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NWRI Contribution No. 91-18

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MANAGEMENT PERSPECTIVE

The International Lake Environment Committee (ILEC) has been conducting a survey of the state of the world's lakes for several years. This survey has the goal of identifying the major environmental stresses on the lakes' limnology and fishery and of providing an overview of the kinds of water management responses that were induced by these stresses and their success. ILEC approached NWRI to coordinate the survey in Canada and co-funded the exercise which was implemented through a contract to Brock University. The overview demonstrated that lakes in the developed regions of Canada were recovering from episodes of eutrophication and contamination while those in more northerly regions or new reservoirs were beginning to show stresses particularly with respect to contamination. This report is an elaboration of a presentation given to the 4th International Conference on Lake Management and Conservation held in Hangzhou, China in September, 1990.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Le Comité international sur l'environnement des lacs (ILEC) effectue depuis plusieurs années une étude sur l'état des lacs à l'échelle mondiale. Celle-ci a pour but de déterminer les principales agressions environnementales sur les propriétés limnologiques des lacs et la pêche, et de fournir un aperçu des différentes interventions en matière de gestion des eaux qui ont été causées par ces agressions et d'indiquer dans quelle mesure elles ont réussi. Le Comité sur l'environnement des lacs s'est adressé à l'INRE afin qu'il coordonne l'étude au Canada et qu'il participe au financement des travaux qui ont été donnés à contrat à l'Université Brock. Selon l'aperçu, les lacs des régions industrialisées du Canada étaient en période de rétablissement suite à des épisodes d'eutrophisation et de contamination tandis que ceux qui se trouvent dans des régions plus au nord ou les nouveaux réservoirs commençaient à manifester des signes d'agression notamment au niveau de la contamination. Le présent rapport élabore de façon plus détaillée un exposé présenté lors de la Quatrième conférence internationale sur la gestion et la conservation des lacs tenue à Hangzhou (Chine), en septembre 1990.

ABSTRACT

The limnological characteristics of 42 lakes in Canada have been assessed using the ILEC questionnaire. In general, these lakes were chosen to be representative of lakes in seven lake regions. The seven natural lake groupings utilized in this survey were the Atlantic, Great Lakes and St. Lawrence Lowland, Boreal and Taiga Shield, Taiga Plain, Boreal Plain and Prairie, Cordilleran, and Arctic Region lakes. The limnology of each group of lakes was strongly influenced by climate and geology as well as the hydrology and morphology of each lake. Human activities in each drainage basin modified these basic characteristics to a greater or lesser degree depending on population density. However, metal mining effluents and flooding resulting from reservoir development produced toxic contamination in water bodies with little or no population pressure. Another human impact, which is not associated with a lake's drainage basin population density, is the emission of acidic and toxic materials in other basins to the atmosphere and its deposition in many other distant basins. While these effects are more measurable in eastern Canada, both the west and the arctic are now receiving measurable depositions of these materials. The water management response to the degradation of lake environments in Canada has been vigorous, particularly in dealing with eutrophication. Several lakes in the survey have responded to point source phosphorus controls as indicated by the disappearance of nuisance algal blooms and their associated water use problems. Point source controls on toxic chemical discharges have also led to lower concentrations of contaminants. Unfortunately, non-point sources and recycling within the aquatic environment of persistent compounds has

limited the decline of some contaminants and they may still be too high for optimum ecosystem functioning and evolution. The experience of water quality management agencies in Canada has shown that long-term monitoring of lake water, sediments, and biota is a very effective way of providing early signs of water quality problems and of measuring the success of water quality management programs.

RÉSUMÉ

Les propriétés limnologiques de 42 lacs au Canada ont été évaluées à l'aide du questionnaire préparé par le Comité international sur l'environnement des lacs. En général, ces lacs ont été choisis comme représentatifs des lacs de sept régions naturelles, soit les régions : de l'Atlantique, des Grands Lacs et des basses-terres du Saint-Laurent, du bouclier boréal et du bouclier de taïga, des plaines de taïga, des plaines boréales et des Prairies, de la Cordillère, et de l'Arctique. Les propriétés limnologiques de chaque groupe de lacs étaient fortement influencées par le climat et les caractéristiques géologiques ainsi que par les caractéristiques hydrologiques et morphologiques de chaque lac. Les activités humaines dans chaque bassin versant modifiaient ces caractéristiques de base à un degré plus ou moins grand selon la densité de la population. Toutefois, les effluents des exploitations minières de métaux et les inondations découlant de la construction de réservoir ont libéré des contaminants toxiques dans des plans d'eau présentant peu ou pas de pression démographique. Une autre répercussion sur l'homme, qui n'est pas associée à la densité de population du bassin versant d'un lac, est l'émission dans l'atmosphère de substances acides et toxiques d'autres bassins et leur dépôt dans de nombreux autres bassins éloignés. Même s'il est plus facile de mesurer ces effets dans l'est du Canada, ces dépôts sont maintenant mesurables dans l'Ouest et l'Arctique. L'intervention en matière de gestion des eaux face à la détérioration de l'environnement des lacs au Canada a été vive, notamment dans le cas de l'eutrophisation. Les mesures de contrôle des émissions ponctuelles de phosphore ont été efficaces pour plusieurs lacs, comme le montrent la disparition des fleurs d'eau nuisibles et les problèmes connexes d'utilisation de l'eau. Des mesures de contrôle des sources ponctuelles au niveau des rejets de produits chimiques toxiques ont également entraîné des concentrations plus faibles de contaminants. Malheureusement, les sources diffuses et le nouveau cycle dans le milieu aquatique des composés persistants ont limité l'élimination de certains contaminants, et leur concentration peut être encore trop élevée pour que l'écosystème puisse fonctionner et évoluer à sa capacité maximale. D'après l'expérience des organismes responsables de la gestion de la qualité de l'eau au Canada, la surveillance à long terme de l'eau des lacs, des sédiments et du biote est un moyen très efficace de

déceler les premiers signes de problèmes au niveau de la qualité de l'eau et de mesurer la réussite des programmes de gestion de la qualité de l'eau.

INTRODUCTION

This survey of the state of Canadian lakes originated when the International Lake Environment Committee (ILEC) proposed a large data gathering exercise in Canada in the winter of 1988. The National Water Research Institute (NWRI) received support from ILEC to conduct the survey which was undertaken in collaboration with Brock University. The survey was carried out using a comprehensive questionnaire developed by ILEC. It was sent to scientists and water quality managers in government agencies and universities across Canada. The questionnaire focussed on limnology and the impacts of eutrophication, siltation, acidification, and toxic contamination.

There have not been many reviews of Canadian lake environments. Larkin (1964) published a comparative study of the factors controlling biological productivity in the larger lakes of Canada. More recently, Janus and Vollenweider (1981) compiled the Canadian contribution to the OECD Cooperative Programme on Eutrophication. This data set was used to test the applicability of the OECD relationships elaborated from European and other North American lakes. It was found that the Canadian lakes behaved in a similar manner to the OECD lakes with respect to annual mean chlorophyll and annual mean phosphorus concentrations although a number of exceptions were identified. The 110 lakes assessed were mostly in the southern portion of Canada. The acidification issue, for lakes in eastern Canada, was reviewed by Jeffries et al. (1986).

To date there has not been a review of Canadian lakes which attempted to assess limnological information simultaneously with lake resource issues like eutrophication, toxic contamination, acidification, siltation and fishery concerns. We believe this is the first attempt.

NATURAL LAKE REGIONS

A quick glance at the map of Canada reveals a land studded with lakes varying in area from tiny ponds to Lake Superior, the largest fresh water lake in the world. On large scale maps there are areas that seem to be devoid of lakes but there are small lakes and ponds everywhere in Canada. Even in the drier parts of the prairies, many wetlands and small lakes exist because snow accumulations are sufficient to make up for evaporation during summer.

The number of lakes in Canada has only been quantified for lakes with areas greater than 100 km^2 (Canadian National Committee, 1975). In Figure 1, the area distribution of the 578 lakes in this class is compared to the area distribution of the 42 lakes in our survey. One can see that to truly reflect the condition of lake environments in Canada, a vast number of smaller lakes would have to be assessed. For example, the logarithmic increase in the number of lakes below 1000 km^2 suggest that there could easily be a million lakes under 1 km^2. This survey of 42 lakes is about equally distributed between lakes greater than 100 km^2 (20 lakes) and lakes less than 100 km^2 (22 lakes). As such, the survey overemphasizes Canada's larger lakes but this probably more equitably represents their importance to its economy and society.

The physiographic, geological and climatological zonation of Canada is fairly distinct and lakes in these zones have similar characteristics. While there are fifteen recognized ecozones in Canada (Environment Canada, 1982), lake regions are not as distinct and they can be grouped in fewer zones. There are, however, many instances when lakes cannot be assigned to one zone because they exist at the boundaries between zones. Figure 2 shows the results of combining the following thirteen zones into five zones: the three zones in the Arctic, the Taiga and Boreal Shield region, the Taiga and Hudson Bay Plains, the Boreal Plain and Prairie and the four Cordilleran zones. This process leaves us with seven proposed lake regions: (1) Arctic; (2) Taiga Plain; (3) Boreal and Taiga Shield; (4) Boreal Plain and Prairie; (5) Cordilleran; (6) Great Lakes and St. Lawrence Lowland; and (7) Atlantic. Two sets of large lakes in Canada have water characteristics modified by tributary contributions from two zones. Firstly, the drainage basin of the Great Lakes includes a section of the Boreal Shield but the lakes are also influenced by the geological and climatological zone to the south. Secondly, the large great lakes of western Canada tend to occur along the geological boundary of the Precambrian Shield rocks and the Paleozoic (carbonate) rocks of the Boreal and Taiga Plains.

In each region a number of lakes were selected which had sufficient information to complete more than half the questionnaire. This selection was not exhaustive and there are more lakes in Canada with this amount of information than the 42 decribed here.

1. Arctic Lakes (Figure 3)

Lakes in this region are exposed to the Arctic climate while the geology varies from Precambrian in the southeast to Mezozoic and Palaeozoic rock in the northwest. There are many large lakes, particularly in the southeastern sector on the shield. Lakes are less numerous in the High Arctic which is actually a cold desert while along coastal plains and poorly drained inland areas, particularly in the western sector near the Mackenzie Delta and Yukon, thermokarst lakes are dominant.

The four examples chosen from this zone are extremely varied as well although there is no thermokarst example. Hazen, the most northerly lake in our survey at 81° North, is a large very deep lake fed by glaciers flowing down from the Grant Land Mountains of Ellesmere Island. Without glacier melt, the lake would probably not exist as the precipitation is only 2.5 cm per year. The lake has only one fish specie (Arctic Char, *Salvelinus alpinus*) and rarely loses its ice cover during the short arctic "summer" when the air temperature rises above 10°C for about a month. Char on Cornwallis Island in the central part of the High Arctic is a small lake used as a drinking water reservoir for the village of Resolute Bay. It was the subject of intensive liminological investigations (Rigler *et al.*, 1978) under the auspices of the IGP between 1968 and 1973.

Another High Arctic lake example was Garrow which is the only meromictic lake in this survey and is presently used as a tailings waste dump for a lead/zinc mine.

Our final example for the zone is P+N which was a nameless lake experimentally eutrophied with phosphorus and nitrogen nutrients between 1979 and 1983. The data used here, however, refer to the conditions before this perturbation. The lake is probably typical of the many headwater lakes dotting the landscape in the Shield area of the southeastern zone of the Arctic.

Some common features of these lakes are the low biological diversity and productivity, the short duration of ice-free conditions which occur every year. Human disturbance of these lakes has been low except for Garrow because of the extremely low population densities.

2. **Taiga Plains (Figures 3 and 4)**

This lake zone is characterized by large rivers draining off the shield in the case of the Hudson Bay lowlands and off the western mountains, the Boreal Plain and the Shield in the case of the Taiga Plains in the Northwest Territories. Lakes are not as numerous as bogs and other wetlands. In the more northerly part of this two-part zone lie two of the large western great lakes; Great Bear and Great Slave. While Great Bear is almost surrounded by the zone and receives much of its water from the area, Great Slave is half in and half out and receives much of its water from the Rocky Mountains via the Athabasca and Peace Rivers. Great Bear is the only example in our survey from this zone but it cannot be considered typical. It is the seventh largest fresh water lake in the world. It is monomictic and very deep at 446 m. There has been some mining in the drainage basin (e.g., uranium, radium, gold and cobalt) but the human population nearby remains tiny mostly engaged in running tourist services like fishing and hunting camps.

3. Boreal and Taiga Shield Lakes (Figure 4)

This lake zone is largest in area and contains the most lakes. The Precambrian Shield which underlays most of the area is made up of intrusive rocks which are resistant to weathering. Most of the lakes have bogs and other wetlands in their drainage basins. The region experiences heavy snow accumulations, especially in the eastern section. Population density is low now and liable to stay that way as the limited soils and harsh climate limit agricultural development. While mining and forestry are the main economic activities, the development of tourism (hunting, fishing, canoeing) and of hydro-electric generation has become important in certain sectors.

Hydro-electric development in the zone has led to the flooding of vast expanses of forest and wetlands. In the last 40 years, over 8000 km^2 of new "lakes" have been created. In many of the reservoirs, the fishery of the original lakes and rivers has been damaged because of high mercury concentrations in the fish which seems to occur when these soils and forest debris are submerged (Bodaly *et al.*, 1984, and Messier and Roy, 1987).

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Two other impacts have become noticeable in the southeastern portion of the region: 1) the occupation of lake shorelines, within a half day drive from major urban centres, by summer cottages; and 2) the deposition of acid rain originating in the industrial areas of the U.S.A. and Canada to the southwest.

The lakes chosen in this region include four large reservoirs (Caniapiscau, La Grande 2, Manicouagan and Southern Indian), three small lakes (Rawson, Laflamme and Whitepine), one lake surrounded by cottages (Muskoka) and one lake in an isolated national park (Western Brook). They all tend to have pH's less than seven except for those lakes that have some sedimentary rocks in their drainage basin (i.e., Western Brook and Southern Indian). The lake with the lowest pH (5.6) was Whitepine, near the large nickel smelter at Sudbury, Ontario. Intensive acid rain impact studies have been conducted at Whitepine and Laflamme which is a small lake within a large forestry study area near Quebec City.

Eutrophication is a problem in Muskoka which is surrounded by vacation cottages and has several large towns in its drainage basin. Rawson is in the Experimental Lakes Area where the now famous tests of the role of phosphorus in lake eutrophication were undertaken (Schindler and Fee, 1974).

As mentioned earlier, mercury is a problem in at least six of the chosen lakes and in Southern Indian the native food fishery is further limited by taste and flesh quality problems. Southern Indian has also experienced a significant siltation problem. This is caused by the flooding of large areas which are underlain with permafrost. The resulting unstable shorelines may take many decades to come into equilibrium (Newbury and McCullough, 1984).

4. **Boreal Plain and Prairie Lakes (Figure 5)**

This lake zone is dotted with smaller and shallower lakes than the other regions. The lakes occur in depressions in the glacial drift that covers most of the region. Some of the lakes occupy river and meltwater channels which now carry much less water than when they were being formed. The northern part of the region is covered with discontinuous aspen forest while the prairie region is generally devoid of trees except near lakes and small ponds. Agricultural development in both sub-regions, especially the prairie sector, has been extensive; concentrating on the production of grain, oil seed and cattle.

Eutrophication has been accelerated in most of the lakes surveyed because of agricultural and urban runoff as well as sewage treatment plant effluents. The region has fairly phosphorus-rich soils and it is likely that many of the lakes would be naturally eutrophic or at least mesotrophic in the absence of these developments (Allan and Williams, 1978). For example, in 885, the production of annually stocked fish is very high because of the high production of zooplankton in these shallow and nutrient-rich systems. Because oxygen depletion under ice in winter is severe, native fish cannot survive and the introduced fish have no competitors (Barica, 1987). Commercial fishing is also operating in Buffalo Pound and Katepwa, although in this case it is a carp fishery. Unfortunately, eutrophication in these two lakes has added significant costs to the City of Regina which draws water from Buffalo Pound for drinking requiring it to extensively treat the water and Katepwa has been receiving treated sewage effluent from the same city obligating it to improve treatment facilities.

In Amisk Lake, one of the symptoms of eutrophication, severe hypolimnetic oxygen depletion, is being fought with the direct injection of oxygen during the winter under ice and during the thermally stratified period in mid-summer. Baptiste is also prone to oxygen depletion which is made more intense because the lake is often incompletely mixed during fall overturn. Wabamun is shallower (11 m) and has a long fetch aligned with the prevailing wind so oxygen depletion rates are compensated by natural re-aeration.

In some areas of this region, saline lakes occur and one example is Miquelon near Edmonton. Surprisingly it does not develop the expected levels of chlorophyll that a total phophorus concentration of 135 micrograms per litre would be expected to produce. The relatively high salinity (3 to 5 g/L) may inhibit the algal populations presently inhabiting the lake (Bierhuizen and Prepas, 1985). The lake's pH of 9.3 is the highest in this survey.

Where measured, the most commonly used herbicides are detectable (e.g., Lindane and 2,4-D). Unfortunately environmental impact of this contamination cannot be evaluated as no comprehensive aquatic ecosystem studies have been undertaken.

5. <u>Cordilleran Lakes</u> (Figure 6)

Larkin and Northcote (1958) characterized the lakes in this complex region and divided it into nine sub-zones. For the purposes of this more general survey, however, only four sub-regions have been adopted. The Coastal sub-zone experiences very heavy precipitation and at higher elevation snow fall maintains permanent snow fields and glaciers. The valleys, however, are mild most of the year. The Montane sub-zone is quite heterogeneous with successive sectors of rain shadow and moist mountain ranges as one transects the area from the Coastal Mountains on the west to the Rocky Mountains in the east. There are some saline lakes in plateaux areas which contrast the glacier fed lakes occurring in valleys. The Boreal sub-zone is much cooler and wet in summer than the Montane. Lakes near the western sector receive much of their water supply from glaciers in the Coastal Mountains. The Tundra sub-zone has a climate similar to the Arctic although the mountainous geography modifies climate to a certain degree.

Because of the mountainous nature of the region, urban centres and their associated industries tend to be situated along the lakes and rivers in the valleys. Measurable eutrophication and contamination has occurred in these lakes.

Acid rain is not a problem in the Cordilleran region although the ability of lake drainage basin soils to neutralize acid rain is particularly low in the southeast. Mining and pulp and paper production have adversely affected some lakes and their fisheries. Contamination from agricultural activities occurs in the Okanagan Valley lakes which are surrounded by fruit tree and grape orchards.

There were two lakes from Vancouver Island selected for the Coastal sub-zone. The highly variable geology of the island can lead to significant differences in water quality. For instance, Buttle lies in a drainage basin dominated by volcanic Triassic and sedimentary Palaeozoic rocks and total phosphorus in the water is near 5 microgram P/L. In contrast, Great Central lies in a drainage basin dominated by Triassic granitic rocks and only has water concentrations of 1.5 microgram P/L. Such a low concentration results in low algal biomass and low fishery production. The algal biomass in Great Central is enhanced by annual aerial fertilization with ammonium phosphate and nitrate to help increase the growth rates and ocean survivability of salmon (O. nerka) (Le Brasseur et al., 1978). This program has been very successful in producing larger runs of returning adult fish for the commercial fishery. The algal biomass in Buttle was inhibited by effluents from a copper-lead-zinc mine which has recently implemented pollution controls.

The survey included six lakes from the Montane subregion. From the Okanagan valley, three lakes were selected which illustrated the effect of size and flushing rate on the extent of eutrophicaion. Wood, Okanagan and Skaha are part of a chain of lakes which received effluents from primary sewage treatment plants until studies in the early 1970's identified the key role of phosphorus in the water quality problems that became noticeable in the 1960's. Tertiary treatment at the sewage treatment plants reversed this eutrophication process although continued urbanization has increased phosphorus loading lately. The limnological response to phosphorus loading decreases and increases was most rapid in Skaha which has the shortest hydraulic residence time (one year).

The other three lakes chosen in this sub-region were all short residence time lakes with large drainage basins covered by forests except for the valley bottoms.

While some bays of Shuswap are showing signs of eutrophication because of agricultural and urban runoff, much of the water supplied to the lake comes from terrain dominated by schists and gneisses which results in low nutrient loading. The lake supports a valued sport fishery and a very important sea-run salmon stock.

Kamloops downstream from Shuswap receives effluents from a pulp and paper mill and a sewage treatment plant serving 60,000 people. Because high natural turbidity, water quality problems have not occurred in the lake but downstream in the outlet river benthic algae have profilerated especially after the pulp mill expanded. Significant improvements have been observed as controls on phosphorus and chemical discharges have been strengthened.

Kootenay is a unique example of eutrophication followed by oligotrophication to a less productive state than that which occurred naturally (Daley et al., 1981).

Initially, concentrations of phosphorus were increased to more than 100 microgram P/L by discharges of a fertilizer factory 200 km upstream. These discharges were eventually controlled and additional nutrient losses occurred in a reservoir subsequently constructed upstream. The lake's ecosystem is also adjusting to the zooplankton, *Mysis relicta*, which was introduced to enhance food resources for the sport fishery in 1949. The results of this introduction were thought to be good initially but the fishery is now less productive. It is possible that the oligotrophication and/or the altered food web are responsible.

The three lakes chosen in the Boreal sub-region are charactrized by long periods of ice cover and high turbidity which lowers plankton productivity. Williston is a large new reservoir (1780 km^2) completed in 1967. Laberge is the last in a series of headwater lakes of the Yukon River which behaves much like a reservoir. It is a good site to study limnological processes that would be dominant in sub-arctic reservoirs which may be proposed as the region is developed. The outlet of Aishihik Lake has been harnessed for hydroelectricity since 1972. Here, shoreline erosion has been increased where permafrost occurs.

6. Great Lakes/St. Lawrence Lowland Lakes (Figure 7)

Almost one-third (7.5 million in 1981) of Canada's population lives within the drainage basin of the Great Lakes and counting the Canadian population living downstream in the entire St. Lawrence River drainage basin brings the portion to one-half. Of the five major lakes in the system, one

(Michigan) is entirely within the U.S. and therefore was not part of this study, and the remaining four (Superior, Huron, Erie, and Ontario) form part of the boundary between the U.S. and Canada. The total population of the Great Lakes Basin is 37 million.

The Great Lakes/St. Lawrence system profoundly influenced the development pattern of the North American continent. This region became among the first interior areas to be settled by Europeans. The rich agricultural soils and the abundance of water for consumptive uses and navigation provide great economic advantages for large industrial enterprises. Throughout the 19th and 20th centuries interconnecting waterways between the lakes have been altered for shipping and canals were constructed between Erie and Ontario and the Hudson River which gave early access to the Atlantic seaboard. Today the St. Lawrence Seaway enables ocean traffic to travel to the head of the lakes from its access point at Montreal. Large shore-based industrial cities such as Toronto on the Canadian side and Buffalo, Cleveland, Detroit and Chicago on the U.S. side sprung up in response to these transportation routes.

The Great Lakes form a lake region on their own as they occupy a major boundary of climate and geology in North America. Much of the drainage basins of Superior, Huron, and to some extent Ontario, are on the Shield while the southern shores of Huron and all the shores of Erie and Ontario are underlain by sedimentary Palaeozoic rocks. As well, the climate of the region is characterized by frequent collisions of continental polar and maritime tropical air masses, both of which are modified as they cross over the lakes.

Two major water quality issues have been addressed in the region over the last 20 years. The first concern was eutrophication caused by accelerating phosphorus loading increases from industrial, agricultural and residential development. In Erie, a combination of morphometry and relatively high phosphorus regeneration from sediments made it more sensitive to these loading increases than the other lakes. There were frequent algal blooms and vast areas of the lake's central basin became anoxic in the hypolimnion. Local newspapers pronounced the lake "dead" in the late 1960's. The situation helped hasten the arrival of the Great Lakes Water Quality Agreement between the U.S.A. and Canada which, among other items, recommended that phosphorus loading be controlled. After loading criteria were adopted in 1972 which were based on Vollenweider's (1971) revolutionary analysis of the causes of lake eutrophication, the concentrations have declined in the two lower lakes, remained constant in Huron and risen slightly in Superior (due to population increases). The biological response has been less dramatic but chlorophyll concentrations have declined somewhat in Erie and Ontario. Shoreline growth of attached algae like *Cladophora* has not been as heavy in recent years and the depletion of oxygen in Lake Erie's central basin has not become more intense (Great Lakes Water Quality Board, 1987).

The second concern was the contamination of the ecosystem with metals and persistent organic chemicals. In the early 1970's, commercial fisheries for Walleye (*Stizostedion vitreum*) in Erie were closed because of high concentrations of mercury in the fish. While this fishery is now open, there is an ongoing problem with organochlorine residues in older and larger fish like trout, salmon, carp, and catfish throughout the lakes. There are annual guidelines published by natural resource agencies advising sports fishermen which species are safe to eat, which ones can be eaten infrequently, and which ones should not be eaten. Perhaps the most affected component of the ecosystem was the wildlife that lived on fish. These include bald eagles, cormorants, gulls and mink. These species have all experienced reproductive and developmental problems, especially during the 1960's and 1970's. Latest evidence suggests that the contamination levels have decreased in the birds in response to lower concentrations in their food and this has led to increasing populations (e.g., cormorants now have 1.3 young/pair as opposed to 0 in the early 1970's (Price and Weseloh, 1986)). Unfortunately, the contamination levels in fish have ceased declining rapidly even though most point sources have been controlled. More direct efforts at decontamination of non-point sources like sediments are being planned for 42 particualrly polluted localities along the Geat Lakes shores.

While the present focus of environmental management has been on the control of toxic chemical inputs, emerging issues are the control of accidental exotic species introductions (e.g., Zebra mussel, Polymorpha dreissena), restoration of shoreline wetlands and optimizing fish stocking strategies within natural limnological and ecosystem constraints.

Besides the Great Lakes in this lake zone, there are many medium size lakes which are locally important. These lakes are intensively used for recreation as their drainage basin population densities are the highest of the six lake regions. The three lakes chosen (Simcoe, Memphremagog and Massawippi) are all experiencing some symptoms of eutrophication and contamination but not acidification because the calcareous nature of the soils have neutralized acid input until now. The larger and older fish in these lakes contain low but measurable quantities of mercury and in some cases organochlorine pesticides and industrial chemicals. For some species, human consumption is restricted to a few meals per year or not at all depending on the concentrations. While the point sources of the organochlorine compounds are being controlled, atmospheric redistribution of these compounds is occurring and even remote headwater lakes will continue to be contaminated to some degree. The major sources of mercury on the other hand is thought to be natural in this region. Whether disturbance of the drainage basin soils and/or acid rain has increased its annual loading to the lakes is a matter of current research.

7. Atlantic Lakes (Figure 7)

This region has a climate and physiography which is fairly distinct from the Boreal Shield zone to the north and the St. Lawrence Lowland zone to the west. While the climate is mostly like that of the lower St. Lawrence, areas close to the cold Atlantic, like Cape Breton Island and the shores of the Bay of Fundy, have a Boreal climate. The geology is complex because Appalachian mountain building has strongly modified the sedimentary and intrusive landforms originating in Mesozoic, Palaeozoic, and Precambrian eras. Because of this complexity, the characteristics of the lakes in this zone cannot be generalized. The one example we have from this zone was Kejimkujik, in Nova Scotia, which is a headwater lake in an area dominated by acidic Palaeozoic intrusive rocks. The area is also exposed to more than 20 kg/ha/yr of wet sulphate deposition from acid rain. These two features result in the lowest lake pH in our survey (4.8). In fact, of 232 lakes sampled for pH in Nova Scotia, 39% had a pH less than or equal to 5 (Jeffries et al., 1986). Even though some areas of New Brunswick have greater acid deposition than Nova Scotia, only 7% of 84 lakes tested had pH's less than or equal to 5. Most of New Brunswick is underlain with sedimentary rock which imparts soils with more buffering capacity.

Many of the lakes are used for recreation although they may become important drinking water reservoirs if water demand exceeds groundwater supplies or the present sources become contaminated by agricultural and forestry chemicals.

CONCLUSIONS

This survey of Canadian lakes has highlighted a significant portion of the limnological research and monitoring that government agencies and universities have undertaken in the last twenty years. Many of the studies were initiated in response to perceived water quality problems so much of the information is on eutrophication, acidification, and contamination. In contrast, only a few pristine lake systems have been studied compared to the lakes with water quality problems. Accordingly, this survey tends to paint a picture of general degradation of Canadian lake environments which is not representative of the more than a million lakes within our country. With respect to the lakes included in the survey, the picture is only qualitative as there is no recognized scale of degradation with which to quantitatively assess the situation. There are, of course, well recognized scales for eutrophication (ultraoligo-, oligo-, meso-, eu-, and hypereutrophic) and for acidification (<5, <5.5, <6, >6 pH). Figures 8 and 9 show the frequency distribution of chlorophyll and pH in the survey. Using the chlorophyll scale (Janus and Vollenweider, 1981) for eutrophication, seven lakes are ultra-oligotrophic, eleven are oligotrophic, nine are meso-trophic, six are eutrophic, and one is hypereutrophic. This scale, like most others, does not however indicate if there have been changes in the trophic status from that which might have been prevalent before large scale human colonization of the lake drainage basins. The detail in the questionnaires documents the fact that while many lakes in Canada are certainly more eutrophic than they were, the recent evidence shows a reversal of this trend in response to phosphorus controls in laundry detergents and in sewage treatment plants.

Using the pH scale, only five lakes in the survey were below pH 6. Once again this does not indicate whether the pH's in the lakes above this level have been declining or increasing. It is recognized that, in general, lake pH's have been declining in northeastern North America, especially in those drainage basins with little soil buffering capacity. Recent policy announcements and legislation in both Canada and the U.S.A. will result in cutbacks of SO_2 emissions from all sources which is encouraging for the future.

Unfortunately, scales for contamination, salination, and siltation await development. As a result, the evaluation of the seriousness of contamination, for example, remains a qualitative judgement with no yardsticks to fully measure the situation in all its facets. For instance, the long history of contaminant investigation in the Great Lakes has shown trends in concentrations of a variety of metals and organochlorine compounds in water, sediments, and biota, but the earlier work probably missed important ecological effects which are only now being quantified (Colborn et al., 1990). While new tests will undoubtedly show ecosystem impacts at present contaminant concentrations, these concentrations have been declining in recent years in the Great Lakes in response to controls of toxic chemical releases from all sources in the drainage basin. It is hoped that similar trends will be evident in the other lakes in this survey because similar controls are being implemented throughout Canada. Several problems remain, however. One problem is the redistribution of toxic chemicals already released to the environment. This redistribution is mediated by the atmosphere and the movement of migratory birds, mammals, reptiles, and fish from contaminated areas to pristine zones. The relative impact of this "creeping" contamination will be an important area of research in the next decade. Some of the lakes in this survey have probably been contaminated by the atmospheric and animal migration route as there is very little industrial, residential or agricultural development in their drainage basins. Some of the atmospherically derived chemicals are arriving from other continents.

Another problem is the continual contamination of lakes from their sediments. While decontamination reactions and ultimate burial tend to lessen this problem over time if loadings are stopped, the time required for the lake's biota to show negligible concentrations may be decades. In these cases, sediment removal or remediation will have to be implemented. Predicting the clean-up time in lakes is now an active research subject in Canada.

Siltation was a problem in the northwestern reservoirs in this survey which had permafrost in their shorelines. Sedimentation rates in other western lakes and reservoirs were often high due to natural erosion in their drainage basins but their large mean depths will forestall the infilling of these lakes for many centuries.

Salination was only identified in one lake and it may be a natural process. The process, however, is a concern for much of the prairie lake region, especially if the climate warming scenario is correct. The salination of soils in this zone which results from the agricultural practices would eventually lead to salination of many water bodies.

While the overview of the problems encountered and identified in this survey could be a little pessimistic, we think that these impacts will diminish especially in southern Canada where pollution effects have been greatest. On the other hand, the status of the more northerly lakes is very good but it may decline over the next few decades as there are more visitors or residents who, by their activities, affect the fish and wildlife populations through harvest, disturbance, contamination, or the introduction of exotic species. Also, the status of northern reservoirs which have been constructed or are being planned will be dependent on the way the land is cleared before or after flooding as this affects the level of mercury contamination in the fish populations. This natural but accelerated mercury contamination takes a long time to subside as experience in more southerly reservoirs shows. Research on methods to remediate or prevent this potentially large areal contamination by mercury is sorely needed.

This Canadian survey and the worldwide ILEC survey has demonstrated the important fact that lakes and reservoirs are sensitive indicators of environmental processes and human impacts on those processes throughout their drainage basins and even beyond them because of the atmospheric linkage. Long-term comprehensive monitoring of representative lakes in all of the world's lake regions should begin at once so that water quality problems are quickly identified and used as the evidence required to ensure that benign residential, agricultural, industrial and extractive resource development is practised. As population densities increase around the world, the impact by each person will have to be decreased just to keep impacts at present levels, which, in many cases, are now too high to ensure optimum aquatic ecosystem functioning and evolution.

To attain the goal of sustained ecosystem health, there will have to be a significant shift in the focus of water management. To date, water management technique has involved the implementation of policies to maintain water quality sufficient for specific water uses (e.g., irrigation, drinking, swimming, industrial processes). In many cases, these policies do not ensure the viability of the aquatic biological resource because its use may not be high now or it may not be as economically valuable as the water uses. Setting water quality standards which ensure the long-term functioning and evolution of aquatic ecosystems will result in meeting the objectives for both water resource uses as well as the ecosystem's survival.

REFERENCES

Allan, R.J. (1991). An historical overview of toxic chemical concentrations and trends in water and sediments of the Laurentian Great Lakes. (These Proceedings.)

Allan, R.J. and Williams, J.D.H. (1978). Trophic status related to sediment chemistry of Canadian Prairie lakes. J. Environmental Quality 7: 99-106.

Bierhuizen, J.F. and Prepas, E.E. (1985). Relationship between nutrients, dominant ions and phytoplankton standing crop in prairie saline lakes. Can. J. Fish. Aquat. Sci. 42: 1588-1594.

Barica, J. (1987). Water quality problems associated with high productivity of prairie lakes in Canada: a review. Water Quality Bulletin 12: 107-114.

Bodaly, R.S., Hecky, R.E. and Fudge, R.J.P. (1984). Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. Can. J. Fish. Aquat. Sci. 41: 682-691.

Canadian National Committee (1975). Canadian Survey on the Water Balance of Lakes. International Hydrological Decade Report. Environment Canada, Ottawa.

Colburn, T.E., Davidson, A., Green, S.N., Hodge, R.A., Jackson, C.I. and Liroff, R.A. (1990). Great Lakes: Great Legacy? The Conservation Foundation (Washington, DC, U.S.A.) and The Institute for Research on Public Policy (Ottawa, Canada).

Daley, R.J., Carmack, E.C., Gray, C.B.J., Pharo, C.H., Jasper, S. and Wiegand, R. (1981). The effects of upstream impoundments on the limnology of Kootenay Lake, B.C. Inland Waters Directorate Scientific Series No. 117, 98 pp.

Environment Canada (1982). Ecozones of Canada. Lands Directorate, Ottawa.

Great Lakes Water Quality Board (1987). Report on Great Lakes Water Quality. Report to the International Joint Commission, Windsor, Ontario, Canada.

Janus, L.L. and Vollenweider, R.A. (1981). The OECD Cooperative Programme on Eutrophication. Canadian Contribution. Inland Waters Directorate Scientific Series No. 131.

Jeffries, D.S., Wales, D.L., Kelso, J.R.M. and Linthurst, R.A. (1986). Regional chemical characteristics of lakes in North America: Part I - Eastern Canada. Water Air, and Soil Pollution 31: 551-567.

Le Brasseur, R.J., McAllister, C.D., Barraclough, N.E., Kennedy, O.D., Manzer, J., Robinson, D. and Stephens, K. (1978). Enhancement of Sockeye Salmon (O. nerka) by lake fertilization in Great Central Lake: Summary Report. J. Fish. Res. Board Canada 35: 1580-1596.

Messier, D. and Roy, D. (1987). Concentrations en mercure chez les poissons au complexe hydroelectrique de la Grande Rivière. Naturaliste Can. 114: 357-368.

Newbury, R.W. and McCullough, G.W. (1984). Shoreline erosion and restabilization in Southern Indian Lake reservoir. Can. J. Fish. Aquat. Sci. 41: 558-566.

Price, I.M. and Weseloh, D.V. (1986) Increased numbers and productivity of double-crested cormorants, *Phalacrocorax auritus*, on Lake Ontario. Canadian Field-Naturalist 100(4): 474-482.

Rigler, F.J. (1978). Limnology in the high Arctic: a case study of Char Lake. Verh. Internat. Verein. Limnol. 20: 127-140.

Schindler and Fee (1974). Experimental Lakes Area: Whole lake experiments in eutrophication. J. Fish. Res. Board Canada 31: 937-953.

Vollenweider, R.A. (1971). Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD Environment Direcorate Report, Paris, France.

TABLE 1: Physical Characteristics

Lake	Area km²	Volume km³	Mean Depth m	Maximum Depth m	Catchment Area km²	Residence Time yr	Mixing Type	River System and Ocean Drainage
ARCTIC LAKES								
Char	0.526	0.0054	10.2	27.5	4.35	10	cMono	Direct-Arctic
Garrow	4.18	0.102	24.5	50	10.5	3	Mero-	Direct-Arctic
Hazen	452	-	-	280	-	-	Amict-cMono	Direct-Arctic
P+N	0.07	0.00023	3.3	10.2	0.029	3	cMono	Direct-Hudson Bay
TAIGA PLAIN LAKES								
Great Bear	31,153	2,236	71.7	446	114,717	124	cMono	Mackenzie R.-Arctic
BOREAL AND TAIGA SHIELDS LAKES								
Caniapiscau (R)	4285	53.8	12.6	49	36,800	2.2	Dimic	La Grande R.-Hudson Bay
Laflamme	0.06	0.00012	2	5.3	0.69	0.16	Poly-Dimic	St. Lawrence R.-Gulf of St. Lawrence
La Grande 2 (R)	2835	61.7	22	137	176,810	0.53	Dimic	La Grande R.-Hudson Bay
Manicouagan (R)	1,950	142	85	350	29,241	8	Dimic	Manicouagan R.-Gulf of St. Lawrence
Muskoka	89.4	1.39	15.5	67	1,780	-	Dimic	Huron-St. Lawrence R. & Gulf
Opinaca (R)	1040	8.5	8.2	51	36,800	0.34	Poly	La Grande R.-Hudson Bay
Rawson	0.543	0.001	10.5	30.4	0.337	6	Dimic	Nelson R.-Hudson Bay
Southern Indian (R)	2391	23.4	9.8	30	242,000	0.8		Nelson/Churchill R.-Hudson Bay
White Pine	0.67	0.0039	5.9	22	3.28	2.6	Dimic	Huron-St. Lawrence R. & Gulf
Western Brook	22.8	1.65	72.5	165	171	15.4	Dimic	Direct-Gulf of St. Lawrence
BOREAL PLAIN AND PRAIRIE LAKES								
Amisk	5.15	0.1	15.5	60	244	8	Dimic-Mero	Churchill R.-Hudson Bay
Baptiste	9.81	0.085	8.6	27	288	6	Dimic-Mero	Mackenzie R.-Arctic
Buffalo Pound	29.5	0.898	3	5.6	3,310	1.5	Poly	Nelson R.-Hudson Bay
Diefenbaker (R)	430	9.4	21.6	66	149,000	2.5	Poly	Saskatchewan/Nelson R.-Hudson Bay
Katepwa	16.1	0.232	14.4	23	12,040	-	Dimic-Mero	Nelson R.-Hudson Bay
Miquelon	8.72	0.0237	2.7	6	35.4	-	Poly	No outlet
Wabamun	81.8	0.513	6.3	11	259	100	Poly	Saskatchewan-Nelson R.-Hudson Bay
Lake #885	0.24	0.000456	1.9	3		-	Poly	Nelson R.-Hudson Bay

TABLE 1: Physical Characteristics (cont'd)

Lake	Area km^2	Volume km^3	Mean Depth m	Maximum Depth m	Catchment Area km^2	Residence Time yr	Mixing Type	River System and Ocean Drainage
CORDILLERAN LAKES								
Aishihik (R)	146	4.38	30	120	2,576	14.6	Dimic	Alsek R.-Pacific
Buttle	35.3	1.72	48.8	125	705	1	wMono	Campbell R.-Str. of Georgia
Great Central	51	6.32	124	294	308	3.7	wMono	Stamp R.-Str. of Georgia
Kamloops	52	3.7	71	143	39,000	0.16	Dimic	Fraser R.-Str. of Georgia
Kootenay	389	36.7	94	154	45,584	1.8	Dimic	Columbia R.-Pacific
Laberge	201	10.8	54	146	31,500	1	Dimic	Yukon R.-Bering Sea
Okanagan	351	24.6	76	230	6,188	53	wMono	Columbia R.-Pacific
Shuswap	310	19.1	62	161	16,200	2.1	Dimic	Fraser R.-Str. of Georgia
Skaha	20.1	0.558	26	55	828*	1.2	Dimic-wMono	Columbia R.-Pacific
Williston (R)	1,779	70.3	43	166	72,000	2.2	Dimic	Mackenzie R.-Arctic
Wood	9.3	0.2	21.5	34	190	17	Dimic-wMono	Columbia R.-Pacific
GREAT LAKES/ ST. LAWRENCE LOWLANDS								
Erie	25,700	484	19	64	84,500*	2.6	Dimic	St. Lawrence R.-Gulf of St. Lawrence
Ontario	19,100	1,640	86	245	79,600*	7.4	Dimic	St. Lawrence R.-Gulf of St. Lawrence
Huron	59,500	3,540	59	230	131,300*	21	Dimic	St. Lawrence R.-Gulf of St. Lawrence
Superior	82,100	12,100	147	406	128,000	170	Dimic	St. Lawrence R.-Gulf of St. Lawrence
Massawippi	17.9	0.745	41.6	85.7	586	1.5	Dimic	St. Lawrence R.-Gulf of St. Lawrence
Memphremagog	102	1.7	15.5	107	1,764	1.7	Dimic	St. Lawrence R.-Gulf of St. Lawrence
Simcoe	725	11.6	15	41	2,840	16	Dimic	L. Huron-St. Lawrence R.-Gulf of St. Lawrence
ATLANTIC LAKES								
Kejimkujik	26.3	0.106	4.35	19.2	289	0.17	Poly-	Mersey R.-Atlantic

* Not including drainage area of upstream lake.

TABLE 2: Chemical, Biological and Development Characteristics

Lake	TP µg/L	TN µg/L	Chlorophyll a µg/L	pH	Contaminants	Population & Density #	Population & Density #/km²	Development and Uses
ARCTIC LAKES								
Char	4	70	0.3	7.8	-	0	0	Drinking water
Garrow	10	-	0.25	7.3	Pb, Zn	150	14	Mine waste disposal
Hazen	-	-	-	7.9	-	10	>0.01	National park
P+N	7.5	500	1.5	6.8	OC's	0	0	Experimental
TAIGA PLAIN LAKES								
Great Bear	-	-	-	7.9	-	700	0.006	Sport fishing
BOREAL AND TAIGA SHIELDS LAKES								
Caniapiscau (R)	9	-	-	5.8	Hg	10	0.0003	Hydroelectric reservoir
Laflamme	42	-	-	6.3	-	0	0	Experimental
La Grande 2 (R)	15	-	4.2	6.4	Hg	25	0.0001	Hydroelectric reservoir
Manicouagan (R)	-	400	-	5.8	Hg	500	0.017	Hydroelectric reservoir, sport and commercial fishing
Muskoka	11	400	5.3	6.8	Hg	40,000	22	Residential and recreational sport fishing
Opinaca (R)	20	-	1.7	5.9	Hg	0	0	Hydroelectric reservoir
Rawson	10	300	2.5	6.5		10	29	Experimental
Southern Indian (R)	20	350	3.9	7.7	Hg	10,000	0.04	Hydroelectric reservoir, sport and commercial fishing
White Pine	4	-	1.3	5.6	-	0	0	Experimental
Western Brook	2	-	0.6	7.1	-	0	0	National park
BOREAL PLAIN AND PRAIRIE LAKES								
Amisk	45	-	10	8.3	-	100	0.4	Agriculture, recreation, sport fishing, experimental
Baptiste	55	1,000	20	7.7	-	100	0.3	Agriculture, recreation, sport fishing
Buffalo Pound	100	950	14	8.2	H, Hg	4,500	1.4	Agriculture, commercial fishing, drinking water
Diefenbaker (R)	14	520	2	8.4	H, 2,4-D, Hg	845,000	5.7	Agriculture, oil extraction, cities, irrigation water, sport fishing
Katepwa	600	1,150	-	8.2	Hg, As	300,000	25	Agriculture, cities, recreation
Miquelon	135	5,100	2.3	9.3	Saline	100	2.8	Recreation
Wabamun	32	880	12.4	8.4	-	100	0.4	Recreation, thermal electric cooling water
Lake #885	300	6,000	100	8.5	-	10	2	Agriculture, fish farming

TABLE 2: Chemical, Biological and Development Characteristics (cont'd)

Lake	TP µg/L	TN µg/L	Chlorophyll a µg/L	pH	Contaminants	Population & Density #	#/km²	Development and Uses
CORDILLERAN LAKES								
Aishihik (R)	20	-	-	-	-	25	0.009	Hydroelectric reservoir
Buttle	5	110	0.75	7.2	Cu, Pb, Zn, Cd, Hg	0	0	Mine waste disposal, hydroelectric reservoir
Great Central	1.5	230	1.2	6.7	-	60	0.19	Recreation, forest harvesting, sport fishing, fertilization for salmon enhancement
Kamloops	10	200	1.75	7.5	OC's	80,000	2.1	Forest harvesting, pulp and lumber, cities, sport fishing
Kootenay	6	-	2.0	8.0	-	50,000	1.1	Forest harvesting, pulp and lumber, mining, cities, sport fishing, recreation and hydroelectricity
Laberge	5	100	0.6	7.7	-	19,000	0.6	City, sport fishing, recreation
Okanagan	9	190	1.4	8.3	OC's, Hg	125,000	20	Cities, forest harvesting, lumber, agriculture, recreation, sport fishing
Shuswap	4	-	1.5	7.6	-	15,000	0.1	Forest harvesting, lumber, agriculture, recreation, sport fishing
Skaha	15	260	5	8.2	Chlorophenols	35,000	42	Forest harvesting, lumber, agriculture, cities, recreation, sport fishing
Williston (R)	6	130	2.5	7.0	OC's	12,000	0.17	Forest harvesting, lumber and pulp, sport fishing, hydroelectric reservoir
Wood	70	460	5.5	8.1	Hg	4,000	21	Forest harvesting, agriculture, residential development, recreation and sport fishing

TABLE 2: Chemical, Biological and Development Characteristics (cont'd)

Lake	TP µg/L	TN µg/L	Chlorophyll a µg/L	pH	Contaminants	Population & Density #	#/km²	Development and Uses
GREAT LAKES/ ST. LAWRENCE LOWLANDS								
Erie	15	350	3	8.2	OC's, Hg	12.9 Mill	15	Cities, industry, agriculture, recreation, sport and commercial fishing, drinking water, navigation
Ontario	10	500	2.5	8.1	OC's, Hg	6.6 Mill	83	Cities, industry, agriculture, recreation, sport and commercial fishing, drinking water, navigation
Huron	5	400	1.0	8.4	OC's, Hg	2.4 Mill	18	Cities, industry, agriculture, recreation, sport and commercial fishing, drinking water, navigation, mining, forest harvesting, and pulp
Superior	2.5	400	1.0	8.0	OC's	750,000	5.9	Forest harvesting, pulp, mining, cities, commercial and sport fishing, navigation
Massawippi	18	340	2.0	7.9	Hg	5,000	8.5	Recreation, sport fishing
Memphremagog	12	440	3.0	7.5	-	20,000	11	Agriculture, cities, recreation, sport fishing
Simcoe	17	-	2.0	8.2	Hg	250,000	88	Agriculture, cities, recreation, sport fishing, drinking water
ATLANTIC LAKES								
Kejimkujik	9.1	760	2.0	4.8	-	200	0.7	National park

OC's = organochlorine compounds; HCH = Hexachlorocyclohexane; 2,4-D = 2,4 Dichlorophenoxyacetic acid.

FIGURE CAPTIONS

Figure 1: Lake area frequency distribution.
Left: Canadian Lake Survey, 42 lakes.
Right: All Canadian lakes greater than 100 km^2, 578 lakes.

Figure 2: Simplified ecozones of Canada in which lakes of similar characteristics are found. All lakes and reservoirs greater than or equal to 1500 km^2 are indicated.

Figure 3: Arctic lake region, including portions of the Taiga Plain and Taiga Shield zone.

Figure 4: Boreal and Taiga Shield lake region. Taiga Plain (TP) and Atlantic (A) regions are indicated.

Figure 5: Boreal Plain and Prairie lake region. Cities are indicated by open lettering.

Figure 6: Cordilleran lake region including the coastal, montane, boreal and tundra sub-regions.

Figure 7: Great Lakes/St. Lawrence Lowland and Atlantic lake regions.

Figure 8: Growing season average chlorophyll a frequency distribution in 34 lakes from the survey.

Figure 9: Average water column pH frequency distribution in the 42 lakes of the survey.

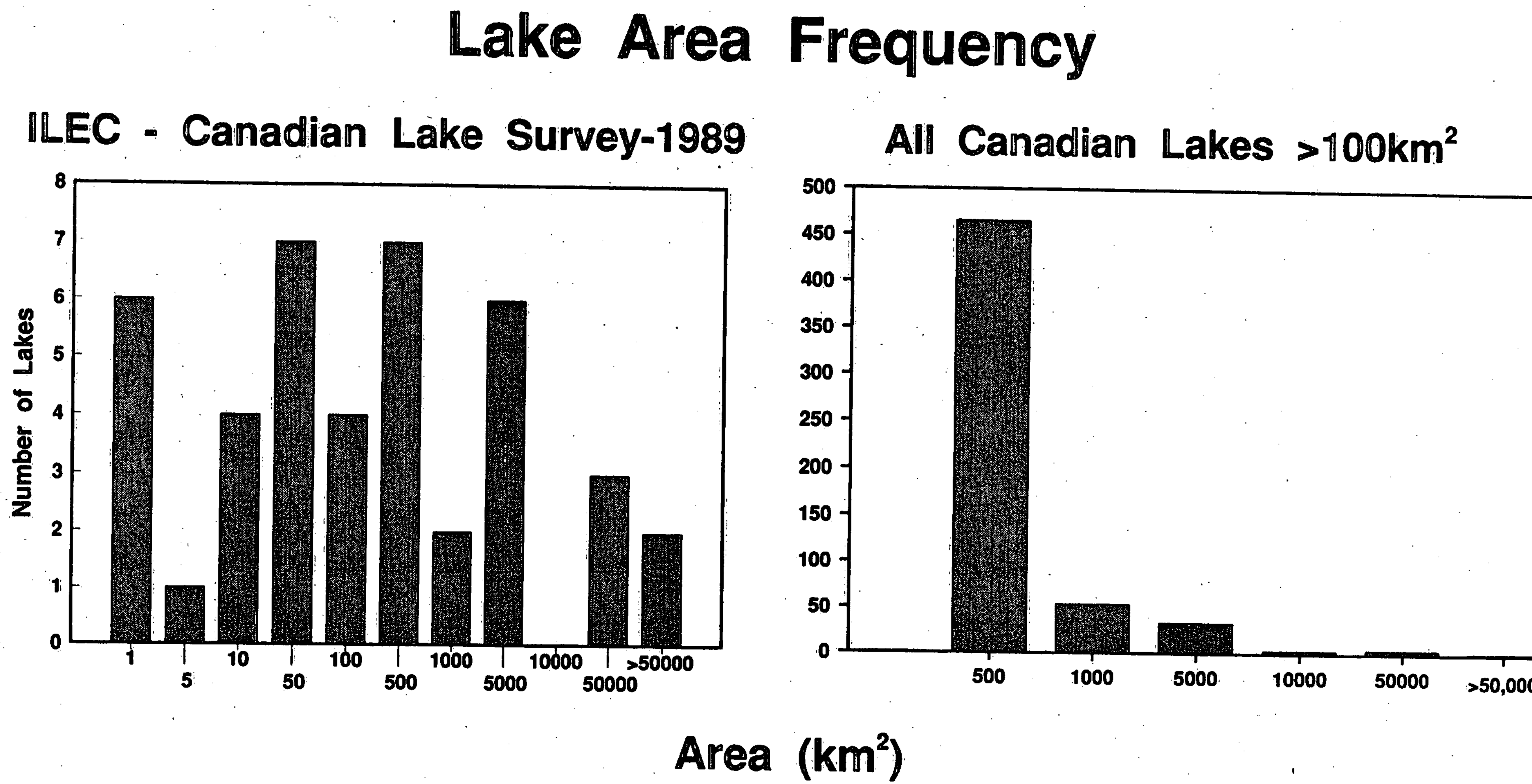
Lake Area Frequency
ILEC - Canadian Lake Survey-1989
Number of Lakes
0
1
2
3
4
5
6
7
8
1
5
10
50
100
500
1000
5000
10000
50000
>50000
All Canadian Lakes >100km²
0
50
100
150
200
250
300
350
400
450
500
500
1000
5000
10000
50000
>50,000
Area (km²)

FIGURE 1

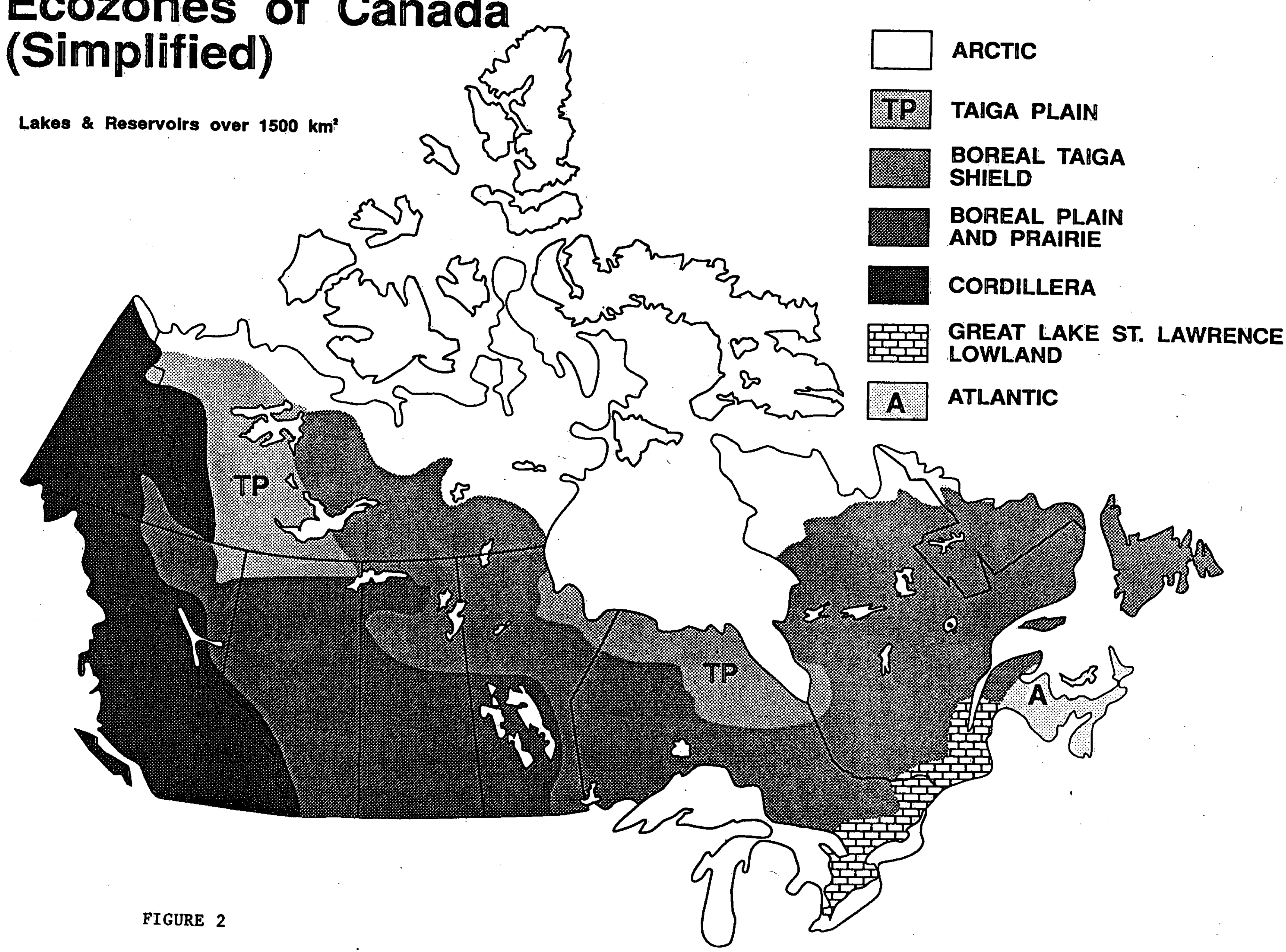
Ecozones of Canada
(Simplified)
Lakes & Reservoirs over 1500 km²
ARCTIC
TP
TAIGA PLAIN
BOREAL TAIGA SHIELD
BOREAL PLAIN AND PRAIRIE
CORDILLERA
GREAT LAKE ST. LAWRENCE LOWLAND
A
ATLANTIC
TP
TP
A

FIGURE 2

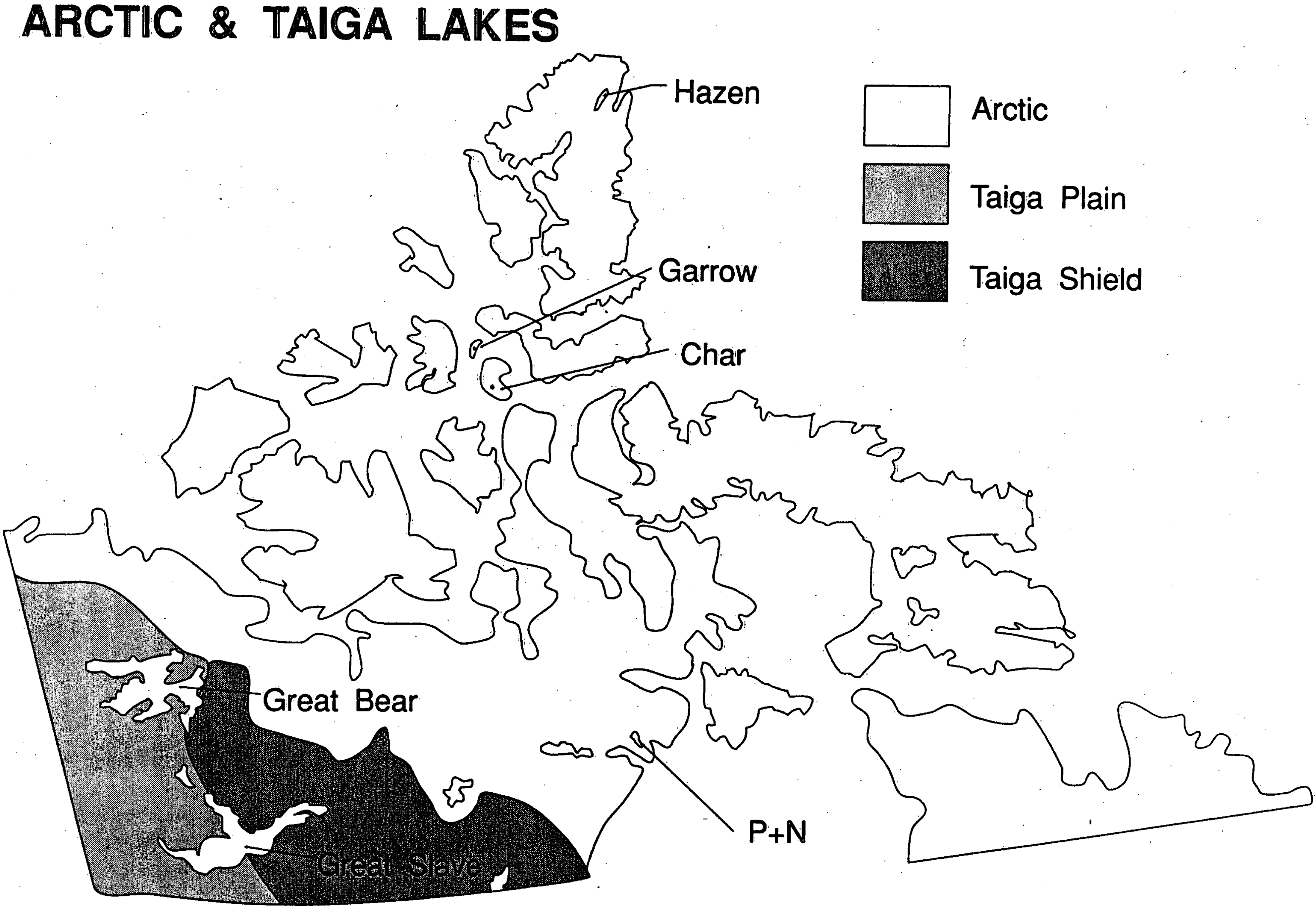
ARCTIC & TAIGA LAKES
Hazen
Garrow
Char
Great Bear
Great Slave
P+N
Arctic
Taiga Plain
Taiga Shield

FIGURE 3

Boreal & Taiga Shield Lakes

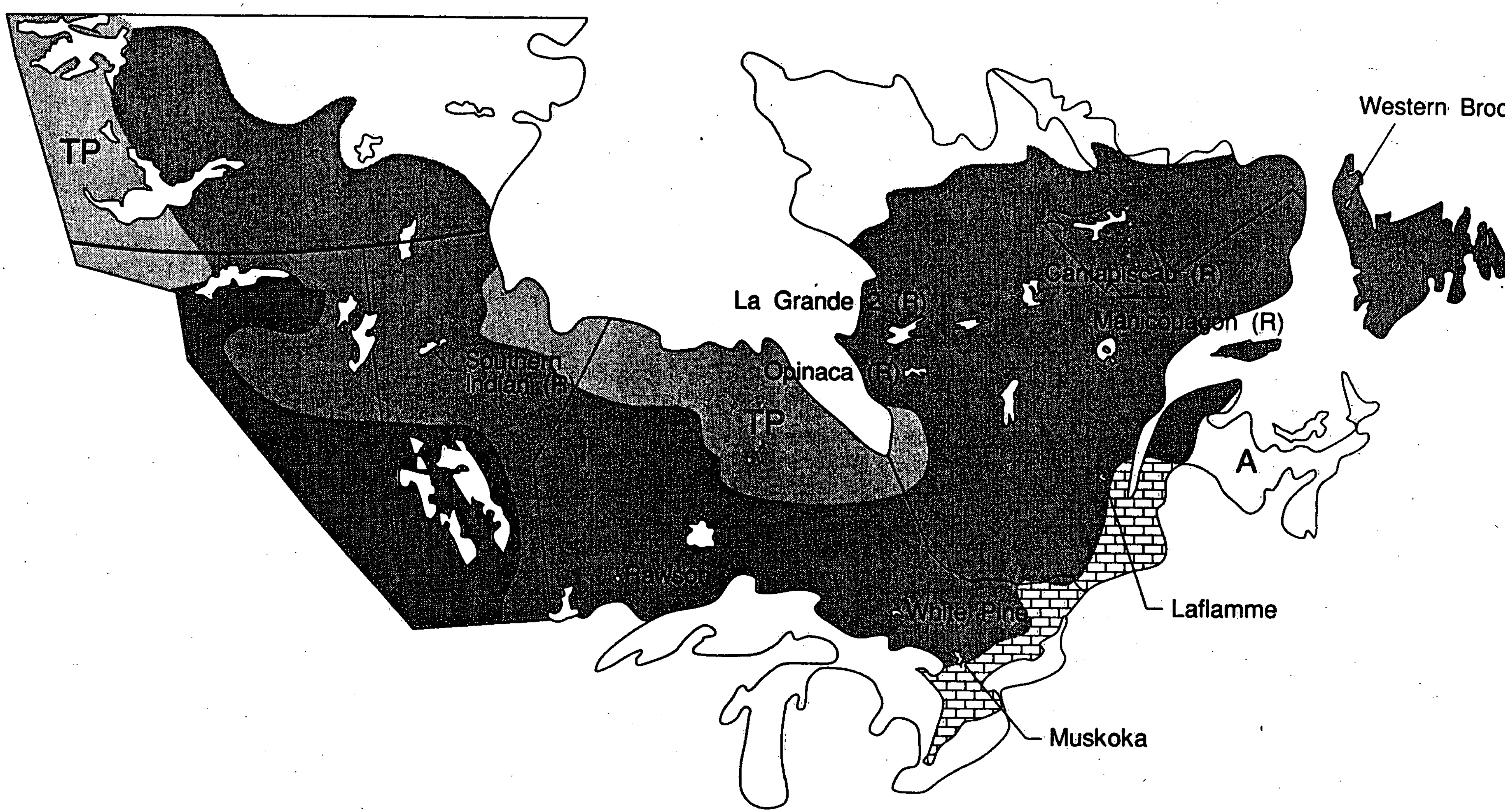

FIGURE 4

Boreal Plain & Prairie Lakes

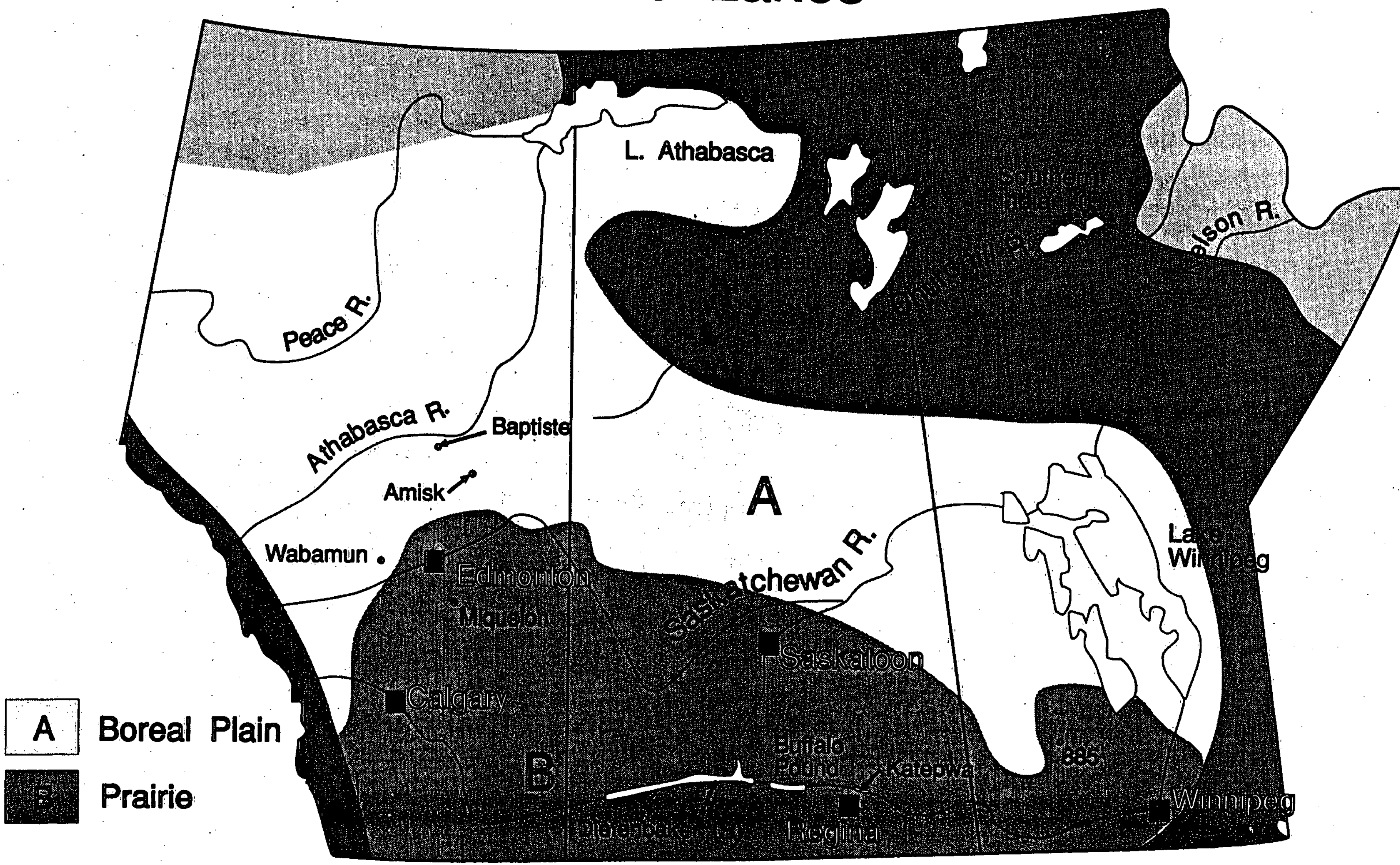

FIGURE 5

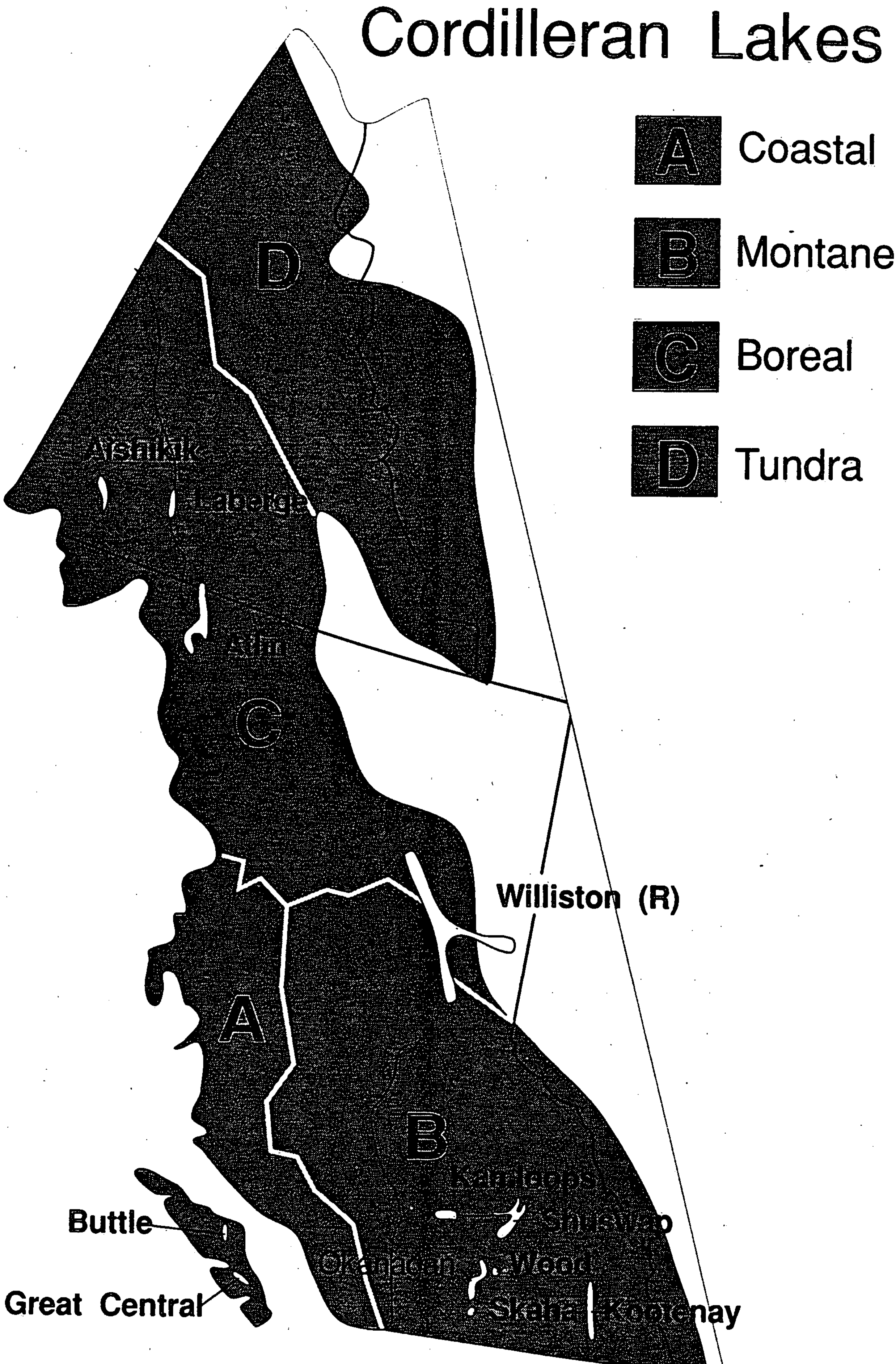
Cordilleran Lakes
A Coastal
B Montane
C Boreal
D Tundra
Williston (R)
Buttle
Great Central

FIGURE 6

Great Lakes/St. Lawrence Lowland and Atlantic Lakes

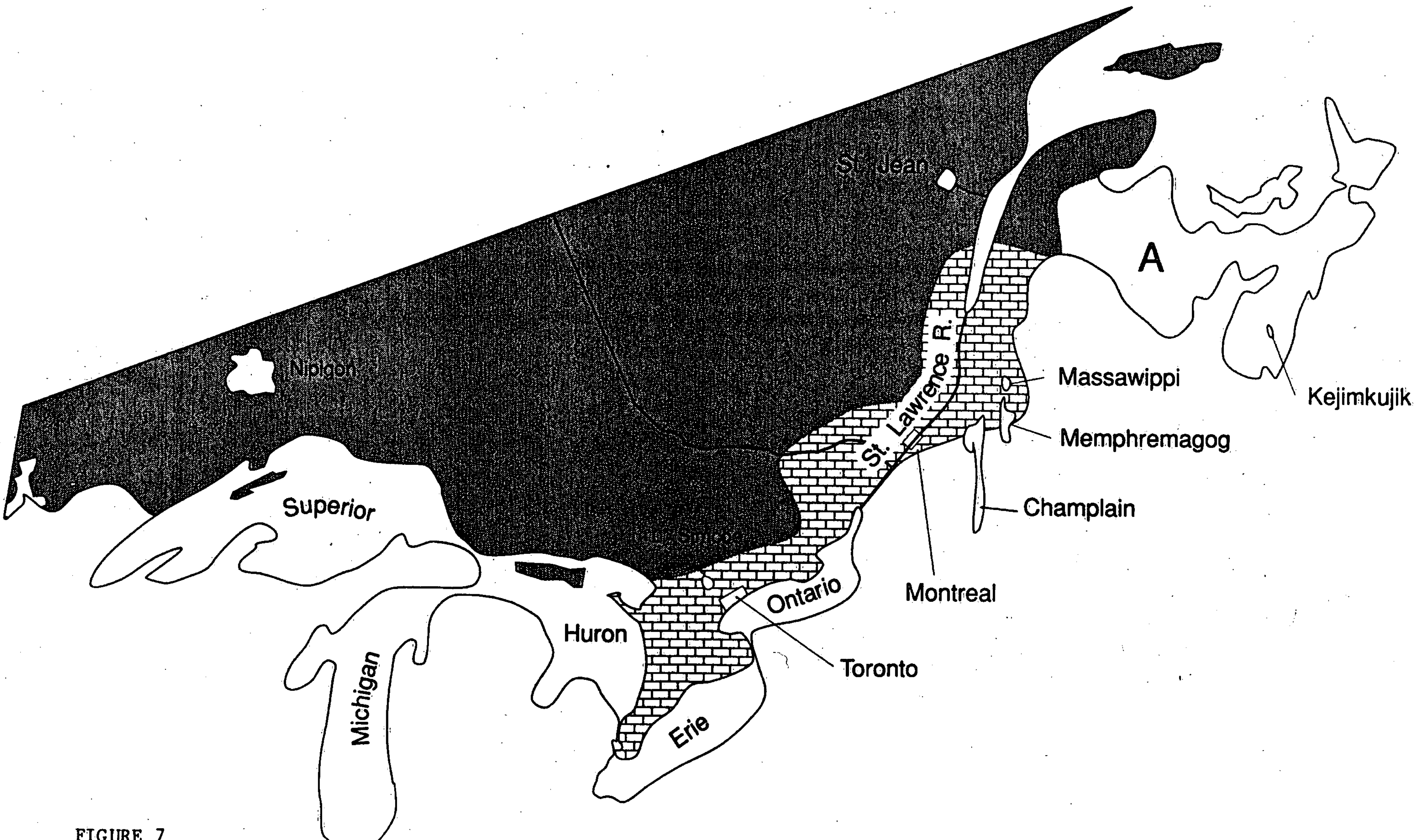

FIGURE 7

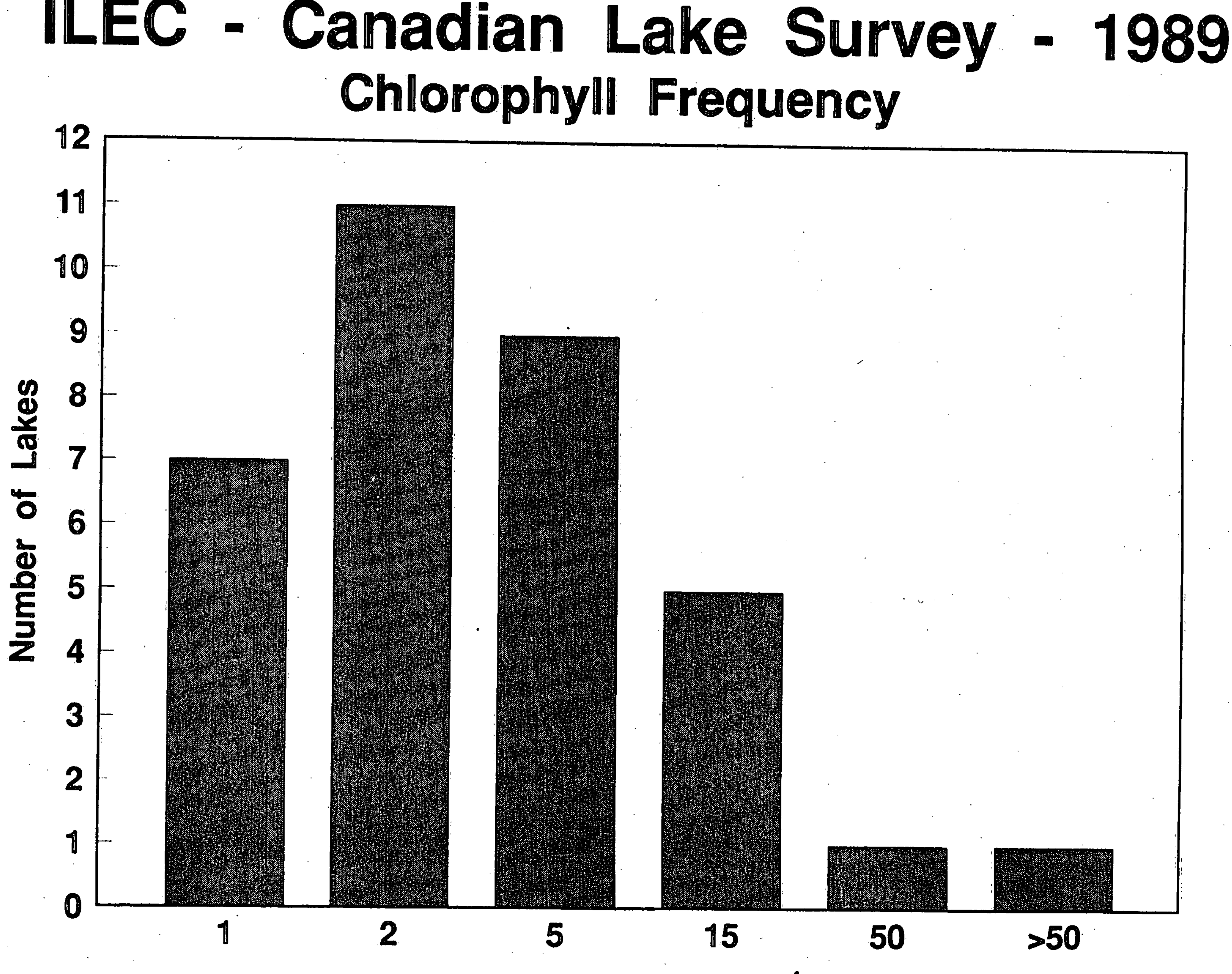
ILEC - Canadian Lake Survey - 1989
Chlorophyll Frequency
Number of Lakes
0
1
2
3
4
5
6
7
8
9
10
11
12
1
2
5
15
50
>50
Chlorophyll (µg Chla/L)

FIGURE 8

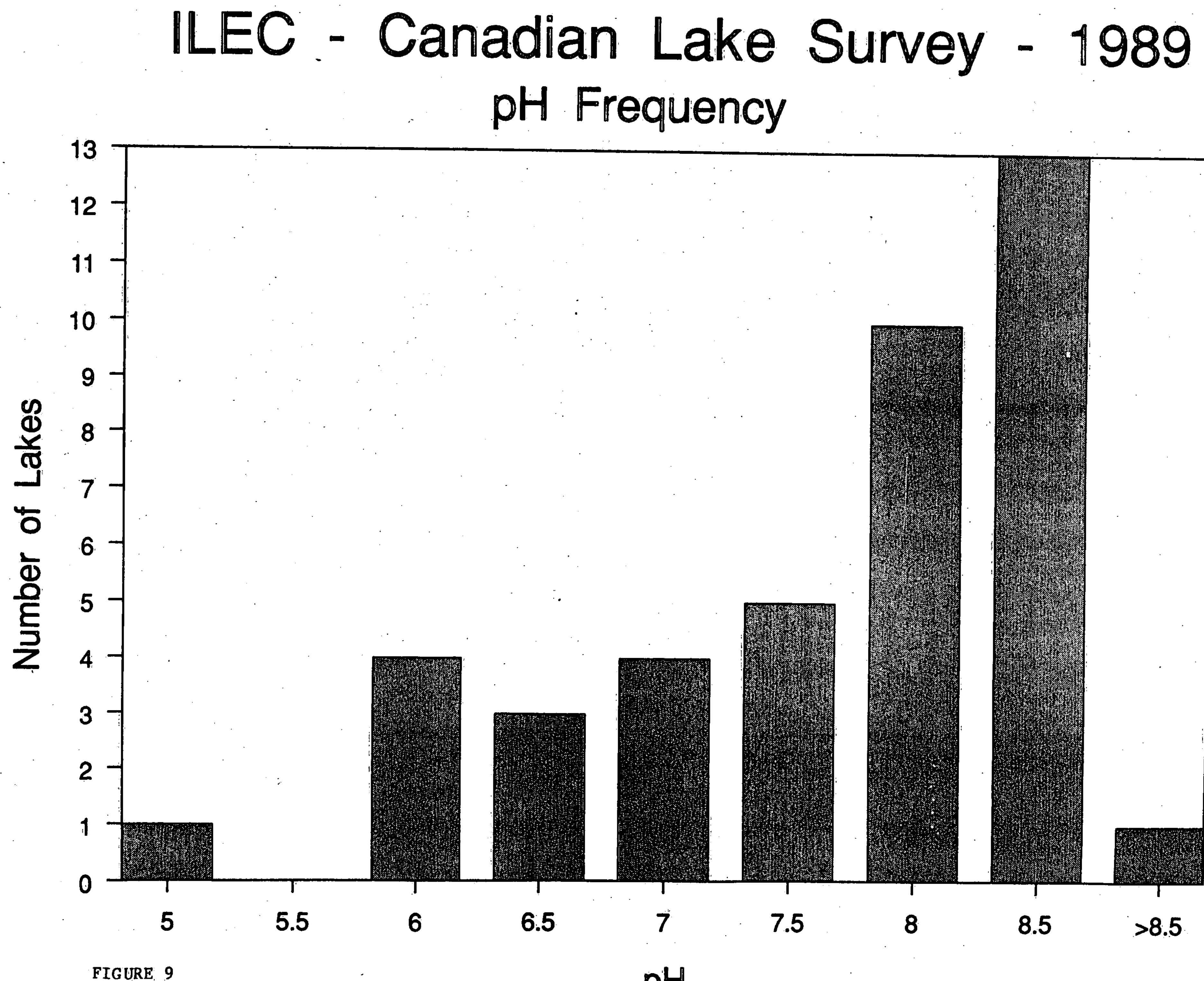
ILEC - Canadian Lake Survey - 1989
pH Frequency
Number of Lakes
13
12
11
10
9
8
7
6
5
4
3
2
1
0
5
5.5
6
6.5
7
7.5
8
8.5
>8.5
pH

FIGURE 9

APPENDIX 1: **QUESTIONNAIRE CORRESPONDENTS:**

ARCTIC

Char:	H. Welch Freshwater Institute Department of Fisheries and Oceans Winnipeg, Manitoba
Garrow:	M. Dickman Brock University St. Catharines, Ontario
Hazen:	L. Johnson Freshwater Institute Department of Fisheries and Oceans Winnipeg, Manitoba
P+N:	H. Welch Freshwater Institute Department of Fisheries and Oceans Winnipeg, Manitoba

TAIGA PLAIN

Great Bear:	L. Johnson Freshwater Institute Department of Fisheries and Oceans Winnipeg, Manitoba

BOREAL AND TAIGA SHIELD

Caniapiscau:	M. Kislalioglu and F. Berkes Brock University St. Catharines, Ontario
Laflamme:	M. Dickman Brock University St. Catharines, Ontario
La Grande 2:	M. Kislalioglu and F. Berkes Brock University St. Catharines, Ontario
Manicouagan:	N. Chartrand Hydro Quebec Montreal, Quebec

<u>Muskoka</u>:		M. Dickman Brock University St. Catharines, Ontario
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