes (n = 78)	Code[a]	Aquatic association								
			ELBR[b]	ER	DUAL	UT	NUSP	SAEL	SEPE	SFPO	SA
Morphometric variables											
Area (ha)											
Very small (5–15)	42	SU1	33	38	29	29	48	5	10	5	14
Small (16–40)	36	SU2	31	17	28	17	44	31	28	11	11
Maximum depth (m)											
Very shallow (≤ 2)	33	PX1	45	27	33	24	49	24	18	12	21
Shallow to medium (3–22)	45	PX2	22	29	24	22	44	11	18	4	7
Sublittoral slope[c]											
Gentle	28	BN1	54	32	43	21	46	11	11	0	21
Moderate	30	BN2	27	23	33	27	43	13	10	0	13
Shoreline development index[f]											
Circular (1.0–1.3)	23	ID1	22	22	18	22	61	22	22	13	0
Semi-circular (1.4–3.0)	55	ID2	36	31	33	24	40	15	16	6	18
Shoreline reticulation index[g]											
Low	20	IRa(1)	35	50	35	10	35	15	15	0	10
Medium	40	IRb(1)	23	15	18	25	45	23	15	8	13
High	18	IRc(2)	50	33	44	33	61	6	28	17	17
Physical and chemical variables											
Colour (Hazen units)											
Clear water (1–20)	31	CO1	39	33	36	26	58	13	19	10	7
Coloured water (21–40)	30	CO2	33	27	30	27	43	20	10	10	20
Dark water (41–100)	17	CO3	18	6	12	12	29	18	29	0	12
Turbidity (Jackson units)											
Low (< 1.0)	30	TU1	33	43	33	37	37	17	20	3	17
Moderate (1.0–1.9)	39	TU2	26	18	28	15	54	15	13	10	5
High (2.0–3.3)	9	TU3	56	22	11	11	44	22	33	11	33
Summer pH											
Fairly acidic (4.4–5.0)	10	PHa(1)	0	10	20	50	20	0	10	0	0
Moderately acidic (5.1–5.5)	10	PHb(1)	10	40	30	10	30	10	40	10	0
Neutral (5.6–6.9)	47	PHc(2)	40	34	28	23	47	23	15	9	21
Alkaline (7.0–8.5)	11	PHd(2)	46	9	36	9	82	9	18	9	0
Alkalinity (mg $CaCO_3$/L)											
Very poorly buffered (0–3)	38	AC1	37	29	34	26	42	8	13	0	18
Poorly buffered (4–10)	15	AC2	47	33	53	20	27	13	7	7	13
Well buffered (11–35)	14	AC3	14	29	0	36	50	43	43	21	0
Very well buffered (> 35)	11	AC4	18	18	9	0	82	18	18	18	9
Conductivity (μS/cm)											
Low (8–25)	47	CD1	26	32	21	26	40	21	15	9	15
Moderate to high (25–200)	31	CD2	42	23	39	19	55	10	23	7	10
Calcium saturation index[h]											
Very well buffered (0–3)	19	IS1	37	21	21	5	68	21	21	16	5
Moderately buffered (3.1–5.1)	37	IS2	32	30	27	27	38	24	19	8	19
Poorly buffered (5.2–6.6)	22	IS3	27	32	36	32	36	0	14	0	9
Tannins and lignins (mg/L)											
Low to moderate (0.1–1.0)	29	TL1	41	45	31	28	62	10	14	3	7
Moderate to high (1.1–3.6)	49	TL2	27	18	27	20	37	20	20	10	16
Sulphates (mg SO_4/L)											
Low (2.0–3.5)	14	SF2	14	21	7	43	43	50	7	14	7
High (3.5–8.0)	64	SF3	36	30	33	19	47	9	20	6	14
Aluminum (mg/L)											
Low (0.02–0.05)	25	AL1	44	32	32	24	72	12	4	4	8
Moderate (0.06–0.10)	28	AL2	39	36	32	18	39	25	25	11	25
High (0.11–0.5)	25	AL3	12	16	20	28	28	12	24	8	4
C/N ratio (organic)											
Very low (8.0–30.0)	28	CN1	36	36	39	21	46	14	18	14	11
Low (30.1–39.9)	24	CN2	38	14	25	25	54	25	13	4	21
Moderate to high (40.0–135.0)	26	CN3	23	31	19	23	39	12	23	4	8

Appendix 1 (continued)
Percentage of southern Quebec study lakes having a given association of aquatic plants

Variables	Number of lakes (n = 78)	Code[a]	Aquatic association								
			ELBR[b]	ER	DUAL	UT	NUSP	SAEL	SEPE	SFPO	SA
Biological variables											
Total phosphorus (mg/L)											
Oligotrophic (0.005–0.01)	32	PT1	28	34	22	13	53	22	31	16	6
Meso-eutrophic (0.011–0.04)	46	PT2	35	24	33	30	41	13	9	2	17
Toxicity											
No problem	58	TX0	36	36	26	19	53	17	19	10	12
Possible problems	20	TX1	20	5	35	35	25	15	15	0	15
Calcium (mg/L)											
Very low (< 1.5)	13	CEa(1)	0	15	20	27	20	7	7	7	0
Low (1.5–2.9)	46	CEb(1)	37	35	26	26	46	22	17	7	20
Medium to high (> 2.9)	19	CEc(2)	42	21	37	11	63	11	26	11	5
Chlorophyll "a" (mg/m³)											
Extremely low (0.3–1.0)	12	YAa(1)	25	8	33	25	42	33	25	8	0
Very low (1.1–2.0)	25	YAb(1)	36	48	32	28	40	4	8	4	12
Low (2.1–11.5)	37	YAc(2)	35	19	27	22	51	22	19	8	19
Pedological variable											
Organic sediments											
Few (≤ 33% of shore)	10	SO1	40	30	30	10	30	40	20	0	20
Fairly large amounts (33–100% of shore)	48	SO2	40	27	40	27	48	6	8	0	17
Overall average	78		32	28	28	23	46	17	18	8	13

[a]The formula for the code is: XXz(i), where XX is the variable, z is a state of the variable before consolidation of the data matrix, and i is the state after consolidation. If z = i, i is omitted.
[b]DUAL = *Dulichium arundinaceum* and algae; ELBR = *Eleocharis smallii* and *Brasenia schreberi*; ER = *Eriocaulon septangulare*; NUSP = *Nuphar variegatum* and *Sparganium* sp.; SA = *Sagittaria latifolia*; SAEL = *Sparganium angustifolium* and *Eleocharis uniglumis*; SEPE = *Sparganium eurycarpum* and *Potamogeton epihydrus*; SFPO = *Sparganium fluctuans* and *Potamogeton oakesianus*; UT = *Utricularia vulgaris*.
[c]According to Gilbert *et al.* (1985).
[d]According to Shilts (1981).
[e]According to Jurdant *et al.* (1977).
[f]According to Joyner (1980).
[g]See Table 5.
[h]According to Kramer (1981) in Dupont (1984).

Appendix 2
Percentage of northern Quebec study lakes having a given association of aquatic plants

Variables	Number of lakes (n = 68)	Code[a]	Aquatic associations DR[b]	HI	ME	PO	SC
Eco-geographical variables							
Ecological subzone[c]							
High semi-arctic	8	SZ1	0	0	0	13	38
Mountainous semi-arctic	56	SZ2	7	5	9	5	4
Low semi-arctic	4	SZ3	0	0	0	0	50
Ecoregion[c]							
George River area	11	ER1	18	0	0	9	27
de Pas River area	57	ER2	4	5	9	5	7
Ecological landscape[c]							
Arctic tundra	8	PE1	25	0	0	13	0
Alpine tundra	7	PE2	0	0	0	0	43
Muskeg	15	PE3	0	7	7	0	7
Taiga	38	PE4	5	5	11	8	8
Elevation (m)							
Average (350–450)	18	AT1	11	0	11	6	17
High (451–600)	50	AT2	4	6	6	6	8
Sensitivity to acidification[d]							
Average	47	SA1	4	6	11	2	11
High	21	SA2	10	0	0	14	10
Morphometric variables							
Area (ha)							
Very small (3–15)	17	SU1	0	6	6	6	12
Small (16–75)	51	SU2	8	4	8	6	10
Maximum depth (m)							
Very shallow (≤ 2)	51	PX1	6	4	8	4	6
Shallow (3–11)	17	PX2	6	6	6	12	24
Sublittoral slope							
Gentle	35	BN1	3	3	6	3	11
Moderate	33	BN2	9	6	9	9	9
Shoreline development index[e]							
Circular (1.0–1.3)	36	ID1	8	0	6	6	6
Semi-circular (1.4–3.0)	32	ID2	3	9	9	6	16
Shoreline reticulation index[f]							
Low	20	IRa(1)	0	0	0	10	20
Medium	32	IRb(2)	13	6	15	6	9
High	16	IRc(2)	0	6	13	0	0
Physical and chemical variables							
Colour (Hazen units)							
Clear water (1–20)	49	CO1	6	4	4	8	12
Coloured water (21–40)	18	CO2	6	6	17	0	6
Turbidity (Jackson units)							
Low (< 1.0)	19	TU1	0	11	0	16	21
Moderate (1.0–1.9)	32	TU2	9	0	13	3	6
High (2.0–8.0)	17	TU3	6	6	6	0	6
Summer pH							
Very acidic (3.0–4.5)	7	PHa(1)	0	0	0	0	0
Neutral (5.6–6.9)	47	PHb(2)	9	2	11	6	9
Alkaline (7.0–8.6)	14	PHc(2)	0	14	0	7	21
Alkalinity (mg $CaCO_3$/L)							
Very poorly buffered (0–3)	11	AC1	18	0	0	9	0
Poorly buffered (4–10)	45	AC2	4	2	11	4	7
Well buffered (11–35)	12	AC3	0	17	0	8	33
Conductivity (µS/cm)							
Low (3–25)	49	CD1	8	2	10	6	6
Moderate to high (26–40)	18	CD2	0	11	0	6	22
Calcium saturation index[g]							
Very well buffered (0.5–3.0)	13	IS1	0	15	0	8	31
Moderately buffered (3.1–5.1)	47	IS2	9	2	11	6	6

Appendix 2 (continued)
Percentage of northern Quebec study lakes having a given association of aquatic plants

Variables	Number of lakes (n = 68)	Code[a]	Aquatic associations DR[b]	HI	ME	PO	SC
Tannins and lignins (mg/L)							
Low to moderate (0.1–1.0)	54	TL1	4	6	4	7	11
Moderate to high (1.1–1.5)	13	TL2	15	0	23	0	8
Sulphates (mg SO_4/L)							
Very low (0.3–1.5)	42	SF1	7	5	10	7	10
Low (1.6–3.5)	16	SF2	6	6	6	6	19
High (3.6–83.0)	9	SF3	0	0	0	0	0
Aluminum (mg/L)							
Low (0.03–0.05)	38	AL1	5	8	5	5	16
Moderate (0.06–0.10)	18	AL2	0	0	17	6	6
High (0.11–3.35)	11	AL3	18	0	0	9	0
Biological variables							
Chlorophyll "a" (mg/m³)							
Extremely low (0.1–1.0)	30	YAa(1)	10	7	7	10	20
Very low (1.1–2.0)	19	YAb(2)	0	5	16	5	0
Low (2.1–5.0; 64.0)	19	YAc(2)	5	0	0	0	5
Calcium (mg/L)							
Very low (0.4–1.4)	38	CEa(1)	11	0	13	8	8
Low (1.5–2.9)	18	CEb(2)	0	6	0	0	6
Medium to high (3.0–10.0)	11	CEc(2)	0	18	0	9	27
Toxicity							
No problem	56	TX1	7	5	7	7	13
Possible problems	6	TX2	0	0	17	0	0
Serious problems	6	TX3	0	0	0	0	0
Pedological variable							
Organic sediments							
Few (≤ 33% of shore)	47	SO1	6	4	9	9	9
Fair amounts (33–80% of shore)	21	SO2	5	5	5	0	14
Overall average			6	4	7	6	10

[a] The formula for the code is: XXz(i), where XX is the variable, z is a state of the variable before consolidation of the data matrix, and i is the state after consolidation. If z = i, i is omitted.
[b] DR = *Drepanocladus exannulatus*, HI = *Hippuris vulgaris*, ME = *Menyanthes trifoliata*, PO = *Potamogeton filiformis*, SC = *Scorpidium scorpioides*.
[c] According to Gilbert *et al.* (1985).
[d] According to Shilts (1981).
[e] According to Joyner (1980).
[f] See Table 5.
[g] According to Kramer (1981) in Dupont (1984).

Appendix 3
Percentage of southern Quebec sampling sites having a given association of riparian plants

Variables	Number of soil samples (n = 292)	Code[a]	Riparian associations TY[b]	C	MY	MYCH	CHMY	CH	MECHMY	PNCH	BOB	ALMY	ALC
Eco-geographical variables													
Ecological zone[c]													
Boreal	25	ZE2	0	44	12	20	16	12	4	8	12	8	24
Cool temperate	267	ZE3	3	20	5	10	13	9	8	1	2	2	6
Subzone[c]													
Boreal	25	SZ4	0	28	0	16	8	12	0	4	8	8	20
Transitional wet	89	SZ5	0	21	4	4	8	10	6	3	1	0	7
Mid wet	97	SZ6	2	20	4	9	18	11	7	1	2	1	6
Low mid wet	14	SZ7	14	36	0	29	43	0	21	7	21	21	21
Low wet	75	SZ8	5	19	11	16	9	5	9	0	0	3	4
Ecoregion[c]													
Upper Laurentians	24	ER3	0	42	13	21	13	13	0	4	13	8	33
Baskatong	89	ER4	0	17	1	3	6	12	4	2	0	0	3
Middle Laurentians	97	ER5	2	20	4	9	18	9	7	1	2	1	6
Appalachians	14	ER6	14	43	0	29	50	0	29	14	21	21	21
Outaouais	75	ER7	5	19	11	16	9	5	9	0	0	3	4
Ecological landscape[c]													
Coniferous forest	116	PE5	1	22	4	9	9	14	8	4	3	3	9
Ring of coniferous and deciduous	68	PE6	4	25	4	16	21	9	13	0	1	4	6
Mixed forest	87	PE7	1	21	5	9	14	5	3	1	3	0	7
Deciduous forest	21	PE8	14	19	19	19	14	5	5	0	0	10	10
Elevation (m)													
Average (213–450)	242	AT1	3	19	6	10	12	9	7	1	2	2	6
High (451–914)	50	AT2	2	36	2	16	18	12	8	8	8	6	18
Sensitivity to acidification[d]													
Medium	37	SA1	11	27	14	27	22	3	22	5	8	11	14
High	255	SA2	2	21	4	9	12	10	5	2	2	2	7
Pedological variables													
Laboratory pH													
Extremely acidic (3.5–4.0)	75	PLa(1)	4	24	15	5	19	37	19	4	—[e]	—	1
Highly acidic (4.1–4.5)	80	PLb(1)	1	33	6	10	20	14	10	3	—	—	3
Fairly acidic (4.6–5.0)	77	PLc(2)	3	20	3	12	6	5	0	0	—	—	10
Average to low acidity (5.1–6.2)	52	PLd(2)	0	50	10	13	4	0	0	0	—	—	15
Total nitrogen (%)													
Low (0.03–1.50)	113	NTa(1)	2	41	4	4	8	13	7	2	—	—	9
Average (1.51–2.40)	144	NTb(2)	1	33	4	10	16	18	8	1	—	—	5
High (2.41–2.95)	24	NTc(2)	0	46	8	29	8	0	0	0	—	—	4
Organic matter (%)													
Moderate (1–60)	74	MO1	1	62	7	7	0	1	0	0	—	—	18
High (61–88)	70	MO2	0	40	9	13	9	10	3	0	—	—	6
Very high (89–99)	137	MO3	1	23	1	8	20	24	12	3	—	—	1
Calcium (μeq/100 g)													
Low (0.2–10.0)	125	CAa(1)	0	42	3	4	13	19	2	2	—	—	6
Average (10.1–25.0)	110	CAb(2)	1	34	4	10	10	15	13	2	—	—	6
High (25.1–99.9)	46	CAc(2)	4	33	9	20	15	2	4	0	—	—	9
Magnesium (μeq/100 g)													
Low (0.3–3.0)	150	MGa(1)	1	47	5	5	12	14	2	0	—	—	7
Average (3.1–6.0)	103	MGb(2)	1	26	4	11	14	17	10	3	—	—	8
High (6.1–50.4)	28	MGc(2)	4	29	0	21	7	7	21	4	—	—	0
Potassium (μeq/100 g)													
Low (0.01–0.30)	146	K1	1	45	5	8	13	8	8	1	—	—	8
High (0.31–2.63)	135	K2	1	30	4	10	11	22	5	2	—	—	4
Overall average	292		1	22	5	10	13	9	8	1	3	2	8

[a]The formula for the code is: XXz(i), where XX is the variable, z is a state of the variable before consolidation of the data matrix, and i is the state after consolidation. If z = i, i is omitted.
[b]TY = cattails, C = sedges, MY = myrica, MYCH = myrica with leatherleaf, CHMY = leatherleaf with myrica, CH = leatherleaf, MECHMY = tamarack with leatherleaf and myrica, PNCH = black spruce with leatherleaf, BOB = riparian white birch, ALMY = alder with myrica, ALC = alder with sedge.
[c]According to Gilbert *et al.* (1985).
[d]According to Shilts (1981).
[e]Missing value.

Appendix 4
Percentage of northern Quebec sampling sites having a given association of riparian plants

Variable	Number of soil samples (n = 345)	Code[a]	Riparian associations LI[b]	C	CBG	CME	CPN	PNSP	MEPNSP	MEBG	BGEP	BG	SA
Eco-geographic variables													
Ecological subzone[c]													
High semi-arctic	43	SZ1	7	16	14	2	5	0	0	0	0	12	0
Mountainous semi-arctic	272	SZ2	2	15	6	13	9	4	4	6	2	0	3
Low semi-arctic	29	SZ3	0	10	7	7	7	7	0	3	3	0	10
Ecoregion[c]													
George River area	58	ER1	9	16	14	2	3	0	0	0	0	9	0
de Pas River area	286	ER2	1	14	6	13	9	4	3	6	2	0	4
Ecological landscape[c]													
Arctic tundra	43	PE1	7	16	14	0	5	0	0	0	0	9	0
Alpine tundra	35	PE2	9	11	11	9	3	3	0	0	3	3	0
Muskeg	83	PE3	0	17	2	13	8	4	4	7	0	0	5
Taiga	183	PE4	1	14	7	13	10	4	4	6	3	0	4
Elevation (m)													
Average (351–450)	103	AT1	1	16	7	10	7	4	1	3	0	3	5
High (451–580)	241	AT2	3	14	7	11	9	3	4	6	2	1	3
Sensitivity to acidification[d]													
Average	248	SA1	2	14	6	10	10	4	4	5	2	1	4
High	96	SA2	2	16	10	11	5	2	0	4	0	3	3
Pedological variables													
Laboratory pH													
Extremely acidic (3.5–4.0)	22	PLa(1)	0	18	5	5	23	14	5	5	5	0	5
Highly acidic (4.1–4.5)	54	PLb(1)	7	17	11	15	24	7	6	0	4	6	0
Fairly acidic (4.6–5.0)	161	PLc(2)	4	29	11	20	11	6	2	4	1	1	6
Average to low acidity (5.1–6.2)	108	PLd(2)	4	36	8	17	3	3	3	6	4	4	7
Total nitrogen (%)													
Low (0.01–1.50)	83	NTa(1)	14	11	11	11	6	5	4	5	10	7	5
Average (1.51–2.40)	122	NTb(2)	2	31	13	10	13	9	2	4	0	2	8
High (2.41–3.41)	140	NTc(2)	1	36	6	28	13	4	3	4	0	0	3
Organic matter (%)													
Moderate (1–60)	22	MO1	55	55	55	36	23	18	14	23	32	27	36
High (61–88)	198	MO2	2	25	7	13	5	2	2	3	1	2	4
Very high (89–98)	125	MO3	0	29	6	22	19	10	3	3	0	0	2
Calcium (μeq/100 g)													
Low (0.3–10.0)	132	CAa(1)	9	16	13	11	16	4	5	5	5	5	3
Average (10.1–25.0)	157	CAb(2)	1	39	8	20	8	8	3	3	5	1	4
High (25.1–96.4)	56	CAc(2)	2	27	7	23	9	5	0	7	0	2	13
Magnesium (μeq/100 g)													
Low (0.0–3.0)	149	MGa(1)	7	22	13	16	11	2	3	3	5	5	2
Average (3.1–6.0)	92	MGb(2)	4	39	9	13	12	10	3	4	0	0	3
High (6.1–92.3)	104	MGc(2)	0	28	6	23	11	8	2	6	1	1	12
Potassium (μeq/100 g)													
Low (0.03–0.30)	185	K1	6	24	10	17	13	5	4	3	3	3	3
Average (0.31–4.47)	160	K2	3	33	9	18	9	6	1	6	1	2	8
Overall average	354		2	14	7	11	9	3	3	5	2	1	3

[a]The formula for the code is: XXz(i), where XX is the variable, z is a state of the variable before consolidation of the data matrix, and i is the state after consolidation. If z = i, i is omitted
[b]LLI = lichens, C = sedges, CBG = sedges with scrub birch, CME = sedges with tamarack, CPN = sedges with black spruce, PNSP = black spruce with sphagnum, MEPNSP = tamarack with black spruce and sphagnum, MEBG = tamarack with scrub birch, BGEP = scrub birch with spruce, BG = scrub birch, SA = willows.
[c]According to Gilbert *et al.* (1985).
[d]According to Shilts (1981).

Appendix 5
Aids to interpreting correspondence analyses for aquatic vegetation

Subject of analysis, dimensions of matrix, total variance of multi-dimensional cluster, percentage of total variance explained by principal factors	Environmental variables contributing most to the variance of the factors (percent absolute contribution to factor)[a]	Aquatic associations whose distribution is most affected by the factors (percent relative contribution of factor)[b]
Eco-geographical variables		
Southern Quebec (3 variables — 9 states and 9 combinations; total variance = 0.192)		
First factor (60%)	AT2(29 +), ER6(23 +), ER3(17 +); ER7(12 −)[c]	SFPO(75 +), SAEL(67 +); ELBR(76 −), DUAL(70 −), ER(69 −)
Second factor (31%)	ER6(33 +); ER3(44 −)	SEPE(69 +); UT(85 −), SA(45 −)
Third factor (5%)	AT2(36 +), ER7(30 +); AT1(11 −), ER6(11 −)	
Northern Quebec (4 variables — 9 states and 5 combinations; total variance = 0.303)		
First factor (57%)	SZ2(15 +); SZ1(24 −), SZ3(18 −), ER1(17 −)	ME(84 +), HI(77 +); SC(76 −)
Second factor (29%)	SA2(43 +); SZ3(21 −), SA1(19 −)	PO(65 +), DR(63 +)
Third factor (11%)	AT2(17 +), SZ1(14 +); AT1(33 −), ER1(17 −)	DR(35 −)
Effect of acidity		
Southern Quebec (5 variables — 10 states and 9 combinations; total variance = 0.049)		
First factor (52%)	PH2(11 +), PX1(10 +); PH1(54 −), PX2(11 −)	SA(75 +), ELBR(67 +), SAEL(43 +); UT(59 −), SEPE(56 −), DUAL(47 −), ER(46 −)
Second factor (26%)	CE1(17 +); CE2(53 −), IR2(20 −)	SAEL(40 +); SFPO(43 −), NUSP(38 −)
Third factor (10%)	IR2(24 +), PX1(14 +); PX2(15 −), IR1(11 −), CE2(11 −)	SFPO(45 +); NUSP(36 −)
Northern Quebec (5 variables — 9 states and 5 combinations; total variance = 0.238)		
First factor (67%)	CE1(16 +); CE2(30 −), IR1(24 −)	ME(94 +), DR(81 +); SC(93 −)
Second factor (29%)	CE2(34 +), IR2(11 +); IR1(30 −), CE1(18 −)	H1(87 +); PO(79 −)
Third factor (4%)	YA1(26 +); YA2(59 −)	

[a]This is the percentage of variance of the factor explained by the variable. Only those variables are shown that contribute more than the theoretical equal contribution (e.g., more than 11.11% if there are 9 variables).
[b]This is the percentage of variance in the association's distribution that is explained by the factor. For each factor, only those associations are shown for which more than 35% of variance is attributable to one factor.
[c]The codes for variables and associations are those given in Appendices 1 and 2. " + " and " − " indicate whether the correlation with the factor is positive or negative.

Appendix 6
Aids to interpreting correspondence analyses for riparian vegetation

Subject of analysis, dimensions of matrix, total variance of multi-dimensional cluster, percentage of total variance explained by principal factors	Environmental variables contributing most to the variance of the factors (percent absolute contribution to factor)[a]	Riparian associations whose distribution is most affected by the factors (percent relative contribution of factor)[b]
Eco-geographical variables		
Southern Quebec (4 variables — 12 states and 11 combinations; total variance = 0.147)		
First factor (43%)	ER4(19 +), PE5(11 +); PE8(19 −), ER7(17 −), SA1(15 −)[c]	C(68 +) CH(62 +); TY(91 −), MYCH(80 −), MY(45 −), ALMY(35 −)
Second factor (29%)	ER4(9 +), ER7(8 +); ER6(26 −), AT2(18 −), ER3(15 −)	BOB(89 −), ALC(48 −), ALMY(44 −), PNCH(44 −)
Third factor (13%)	ER3(37 +), PEB(13 +); ER6(22 −), PE6(14 −)	MY(38 +); MECHMY(48 −), CHMY(41 −)
Northern Quebec (3 variables — 8 states and 11 combinations; total variance = 0.167)		
First factor (72%)	PE1(59 +), PE2(12 +)	BG(94 +), CBG(89 +), LI(63 +), C(35 +); MEBG(81 −), CPN(65 −), MEPNSP(65 −), PNSP (62 −), CME(60 −), SA(44 −)
Second factor (18%)	PE2(23 +); AT1(28 −), PE3(17 −), SA2(15 −)	BGEP(81 +), LI(33 +); C(53 −), SA(46 −)
Third factor (5%)	PE2(33 +), SA2(28 +); PE1(28 −)	CME(33 +)
Pedological variables		
Southern Quebec (5 variables — 11 states and 9 combinations; total variance = 0.220)		
First factor (77%)	MO1(18 +), PL2(17 +); MO3(16 −), PL1(11 −)	C(93 +), ALC(91 +); CH(88 −), CHMY(84 −), MECHMY(82 −), PNCH(81 −)
Second factor (11%)	CA1(31 +), MG1(18 +); CA2(20 −), MG2(17 −)	MYCH(71 −)
Third factor (6%)	NT1(27 +), MO1(16 +); NT2(17 −), MO2(15 −)	TY(35 −)
Northern Quebec (5 variables — 11 states and 11 combinations; total variance = 0.190)		
First factor (66%)	NT1(25 +), MO1(19 +), CA1(10 +); NT2(7 −)	LI(95 +), BGEP(93 +), BG(88 +), MEPNSP(38 +), CBG(35 +); C(89 −), CME(79 −)
Second factor (20%)	MO3(26 +), PL1(21 +); MO1(7 −), MO2(7 −)	CPN(82 +), PNSP(64 +); SA(54 −)
Third factor (8%)	MG1(24 +), CA1(9 +), PL1(8 +); MG2(17 −)	CBG(35 +); MEBG(59 −)

[a]This is the percentage of variance of the factor explained by the variable. Only those variables are shown that contribute more than the theoretical equal contribution (e.g., more than 11.11% if there are 9 variables).
[b]This is the percentage of variance in the association's distribution that is explained by the factor. For each factor, only those associations are shown for which more than 35% of variance is attributable to one factor.
[c]The codes for variables and associations are those given in Appendices 3 and 4. " + " and " − " indicate whether the correlation with the factor is positive or negative.

Literature cited

Able, K.P.; Noon, B.R. 1976. Avian community structure along elevational gradients in the northeastern United States. Oecologia 26:275-294.

Almer, B.; Dickson, W.; Ekstrom, C.; Hornstrom, E. 1978. Sulphur pollution and the aquatic ecosystem. Pages 272-311 *in* Nriagu, J.O. *et al.*, eds. Sulphur in the Environment Part II. Ecological Impacts. John Wiley & Sons, Toronto, Ontario. 482 pp.

Austin, M.P. 1976. Performance of four ordination techniques assuming three different non-linear species response models. Vegetatio 33:43-49.

Beaver, D.L.; Osborn, R.G.; Custer, T.W. 1980. Nest-site and colony characteristics of wading birds in selected Atlantic coast colonies. Wilson Bull. 92:200-220.

Bell, H.L. 1971. Effects of low pH on the survival and emergence of aquatic insects. Water Res. 5:313-319.

Benzécri, J.P. 1973. L'analyse des données. Volume II. L'analyse des correspondances. Dunod, Paris. 619 pp.

Blondel, J.; Ferry, C.; Frochot, B. 1970. La méthode des indices ponctuels d'abondance (I.P.A.) ou des relevés d'avifaune par "stations d'écoute". Alauda 38:55-71.

Bobée, B.; Grimard, Y.; Lachance, M.; Tessier, A. 1982. Nature et étendue de l'acidification des lacs du Québec. Rapp. sci. n° 140. Minist. de l'Environnement, Québec. Serv. de la qual. des eaux. 243 pp.

Bobée, B.; Lachance, M.; Haemmerli, J.; Tessier, A.; Charette, J.Y.; Kramer, J. 1983. Évaluation de la sensibilité à l'acidification des lacs du sud du Québec et incidences sur le réseau d'acquisition de données. INRS-Eau, Sci. Rep. No. 157, 198 pp. 4 annexes, 1 appendix.

Braun-Blanquet, J. 1932. Plant sociology. McGraw-Hill, New York. 439 pp.

Clark, K.; Fischer, K. 1981. Acid precipitation and wildlife. Can. Wildl. Serv. Wildl. Toxicol. Div., Ms. Rep. No. 43. Environment Canada, Ottawa. 95 pp.

Cody, M.L. 1974. Competition and the structure of bird communities. Monographs in population biology. 7. Princeton Univ. Press, N.J. 318 pp.

Collins, N.C.; Zimmerman, A.P.; Knoechel, R. 1981. Comparison of benthic infauna and epifauna in acidified and non acidified Ontario lakes. Pages 35-48 *in* Singer, R., ed. Effects of acid precipitation on benthos. Proceedings of a regional symposium on benthic biology. North Am. Benthological Soc.

Couillard, L.; Grondin, P. 1986. La végétation des milieux humides du Québec. Les publ. du Québec, Québec. 400 pp.

Cowling, E.B. 1978. Effects of acid precipitation and atmospheric deposition on terrestrial vegetation. Pages 47-63 *in* Galloway, J.N.; Cowling, E.B.; Gorham, E.; McFee, W.W., eds. A national program for assessing the problem of atmospheric deposition (acid rain). Rep. Counc. Environ. Qual., Fort Collins, Co. 97 pp.

Crowder, A.A.; Bristow, J.M.; King, M.R. 1977. The aquatic macrophytes of some lakes in southern Ontario. Nat. Can. 104:457-464.

Crum, H.A.; Steere, W.A.; Anderson, L.F. 1973. A new list of mosses of North America north of Mexico. Bryologist 76:85-130.

Damman, A.W.H. 1964. Some forest types of central Newfoundland and their relation to environmental factors. For. Sci. Monogr. 8:1-62.

Danell, K.; Sjoberg, K. 1978. Abundance and productivity of ducks on boreal lakes in northern Sweden. Ann. Zool. Fenn. 16:123-128.

Dansereau, P.; Segadas-Vianna, F. 1952. Ecological study of the peat bogs of eastern North America. Structure and evolution of vegetation. Can. J. Bot. 30:490-520.

Darveau, M.; Bellefleur, P. 1984. Dynamique de la végétation d'emprises de lignes de transport d'énergie. Can. J. Bot. 62:1730-1738.

DesGranges, J.-L. 1980. Avian community structure of six forest stands in La Mauricie National Park, Québec. Can. Wildl. Serv. Occas. Pap. No. 41. 32 pp.

DesGranges, J.-L., ed. 1985. L'acidité des lacs et les canards : première étape. Technical report prepared for "Environment 2000" by Ducks Unlimited and Can. Wildl. Serv.

DesGranges, J.-L.; Brodeur, J. 1985. Effets de l'acidité des lacs et de la compétition avec les poissons sur l'alimentation et la croissance de deux espèces de canetons du bouclier laurentien. Première étape. *In* DesGranges, J.-L., ed. 1985. L'acidité des lacs et les canards : première étape. Technical report prepared for "Environment 2000" by Ducks Unlimited and Can. Wildl. Serv.

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

DesGranges, J.-L.; Hunter, M.J. 1987. Duckling response to lake acidification. Trans. North Am. Wildl. Nat. Resour. Conf. 52:636-644.

DesGranges, J.-L.; Laporte, P. 1979. Aperçu préliminaire de la situation des huarts (Gaviidae) au Québec. Unpubl. rep. Quebec Reg. Can. Wildl. Serv. 35 pp.

DesGranges, J.-L.; Rodrigue, J. 1986. Influence of acidity and competition with fish on the development of ducklings in Quebec. Water Air Soil Pollut. 30:743-750.

Ducruc, J.-P.; Zarnovican, R. 1976. Notes sur l'écologie de trois espèces ligneuses à la bordure méridionale de la baie d'Ungava, Nouveau-Québec : *Betula glandulosa* Michx., *Larix laricina* (Du Roi) K. Koch, *Picea mariana* (Mill.) BSP. Can. J. Bot. 54:1775-1783.

Dugas, J. 1970. Minéralisation métallique dans la fosse du Labrador. Minist. des richesses nat. du Québec, Dir. gen. des mines. Étude spéc. n° 5. 27 pp. + 2 maps.

Duncan, D.B. 1975. T-tests and intervals for comparisons suggested by the data. Biometrics 31:339-359.

Eadie, J.M.; Keast, A. 1982. Do Goldeneye and Perch compete for food? Oecologia 55:225-230.

Environment Canada. 1982. Canadian climate normals. 1951-1980. Vol. 2: Temperature; Vol. 3: Precipitation; Vol. 4: Degree days. Environment Canada, Atmos. Environ. Serv. 306, 602, and 280 pp.

Eriksson, M.O.G. 1979. Competition between freshwater fish and Goldeneyes (*Bucephala clangula*) for common prey. Oecologia 41:99-107.

Eriksson, M.O.G. 1983. The role of fish in the selection of lakes by non piscivorous ducks: Mallard, Teal and Goldeneye. Wildfowl 34:27-32.

Eriksson, M.O.G. 1984. Acidification of lakes: effects on waterbirds in Sweden. Ambio 13(4):260-262.

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

Erskine, A.J. 1977. Birds in boreal Canada: communities, densities and adaptations. Can. Wildl. Serv. Rep. Ser. No. 41:1-71.

Ewert, D. 1982. Birds in isolated bogs in Central Michigan. Am. Midl. Nat. 108:41-50.

Fasham, M.J.R. 1977. A comparison of non-metric multidimensional scaling, principal components and reciprocal averaging for the ordination of coenoclines, and coenoplanes. Ecology 58:551-561.

Ferguson, P.; Lee, J.A.; Bell, J.N.B. 1978. Effects of sulphur pollutants on the growth of *Sphagnum* species. Environ. Pollut. 16:151-162.

Fremlin, G., ed. 1974. The National Atlas of Canada. Macmillan Co., Toronto and Energy, Mines and Resources Canada, Ottawa. 252 pp.

Frenette, J.J. 1986. Effet de l'acidité sur les communautés ichtyologiques de 17 lacs du Témiscamingue. Dir. des relevés aquat., minist. de l'Environnement, Québec. Rapp. PA-23. 102 pp.

Gauch, H.G.; Whittaker, R.H.; Wentworth, T.R. 1977. A comparative study of reciprocal averaging and other ordination techniques. J. Ecol. 65:157-174.

Gaudreau, L. 1979. La végétation et les sols des collines Tanginan. Abitibi-Ouest, Québec. Lab. d'écol. for., Univ. Laval, Québec. Étude écol. n° 1. 391 pp.

Gauthier, R. 1980. La végétation et les sphaignes du parc des Laurentides, Québec. Lab. d'écol. for., Univ. Laval, Québec. Étude écol. n° 3, 634 pp.

Gilbert, G.; Hélie, R.G.; Mondoux, J.M.; Li, L.K. 1985. Ecosystem sensitivity to acid precipitation for Quebec. Lands Dir., Environment Canada, Quebec Reg. Ecol. Land Classif. Ser. No. 20. 96 pp.

Gilbert, G.; Mondoux, J.M.; Quirion, M. 1981. Les écodistricts du Québec. Lands Dir., Environment Canada, Quebec Reg. 19 pp. + maps and appendices.

Gorham, E.; Bayley, S.E.; Schindler, D.W. 1984. Ecological effects of acid deposition upon peatlands: a neglected field in "acid-rain" research. Can. J. Fish. Aquat. Sci. 41:1256-1268.

Grahn, O. 1977. Macrophyte succession in Swedish lakes caused by deposition of airborne acid substances. Water Air Soil Pollut. 7:295-305.

Grandtner, M.M. 1960. La forêt de Beauséjour, Comté de Lévis, Québec. Étude phytosociologique. Fonds de rech. for., Univ. Laval, Québec. Contrib. n° 7. 62 pp.

Grimard, Y. 1984. Réseau d'échantillonnage des précipitations du Québec : sommaire des données de la qualité des eaux de précipitation 1981-1982-1983. Minist. de l'Environnement, Québec, Serv. de la qual. des eaux, Rapp. PA-11. 163 pp.

Grondin, P.; Ouzilleau, J. 1980. Les tourbières du sud de la Jamésie, Québec. Géogr. phys. et quaternaire 34:267-299.

Haapanen, A.; Nilsson, L. 1979. Breeding waterfowl populations in Northern Fennoscandia. Ornis Scand. 10:145-219.

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

Haines, T.A.; Hunter, M.L. 1982. Waterfowl and their habitat: threatened by acid rain? Pages 177-187 *in* Fourth Int. Waterfowl Symp., Ducks Unlimited, New Orleans, La.

Hilden, O. 1964. Ecology of duck populations in the island group of Valassaaret, Gulf of Bothnia. Ann. Zool. 1:153-277.

Hill, M.O. 1974. Correspondence analysis: a neglected multivariate method. Appl. Stat. 23:340-354.

Hultberg, H.; Grahn, O. 1976. Effects of acid precipitation on macrophytes in oligotrophic Swedish lakes. J. Great Lakes Res. 2 (Suppl. 1): 208-217.

Hunter, M.L.; Jones, J.J.; Gibbs, K.E.; Moring, J.R. 1986. Duckling responses to lake acidification: do black ducks and fish compete? Oikos 47:26-32.

Hunter, M.L.; Jones, J.J.; Gibbs, K.E.; Moring, J.R.; Brett, M. 1985. Interactions among waterfowl, fishes, invertebrates, and macrophytes in four Maine lakes of different acidity. U.S. Fish and Wildl. Serv., East. Energy and Land Use Team. Biol. Rep. 80(40.20). 80 pp.

IEC Beak. 1985. Utilisation de modèles trophiques et de la structure des communautés planctoniques pour déterminer les effets de l'acidité et de facteurs environnementaux particuliers sur la chaîne alimentaire dans les lacs du Québec. Technical report prepared for Department of Fisheries and Oceans and Can. Wildl. Serv. Project 1173.1, 2 vols. Québec.

Jeglum, J.K. 1973. Boreal forest wetlands near Candle Lake, Saskatchewan. II. Relationships of vegetational variation to major environmental gradients. Musk-ox 12:32-48.

Joyner, D.E. 1980. Influence of invertebrates on pond selection by ducks in Ontario. J. Wildl. Manage. 44:700-705.

Jurdant, M.; Bélair, J.-L.; Gerardin, V.; Ducruc, J.-P. 1977. L'inventaire du Capital-Nature. Méthode de classification et de cartographie écologique du territoire (3ᵉ approximation). Lands Dir., Environment Canada, Quebec Reg. Ecol. Land Classif. Ser. No. 2. 202 pp.

Karr, J.R.; Roth, R.R. 1971. Vegetation structure and avian diversity in several New World areas. Am. Nat. 105:423-435.

Kerekes, J.; Freedman, B.; Howell, G.; Clifford, P. 1984. Comparison of the characteristics of an acidic eutrophic, and an acidic oligotrophic lake near Halifax, Nova Scotia. Water Pollut. Res. J. Can. 19:1-10.

Lachance, M.; Bobée, B.; Grimard, Y. 1985. Sensitivity of southern Quebec lakes to acidic precipitation. Water Air Soil Pollut. 25:115-132.

Laven, R.D. 1982. Establishing homogeneity in studies of forest succession. For. Ecol. Manage. 4:161-177.

Legendre, L.; Legendre, P. 1979. Écologie numérique. 2. La structure des données écologiques. Masson, Paris and Presses univ. du Québec, Montréal. 247 pp.

Levins, R. 1968. Evolution in changing environments. Monographs in population biology No. 2. Princeton Univ. Press, Princeton, N.J. 120 pp.

Marie-Victorin, F. 1964. Flore laurentienne. 2nd. ed. Presses univ. de Montréal, Montréal. 925 pp.

McLaren, M.A.; McLaren, P.L. 1981. Relative abundances of birds in boreal and subarctic habitats of Northwestern Ontario and Northeastern Manitoba. Can. Field-Nat. 95:418-427.

McNicol, D.K.; Bendell, B.E.; Ross, R.K. 1987. Studies of the effects of acidification on aquatic wildlife in Canada: Waterfowl and trophic relationships in small lakes in northern Ontario. Can. Wildl. Serv. Occas. Pap. No. 62.

Memorandum of Intent. 1983. Memorandum of intent on transboundary air pollution: Impact assessment. Canada-US, Working Group No. 1. Final report. 600 pp.

Mercer, E.H. 1966. The use of the word "keratin". Adv. Biol. Skin 9:556-558.

Milette, P.; Fontaine, D. 1975. Étude phyto-écologique de six tourbières du tiers inférieur du parc national de la Mauricie, Québec. Fac. de for. géod., Univ. Laval, Québec. (Unpubl. B.Sc. thesis.) 256 pp.

Moreau, G.; Barbeau, C.; Frenette, J.J.; Lévesque, F.; Saint-Onge, J.; Simoneau, M. 1984. Influence des précipitations acides sur les populations d'Ombles de fontaine (*Salvelinus fontinalis*) de la réserve des Laurentides. Dir. gén. des relevés aquat., minist. de l'Environnement, Québec. Rapp. PA-7. 124 pp.

Moyle, J.B. 1961. Aquatic invertebrates as related to larger water plants and waterfowl. Minnesota Dep. Conserv. Invest. Rep. No. 233. 24 pp.

Murphy, S.M.; Kessel, B.; Vining, L.J. 1984. Waterfowl populations and limnologic characteristics of taiga ponds. J. Wildl. Manage. 48:1156-1163.

Nilsson, S.G. 1979. Density and species richness of some forest bird communities in south Sweden. Oikos 33:392-401.

Nilsson, S.G.; Nilsson, I.N. 1978. Breeding bird community densities and species richness in lakes. Oikos 31:214-221.

Noon, B.R.; Dawson, D.K.; Inkley, D.B.; Robbins, C.S.; Anderson, S.H. 1980. Consistency in habitat preference of forest bird species. Trans. North Am. Wildl. Nat. Resour. Conf. 45:226-244.

Nyholm, N.E.I. 1981. Evidence of involvement of aluminum in causation of defective formation of eggshells and of impaired breeding in wild passerine birds. Environ. Res. 26:363-371.

Nyholm, N.E.I.; Myhrberg, H.E. 1977. Severe eggshell defects and impaired reproductive capacity in small passerines in Swedish Lapland. Oikos 29:336-341.

Ormerod, S.J.; Tyler, S.J.; Lewis, J.M.S. 1985. Is the breeding distribution of Dippers influenced by stream acidity? Bird Study 32:33–40.

Patterson, J.H. 1976. The role of environmental heterogeneity in the regulation of duck populations. J. Wildl. Manage. 40:22–32.

Pehrsson, O. 1974. Nutrition of small ducklings regulating breeding area and reproductive output in the long-tailed duck, *Clangula hyemalis*. Int. Congr. Game Biol. 11:259–264.

Pehrsson, O. 1979. Feeding behaviour, feeding habitat utilization and feeding efficiency of Mallard ducklings (*Anas platyrhynchos* L.) as guided by domestic duck. Viltrevy 10:193–218.

Pehrsson, O. 1984. Relationships of food to spatial and temporal breeding strategies of mallards in Sweden. J. Wildl. Manage. 48:322–339.

Potvin, P.; Grimard, Y. 1983. Étude de la qualité du milieu aquatique de 67 lacs à sauvagine de la région de Schefferville, Québec. Serv. de la qual. des eaux, minist. de l'Environnement, Québec. Rapp. PA-8. 153 pp. et annexes.

Prodon, R.; Lebreton, J.D. 1981. Breeding avifauna of a Mediterranean succession: the holm oak and cork oak series in the eastern Pyrénées, 1. Analysis and modelling of the structure gradient. Oikos 37:21–38.

Raddum, G.G. 1980. Comparison of benthic invertebrates in lakes with different acidity. Page 330 *in* Drablos, D. and Tollan, A., eds. Ecological impact of acid precipitation. Proc. Int. Conf. Ecol. Impact Acid Precip. Norway, SNSF project.

Reed, A. 1978. Canadian Waterfowl Management Plan — Quebec. Can. Wildl. Serv., Quebec Reg. Internal Rep. 18 pp.

Rice, J.; Ohmart, R.D.; Anderson, B.W. 1983. Turnovers in species composition of avian communities in contiguous riparian habitats. Ecology 64:1444–1455.

Richard, Y. 1985. Influence du niveau d'acidité des milieux lacustres sur la faune ichtyologique de la région de Portneuf, Québec. Dir. des relevés aquat., minist. de l'Environnement, Québec. Rapp. PA-15. 197 pp.

Ringelman, J.K.; Longcore, J.R. 1982. Movements and wetland selection by brood-rearing Black Ducks. J. Wildl. Manage. 46:615–621.

Ringelman, J.K.; Longcore, J.R.; Owen, R.B. 1982. Breeding habitat selection and home range of radio-marked black ducks (*Anas rubripes*) in Maine. Can. J. Zool. 60:241–248.

Robbins, C.S. 1981*a*. Effect of time of day on bird activity. Pages 275–286 *in* Ralph, C.J. and Scott, J.M., eds. Estimating numbers of terrestrial birds. Stud. Avian Biol. 6:275–286.

Robbins, C.S. 1981*b*. Bird activity levels related to weather. Pages 301–310 *in* Ralph, C.J. and Scott, J.M., eds. Estimating numbers of terrestrial birds. Stud. Avian Biol. 6:301–310.

Rodrigue, J.; DesGranges, J.-L. 1989. Étude de la qualité du milieu aquatique et des composantes biologiques de 81 lacs à sauvagine du Québec méridional. Dir. gén. des relevés aquat., minist. de l'Environnement, Québec. Rapport PA 89-01. 105 pp. + annexes.

Rotenberry, J.T. 1978. Components of avian diversity along a multifactorial climatic gradient. Ecology 59:693–699.

Rousseau, J. 1952. Les zones biologiques de la péninsule Québec-Labrador et l'hémi-arctique. Can. J. Bot. 30:436–474.

Rov, N. 1975. Breeding bird community structure and species diversity along an ecological gradient in deciduous forest in western Norway. Ornis Scand. 6:1–14.

Rowe, J.S. 1972. Forest regions of Canada. Can. For. Serv. Publ. No. 1300. 172 pp. + map.

Rubec, C.D.A. 1981. Characteristics of terrestrial ecosystems impinged by acid precipitation across Canada. Lands Dir., Environment Canada. Work. Pap. No. 19. 32 pp.

Schreiber, R.K.; Fischer, K.L. 1983. Acid stress on forest habitats: implications for terrestrial wildlife. Presented at the Acid Rain and Forest Resources Conference sponsored by Can. For. Serv. and Environment Canada and held in Quebec City (Que.), 14–17 June 1983.

Shilts, W.W. 1981. Sensitivity of bedrock to acid precipitation: modification by glacial processes. Geol. Surv. Can. Pap. 81-14. 7 pp. + maps.

Short, J.J. 1979. Patterns of alpha-diversity and abundance in breeding bird communities across North America. Condor 81:21–27.

Silieff, E.; Hussell, D.J.T. 1982. Ontario Lakes Loon Survey Progress Report No. 1:1982. Long Point Bird Observatory. Unpubl. rep.

Stauffer, D.F.; Best, L.B. 1980. Habitat selection by birds of riparian communities: evaluating effects of habitat alterations. J. Wildl. Manage. 44:1–15.

Swift, B.L.; Larson, J.S.; DeGraaf, R.M. 1984. Relationship of breeding bird density and diversity to habitat variables in forested wetlands. Wilson Bull. 96:48–59.

Tarnocai, C. 1980. Canadian wetland registry. Pages 9–39 *in* Rubec, C.D.A. and Pollet, F.C., eds. Proceedings of a workshop on Canadian Wetlands. Lands Dir, Environment Canada. Ecol. Land Classif. Ser. No. 12.

Terborgh, J. 1971. Distribution on environmental gradients: theory and a preliminary interpretation of distributional patterns in the avifauna of the Cordillera Vilcabamba, Peru. Ecology 52:23–40.

Tramer, E.J. 1974. On latitudinal gradients in avian diversity. Condor 76:123–130.

Trewartha, G. 1968. An introduction to climate. McGraw-Hill. 408 pp.

Vincent, G.A.; Bergeron, Y. 1983. La caractérisation d'herbiers aquatiques du lac des Deux-Montagnes (Québec) à partir de paramètres physiques de l'eau. Can. J. Bot. 61:400–411.

Vitt, D.H.; Bayley, S. 1984. The vegetation and water chemistry of four oligotrophic basin mires in northwestern Ontario. Can. J. Bot. 62:1485–1500.

Wiens, J.A. 1973. Pattern and process in grassland bird communities. Ecol. Monogr. 43:237–270.

Wile, I.; Miller, G.E.; Hitchin, G.G.; Yan, N.D. 1985. Species composition and biomass of macrophyte vegetation of one acidified and two acid-sensitive lakes in Ontario. Can. Field-Nat. 99:308–312.

Wright, R.F.; Dale, T.; Gjessing, E.T.; Hendrey, G.; Henriksen, A.; Johannessen, M.; Muniz, I.P. 1976. Impact of acid precipitation on freshwater ecosystems in Norway. Water Air Soil Pollut. 6:483–499.

Zarnovican, R.; Bélair, J.L. 1979. Les tourbières de la Baie James : la végétation et les sols. Lands Dir., Environment Canada. Ecol. Land Classif. Ser. No. 9. 37 pp.

Zoltai, S.C.; Pollett, F.C.; Jeglum, J.K.; Adams, G.D. 1975. Developing a wetland classification for Canada. Pages 497–511 *in* Bernier, B. and Winget, C.H., eds. Proceedings of the Fourth Conference on North American Forest Lands, Quebec City, Québec, 1973.

List of common and scientific names of bird species mentioned in the text

Alder Flycatcher	*Empidonax alnorum*
American Bittern	*Botaurus lentiginosus*
American Tree Sparrow	*Spizella arborea*
American Robin	*Turdus migratorius*
American Redstart	*Setophaga ruticilla*
Arctic Tern	*Sterna paradisaea*
Barn Swallow	*Hirundo rustica*
Bay-breasted Warbler	*Dendroica castanea*
Belted Kingfisher	*Ceryle alcyon*
Black Duck	*Anas rubripes*
Black Scoter	*Melanitta nigra*
Black-and-white Warbler	*Mniotilta varia*
Black-capped Chickadee	*Parus atricapillus*
Black-throated Blue Warbler	*Dendroica caerulescens*
Black-throated Green Warbler	*Dendroica virens*
Blackburnian Warbler	*Dendroica fusca*
Blackpoll Warbler	*Dendroica striata*
Blue Jay	*Cyanocitta cristata*
Boreal Chickadee	*Parus hudsonicus*
Canada Warbler	*Wilsonia canadensis*
Canada Goose	*Branta canadensis*
Cape May Warbler	*Dendroica tigrina*
Cedar Waxwing	*Bombycilla cedrorum*
Chestnut-sided Warbler	*Dendroica pensylvanica*
Chimney Swift	*Chaetura pelagica*
Common Snipe	*Gallinago gallinago*
Common Grackle	*Quiscalus quiscula*
Common Merganser	*Mergus merganser*
Common Loon	*Gavia immer*
Common Yellowthroat	*Geothlypis trichas*
Common Redpoll	*Carduelis flammea*
Common Goldeneye	*Bucephala clangula*
Dark-eyed Junco	*Junco hyemalis*
Eastern Kingbird	*Tyrannus tyrannus*
Eastern Wood-Pewee	*Contopus virens*
Evening Grosbeak	*Coccothraustes vespertinus*
Fox Sparrow	*Passerella iliaca*
Golden-crowned Kinglet	*Regulus satrapa*
Gray Jay	*Perisoreus canadensis*
Gray-cheeked Thrush	*Catharus fuscescens*
Great Crested Flycatcher	*Myiarchus crinitus*
Greater Scaup	*Aythya marila*
Green-winged Teal	*Anas crecca*
Hairy Woodpecker	*Picoides villosus*
Hermit Thrush	*Catharus guttatus*
Herring Gull	*Larus argentatus*
Hooded Merganser	*Lophodytes cucullatus*
Horned Lark	*Eremophila alpestris*
Killdeer	*Charadrius vociferus*
Lapland Longspur	*Calcarius lapponicus*
Least Flycatcher	*Empidonax minimus*
Least Sandpiper	*Calidris minutilla*
Lincoln's Sparrow	*Melospiza lincolnii*
Magnolia Warbler	*Dendroica magnolia*
Mourning Warbler	*Oporornis philadelphia*
Nashville Warbler	*Vermivora ruficapilla*
Northern Flicker	*Colaptes auratus*
Northern Waterthrush	*Seiurus noveboracensis*
Northern Parula	*Parula americana*
Olive-sided Flycatcher	*Contopus borealis*
Osprey	*Pandion haliaetus*
Ovenbird	*Seiurus aurocapillus*
Palm Warbler	*Dendroica palmarum*
Philadelphia Vireo	*Vireo philadelphicus*
Pileated Woodpecker	*Dryocopus pileatus*
Pine Siskin	*Carduelis pinus*
Pine Grosbeak	*Pinicola enucleator*
Purple Finch	*Carpodacus purpureus*
Red-breasted Merganser	*Mergus serrator*
Red-breasted Nuthatch	*Sitta canadensis*
Red-eyed Vireo	*Vireo olivaceus*
Red-necked Phalarope	*Phalaropus lobatus*
Red-winged Blackbird	*Agelaius phoeniceus*
Ring-necked Duck	*Aythya collaris*
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Ruby-crowned Kinglet	*Regulus calendula*

Ruby-throated Hummingbird	*Archilochus colubris*
Ruffed Grouse	*Bonasa umbellus*
Rusty Blackbird	*Euphagus carolinus*
Savannah Sparrow	*Passerculus sandwichensis*
Scarlet Tanager	*Piranga olivacea*
Semipalmated Plover	*Charadrius semipalmatus*
Short-billed Dowitcher	*Limnodromus griseus*
Solitary Sandpiper	*Tringa solitaria*
Solitary Vireo	*Vireo solitarius*
Song Sparrow	*Melospiza melodia*
Spotted Sandpiper	*Actitis macularia*
Swainson's Thrush	*Catharus ustulatus*
Swamp Sparrow	*Melospiza georgiana*
Tennessee Warbler	*Vermivora peregrina*
Tree Swallow	*Tachycineta bicolor*
Water Pipit	*Anthus spinoletta*
White-crowned Sparrow	*Zonotrichia leucophrys*
White-throated Sparrow	*Zonotrichia albicollis*
Wilson's Warbler	*Wilsonia pusilla*
Winter Wren	*Troglodytes troglodytes*
Wood Thrush	*Hylocichla mustelina*
Yellow Warbler	*Dendroica petechia*
Yellow-bellied Flycatcher	*Empidonax flaviventris*
Yellow-bellied Sapsucker	*Sphyrapicus varius*
Yellow-rumped Warbler	*Dendroica coronata*

Other publications in the Occasional Papers series

No. 1
Birds protected in Canada under the Migratory Birds Convention Act, 4th ed. Publication bilingue.
Cat. No. CW69-1/1. Publ. 1957, rev. 1980.
No. 2
Canadian bird names, French, English and scientific. Publication bilingue.
Cat. No. CW69-1/2. Publ. 1957, rev. 1972.
No. 3
Use of aerial surveys by the Canadian Wildlife Service by D.A. Benson. Out of print.
Cat. No. CW69-1/3. Publ. 1963, repr. 1966.
No. 4
Queen Elizabeth Islands game survey, 1961 by J.S. Tener.
Cat. No. CW69-1/4. Publ. 1963, repr. 1972.
No. 5
Age determination in the polar bears by T.H. Manning.
Cat. No. CW69-1/5. Publ. 1964, repr. 1973.
No. 6
A wildlife biologist looks at sampling, data processing and computers by D.A. Benson.
Out of print.
Cat. No. R69-1/6. Publ. 1964.
No. 7
Preliminary report on the effects of phosphamidon on bird populations in New Brunswick by C.D. Fowle. Out of print.
Cat. No. R69-1/7. Publ. 1965.
No. 8
Birds of Nova Scotia—New Brunswick border region by G.F. Boyer.
Cat. No. CW69-1/8. Publ. 1966, repr. 1981.
No. 9
Effects of dietary methylmercury on Ring-necked Pheasants, with special reference to reproduction by N. Fimreite.
Cat. No. R69-1/9. Publ. 1971.
No. 10
Trends in populations of barren-ground caribou over the last two decades: a re-evaluation of the evidence by G.R. Parker.
Cat. No. CW69-1/10. Publ. 1971, repr. 1972.
No. 11
The Canada migratory game bird hunting permit and related surveys by D.A. Benson.
Cat. No. R69-1/11. Publ. 1971.
No. 12
Observations on duck hunting in eastern Canada in 1968 and 1969 by H.J. Boyd.
Cat. No. R69-1/12. Publ. 1971.
No. 13
Evaluation of ecological effects of recent low water levels in the Peace-Athabasca Delta by H.J. Dirschl.
Cat. No. CW69-1/13. Publ. 1972.
No. 14
The Great Cormorants of eastern Canada by A.J. Erskine.
Cat. No. CW69-1/14. Publ. 1972.
No. 15
Distribution of barren-ground caribou harvest in north-central Canada by G.R. Parker.
Cat. No. CW69-1/15. Publ. 1972.
No. 16
Bird migration forecasts for military air operations by H. Blokpoel.
Cat. No. CW69-1/16. Publ. 1973.
No. 17
Waterfowl populations on the Peace-Athabasca Delta. 1969 and 1970 by D.J. Neiman and H.J. Dirschl.
Cat. No. CW69-1/17. Publ. 1973.
No. 18
Gammarus predation and the possible effects of *Gammarus* and *Chaoborus* feeding on the zooplankton composition in some small lakes and ponds in western Canada by R.S. Anderson and L.G. Raasveldt.
Cat. No. CW69-1/18. Publ. 1974.
No. 19
A summary of DDE and PCB determinations in Canadian birds, 1969 to 1972 by M. Gilbertson and L. Reynolds.
Cat. No. CW69-1/19. Publ. 1974.
No. 20
Development of a simulation model of Mallard Duck populations by C.J. Walters, R. Hilborn, E. Oguss, R.M. Peterman and J.M. Stander.
Cat. No. CW69-1/20. Publ. 1974.
No. 21
Use of museum specimens in toxic chemical research by A.M. Rick.
Cat. No. CE69-1/21. Publ. 1975.
No. 22
Impoundments for waterfowl by W.R. Whitman.
Cat. No. CW69-1/22. Publ. 1976.
No. 23
Minimizing the dangers of nesting studies to raptors and other sensitive species by R.W. Fyfe and R.R. Olendorff.
Cat. No. CW69-1/23. Publ. 1976.
No. 24
Waterfowl damage to Canadian grain: current problems and research needs by L.G. Sugden.
Cat. No. CW69-1/24. Publ. 1976.
No. 25
Census techniques for seabirds of arctic and eastern Canada by D.N. Nettleship.
Cat. No. CW69-1/25. Publ. 1976.
No. 26
Notes on the present status of the polar bear in James Bay and Belcher Islands area by Charles Jonkel, Pauline Smith, Ian Stirling and George B. Kolenosky.
Cat. No. CW69-1/26. Publ. 1976.
No. 27
Limnological and planktonic studies in the Waterton Lakes, Alberta by R. Stewart Anderson and Roderick B. Green.
Cat. No. CW69-1/27. Publ. 1976.
No. 28
Birds and mammals of the Belcher, Sleeper, Ottawa, and King George Islands, Northwest Territories by T.H. Manning.
Cat. No. CW69-1/28. Publ. 1976.
No. 29
Developments in PPS sampling—Impact on current research by A.R. Sen.
Cat. No. CW69-1/29. Publ. 1976.
No. 30
Dynamics of snowshoe hare populations in the Maritime Provinces by Thomas J. Wood and Stanley A. Munroe.
Cat. No. CW69-1/30. Publ. 1977.
No. 31
Migration and population dynamics of the Peace-Athabasca Delta goldeye population by D.B. Donald and A.H. Kooyman.
Cat. No. CW69-1/31. Publ. 1977.
No. 32
The effects of fire on the ecology of the Boreal Forest, with particular reference to the Canadian north; a review and selected bibliography by John P. Kelsall, E.S. Telfer and Thomas D. Wright.
Cat. No. CW69-1/32. Publ. 1977.
No. 33
The ecology of the polar bear *(Ursus maritimus)* along the western coast of Hudson Bay by Ian Stirling, Charles Jonkel, Pauline Smith, Richard Robertson and Dale Cross.
Cat. No. CW69-1/33. Publ. 1977.

No. 34
Canvasback habitat use and production in Saskatchewan parklands by Lawson G. Sugden.
Cat. No. CW69-1/34. Publ. 1978.
No. 35
The diets of muskoxen and Peary caribou on some islands of the Canadian High Arctic by Gerald R. Parker.
Cat. No. CW69-1/35. Publ. 1978.
No. 36
Observations of Mallards in the parkland of Alberta by Michael F. Sorensen.
Cat. No. CW69-1/36. Publ. 1978.
No. 37
The wildlife valuation problem: A critical review of economic approaches by William A. Langford and Donald J. Cocheba.
Cat. No. CW69-1/37. Publ. 1978.
No. 38
Spatial changes in waterfowl habitat, 1964-74, on two land types in the Manitoba Newdale Plain by G.D. Adams and G.G. Gentle.
Cat. No. CW69-1/38. Publ. 1978.
No. 39
Patterns of pelagic distribution of seabirds in western Lancaster Sound and Barrow Strait, Northwest Territories, in August and September 1976 by D.N. Nettleship and A.J. Gaston.
Cat. No. CW69-1/39. Publ. 1978.
No. 40
Responses of Peary caribou and muskoxen to helicopter harassment by Frank L. Miller and Anne Gunn.
Cat. No. CW69-1/40. Publ. 1979.
No. 41
Avian community structure of six forest stands in La Mauricie National Park, Quebec by J.-L. DesGranges. Disponible également en français.
Cat. No. CW69-1/41E. Publ. 1979.
No. 42
Population ecology studies of the polar bear in northern Labrador by Ian Stirling and H.P.L. Kiliaan. Disponible également en français.
Cat. No. CW69-1/42E. Publ. 1980.
No. 43
Census methods for murres, *Uria* species; a unified approach by T.R. Birkhead and D.N. Nettleship. Disponible également en français.
Cat. No. CW69-1/43E. Publ. 1980.
No. 44
Population ecology studies of the polar bear in the area of southeastern Baffin Island by Ian Stirling, Wendy Calvert, and Dennis Andriashek.
Disponible également en français.
Cat. No. CW69-1/44E. Publ. 1980.
No. 45
Polynyas in the Canadian Arctic by Ian Stirling and Holly Cleator, eds.
Disponible également en français.
Cat. No. CW69-1/45E. Publ. 1981.
No. 46
The Lesser Snow Geese of the eastern Canadian Arctic by H. Boyd, G.E.J. Smith, and F.G. Cooch. Disponible également en français.
Cat. No. CW69-1/46E. Publ. 1982.
No. 47
The distribution and abundance of seals in the eastern Beaufort Sea, 1974-79 by Ian Stirling, Michael Kingsley, and Wendy Calvert. Disponible également en français.
Cat. No. CW69-1/47E. Publ. 1982.
No. 48
Foraging behaviour of Peary caribou in response to springtime snow and ice conditions by F.L. Miller, E.J. Edmonds, and A. Gunn. Disponible également en français.
Cat. No. CW69-1/48E. Publ. 1982.
No. 49
A review of some important techniques in sampling wildlife by A.R. Sen.
Disponible également en français.
Cat. No. CW69-1/49E. Publ. 1982.
No. 50
Intensive regulation of duck hunting in North America: its purpose and achievements by Hugh Boyd. Disponible également en français.
Cat. No. CW69-1/50E. Publ. 1983.
No. 51
Human dimensions of migratory game-bird hunting in Canada by Shane A.D. Parker and Fern L. Filion. Disponible également en français.
Cat. No. CW69-1/51E. Publ. 1984.
No. 52
Components of hunting mortality in ducks by G.S. Hochbaum and C.J. Walters. Disponible également en français.
Cat. No. CW69-1/52E. Publ. 1984.
No. 53
The interpretation of aerial surveys for seabirds: some effects of behaviour by A.J. Gaston and G.E. J. Smith. Disponible également en français.
Cat. No. CW69-1/53E. Publ. 1984.
No. 54
Waterfowl studies in Ontario, 1973-81 by S.G. Curtis, D.G. Dennis, and H. Boyd, eds. Disponible également en français.
Cat. No. CW69-1/55E. Publ. 1985.
No. 55
The reported kill of ducks and geese in Canada and the USA, 1974-82 by Hugh Boyd. Disponible également en français.
Cat. No. CW69-1/55E. Publ. 1985.
No. 56
Population dynamics of the Common Loon *(Gavia immer)* associated with mercury-contaminated waters in northwestern Ontario by J.F. Barr.
Disponible également en français.
Cat. No. CW69-1/56E. Publ. 1986.
No. 57
The Ring-billed Gull in Ontario: a review of a new problem species by H. Blokpoel and G.D. Tessier. Disponible également en français.
Cat. No. CW69-1/57E. Publ. 1986.
No. 58
The birds of the Creston Valley and southeastern British Columbia by R.W. Butler, B.G. Stushnoff, and E. McMackin. Disponible également en français.
Cat. No. CW69-1/58E. Publ. 1986.
No. 59
Estimating densities of birds at sea and the proportion in flight from counts made on transects of indefinite width by A.J. Gaston, B.T. Collins and A.W. Diamond. Disponible également en français.
Cat. No. CW69-1/59E. Publ. 1987.
No. 60
Waterfowl breeding population surveys, Atlantic Provinces by A.J. Erskine, ed. Disponible également en français.
Cat. No. CW69-1/60E. Publ. 1987.
No. 61
A survey of Lesser Snow Geese on Southampton and Baffin islands, NWT, 1979 by A. Reed, P. Dupuis and G.E.J. Smith. Disponible également en français.
Cat. No. CW69-1/61E. Publ. 1987.
No. 62
Studies of the effects of acidification on aquatic wildlife in Canada: waterfowl and trophic relationships in small lakes in northern Ontario by D.K. McNicol, B.E. Bendell and R.K. Ross. Disponible également en français.
Cat. No. CW69-1/62E. Publ. 1987.
No. 63
Bison ecology in relation to agricultural development in the Slave River lowlands, NWT by H.W. Reynolds and A.W.L. Hawley, eds.
Cat. No. CW69-1/63E. Publ. 1987.
No. 64
A simulation model for the Greater Snow Goose population by J. Gauvin and A. Reed. Disponible également en français.
Cat. No. CW69-1/64E. Publ. 1987.
No. 65
The birds of the Fraser River delta: populations, ecology and international significance by R.W. Butler and R.W. Campbell.
Cat. No. CW69-1/65E. Publ. 1987.
No. 66
Mortality of migratory barren-ground caribou on the calving grounds of the Beverly herd, Northwest Territories, 1981-83 by F.L. Miller, E. Broughton and A. Gunn.
Cat. No. CW69-1/66E. Publ. 1988.

Canada