Effects of Acid Precipitation on Lake and River Ecosystems in Quebec: Review of Department of Fisheries and Oceans Research Activities (1981–1985)

Division de l'Habitat du poisson

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Department of Fisheries and Oceans. 1987. Effects of acid precipitation on lake and river ecosystems in Quebec: Review of Department of Fisheries and Oceans research activities (1981-1985). Can. Tech. Rep. Fish. Aquat. Sci. 1554. ix + 65 p.

This document reviews research activities carried out in Quebec by the Department of Fisheries and Oceans under its acid precipitation study program. Physicochemical surveys of lakes have made it possible to identify the areas in the Precambrian Shield that are the most sensitive to acidification and those that are subject to the highest levels of acid deposition. In this report, we briefly review the results of a study on the response to acid precipitation of a subwatershed of the Des Escoumins River. We also provide an overview of surveys of invertebrate and fish communities as well as the results of experiments conducted in the field (flesh metal concentrations, incubation of salmon eggs and fry) and the laboratory (lethal and avoidance dosages of aluminum). Finally, we present an outlook for the next five-year research program.

RÉSUMÉ

Department of Fisheries and Oceans. 1987. Effects of acid precipitation on lake and river ecosystems in Quebec: Review of Department of Fisheries and Oceans research activities (1981-1985). Can. Tech. Rep. Fish. Aquat. Sci. 1554: ix + 65 p.

Ce document présente une rétrospective des activités de recherche réalisées au Québec par le ministère des Pêches et des Océans dans le cadre de son programme d'étude des précipitations acides. Des inventaires physico-chimiques de lacs ont permis de circonscrire les zones du bouclier précambrien les plus sensibles et les plus affectées par l'acidification. On résume brièvement les résultats de l'étude de la réponse d'un sous-bassin versant de la rivière des Escoumins face aux retombées atmosphériques. On synthétise également les inventaires des communautés d'invertébrés et de poissons ainsi que les résultats des expériences menées sur le terrain (teneurs en métaux dans les chairs; incubation d'oeufs et d'alevins de salmonidés) et en laboratoire (dose létale et d'évitement de l'aluminium). On présente finalement une prospective du prochain programme quinquennal de recherche.

PREFACE

Under its research program on the effects of acid precipitation on aquatic environments, the Department of Fisheries and Oceans reviewed the research projects conducted in Quebec by the Fish Habitat Division between 1981 and 1985. This report was prepared by Denis Brouard of Gilles Shooner et Associés Inc. and Marius Lachance of the Institut National de la Recherche Scientifique. Yvan Vigneault served as the scientific authority for the Department of Fisheries and Oceans. Further contributions to the preparation of this document were made by André Ahern and Ghislain Verreault, also of DFO. This document is a translation of the following report: Ministère des Pêches et des Océans 1987. Effets des précipitations acides sur les écosystèmes lacustres et fluviaux du Québec: rétrospective des activités de recherche du ministère des Pêches et des Océans (1981-1985). Rapp. techn. can. sci. halieut. aquat. 1554: x + 68 p.

INTRODUCTION

In the context of research into acid precipitation in Quebec, the Department of Fisheries and Oceans (DFO) has been involved since 1981 in study of the repercussions of Long-Range Transportation of Airborne Pollutants (LRTAP) on fish and fish habitat. Acid precipitation is a phenomenon of tremendous scope and represents a threat to the sensitive aquatic environments of the Canadian Shield. Accordingly, a large number of research activities have already been carried out. Efforts have focussed primarily on assessment of the effects of acid rain on aquatic environments in Quebec and development of our understanding of the physical, chemical, and biological mechanisms through which acidification of aquatic habitats affects biological communities and fish in particular.

After five years of research effort, DFO-Quebec felt the time had come to prepare a review of the research activities it has carried out to date in Quebec. Such a review is an indispensable step in assessment of the department's research program and preparation for possible selection of new goals.

The research activities covered in the review will be examined with the following objectives:

- highlighting of knowledge acquired on biological and chemical phenomena that are likely to be affected by acidification of aquatic habitats;
- integration of the entire body of knowledge to permit establishment of a diagnosis for the effect of acid precipitation on lake and river ecosystems in Quebec;
- use and integration of knowledge acquired over the five years of study with a view to the possible establishment of an ecological monitoring network.

DFO-QUEBEC MANDATE AND RESEARCH ACTIVITIES

DFO, under its enabling legislation, is responsible for the regulation, protection and preservation of Canadian fisheries (in both ocean and inland waters). This sectorial responsibility extends not only to aquatic organisms, but also to the quality of their habitats.

Research activities carried out in connection with the acid rain problem are essentially intended to permit fulfillment of DFO's two priority mandates with regard to the effects of environmental acidification on aquatic wildlife. The first of these mandates involves protection of freshwater and anadromous fish species while the second concerns long-term maintenance of fish resources of sport or commercial interest for the benefit of Canadian society and the country's economy.

From a general viewpoint, activities conducted by DFO in Quebec have fallen under the LRTAP research program. DFO-Quebec's basic objective is thus in keeping with the national objective: production of the scientific data required for assessment of the effects of acid precipitation in aquatic environments that should help to reduce atmospheric pollutant emissions at source.

More specifically, the objectives of DFO-Quebec can be broken down into four components:

- assessment of the physicochemical quality of water in Quebec lakes and rivers;

- acquisition of an understanding of the effects of changes in aquatic habitat quality on biological communities;

- measurement of the impact of acidification on the reproduction and survival of fish populations of sport or commercial interest;

- assessment of metal toxicity in fish under various acid stress conditions.

These objectives are ultimately intended to lead to satisfactory scientific answers to the following questions:

- What is the specific status of Quebec lake environments subjected to acid precipitation?

- What is the specific status of Quebec salmon rivers subjected to acid precipitation?

- What are the specific physical, chemical and biological mechanisms linking chemical deterioration of aquatic habitats and changes (structural and functional) in the various indigenous biological communities and fish in particular?

The various studies carried out under the sponsorship of the Department of Fisheries and Oceans can be classified in four separate groups: biophysical surveys, specific _in situ_ studies, specific laboratory studies, and ecological monitoring network research.

These studies are listed in Tables 1 and 2, where they are grouped according to whether they dealt with lake or river ecosystems. The tables indicate the agencies responsible for performing the studies and provide report references (P for technical reports and R for internal reports, see Annex 1). The activities described in Tables 1 and 2 will be examined in the following order:

- physicochemical quality of aquatic systems;

- biological characteristics of aquatic communities;

- ecological monitoring network for salmon rivers.

PHYSICOCHEMICAL QUALITY OF AQUATIC SYSTEMS

In 1981-1983, faced with a lack of information on physicochemical water quality, DFO undertook a vast program to survey the physicochemical quality of lakes in the Precambrian Shield and salmon rivers on the North Shore (Table 1). All these lakes and rivers (with the exception of three lakes in the Lower St Lawrence region) are located in the portion of Quebec that has been identified as highly sensitive to acidification (Altshuller and McBean 1980; Shilts 1981; Harvey _et al._ 1981). The area is contained within the Canadian Shield to the south of the 52nd parallel and on the north shore of the St Lawrence River.

STUDIES CONDUCTED IN LAKE AND RIVER ENVIRONMENTS

At the end of the summer of 1981, DFO (Langlois _et al._ 1983) undertook sampling of 198 headwater lakes distributed over five hydrographic regions (Outaouais, Mauricie, Saguenay-Lac St Jean, North Shore, and Abitibi-James Bay) and grouped in terms of 17 bases of operations (Table 3).

Table 1. Activity carried out in Quebec lake environments by the Department of Fisheries and Oceans (1981-1985).

Nature of activities	1981	1982	1983		1984	1985
Ia) Physicochemical surveys	198 lakes (Sept.-Oct.) National survey (P2[1])	251 lakes (August-Sept.) National survey (P10[1])	50 lakes (summer) Maniwaki: Sept-Iles: Schefferville (R14,R15[1])	13 lakes (summer) Outaouais: Gaspésie North Shore (P9[1])		
Ib) Biological surveys Phytoplankton Zooplankton Fish Benthos	 176 lakes (R6, R7[1]) 37 lakes (R2[1]) 38 lakes (P5[1]) 35 lakes (R5[1]) (P2[1])	 54 lakes (R9[1]) 54 lakes (R3[1]) 54 lakes (R8[1]) 54 lakes (R5[1]) (R16[1])	 50 lakes 50 lakes 50 lakes 50 lakes (R14, R15[1])	 14 lakes (P9[1])		
II- Specific "in situ" studies	Study of brook trout egg and fry mortality Portneuf: 1981-82; Zec des Martres: 1982-83 (P7, R21[1])					
		Study of brock trout population (Lake Laflamme) (Autumn 1982, Spring 1983, Summer 1983, Autumn 1983) (P8[1])			Survival study of brock trout eggs and fry at Lake Laflamme during the melt period (Autumn 1984, Winter and Spring 1985)	
			Comparative biology study (phytoplankton, zooplankton) of two groups of Lakes in the Outaouais (Summer 1983) (R4, R10[1])			
III- Specific laboratory studies		Biochemical dating of dead eggs by isoelectric focalization technique (P7, R11[1])				

[1] Annex 1

Table 2. Activity carried out in salmon rivers on the North Shore by the Department of Fisheries and Oceans (1981-1985).

Nature of activities	1981	1982	1983	1984	1985
I- Biophysical surveys	Monthly sampling of 23 rivers on the Upper and Middle North Shore (June 81 - July 82) (R22[1])	Periodical sampling of 21 rivers on the Upper, Middle and Lower North Shore (R12, R22[1])			
II- Specific <u>in situ</u> studies	Physicochemical sampling of 4 salmon river on the Upper North Shore (Winter 80, Spring - Summer 81) (SAGE INC.) (P1[1])	Spring physicochemical sampling, upstream sector of the Des Escoumins River (SHOONER INC.) (P4[1])	Studies of experimental site on the Cassette River (Des Escoumins watershed): model of the cycle chemical, hydrochemical balance and mortality and bio-accumulation of Al and Mn on salmon eggs and fry. (Autumn- Winter-Spring 1983-84) (P11[1]) (R17, R18, R19[1])		
III- Specific laboratory studies		Aluminium ecotoxicology for salmon and brook trout (P3[1])	Al an Mn bioaccumulation on salmon eggs and fry (P11, R18[1])	Speciation of the aluminum, Cassette River (Spring 1984) (R13[1])	
IV- Monitoring network			Periodical sampling of 17 rivers on the Upper, Middle and Lower North Shore (MPO) (R22[1]) Biological monitoring: - respiratory activity of bacteria and fungi - macrobenthic communities - salmon eggs and fry (P13, P14, R23[1])		

[1] Annex 1

A second series of sampling operations was conducted over the summer of 1982 to complement and refine the data collected in 1981 (Langlois et al. 1985). Specifically, the purpose of the second series was to improve the representativeness of the area by selecting lakes in regions not covered in 1981 (Table 3) and by sampling lakes of different categories. Of the 251 lakes sampled in 1982, 38 and 17 were second- and third-order lakes respectively, while 24 were bog lakes. The 1982 survey also took in 102 lakes which had already been sampled in 1981. Thus, a total of over 350 lakes were sampled over the two-year period.

In 1983, two series of sampling operations with more specific objectives (Table 1) were added to the previous series. The physicochemical surveys conducted during these two series of sampling operations were intended to complement biological surveys. The first series of 1983, carried out jointly by DFO and the Canadian Wildlife Service (CWS), was for the purpose of studying trophic relations in Quebec lakes; this series took in 50 lakes distributed over four different regions (Table 3) on the basis of level of exposure to atmospheric acid deposition and level of sensitivity to acidification (Pope et al. 1985).

The second series of 1983 was for the purpose of identifying the characteristics of arctic char habitats in Quebec (Le Jeune et al. 1984). The survey covered 13 lakes distributed over several Quebec regions (Table 3).

Between 1981 and 1985, 33 salmon rivers on the Upper, Middle, and Lower North Shore were sampled on a regular basis, either monthly or seasonally (Table 4 and Fig. 1). Sampling operations took in 23 rivers in 1981-1982 and were modified over the next two years:

- in 1982-1983 to include rivers on the Lower North Shore (Brouard 1984);
- in 1984-1985 to complement the spatial survey and increase station density on several rivers that were representative in terms of acidity gradient and sensitivity (Walsh and Vigneault 1986). These sampling operations were subsequently integrated with activities for the ecological monitoring network.

While the sampling operations were in progress, specific river studies were being conducted (Table 2):

- over the course of 1981, monthly sampling of four salmon rivers on the North Shore permitting assessment of their high sensitivity to acidification (Brouard et al. 1982);
- in the spring of 1982, daily sampling of water quality in the upstream sector of the Des Escoumins River watershed permitting assessment of the influence of hydrometeorological conditions (Brouard et al. 1983);
- from November 1983 to October 1984, an integrated study of biotic and abiotic components in a subwatershed of the Des Escoumins River (Cassette River) (Brouard and Lachance 1986).

Lake environments

Results obtained through the surveys of lakes in the shield make it possible to describe the spatial variation in physicochemical quality of lake waters in this portion of Quebec below the 52nd parallel. More specifically, these results allow identification of zones of greater or lesser sensitivity to acidification and detection within these zones of a significant influence of atmospheric

Table 3. Number of lakes sampled for physicochemical quality (1981-1983 surveys).

Quebec regions (bases of operations)	1981	1982	1983	
			a	b
Schefferville			13	
Blanc-Sablon	7	12		
Natashquan	10			
Havre Saint-Pierre	10	17		2
Sept-Iles	12	12	6	2
Baie-Comeau	10			2
Manicouagan	10	18		
Gagnon	11	9	5	
Chute-des-Passes	13	20		
Alma	12	10		
Roberval	12	10		
La Tuque	15	19		
Québec	8			1
Maniwaki	19	37	26	3
Clova	12	10		
Senneterre	9	10		
Chapais	16	30		
Némiscau	12	17		
Saint-Michel-des-Saints		10		
Lac Albanel		10		
Rimouski				3
TOTAL	198	251	50	13

Table 4. Salmon rivers sampled under the Fisheries and Oceans program, 1981-1985 (from Walsh and Vigneault 1986).

Rivers	Wathershed drainage (km²)	Number of stations				
		81	82	81-82	82-83	84-85
Charlevoix						
Petit Saguenay	817	1				
Saguenay Lac St-Jean						
Sainte-Marguerite	2 132	1			1	
Upper North Shore						
Des Escoumins	798	1	6	1	1	1
Des Petits Escoumins	139	1				
Laval	648			1		6
Bersimis	18 700			1	1	
Aux Outardes	19 062			1	1	
Manicouagan	45 843			1	1	
Mistassini	165			1		1
Godbout	1 575			1	1	
De La Trinité	562			1	1	6
Petite Trinité	198			1		
Au Calumet	103			1		
Aux Rochers	4 170			1		1
Middle North Shore						
Moisie	19 192			1	1	
Matamec	684			1	1	6
Pigou	172			1		1
Tortue	793			1		
Aux Graines	40			1		
A la Chaloupe	205			1		
Au Tonnerre	694			1	1	1
Jupitagon	218			1		1
Magpie	7 641			1	1	
St-Jean	5 594			1		
Mingan	2 344			1		
Romaine	14 349			1	1	
De la Corneille	559				1	1
Watshishou	1 065				1	1
Lower North Shore						
Natashquan	16 110				1	
Musquaro	3 626				1	1
Olomane	5 439				1	
Etamamiou	3 030				1	1
Du Petit Mécatina	19 580				1	1
Du Gros Mécatina	992				1	
St-Augustin	9 894				1	
Frequency of samples		month melt: week	day	month	quarter	
Number of rivers		4	1	23	21	15

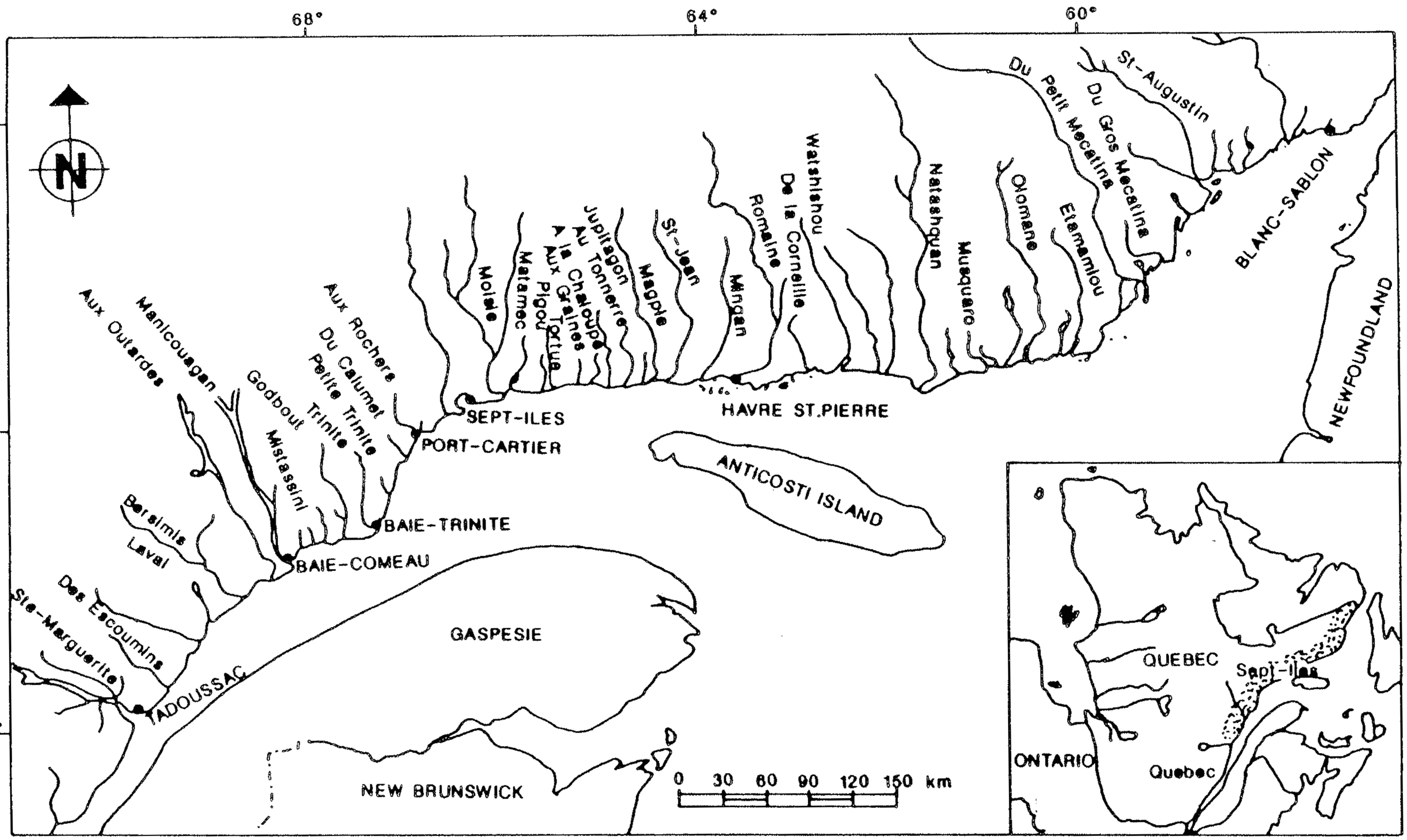

Fig. 1. Geographical location of salmon rivers surveyed over the 1981-1985 period (from Walsh and Vigneault 1986).

deposition on the physicochemical quality of lake environments.

Because of the improved representativeness of the study area (251 lakes in 1982) and greater precision in chemical assays, only the results of the 1982 survey have been retained for interpretation purposes. However, the data from the 1981 and 1983 surveys are consistent with those from the 1982 survey.

The level of lake mineralization, which is used as an indicator of sensitivity to the effects of acidification, varies fairly substantially in some parts of Quebec. Particularly high values are noted for calcium, magnesium, and alkalinity in the lakes of the Chapais and Albanel bases and some of the lakes in the vicinity of Maniwaki (Table 5), indicating the local presence of calcareous deposits and carbonate rock. However, looking at Quebec as a whole, we see that most of the study area, which rests on granite or granite gneiss, has low resistance to acidification. More than 72% of the lakes sampled in 1983 exhibited alkalinity of less than 100 uEq/L, the threshold considered by many authors to be an indicator of extreme sensitivity to acidification (Bobée et al. 1982; OME 1979).

If we give particular attention to lakes within a strip of land approximately 300 km wide extending from the Outaouais region to Labrador along an axis parallel to the north shore of the St Lawrence River (upper portion of Table 5), we note that sensitivity to acidification, estimated from lake mineralization levels, gradually increases from the southwest to the northeast, reaching a maximum in the area of Sept Iles. Calcium and magnesium levels gradually drop from 347 and 98 uEq/L respectively in the Maniwaki area to 34 and 13 uEq/L in the Sept Iles area. These levels then rise slightly in the Havre Saint Pierre and Blanc Sablon areas. This mineralization gradient indicates that climatic, soil, and physiographical factors combine with the geological features of the rocky substrate to explain the degree of resistance to acidification.

Sulfate concentrations also drop markedly going from the southwest to the northeast (Fig. 2 and Table 5). In the Outaouais region (bases at Maniwaki and Saint Michel des Saints), average sulfate concentrations are twice as high as in the lakes of the Saguenay-Lac St Jean region (Roberval, Alma, Chute des Passes) and the Abitibi-James Bay region (Némiscau, Chapais, Lac Albanel), and four times as high as in the lakes of the North Shore (Gagnon, Sept Iles, Havre Saint Pierre, Blanc Sablon). According to Harvey et al. (1981), the natural sulfate concentration in lakes of the Canadian Shield should not exceed 60 uEq/L and should probably be in the neighborhood of 30 uEq/L. On the North Shore, observed concentrations (36 to 45 uEq/L) were fairly close to the estimated natural concentration.

In the lakes of the shield, sulfate concentrations are considered to be the best indicator of the influence of atmospheric deposition on the physical chemistry of the water. Because of the chemical composition of the rocky substrate of the shield (granite, granite gneiss), geological sulfate input is generally low; we do not have any indications that would explain the observed sulfate gradient for Quebec lakes on the basis of bedrock geology and surface deposits. Moreover, the highly significant correlation observed by Dupont and Grimard (1985) between sulfates in Quebec lakes and sulfates in precipitation clearly shows the determinant influence of this atmospheric invader. The highest concentrations of SO_4^{-2} in both precipitation and lakes are found in the southwestern and western portions of the study area, near the main sources of sulfur dioxide (SO_2 emissions responsible for the transformation of H_2SO_4 in rain. These sources are primarily located at Rouyn-Noranda, Quebec, and Sudbury, Ontario, and in the midwestern United States. The presence of this sulfate gradient in Quebec lakes thus allows us to

Table 5. Physicochemical composition of lakes in the Canadian shield (Quebec) sampled during the summer of 1982: regional averages (adapted from Langlois *et al.* 1985).

Bases of operations	Number of lakes	Cond. (µS/cm)	Ca^{+2} (µEq/L)	Mg^{+2} (µEq/L)	Alkalinity (µEq/L)	SO_4^{-2} (µEq/L)	pH	Al (µg/L) *	Mn (µg/L) *	Colour (H.u)	Dissolved org. car. (mg/L)
Maniwaki	37	58.3	347.0	98.3	370.0	149.0	7.2	40.0	12.7	25.7	5.1
Saint-Michel-des-Saints	10	32.2	119.0	48.5	62.9	131.0	6.5	29.3	8.7	12.4	3.8
Clova	10	29.5	90.5	41.4	47.7	100.0	6.6	47.0	14.0	21.0	3.7
La-Tuque	19	28.9	93.4	34.3	50.9	103.1	6.3	81.2	13.8	39.8	7.4
Roberval	10	19.5	50.5	27.9	31.8	64.6	6.1	59.0	16.0	20.5	5.1
Alma	10	18.1	71.1	26.3	56.2	68.7	6.8	86.4	7.8	28.8	5.6
Chute-des-Passes	20	14.1	69.7	23.2	32.7	65.6	6.4	161.0	18.6	52.0	6.1
Manicouagan	18	12.7	55.7	22.9	31.9	59.0	5.9	157.0	11.4	53.8	6.9
Gagnon	8	12.9	60.7	24.9	56.9	37.0	6.7	85.8	3.3	12.2	3.4
Sept-Iles	12	13.3	34.4	13.5	11.7	45.1	5.5	170.5	13.2	42.9	6.9
Havre-Saint-Pierre	17	8.6	44.0	14.7	32.4	40.4	6.1	117.0	4.5	23.2	4.8
Blanc-Sablon	12	14.6	52.4	24.5	53.1	36.5	6.3	97.8	6.2	33.3	7.2
Senneterre	10	15.9	62.6	24.3	18.9	83.3	5.9	108.0	16.3	31.0	5.2
Némiscau	17	12.4	41.9	15.8	21.8	52.7	6.0	106.0	12.1	40.9	6.2
Chapais	30	34.8	235.0	141.0	329.0	60.4	7.1	52.6	13.6	41.8	6.3
Lac Albanel	10	20.0	119.1	48.5	113.0	56.2	7.1	105.0	14.4	28.5	5.6

* Total forms measured from unfiltered samples.

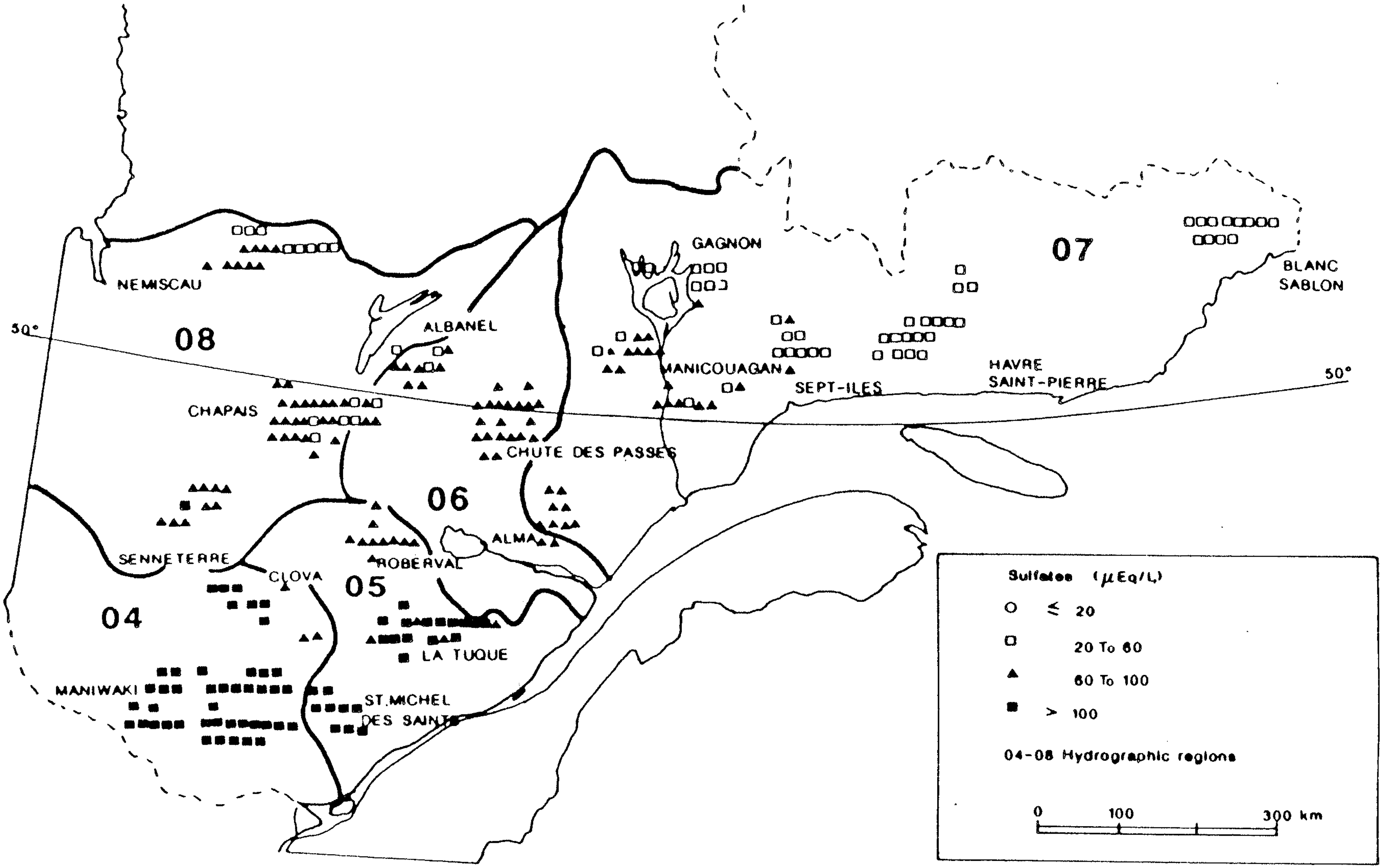

Fig. 2. Geographical distribution of lakes in terms of sulfate concentration (μEq/L) (from Langlois et al. 1985).

deduce fairly clearly that sulfate concentrations in lakes have increased over recent decades following the rise in SO_2 emissions.

In a natural environment not affected by acid precipitation, chemical weathering of soil and rock is due to the action of carbonic acid on minerals in the basin. Under such circumstances, the major ions released are the cations Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+} and the anion HCO_3^-: The increase in rain acidity caused by the presence of strong acids such as H_2SO_4 apparently produces accelerated weathering of minerals and a higher incidence of the SO_4^{-2} anion in surface waters.

In the absence of reliable historical data, it has been difficult to date to determine whether a substantial increase in cation levels has occurred in the surface waters of areas exposed to acid precipitation. The presence of a calcium and magnesium concentration gradient along a NE-SW axis (Table 5) suggests that such an increase may have taken place. It should be mentioned, however, that other factors such as climate, soil texture and thickness, physiography, and presence of vegetation also play an explanatory role. For example, the fairly low average altitude of lakes in the Maniwaki area (242 m) may partially explain the high calcium and magnesium levels found locally (Table 5). If we exclude bog lakes and lakes at altitudes below 240 m, the average calcium concentration for the 13 higher altitude lakes is 182 uEq/L rather than the figure of 347 uEq/L recorded for the 37 lakes in the Maniwaki area (Table 5). Note that the altitude of 240 m reportedly corresponds with the original level of the prehistoric Gatineau glacial lake at the time of its separation from the Champlain Sea (Pope <u>et al.</u> 1985).

The second effect of atmospheric transportation of sulfur compounds is gradual displacement of natural bicarbonate ions in surface waters by sulfate ions from precipitation. This effect can be assessed by examining the alkalinity/sulfate ratios presented in Fig. 3. For the study lakes as a whole, alkalinity is considered a good approximation of bicarbonate ion concentration. The majority of the lakes sampled in 1982 had alkalinity/sulfate ratios below 1.0. Only the lakes in the Chapais, Albanel, and Blanc Sablon areas and a number of the lakes near Maniwaki and Gagnon don't appear to be affected by an excess of sulfates in relation to bicarbonate ions.

If we group the lakes into three sulfate classes (over 100, between 50 and 100, and under 50 uEq/L) and examine the distribution of alkalinity/sulfate ratios (Table 6), we obtain an indication of the extent to which Quebec lakes are affected in terms of varying levels of exposure to atmospheric sulfates. These three zones can also be classified on the basis of medium (zone I), high (zone II), or very high (zone III) sensitivity. Table 6 shows that the effect of acid rain is being felt in the three zones, but to different degrees. In zone I, where lake sensitivity is lowest, heavy exposure to atmospheric sulfates results in a very high proportion of lakes with alkalinity/sulfate ratios between 0.25 and 1.0. If we exclude low altitude lakes in the Maniwaki area, 80% of the remaining lakes fall into this range. Zone II, with higher sensitivity, also has a large proportion of lakes with alkalinity/sulfate ratios between 0.25 and 1.0, but these ratios are more widely dispersed than in zone I. In zone III, where sensitivity is very high, we find equal proportions of ratios above and below unity. In sum, we see that over the whole of the province lakes are affected by sulfates of atmospheric origin.

When atmospheric acid loading exceeds the capability of a drainage basin to neutralize acid inputs, the surplus H^+ ions are dumped directly into the water course. Alkalinity is then lost and pH drops. This phenomenon is likely to be found in drainage basins where the bedrock is difficult to weather and surface deposits are practically inexistent (frequent rock outcrops).

Lakes in which pH values below 5.5 were observed are infrequent (15) and located almost entirely in the Manicouagan and Sept Iles areas, where high organic matter content (average colour = 54 and 43 H.u. for Manicouagan and Sept Iles respectively) can explain these low pH values. In general, the pHs observed during this survey were higher than those recorded during two previous surveys (Langlois et al. 1983; Bobée et al. 1982); the difference is difficult to explain.

Atmospheric acid inputs are likely to encourage dissolution of oxides and hydroxides of metals such as Al and Fe present in the soil and rock of the drainage basin (with accompanying release of the trace metals associated with these phases). There is therefore increased mobility of metal ions, some of which, such as Al^{+3}, are particularly toxic for aquatic organisms.

Solubility of aluminum in water depends very heavily on pH. It is negligible at pHs between 5.5 and 6.5, depending on concentrations of organic matter, and increases at values above or below this range (Driscoll et al. 1980). At pH 5.0-5.2, the forms Al^{+3}, $Al(OH)^{+2}$, and $Al(OH)_2^+$ are predominant, while at pH over 6.5, the following forms are found (in order of decreasing incidence): $Al(OH)_4^-$, $Al(OH)_3$, $Al(OH)_2^+$, and $Al(OH)^{+2}$. Note that aluminum is also found adsorbed on particles in suspension and in complexes with organic matter in natural waters at various pHs. The toxicity of aluminum is related to the inorganic labile form. At pH > 5.5, the fraction of inorganic aluminum is highly insoluble and, therefore, not available. Below this threshold, however, toxicity increases rapidly.

During the 1982 survey (Langlois et al. 1985), it was observed that the lakes with the highest total aluminum levels were located primarily on the North Shore, in the vicinity of Sept Iles, Manicouagan, Chute des Passes, and, to a lesser extent, Havre Saint Pierre (Table 5); concentrations commonly exceed 100 ug/L. Among the lakes in southwestern Quebec, which are exposed to the greatest levels of acid fallout, few exhibit high concentrations. These results suggest that the high aluminum concentrations encountered in the lakes of the North Shore are associated with some phenomenon other than mobilization of aluminum by acid precipitation. The occurrence in these waters of pronounced colour (average colour = 43, 54, and 52 H.u. for the Sept Iles, Manicouagan, and Chute des Passes bases respectively) and rather high concentrations of organic carbon (respective averages of 6.9, 6.9, and 6.1 mg/L) is indicative of the presence of high organic matter concentrations. In these lakes, aluminum would thus appear to be primarily associated with organic matter. It should be noted that the lethal toxicity of aluminum in the presence of organic matter is considerably attenuated (Van Collie et al. 1983).

In sum, the lake surveys show that the physicochemical quality of lakes in the Canadian Shield is significantly influenced by acid precipitation and that this influence is particularly strong in western Quebec (Outaouais, Mauricie, and Abitibi-James Bay). The influence primarily manifests itself via the displacement of natural bicarbonates in the lakes by atmospheric sulfates. Examination of alkalinity/sulfate ratios in the lakes indicates that, despite an acidification gradient in a direction opposite to that of the atmospheric deposition gradient, the effect is felt to varying degrees throughout Quebec. The area taking in the bases at Roberval, Alma, Chute des Passes, and Manicouagan, in spite of its lighter exposure to atmospheric fallout, is affected at least as much as the area to the south because of greater sensitivity. More than 80% of the lakes studied in this area have alkalinity/sulfate ratios of less than one. Even the North Shore area, which is exposed to only

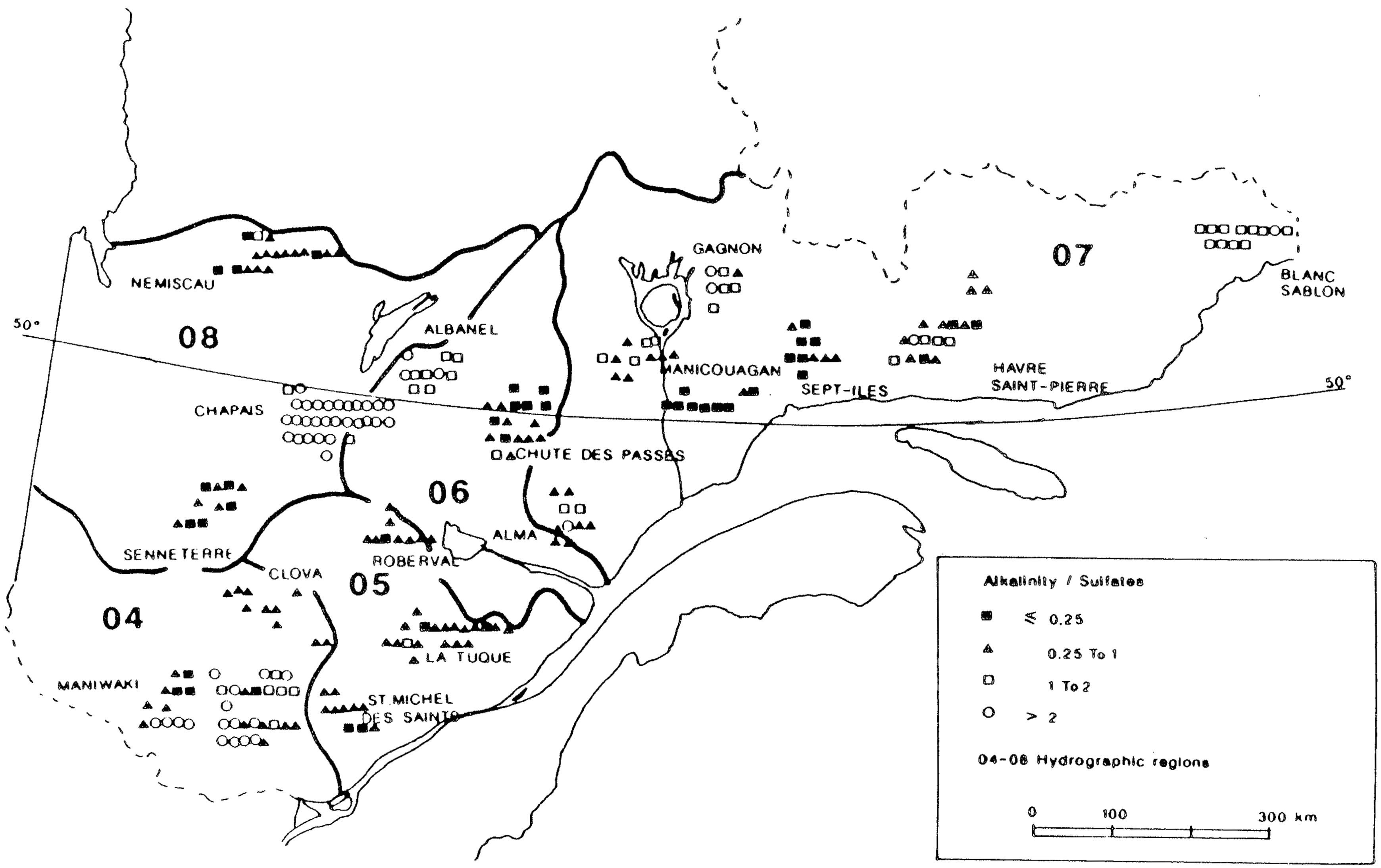

Fig. 3. Geographical distribution of lakes in terms of alkalinity/sulfate ratio (from Langlois et al. 1985).

Table 6. Classification of lakes by means of the alkalinity/sulfate ratio within three zones of exposure to atmospheric sulfates.

Zone[a]	Number of lakes	Alkalinity/sulfate ratio			
		< 0.25	0.25 à 1	1 à 2	> 2
I	64	8 (12.5)[c]	44 (68.8)	2 (3.1)	10[b] (15.6)
II	58	15 (25.9)	34 (58.6)	8 (13.8)	1 (1.7)
III	50	10 (20.0)	15 (30.0)	21 (42.0)	4 (8.0)
Total	172	33 (19,2)	93 (54,1)	31 (18,0)	15 (8,7)

[a] - zone I ($[SO_4]$ > 100 µEq/L) bases at Maniwaki, Saint-Michel-des-Saints, Clova and la Tuque (with the exception of peat bog at Maniwaki).

- zone II ($[SO_4]$ included between 50 and 100 µEq/L) bases at Roberval, Alma, Chute-des-Passes and Manicouagan.

- zone III ($[SO_4]$ < 50 µEq/L) bases at Gagnon, Sept-Iles, Havre Saint-Pierre and Blanc-Sablon.

[b] Of the 10 lakes with $HCO_3/SO_4^{-2} > 2$, nine were at altitudes less than 240 m.

[c] The numbers in parentheses indicate the percentage of lakes within each class of alkalinity/sulfate ratios.

limited acid deposition, is influenced to a certain extent, 50% of the lakes studied exhibiting ratios below unity.

Current data obtained through the 1982 survey do not permit clear linking of lake acidity with atmospheric deposition. The number of acid lakes (pH ≤ 5.5) is low and these lakes are primarily located in areas that are exposed to only limited atmospheric fallout. It is difficult at this point to distinguish the respective contributions of natural sources of acidity (organic acids) and atmospheric inputs.

River environments: surveys

The physicochemical survey of 33 salmon rivers on the North Shore showed the high sensitivity to acidification of the rivers draining this portion of Quebec (Fig. 1). The level of mineralization in the rivers is as low as it is in the lakes of the area. Conductivity is between 13 and 29 uS/cm on average (Walsh and Vigneault 1986), and more than 50% of the rivers exhibit mean conductivity under 20 uS/cm (Table 7). Alkalinity, which permits assessment of the capability of the drainage basin to neutralize atmospheric inputs by means of the carbonate system, is also very low. Except for five rivers located in the southern portion of the Upper North Shore and the Moisie River on the Middle North Shore, mean alkalinity was under 100 uEq/L in all rivers sampled. This threshold is generally considered to be an indicator of acidification. Eleven of these rivers exhibited average alkalinity approaching zero (≤ 40 uEq/L). Most are located on the Lower North Shore and in the eastern portion of the Middle North Shore.

Annual mean figures for alkalinity do not permit full assessment of river sensitivity, since they do not show the magnitude of seasonal variations. In the spring, after massive inputs of H^+ ions are received from meltwater and the abundant rains that fall at this time of year, alkalinity drops substantially to nearly zero in most of the rivers under study. It was found that 30 rivers out of 33 exhibited minimum alkalinity values under 40 uEq/L (Walsh and Vigneault 1986). These alkalinity values show that the neutralization capability of the river drainage basins is only just sufficient to counter acid inputs from meltwater and spring rain.

The importance of sulfates as an indicator of airborne atmospheric inputs was shown during the analysis of Quebec lake survey results. In the rivers of the North Shore, mean sulfate content ranged from 23 to 73 uEq/L along a west to east gradient. Walsh and Vigneault (1986) obtained a highly significant correlation between mean sulfate content and longitude. This sulfate concentration gradient, which is consistent with that previously noted for lakes across Quebec, confirms the predominant influence of distant pollution sources located primarily in Ontario (Sudbury), southwestern Quebec (Noranda), and the states of the American Midwest.

The lowest mean values observed on the Lower North Shore (20 to 30 uEq/L) are likely fairly close to natural background levels. Harvey et al. (1981) estimated natural sulfate concentrations in the rivers at approximately 30 uEq/L. In northern Quebec, far from the major sulfur emission sources, Bobée et al. (1982) obtained a mean value of 33uEq/L for 22 lakes. Similar levels (36.5 uEq/L mean) were found by Langlois et al. (1985) for lakes in the vicinity of Blanc Sablon.

The geology of the North Shore could provide clues to the origin of this natural concentration in surface waters. However, what we find in the region is a gneiss series, composed of grey and granite gneiss, interspersed with anorthosites, charnockites, acidic rock, and gabbros. These rocks are not easily weathered and generally contain little sulfur. It appears unlikely that chemical weathering of the rocks and soils of the North Shore contributes substantially to the sulfate content of the waters draining this part of Quebec. Observation of wet atmospheric deposition of 17 to 22 kg SO_4/ha-yr (Brouard and Lachance 1986; Grimard 1984), combined with the fact that the sulfate anion is generally not trapped in the watershed (SNSF 1980), also support the conclusion that the sulfates are essentially of atmospheric origin. Thus, the natural concentration in surface waters appears to be mainly attributable to distant natural sources (volcanoes, oceans, wetlands) and widespread circulation of sulfur in the upper atmosphere (Canada-United States 1982). The observed sulfate concentration ranges on the Middle and Upper North Shore, which are on average 1.5 and 2 times as high, respectively, as those found on the Lower North Shore, indicate that anthropic sulfur sources may contribute 25 to 50% of mean sulfate content in the rivers of the Middle and Upper North Shore.

As noted above, one of the main effects of acidification of an aquatic environment by precipitation is gradual displacement of natural bicarbonate ions in surface waters by sulfate ions from precipitation (Bobée et al. 1982; Dickson 1975). The HCO_3^-/SO_4^{-2} ratio thus provides an indicator of acidification if we keep in mind that the denominator accounts for sulfates of both natural and anthropic origin.

In the rivers of the North Shore as a whole, HCO_3^-/SO_4^{-2} ratios calculated on an annual basis cover a wide range (Table 7). With the exception of five rivers in the southwestern portion of the Upper North Shore and the Moisie River, most rivers have a ratio under or slightly over 1.0. In view of the low mean alkalinity values, a slight increase in atmospheric sulfate fallout, which would raise sulfate concentrations at the expense of bicarbonates, could cause a substantial drop in the HCO_3^-/SO_4^{-2} ratio for rivers throughout the North Shore. For example, on the Middle North Shore, all the rivers except the Moisie would then have ratios below 1.0. Moreover, examination of the minimum HCO_3^-/SO_4^{-2} values presented by Walsh and Vigneault (1986), gives an indication of the possible magnitude of this drop. All the rivers sampled, with the exception of the Moisie, exhibit values under 1.0 at some point in the yearly cycle (generally in the spring) following fluctuations in inputs from meltwater and rain.

The annual pH range recorded for rivers throughout the North Shore (Table 7) reflects the low alkalinity values encountered and the generally low level of mineralization of the waters. Relatively high concentrations of organic anions (36% of total anions on average, according to Walsh and Vigneault 1986) also help to explain the low pH values that were generally found.

In environments where alkalinity is low and large quantities of snow accumulate in winter, pH is subject to generally substantial variations during the spring melt period. In several salmon rivers on the North Shore, observations indicated that water pH dropped by more than one unit in the spring following the large-scale release of H^+ ions which had accumulated in snow. Among the salmon rivers of the North Shore, Walsh and Vigneault (1986) noted that 21 rivers out of 33 exhibited a minimum pH below 6.0 and that this value was generally obtained in the spring (in 65% of cases). Among the same rivers (Fig. 1), 11 had a minimum pH of less than 5.5:

Upper North Shore	Middle North Shore	Lower North Shore
Trinité	Matamec	Musquaro
Aux Rochers	Pigou	Olomane
	Tortue	Du Gros
	Aux Graines	Mécatina
	A la Chaloupe	
	Jupitagon	

Table 7. Breakdown of number of salmon rivers surveyed in terms of location (Upper, Middle or Lower North Shore) and in terms of three classes of annual mean values for physicochemical parameters (from Walsh and Vigneault 1986).

Region	Number of rivers	Conductivity (µS/cm)			Alkalinity (µEq/L)			Sulfates (µEq/L)			Alkalinity/sulfate		
		20	20 à 25	⩾ 25	40	40 à 100	⩽ 100	30	30 à 50	⩾ 50	0,5	0,5 à 1,0	⩾ 1,0
U.N.S.	12	5	4	3	2	7	3	0	4	8	0	7	5
M.N.S.	14	7	5	2	5	8	1	1	11	2	1	4	9
L.N.S.	7	6	1	0	4	3	0	6	1	0	2	1	4

Region	Number of rivers	pH			Color (H.u.)			Aluminum (µg/L)		
		6.0	6.0 à 6.5	⩾ 6.5	30	30 à 40	⩾ 40	100	100 à 200	⩾ 200
U.N.S.	12	0	5	7	3	3	6	0	2	10
M.N.S.	14	8	4	2	5	4	5	0	3	11
L.N.S.	7	2	5	0	2	3	2	0	4	3

U.N.S. Upper North Shore
M.N.S. Middle North Shore
L.N.S. Lower North Shore

Considering that pHs of on the order of 5.0 to 5.5 can affect the development and hatching of Salmo Salar eggs, there is every reason for concern. It is possible, for some rivers, that pH levels would have been even lower than those observed if the springtime sampling had been conducted slightly before or after the peak of the melt. Moreover, these pH values were measured at the mouths of the rivers. Since bicarbonate levels generally drop as one proceeds upstream, there is reason to believe that even greater pH variations could occur in the intermediate and upper portions of the water courses, where spawning grounds are generally located.

Total aluminum concentrations (unfiltered samples) in the rivers of the North Shore are generally high. Average concentrations ranged from 132 ug/L for the Etamamiou River to 1382 ug/L for the Saint Jean River. Most rivers (24 out of 33) exhibited mean values in excess of 200 ug/L (Table 7). Extreme concentrations (> 1000 ug/L) were observed mainly on the Upper North Shore in the northeast Sainte Marguerite, Des Escoumins and Laval rivers and particularly in the Saint Jean River on the Middle North Shore.

The speciation of the aluminum present was not indicated. In view of colour values (between 25 and 45 H.u. on average; Table 7), dissolved organic carbon levels (between 4 and 8 mg/L), and pH levels (> 5.5), aluminum in the organic form probably predominates in most of the rivers. . In the watershed of the Cassette River during the spring melt period, Campbell et al. (1984) found that organic + adsorbed aluminum was the prevalent form.

The relative incidence of monomeric inorganic aluminum (Al^{+3}, aluminum hydroxides, and aluminum fluorides) varies according to pH. It can be assumed that the forms Al^{+3}, $Al(OH)^{+2}$, and $Al(OH)_2^{+}$ predominate at pH 5.0 to 5.2, while at pH over 6.5 the form $Al(OH)_4^{-}$ is prevalent. The quantities of these forms in the waters of North Shore rivers are worthy of study because of the toxicity of certain forms (such as Al^{+3}) for aquatic life (Van Coillie et al. 1984).

In sum, as a whole, the salmon rivers on the North Shore of the St Lawrence exhibit very high sensitivity to the effects of acidification because of the very low level of mineralization of the waters and the limited buffering capacity of the watersheds. The west-east gradient for sulfate concentrations indicates that the area is influenced by distant sulfur sources to the southwest. For most of the rivers, atmospheric sulfate deposition appears to be approximately 20 kg SO_4/ha-yr, which is the acceptable threshold suggested by the Canada-United States working group (1982) for the protection of moderately sensitive aquatic biota. A slight increase in atmospheric sulfate fallout could result in a considerable decrease in the HCO_3^-/SO_4^{-2} ratio and a substantial rise in river acidity.

Moreover, the rivers of the North Shore are subject to pronounced pH drops during the melt period, with pH falling to below 5.5 in many. These seasonal fluctuations and the presence of high levels of metals could become critical for fish.

River environments: specific studies

The first specific river study was conducted to determine the sensitivity to acidification of four salmon rivers on the North Shore: the Petit Saguenay, Sainte-Marguerite, Des Petits Escoumins, and Des Escoumins rivers. More specifically, the study brought to light seasonal differences in the physicochemical quality of the water in these river systems while stressing the contributions of atmospheric inputs and certain hydrometeorological conditions encountered during the sampling period (Brouard et al. 1982; Van Coillie et al. 1982).

The study also included a detailed interpretation (Lachance et al. 1983) of variations in sulfate, calcium, nitrate, and H^+ ion concentrations in the Sainte-Marguerite River (Fig. 4) and a description of the processes governing the physicochemical composition of the waters during the spring melt.

The premature melt starting in late February appears to have triggered the migration of ions in the snow. The drop in sulfate concentrations at the start of the melt period apparently corresponds with a decrease in sulfates from snow reserves following the first melt. The subsequent increase in sulfates during and after the melt coincides with the melting of the new reserves of snow which accumulated during the month of March. For calcium, the peak observed at the very start of the melt corresponds with piston flow of water that had been in prolonged contact with the minerals of the watershed. The increase in H^+ ion concentrations only became substantial on one occasion (pH 5.9); this increase, which occurred at the end of the first spring flooding, can be explained by the electroneutral condition in these waters. For nitrates, variations are more difficult to interpret but maximum observed levels over the spring show the influence of nitrates accumulated in the snow and released during the melt period.

The goal of the second specific river study was to determine with greater precision the influence of springtime hydrometeorological conditions on daily variations in the physicochemical quality of waters in the upstream sector of the Des Escoumins River (Brouard et al. 1983; Lachance et al. 1987). Over the months of March and April, surface water samples were taken daily at three stations on the main section of the river and at three stations on small watershed tributaries.

Analysis of observed variations and interrelationships between stations for each of the measured parameters made it possible to characterize the spatiotemporal dynamics of water physicochemical quality during the spring melt. Findings included the following:

- stations on the main section of the Des Escoumins River recorded similar behaviour;
- during the melt period, the tributaries with small watersheds are subject to much greater water quality fluctuations than the larger tributaries, even where the base alkalinity level (in wintertime) is higher;
- prevailing springtime conditions in small tributaries, where spawning grounds are often located, cannot be extrapolated from information on the main section of the same water course;
- some of the conditions observed during the spring of 1982, including strong fluctuations in pH, alkalinity, and aluminum content, suggest a potential risk for salmonids in the longer term, particularly in small watershed tributaries.

During the period from November 1983 to October 1984, an integrated study was conducted (Brouard and Lachance 1986) into biotic and abiotic components in a subwatershed of the Des Escoumins River (Cassette River). One of the primary objectives of the study was to determine the contributions of the various biotic and abiotic components to the ability to neutralize atmospheric acid deposition over a small watershed (40 km^2).

Among the abiotic components which play an important role in relation to the physicochemical composition of the waters of the Cassette River, watershed soil properties and precipitation physicochemical quality received particular attention.

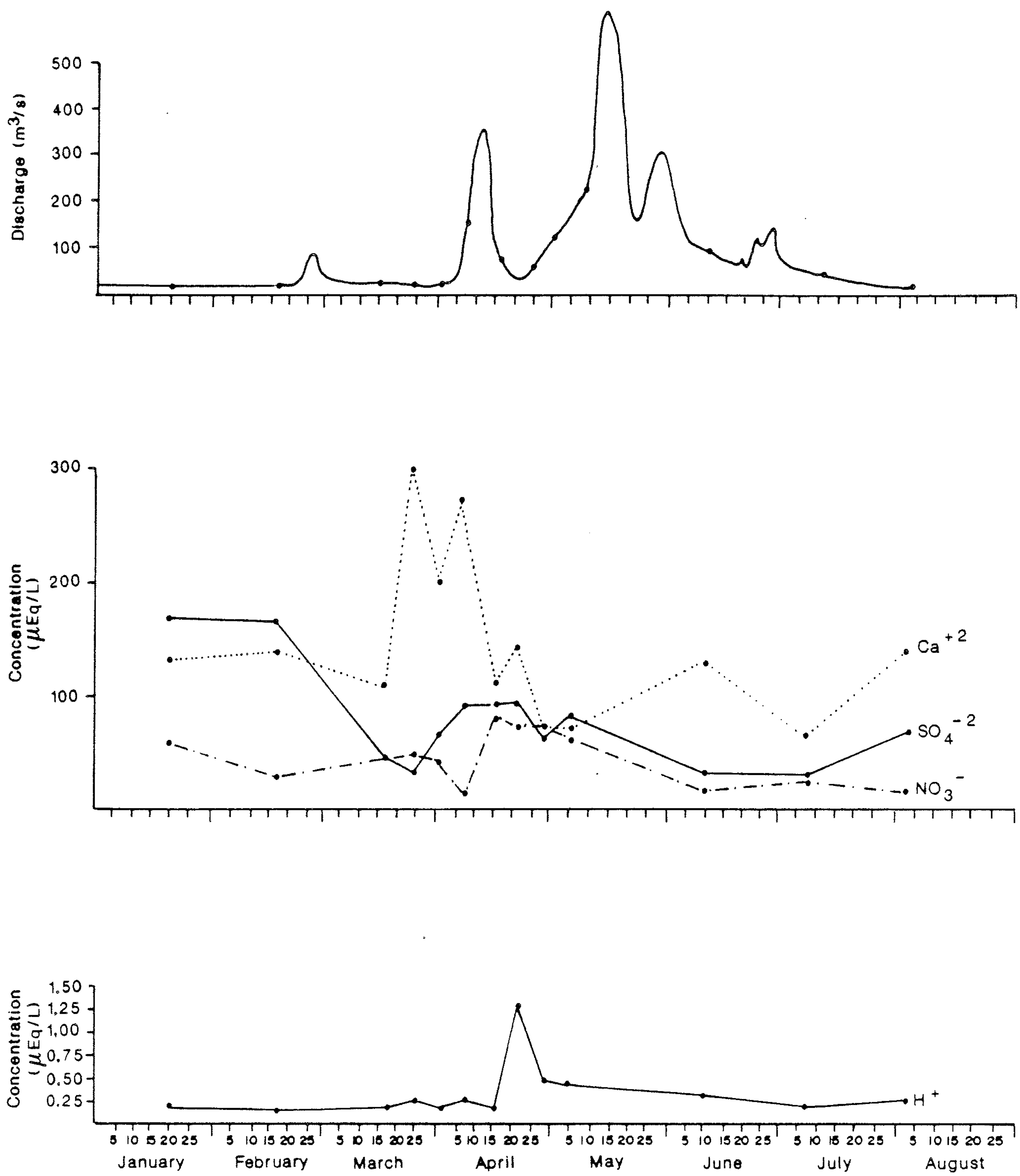

Fig. 4. Time variation in rate of flow and calcium, sulfate, nitrate and hydrogen ion concentrations for the Sainte-Marguerite River (from Brouard <u>et al.</u> 1982).

Among the soils identified in the Cassette River watershed (podzols, brunisols, organic soils, and regosols), humo-ferric and ferro-humic podzols predominate (Brouard et al. 1984). Results from analyses of four podzols are shown in Table 8.

The podzols are usually formed, at the surface, of a fairly thick layer of forest humus (LHF horizons) where both organic acids and bases (Ca^{+2}, Mg^{+2}, K^{+}) are released. The presence of these acids, combined with leaching of the bases, contributes to the creation of very acid conditions (mean pH: 3.0) in this surface organic layer. The Ae mineral horizon, which forms a layer directly below the LHF horizon, plays an important role with regard to mobilization of metals such as Al and Fe because of its acidity (mean pH: 3.38). The B mineral horizons (B diagnostic and BC) are where organometallic complexes involving iron and aluminum are formed. Organic carbon, iron, and aluminum levels are generally substantial.

Because of its strong presence in soils and its high degree of chemical activity, aluminum plays a major role in controlling potential acidity for aquatic organisms. It is therefore important to know to what extent and in what forms aluminum is leached and ends up in rivers and lakes.

Interesting results on this subject are provided by Hendershot et al. (1984), who studied aluminum speciation and movement in three watersheds of southern Quebec. The authors showed that during intensive hydrological events soil solution pH decreases while the soluble aluminum level increases. Moreover, during such events, aluminum content in surface waters was linked to that in the soil solution. It would appear that the chemical properties of upper soil horizons located near water courses govern movements of aluminum toward surface waters.

In assessing the contribution of atmospheric inputs to the physicochemical quality of surface waters in a drainage basin, it is important to know not only the mean physicochemical composition of local precipitation but also the physicochemical quality of ground snow and the time variation in snow quality as well as the effects of interception of precipitation by forest cover.

Mean concentration values measured in precipitation over the study period fall within the range of values obtained by the Quebec precipitation sampling network (REPO - Réseau d''échantillonnage des précipitations du Québec; Grimard 1984). Measured levels for sulfates (2.9 to 131.2 uEq/L) and pH (3.7 to 5.0) confirm that the study area is subject to substantial acid fallout.

Brouard and Lachance (1986) have shown that interception of precipitation by forest cover can significantly modify the physicochemical composition of snow precipitation; the effect was even more pronounced with ground snow (Table 9). Mean values obtained under forest cover are significantly higher than those obtained in clearings for all measured chemical variables (Cl^{-}, SO_4^{-2}, Na^{+}, $K2^{+}$, Mg^{+2}). Two hypotheses may explain this increase in soil ion concentrations under forest cover:

- an exchange process with organic matter from the trees, which could explain the concentration increases for ions such as potassium;

- a physical process related to insolation and thermal exchanges with the atmosphere, which would produce slower migration of ions under forest cover.

Examination of the hydrochemical balance of a watershed is an essential approach to understanding the movement and circulation of

Table 8. Mean chemical compositions from analyses of four humo-ferric podzols taken at four stations in the watershed of the Cassette River (1983) (from Brouard and Lachance 1986).

Horizon		pH $CaCl_2$	C %	Fe %	Al %	Fe+Al %	Exchangeable cations Al^{+3} (mEq/100 g)	Exchangeable cations Ca^{+2} (mEq/100 g)	Exchangeable cations Mg^{+2} (mEq/100 g)	Exchangeable cations K^{+} (mEq/100 g)	Total acidity (H^{+} et Al^{+3}) (mEq/100 g)	C.E.C. A (mEq/100 g)	C.E.C. B (mEq/100 g)	BS% A	BS% B	N total %
LHF	$\bar{X}$	3.00	-	-	-	-	1.60	20.70	3.68	1.77	127.00	27.50	116.14	96.00	17.23	1.36
	S	0.24	-	-	-	-	0.35	2.90	0.58	0.39	2.58	2.85	66.78	1.41	1.47	0.15
	N	4	-	-	-	-	4	4	4	4	4	4	4	4	4	4
Ae	$\bar{X}$	3.38	-	-	-	-	1.59	0.47	0.04	0.09	18.00	2.19	18.82	29.50	5.42	0.06
	S	0.17	-	-	-	-	0.83	0.14	0.02	0.03	6.22	0.86	5.94	8.96	4.69	0.01
	N	4	-	-	-	-	4	4	4	4	4	4	4	4	4	4
Bf	$\bar{X}$	4.45	2.05	0.25	0.50	0.75	0.92	0.42	0.04	0.06	39.25	1.43	39.98	45.75	1.73	0.11
	S	0.47	0.45	0.23	0.13	0.35	0.80	0.14	0.01	0.02	4.65	0.69	4.81	29.70	0.88	0.06
	N	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
C	$\bar{X}$	4.40	-	-	-	-	0.79	0.30	0.08	0.04	27.33	1.20	27.93	43.33	2.13	0.04
	S	0.40	-	-	-	-	0.72	0.12	0.09	0.02	5.51	0.78	5.92	29.19	0.99	0.01
	N	3	-	-	-	-	3	3	3	3	3	3	3	3	3	3

C.E.C.: cationic exchange capacity:
- values column A: $\sum$ exchangeable cations (Ca^{+2}, Mg^{+2}, K^{+}, Al^{+3})
- values column B: $\sum$ exchangeable cations (Ca^{+2}, Mg^{+2}, K^{+}) + total acidity

BS: bases - saturation rate:
- column A: $$\frac{\sum \text{exchangeable cations } (Ca^{+2}, Mg^{+2}, K^{+})}{\text{C.E.C. (column A)}} \times 100$$
- column B: $$\frac{\sum \text{exchangeable cations } (Ca^{+2}, Mg^{+2}, K^{+})}{\text{C.E.C. (column B)}} \times 100$$

nutrients and minerals in an ecosystem. For the 1983-1984 hydrological year, wet atmospheric fallout for all components was 29 kg/ha, including 17 kg/ha-yr attributable to sulfates (Table 10). This value is close to the maximum of 20 kg/ha-yr recommended by the Canada-United States working groups (1982) for the protection of aquatic environments that are moderately sensitive to acidification.

Study of the hydrochemical balance provided a basis for classification of major ions in three categories:

- substances for which atmospheric inputs are greater than exported mass (H^+, NO_3^-, NH_4^+);

- substances for which atmospheric inputs are approximately equal to exported mass (Cl^-, SO_4^{-2}); and

- substances for which atmospheric inputs are much smaller than the mass exported to the outlet (Ca^{+2}, Mg^{+2}, Na^+, K^+, HCO_3^-).

Examination of time variation, over the melt period, in pH, calcium, bicarbonate, and sulfate concentrations (Fig. 5), and aluminum speciation (Fig. 6) permits identification of certain important processes which take place during the spring thaw. The substantial drop in bicarbonates (from 168 to 27 uEq/L) which occurs throughout the ascendent phase of the spring runoff hydrograph (April 4 to May 9) indicates that the neutralization capacity of the Cassette River watershed is barely sufficient in springtime when inputs of meltwater and rain are received. The drop in pH, although less pronounced, follows the decrease in bicarbonates. The two minimum values (6.0 units) were obtained at the time of the first flood peak, on April 29 and May 2 (Fig. 5).

On the basis of the complementary study conducted by Campbell et al. (1984), it would appear that organic + adsorbed aluminum is the predominant form of the metal during the spring melt (Fig. 6). The authors suggest that the slight increases in aluminum levels observed over the spring indicate that the basin must contain an aluminum "reservoir" which reacts quickly during the high water period. The upper layer of soil, which contains water with high aluminum and organic matter content, could serve as the aluminum reservoir. The observed peak concentration for total aluminum (176 ug/L) could be due to increased input of sediments in suspension (particulate Al) rather than geochemical mobilization of dissolved aluminum. For monomeric inorganic aluminum (dialyzable and extractable aluminum), the anionic form $Al(OH)_4^-$ clearly predominates over the other forms (hydroxyl, sulfate, and fluoride complexes).

Time variation in sulfate concentrations (Fig. 5) differs from that observed for calcium, bicarbonates, and pH. The maximum (75 uEq/L) was reached at the very beginning of the melt period. Subsequently, levels tapered off gradually to about 50 uEq/L until the start of May.

Analysis of seasonal variation in atmospheric inputs and exports of sulfates (Fig. 7) yields a better understanding of the circulation of this anion and its importance in acidification processes. We saw above that on an annual basis atmospheric sulfate inputs are practically equal to exports. We can deduce from this observation that geological inputs are negligible and that, on an annual basis, the sulfate anion is not trapped in the watershed. Over the spring, the quantity exported becomes twice as high as the atmospheric input. This sulfate deficit is greater than the surplus accumulated over the winter in snow. A relatively high proportion of the sulfates released into surface waters should therefore come from sulfates accumulated in the soil over the summer and fall. This analysis of seasonal variation in sulfate

Table 9. Physicochemical composition of precipitation and ground snow from clearing and forest locations. (from Brouard and Lachance 1986).

Parameters	In clearing					Under forest cover				
	Local precip-itation (mean Winter)	Ground snow mean value				Local precip-itation (mean Winter)	Ground snow Mean value			
		Winter	13/12 07/02 06/03	27/03 03/04 10/04	17/04 25/04 02/05		Winter	13/12 07/02 06/03	27/03 03/04 10/04	17/04 25/04 02/05
H^+ (µEq/L)	40.30	11.40	15.20	14.30	5.23	43.50	12.60	17.70	8.99	7.59
Conductivity (µS/cm)	17.70	6.28	7.80	7.92	3.60	30.50	8.47	9.62	11.00	5.40
NO_3^- (µEq/L)	21.30	6.89	7.80	9.87	3.63	17.00	5.73	8.38	5.10	4.42
Cl^- (µEq/L)	6.91	4.04	3.74	4.67	4.12	39.30	8.86	7.38	13.30	6.40
SO_4^{-2} (µEq/L)	23.10	7.31	8.06	10.20	4.12	74.90	13.30	14.60	20.50	6.20
NH_4^+ (µEq/L)	5.67	2.19	1.99	2.50	2.32	3.30	3.44	2.32	5.80	2.32
Na^+ (µEq/L)	7.74	3.96	3.56	4.27	4.43	27.20	8.21	8.08	11.00	6.07
K^+ (µEq/L)	0.95	0.88	0.64	0.88	1.10	22.10	7.78	3.18	16.30	3.83
Ca^{+2} (µEq/L)	5.38	3.40	1.90	5.42	2.95	25.70	8.94	4.20	18.60	4.25
Mg^{+2} (µEq/L)	3.03	1.98	2.20	1.95	2.10	20.60	4.59	4.94	7.88	1.65
$\sum$ cations (µEq/L)	62.6	23.6	25.3	29.1	18.1	142.0	40.5	40.5	68.4	25.7
$\sum$ anions (µEq/L)	51.4	18.5	19.9	25.0	12.0	133.0	30.8	30.8	52.9	18.7

Table 10. Hydrochemical balance of the Cassette River watershed (from Brouard and Lachance 1986).

Parameters	Atmospheric[1] input (kg/ha)	Quantity[1] (kg/ha)	Balance (kg/ha)
H^+	0.405	0.0024	-0.40
HCO_3^-	-	44.7	44.7
$N-NO_3^-$	2.33	0.58	-1.75
Cl^-	3.90	3.03	-0.87
SO_4^{-2}	16.81	16.28	-0.53
$N-NH_4^+$	1.38	0.25[2]	-1.13
Na^+	2.28	3.93	-1.65
K^+	0.59	2.23	1.65
Ca^{+2}	1.09	15.70	14.60
Mg^{+2}	0.30	2.32	2.02
Total	29.1	89.0	59.9

[1] Equations relating to the calculation of atmospheric input and of quantity exported are presented by Brouard and Lachance (1985).

[2] For NH_4^+, the mean concentration of 0,04 mg/l is from by Brouard et al. (1982) for the Des Escoumins in 1981.

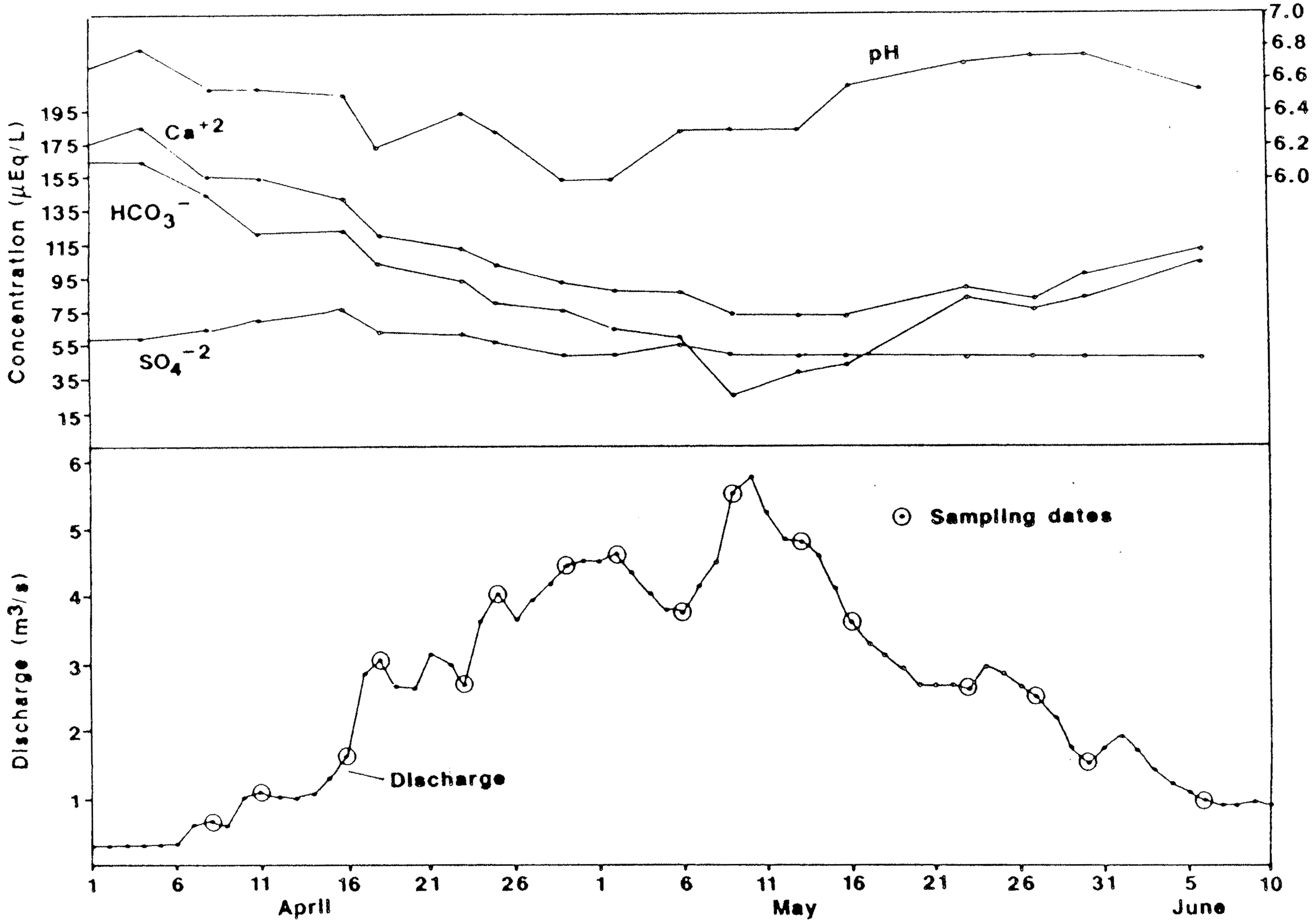

Fig. 5. Time variation in rate of flow, pH and calcium, bicarbonate and sulfate concentration for the Cassette River (spring 1984) (from Brouard and Lachance 1986).

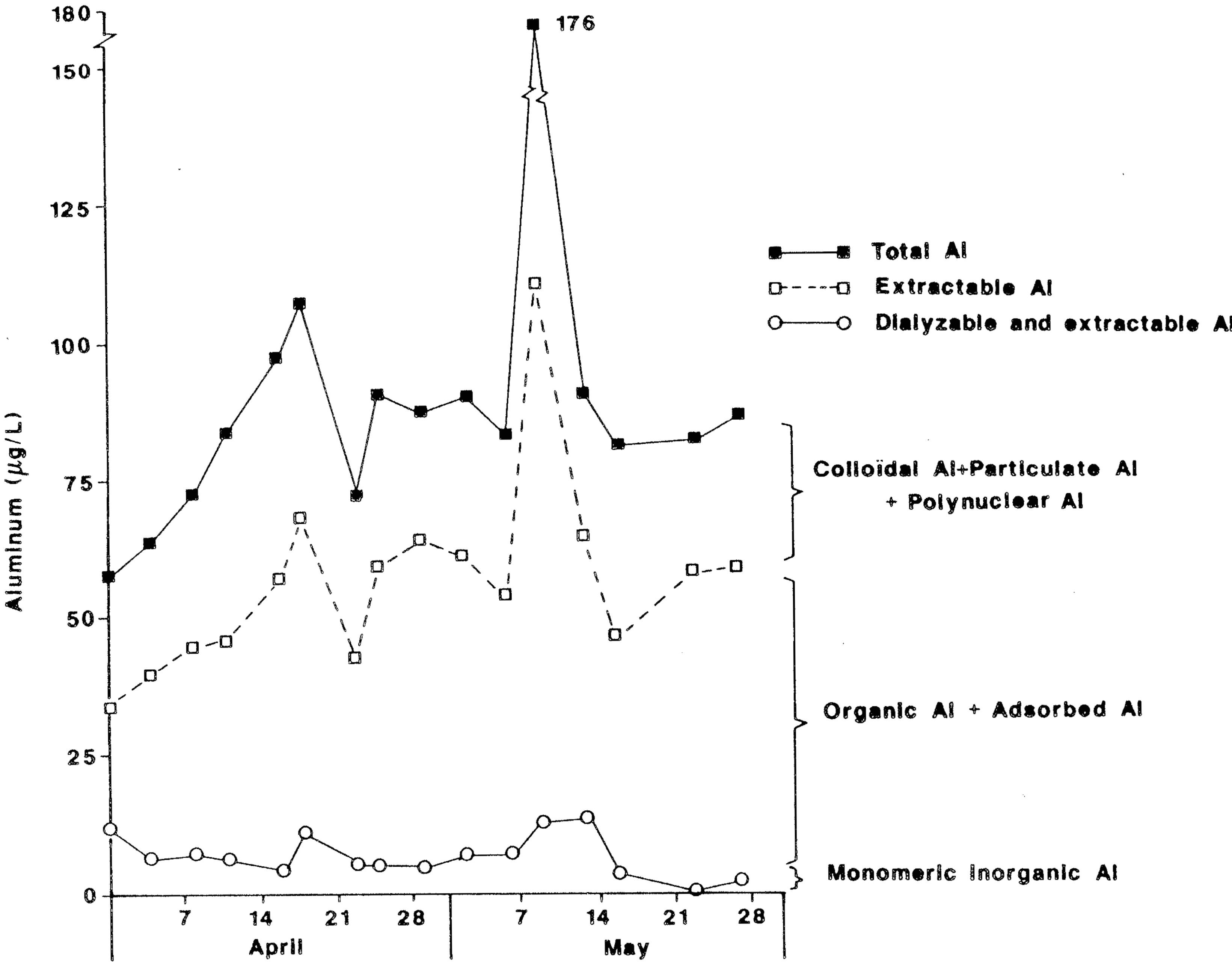

Fig. 6. Time variation in aluminum speciation in the sulfate waters of the Cassette River (spring 1984) (from Campbell et al. 1984).

inputs and exports thus brings to light a new phenomenon. The relatively high concentrations of sulfates found in surface waters during the spring melt period would appear to be due not only to large-scale release of sulfates accumulated in snow reserves but also to a substantial contribution accumulated in soils and vegetation over the preceding summer and fall. The importance of this phenomenon and its ecological implications for explaining springtime shock should be examined in future studies.

In sum, the specific river studies have led to clearer identification of the spatio-temporal dynamics of the surface water acidification phenomenon and the ability of watersheds to tolerate atmospheric acid inputs. Examination of variations in the physicochemical quality of surface waters over the spring has permitted monitoring of the melt phenomenon and ion migration. It has also been shown that organic + adsorbed aluminum is the predominant form during the melt period. The approach of monitoring the atmospheric inputs and exports of a watershed has enabled identification of some of the important processes taking place within the watershed, primarily during the spring thaw. Sulfate accumulation in soils over the summer and fall appears to play an important role in the physical chemistry of waters during the melt period.

BIOLOGICAL CHARACTERISTICS OF AQUATIC COMMUNITIES

INVERTEBRATES

In order to determine whether aquatic communities in Quebec are affected by acid precipitation, DFO-Quebec has conducted surveys and specific studies in lake environments (cf Table 1). A number of the lakes sampled for physical chemistry were surveyed in 1981 (Langlois *et al.* 1983) and 1982 (Pinel-Alloul and Méthot, 1985; Ciupka-Luzzi, 1983) to obtain basic data on invertebrate communities (Table 11). These data included species composition and relative abundance of phytoplankton, zooplankton, and benthos communities. A more specific survey was also conducted to detect regional and temporal influences. In 1983, the effects of acid precipitation on trophic relationships in lake ecosystems were compared for an area with high acid fallout (Maniwaki: 26 lakes) and areas with low acid fallout (Schefferville: 13 lakes; Gagnon: 5 lakes; Sept Iles: 6 lakes) (Pope *et al.* 1985). Variations in the structure and composition of zooplankton communities (Pinel-Alloul et Codin-Blumer 1984) and phytoplankton communities (Désilets 1984) were also studied on a temporal basis correlations do not reflect a cause and effect relationship between the two types of descriptors (phytoplankton and morphometry) since the morphometric parameters act only during the summer of 1983 in two groups of lakes in the Outaouais region (Maniwaki).

Phytoplankton

The biotic components that are likely to react to acidification include phytoplankton communities, which can be directly affected by lowered pH and increased levels of certain metals or indirectly influenced by the effect of acidification on macroscopic communities (fish, benthos, etc).

In Canada, according to Harvey *et al.* (1981), phytoplankton biomass and productivity do not vary significantly between acid and non-acid lakes. This could be explained in part by the increase in photic depth in acid lakes. For all phytoplankton groups, diversity is reduced by acidification, particularly where pH drops below 5.6 (Harvey *et al.* 1981; Dillon *et al.* 1977; Almer *et al.* 1978).

The survey of 176 lakes in 1981 permitted identification of 47 taxons in five major

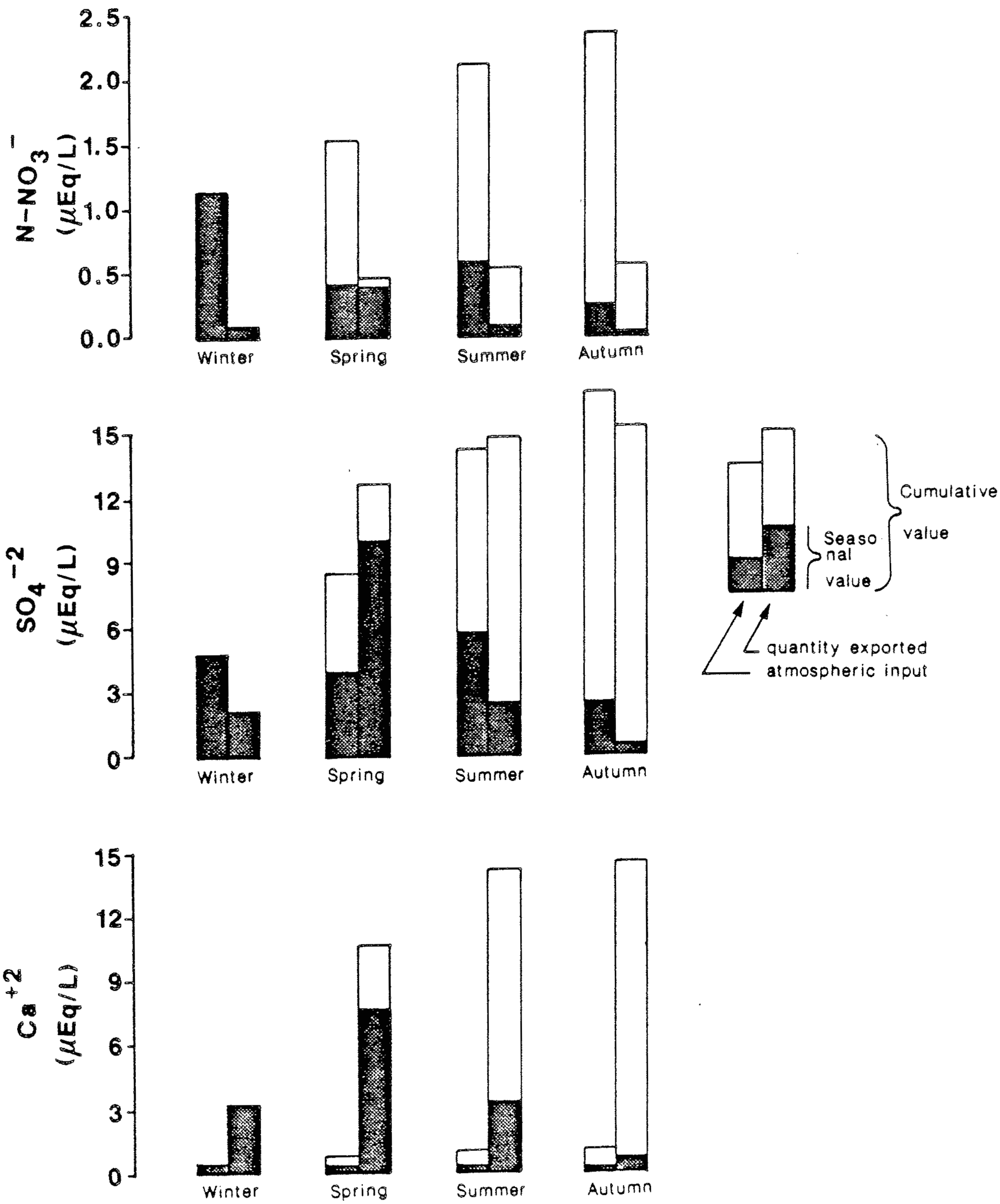

Fig. 7. Seasonal variation in atmospheric inputs and exports of nitrates, sulfates and calcium for the Cassette River (1983-1984) (from Brouard and Lachance 1986).

groups: Chlorophyta, Chrysophyta, Cyanophyta, Pyrrophyta, and Euglenophyta (Richard, 1983). Generic diversity of phytoplankton drops off in the study area as acidity increases (Langlois et al. 1983). The average number of genera is 13.2 in lakes of pH between 4.5 and 5.0 and 17.0 where pH is between 7.5 and 8.0 (Fig. 7).

Total abundance also seems to be affected by lake pH. The highest mean total abundance occurs at pH between 6.0 and 7.0 (Fig. 8). According to Langlois et al. (1983), it appears that the composition of phytoplankton communities in these lakes exhibits a population structure quite similar to that of environments undergoing acidification. This assertion must be considered with reservations, however, since a flash survey conducted on only one occasion in each lake cannot yield a true portrait of the phytoplankton community (which is known to vary substantially over the summer, both qualitatively and quantitatively).

The results of the phytoplankton survey of 54 lakes in 1982 show gradual replacement of Cyanophyta, which are dominant in the western portions of the province (Maniwaki), by Chrysophyta, which are more abundant on the North Shore. Chlorophyta are rarely dominant except in the lakes of the Némiscau area and certain lakes on the North Shore (Manicouagan, Havre Saint Pierre). On the basis of total cell abundance and number of taxons, Désilets (1984) and Pinel-Alloul and Méthot (1985) identified three large homogeneous regions:

- the North Shore, characterized by lower phytoplankton density (1.1 to 1.9 x 10^6 cells/litre) and species diversity (17 to 24 taxons) than elsewhere;
- the western central region (Maniwaki, La Tuque, Némiscau, and Senneterre), represented by a very large number of taxons (26 to 29) and very high phytoplankton density (3.3 to 4.2 x 10^6 cells/litre);
- the Chapais region, which exhibits the highest population density (4.9 to 8.7 x 10^6 cells/litre) and the largest number of species (30 to 42 taxons).

Pinel-Alloul and Méthot (1985) suggested the existence of empirical relationships between phytoplankton species and morphometric variables. It was also noted that the abundance of Cyanophyta, Chlorophyta, and some Chrysophyta could be linked to the longitudinal gradient, trophic enrichment, shallowness, and small volume of lakes. However, Chrysophyta appear to be more abundant in the deep lakes of the North Shore. The authors specify that the suggested correlations do not reflect a cause and effect relationship between the two types of descriptors (phytoplankton and morphometry) since the morphometric parameters act only indirectly by conditioning nutrient inputs and biological productivity in the lakes.

Moreover, the principal component analysis carried out by Pinel-Alloul and Méthot (1985) indicated that the lakes with the highest levels of mineralization and alkalinity supported the phytoplankton communities with the highest densities for Cyanophyta and Chlorophyta. In contrast, acid lakes with high aluminum content show very low diversity and species abundance. In addition, transparent lakes have very low phytoplankton productivity while coloured lakes with high iron and organic carbon levels contain more phytoplankton, in particular Chrysophyta and microflagellates.

On the whole, the multidimensional analysis of phytoplankton variability in terms of physicochemical variations in the water confirmed certain empirical relationships already noted by other authors i.e. declining abundance and

Table 11: Number of lakes sampled for phytoplankton (PH), zooplancton (ZO), benthos (BE) and fish (FI) (surveys and specific studies 1981-1983).

Quebec regions	Surveys												Specific Studies	
	1981				1982				1983				1983	
	*PH	ZO	BE	FI	PH	ZO	BE	FI	PH	ZO	BE	FI	PH	ZO
Shefferville										13				
Blanc-Sablon		2	2	2										
Natashquan		2	2	2										
Havre Saint-Pierre		0	2	2		6								
Sept-Iles		2	1	2		4				6				
Baie-Comeau		2	2	2										
Manicouagan		2	2	2		8								
Gagnon		2	1	2						5				
Chute-des-Passes		3	2	2		6								
Alma		1	2	2										
Roberval		2	2	2										
La Tuque		4	4	4		6								
Québec		2	2	2										
Maniwaki		5	3	4		7				26			7	
Senneterre		2	2	2		5								
Chapais		4	4	4		6								
Némiscau		2	2	2		6								
TOTAL	176	37	35	38		54				50			7	

* The distribution among regions of 176 lakes sampled for phytoplankton is similar to that for the lakes sampled for physicochemical quality (cf. Table 3).

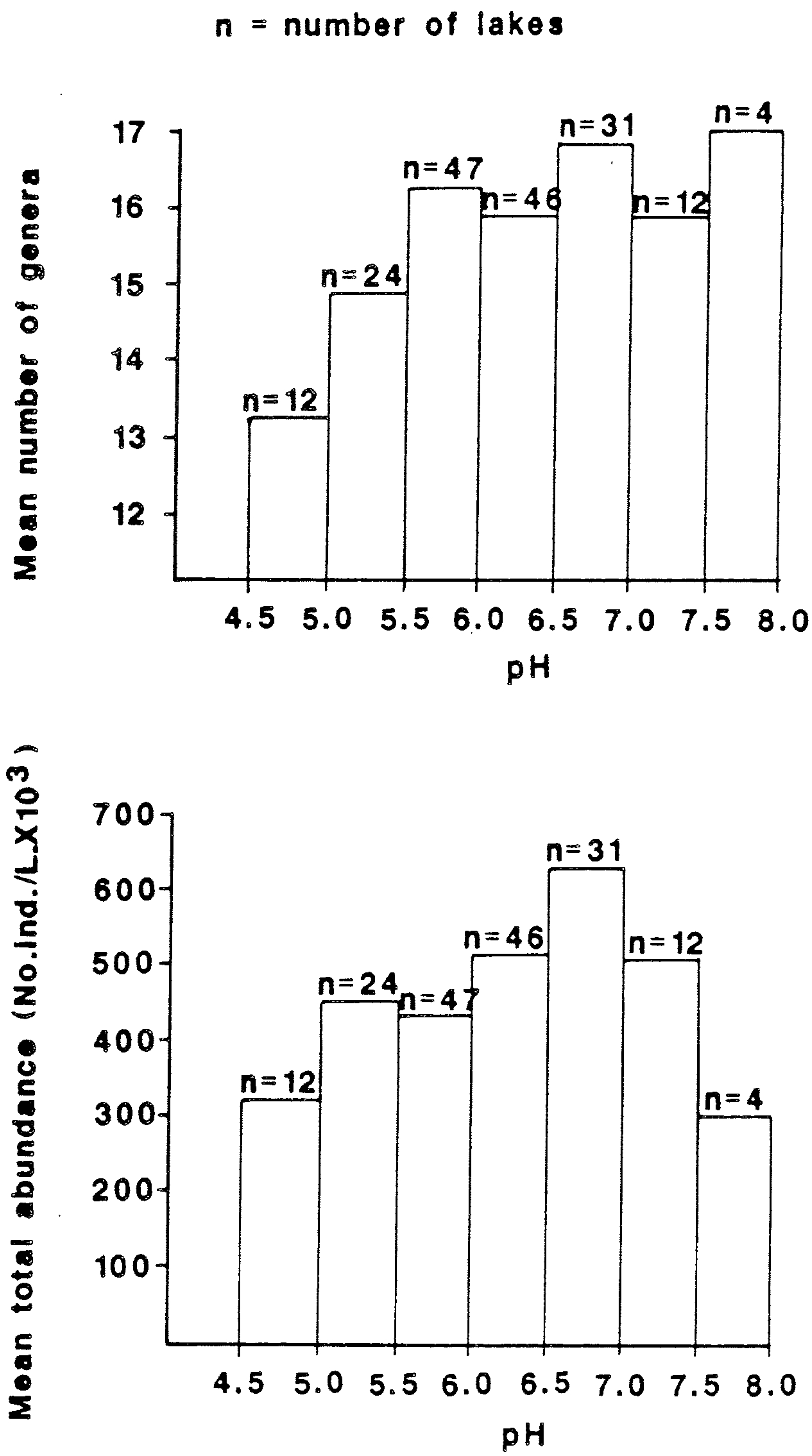

Fig. 8: Phytoplankton. Mean number of genera and mean total abundance by pH class (from Langlois *et al.* 1983).

species diversity with increasing acidity in the environment.

The 1983 survey of 50 lakes in the Maniwaki, Sept Iles, and Schefferville areas was conducted in order to obtain a qualitative description of the plankton, benthos, and fish communities living in lakes which are not only suited to sport fishing and wildfowl but are also likely to be subjected or have been subjected to acidification of natural or anthropic origin (Pope et al. 1985). As a complement, the study also examined the structure of plankton and benthos communities in non-acid lakes in order to verify the influence of predation by fish. In addition, it included an assessment of the probable impact of acidification on the food chain by comparing acid lakes with neutral lakes. For phytoplankton, Pope et al. (1985) showed that species diversity and cell density are generally higher in the southwest of Quebec than in the northeast. In the Maniwaki area and the northeast, acid lakes contain fewer species than alkaline lakes. Highly acid lakes in the Schefferville area (pH 3.0 to 4.2) have lower species diversity than moderately acid lakes (pH 4.8 to 6.1) in the Sept Iles area.

The mean number of species and cell densities for Chlorophyta and Cyanophyta decline going from east to west in Quebec as acidity rises. The apparent sensitivity of Chlorophyta to acidity seems to be consistent with the conclusions drawn by Pinel-Alloul and Méthot (1985) but inconsistent with those drawn by Langlois et al. (1983), who indicate that Chlorophyta are relatively tolerant of acidity. Differences in sampling dates (September-October: Richard, 1983, and Langlois et al. 1983; July-August: Pinel-Alloul and Méthot 1985, and Pope et al. 1985) may explain the observed differences between studies with regard to taxonomical structures, since water temperatures are higher in the west (22 to 26°C) than in the east (10 to 12°C) and populations therefore develop differently.

Désilets (1984) identified phytoplankton samples taken from two groups of lakes in the Outaouais region over the summer of 1983. The author noted that the best-represented groups were (in declining order) Cyanophyta, Chlorophyta, and Chrysophyta. The pH value below which species diversity is reduced is 6.8; this is a very high value in view of the fact that acidity levels generally considered critical in other studies are in the vicinity of pH 5 (Désilets 1984). In studying variability within the two lake groups in the area, it was noted that the species diversity of samples differed quite considerably. This leads us to question the relevance of studying phytoplankton abundance and diversity in connection with environmental monitoring of the effects of acid precipitation on biotic components of the ecosystem, especially since physicochemical variables are not the only factors which are likely to have an influence on the abundance, structure, and diversity of phytoplankton populations in lakes of the Canadian Shield. Inputs of nutrients caused by leaching of soils (Van Dam et al. 1981), the abundance and nature of herbivorous zooplankton (Lynch 1980), and the abundance and productivity of bacterioplankton (Currie and Kalff 1984) are all factors which can influence variability in the abundance, diversity, and structure of phytoplankton communities.

Zooplankton

The zooplankton community can be affected by a number of physical and biological factors: pH, metal concentrations, predation, phytoplankton composition, climate, etc. While it is difficult to isolate changes specifically related to acid precipitation, many researchers have examined the relationship between acidity and zooplankton in Canada and elsewhere in the world (Almer et al. 1978; Allborn and Fair 1981; Henrikson et al. 1980).

In 1981, DFO-Quebec took samples of zooplankton in 37 lakes distributed almost uniformly over the bases of operations employed for the physicochemical survey of 198 lakes in the Canadian Shield. In all, 35 species were recorded (13 Rotifera, 13 Cladocera, and 9 Copepoda). Five species are present in more than 70% of the lakes, and the most abundant of these species is the copepod Leptodiaptomus minutus. Langlois et al. (1983) noted that the diversity of zooplankton communites declines with increased pH (Fig. 9). At pH over 5.5, the observed average was 11.3 species per lake while, at pH below 5.5, the number of species drops gradually to an average of 8.7 in lakes with pH under 5.0. Cladocerans and cyclopoid copepods are the most sensitive to pH drops: the average number of species is 1.8 at pH below 5.0 and 4.8 at pH over 7.0.

Among the cladocerans, the genus Daphnia contains the species most sensitive to low pH: no species from this group are encountered at pH under 5.0. Other studies conducted in Canada and Sweden (Sprules, 1975; Raddum et al. 1980) confirm these results for cladocerans. Species of the calanoid copepod group appear to be fairly resistant to acidity. The main species of this group, Leptodiaptomus minutus, accounts for 40% of the population in more than 46% of the lakes studied. These results are supported by Harvey et al. (1981), who noted that this is one of the commonest species in acid lakes of the Canadian Shield. For rotiferans, relative abundance increases considerably in acid lakes while that of cladocerans and cycloid copepods decreases (Fig. 10).

During the 1982 national survey, a total of 50 zooplankton species were identified (21 Rotifera, 17 Cladocera, and 12 Copepoda) by Pinel-Alloul and Codin-Blumer (1983). These authors noted increased species diversity among these communities following a longitudinal east-west gradient. The lakes with the highest zooplankton counts (100×10^3 org/m^3) are located in the northwest (Chapais, Némiscau, Senneterre), while the lakes with the lowest counts (20×10^3org/m^3) are generally in the southwest (Maniwaki), the centre (La Tuque and Chute des Passes), or the east (Manicouagan and Havre Saint-Pierre) of the study area. In terms of morphometry, Pinel-Alloul and Méthot (1985) observed that small, shallow lakes with high mineralization levels in the west produced high zooplankton biomass densities and mainly harboured communities dominated by copepods (Leptodiaptomus), while the deep, oligotrophic lakes of the east (Havre Saint Pierre, Sept Iles, and Manicouagan) contained zooplankton communities with low density and biomass dominated by rotiferans. Overall relationships between physicochemical and zooplanktonic variables did not permit identification of a relationship between environmental acidity and zooplankton density or biomass except in the case of cyclopoids, for which populations decrease in the acid lakes of the northeast, and rotiferans, for which abundance increases in coloured, acid lakes (Pinel-Alloul and Méthot 1985).

During the 1983 survey, 24 species of pelagic zooplankton were identified in the 50 lakes sampled. Most of the zooplankton communities encountered, in both acid and non-acid lakes, were dominated by a single species of herbivorous calanoid copepod, Leptodiaptomus minutus, which probably receives quite little predation pressure from the various fish species (Pope et al. 1985). Except in one lake, the authors did not observe displacement of this species by a larger herbivorous copepod when predation by fish was inexistent or limited. This contrasts with the European experience where, according to Erikson et al. (1980), large herbivorous copepods dominate acid lakes that have lost their fish. Pope et al. (1985) showed that zooplankton communities in lakes of the Maniwaki area bear a closer resemblance to those of neutral and alkaline lakes than to those of acid lakes in the Sept Iles area. It was also noted that contrary to the predictions of most trophic models (Brooks and Dodson 1965; Zaret 1980) zooplankton

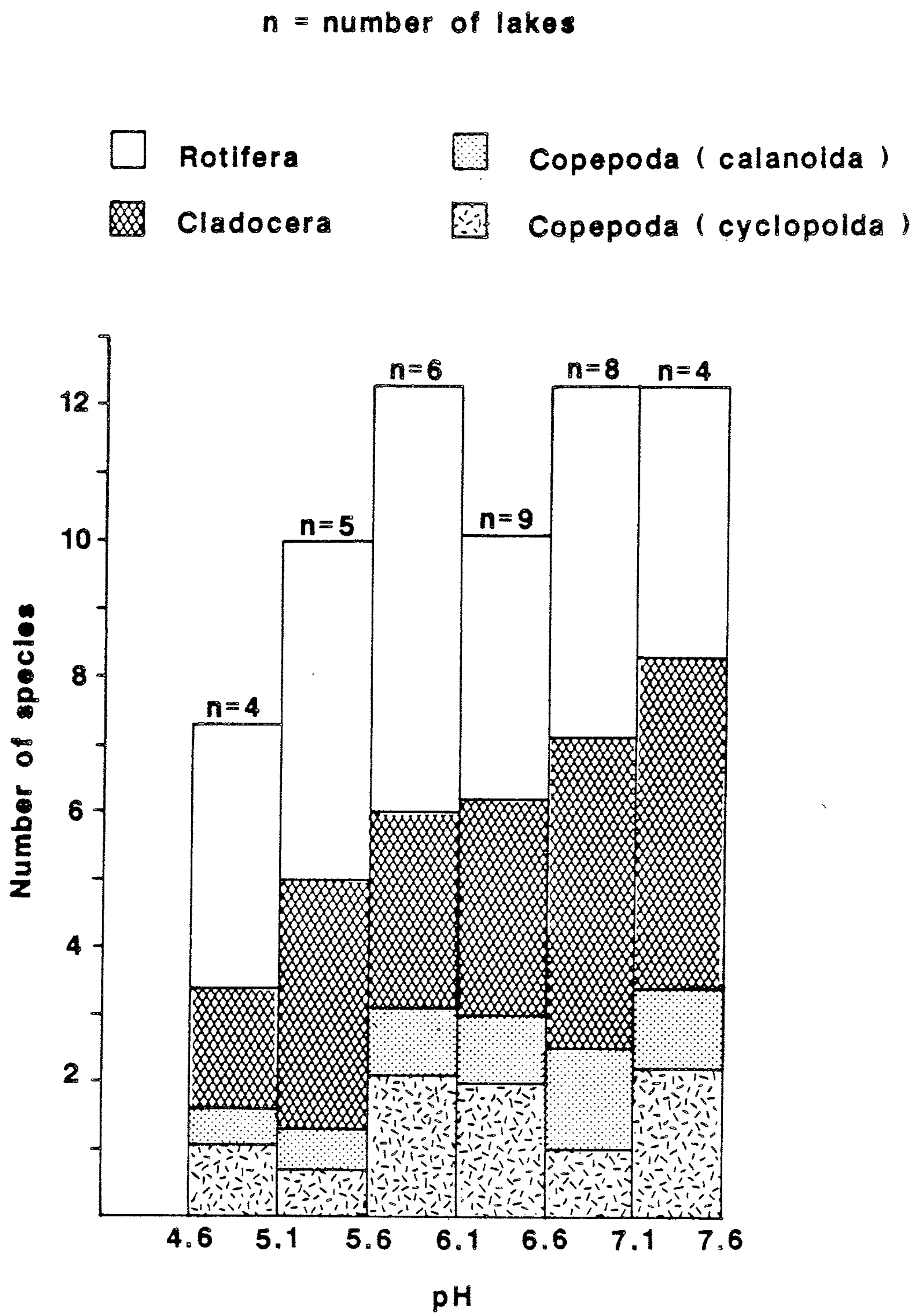

Fig. 9: Zooplankton. Mean number of species by pH class (from Langlois *et al.* 1983).

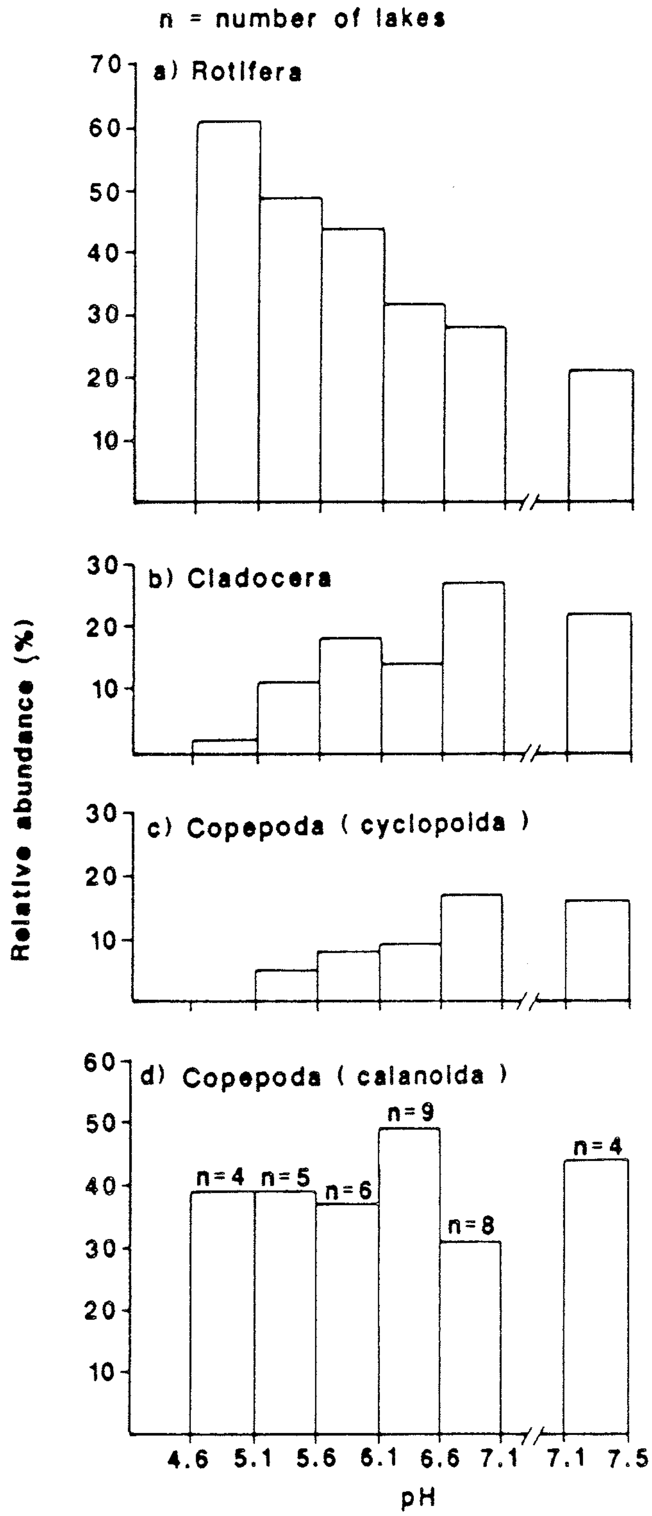

Fig. 10: Relative abundance of different zooplankton groups as a function of pH (from Langlois *et al.* 1983).

communities in which large cladocerans are abundant are more closely associated with lakes containing fish than with fishless lakes.

Benthos

The influence of acid precipitation on benthos has been studied mainly in Norway, Sweden, and the United Kingdom. The direct causes of changes noted in benthic communities have not been clearly established; it is most commonly believed that pH exerts an indirect effect on availability of food, predation, and competition (Harvey et al. 1981).

In the 1981 national survey, the absence of samples taken at various depths and times of the year encouraged Langlois et al. (1983) to proceed with caution in interpreting the results obtained for the 35 lakes sampled (Ménard 1982). None the less, the results did permit identification of certain trends with regard to the influence of the physicochemical quality of water on the composition of benthic communities. Moreover, examination of benthos in relation to the physicochemical composition of sediments did not yield any significant correlation (Langlois et al. 1983). However, total number of organisms and biomass varied significantly with pH (Fig. 11). The highest number of organisms and greatest biomass were found in lakes of pH between 5.5 and 6.5. On either side of this interval the corresponding values are distinctly lower, a situation which appears to be in agreement with the findings of other researchers (Raddum 1980; Nielsen 1980). Contrary to what other authors have observed (Fiance 1978; Bell 1971), abundance of Ephemeroptera did not seem to decline with pH. Another significant finding was the total absence of the amphipod Gamarus, which is common in lakes with pH over 6.4 (Okland 1969). With regard to the survey of 54 lakes conducted in 1982, Ciupka-Luzzi (1983) noted that the sampling was not representative of the environment surveyed in view of the technical and analytic approach employed. The same author therefore feels it would be misleading to attempt to interpret the results obtained in 1982 in relation to the physicochemical quality of the lakes sampled.

After the sampling of 50 lakes in 1983, Pope et al. (1985) summed up the relationship between the structure of benthic communities and acidity and predation levels in the following manner:

- the crustacean Hyatella azteca may be a good indicator of lake acidification, since it is clearly less abundant in acid lakes;

- with regard to aquatic insects, data collected on ephemera are in keeping with observations in the scientific literature to the effect that they are scarce in acid lakes. However, density measurements for Odanata are the same in acid and non-acid lakes except in the Schefferville area, where they are not present in most lakes. The pelagic species Chaoborus, a predator insect which is in turn subject to predation by fish, is more abundant in fishless lakes, at least when the pH is over 4.5. Similarly, Hemiptera and Coleoptera, which are active swimming predators, show a slight tendency to be more numerous in fishless lakes, while epibenthic herbivorous Cladocera are significantly more abundant in fishless, moderately acid lakes than in neutral or alkaline lakes.

- gastropod mollusks are eliminated from acid lakes while pelecypods exhibit a slight drop under moderately acid conditions but disappear in the Schefferville area when acidity becomes extreme.

- Hirudinea tend to disappear from acid waters. The absence or shortage of prey in these lakes (fish, amphibians, invertebrates) is very likely the determining factor, since their population consists mainly of carnivorous predators, blood suckers, and parasites.

In sum, the results obtained from the surveys and specific studies of 1981-1982 show a clear drop in the abundance and diversity of invertebrate communities in acid environments. However, this drop could be due to factors other than acidification, such as biogeographical isolation, morphometric and physicochemical features, or the range of the species involved. On the whole, the results make it possible to characterize Quebec lakes in terms of biology on the basis of the region-to-region acidity gradient within the Canadian Shield. None the less, the knowledge acquired to date is still insufficient to permit us to measure with certainty the repercussions of acid precipitation on invertebrate communities. In our opinion, the spatial sampling effort for biological components was sufficient; however, only spot samples were taken, and this sets strong constraints on interpretation in view of the great seasonal variations that occur among phytoplankton, zooplankton, and benthos invertebrate populations.

FISH

Between 1981 and 1985, DFO-Quebec conducted several surveys of the fish community in Quebec lakes (Table 1). Among the lakes sampled for physical chemistry, subsamples of 38 lakes (Langlois et al. 1983) and 54 lakes (Pinel-Alloul and Méthot 1985; Nadeau 1983) were surveyed in 1981 and 1982 respectively to obtain basic data on the fish community. In addition, a study to complement the biological surveys was carried out to assess the indirect impact of lake acidification on the food chain for fish of interest for sport fishing in an area that receives heavy acid fallout (Maniwaki) and areas that receive less acid fallout (Schefferville, Gagnon, Sept Iles) (Pope et al. 1985). A flash survey of a number of arctic char habitats was conducted in the late summer of 1983.

Moreover, specific in situ and laboratory studies (cf Tables 1 and 2) were carried out with salmonids. In lakes, the in situ studies dealt primarily with brook trout egg and fry mortality (Leclerc et al. 1984; Leclerc 1982), while studies in river environments involved bioassays using Atlantic salmon eggs and fry (Brouard and Lachance 1986). Complementary laboratory work included development of a biochemical dating technique for dead eggs (Chagnon 1984; Leclerc et al. 1984) and studies into the toxic effects of aluminum and manganese on salmonid eggs, fry, and juveniles (Van Coillie et al. 1982; Brouard and Lachance 1986).

Characterization of the fish community

During the fish survey of 1981, a total of 13 species were identified. The commonest species is the brook trout (*Salvelinus fontinalis*), which is found in 53% of the lakes. Two other species, the white sucker (*Castostomus commersoni*) and the northern pike (*Esox lucius*) are present in 26% and 21% of the lakes respectively (Langlois et al. 1983). The results of experimental fishing indicate that the mean pH of the five (5) lakes with a fishing yield of zero is 5.2 (ranging from 4.6 to 5.7). Langlois et al. (1983) noted that the average fishing yield and species diversity of the lakes sampled tends to drop with pH (Fig. 12). It was also noted that brook trout are present at pH below 5.0, whereas the white sucker does not appear unless pH is over 5.0. The absence of the latter species in some lakes could be due to environmental acidity, since Baker and Schofield (1980) showed that *Castostomus commersoni* is more sensitive to acidification than *Salvelinus fontinalis* regardless of development stage. It must be stressed, however, that factors other than the physicochemical quality of the water can explain the absence of all fish or a given species in lakes, since ranges vary from

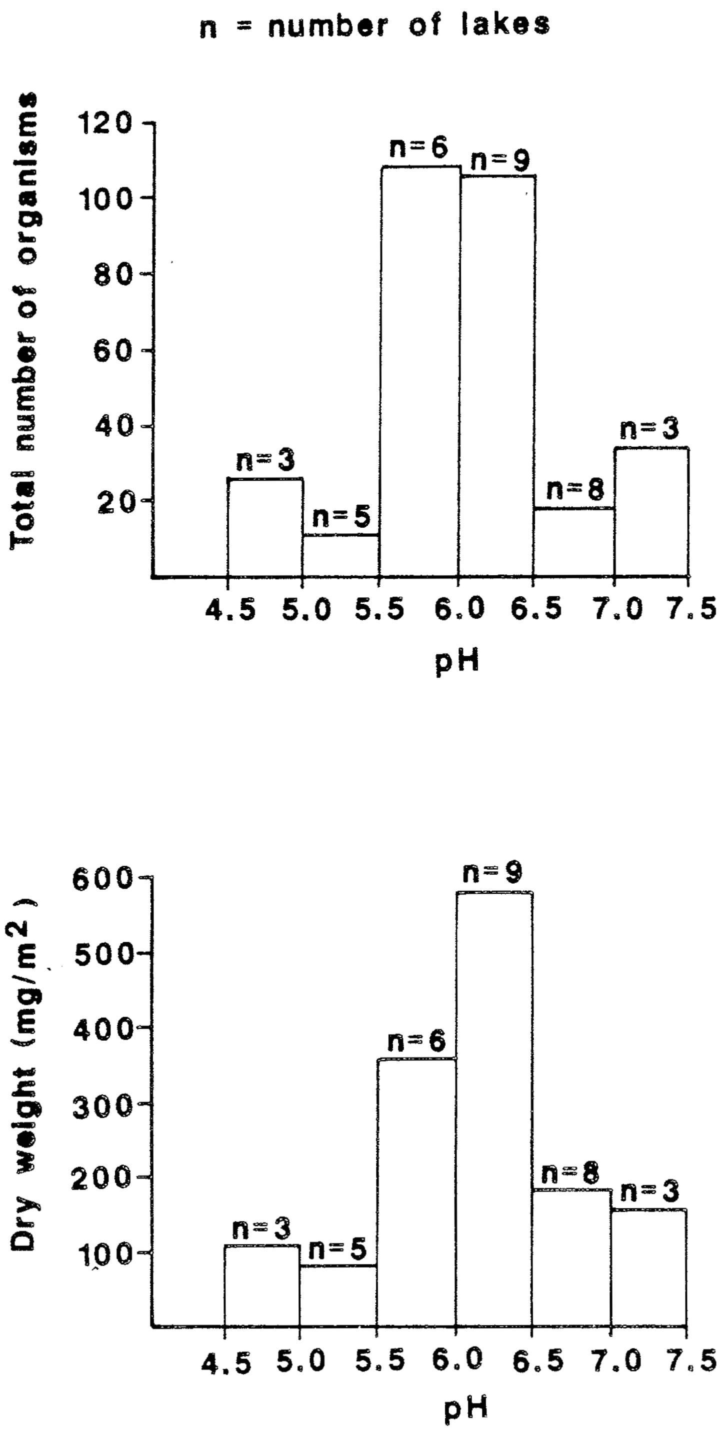

Fig. 11: Benthos. Total number of organisms and biomass (dry weight) as a function of pH (from Langlois et al. 1983).

species to species and it would appear that many lakes are naturally fishless (Langlois et al. 1983). The latter situation is apparently very common on the North Shore, likely because of the inaccessibility of lakes at the heads of watersheds.

The results of the 1982 survey (Pinel-Alloul and Méthot 1985; Nadeau 1983) indicate that the species diversity and total abundance of fish populations seem little affected by pH variability. These data are difficult to interpret since species range and biogeographical isolation may play a more important role than the physical chemistry of the waters at least insofar as species diversity of fish populations in the lakes of the Canadian Shield is concerned (Pinel-Alloul and Méthot 1985).

Nadeau et al. (1984) interpreted results on metal and major ion content in the flesh of fish harvested during the 1981 survey. They were unable, however, to establish a correlation between metal content in flesh and metal concentrations in water and sediments. Phillips (1977) notes with respect to this subject that concentrations in fish muscle tissue may vary not only according to the relative abundance of metals in the environment but also, depending on species, as a function of age, sex, size, weight, feeding habits, and water temperature. Moreover, examination of flesh metal content for several fish species as a function of pH class and alkalinity did not reveal any correlation (Nadeau et al. 1984). Similarly, in a study conducted by Scruton (1983) in lakes of Newfoundland, it was not possible to establish a correlation between aluminum and manganese content in ouananiche (Salmo salar) and brook trout flesh and parameters indicative of acidification (pH, alkalinity, colour, total aluminum, and total manganese). For mercury, on the other hand, Schneider et al. (1979) found that in walleye (Stizostedion vitreum) concentrations were higher in lakes exhibiting low alkalinity.

The study of 54 lakes in the Maniwaki, Sept Iles, and Schefferville areas conducted in 1983 shows that the Wisconsin glaciation had considerable influence on lake colonization by fish in areas of rugged topography and that a number of head lakes are fishless or have fish communities consisting of only a few species (Pope et al. 1985). The study also confirms that the number of species drops and the number of fishless lakes increases with altitude. In the Maniwaki area, low-altitude lakes are characterized by species such as yellow perch (Perca flavescens), northern pike, and centrarchids. Higher altitude lakes are characterized by cold-water species (ie: brook trout and lake trout (Salvelinus namaycush)) often associated with white sucker and minnows of the genus Chrosomus. According to Pope et al. (1985), altitude appears to be a better indicator than lake order for predicting species diversity. In the Maniwaki and Sept Iles areas, water quality is also linked to altitude, since all high-altitude fishless lakes but one have a pH between 4.6 and 5.3. In this area, all lakes below 230 m are alkaline while most of the acid lakes are above 330 m. Pope et al. (1985) note that biogeographical isolation is the primary factor governing diversity of fish communities in the Maniwaki, Sept Iles, and Gagnon areas.

The study was however unable to show that fish communities are negatively affected by the impact of acidification on the food chain for invertebrates because of insufficient sampling effort and, as a result, inadequate representativeness.

Verreault and Langlois (1984) collected basic data on the brook trout population of Lake Laflamme over the fall of 1982 and the summer of 1983 (cf Table 1). Results for growth and fertility did not differ significantly from those obtained for other populations in the Laurentides wildlife reserve. According to the same authors, the massive mortality of more than 500 fish in the spring of 1981 produced a drop in the number of organisms in the young age classes of the

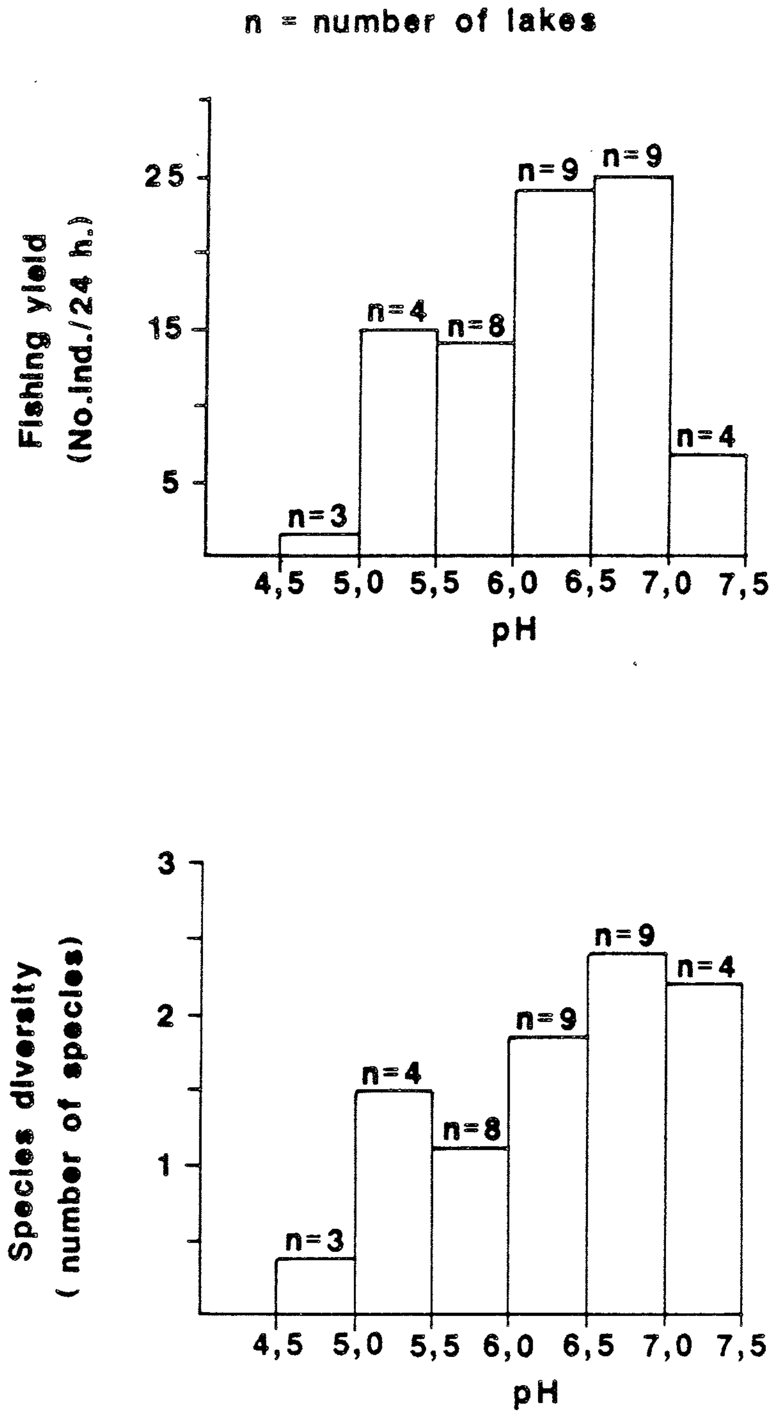

Fig. 12: Fishing yield and species diversity versus pH class (from Langlois *et al.* 1983).

population. The authors feel that the acidity of the water (minimum pH = 4.6), anoxia at depths exceeding 1 m ($O_2 \leq 1.5$ mg/L), and high total aluminum concentrations (240 ug/L) may be the causes of this mortality. A study on brook trout egg and fry survival is currently in progress in Lake Laflamme and should permit confirmation of whether the conditions observed in the lake can influence the survival of the early development stages of this species.

In order to obtain a summary characterization of arctic char (Salvelinus alpinus) habitats in southern Quebec, Le Jeune et al. (1984) took limnological samples over the summer of 1983 (cf Table 1) in 13 lakes in four Quebec Regions: Outaouais, Laurentides, Gaspé, and North Shore. For each of the lakes selected, experimental fishing was carried out and physicochemical analyses were performed. The summer habitat preferred by the arctic char (hypolimnion) regularly exhibits a pH lower than that of the surface layers (epilimnion). In view of the relatively limited sampling efforts, no cause and effect relationship can be established between the presence of arctic char and the acidity of the surveyed lakes.

Survival of salmonid eggs and fry in situ

In 1981-1982, Leclerc (1982) conducted a study of brook trout egg mortality in Parke Lake in the Portneuf reserve. Over the study period (fall 1981 - spring 1982) barely 1.7% of the eggs placed using Whitlock-Vibert boxes in the small inlet of Parke Lake survived until May 5, compared with 9.5% in the main outlet of the same lake. Leclerc (1982) was able to establish a relationship between instantaneous mortality and pH at the small inlet of Parke Lake (Fig. 13), where pH dropped fairly rapidly from April 21 to a minimum of 4.9 on April 30, 1982.

The study begun in 1981-1982 on Parke Lake in the Portneuf reserve was continued in 1982-1983 in the Charlevoix region (Des Martres controlled harvesting area (ZEC)). The tributaries of Barley and Robbé lakes were selected as experimental sites, the first because of low pH and alkalinity (summer pH: 4.4-4.8; alkalinity: 0-10 uEq/L), and the second as a control group (summer pH: 6.7-6.9; alkalinity: 90-110 uEq/L).

At the time of the first measurement of egg mortality on October 26, 1982 (day 35 after fertilization), it was noted, as shown in Table 12, that total mortality patterns were practically the same in the acid and control environments. In fact, there are greater differences between the tributary and outlet of the same lake than between the acid environment and the control environment. According to Leclerc et al. (1984), mortality under acid conditions is primarily of abiotic origin. It would appear to be mainly attributable to pH, with the possible further contribution of a synergy effect involving metals. According to the same authors, residual abiotic mortality was 15% in the control environment (pH = 6.8) and up to 100% in the acid environment (pH = 4.8). Abiotic mortality would seem to begin in the initial cleavage stages, reaching 30% at pH 4.8 and 60% at pH 4.4. It then appears to drop off to nearly zero during the embryo stages and rise to 100% at the time of hatching at pH 4.8 (Fig. 14).

In view of the high rate of biotic mortality in the control environment, new embryonic eggs were placed in the outlet on December 15, 1982 (Table 12). From this date on, it is difficult, we feel, to accurately interpret observed mortality in the acid environment in terms of that in the control environment since, in the control environment, the egg batches were introduced at a less vulnerable stage and had been kept earlier under more favourable physicochemical conditions.

With regard to tissue concentrations, sodium is at least twice as abundant in the control environment as in the acid environment. Chloride concentrations are similar in both environments in October (day 35) but appear to be higher in the acid environment at the time of hatching (February). For copper, concentrations are more than ten times higher among organisms in the acid environment (13.2 versus 1.0 ug/g) over the month of February (days 135 to 149). Iron concentrations are higher in the acid environment than in the control environment at both times.

Embryo development was more rapid in the control environment than in the acid environment, but the less-developed organisms in the acid environment contain more cytoplasmic proteins, indicating, according to Leclerc et al. (1984) that the eggs are adjusting to environmental conditions. A similar protein increase had previously been noted in rainbow trout (Salmo gairdnerii) affected by organic pollution (Wieser and Hinterleitner 1980).

The method for biochemical dating of dead eggs that was developed in connection with this study is worthy of special attention in view of its potential usefulness for monitoring networks. Using the technique of isoelectric focalization, the dating method applied to brook trout (Leclerc et al. 1984) makes it possible to determine the period of mortality for eggs and fry in natural settings. Malate dehydrogenase (MDH) enzyme activity and total soluble protein (PROT) were measured. Temporal assessment of these two parameters led to development of a biochemical egg mortality dating model which, after testing in a natural environment, was used to determine mortality periods between sampling dates.

Laboratory experiments show that the relative level of MDH enzyme activity declines with time after death in brook trout eggs. In contrast, the total soluble protein concentration increases with time or remains close to the initial level (Leclerc et al. 1984). These observations provide a basis for proposing the following rules of interpretation with regard to the post-mortem period:

- if log [MDH] is equal to or greater than 65% of the initial value, the eggs have been dead for 15 days or less;
- if log [PROT] is greater than its initial value, the eggs have been dead for a period of between 15 and 25-30 days;
- if log [MDH] is low (< 45% of initial value) and log [PROT] is significantly lower than its initial value, the eggs have been dead for more than 25-30 days.

The dating model adapted to Atlantic salmon eggs by Chagnon (1984) makes use of three enzymes (lactates, malate dehydrogenase, and glutamate-oxalacetate transminase) to determine on a statistical basis the following mortality periods: under 2 days, between 2 and 8 days, between 11 and 12 days, and between 14 and 24 days. Chagnon (1984) notes that this method is valid over a period of 24 days and could be extended to cover longer periods after further study. Validation of the model is necessary before utilization.

An integrated study of biotic and abiotic components in the watershed of a tributary of the Des Escoumins River (Cassette River) was conducted between November 1982 and October 1984. By using semi-natural incubation apparatus (incubator troughs) to eliminate a good deal of the background noise attributable to biotic mortality (primarily due to predation and fungi), Brouard and Lachance (1986) were able to show that abiotic mortality (primarily due to the physicochemical quality of the water) is approximately 3% for the entire incubation period (200 days) (Fig. 15). Total cumulative mortality (biotic and abiotic) was assessed at 8% in the control

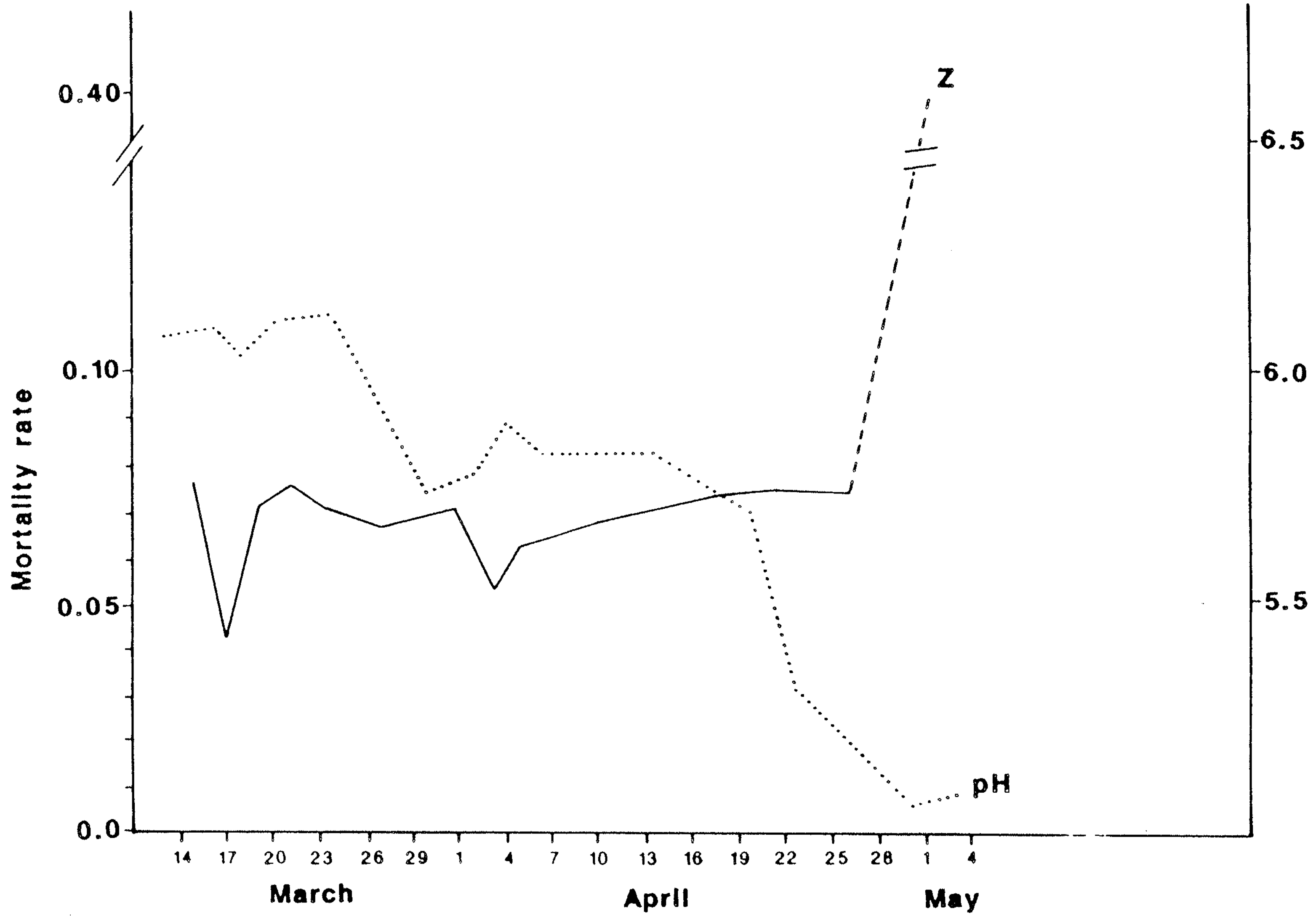

Fig. 13. Relationship between instantaneous mortality rate (Z) and pH in the small inlet of Parke lake during the spring of 1982 (from Leclerc 1982).

Table 12. Summary of operations and results obtained during *in situ* incubations conducted by Leclerc *et al.* (1984).

Measurement date	Time of development (day)	Total mortality (%) *			
		acid environment (Barley)		control environment (Robbé)	
		Tributary	Outlet	Tributary	Outlet
26 Oct. 1982	35	60 ± 15	37 ± 12	71 ± 25	35 ± 41
9 Dec. 1982	79	experiment discontinued (freezing)	33 ± 12	most of the eggs died (infestation)	most of the eggs died (infestation)
15 Dec. 1982	-	-	-	-	eggs replaced in boxes
3 Feb. 1983	135	-	hatching in progress 79 ± 17	-	hatching accomplished with low mortality
10 Feb. 1983	142	-	97 ± 3	-	0
17 Feb. 1983	149	-	100	-	0
25 Feb. 1983	-	-	-	-	-
15 May	228	-	-	-	fry leave the incubation boxes

* The mortality is expressed as the mean ± standard deviation calculated for n = 10.

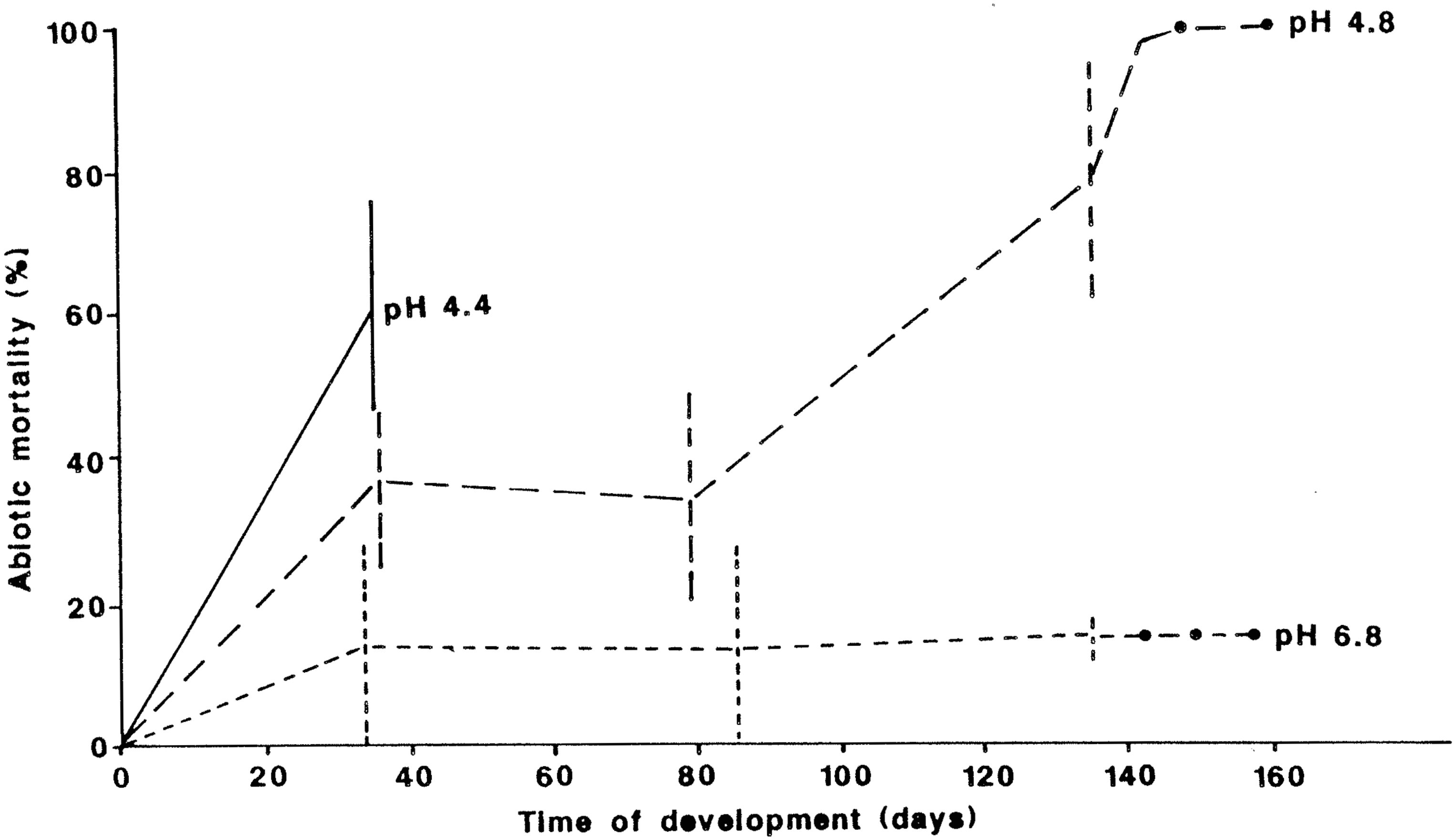

Fig. 14. Abionic mortality (%) as a function of the number of days of development in an acid tributary (pH 4.4), acid outlet (pH 4.8) and the control environment (pH 6.8) (from Leclerc *et al.* 1984).

group. Moreover, Brouard and Lachance (1986) demonstrated that instantaneous mortality rates, primarily of abiotic origin, exhibit a positive correlation with dissolved aluminum levels in surface waters and a negative correlation with descriptors associated with mineralization of waters and the presence of iron. With regard to biocumulation of aluminum and manganese, while it is not significant in natural environments (< 5 ug/g for Al and Mn), complementary laboratory experiments (see Toxic effects of metals) reveal accumulation of aluminum particularly in the post-fertilized egg stage under slightly acid conditions when organic matter is not present. In the light of these observations, the prevailing physicochemical conditions during the incubation period in the Cassette and Des Escoumins rivers would not appear to be currently hampering Atlantic salmon recruitment in the lower portions of these water courses. However, the marked drop in alkalinity observed in the Cassette River during the spring suggests the possibility of a sharp pH drop that could be brought on by a set of spring environmental conditions more critical than those encountered over the study period.

In sum, the results obtained to date are insufficient to assess whether lake fish communities are affected by the acidification process. There are too few existing data on fish to document the disappearance of certain species in acid lakes as has been observed in Scandinavia, New England, Ontario, and Nova Scotia. However, Quebec lakes exhibit the same trends with regard to declines in the diversity of communities at acidic pH. For rivers, it has been noted that prevailing physicochemical conditions in the Cassette and Des Escoumins rivers (Upper North Shore) do not currently affect the survival of Atlantic salmon eggs and fry, at least in the lower portions of the water courses. On the North Shore as a whole, however, the watershed of the Des Escoumins River is among the least sensitive to acidification. Accordingly, there is strong justification for extending *in situ* bioassays to other much more sensitive rivers to obtain a true portrait of the situation for the entire North Shore of the St Lawrence River.

Toxic effects of metals

Acid precipitation encourages the release of metals from relatively acid soil and subsoil into the aquatic environment. The metal ions which are thus caused to enter the waters of streams and rivers can reach concentrations that are toxic for fish. However, toxicity varies greatly according to pH and the different ionic forms of the metal considered. Among the metals likely to be mobilized by the acidification process, aluminum is the one for which concentration in acidified water courses is the most potentially toxic.

In a laboratory study, Van Coillie *et al.* (1983) assessed the toxicity of aluminum in salmonids by simulating the physicochemical conditions found in Canadian Shield waters affected by acid precipitation. The experiments involved Atlantic salmon and brook trout aged 1^+ and 2^+. Lethal and sublethal concentrations were determined for both species and certain physiological responses of the fish were recorded during the bioassays.

The results show that total aluminum toxicity for Atlantic salmon is at least three times as high at pH 4.6 and twice as high at pH 5.5 as for brook trout. The lethal concentration for Atlantic salmon (LC for 50% of organisms after 7 days at 10°C) ranges from 100 to 650 ug/L, depending on experimental conditions; for brook trout, the range is between 480 and 945 ug/L under the same conditions. Preference and detection tests conducted with salmonids showed that the sublethal concentration (effective concentration producing behavioural response in 50% of organisms after 30 minutes at 10°C) ranges from 120 to 1220 ug/L, depending on experimental conditions. Under inorganic conditions,

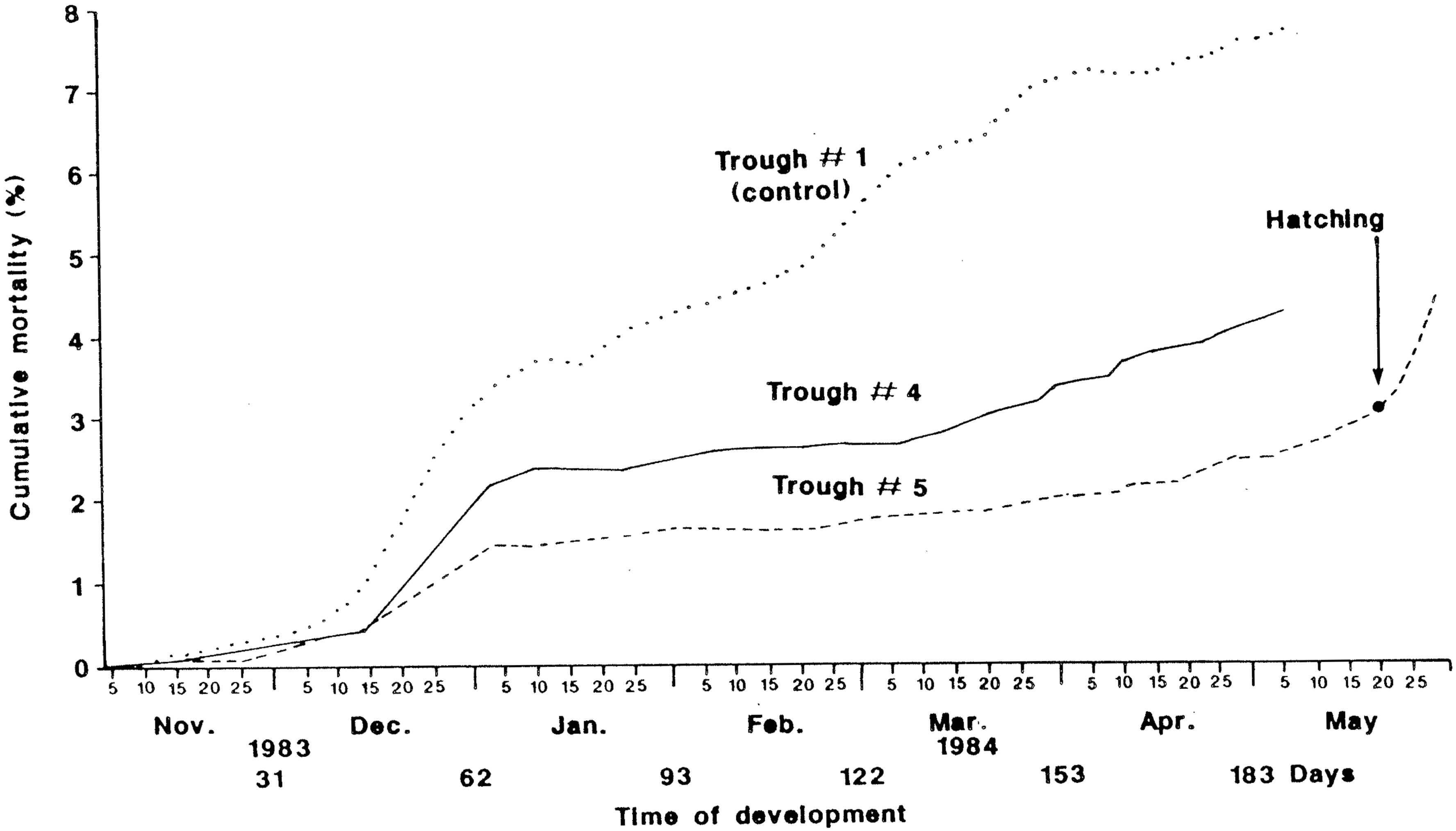

Fig. 15. Time variation in cumulative mortality rate for salmon eggs incubated in troughs in the Cassette River (from Brouard and Lachance 1986).

the biologically exchangeable and potentially toxic labile form of aluminum is the most abundant. However, the presence of organic matter in waters can partially neutralize the toxic effect of aluminum. The physiological effects on the fish included bioaccumulation of aluminum in the gills, which should lead to a substantial increase in oxygen consumption under acid stress conditions. In the light of the lethal and sublethal aluminum toxicity levels for the two species studied, the authors (Van Coillie et al. 1983) suggest that the value of 100 ug/L total aluminum could serve as a standard indicator of aluminum toxicity for salmonids in the very soft inorganic waters that are typical of the rivers and streams of the Canadian Shield, although the organic matter in these waters could attenuate this toxicity.

Data collected during the study on mortality and bioaccumulation under laboratory conditions (Brouard and Lachance 1986) made it possible to establish that lowering pH values to near 5.7 units over a short period (15 days) does not significantly influence the mortality rate of post-fertilized and embryonic salmon eggs. The various incubation conditions encountered during the experiment indicate that the process of aluminum accumulation in salmon eggs is governed by abiotic and biotic factors.

The presence of humic matter attenuates the aluminum incorporation process by more than a factor of four regardless of incubation metal concentrations. Accumulation of aluminum is also influenced by exposure concentration: the concentrations of this metal in eggs appear to be proportional to the concentration originally found in the environment, which could explain the relatively rapid establishment of an equilibrium state and the very limited temporal variations in this parameter noted during in situ incubation.

The three experimental phases carried out in the laboratory made it possible to show that the embryo development stage influences the aluminum accumulation process. Determined for all biological tissue, aluminum is preferentially accumulated as follows: post-fertilized eggs > embryonic eggs > sacfry. This is in agreement with the gradient obtained for cadmium in Salmo salar (Rombough and Garside 1982). The same authors noted that cadmium levels in fry just after hatching are much lower than the levels in eggs, although they are directly proportional.

It is thus possible that the aluminum and manganese detected in the eggs were linked to the chorion rather than the embryo. However, the detection threshold for these metals was certainly too high (2 ug/g for Al, 1 ug/g for Mn) to show any bioaccumulation phenomenon in sacfry.

Other metals are leached by acid precipitation and may reach potentially toxic concentrations for fish (manganese, cadmium). However, Brouard and Lachance (1985) showed that in the laboratory aluminum accumulates more rapidly and clearly more significantly than manganese in salmon eggs. The toxicity of these metals has not received much study to date, and there is very little knowledge of metal toxicity for species other than salmonids either in Quebec or elsewhere in Canada.

CONCLUSION

Analysis of the data gathered from Quebec lakes and rivers has shown that, over the whole of the study area (Canadian Shield south of the 52nd parallel), acid atmospheric deposition is exerting a significant influence on the physicochemical quality of surface waters. This influence is particularly strong in southwestern Quebec (Outaouais, Mauricie, Abitibi-James Bay) and manifests itself primarily in the form of displacement of natural bicarbonates in lake water by sulfates of atmospheric origin.

It has been noted that sensitivity to acidification, assessed on the basis of mineralization of surface waters, gradually increases from the southwest to the northeast, with a maximum on the Middle and Lower North Shore. At the same time, there is an atmospheric sulfate deposition gradient running in the opposite direction to the sensitivity gradient. Examination of alkalinity/sulfate ratios in lakes shows that the combined effect of these two factors is felt to differing degrees right across Quebec. Thus, lakes in the vicinity of the Roberval, Alma, Chute des Passes, and Manicouagan bases, while they receive less acid deposition, are affected as much as or more than more southerly lakes because of their greater sensitivity. In over 80% of the lakes considered within this zone, the HCO_3^-/SO_4^{-2} ratio is less than unity. The corresponding zone on the North Shore, which receives atmospheric fallout of on the order of the target figure of 20 kg/ha-yr, is also affected; 50% of the lakes and 43% of the rivers sampled in this zone exhibit a ratio under unity.

In the rivers of the North Shore, as a whole, significant pH drops are observed during the spring melt period; water pH declines to under 5.5 in many cases. These rivers are primarily located in the eastern portion of the Upper North Shore (Trinité and Aux Rochers), on the Middle North Shore (Matamec, Pigou, Tortue, Aux Graines, A la Chaloupe, and Jupitagon), and on the Lower North Shore (Musquaro, Olomane, and Du Gros Mécatina). The seasonal fluctuations, combined with high metal content (total aluminum concentrations in excess of 200 ug) can become critical for the development and hatching of Salmo salar eggs. The toxic potential of aluminum must still be determined, however, since it depends on local chemical speciation.

The specific studies conducted in the watersheds of the Cassette and Des Escoumins rivers (Upper North Shore) have made it possible to monitor the melting and ion migration phenomenon and assess its importance with regard to springtime acid shock. During the spring period, organic + adsorbed aluminum proved to be the predominant form. The results of the hydrochemical balance established for the watershed of the Cassette River have brought to light a new phenomenon. The relatively high concentrations of sulfates found in surface waters during the melt period would appear to be due not only to massive release of sulfates accumulated in snow reserves but also to a substantial contribution of sulfates accumulated in soils and vegetation over the preceding summer and fall. The scope of this phenomenon and its ecological repercussions in terms of explaining springtime acid shock should be examined in future studies.

Results from the biophysical surveys of lake environments show a drop in the abundance and diversity of invertebrate communities (phytoplankton, zooplankton, and benthos) as a function of environmental acidity. Since it is difficult at this stage to distinguish between the relative contributions of natural and atmospheric sources of acidity, we cannot measure with certainty the repercussions of acid rain on lake invertebrate communities in Quebec.

For fish communities, the lake surveys have not made it possible to show a cause and effect relationship between atmospheric deposition and observed declines in abundance and diversity under acid conditions. Moreover, several groups of invertebrates that are important in fish diets continue to survive under acid conditions at densities comparable to those for neutral and alkaline conditions. It is therefore difficult to explain the absence of fish in these acid lakes in terms of a negative impact of acidification on the invertebrate community. The observed trends may be attributable in large part to the effect of biogeographical isolation.

With respect to river environments, it has been shown that the currently prevailing physicochemical conditions in the Cassette (min pH: 6.0) and Des Escoumins (min pH: 5.6) rivers do not affect the survival of Atlantic salmon eggs and fry; the observed mortality rates in the incubation troughs ranged from 3% (abiotic) to 8% (biotic and abiotic).

OUTLOOK

In 1981, under its mandate for the conservation, restoration, and development of fish habitat and the Canadian program of study on the repercussions of Long-Range Transportation of Airborne Pollutants (LRTAP), DFO began a vast program of research into the impact of acid precipitation on aquatic environments. The primary objective of DFO in connection with a program of this type is to provide full relevant scientific data for the preparation of an international agreement (Canada-USA) on limitation of atmospheric pollution sources.

In order to provide a visual representation of how DFO energies have been deployed, we have prepared Fig. 16, which gives an arbitrarily grouped breakdown of 1981-1985 monetary resources allocated to the various areas of activity to which DFO has devoted special attention. The figure also gives a summary projection of the future breakdown of resources for the 1986-1990 period.

With the facts now established in Quebec regarding the chemical deterioration of aquatic habitats in the salmon rivers of the North Shore and lake environments primarily in the Laurentide, Mauricie, and Maniwaki areas, and the identification of high potential risks for aquatic organisms (particularly Atlantic salmon, brook trout, and walleye), the need has arisen for the Fish Habitat Division of the Department of Fisheries and Oceans to make provision in the short and medium-term for corrective action and to orient the implementation of such action through the immediate establishment (1985) of an ecological monitoring network covering (a) the salmon rivers of the North Shore and (b) the lake environments most representative of the current situation in Quebec.

It is therefore understandable that the effort primarily dedicated to surveys during the 1981-1985 period should now be shifted to ecological monitoring of lakes and rivers (Fig. 16). This means that while seasonal physicochemical monitoring of the most representative aquatic environments will be maintained, additional emphasis will be given to identification and validation of biological indicators of present and future acid stress. Here as well, specific in situ and in vitro research will help to improve our understanding of cause and effect relationships involving chemical deterioration of aquatic habitats versus the lethal or sublethal responses of the exposed aquatic organisms. The "natural acidity versus acidity of atmospheric origin" aspect also remains a major point of interest for future years of research.

SALMON RIVERS ON THE NORTH SHORE

Over 1985 and 1986, in situ monitoring of the development and survival rate of salmon eggs and sacfry was carried out to confirm the actual damage associable with the critical physicochemical conditions identified in four rivers of the North Shore (Laval, Trinité, Aux Rochers, and McDonald).

This work will continue with the addition of the Jupitagon and Matamec rivers on the

Middle North Shore. While involving pre-summer or fall catches of spawners, in situ effort will focus on springtime acid shock corresponding with the most critical time for organisms in the early development stages. Aluminum bioaccumulation and heavy metal concentrations in eggs and sacfry and aluminum speciation in surface waters and interstitial environments are the main chemical considerations that will receive special attention in connection with the 1986-1990 ecological monitoring network.

Research will also be directed at in situ and in vitro identification and validation of physiological and/or biochemical indicators of acid stress felt by juveniles and parr living in environments that are currently acid on the North Shore. All these research components will contribute to optimization of the scientific yield (development of technical capability and acquisition of new scientific knowledge) expected from an ecological monitoring network.

In addition to the studies on salmon, DFO-Quebec intends to develop and validate a series of biological indicators that will be more sensitive to the gradual modifications characteristic of temporal acidification of aquatic environments. These indicators could serve as warning signs and would be useful for beginning possible corrective action to minimize the impact on current salmon populations. Accordingly, study of the structures of macrobenthic communities and measurement of respiratory activity among bacteria and fungi communities were undertaken in 1984-1985 and should be extended in coming years to cover the entire North Shore ecological monitoring network. The short-term objective is to construct an easy-to-use impact grid taking the various trophic levels into account and stressing chemical deterioration indicators for aquatic habitats associable with pH drops (acidophobes/ acidophiles) or toxic metal (heavy metal) concentration increases in the environment. In combination with sublethal stress indicators to be developed for indigenous juveniles and parr, this approach will enhance the anticipated scientific yield from the river ecological monitoring network.

LAKE ENVIRONMENTS

Determination of satisfactory standards for the effective protection of aquatic habitats is the final product that DFO expects from its research program into the effects of acid precipitation. Identification of the current chemical status of Quebec lakes and subsequent determination of the anticipated potential risks for aquatic organisms have been (chemical surveys, 1981-1982) and will continue to be (temporal monitoring, 1986-1990) essential preliminary steps toward the establishment of such standards. Since it has also been aware of the need to validate the various chemical status results obtained, DFO has been working since 1981 on the analysis and development of biological tools permitting in situ comparison of responses by aquatic communities to the various sets of chemical conditions observed.

From interpretation of results from the 1981-1982 biological surveys, a need has become apparent to adjust protocols and orient scientific effort in the following manner: (1) limiting of chemical and biological sampling to the spring period; (2) concentration of temporal sampling effort within one or two experimental areas, preferably the Mauricie and North Shore regions; (3) focussing of the acquisition of technical capability primarily on the search for acidophobic-acidophilic plankton indicators and the monitoring of eggs and sacfry of salmonids, percids, and cyprinids.

Traditional studies of fish population structures requiring exhaustive sampling effort can be carried out on a limited number of lakes selected beforehand as representative of the regional acidification gradient. Lake Laflamme is currently being used in a pilot

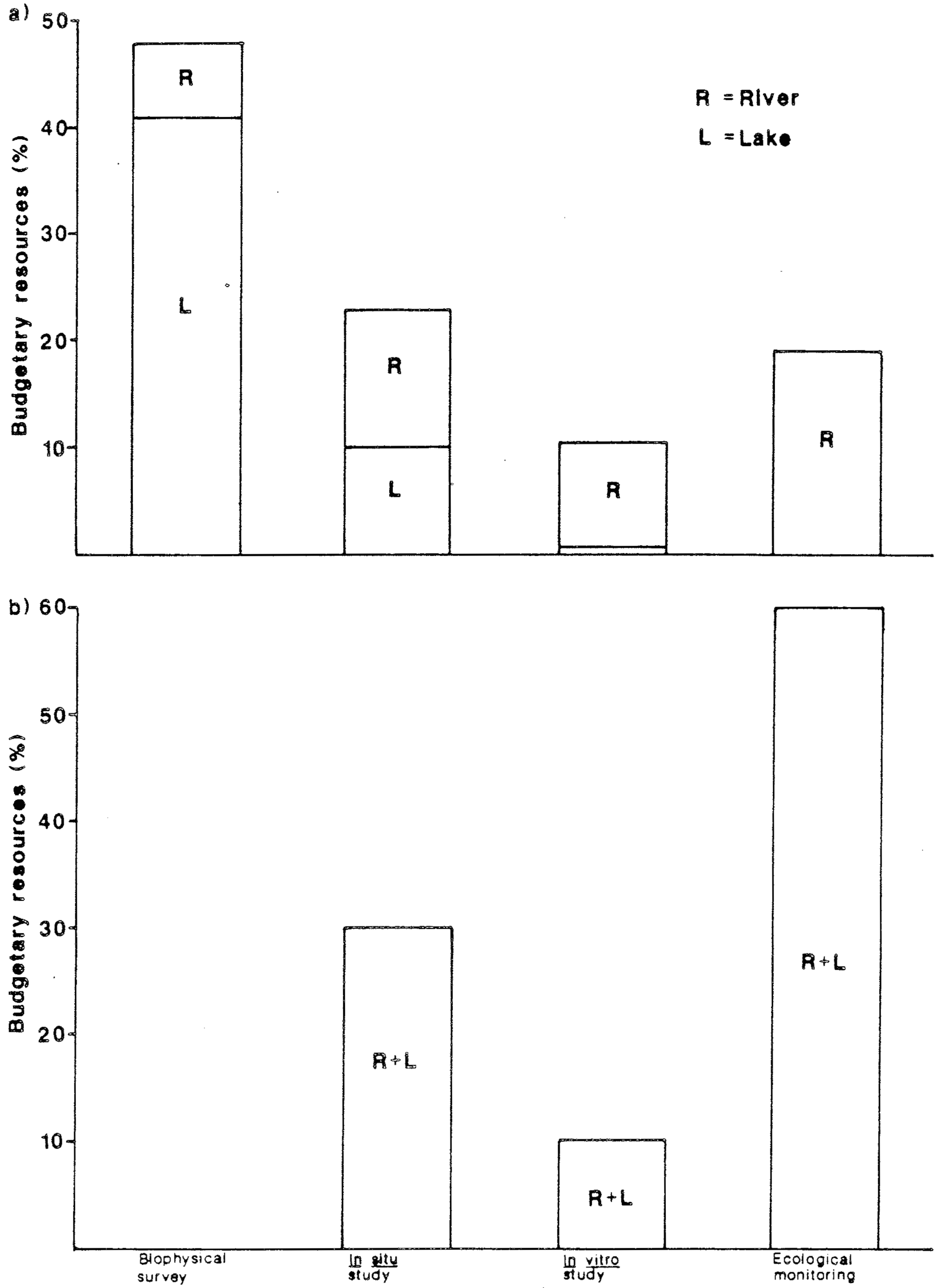

Fig. 16. Allocation of budgetary resources for 1981-1985 and forecast for 1986-1990.

project (1985-1986) for validation of the use of in situ bioassays as indicators of the acid stress actually felt by sacfry in the spring. Determination of physiological indicators (gill deformation, opercula metal levels) in the juvenile and adult stages of salmonids, percids, and cyprinids will also be a major component of specific in situ research.

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P1. Brouard, D., M. Lachance, G. Shooner et R. Van Coillie. 1982. Sensibilité à l'acidification de quatre rivières à saumon de la Côte-Nord du Saint-Laurent (Québec). Rapp. tech. can. sci. halieut. aquat. 1109: v + 56 p.

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