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PREFACE

After the writing of this thesis, a new species name for the Acadian whitefish was published (Scott, W.B. 1987. A new species name for the Atlantic whitefish: *Coregonus huntsmani* to replace *Coregonus canadensis*. Can. J. Zool. 65: 1856-1857.). To preserve continuity with previous literature, the species has been refered to as the Acadian whitefish, *Coregonus canadensis*, Scott, 1967, throughout this thesis. Subsequent reference to the species should be as the Atlantic whitefish *Coregonus huntsmani*, Scott, 1987.

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ABSTRACT

Principal component and discriminant function analyses of morphological variation in whitefish populations from the Canadian Maritime Provinces support the recognition of the Acadian whitefish, *Coregonus canadensis* Scott, 1967, as a valid species, distinct from the lake whitefish species complex, *Coregonus clupeaformis* (Mitchill). Ten meristic and forty-three morphometric characters were examined and the species were best discriminated by vertebrae number (> 99% separation) and mouth shape. Lake whitefish had a subterminal mouth and vertebral counts from 58-64 ($\overline{X}$=60.6) while Acadian whitefish had a more terminal mouth and vertebral counts from 64-67 ($\overline{X}$=65.3). Acadian whitefish and lake whitefish were also fixed for alternate alleles at two of eight genetic loci examined and Acadian whitefish had unique alleles at two other loci not predicted by present genetic models for lake whitefish. Preliminary morphological and electrophoretic data, while not conclusive, suggest the Acadian whitefish could be a cisco (subgenus, *Leucichthys*).

Considerable morphological variation was found between lake whitefish populations in the Maritimes region. Lake whitefish from the Mira River, N.S. and Kerr Lake, N.B. were found to be completely distinct from all other lake whitefish examined in canonical variates analyses although not in principal component analyses. These analyses revealed no basis to distinguish whitefish specimens from Square Lake, Me., identified as the dwarf Stanley's whitefish, *Coregonus stanleyi* Kendall, 1903, from *Coregonus clupeaformis*. However, electrophoretic and reproductive criteria from previous studies still support their separation as species.

Extensive field surveys in Nova Scotia found the Acadian whitefish to be restricted to Minamkeak, Milipsigate and Hebb Lakes in the Petite Rivière watershed, Lunenburg Co., and the Annis River, in the Tusket River watershed, Yarmouth Co. It is highly likely that Acadian whitefish are already extirpated from the main branch of the Tusket River. Lacustrine populations in the upper Petite Rivière watershed are landlocked while in the Tusket River watershed, Acadian whitefish are anadromous.

Data on the habitat and biology of the Acadian whitefish were collected to study the ecological requirements of the species. The data were compared to similar data collected from lake whitefish populations in Nova Scotia and suggests the two species may occupy different ecological niches. The data also indicate the seriousness of acidification to the survival of Acadian whitefish. In the mid-winter pH depression in 1984/85, pH dropped to at least 5.0 in the Annis River, 4.6 in the Tusket River, and 4.5, 4.9, 5.5 in Hebb, Minamkeak and Milipsigate Lakes respectively.

The restricted distribution of the Acadian whitefish is suggested to be the result of man-made habitat alterations, ecological factors and historical factors associated with the Wisconsin Ice Age. There is geological evidence for an ice-free area in southwestern Nova Scotia that could have served as a Late Wisconsin refugium for the Acadian whitefish.

RESUMÉ

L' étude de la variation morphologique entre des populations de corégones des provinces Maritimes du Canada supporte la reconnaissance du corégone d' Acadie, *Coregonus canadensis* Scott, 1967, comme espèce valide, bien distincte du grand corégone, *Coregonus clupeaformis* (Mitchill). Les caractères les plus distinctifs sont la forme de la bouche et le nombre de vertebres. Le corégone d' Acadie a une bouche terminale et un nombre de vertebres entre 64-67 ($\overline{X}$=65.3) tandis que le grand corégone a une bouche sous-terminale et un nombre de vertebres entre 58-64 ($\overline{X}$=60.6). Le corégone d' Acadie et le grand corégone possèdent des allèles différentes pour deux de huit loci génétiques examines. Le corégone d' Acadie possède également des allèles chez deux loci qui ne sont pas connues pour le grand corégone. Les donnees préliminaires des études morphologique et électrophorètique suggèrent que le corégone d' Acadie pourrait être un cisco (sous-genre, *Leucichthys*).

Il existe beaucoup de variation morphologique entre les populations du grand corégone des provinces Maritimes. Les grands corégones de la rivière Mira, N.E., et du lac Kerr, N.B., se distinguent tout à fait des autres grands corégone dans les analyses de facteurs canoniques mais pas dans les analyses des composantes principales. Ces deux types d' analyses n' ont pas pu distinguer les corégones du lac Square, Me. qui avaient été identifiés comme *Coregonus stanleyi* par Kendall (1903).

Les études sur le terrain en Nouvelle-Ecosse ont démontrées que le corégone d' Acadie se trouve seulement dans les lacs Minamkeak, Milipsigate et Hebb dans le bassin de Petite Rivière, Lunenburg Co. et dans la rivière Annis du bassin de la rivière Tusket, Yarmouth Co. L' espèce est peut-être déjà extirpée de la rivière Tusket comme

telle. Les populations du corégone d' Acadie dans le bassin de la Petite Rivière sont cantonnées tandis que l' espèce est anadrome dans le bassin de la rivière Tusket.

De l' information au sujet de l' habitat et la biologie du corégone d' Acadie a été accumulée afin de déterminer les besoins écologiques de l' espèce. Une comparison avec des populations du grand corégone de la Nouvelle-Écosse a été effectuée et suggère que les deux espèces occupent des niches écologiques différentes. Les données recueillies démontrent aussi le problème grandissant de l' acidification pour la survie du corégone d' Acadie. A l' hiver 1984/85 le pH a diminué jusqu' à au moins 5.0 dans la rivière Annis, 4.6 dans la rivière Tusket et 4.5, 4.9, 5.5 dans les lacs Hebb, Minamkeak et Milipsigate respectivement.

La distribution restreinte du corégone d' Acadie est croit-on le résultat des altérations d' habitat causées par l' Homme, d' évènements écologiques et d' évènements associés avec la périod glaciaire du Wisconsin. Il y a de l' évidence géologique pour une région qui aurait echappée la calotte glaciaire dans le sud-ouest de la Nouvelle-Ecosse et aurait pu servir comme refuge pour le corégone d' Acadie à la fin du Wisconsin.

INTRODUCTION

The extinction of species through the activities of man is rapidly becoming a crisis of major proportions. The current rate of extinction is about 400 times that recorded through recent geological time and rivals the rates of major catastrophes in the fossil record (Wilson, 1985). On a world-wide basis, a conservative estimate of the extinction rate is about one species per day (Meyers, 1985). By the year 2000, the Global 2000 Report (1980-1981) projects a loss of as many as 20% of existing species.

In Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed nine mammals, eight birds, one reptile, four fish and fifteen plants as endangered in 1987. The Acadian whitefish, *Coregonus canadensis* Scott, 1967, which appeared on this list, was classified as endangered in 1983 following a field survey which found the species surviving in southern Nova Scotia (Edge, 1984). This species, a member of the commercially important coregonine fishes, is one of the few freshwater fish species endemic to Canada.

The Acadian whitefish was first recognized as a new species by Leim and Scott (1966). Since this recognition, there has not been a study of the systematics of the species and there has been little effort to determine its distribution or ecological requirements. The need for this information is readily apparent. There is still uncertainty among a few biologists as to whether the Acadian whitefish is a valid species. As well, habitat acidification in southern Nova Scotia threatens the survival of the Acadian whitefish (Edge, 1984; Ono et al., 1985; McAllister et al., 1985). This thesis addresses the lack of information on the Acadian whitefish and provides results from studies of the systematics, distribution, ecology and zoogeography of the species.

Chapter I
SYSTEMATICS

1.1 Introduction

The evolutionary relationships of whitefishes within the genus *Coregonus* have presented problems for systematists since the time of Linnaeus. The confusing morphological plasticity of species in this genus has been shown to be the result of both environmental and genetic factors (Hile, 1937; Svardson, 1952; Loch, 1974; Todd et al., 1981). A lack of consideration for these different causes of morphological variation by early systematists lead to the description of many species and subspecies based on variation largely environmentally determined. Many of these taxa have been synonomized, yet the existence of sympatric population pairs in some morphological species is now recognized by calling them "species complexes" (McPhail and Lindsey, 1970) with the implication that some complexes may be comprised of two or more sibling species.

Since its first recognition, the Acadian whitefish has been the subject of considerable nomenclatural confusion. While a description of the species was given by Leim and Scott (1966) under the vernacular name Atlantic whitefish, a scientific species name was not published and type spécimens were not designated. The species was subsequently refered to as the Atlantic whitefish, *Coregonus canadensis* by Scott (1967) despite the prior usage of this name. *Coregonus canadensis* Scott, 1967 is a junior primary homonym of *Coregonus nasus canadensis* Berg, 1932 (McAllister et al. 1985).

The name Acadian whitefish was proposed for the species by Legendre (1978) because of the more precise geographic connotation than Atlantic (whitefishes occur on both sides of the North Atlantic in saline and freshwaters). Considering the lack of a detailed description for the Acadian whitefish and the plasticity of many species in the genus *Coregonus*, some biologists have doubted whether it is a valid species.

The Acadian whitefish can be readily distinguished from most North American whitefish species within the genus *Coregonus*. The genus can be divided into two subgenera, the plankton feeding ciscoes (subgenus *Leucichthys*) and the typically benthic feeding true whitefishes (subgenus *Coregonus*) (Lindsey, 1981). Scott and Crossman (1973) reported that gill rakers counts ranged from 23-27 for Acadian whitefish, while most ciscoes had more than 32 gill rakers. The only ciscoe exhibiting gill raker numbers that overlapped with the Acadian whitefish was the deepwater ciscoe, *Coregonus johannae* from the Great Lakes (25-36). This species is readily distinguished however, by having fewer vertebrae (56-58) than the Acadian whitefish (63 or 64). Within the true whitefishes, the Acadian whitefish can be distiguished from all species by its terminal mouth and from the broad whitefish, *Coregonus nasus*, by maxilla shape, the latter having a broader maxilla with a length less than twice its width. However, the distinction between the Acadian whitefish and the lake whitefish species complex, *Coregonus clupeaformis* (Mitchell), is not as apparent and these two species have been confused in the past (Piers, 1927; Dymond, 1947; Smith, 1952; Livingstone, 1953; Semple, 1979).

The lake whitefish has been shown to exhibit a wide range of morphological and biochemical variation across North America (Koelz, 1929, 1931; Fenderson, 1964; Lindsey et al., 1970; Franzin and Clayton, 1977; Ihssen et al., 1981a). The lake whitefish has also been found to occur as sympatric sibling species pairs in the Yukon Territory (Lindsey, 1963; Bodaly, 1979), Ontario (Kennedy, 1943), Quebec, (Lindsey, 1979MS), Labrador, (Bruce, 1984), and the State of Maine (Fenderson, 1964; Kirkpatrick and Selander, 1979). The species within a pair are morphologically similar although ecological differences such as habitat preferences or spawning habits can be quite distinctive and result in reproductive isolation. This wide range of phenotypic variation has presented a problem of clearly distinguishing the Acadian whitefish from the lake whitefish species complex.

Scott and Crossman (1973) distinguished the Acadian whitefish on the basis of having more lateral line scales (91-100) than lake whitefish (70-85) and by the presence of a terminal mouth (or nearly so) with small but well developed teeth in the adults. The lake whitefish was reported to have an obviously subterminal mouth lacking such teeth except in juveniles under 100 mm. However, lake whitefish have been reported to have lateral line scale counts as high as 97 (Koelz, 1931; Scott and Crossman, 1973) and individual variation in mouth shape or in the location and development of teeth has not been well characterized in the two species.

The lack of a well defined morphological distinction between Acadian whitefish and lake whitefish prompted this study to test whether the Acadian whitefish is conspecific with the lake whitefish. The Acadian whitefish is not known to occur in sympatry with the lake whitefish and thus the biological species concept (eg. Mayr, 1969) could not be rigorously applied to test conspecificity. Instead, the criteria for species recognition was primarily pragmatic and phenetic similar to Todd et al. (1981). Populations were considered to belong to different species if they were significantly phenotypically distinct and the distinction could be inferred to be genetically and not environmentally based. The hypothesis of a lack of a genetically based phenotypic distinction between Acadian whitefish and lake whitefish was tested by analyses of morphological and biochemical variation between whitefish populations in the Canadian Maritime Provinces.

1.2 Methods and materials

Whitefish specimens examined in this study were obtained from museums or were collected by the author during field surveys conducted in Nova Scotia. Museum collections were fixed in formalin and preserved in either isopropyl or ethyl alcohol whereas specimens collected in Nova Scotia by the author were frozen for electrophoretic studies and later preserved in 50% isopropyl alcohol after formalin fixation. Visits to the following institutions were made to examine their whitefish collections: Nova Scotia Provincial Museum, Halifax, N.S. (NSPM); National Museum of Natural Sciences, Ottawa, Ont. (NMC); Royal Ontario Museum, Toronto, Ont. (ROM); Cornell University, Ithaca, N.Y. (CUM); Harvard University, Boston, Ma. (HMCA); American Museum of Natural History, New York, N.Y. (AMNH); Smithsonian Institute, Washington, D.C. (USNM); Philadelphia Academy of Science, Philadelphia, Pa. (MPAS).

Data on the whitefish collections examined in this study are presented in Table 1 and the geographic distribution of these collections is shown in Figure 1. This figure defines the study area in this thesis called the Maritimes region. All capture data associated with the author's whitefish collections from Nova Scotia and all morpholgical data collected in this study are deposited in the National Museum of Natural Sciences, Ottawa, Ont. (NMC).

A total of 260 whitefish specimens were examined in a study of morphological variation. Ten meristic characters and forty-four morphometric characters were counted and measured. Meristic counts were made on the left side of specimens under a dissecting microscope although counts on larger specimens were made with the naked eye. Vertebrae counts were made on radiographs. Morphometric measurements were made on the left side of specimens with digital Yushio calipers to .01 mm accuracy. A list of the characters examined is in Table 2 and those not described by other authors are

TABLE 1. Collection data for whitefish specimens examined in morphological studies.

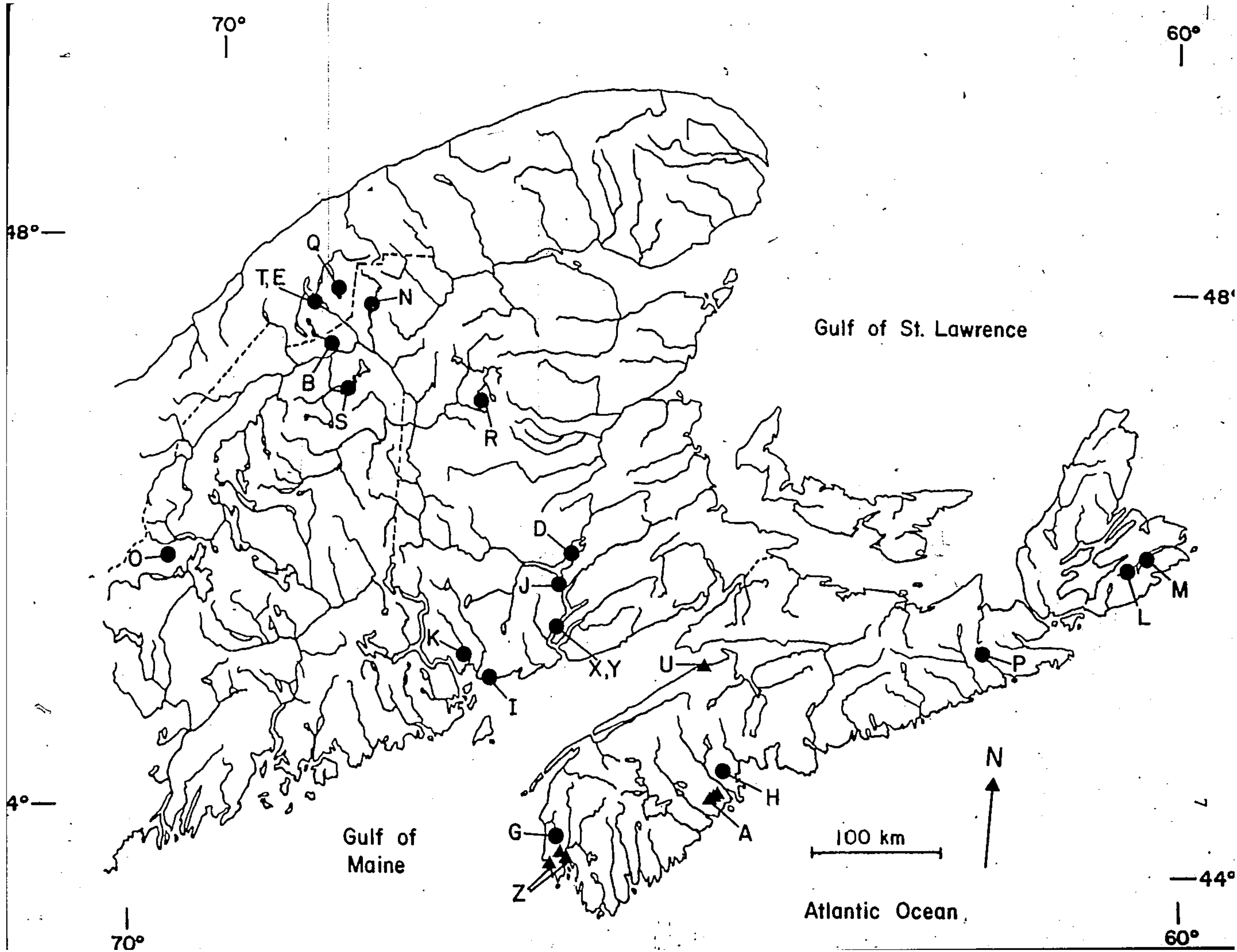
Coregonus canadensis

CODE	LOCALITY	NUMBER	CAPTURE DATE	CATALOGUE NO.
Z	Tusket River, Yarmouth Co. N.C.	1	Aug.31, 1954	ROM 16676
Z	" "	1	1954	ROM 16276
Z	" "	4	May 7, 1964	ROM 22911
Z	" "	1	Apr.10, 1951	ROM 15074
Z	" "	1	Oct.21, 1954	ROM 16672
Z	" "	1	Nov.1, 1954	ROM 16673
Z	" "	1	Nov.4, 1954	ROM 16674
Z	" "	1	Oct.27, 1954	ROM 16675
Z	Annis River, Yarmouth Co., N.S.	1	Oct.11, 1982	NMC82-684
Z	" "	1	Oct.12, 1982	NMC82-689
Z	Yarmouth Harbour, "	1	June 12,1940	ROM 13181
U	Hall's Harbour, Kings Co., N.S.	1	May 31, 1958	ROM 19446
A	Hebb Lake, Lunenburg Co., N.S.	6	Nov.12, 1982	NMC82-805-7
A	" "	4	May 24, 1983	NMC83-188
A	" "	3	July 12,1983	NMC84-1456
A	Milipsigate Lake, "	5	August, 1955	ROM 17658-62
A	" "	9	Sept. 1982	NMC82-614-23
A	" "	2	Nov. 1982	NMC82-789
A	Minamkeak Lake, "	5	Nov. 9, 1982	NMC82-802-3
	TOTAL	49		

Coregonus clupeaformis

CODE	LOCALITY	NUMBER	CAPTURE DATE	CATALOGUE NO.
G	Lake George, Yarmouth Co., N.S.	21	Oct. 7, 1982	NMC82-664-7
G	" "	1	Sept.25,1983	NMC84-1454A
H	Caribou Lake, Lunenburg Co., N.S.	1	Sept.27,1982	NMC82-632
H	Little Mushamush Lake, "	2	Sept.28,1982	NMC82-638
F	Annis Lake, N.S.	1	--	ROM 23296
P	Pringle Lake, Guysborough Co.,N.S.	7	July 27,1973	ROM 29118
L	Salmon River, Cape Breton Co.,N.S.	5	June 22,1982	ROM 40367
M	Mira River, "	14	Jan., 1983	NMC84-1409-15
M	" "	25	July 5, 1983	NMC84-1409-15
D	Grand Lake, N.B.	12	Nov.16, 1958	ROM 21677
J	Saint John River, N.B.	20	May 20, 1970	--
Y	" " "	1	--	USNM-45459
X	" " "	1	Aug.28, 1957	ROM 18829
I	Black's Harbour, N.B.	1	--	ROM 19447
K	Kerr Lake, N.B.	1	July 3, 1945	ROM 13854
K	" "	22	July 13,1950	ROM 25331
R	Trouser's Lake, N.B.	3	May 17, 1964	ROM 22844
B	Baker Lake, N.B.	3	Sept. 1942	ROM 13440-2
N	Third Lake, N.B.	26	June 20,1939	ROM 10851-2
Q	Squatook Lake, Temiscouata Co., Que.	1	July, 1893	USNM 45457
T	Lake Temiscouata, " "	26	Oct. 1951	NMC 71-79
E	" "	6	Nov.13, 1980	NMC 80-1205
S	Square Lake, Me.	23	Nov.10, 1903	USNM 88414
O	Long Pond, Me.	12	1958	ROM 23769
	TOTAL	211		

Figure 1: Geographic distribution of whitefish collections examined from the Maritimes region. Acadian whitefish (▲): A- Minamkeak, Milipsigate and Hebb Lakes; Z- Tusket River, Annis River, Yarmouth Harbour; U- Hall's Harbour. Lake whitefish ●: B- Baker Lake; D- Grand Lake; E- Lake Temiscouata (1980); G- Lake George; H- Little Mushamush and Caribou Lakes; I- Black's Harbour; J- Saint John River; K- Kerr Lake; L- Salmon River; M- Mira River; N- Third Lake; O- Long Pond; P- Pringle Lake; Q- Squatook Lake; R- Trousers Lake; S- Square Lake; T- Lake Temiscouata (1951); X, Y- Saint John River.


70°
60°
48°
44°
Gulf of St. Lawrence
Gulf of Maine
Atlantic Ocean
100 km
N
Q
T,E
N
B
S
R
O
D
J
K
X,Y
I
U
P
L
M
H
A
G
Z

defined as follows: snout to eye margin length - the distance between the anterior tip of the snout and the margin of the skin anterior to the eye; suborbital depth - the vertical distance between the ventral margin of the orbit and the ventral contour of the head; pupil diameter - the horizontal diameter of the pupil; nare diameter - the width of the anterior nare flap at its base; internaral width - the distance between the medial bases of the anterior nare flaps; pectoral and pelvic fin base length - measured by drawing the fin away from the body and lightly clamping the fin base as close as possible to the body with calipers; pre-pectoral length - the distance from the tip of the snout to the base of the first anterior pectoral fin ray; pre-pelvic length - the distance from the tip of the snout to the base of the first anterior pelvic fin ray; anal to caudal length - the distance from the origin of the anal fin to the base of the first lower procurrent caudal ray; pelvic axillary process length - the distance from the base of the first anterior pelvic ray horizontally back to the posterior free tip of the pelvic axillary scale; pre-pectoral depth - the depth of the body through the origin of the pectoral fin; isthmus length - the distance from the anterior tip of the lower jaw to the notch where the branchiostegal membranes join; adipose base length - the distance from the origin of the adipose fin to the posterior base of the fin as grasped lightly by calipers; gill filament length - the length of the longest gill filament at the sharpest angle of the first gill arch.

Since morphometric characters are measures of the absolute sizes of body parts, differences in the size of specimens resulting from sampling bias will influence assessments of similarity between samples. For this reason, it has been suggested that populations should be compared in terms of shape variates free from the effects of size variation (Reist, 1985; 1986).

A number of methods have been used to derive size-free shape variates from morphometric data. These include univariate transformations such as logarithms, ratios,

TABLE 2. List of morphological characters examined following: (1) Koelz (1929), (2) Hubbs and Lagler (1958), (3) Lindsey (1962), (4) Loch (1974), (5) Bodaly (1979), (6) Casselman et al. (1981), (7) see thesis text.

MERISTIC CHARACTERS

Dorsal fin rays	(2)	Scales above lateral line	(2)
Anal fin rays	(2)	Scales below lateral line	(2)
Pectoral fin rays	(2)	Lateral line scales	(2)
Pelvic fin rays	(2)	Gill rakers	(2)
Branchiostegal rays	(2)	Vertebrae	(2)

MORPHOMETRIC CHARACTERS

Width of gape	(2)	Pre-dorsal length	(2)
Head length	(6)	Snout to anal length	(1)
Snout to eye margin length	(7)	Pre-pectoral length	(7)
Postorbital length	(2)	Pre-pelvic length	(7)
Suborbital depth	(7)	Dorsal to adipose length	(1)
Eye diameter	(5)	Pectoral-ventral length	(1)
Orbital diameter	(6)	Ventral-anal length	(1)
Pupil diameter	(7)	Anal to caudal length	(7)
Nare diameter	(7)	Adipose to caudal length	(1)
Internaral width	(7)	Pelvic axillary process length	(7)
Interorbital width	(3)	Head depth	(6)
Upper jaw length	(2)	Pre-dorsal depth	(4)
Maxillary width	(3)	Caudal peduncle depth	(2)
Height of dorsal fin	(2)	Pre-pectoral depth	(7)
Height of anal fin	(2)	Anal depth	(4)
Length of pectoral fin	(2)	Eyeball diameter	(1)
Length of pelvic fin	(2)	Isthmus length	(7)
Adipose fin length	(3)	Adipose base length	(7)
Length of dorsal base	(2)	Snout length	(2)
Length of anal base	(2)	Gill raker length	(6)
Pectoral fin base length	(7)	Gill filament length	(7)
Pelvic fin base length	(7)	Standard length	(2)

residuals, and allometric adjustments. Multivariate methods are also available such as removing size by equating it with the first principal component in a principal component analysis on untransformed or logged data. Intuitively it would seem inappropriate to attempt to account for all size effects in the data based on only one character such as standard length. However, at present, univariate methods are generally more simple and easily applied, their effects on data well known and, depending on the purpose of the study, have proven useful in many systematic studies.

In this study, an attempt to remove size effects from morphometric data used the regression-related technique of calculating residuals. Reist (1985) compared a number of univariate methods to adjust for size differences in fish samples and found residuals to be a preferred technique. This method minimized the influence of size variation and had few adverse effects on the data set.

All morphometric data were first transformed to natural logarithms producing a more linear relationship between variables and closer approximations to univariate normality. In order to attribute more equal weight among characters of widely different absolute values (e.g. nare diameter vs. preanal length) and variance, the data were also standardized to mean=0 and standard deviation=1. The morphometric characters were then transformed into shape variates (residuals) by expressing them as the deviation of individuals from the pooled within group regression line describing the size relationship between a character and standard length. This deviation, orthogonal to the size relationship, should be independent of size and reflect the residual variation resulting from measurement error and the biological deviation of individuals from the structural relationship (Kuhny and Marcus, 1977).

None of the morphological characters in this study provided complete separation between the Acadian whitefish and lake whitefish. For this reason the covariation of characters was also investigated by a Principal Component Analysis using the Statistical Analysis System (SAS) Princomp procedure. This multivariate procedure summarizes the simultaneous covariation of many characters and ordinates individuals to allow an a priori assessment of whether individuals fall into distinct groups. Whitefish were labeled according to their collection localities for principal components analyses to avoid *a priori* bias in identifying Acadian and lake whitefish.

Meristic and morphometric characters were analyzed separately as suggested by Ihssen et al.(1981b) and together. When analyzed separately, the principal component analysis was done on a variance/covariance data matrix. The use of this matrix rather than the correlation coefficient matrix implies a certain knowledge of the data set and purpose to the study (Neff and Marcus, 1980). The variance/covariance matrix attributes more weight to variable characters and in systematic studies of morphological variation this approach is often of interest. Particularily for morphometric studies where all measurements are made in one unit (ie. millimeters), the use of a variance/covariance matrix has been reecommended (Neff and Marcus, 1980; Bookstein et al., 1985). When meristic and morphometric characters were analyzed together, however, a correlation coefficient matrix was used as is suggested when characters have been measured in different units and variation between characters is a function of scaling (Neff and Marcus, 1980).

On the basis of an *a priori* recognition of Acadian whitefish and lake whitefish in the principal component analyses, a canonical variate analysis (CVA) using the SAS Canvar Procedure was performed on these taxa. This *a posteriori* method assumes statistical differences between already defined groups and thus analyzes groups of individuals rather than individuals. In the case where only two groups are being analyzed on the first canonical axis, this method is equivalent to a dis iminant function analysis (DFA). A simple ANOVA and a stepwise Discriminant Analysis accounting for character corelation were then performed to test which characters were significantly different between the Acadian whitefish and the lake whitefish.

An electrophoretic study of isozymes was performed on Acadian whitefish and lake whitefish to see if they could be distinguished by biochemical characters. Whitefish specimens were collected by the author during surveys in Nova Scotia and were frozen (-20°C) immediately after capture. A total of 20 Acadian whitefish and 55 lake whitefish were studied and a list of specimens examined is presented in Table 3. The six specimens of Arctic cisco, *Coregonus autumnalis*, from Cape Bathurst, NWT, were made available for comparative purposes by Dr. J.W. Clayton.

Tissue samples of white muscle, heart muscle and liver were analyzed by horizontal starch gel electrophoresis in the lab of Dr. J.W. Clayton, Freshwater Institute, Winnipeg, Manitoba. Four enzyme systems comprising eight loci were examined. Lactate dehydrogenase (LDH) phenotypes were analyzed following methods described by Clayton and Franzin (1970). Malate dehydrogenase (MDH) phenotypes were studied following Franzin and Clayton (1977) and Gylcerol-3-phosphate dehydrogenase (GPDH) following Clayton et al. (1973). Isocitrate dehydrogenase (IDH) phenotypes were analyzed following standard methods used in the lab of J.W. Clayton. The electrophoretic techniques were performed by the author and assistance in interpreting phenotype banding patterns was given by J.W. Clayton. An unweighted pair-group arithmetic average (UPGMA) cluster analysis (Sneath and Sokal, 1973) summarizing population affinities was calculated using Nei's genetic distances between populations (Nei, 1972; 1978).

Geographic variation within the lake whitefish species complex in the Maritimes region was studied by principal component and canonical variates analyses of the previously labeled populations. Meristic and morphometric data sets were analyzed separately and together. Mahalanobis distances (the square of the euclidian distance in canonical variates space between population centroids) were used in a UPGMA cluster analysis to summarize relationships between populations with more than one specimen.

TABLE 3. Sample sizes of whitefish specimens examined in electrophretic studies.

LOCALITY	ISOZYMES				
	GPDH	IDH	MDH	LDH_S	LDH_H
ACADIAN WHITEFISH					
Minamkeak Lake, N.S.	4	2	2	1	2
Milipsigate Lake, N.S.	1	-	1	1	-
Hebb Lake, N.S.	13	5	10	7	3
Annis River, N.S.	2	2	1	-	1
TOTAL	20	9	14	9	6
LAKE WHITEFISH					
Lake George, N.S.	20	6	12	10	-
Mira River, N.S.	35	24	32	25	6
TOTAL	55	30	44	35	6
ARCTIC CISCO					
Cape Bathurst, N.W.T.	6	6	6	6	6

1.3 Results

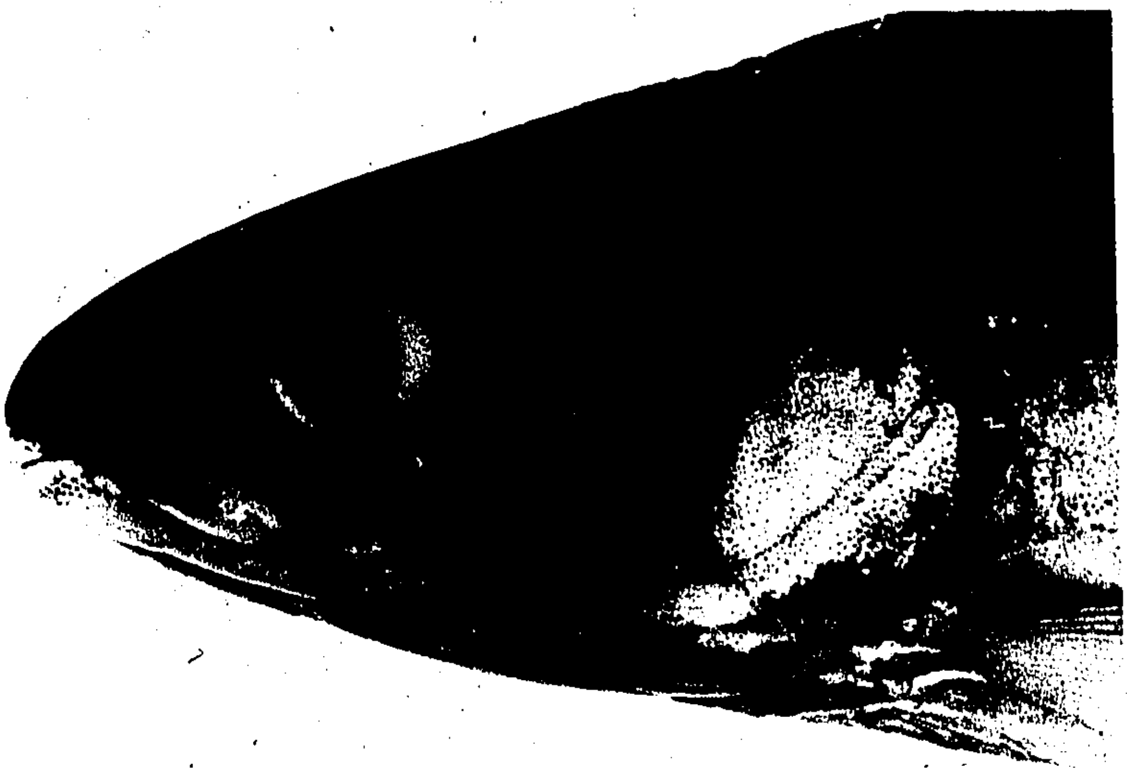
One of the characters used by Scott and Crossman (1973) to distinguish Acadian whitefish and lake whitefish was mouth shape. Examination of whitefish specimens in this study also found mouth shape to be a good, simple external distinguishing character between these two taxa. The Acadian whitefish had a rounder snout profile and a more terminal mouth than the pointed snout profile and subterminal mouth characteristic of lake whitefish (Figure 2). However, considerable individual variation in mouth shape was found in both taxa (Figure 3) and thus the use of this character to recognize Acadian whitefish is open to some subjectivity depending upon the experience of the observer.

Specimens in Figure 2 also show the different arrangement of pearl organs on the heads of Acadian and lake whitefish. A ventral notch in the adipose eyelid was observed on many Acadian whitefish although it is not readily visible in all photographs. This notch was found on 31 Acadian whitefish (82% of the specimens examined) compared to only 19 lake whitefish (11% of the specimens examined).

A summary of meristic data is presented in Table 4. The multivariate analysis of this meristic data indicated the presence of two distinct groupings of individuals corresponding to Acadian whitefish and lake whitefish specimens (Figure 4). The first principal component (PC I) accounted for 86% of the variation in the data and weighted lateral line scales most heavily followed by vertebrae and gill rakers. PC III accounted for 2% of the variation and vertebrae count was weighted most heavily followed by anal fin rays and lateral line scales. A plot of PC I against PC II showed good although not complete separation of Acadian whitefish and lake whitefish groups. Similarily a PCA on the same data using a correlation matrix found good although not complete separation of Acadian from lake whitefish. Since all biologically important

Figure 2: Photographs of the Acadian whitefish (top) and lake whitefish (bottom). Acadian whitefish - caught Oct. 11, 1982 in the Annis River, NMC 82-684, specimen Y3902. Lake whitefish - caught Nov. 16, 195[illegible] in Grand Lake, N.B., ROM 21677, specimen #4.

Figure 3: Photographs of the Acadian whitefish (top) and Stanley's whitefish (bottom). Acadian whitefish - caught Nov. 12, 1982, in Hebb Lake, N.S., NMC 82-806, specimen Y3904. Stanley's whitefish - caught Nov. 10, 1903 in Square Lake Thoroughfare, Me., USNM 88414, specimen 20.



variation is not necessarily found on the first two axes of a PCA (Neff and Marcus, 1980) and because the data was being analyzed for group structure, the existence of two groups, separated by a substantial gap in Figure 4 was interpreted as indicating that all the Acadian whitefish were morphologically distinct from the lake whitefish specimens.

When PCA was performed on morphometric data, two groups corresponding to Acadian whitefish and lake whitefish were also discernible (Figure 5). PC I accounted for 33% of the data variation and weighted nare diameter most heavily followed by adipose fin base length and adipose fin length. PC II accounted for 14% of the variation and gill raker length was weighted most heavily followed by isthmus length and length of the pelvic axillary process.

The distinction of Acadian whitefish and lake whitefish was also supported by PCA's done on the same morphometric data set transformed by two different methods of removing size effects. When the data was standardized to mean=0 and standard deviation=1 after calculating residuals instead of before, the plot of the first two principal component axes separated all Acadian whitefish from lake whitefish. This separation was not as distinct and accounted for 38% of the variation in the data on the first two axes compared to 47% in the former method. Acadian whitefish and lake whitefish also formed two distinct groups when the morphometric data was transformed to logarithms and size effects were removed by removing PC I. The subsequent plot of PC II against PC III (shape components) accounted for 3% of the variation in the data whereas PC I (size component) accounted for 92% of the variation.

The clearest distinction between Acadian whitefish and lake whitefish was found when the meristic and morphometric data were analyzed together by PCA (Figure 6). PC I accounted for 22% of the variation and weighted eye diameter then pectoral fin length and lateral line scales most heavily. PC II accounted for 14% of variation and

TABLE 4. Variation of meristic characters between whitefish populations showing mean (standard error) and sample size. SAL - scales above lateral line, SBL - scales below lateral fine, LLS - lateral line scales, DFR - dorsal fin rays, AFR - anal fin rays, PCFR - pectoral fin rays, PLFR - pelvic fin rays, BRR - branchiostegal rays, GR - gill rakers, VERT - vertebrae, ENF - eyelid notch frequency.

LOCALITY	SAL	SBL	LLS	DFR	AFR	PCFR	PLFR	BRR	GR	VERT	ENF
ACADIAN WHITEFISH											
Hebb Lake, N.S.	10.30(0.483) 10	9.00(0.0) 8	95.00(2.507) 8	13.58(0.669) 12	14.50(0.756) 8	16.64(0.505) 11	12.00(0.408) 13	8.80(0.422) 10	26.64(0.809) 11	65.70(0.823) 10	.70
Millipsigate L., "	10.88(0.641) 8	8.89(0.333) 9	92.00(2.887) 7	13.67(0.778) 12	14.10(0.568) 10	16.55(0.522) 11	12.07(0.267) 14	8.67(0.651) 12	26.18(0.951) 11	64.86(0.690) 7	.90
Minamkeak L., "	10.75(0.500) 4	9.00(0.000) 3	91.00(4.243) 2	13.80(0.837) 5	14.20(0.447) 5	17.00(0.000) 5	12.00(0.000) 5	8.40(0.894) 5	27.80(1.633) 4	65.00(1.000) 3	.60
Annis River, N.S.	10.00(0.000) 2	8.00(0.000) 2	95.50(0.707) 2	15.00(0.000) 2	15.00(0.000) 2	16.50(0.707) 2	12.00(0.000) 2	8.50(0.707) 2	26.50(0.707) 2	66.00(0.000) 2	1.00
Tusket River, "	10.85(0.376) 13	9.15(0.376) 13	94.23(3.468) 13	14.69(0.480) 13	13.92(0.760) 13	16.92(0.494) 13	12.23(0.439) 13	8.46(0.529) 13	26.46(0.776) 13	65.08(0.494) 13	.91
TOTAL	10.65(0.538) 37	9.03(0.296) 35	93.81(3.187) 32	14.01(0.821) 44	14.18(0.692) 38	16.74(0.497) 42	12.09(0.351) 47	8.60(0.587) 42	26.49(0.870) 41	65.26(0.741) 35	.82
LAKE WHITEFISH											
Mushamush R.Lakes	9.67(0.577) 3	9.00(0.000) 2	78.33(5.033) 3	13.67(0.577) 3	16.00(0.000) 3	18.67(0.577) 3	12.33(0.577) 3	9.00(1.000) 3	26.33(1.155) 3	60.00(1.000) 3	.00
Lake George, N.S.	10.00(0.471) 19	8.63(0.496) 19	81.20(3.075) 15	14.16(0.765) 19	16.32(0.749) 19	17.33(0.730) 21	12.00(0.324) 20	8.714(0.717) 21	25.14(0.964) 21	61.33(0.840) 18	.00
Pringle Lake, N.S.	10.57(0.535) 7	9.71(0.488) 7	75.00(2.236) 7	14.29(0.756) 7	14.86(0.378) 7	18.14(0.690) 7	12.43(0.535) 7	8.71(0.488) 7	30.86(0.690) 7	59.43(0.787) 7	.00
Salmon River, N.S.	10.40(0.548) 5	9.40(0.548) 5	68.00(1.414) 5	13.60(0.548) 5	14.20(0.447) 5	17.00(0.707) 5	12.20(0.447) 5	9.20(0.447) 5	23.20(0.837) 5	60.00(0.707) 5	.50
Mira River, N.S.	9.51(0.689) 37	8.31(0.457) 36	70.06(2.904) 33	13.97(0.788) 38	14.86(0.762) 36	16.55(0.828) 38	11.97(0.677) 38	8.92(0.673) 38	22.58(0.894) 36	60.47(0.615) 34	.00

TABLE 4. (cont'd.) Variation of meristic characters between whitefish populations showing mean (standard error) and sample size. SAL - scales above lateral line, SBL - scales below lateral line, LLS - lateral line scales, DFR - dorsal fin rays, AFR - anal fin rays, PCFR - pectoral fin rays, PLFR - pelvic fin rays, BRR - branchiostegal rays, GR - gill rakers, VERT - vertebrae, ENF - eyelid notch frequency.

LOCALITY	SAL	SBL	LLS	DFR	AFR	PCFR	PLFR	BRR	GR	VERT	ENF
Lake whitefish (cont'd.)											
Grand Lake, N.B.	9.67(0.492) 12	8.55(0.522) 11	76.67(3.892) 12	14.00(0.426) 12	15.25(0.622) 12	17.33(0.651) 12	12.50(0.522) 12	8.92(0.515) 12	24.33(1.155) 12	59.67(0.651) 12	.25
St.John River, "	10.10(0.447) 20	8.10(0.308) 20	77.10(2.789) 20	13.95(0.686) 20	14.60(0.821) 20	16.40(0.598) 20	12.10(0.308) 20	8.70(0.470) 20	24.50(1.192) 20	60.35(1.226) 20	.00
Kerr Lake, N.B.	10.61(0.722) 23	8.57(0.598) 21	69.32(3.061) 22	13.91(0.996) 23	14.48(0.730) 23	17.70(0.559) 23	12.30(0.470) 23	8.70(0.559) 23	30.14(0.990) 22	59.35(0.647) 23	.43
Square Lake, Me.	9.87(0.344) 23	8.17(0.388) 23	78.39(3.526) 23	13.61(0.583) 23	15.83(0.650) 23	16.43(0.788) 23	12.26(0.449) 23	8.22(0.422) 23	25.00(1.446) 23	61.29(0.722) 23	.04
L.Temiscouata,Que.	10.03(0.400) 32	8.61(0.495) 31	85.69(3.393) 32	13.41(0.762) 32	15.97(0.933) 32	16.50(0.762) 32	12.09(0.296) 32	8.78(0.659) 32	25.41(1.316) 32	61.31(1.061) 32	.00
Long Pond, Me.	10.11(0.333) 9	8.35(0.452) 12	74.08(2.314) 12	14.17(0.577) 12	16.33(0.888) 12	16.17(0.577) 12	12.75(0.452) 12	8.75(0.452) 12	27.83(0.937) 12	60.67(1.073) 12	.17
Baker Lake, N.B.	10.67(0.577) 3	9.00(1.000) 3	79.33(2.887) 3	13.33(0.577) 3	15.33(0.577) 3	17.00(1.000) 3	12.00(0.000) 3	8.33(0.577) 3	26.33(0.577) 3	61.33(0.577) 3	.33
Trouser's L., "	10.33(0.471) 3	8.67(0.577) 3	82.33(2.887) 3	14.33(0.577) 3	15.00(0.000) 3	16.00(1.000) 3	12.00(0.000) 3	8.33(0.577) 3	23.33(0.577) 3	62.00(1.000) 3	.00
Third Lake, N.B.	11.00(0.000) 2	9.50(0.707) 2	81.50(3.536) 2	13.00(0.000) 2	15.50(0.707) 2	16.00(0.000) 2	12.50(0.707) 2	8.50(0.707) 2	27.50(2.121) 2	62.50(0.707) 2	1.00
TOTAL/MEAN	10.02(0.634) 205	8.50(0.593) 201	76.64(6.434) 198	13.85(0.767) 209	15.33(0.993) 208	16.84(0.993) 211	12.19(0.500) 210	8.73(0.622) 211	25.44(2.754) 204	60.61(1.138) 202	.11

Figure 4: Principal component analysis summarizing covariation of ten meristic characters. Acadian whitefish are coded by A, Z, U. For lake whitefish populations see codes in Figure 1.

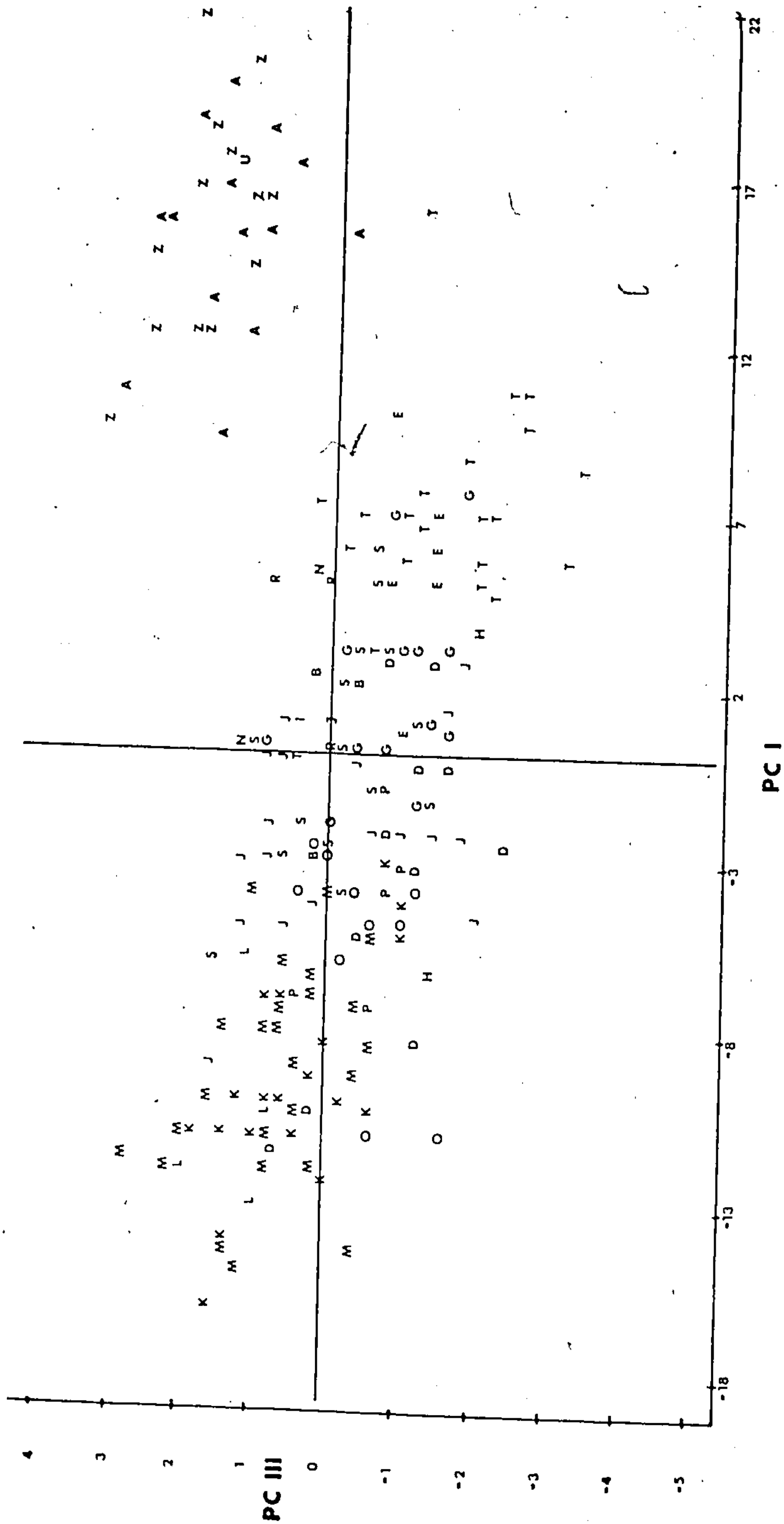
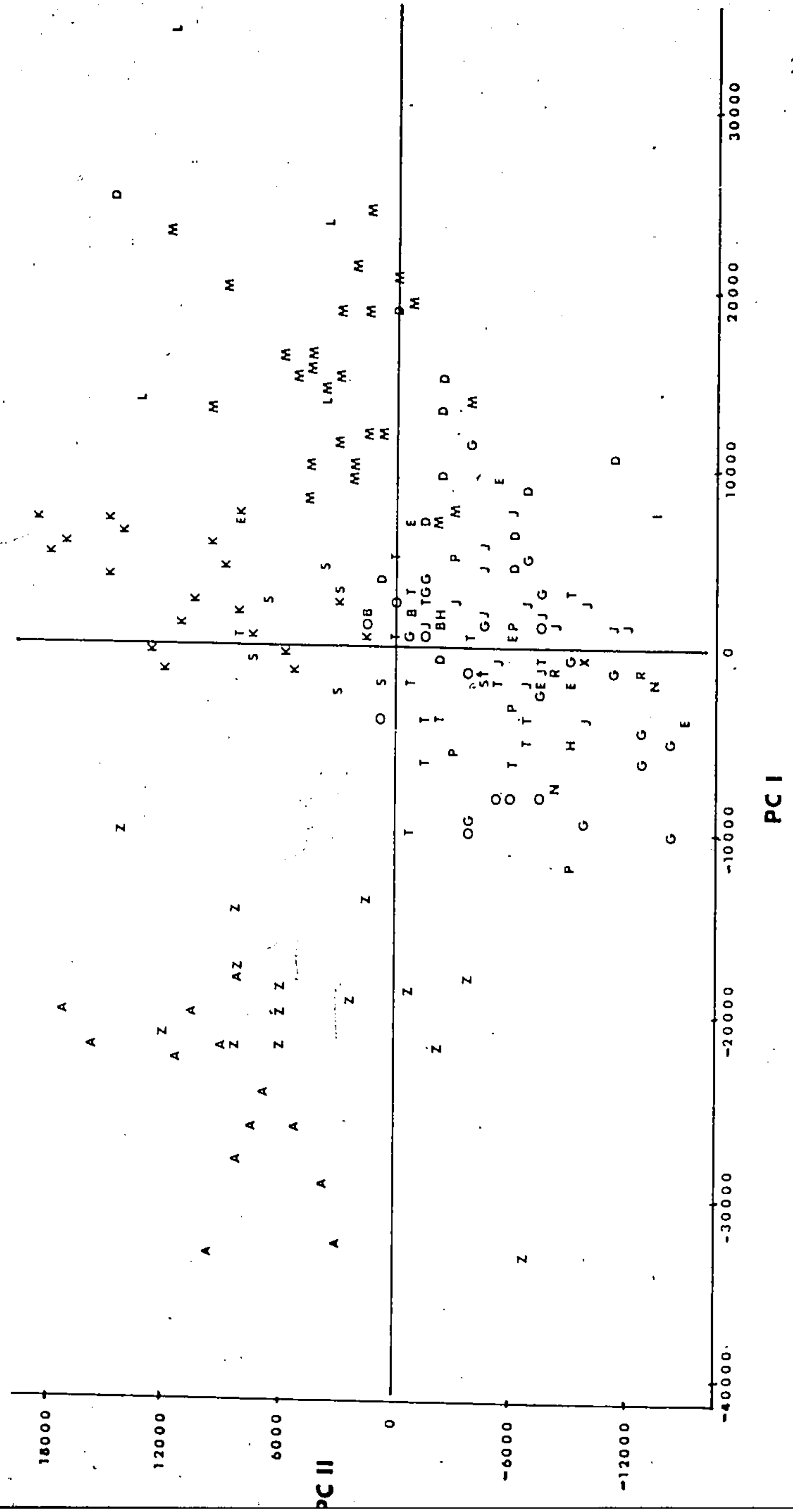

PC I
-18
-13
-8
-3
2
7
12
17
22
PC III
4
3
2
1
0
-1
-2
-3
-4
-5

Figure 5: Principal component analysis summarizing covariation of forty-three morphometric characters. Acadian whitefish are coded A and Z. For lake whitefish population codes see Figure 1.


PC I
30000
20000
10000
0
-10000
-20000
-30000
-40000
PC II
18000
12000
6000
0
-6000
-12000

weighted pelvic axillary process length most heavily followed by gape and anal fin to caudal fin length. The two clearly discernable groups in Figure 6 along with similar groupings from separate analyses of meristic and morphometric data sets give support to recognizing the Acadian whitefish as morphologically distinct from lake whitefish populations.

Discriminant function analyses (canonical variate axis I) of meristic and morphometric data sets indicated the clear distinction (significant at $p < .0001$) of the Acadian whitefish and the lake whitefish (Figures 7 and 8). In analyses of meristic data, the variables giving the most separation between these two groups were, in order, vertebrae, anal fin rays and scales above the lateral line. The variables giving the most separation in the analysis of morphometric data were, in order, pre-pectoral depth, predorsal length and pectoral fin length.

An analysis of variance on meristic and morphometric characters showed that the Acadian whitefish and lake whitefish were significantly different ($p < .01$) for 35 of 53 characters (Table 5). Accounting for the correlation between many characters a stepwise Discriminant Analysis found the two taxa were significantly different ($p < .01$) for 10 characters (Table 6). An analysis of variance found Acadian whitefish from the Tusket River watershed to be significantly different ($p < .01$) from Acadian whitefish in the Petite Riviere watershed lakes for 19 of 53 characters. These characters in decreasing order of significant difference were; gill raker length, number of dorsal fin rays, length of pelvic fin, pectoral fin base length, height of anal fin, caudal peduncle depth, height of dorsal fin, length of pectoral fin, pelvic fin base length, adipose fin length, internaral width, pectoral-ventral length, maxillary width, pre-pelvic length, snout length, orbital diameter, nare diameter, upper jaw length, anal to caudal length.

The best taxonomic character to distinguish Acadian whitefish and lake whitefish was the number of vertebrae. This character could correctly separate over 99% of the

Figure 6: Principal component analysis summarizing covariation of ten meristic and forty-three morphometric characters. Acadian whitefish are coded A and Z. For lake whitefish population codes see Figure 1.

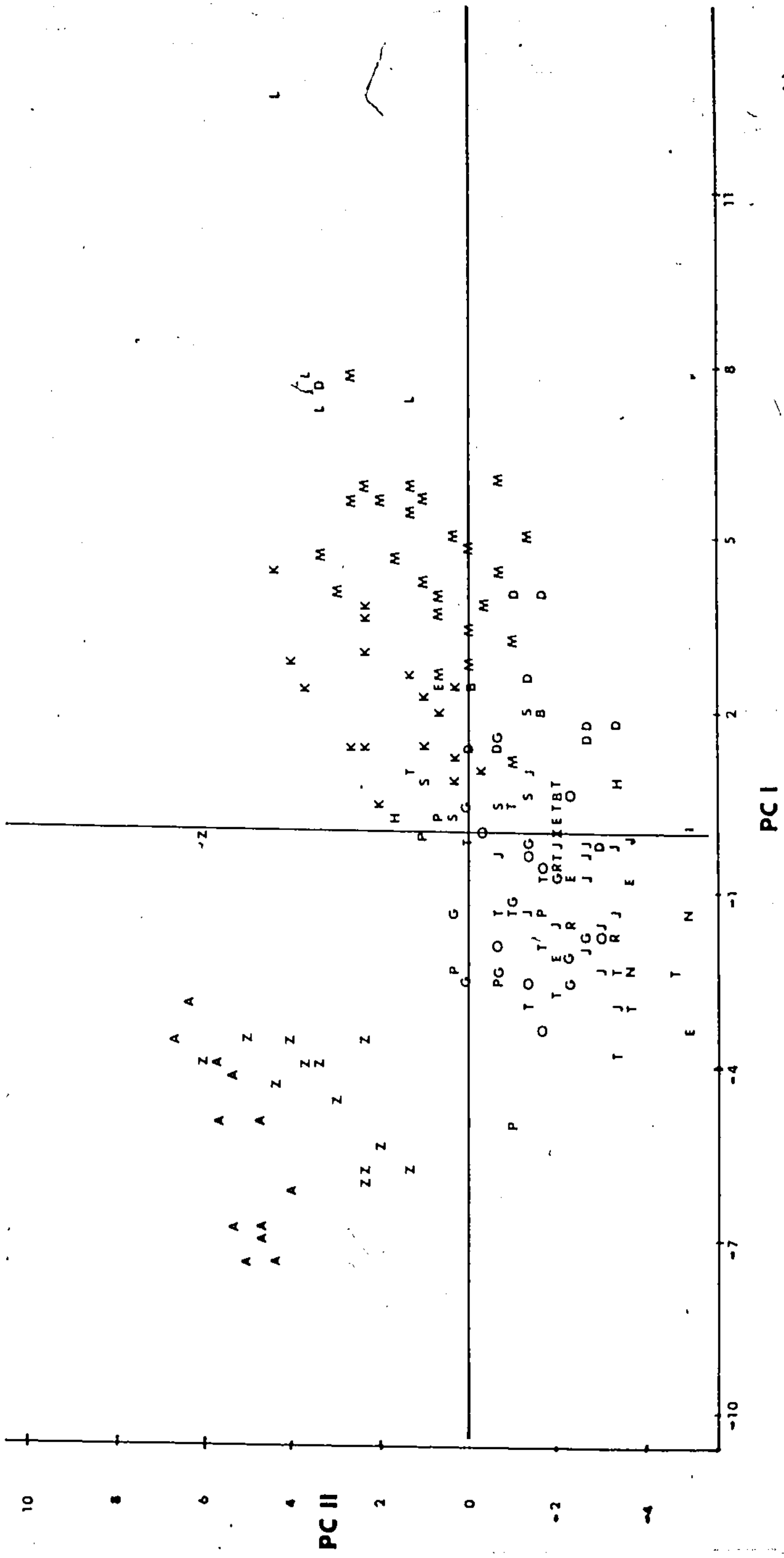

PC I
PC II
-10
-7
-4
-1
2
5
8
11
10
8
6
4
2
0
-2
-4

Figure 7: Discriminant function analysis of ten meristic characters.

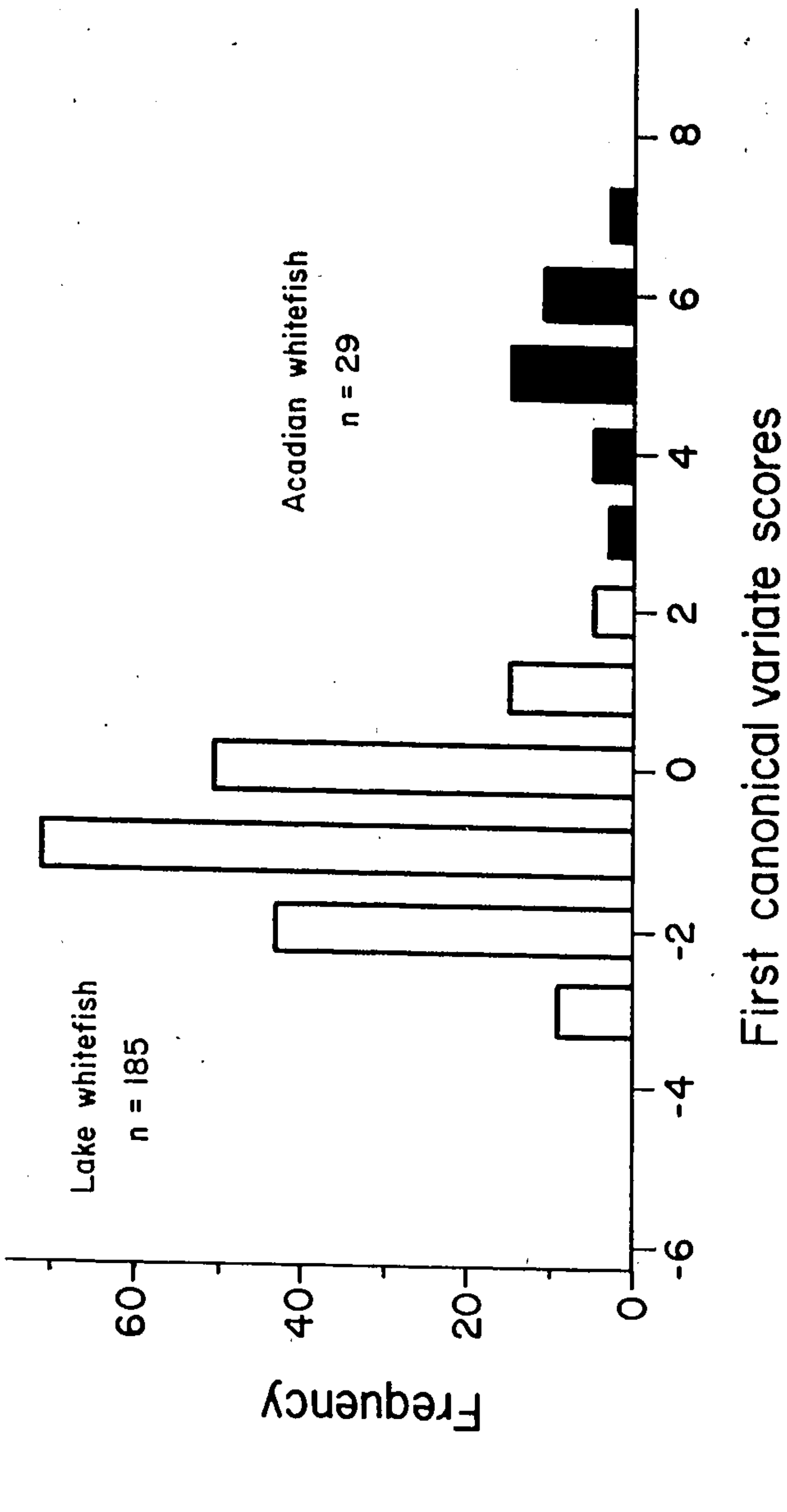

Lake whitefish
n = 185
Acadian whitefish
n = 29
Frequency
0
20
40
60
-6
-4
-2
0
2
4
6
8
First canonical variate scores

Figure 8: Discriminant function analysis of forty-three morphometric characters.

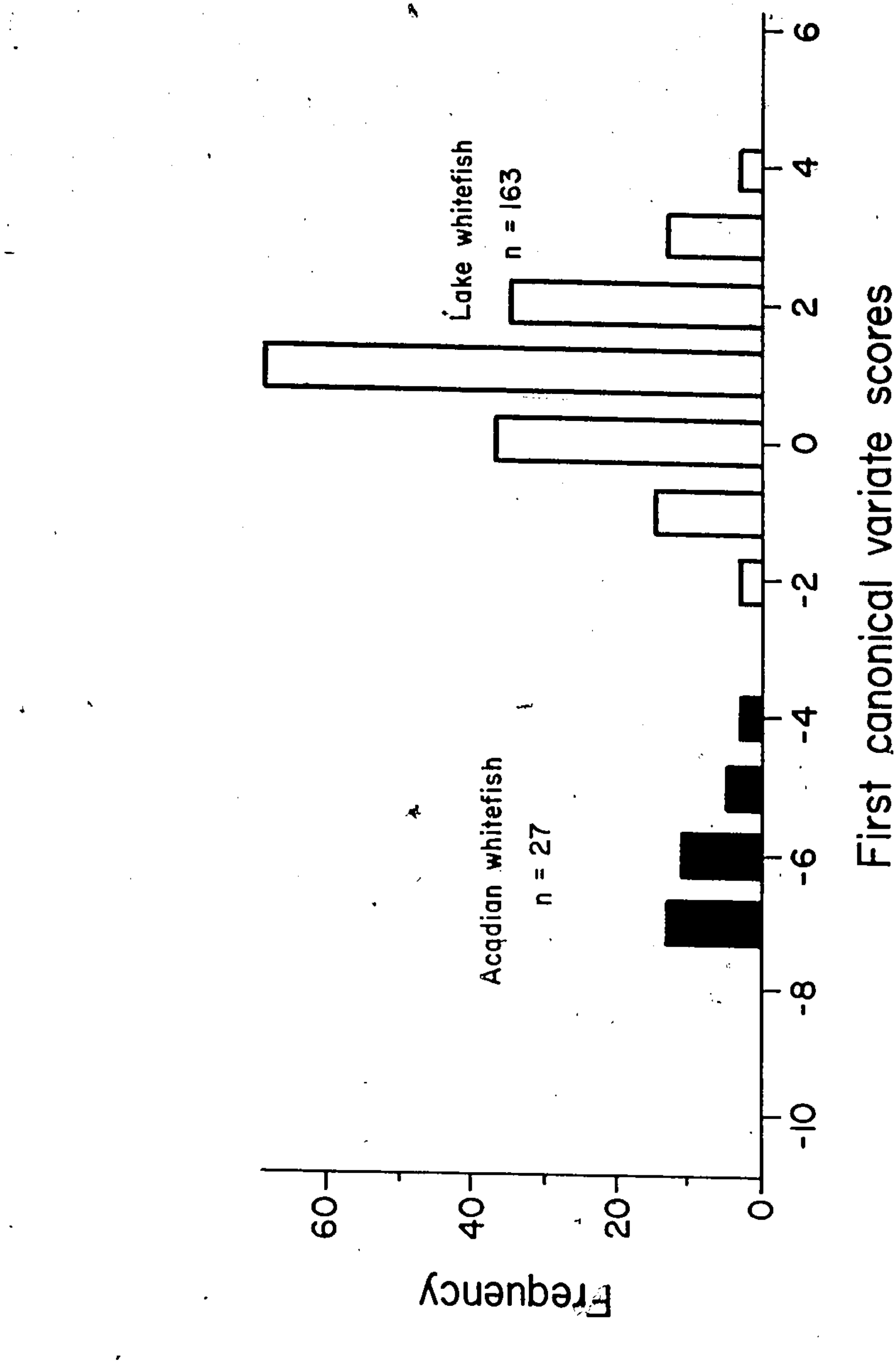

Lake whitefish
n = 163
Acadian whitefish
n = 27
-10
-8
-6
-4
-2
0
2
4
6
First canonical variate scores
0
20
40
60
Frequency

TABLE 5. Morphological characters showing a significant difference between Acadian whitefish and lake whitefish (P<0.01). Meristic characters are raw data while morphometric characters are residual values.

CHARACTER	ACADIAN WHITEFISH NO.	ACADIAN WHITEFISH $\bar{X}$	LAKE WHITEFISH NO.	LAKE WHITEFISH $\bar{X}$	F VALUE	PROB >F
Vertebrae	35	65.26	202	60.61	543.40	.0001
Adipose-caudal length	33	-7190.33	204	884.66	310.00	"
Adipose base length	33	-11174.55	204	1566.25	278.94	"
Nare diameter	33	-11589.64	203	1623.34	221.02	"
Lateral line scales	32	93.81	198	76.64	218.63	"
Pelvic axillary process len.	33	7214.58	204	-1180.51	207.53	"
Adipose fin length	33	-7755.67	202	895.32	172.04	"
Height of anal fin	31	-4962.39	186	682.62	162.07	"
Eye diameter	33	-7248.42	200	1350.50	158.47	"
Pectoral fin length	33	-4542.88	202	749.79	125.71	"
Pectoral-ventral len.	33	2635.15	204	-430.74	97.64	"
Pre-dorsal length	33	1538.67	203	-171.69	92.54	"
Pre-pelvic rays	33	1304.61	203	-208.00	84.96	"
Anal fin rays	38	14.18	208	15.33	50.84	"
Anal base length	32	-2903.22	204	358.87	45.88	"
Anal-caudal length	32	-2363.47	204	320.79	42.54	"
Ventral-anal length	32	-1764.69	204	230.03	37.01	"
Width of gape	33	2353.30	203	-678.38	36.76	"
Maxillary width	33	-2884.97	203	533.07	36.14	"
Scales above lateral l.	37	10.65	205	10.02	32.24	"
Upper jaw length	33	1823.97	203	-344.77	28.67	"
Scales below lateral l.	35	9.03	201	8.50	26.37	"
Pectoral base length	33	-2119.27	204	220.93	25.80	"
Anal depth	32	-1186.00	204	224.28	22.41	"
Dorsal base length	33	-1504.94	204	277.51	20.67	"
Gill filament length	32	1344.60	196	-240.46	14.30	.0002
Eyeball diameter	33	-1985.36	199	436.64	13.71	.0003
Pupil diameter	33	-2768.70	200	978.12	12.74	.0004
Interorbital width	32	1131.81	201	-70.00	12.42	.0005
Pre-anal length	32	343.13	203	-62.18	10.46	.0014
Pre-pectoral length	33	-853.70	203	207.82	9.68	.0021
Pre-pectoral depth	31	-755.23	204	142.82	9.14	.0028
Internaral width	32	1732.09	203	-122.32	8.39	.0041
Isthmus length	31	1444.45	199	-285.66	7.54	.0065
Pre-dorsal length	33	-732.15	204	114.46	7.01	.0086

TABLE 6. Morphological characters showing a significant difference (P<0.01) between Acadian whitefish and lake whitefish after accounting for character corelations in a SAB stepwise discriminant analysis.

CHARACTER	F VALUE	PROB > F
Vertebrae	413.93	.0001
Adipose-caudal length	85.13	"
Anal fin rays	46.96	"
Pelvic axillary process length	30.90	"
Anal fin height	28.08	"
Dorsal fin height	26.61	"
Lateral line scales	11.95	.0007
Width of gape	20.95	.0001
Nare diameter	12.63	.0005
Interorbital width	7.15	.0083

specimens (Figure 9). Only one lake whitefish specimen from Lake Temiscouata, Quebec, was found to have a vertebrae count (64) that overlapped the range found in Acadian whitefish (64-67). This specimen also had a lateral line scale count (90) that overlapped with Acadian whitefish (88-100) but it was distinguished in multivariate analyses of morphological variation.

Adipose-caudal length, adipose base length, nare diameter, lateral line scales and the length of the pelvic axillary process were found to show a highly significant difference between Acadian whitefish and lake whitefish (Table 5). Lateral line scales could have some identification value as they could separate 93% of the whitefish specimens examined (Figure 10). Anal fin rays were significantly different although considerable overlap in counts was observed. Principal anal ray counts showed some discriminating value (Figure 11).

A summary of allele phenotype frequencies from the electrophoretic study is presented in Table 7. Due to tissue storage problems, it was not possible to analyze each enzyme system in all specimens. The Acadian whitefish were found to show clear biochemical differences from lake whitefish. The two taxa were fixed for alternate alleles at the GPDH-A and B loci and showed very different allele frequencies at the loci for IDH-A, IDH-B and MDH-B. The Acadian whitefish was found to have unique alleles not predicted by genetic models for lake whitefish. Although only ten Acadian whitefish were examined for MDH-B polymorphism, all specimens were found to have a unique allele unknown from lake whitefish despite extensive studies of this latter species from across North America by Dr. J.W. Clayton. Four of nine Acadian whitefish examined for LDH (skeletal muscle) polymorphism showed banding patterns not predicted by genetic models for this locus in lake whitefish.

A dendrogram calculated using Nei's genetic distance between populations found Acadian whitefish to be more different from the lake whitefish than the Arctic cisco

Figure 9: Frequency histogram of vertebrae counts.

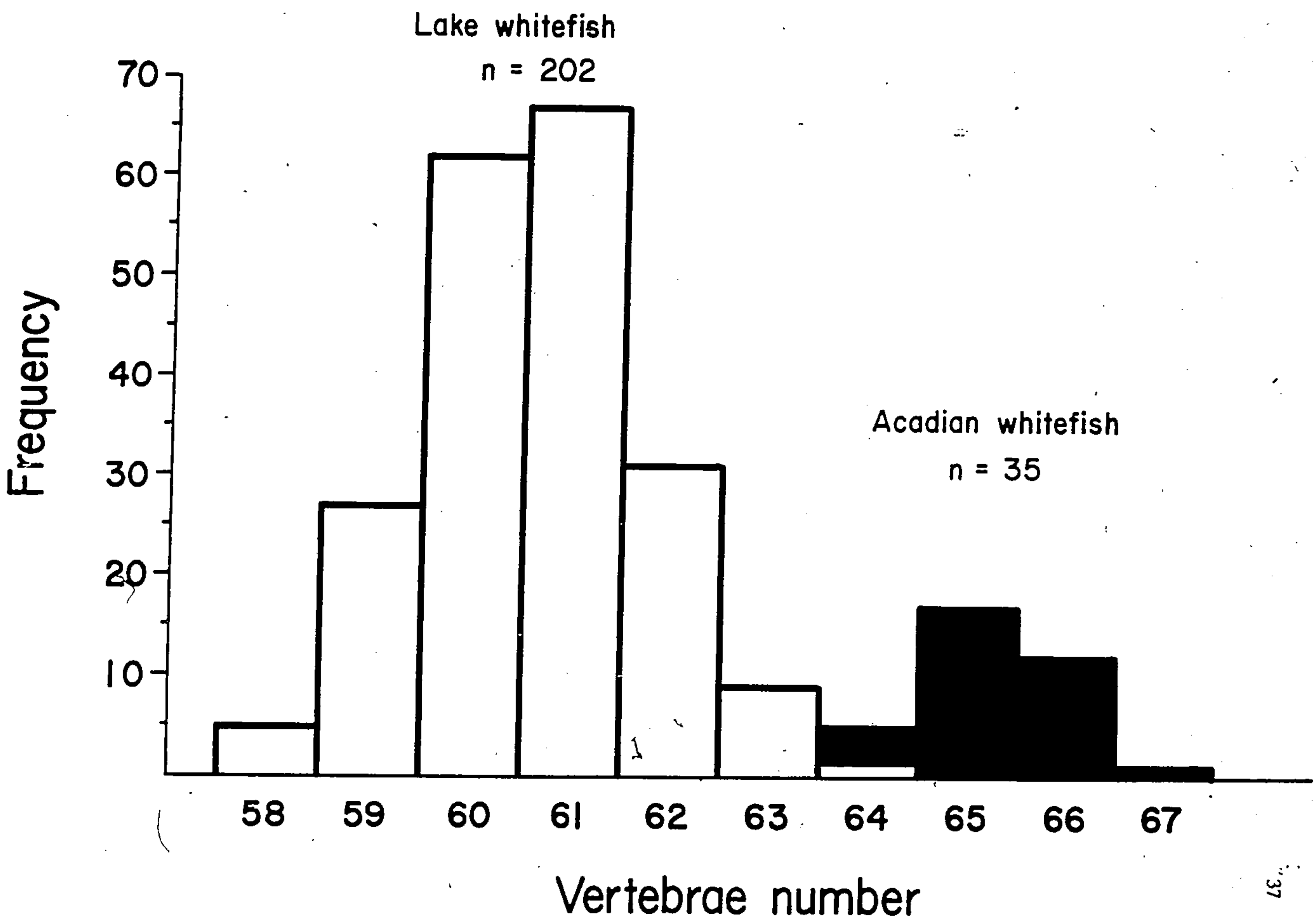

Lake whitefish
n = 202
Acadian whitefish
n = 35
Frequency
70
60
50
40
30
20
10
58
59
60
61
62
63
64
65
66
67
Vertebrae number

Figure 10: Frequency histogram of lateral line scales.

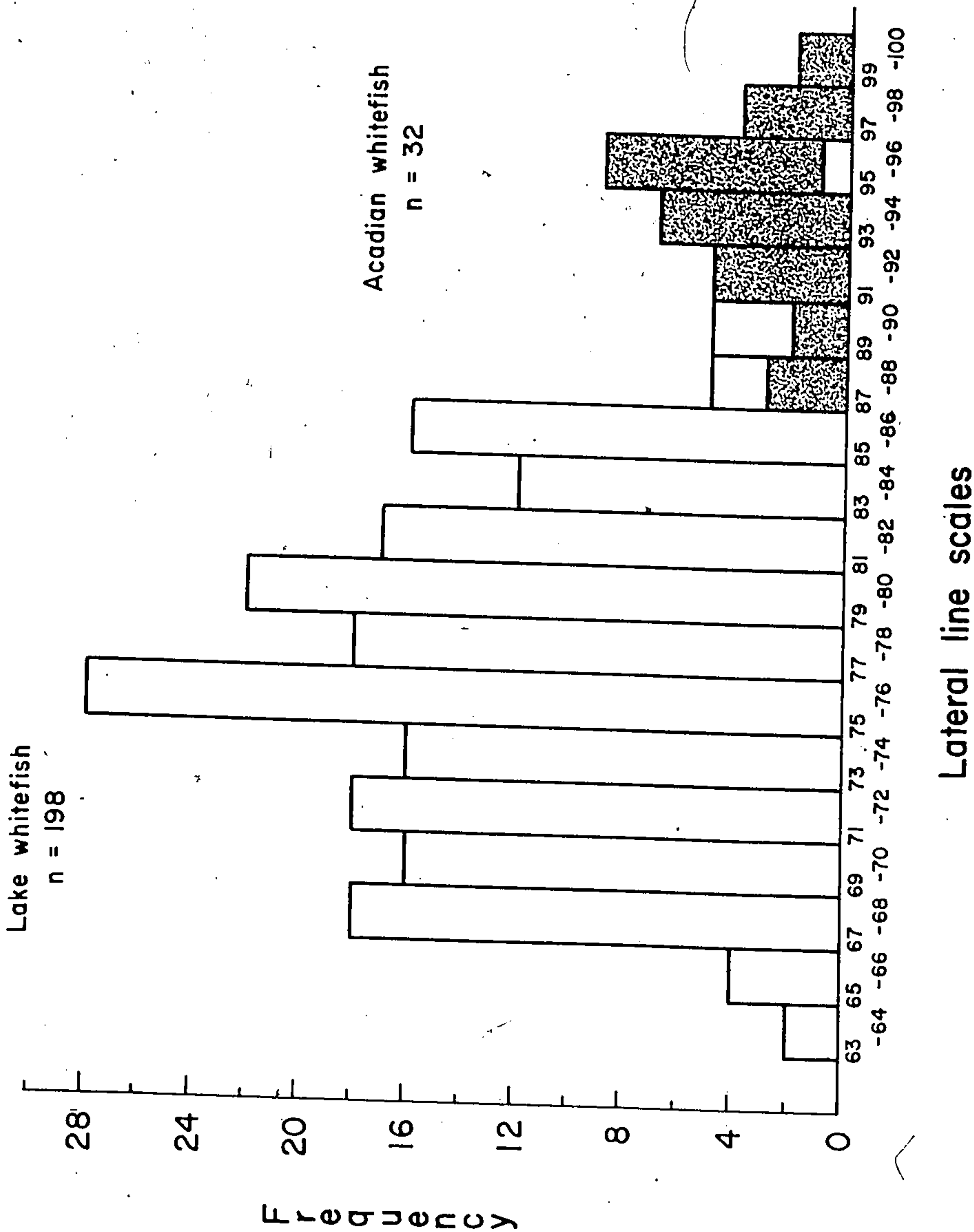

Lake whitefish
n = 198
Acadian whitefish
n = 32
Frequency
0
4
8
12
16
20
24
28
63 -64
65 -66
67 -68
69 -70
71 -72
73 -74
75 -76
77 -78
79 -80
81 -82
83 -84
85 -86
87 -88
89 -90
91 -92
93 -94
95 -96
97 -98
99 -100
Lateral line scales

Figure 11: Frequency histogram of principal anal fin ray counts.

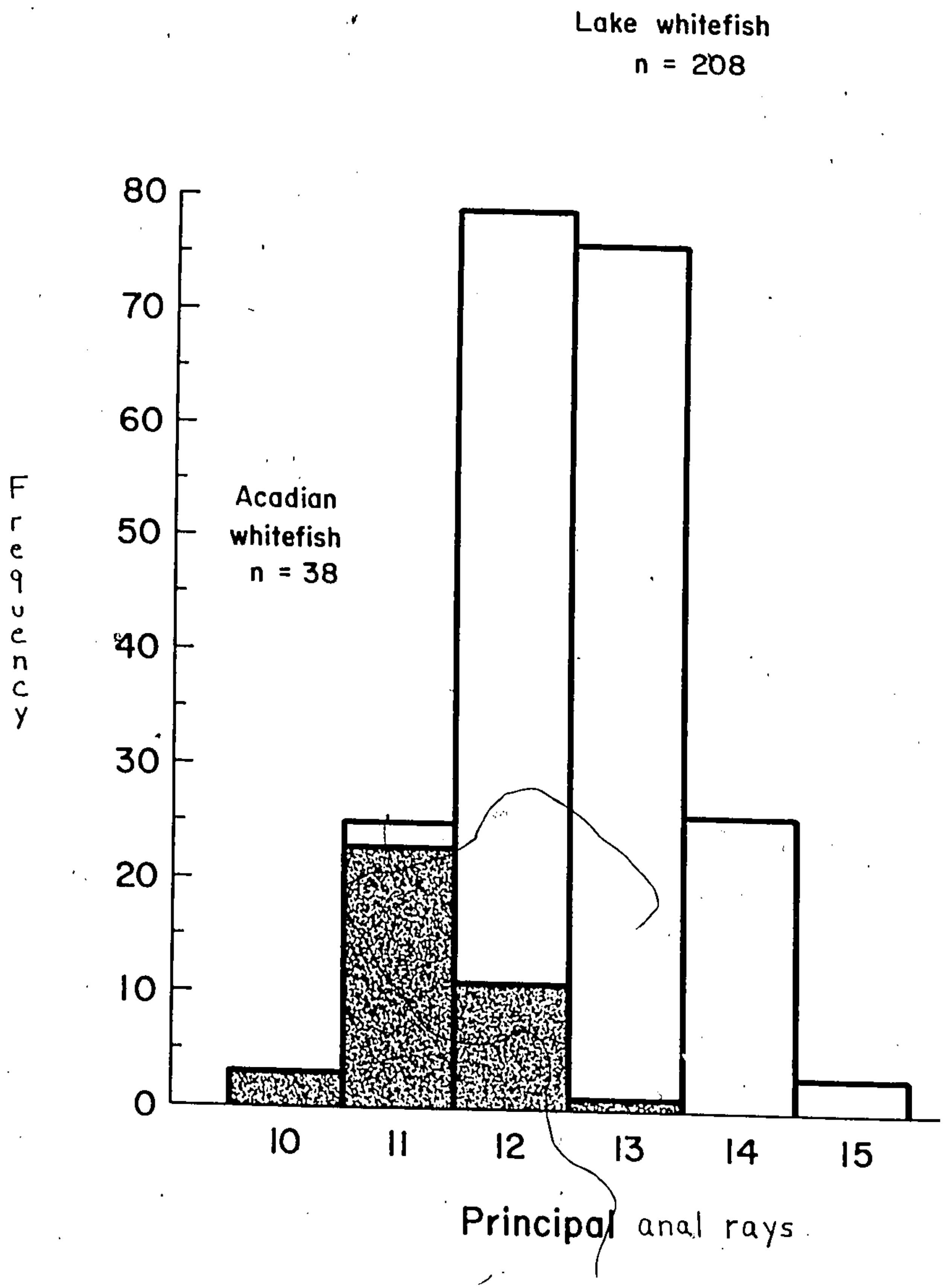

Lake whitefish
n = 208
Acadian
whitefish
n = 38
Frequency
80
70
60
50
40
30
20
10
0
10
11
12
13
14
15
Principal anal rays

TABLE 7. Allelic frequencies from electrophoretic studies of biochemical variation in whitefish populations.

LOCI — ALLELES

1) GPDH

	NO.	A_1	A_2	B_1	B_2	B_3	B_4
Arctic cisco	6	.67	.33	.33	.08	.59	
Acadian whitefish	20	1.00			1.00		
Lake whitefish							
Mira River	35		1.00	.44		.56	
Lake George	20		1.00	.90		.10	

2) IDH

	NO.	A_1	A_2	B_1	B_2	B_3	B_4
Arctic cisco	6	.83	.17		.08		.92
Acadian whitefish	5	.80	.20		.30	.20	.50
Lake whitefish							
Mira River	24	.52	.48			1.00	
Lake George	6		1.00		.90	.10	

3) MDH

	NO.	A_1	A_2	B_1	B_2
Arctic cisco	6				
Acadian whitefish	14	1.00		1.00	
Lake whitefish					
Mira River	32	.53	.47	.13	.87
Lake George	12	1.00		.54	.46

4) LDH (skeletal muscle)

	NO.	A_1	A_2	A_3
Arctic cisco	6	.41	.59	
Acadian whitefish	9	.50	.50	
Lake whitefish				
Mira River	25	.31	.69	
Lake George	10		1.00	

5) LDH (heart muscle)

	NO.	A_1	A_2	A_3
Acadian whitefish	6	1.00		
Lake whitefish				
Mira River	6	.80	.20	

(Figure 12). The lake whitefish populations from the the Mira River and Lake George were found to have different allele frequencies at 6 of 7 loci examined. Both populations were fixed for the GPDH-A_2 allele although at the IDH-B locus, the Mira River population was fixed for the B_3 allele while the Lake George population had the B_2 allele at a frequency of .90.

The analysis of geographic variation in the lake whitefish species complex found considerable meristic variation between populations (Table 4). Populations from the Mira River, N.S. and Kerr Lake, N.B., were characterized by unusually low counts of lateral line scales for the species. Gill raker counts were also variable. High counts were observed in populations from Kerr Lake and Pringle Lake, N.S. while the Mira River population had unusually low counts for eastern North America (Figure 13).

The multivariate analysis of lake whitefish populations did not reveal any population to be a clearly distinct group in principal component analyses of meristic or morphometric data sets or when the two data sets were analyzed together. Canonical variate analyses, however, revealed the distinctiveness of lake whitefish populations from the Mira River, N.S. and Kerr Lake, N.B. (and Salmon River, N.S., see below). Both of these populations could be distinguished from all other lake whitefish populations in analyses of morphometric data (Figure 14) and when meristic and morphometric data were analyzed together (Figure 15). In the canonical variates analysis of meristic data, there were no distinctive lake whitefish populations.

In the CVA of morphometric data, the variables giving the most separation of the Mira River population (CV axis 1) were, in order, head length, head depth and postorbital length. Those variables best separating the Kerr Lake population (CV axis 2) were in order, pre-pelvic length, pectoral-ventral length and pre-pectoral depth. When meristic and morphometric data were analyzed together, the Mira River population was best separated, in order, by anal fin rays, gill raker number and scales above the

Figure 12: Dendrogram (UPGMA) of mean genetic distances between whitefish populations based on seven polymorphic loci.

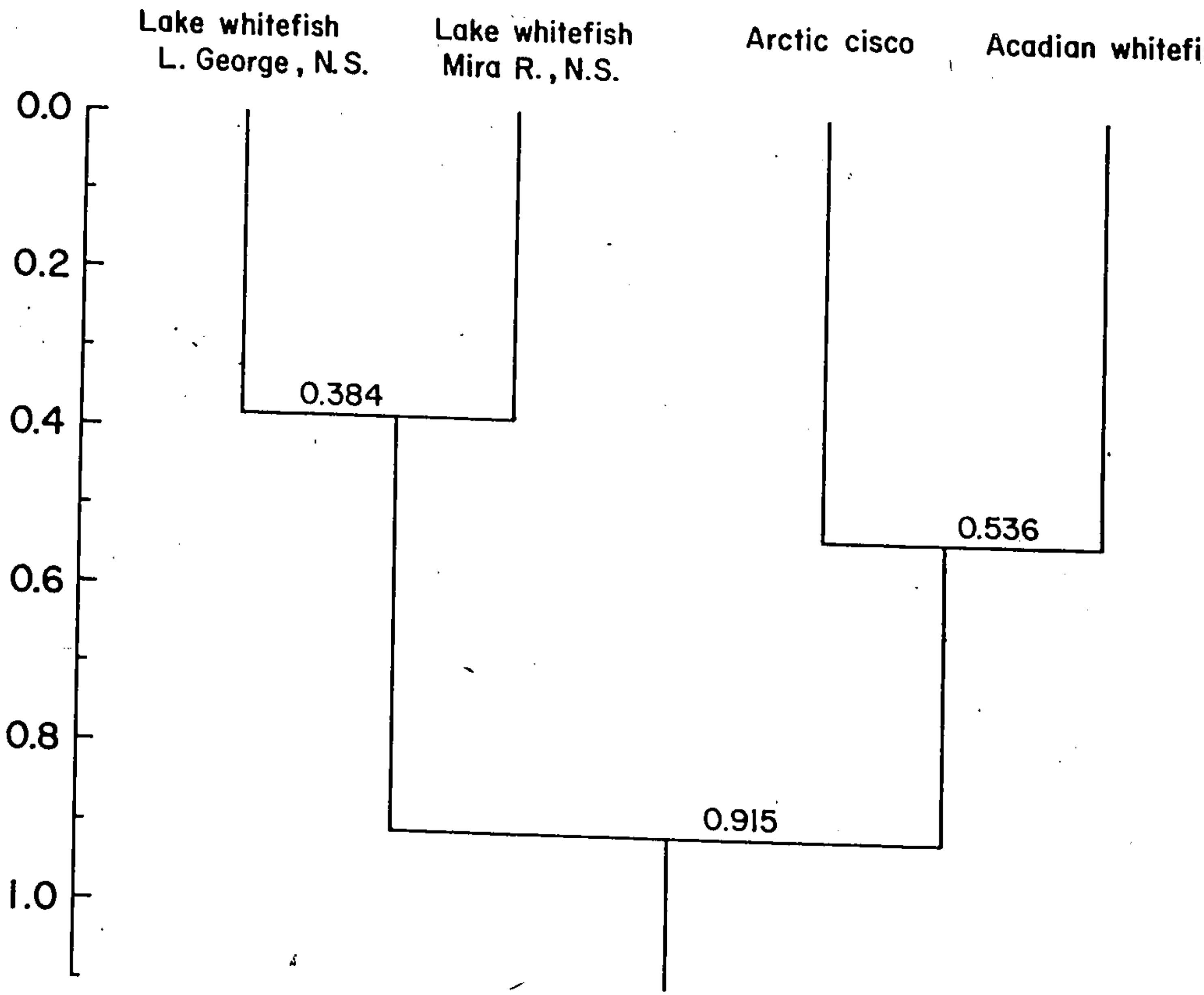
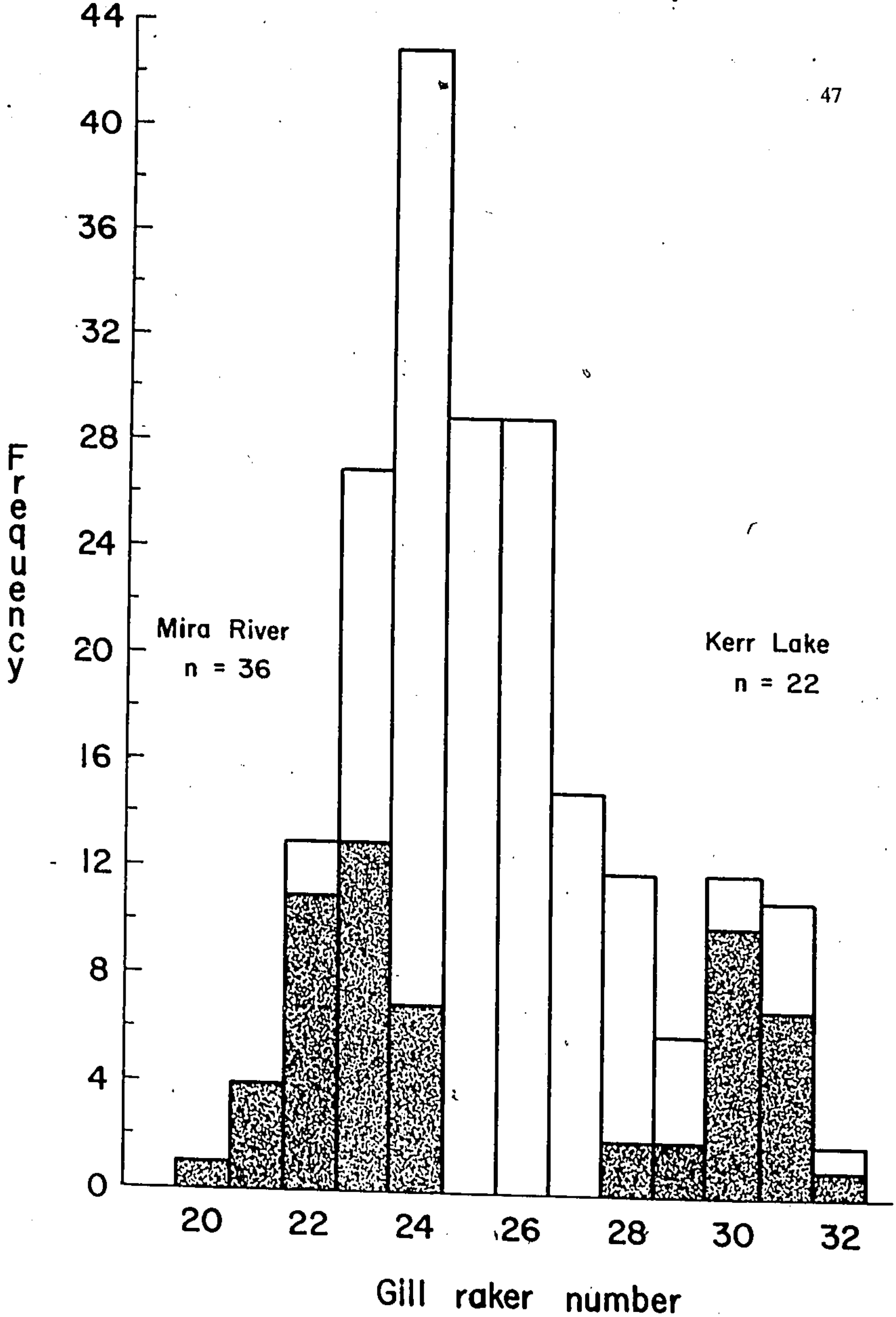

Lake whitefish L. George, N.S.
Lake whitefish Mira R., N.S.
Arctic cisco
Acadian whitefi
0.0
0.2
0.4
0.6
0.8
1.0
0.384
0.536
0.915

Figure 13: Frequency histogram of gill raker counts from lake whitefish specimens, highlighting populations from the Mira River, N.S. and Kerr Lake, N.B. Total lake whitefish sample size is 204 specimens.



44
40
36
32
28
24
20
16
12
8
4
0
Frequency
Mira River
n = 36
Kerr Lake
n = 22
20
22
24
26
28
30
32
Gill raker number

Figure 14: Canonical variate analysis of forty-three morphometric characters from lake whitefish populations. Lake whitefish from the Mira River, N.S., are coded M and those from Kerr Lake, N.B., are K. For other populations see Figure 1.

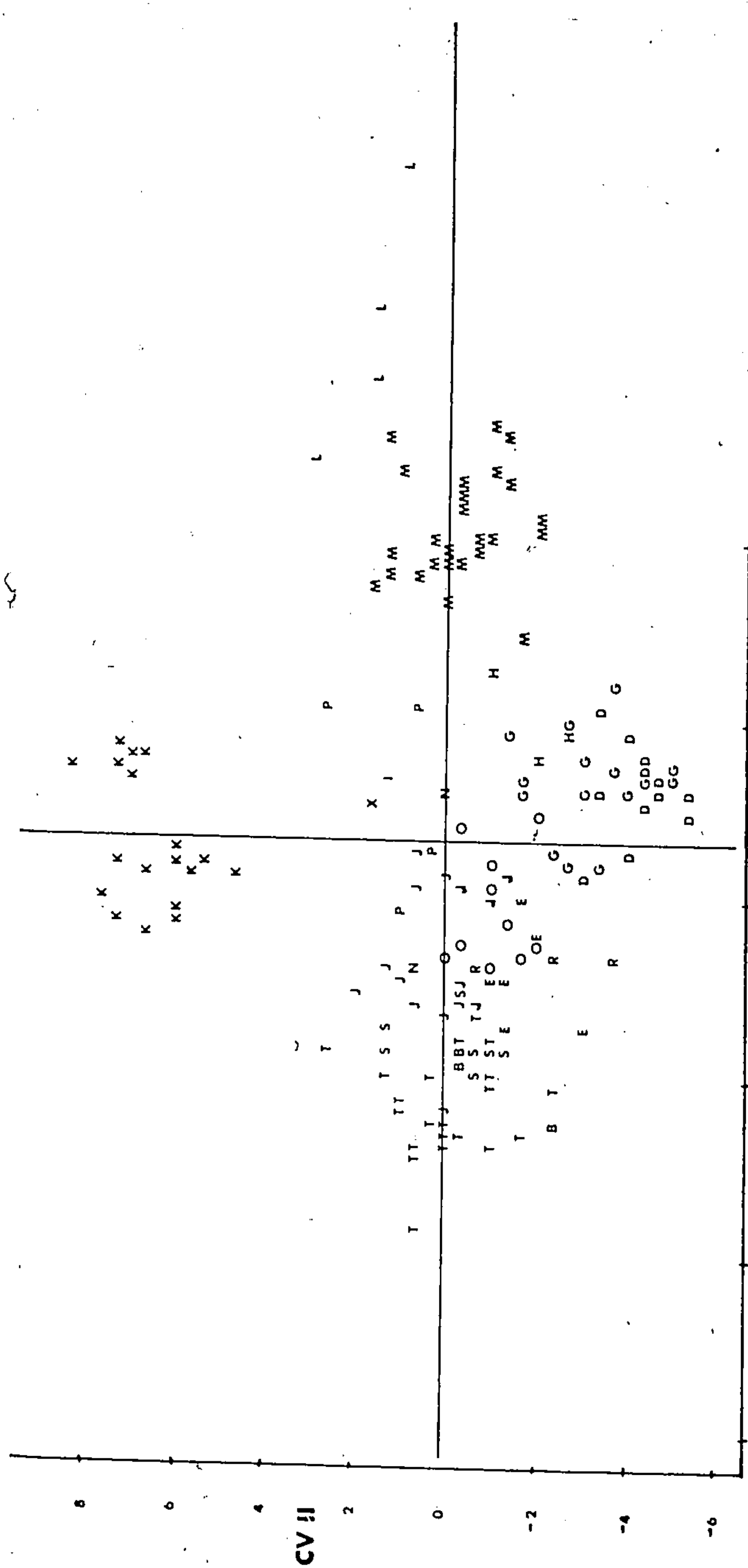
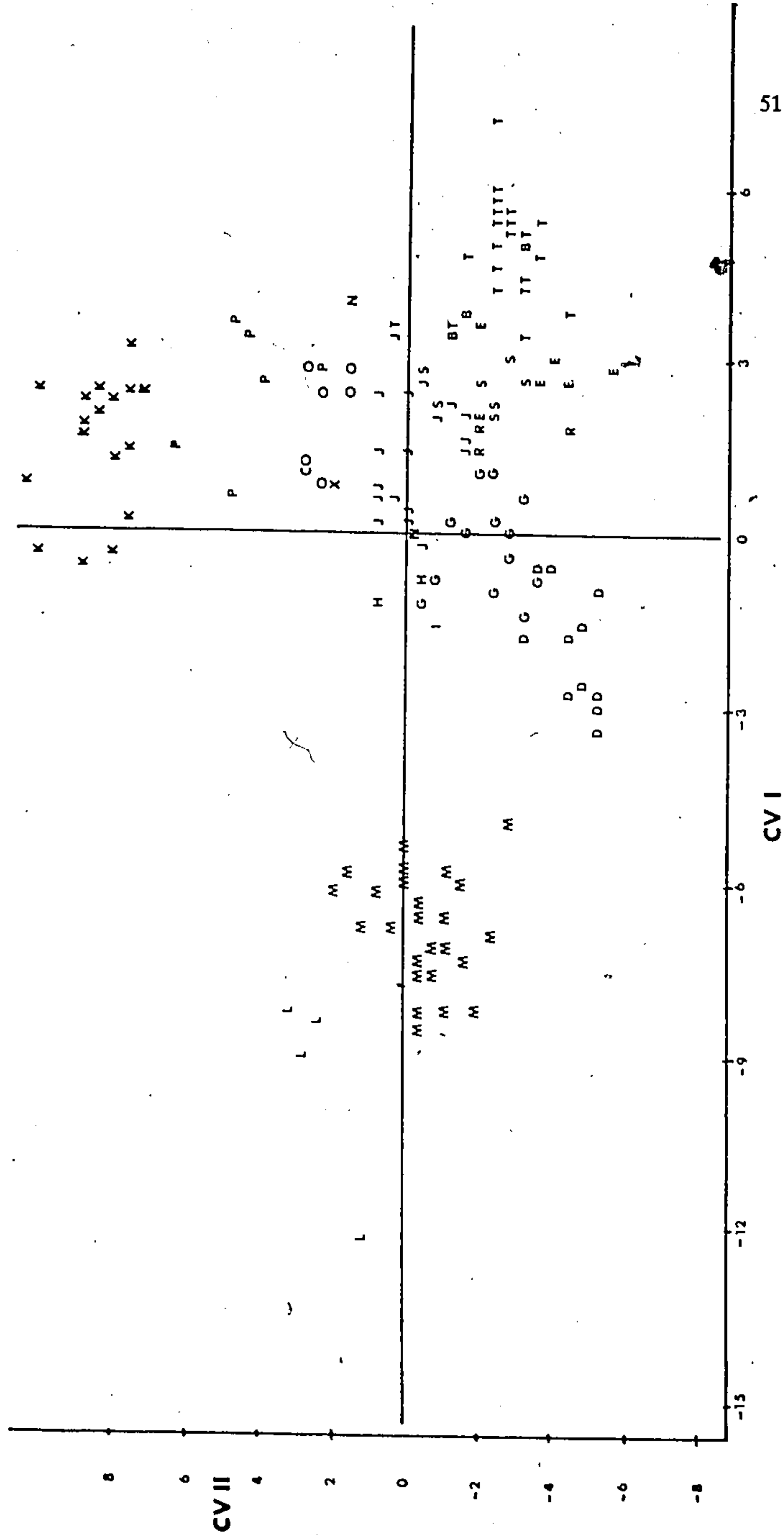

CV I
CV II

Figure 15: Canonical variate analysis of ten meristic and forty-three morphometric characters from lake whitefish populations. Lake whitefish from the Mira River, N.S., are coded M and those from Kerr Lake, N.B., K.

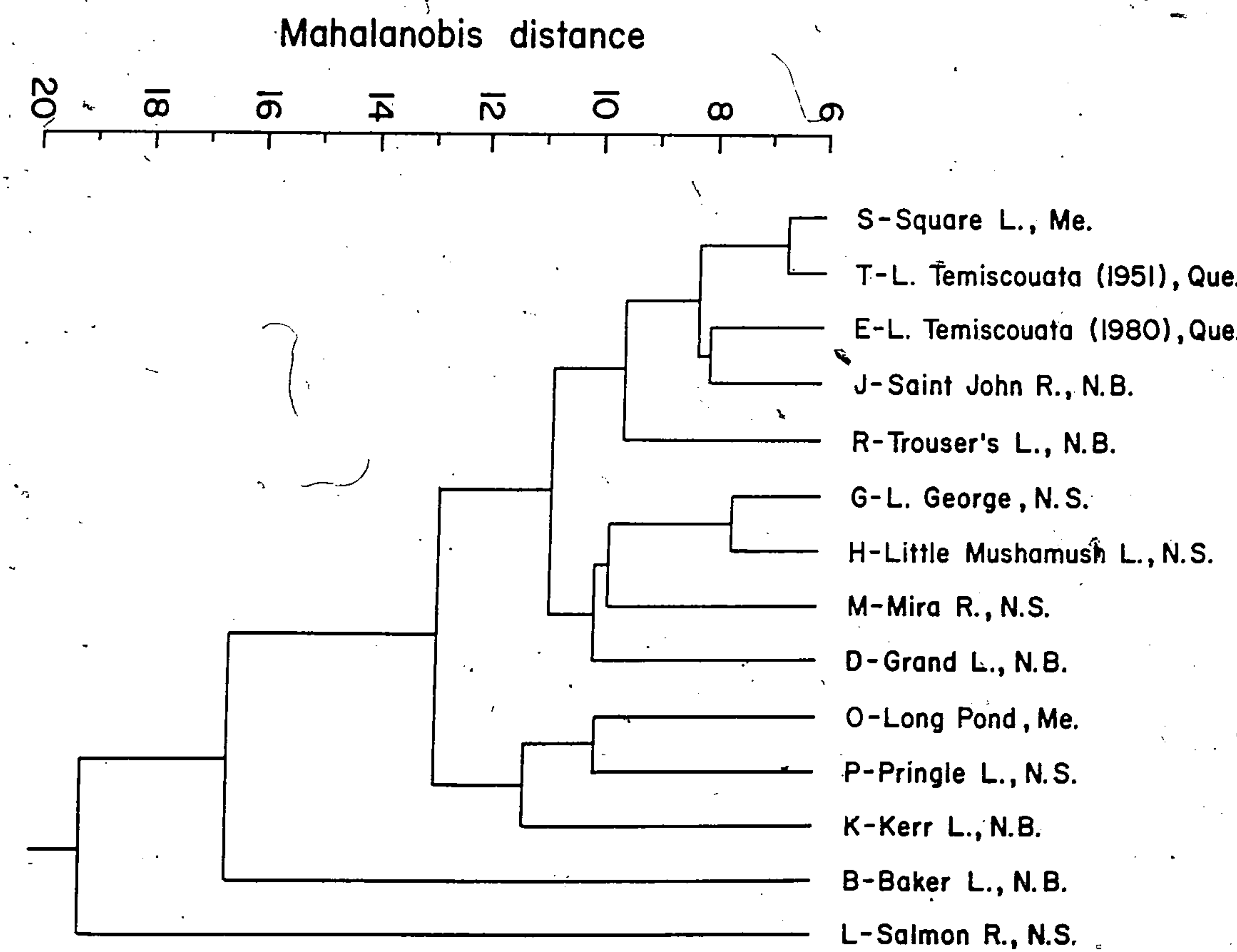

CV I
CV II

lateral line (CV axis 1) and the Kerr Lake population by gill raker number, scales above the lateral line and anal fin rays (CV axis,2).

Five specimens from the Salmon River in Cape Breton, N.S., were also found to have distinctive morphological differences. This population was most similar to lake whitefish from the Mira River in the canonical variates analysis and had similar gill raker and lateral line scale counts. The Salmon River is a tributary of the Mira River and the two collection sites were less than 10 km apart. These specimens were probably either strays from the Mira River population or from a closely related population.

The morphological affinities between lake whitefish populations based on Mahalanobis distances from an analysis of meristic and morphometric data together, are presented in the cluster analysis in Figure 16. The morphological affinities reflect geographic distances between populations to some degree; Nova Scotia populations and those from New Brunswick tend to group separately except for the populations that were found to have high counts of gill rakers. Populations from Kerr Lake, N.B., Long Pond, Me., and Pringle Lake, N.S. group together but are widely separated geographically. The populations from the Saint John River, N.B., show considerable similarity and interestingly, the Square Lake, Me., population is shown closer to the Lake Temiscouata, Que., population than a second sample from the latter locality. Specimens of whitefish from Square Lake and Lake Temiscouata show considerable similarity in head shape having a more rounded snout profile and a mouth that could be described as nearly terminal. This unique head shape was the basis for the description of a new species, *Coregonus stanleyi* from the Cross Lake Thoroughfare, Me., by Kendall (1903) (see Figure 3). The present multivariate analyses of specimens from Square Lake did not find sufficient morphological differences however, to significantly distinguish this population from the other populations of lake whitefish examined in this study.

Figure 16: Dendrogram (UPGMA) of Mahalanobis distances between lake whitefish populations from canonical variate analysis of ten meristic and forty-three morphometric characters.



Mahalanobis distance
20
18
16
14
12
10
8
6
S-Square L., Me.
T-L. Temiscouata (1951), Que.
E-L. Temiscouata (1980), Que.
J-Saint John R., N.B.
R-Trouser's L., N.B.
G-L. George, N.S.
H-Little Mushamush L., N.S.
M-Mira R., N.S.
D-Grand L., N.B.
O-Long Pond, Me.
P-Pringle L., N.S.
K-Kerr L., N.B.
B-Baker L., N.B.
L-Salmon R., N.S.

1.4 Discussion

The morphological and biochemical data presented in this study provide evidence to support the recognition of the Acadian whitefish as a valid species. The multivariate analyses of meristic and morphometric variation showed complete separation of Acadian whitefish from lake whitefish. The Acadian whitefish was found to be significantly different from lake whitefish for 35 of 53 morphological characters examined and vertebrae number alone separated over 99% of the specimens. The electrophoretic analysis of biochemical variation also provided complete separation of Acadian and lake whitefish. There were fixed allele differences between the two taxa and unique alleles were found in the Acadian whitefish. These results indicated that there were highly significant phenotypic differences between Acadian whitefish and lake whitefish.

The possibility of environmental factors contributing to phenotypic divergence has always posed a problem for recognizing species within the genus *Coregonus* (Todd et al., 1981). A lack of evidence of genetic differences must caution the inference of reproductive isolation on allopatric populations that show phenotypic differences. Acadian whitefish and lake whitefish were best distinguished by vertebrae number which has been shown to have a strong genetic basis in fishes (Taning, 1952; Baxter, 1958; Lindsey, 1961). The difference between vertebrae number in Acadian whitefish (64-67, $\overline{X}$=65.3) and lake whitefish (58-64, $\overline{X}$=60.6) was quite large and probably reflects genetic differences considering the known range of vertebrae counts for lake whitefish from across North America is consistently lower at 55-64 (Scott and Crossman, 1973).

Since morphological characters can reflect the effects of many genetic loci, the highly significant differences between the Acadian whitefish and lake whitefish for 35 of 53 characters examined would also suggest there are considerable genetic differences between the two. The consistent pattern of distinct clusters for Acadian whitefish and lake whitefish in principal component analyses of both meristic and morphometric character sets probably reflects these genetic differences. Such distinctive gaps between two taxa in principal component analyses have been suggested as suitable criteria for recognizing species (Neff and Marcus, 1980; Todd et al., 1981).

Although morphological characters can measure the effects of a large number of genetic loci, it is usually not known how many loci are responsible for morphological divergence and to what extent environmental factors have influenced this divergence. The phenotypic expression of biochemical characters is, however, largely independent of environmental influences (Lewontin, 1974; Allendorf and Utter, 1979). Although proteins like isozymes may be several regulatory steps from the actual genotype, a direct relationship exists between phenotype and allelic differences at individual genetic loci.

It is generally desirable to study many genetic loci and individuals in electrophoretic studies (Lewontin, 1974; Ferguson, 1980; Ihssen et al., 1981b). However, the few loci examined in this study provide sufficient evidence to suggest the Acadian whitefish is a valid species distinct from lake whitefish. These loci are known to be highly polymorphic in lake whitefish (Franzin and Clayton, 1977) and have been shown by extensive breeding studies to have a genetic basis (Clayton and Franzin, 1970; Clayton et al., 1973; Franzin and Clayton, 1977; Imhof et. al., 1980). Knowledge of this genetic basis has provided a sound basis for interpreting the degree of genetic divergence found between populations within the lake whitefish species complex (Franzin and Clayton, 1977; KirkPatrick and Selander, 1979; Ihssen et al., 1981a).

The Acadian whitefish and lake whitefish were fixed for alternate alleles at two loci and the Acadian whitefish was also found to have unique alleles not predicted by genetic models for lake whitefish. Considering that electrophoresis may detect as few as 20-30% of amino acid substitutions (Lewontin, 1974) and thus underestimate genetic differences, the degree of genetic divergence between Acadian whitefish and lake whitefish is probably quite significant.

The Acadian whitefish and lake whitefish from Nova Scotia were found to be fixed for alternate alleles at the GPDH-A locus. If one assumes that allele banding patterns for these species are directly comparable (i.e. alleles of similar electrophoretic mobility are identical) then the high frequency of the A_1 allele in Acadian whitefish is of considerable zoogeographic interest. The A_1 allele in lake whitefish is only found at low frequencies west of the Great Lakes with the highest frequencies reported from the Yukon (Franzin and Clayton, 1977). In studies of lake whitefish from Ontario (Casselman et al., 1981; Ihssen et al., 1981a) and Maine (KirkPatrick and Selander, 1979) the GPDH-A locus was reported to be monomorphic. While these studies did not indicate which allele was fixed, it was probably for the A_2 allele similar to lake whitefish studied from Maine, Quebec and New Brunswick (Dr. J.W. Clayton, unpublished data) and those from Nova Scotia examined in this study. Franzin and Clayton (1977) found allele frequency differences for the A_1 locus in western Canada to be more consistent with postglacial dispersal movements of lake whitefish from Wisconsin refugia where alleles were subject to isolation and fixation rather than postglacial selection. They suggested the A_1 allele might have had a Bering refugium origin with subsequent eastward dispersal. That the Acadian whitefish appears fixed for the same A_1 allele that exists only in low frequencies in lake whitefish from west of the Great Lakes indicates the considerable genetic divergence between these two taxa. The likelihood of this genetic difference arising from recent differences in selective pressures, genetic drift or founder effects would appear to be small.

Similar to the GPDH-A locus, the Acadian whitefish appeared to be fixed for an allele at the GPDH-B locus that has not been found in lake whitefish populations from eastern Canada. The B_2 allele, fixed in Acadian whitefish, was not found in lake whitefish populations examined from Cliff Lake, Me., Lake Temiscouata, Que., and Grand Lake, N.B. (Dr.J.W.Clayton, unpublished data) nor in the lake whitefish from Nova Scotia examined here. This allele was found to be ubiquitous in lake whitefish populations from western Canada (Franzin and Clayton, 1977) and probably also occurs in lake whitefish from the Great Lakes region (Casselman et al., 1981; Ihssen et al., 1981a) and some populations in Maine (KirkPatrick and Selander, 1979). The presence of the B_2 allele in the latter eastern populations is difficult to confirm because the electrophoretic methods used in those studies were different from those used in this study. However, the lack of this B_2 allele in lake whitefish populations from the Maritimes region and its high frequency in the Acadian whitefish again suggests considerable genetic differences between these two taxa.

In summary, the morphological and biochemical evidence in this study rejects the hypothesis that there is no genetically based phenotypic distinction between Acadian whitefish and lake whitefish. The significant phenotypic differences found between the two species appear to reflect considerable genetic differences and probable reproductive isolation.

Taxonomic position of the Acadian whitefish

The taxonomic position of the Acadian whitefish has been considered uncertain (Behnke, 1972). On the basis of gill raker counts, traditionally a diagnostic character in whitefish taxonomy, the Acadian whitefish would be classified in the subgenus *Coregonus* (true whitefishes) and would appear most closely related to lake whitefish. However, there is conflicting evidence to suggest that it should be classified within the subgenus *Leucichthys* (ciscos).

The mouth of the Acadian whitefish is unlike the subterminal mouth of lake whitefish and is more characteristic of the terminal mouth of some ciscos. Behnke (1972) noted that the shape of the maxilla of Acadian whitefish suggested affinities to the ciscos. The present study found the Acadian whitefish to have a discernable notch in the adipose eyelid of 82% of the specimens examined which was found in only 11% of lake whitefish specimens. This notch was reported by McPhail and Lindsey (1970) to be present in ciscos and whitefish species in the genus *Prosopium* but absent in the true whitefishes. It is perhaps of interest to note that most populations of lake whitefish examined in this study lacked the notch and that almost half of the lake whitefish specimens with this notch were from Kerr Lake, N.B., a population having relatively high gill raker counts more similar to ciscos.

Within the cisco subgroup, the Acadian whitefish shows a number of affinities to the Arctic cisco, *Coregonus autumnalis*. While many ciscos are characterized by a superior mouth position, the Arctic ciscoe has a terminal mouth (Scott and Crossman, 1973) which at times has been described as possessing retrorse upper jaws (Walters, 1955). As well, the high number of vertebrae and lateral line scales that best distinguish the Acadian whitefish from lake whitefish are more characteristic of the Arctic cisco.

The biochemical data in the present study was also found to suggest affinities between the Acadian whitefish and the Arctic cisco. This interpretation must be made cautiously however, since electrophoresis of proteins can detect genetic differences but has limited potential for indicating genetic similarities. If identical banding patterns for these species are the result of identical alleles, the similarities between the Acadian whitefish and the Arctic cisco could be significant. The GPDH-A_1 allele, which is fixed in the Acadian whitefish, has never been reported in frequencies higher than 0.23 in lake whitefish (Franzin and Clayton, 1977; Kirkpatrick and Selander, 1979; Ihssen et al., 1981a) but was found in high frequency in the Arctic cisco (0.67).

While the Acadian whitefish has a number of morphological and biochemical similarities to the Arctic cisco, these two species have highly different gill raker counts. Gill rakers have long been recognized as a valuable character in whitefish taxonomy (Svardson, 1952; Lindsey, 1981). However, to classify the Acadian whitefish as a true whitefish solely on the basis of gill raker count could place undue weight on this one charcter and not recognize the importance of many other characters.

Traditionally, much weight has been given to gill rakers in whitefish taxonomy because of their strong genetic control which can be used to infer overall genetic similarity. While the strong genetic control of gill rakers would give this character a degree of immunity from environmental modification over a short period (i.e. a number of generations), it would not preclude changes over a long evolutionary period. Gill rakers are closely associated with feeding habits in whitefishes (Svardson, 1952; 1965; Kliewer, 1970; Bodaly, 1979) and changes in food availability could produce strong selective pressures on gill raker number resulting in significant changes over a long evolutionary period. Therefore, the use of similar gill raker counts to infer overall genetic similarity between whitefish species should be made cautiously considering distantly related species could show convergent evolution in feeding habits.

Lindsey (1981) cautioned the over reliance on gill raker number in whitefish taxonomy. *Prosopium*, a genus normally with low-rakered species has evolved a high-rakered form in Great Bear Lake, Ua., the Bonneville whitefish *P. gemmiferum* (35-45) which was first thought to be a cisco. As well, the true whitefishes, normally with low-rakered species, have evolved populations within the *C. laveratus* species complex in Europe with gill raker counts of over 60 (Svardson, 1979). It is interesting to note the comment of Lindsey (1981) that " unlike *Coregonus* and *Prosopium*, *Leucichthys* has nowhere produced a form with a very low gill raker count nor a body form highly adapted to bottom feeding ". The data presented in this thesis, while not conclusive, suggest the Acadian whitefish could be such a form.

Geographic variation in the lake whitefish species complex

The analysis of geographic variation of whitefish populations from the Maritimes Region revealed many of the problems inherent in describing the enormous amount of biological diversity within coregonid fishes. While it was possible to distinguish readily the Acadian whitefish as a valid species distinct from the biological variation found within the lake whitefish species complex, the latter species complex appears to defy conventional taxonomic analysis.

Two populations of lake whitefish in the Maritimes Region showed significant morphological differences from all the other populations. The lake whitefish from the Mira River, N.S. and Kerr Lake, N.B., had unusual gill raker and lateral line scale counts and could be completely separated from all other specimens on canonical axes in the canonical variates analysis. The lack of separation of these two populations in principal component analyses however, would suggest their distinctiveness was not sufficient to recognize them as species.

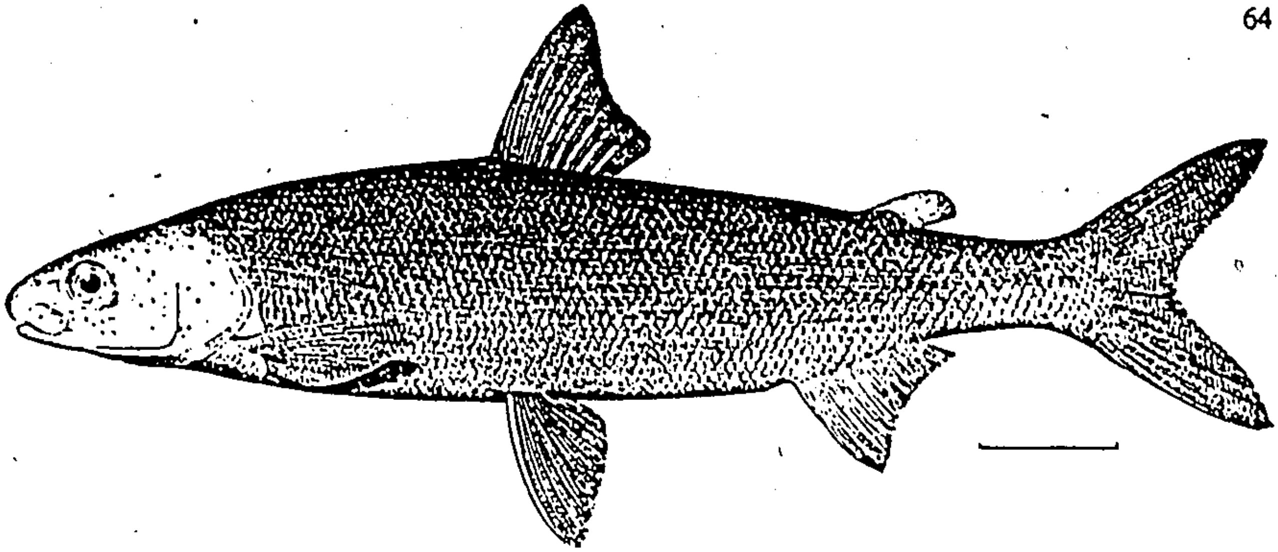
The distinctiveness of lake whitefish populations from the Mira River and Kerr Lake is probably the result of the contribution of both environmental and genetic factors. The multivariate morphological distinctiveness of these populations probably reflects genetic differences to some degree since it is unlikely that environmental factors would have resulted in the divergence of many different meristic and morphometric characters. The unusual gill raker counts of these populations also probably reflects genetic differences. Gill rakers have long been used to study the population structure of the lake whitefish species complex because of their strong genetic basis (Loch, 1974; Lindsey, 1981). Transplanting studies have shown that when lake whitefish are introduced into a new lake, many morphological characters can be significantly altered in subsequent generations while gill raker number may change very little (Loch, 1974). While gill raker number cannot be considered immune to environmental modification (Lindsey, 1981), it is unlikely that environmental factors would cause differences of this magnitude between populations in such relatively close geographic proximity.

Within the current taxonomic framework, morphologically divergent lake whitefish populations from the Mira River and Kerr Lake are probably best recognized within the general stock concept (see Ihssen et al., 1981b). While the Mira River population might be sufficiently distinct to be described as a subspecies in another species, it is probably best recognized as a genetically unique stock. To describe this population as a subspecies could lead to a proliferation of new subspecies names from across the range of the lake whitefish species complex. However, by avoiding this nomenclatural complexity, one risks losing the ability to adequately express the genetic diversity needed for fisheries management and preservation of unique genetic adaptations.

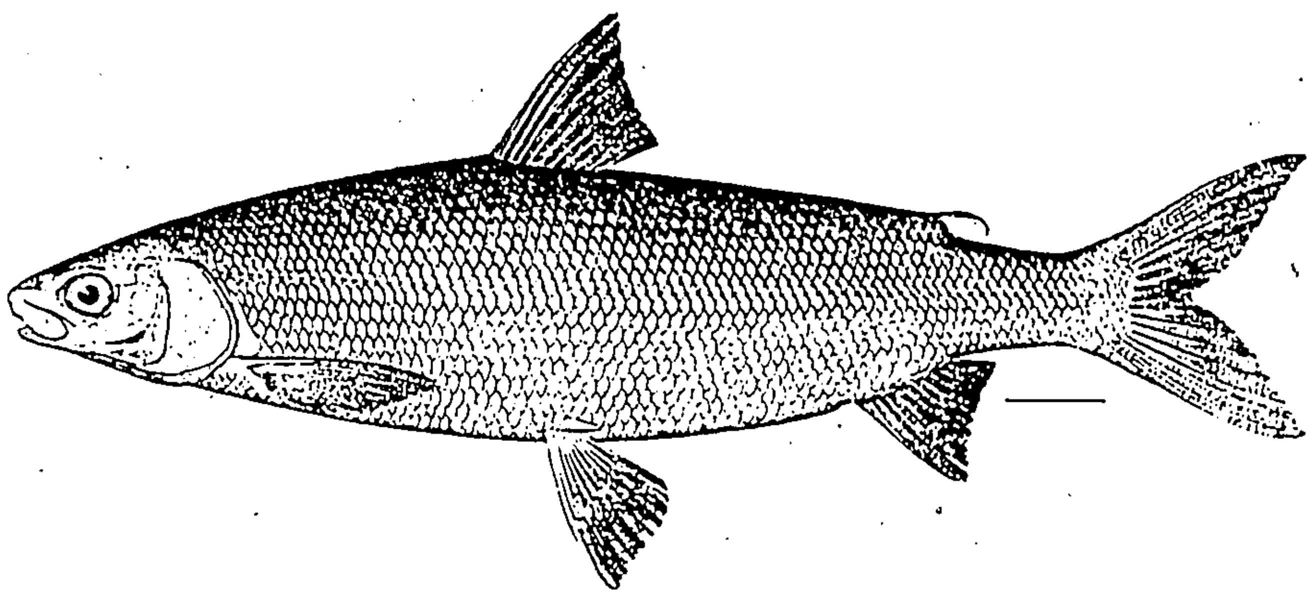
In contrast to lake whitefish from the Mira River and Kerr Lake, lake whitefish from Square Lake, Me., were not found to be morphologically distinct from other lake whitefish populations in the Maritimes Region. The specimens examined from Square Lake had been caught in 1903 by Dr. Kendall and were identified as *Coregonus stanleyi*. It had been anticipated that these specimens might have shown a morphological distinctiveness that reflected their prior taxonomic recognition.

Stanley's whitefish, *Coregonus stanleyi*, was described by Kendall (1903) from the Cross Lake Thoroughfare, just upstream from Square Lake. It was distinguished from the lake whitefish, its most similar relative, mainly on the basis of a more "sharply rounded" and less truncated snout (Figure 17). The new species was also characterized by a "shorter appearance of the head" and, on average, more and longer gill rakers than the lake whitefish. While morphological evidence for recognizing Stanley's whitefish was not strong, Kendall also reported its smaller adult size and earlier spawning period than lake whitefish in the same lake.

Figure 17: Drawings of Stanley's whitefish, *Coregonus stanleyi* (top) and the lake whitefish, *Coregonus labradoricus* (= *C. clupeaformis*) (bottom) taken from Kendall (1903).



Coregonus stanleyi Kendall, new species.



Coregonus labradoricus Richardson.

There has not been a proper taxonomic study of *C. stanleyi* since its first description. While studies by Fenderson (1964) and Kirkpatrick and Selander (1979) have provided evidence to support its genetic distinctiveness, fishery biologists in Maine do not recognize it as a distinct species but refer to it as an anomaly of scientific interest (Basely, 1981MS). Though somewhat subjective, the possession of a rounded snout could be recognized by the author in the present study and it may have some taxonomic value. Whether all other dwarf populations possess this snout is unknown.

Fenderson (1964) reported finding the unusually small, mature whitefish in 22 lakes in northern Maine although he made no reference to Kendall (1903). This dwarfed form was usually mature by the age of one or two years and seldom lived beyond four years. In most lakes it occurred sympatrically with "normal" lake whitefish which typically did not mature untill age four and lived to an age of 12 years. Under these sympatric conditions, lakes were found to have whitefish populations with bimodal gill raker distributions. The dwarf specimens in some lakes had high gill raker counts that in some cases did not overlap with the range of lower counts in the "normal" specimens. Fenderson concluded there was "at least a partial barrier to gene flow " between some sympatric dwarf and normal populations on the basis of gill raker, erythrocyte antigen and spawning season differences.

In an electrophoretic study, Kirkpatrick and Selander (1979) found differences between sympatric dwarf and normal populations in Second Musquacook Lake, Me. These populations had significantly different allele frequencies at three of four genetic loci that were polymorphic. These authors concluded that the dwarf and normal whitefishes in the Allagash Basin of Maine were independent gene pools and specifically distinct.

At present there seems little doubt that there are at least two biological species (e.g. Mayr, 1969) within the lake whitefish species complex in the Maritimes region.

Dwarf populations are known to occur in at least 28 lakes in northern Maine (M. Basely, in litt., 1986) and a dwarf population also probably occurs in Lake Temiscouata, Que. (Lindsey, 1979MS). Many dwarf populations occur sympatrically with "normal" populations and at one locality, Second Musquacook Lake, Me., the sympatric populations have been shown to have differences in growth rate, age at maturity, gill raker counts, erythrocyte antigens, allele frequencies and spawning times indicative of reproductive isolation (Fenderson, 1964; Kirkpatrick and Selander, 1979). A problem remains though, of whether all the dwarf populations are representative of a monophyletic group.

The geographic proximity of the dwarf populations in northern Maine, many from adjacent lakes in the upper Saint John River, would suggest a common origin for the dwarfed forms. However, the considerable morphological and ecological variation between dwarf populations was found by Fenderson (1964) to preclude a proper systematic assessment of the dwarf form. Fenderson reported dwarf populations alone in lakes that had lower gill raker counts than some normal populations. There was also evidence of three reproductively isolated populations of whitefish occurring in Spider Lake, Me., two dwarf populations and one normal. At present there is not sufficient information to determine if the dwarf populations from the Maritimes region represent a monophyletic species.

Chapter II
DISTRIBUTION

2.1 Introduction

The distribution of the Acadian whitefish *Coregonus canadensis* has been uncertain, in large part due to its confusion with the the lake whitefish, *Coregonus clupeaformis*. The Acadian whitefish was first reported from Milipsigate Lake, Lunenberg Co., as a variable form of the lake whitefish (Piers, 1927). It was not recognized as a new species until Scott (1967) described the Acadian whitefish from Milipsigate Lake and the Tusket River, Yarmouth Co. There has also been a lack of adequate surveys to determine if other populations existed. Available information on the distribution of the Acadian whitefish has been summarized recently by Edge (1984) and McAllister et al. (1985).

The distribution of lake whitefish in Nova Scotia has also been uncertain. Lake whitefish are widespread across boreal North America and have long been known from New Brunswick and Maine (Perley, 1852; Basley, 1981MS). They were first reported from Nova Scotia by Semple (1973) although whether present lake whitefish populations in Nova Scotia are native populations or the result of previous stocking attempts is not known. Lake whitefish from the Great Lakes were introduced into many lakes in Nova Scotia from 1878 to 1901 by a stocking program carried out by the Federal Department of Marine and Fisheries.

Since the description of the Acadian whitefish, there has been little effort to determine whether other populations of the species exist, or even if the known populations of the species were surviving. A preliminary field survey was conducted from September to November, 1982 and found Acadian whitefish surviving in Minamkeak, Milipsigate and Hebb Lakes within the Petite Rivière watershed, Lunenburg Co., and in the Annis River, a tributary of the Tusket River, Yarmouth Co., (Edge, 1984). The results of subsequent field surveys along with literature and museum collection records of Acadian and lake whitefish from the Maritimes region are reported here.

2.2 Materials and methods

Field surveys were conducted in Nova Scotia during September to November, 1982; May to September, 1983 and February, 1985. These surveys involved conducting lake surveys and collecting fish from streams, rivers, estuaries and in a few cases from the nearshore marine environment. Representative fish collections from each locality were preserved and deposited in the National Museum of Natural Sciences, Ottawa, Ontario (NMC 82-617 to 807, NMC 83-175 to 195, NMC 83-1401 to 1480).

Lakes were chosen to be surveyed on the basis of large size, proximity to known localities of Acadian whitefish, ease of access, verbal reports from residents and lack of previous survey information. In many cases, lakes were surveyed by setting two bottom, one midwater and one surface gillnet overnight and seining the shoreline. The gillnets were 75m long with 15m panels of 25mm, 37.5mm, 50mm, 62.5mm and 75mm stretched mesh. The seines used included nets of 5m, 10m, and 15m length with stretched mesh sizes of 1mm, 2mm and 3mm respectively. Additional equipment used, but to a lesser extent, included two small hoopnets, a small trapnet, minnow traps and angling gear. The hoopnets were about 1m in diameter with 5m wings and a stretched mesh size of about 5mm. The trapnet was about 1m x 1m x 1.5m with 10m wings and a stretched mesh size of about 5mm.

Museum collections and literature records of whitefish from the Maritimes region were studied in an attempt to discern misidentified records of Acadian whitefish. Literature records of whitefish in the Maritimes region were also used to discern distribution localities and to provide historical dates for deciding whether lake whitefish populations pre-dated known introduction attempts. The introduction localities were obtained from the annual reports of the Department of Marine and Fisheries and information on whitefish localities was reviewed from the following sources: Perley (1852), Adams (1873), Lanman (1874), Cox (1893), Cox (1896a), Cox (1896b), Evermann and Smith (1896), Cox (1899), Kendall (1903), Evermann and Goldsborough (1907a), Kendall (1914), Huntsman (1922), Piers (1927), Koelz (1931), McKenzie (1943), Smith (1952), Livingstone (1953), Huntsman (1953MS), Scott and Crossman (1959), Leim and Day (1959), Bigelow (1963), Fenderson (1964), Leim and Scott (1966), Scott (1967), Meth (1972MS), Semple (1973), Kerekes et al. (1975MS), Scott and Crossman (1973), Gilhen (1974), Kirkpatrick and Selander (1979), Basley (1981MS), Edge (1984) and Alexander et al. (1985MS).

2.3 Results and Discussion

A summary of all field survey localities in Nova Scotia is shown in Figure 18. These surveys confirmed the existence of Acadian whitefish in Milipsigate Lake and produced the first records of Acadian whitefish from Minamkeak and Hebb Lakes in the Petite Rivière watershed. The surveys also caught two specimens of Acadian whitefish in the Annis River, Yarmouth Co. A survey of local residents and fishermen around the Tusket River by Gilhen (1977MS) suggested a run of Acadian whitefish would be found in the Annis River. The field surveys also produced the first records of lake whitefish from Lake George, Yarmouth Co., Caribou Lake, Lunenburg Co. and the Mira River, Cape Breton Co. The presence of lake whitefish in Little Mushamush Lake, Lunenburg Co. was also confirmed. Alexander et al., (1985MS) had first discovered lake whitefish in this lake in 1977.

The distribution of Acadian and lake whitefish in the Maritimes region as determined by recent field surveys, museum collections and literature records is summarized in Figure 19. The localities marking lake whitefish introductions were obtained from the annual reports of the Department of Marine and Fisheries and additional information on these introductions is presented in Table 8.

The distribution of Acadian whitefish appears to be very restricted and curiously disjunct. The species is confined to the Petite Rivière watershed and the Tusket River watershed although specimens have been caught in seawater from Halls Harbour, Annapolis Co. and Yarmouth Harbour, Yarmouth Co. Leim and Scott (1966) had suggested that Acadian whitefish might occur in other watersheds in Nova Scotia although the recent field surveys do not indicate this. While Acadian whitefish were found to be more widespread within the Petite Rivière and Tusket River watersheds than previously believed, there is no evidence yet to indicate the species occurs outside these two watersheds.

The Tusket River population of Acadian whitefish is known to be anadromous (Scott and Crossman, 1973; Edge, 1984). Specimens have been caught in the Tusket estuary at Wedgeport and in the Annis estuary just above its confluence with the Tusk-

Figure 18: Field survey localities in Nova Scotia showing fish collections made by seines (●) and overnight gillnets and trapnets (▲). Some symbols cover more than one collection locality.

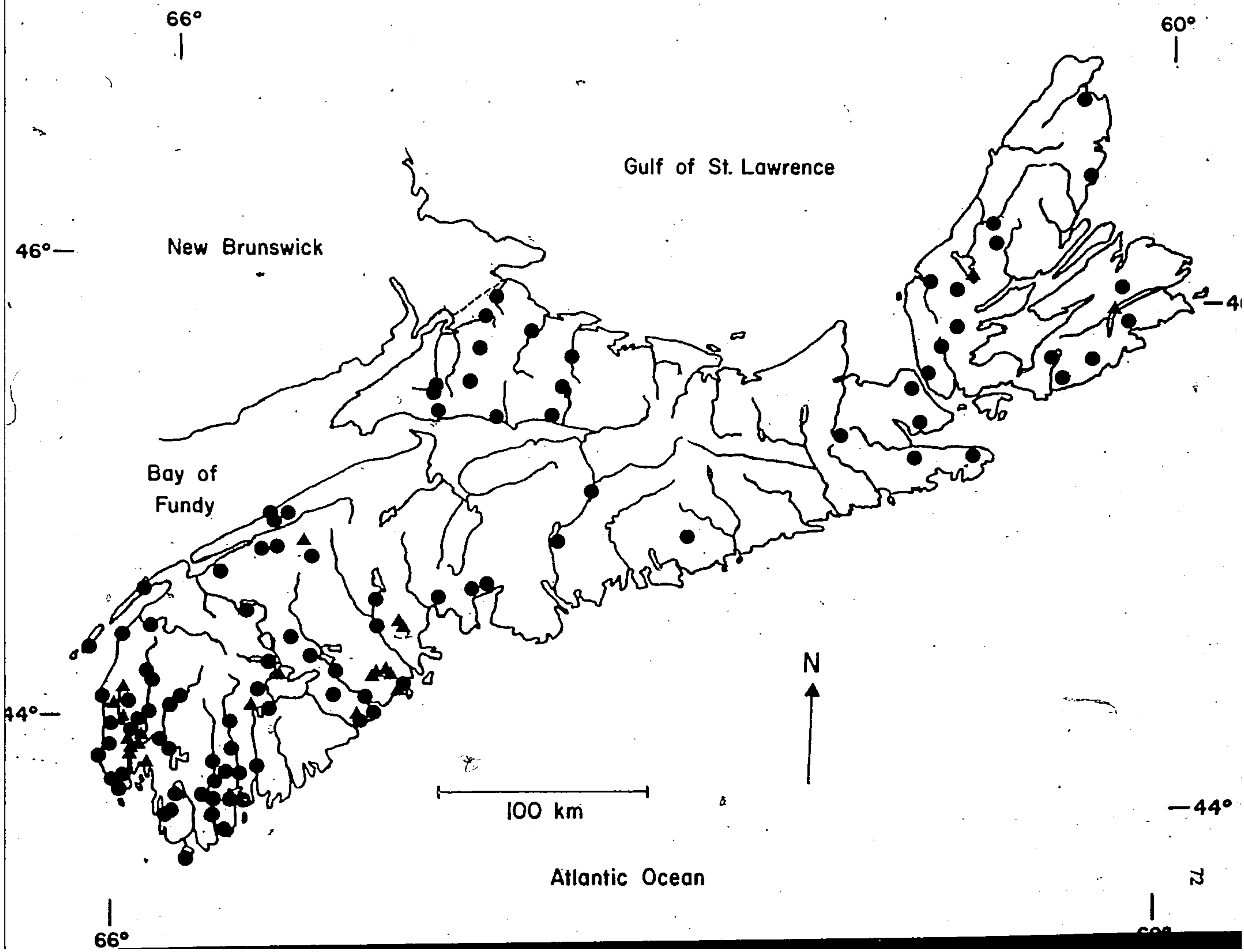

66°
60°
Gulf of St. Lawrence
46°
New Brunswick
Bay of
Fundy
N
44°
100 km
Atlantic Ocean
66°

Figure 19: Distribution of Acadian whitefish (▲), lake whitefish (●) and lake whitefish introduction records (1878-1901) (○) in the Maritimes region. Distribution spots may cover more than one locality record.

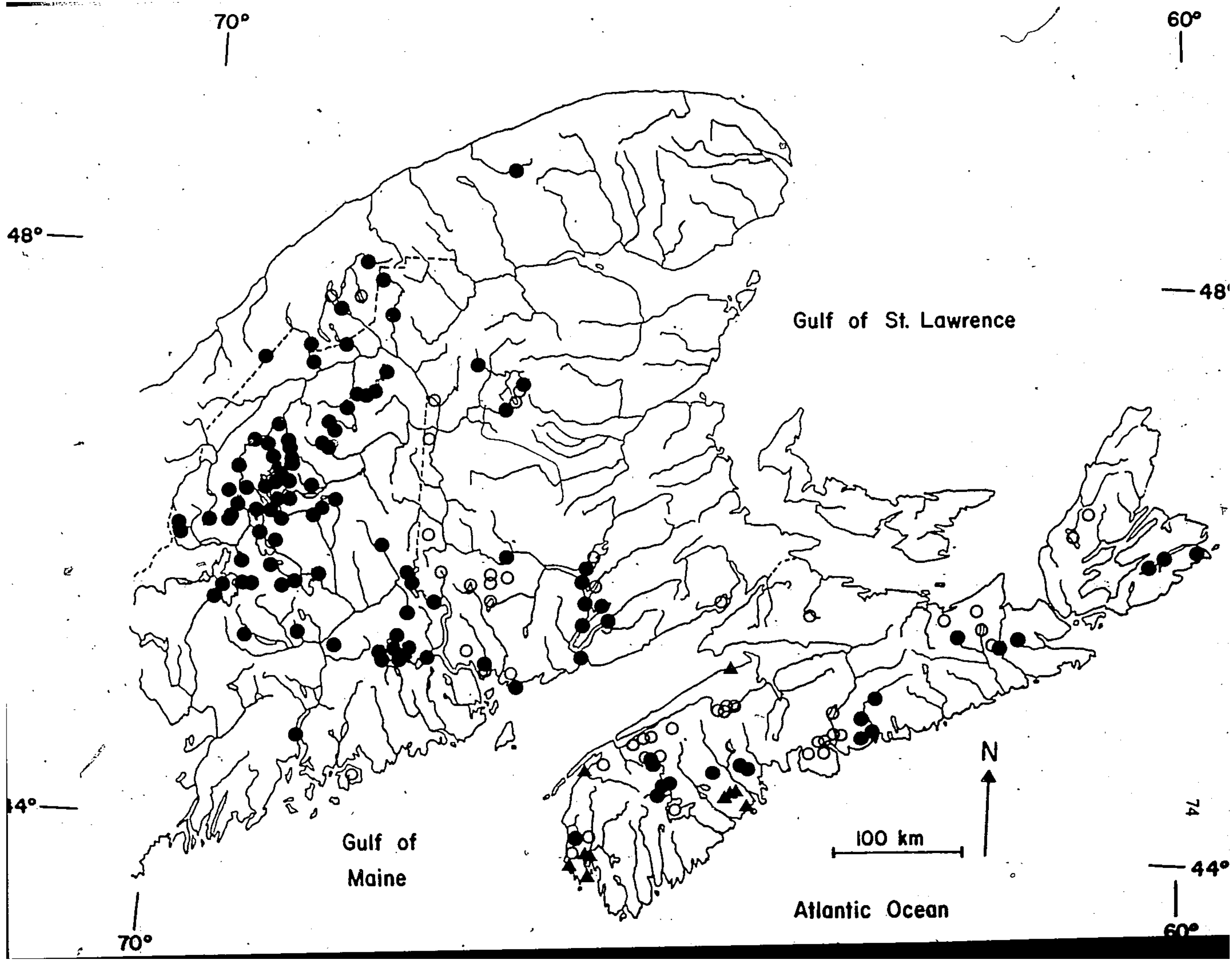

70°
60°
48°
48°
Gulf of St. Lawrence
44°
44°
N
100 km
Gulf of
Maine
Atlantic Ocean
70°
60°

TABLE 8. Introduction records of lake whitefish in Nova Scotia and New Brunswick (1878-1901)

LOCALITY	NO. OF INTRODUCTION	TOTAL NO. FISH	INTRODUCTION YEARS
NOVA SCOTIA			
Beeler's L., Annapolis Co.	2	600,000	1892-3
George L. "	1	250,000	1891
LaRose L. "	1	500,000	1896
Milford L. "	1	200,000	1889
Paradise L. "	10	5,600,000	1891-94,1896-1901
Roundhill L. "	4	1,400,000	1890,93,96,98
Goshen L., Guysborough Co.	2	700,000	1899-1900
Lochaber L., Antigonish Co.	3	1,500,000	1889,94,1901
St.Joseph's L., "	2	1,800,000	1894-95
Folly L., Cumberland Co.	1	20,000	1878
Hains & Porter L., Digby Co.	1	800,000	1895
Governor's L., Halifax Co.	2	350,000	1887,89
Grand L. "	8	4,170,000	1878,87-93
Hubley's L. "	5	1,200,000	1887,89,91-93
Lily L. "	1	10,000	1878
Neal's L. "	1	150,000	1887
Sandy L. "	12	4,810,000	1878,86-91,94-97, 1900
L. Thomas "	1	300,000	1893
Williams L. "	10	4,950,000	1887-93,97-98,1901
Ainsley L., Inverness Co.	3	2,200,000	1895-96,98
Lake au Law "	5	4,300,000	1896,98-1901
Aylesford L., Kings Co.	1	250,000	1890
Gaspereau L., "	2	500,000	1889,92
L. George "	1	300,000	1893
Loon L. "	1	300,000	1893
McPherson's L., Pictou Co.	3	1,050,000	1899-1901
L. Rossignol, Queen's Co.	1	500,000	1889
Brazil L., Yarmouth Co.	4	2,500,000	1898-1901
Milton L. "	1	500,000	1895
NEW BRUNSWICK			
Lakesville L., Carleton Co.	7	2,242,000	1886,88-90,93-94,96
Sumerville L. "	1	325,000	1886
Jones L. "	4	880,000	1891-94
Long L., Victoria Co.	7	2,540,000	1889,93-97,1901
Portage L. "	4	821,000	1887,89,91-92

TABLE 8. (cont'd)

LOCALITY	NO. OF INTRODUCTION	TOTAL NO. FISH	INTRODUCTION YEARS
NEW BRUNSWICK			
Meadow L., Victoria Co.	1	300,000	1887
Tomlinson L. "	1	156,000	1888
Rapid des Femmes Pond "	1	156,000	1888
Bolieu's Pond "	3	720,000	1899-1901
Skiff L., York Co.	2	650,000	1887,89
Magaguadavic L., York Co.	5	2,624,000	1887-91
Harvey L. "	14	5,717,000	1888-1901
Oromocto L. "	14	4,452,000	1888-1901
L. George L. "	10	3,420,000	1892-1901
L. Yo Ho "	10	2,940,000	1892-1901
Baldhead L. "	5	1,520,000	1897-1901
Forest L. "	1	560,000	1900
Chamcook L., Charlotte Co.	1	400,000	1887
Foster L. "	8	2,650,000	1889,91-93,97-99, 1901
L. Utopia "	1	220,000	1892
Mohanneous R. "	1	320,000	1900
Bryam Pond, Madawaska Co.	3	480,000	1893-94,96
German Town L., Albert Co.	1	320,000	1896
Washademoac L., Queen's Co.	1	320,000	1899
Grand L. "	1	320,000	1899
QUEBEC			
L. Temiscouata, Temis. Co., Que.	1	320,000	1894
Squatook L., Temis. Co., Que.	1	360,000	1891

et River. There are no reports known of Acadian whitefish being caught in the Tusket River watershed much above the influence of tidal waters. Despite large migrations up the fish ladder at the Tusket River dam in the past, there are no records known to the author from above the Lake Vaughn reservoir. It is probable that the species does not migrate into freshwater to any great extent although further surveys would be needed to substantiate this.

While the collections from Halls Harbour and Yarmouth Harbour could indicate other as yet undetected anadromous populations of Acadian whitefish exist, available information would suggest that they are from the Tusket River. The summer capture dates of these marine collections are consistent with the known seasonal migration patterns of the Acadian whitefish in the Tusket River and despite extensive commercial fisheries for other anadromous species in the Maritimes region, there have been no further reports of Acadian whitefish from other rivers.

A further locality for the Acadian whitefish has been included in Figure 19 on the basis of a report by Huntsman (1922). He reports of two " doubtfully identified " whitefish being seined from the mouth of the Sissiboo River, Digby Co., N.S., by Dr. P. Cox on September 19, 1919. Dr. Cox identified the specimens as *Coregonus quadrilateralis* (= *Prosopium cylindraceum*), however the specimens were subsequently lost and a correct identification is no longer possible. Based on the capture of the specimens in full seawater (Bigelow, 1963), the superficial resemblance of Acadian whitefish and round whitefish and the lack of any records of round whitefish closer than northern New Brunswick and Maine, these specimens were probably Acadian whitefish. Their capture near the mouth of the Sissiboo River in September could suggest there was an andromous run of Acadian whitefish in this river at one time or the fish could have strayed from the Tusket River.

The Acadian whitefish populations in the Petite Rivière watershed are landlocked and it is not known whether they were anadromous at one time or not. The area around the Petite Rivière was first settled in the 1600's and the subsequent building of mill dams along the river was extensive (Dunfield, 1985). While these mill dams would have obstructed the river to varying degrees, the building of a dam at the foot of Hebb Lake in 1901 effectively blocked any upstream migration of fish. There does not seem to be any record of fish ladders or other provisions to allow fish passage at this point since the construction of the dam.

The Acadian whitefish populations occur upstream of this dam in Hebb, Milipsigate and Minamkeak Lakes. Until recently there had been no verified specimens of Acadian whitefish caught below the dam despite mention by anglers of occasional catches in the Petite Rivière near Conquerall and in Fancy Lake (E. Mandaggio, personal communication). However, a commercial fisherman on the river, Douglas Bell, preserved an Acadian whitefish that he caught from the estuary of the Petite Rivière in May, 1986. At present there is not enough information to decide whether this specimen is from an original anadromous run pre-dating river obstructions or whether the specimen strayed from the lake populations upstream. Douglas Bell has been catching specimens for a number of years at the mouth of the Petite Rivière which might suggest a native migrating population rather than continuous straying from upstream lakes.

While landlocked Acadian whitefish appear to have been confined to the Petite Rivière watershed, they may have occurred previously in the Medway River watershed. Minamkeak Lake, the uppermost lake containing Acadian whitefish on the Petite Rivière watershed previously flowed into the Medway River. Around 1905, dynamite was used to create an outflow from Minamkeak Lake into Milipsigate Lake and the original outflow of Minamkeak Lake into the Medway River was blocked. It is not known whether the present population of Acadian whitefish in Minamkeak Lake is the result of upstream dispersal from Milipsigate Lake or whether this population occurred in Minamkeak Lake before the outflow alterations. Evidence from Piers (1927) of whitefish captures in the stream connecting Minamkeak Lake and Milipsigate Lake and of the species preference for swift flowing water, might suggest upstream dispersal of whitefish from Milipsigate Lake.

In contrast to the Acadian whitefish, the distribution of lake whitefish in Nova Scotia appears less restricted than previously believed. Accounts by Scott (1967) and Scott and Crossman (1973) do not report lake whitefish from Nova Scotia and the records of Piers (1927), Dymond (1947) Smith (1952) and Livingstone (1953) were actually Acadian whitefish. Subsequently Semple (1973), Kerekes (1975MS) and Alexander et al. (1985MS) have documented the lake whitefish in a number of lakes in the Province. The surveys conducted during the present study found lake whitefish in a number of new localities where local residents and anglers were often not aware of their existence.

While lake whitefish have been recorded throughout the Maritimes region, whether populations are native is not known. The artificial propagation of lake whitefish in North America was believed to have been started by Samuel Wilmot in 1867 at Newcastle, Ont. (Prince, 1900). Subsequent Federal hatcheries were established in the Maritime region at Bedford, N.S. in 1876, and at Grand Falls on the Saint John River, N.B. in 1880. These hatcheries were mainly built to supplement declining Atlantic salmon runs but they also distributed lake whitefish received from hatcheries in Ontario. Whitefish were received at the Bedford hatchery and distributed throughout Nova Scotia from 1878 to 1901 and they were received at the Saint John hatchery and distributed throughout New Brunswick and parts of the Gaspe region of Quebec from 1886 to 1901. While there were other hatcheries in eastern Canada during this time period, they were involved with the introduction of Atlantic salmon and trout and there are no

Federal introductions of lake whitefish in the Maritimes region known other than from the Bedford and Saint John hatchery records. Lake whitefish were also introduced into lakes in Maine by hatcheries in that state although only a few localities known to the author are shown in Figure 19.

Despite present lake whitefish populations being found in localities throughout the Maritimes region where there are no records of these Federal introductions, it is still difficult to ascertain whether they are native. It is possible that there were other unrecorded introductions or that introduced whitefish could have dispersed and established themselves elsewhere. The lake whitefish populations around Kejimikujik National Park, N.S. are believed to be the result of unrecorded introductions by a fishing club (Kerekes, 1975MS) and while there are no records of whitefish being introduced into Lake George, Yarmouth Co. or Long Lake, Richmond Co. in Nova Scotia, there are fish hatcheries on these lakes.

Early natural history accounts are probably the best method for determining whether lake whitefish populations are native. Lake whitefish were not actively distributed by Federal hatcheries in Nova Scotia and New Brunswick until about 1887. Lake whitefish populations recorded before this time period are therefore probably native populations.

The earliest report of lake whitefish from the Maritime region known to the author is the account of Perley (1852). He mentions of lake whitefish from Maine in the Fish River Lakes and from New Brunswick in the Madawaska River, the Saint Francis River Lakes, Grand Lake (St. Croix system), the lower Saint John River, Saint John harbour, Darling's Lake and from Lake Temiscouata, Que. Other early records of lake whitefish are from Moosehead, Pocompus and other lakes in the central, northern and northeastern portions of Maine (Atkins, 1867-1868, in Kendall, 1903) and from the Tobique Lakes, N.B. (Adams, 1873). These populations were undoubtedly native although there were subsequent introductions of lake whitefish into Lake Temiscouata, Que. (Table 8).

While there are no such historical records for whitefish in Nova Scotia the presence of a native population of lake trout, *Salvelinus namaycush* in Sherbrook Lake, Lunenberg Co. would suggest that dispersal means were present for whitefish to enter Nova-Scotia following the Wisconsin ice retreat. Lake trout have been known in Sherbrook Lake from angler accounts since at least 1864 (DesBrisay, 1980) before the existence of any fish hatcheries. Edge et al. (MS in preparation) provides evidence to suggest that lake whitefish from the Mira River and Grand Lake on Cape Breton Island are native populations. It is also of interest to note that there is no evidence that any of the recorded whitefish introductions into Nova Scotia survived and Piers (1927) suggested these attempts utterly failed to be successful.

It is apparent from recent field surveys that populations of Acadian whitefish and lake whitefish in Nova Scotia have often gone undetected for long periods of time. Smith (1952) also found this to be the case in the discovery of lake whitefish in Kerr Lake, N.B. It is possible that deepwater preferences, small population sizes and relatively poor angling potential have enabled freshwater populations to escape detection. It seems remarkable, however, that a large anadromous run of Acadian whitefish in the Tusket River could have gone largely unrecognized until the discovery of the species in the 1960's. There is no historical mention of this run from reports on the Tusket River fisheries in the annual reports of the Department of Marine and Fisheries. This is a reflection of the poor support given to systematic work in Canada.

A continued field survey program is needed to identify any further populations of Acadian whitefish. There are still a number of suitable, unsurveyed lakes in Nova Scotia that could contain Acadian whitefish. This need is particularily apparent considering populations could be lost, before they are even discovered, through acidification and other environmental threats.

Chapter III
ECOLOGY

3.1 Introduction

An understanding of the ecological requirements of a species is essential to its proper management and preservation. While substantial information has been collected on the ecology of many species of whitefish, very little was known about the ecology of the Acadian whitefish. Even basic information such as spawning requirements is still not known for the species.

Until recently, speculation on the ecological requirements of the Acadian whitefish was based on extrapolations from other whitefishes. Whitefish species are generally considered as cold water species requiring habitats with suitably cool water for the incubation of eggs and survival of subsequent life history stages. They occur typically in oligotrophic lakes, although a few species are found more often in rivers. A number of species have been caught as adults in brackish waters but they are rarely found away from river mouths being intolerant of full seawater (Scott and Crossman, 1973).

The Acadian whitefish is known to be anadromous in the Tusket River and the species has adapted to a completely freshwater habitat in lakes within the Petite Rivière watershed (Scott and Crossman, 1973; Edge, 1984). However there is very little information on the ecology of the Acadian whitefish in these two different habitats. Information on the habitat preferences and feeding habits of adults is scanty and there is virtually nothing known of the species spawning time, spawning grounds or early life history stages.

The Acadian whitefish has managed to survive many alterations to its natural habitat although the species is much less abundant now than it was in the past (Scott and Crossman, 1973; Gilhen, 1977MS; Edge, 1984). The decline of the Acadian whitefish probably occurred along with the decline of other anadromous species like the Atlantic salmon as a result of the construction of dams, over-fishing and acidification. The following chapter reviews the historical background of habitat alterations and over-fishing that have contributed to the decline of the Acadian whitefish. The problem of acidification is also briefly reviewed and data obtained from recent field studies of the ecology of the Acadian whitefish is presented.

3.1.1 Historical background

With the arrival of settlers from Europe, many dams were built along rivers and streams in Nova Scotia to power grist mills and saw mills. Anadromous fish were plentiful and little thought was given to controlling fishing or to constructing fish ladders and other means of preserving adequate habitat for fish. By the mid 1840's, the salmon fishery throughout eastern North America was declining as a result of the ever increasing number of mill dams and the unrestricted netting by fishermen (Dunfield, 1985). According to Davis (1974), " it has been calculated that at least 50% of the aboriginal salmon habitat in eastern North America was totally eliminated as productive ground by 1850, with an additional 25% being appreciably reduced in production capacity by being partially obstructed by dams or damaged by the pollutants of agricultural and industrial society."

While there is no mention of a fishery for Acadian whitefish in historical accounts known to the author, the species has been sought for a limited local consumption in the Tusket River and Petite Rivière watershed lakes for many years (Piers, 1927; E.Mandaggio, L.Earl and J.Hatfield, pers. comm.; J. March, *in litt*, 1985, see Appendix 3). Acadian whitefish were also caught incidently in large numbers in the gaspereau fishery on the Tusket River in the past (Gilhen, 1977MS; L.Earl and J.Hatfield, personal communication). The increased fishing pressure in the 1800's that contributed to the decline of commercially important anadromous species would probably have had some impact on the abundance of Acadian whitefish as well.

While fishing pressure undoubtedly contributed to the decline of the Acadian whitefish in the Tusket River watershed, the construction of a hydro-electric dam on the Tusket River at Tusket Falls in 1929 appears to have had a tremendous impact on the abundance of the species in this river. This structure is at the limit of the influence of high tide and before the construction of the dam was an area of fast flowing rapids just below a small lake which supported good fishing (Erskine, 1971). The dam considerably altered the habitat upstream by creating the Lake Vaughn reservoir. What was once a series of small lakes connected by fast flowing water was turned into larger reservoirs with only a few short sections of fast flowing water.

At present there are dams which obstruct the Tusket River at the foot of Lake Vaughn and Raynards Lake but there are no dams on the Annis River until much further up in the watershed. The Tusket River dam is actually composed of two dams, the powerhouse dam which generates electricity and about 1 km to the east, a holding dam which helps to contain and control the water levels in Lake Vaughn. When the powerhouse dam was originally built, there was no means to deter fish from migrating through the sluices of the dam and as a result many Acadian whitefish were probably killed by the turbine blades (Gilhen, 1977MS). Screens were installed to prevent fish migration through the sluices in 1940 although they were subsequently removed when they became repeatedly clogged.

A series of fish ladders were built to permit fish passage around the Tusket River dams, but they were usually rather ineffective (Gilhen, 1977MS). They were often built in places that were difficult for fish to find and while their designs may have been effective for some anadromous species, their effectiveness for Acadian whitefish was not a concern. The present fish ladder at the powerhouse dam was constructed in 1979 and is used by salmon and gaspereau although it is unknown whether it is used by Acadian whitefish.

Another problem associated with fish ladders at the Tusket River dam has been the lack of sufficient attraction water to enable fish to detect the entrance of the ladders. The fall upstream migration of Acadian whitefish does not coincide with anadromous migrations of other commercially important species in the river and thus water flows in the fish ladders have often been too low for Acadian whitefish. In the fall of 1982 during the migration period of the Acadian whitefish, there was little attraction water coming down the powerhouse dam fish ladder which may have resulted in fish not being able to find the ladder. The only other fish ladder on the Tusket River at this time was at the holding dam and the water flow was so low that no fish passage was possible.

In addition to the direct obstruction of the Acadian whitefish migration, the construction of the Tusket River dam caused other problems as well. On several occasions to the author's knowledge, the Lake Vaughn reservoir has been drained to allow work on the dam. This happened in 1981, and the impact of these low water levels on the Acadian whitefish is not known. The construction of the Tusket River dam also allowed people easy access to catch migrating fish in fish ladders. One resident remembers seeing men pitchforking Acadian whitefish from a fish ladder into a truck to be used as fertilizer in nearby fields (W.B.Scott, personal communication).

Unlike the Tusket River where the river was obstructed fairly recently, the Petite Rivière has a long history of obstructions and habitat alterations that could have affected the Acadian whitefish. Saw mills on the Petite Rivière date from the early 1700's and at least 24 mills existed on this small river according to a map of the area dating from 1864. As far back as 1868, Frederick Vieth spoke of the Petite Rivière as "... stopped at all points by milldams ... in days gone by, vast quantities of gaspereau frequented this stream and salmon to a considerable extent" (in Lunenburg County District Planning Commission, 1980). Along with dam obstructions the harbour of the Petite Rivière was so severely netted by fishermen in the 1850's and 1860's that one observer noted: "it would be quite impossible for the smallest of living things in the water to pass the obstructions" (in Dunfield, 1985).

As early as 1901, the Petite Rivière was completely obstructed at the foot of Hebb Lake by the construction of a hydro-electric dam. There has never been a means for upstream passage for fish at this dam since its construction and one of the earliest sawmills in the watershed was formerly located at the site. If the Acadian whitefish was once anadromous in the upper Petite Rivière basin, the populations now confined to lakes must have been landlocked by 1901. However, Edgar March, a local resident and angler who first forwarded Acadian whitefish to Harry Piers of the Nova Scotia Provincial Museum for identification in the 1920's, remembered catching Acadian whitefish in Milipsigate Lake as a boy in the 1870's (John March (son of E.March) in litt., 1985, see Appendix 3). This was before the construction of the hydro-electric dam and considerably upstream from this site which suggests that Acadian whitefish may have been landlocked much earlier by mill dams, or perhaps a natural barrier, or were simply non-migratory before the coming of Europeans. At present, there are dams obstructing the Petite Rivière at the foot of Minamkeak, Milipsigate and Hebb Lakes. Sawmill dams have been removed and a dam built in 1939 at Conqueral Mills below Fancy Lake was breached in 1977..

The habitat of the Acadian whitefish in the Petite Rivière lakes is protected to some degree by Provincial legislation. The town of Bridgewater (population 6,010 in 1976) has received its water supply from Hebb Lake since the turn of the century and the maintenance of water quality in the watershed has been a concern. The area surrounding Hebb Lake and Milipsigate Lake was designated a Protected Water Area under provisions of the Water Act in 1964. The area around Minamkeak Lake was similarily designated in 1975. The Minamkeak Lake and Milipsigate-Hebb Lakes protected water areas cover approximately one half of the total watershed and protect against lakeshore development, recreational activities and the dispersal of sewage, biocides or garbage near the lakes. Unfortunately this legislation is not effective protection from environmental threats such as acid precipitation.

3.1.2 Acidification

Acid precipitation is a result of the emission of large quantities of the oxide gases of sulphur and nitrogen from the burning of fossil fuels and the smelting of certain ores. Once in the atmosphere, chemical reactions take place to transform the oxides into dilute solutions of strong acids which then return to the earth in the form of acid rain or snow. Parts of the northeastern United States and Ontario have been the primary sources of acid precipitation in North America to date. However, because the prevailing winds over Nova Scotia are generally from a western direction on an annual basis, the province is frequently affected by weather systems approaching from the Great Lakes basin and Atlantic coastal states (Gates, 1981MS). These weather systems appear to be responsible for much of the acid precipitation now affecting Nova Scotia. Underwood (1981MS) has shown that the acidity of precipitation is most pronounced in the southwestern part of the province which has little industry and that the acidity of precipitation is less in eastern Nova Scotia. At present the annual mean pH of precipitation in Nova Scotia is in the range of 4.4 to 4.6 (Watt et al., 1983; Kerekes et al., 1982).

The degree to which lakes and rivers are susceptible to acidification has been found to be largely dependent on the surrounding geological landscape and biological processes in the water bodies (Schindler et al., 1986). In general the susceptibility of a water body to acidification is proportional to its alkalinity. The presence of limestone deposits or other sources of alkalinity in a watershed will thus influence water pH.

Nova Scotia has been an area identified as very sensitive to acidification (Kelso et al., 1986). The landscape is a glacially scoured terrain with only local areas of good soil development and limestone deposits. Studies of the geographic variation of pH among rivers in Nova Scotia have reflected the importance of these buffering deposits in determining river pH. Watt et al. (1983) studied twenty-three rivers in Nova Scotia and found that river pH was closely corelated with geology. In 1980/81 the range of mean annual pH for fourteen rivers in granite/greywacke bedrock areas was 4.67-5.29. The pH range for eight rivers on slate bedrock was 5.25-6.09 and one river in a limestone area had a pH that ranged from 6.18-7.18.

The lakes and rivers in southwestern Nova Scotia have been found to be particularily sensitive to acidification (Farmer et al., 1980; Kerekes et al., 1982; Watt et al., 1983). Most lakes and rivers occur on granite/greywacke bedrock where they often have very low levels of dissolved solids and lack the capacity to buffer substantial acid inputs. Sphagnum bogs are widespread and these bogs release organic acids imparting a tea colour and naturally low pH to the water. A number of rivers now have a mean annual pH of below 4.7 and there is considerable evidence documenting the detrimental impact of this degree of acidification on a wide variety of aquatic organisms (see reviews by Haines, 1981; Kelso et al., 1986).

Perhaps the most dramatic impact of acidification to date has been the decline and loss of many fish populations. The effects of acidification on fish can include direct mortality, reproductive failure, altered growth rates, gill and skeletal deformities and increased uptake of heavy metals (Haines, 1981). The impact of acidification on the Acadian whitefish is difficult to ascertain as the species tolerance to acidity is not known. However, from the fact that a number of native Atlantic salmon populations in southwestern Nova Scotia are now presumed extinct, including the Tusket River population (Watt et al., 1983), it is apparent that information on the ecological requirements of the Acadian whitefish is needed quickly. This chapter provides information on the characteristics of the habitat of the Acadian whitefish and some aspects of its behavior in an attempt to study the ecological requirements of the species. A comparison of the ecology of the Acadian whitefish and lake whitefish from the Maritimes region is also made.

3.2 Materials and Methods

A study of the physical, chemical and biological characteristics of the habitat of the Acadian whitefish was conducted in the Petite Rivière watershed. This watershed was chosen over the Tusket River watershed because of its smaller, more manageable size and easier access. In addition, the Acadian whitefish populations in the Petite Rivière lakes were more abundant and more easily studied than the small anadromous population in the Annis River.

Information on the physical characteristics of the Petite Rivière watershed was obtained from Lunenburg County District Planning Commission (1980), Roland (1982), and personal observations. Fourteen, twenty and forty depth sounding transects were run to determine bathymetric maps for Minamkeak, Milipsigate and Hebb Lakes respectively.

The recent threat of acidification in Nova Scotia has resulted in an extensive water sampling program being conducted throughout the province by the Department of Fisheries and Oceans. In order to allow measurements of acidification of the habitat of the Acadian whitefish to be compared with other areas in Nova Scotia, water chemistry samples were analyzed by the laboratory of Dr. W. Watt of the Department of Fisheries and Oceans in Halifax, N.S. Water samples were obtained from nine stations in the Petite Rivière watershed on a regular basis from May, 1983 to April,1984 and on an occasional basis from the Tusket River watershed. The water samples were collected in polyethylene 500 ml bottles, usually in the late afternoon, and immediately returned to a fridge in the lab in Halifax for analysis within 24 hours of collection.

The water chemistry parameters analyzed included pH, alkalinity, conductivity, colour and on a few occasions acidity and hardness. The chemical analyses were performed using techniques described in Environment Canada (1981): total hardness as $CaCO_3$ by EDTA titration to Eriochrome Black T colour change; total alkalinity as $CaCO_3$ by potentiometric titration with H_2SO_4 to pH endpoints of 4.5 and 4.2; and acidity similarily to a pH end point of of 8.3. A Metrohm Herisau pH meter was used to determine pH and specific conductance was determined at 25°C by a Metrohm Herisau conductivity meter. Apparent colour was measured with a Helige Aqua Tester. Additional field measurements of temperature and dissolved oxygen were measured with YSI meters.

The distribution and abundance of fish in the Petite Rivière and Tusket River watersheds was studied using a number of fishing methods. These included seines, gillnets, hoopnets, minnow traps, angling gear and a small trapnet as described previously.

Stomach content analysis of whitefish specimens was done after reviewing Hyslop (1980). Stomach contents were removed from preserved fish and analyzed according to numerical and % occurrence methods. While a gravimetric method would also have been desirable, because the stomach contents were often at different stages of digestion a comparison between the biomass of food items would have been biased. Food items were identified to the level of Order (i.e. Amphipoda, Diptera) and where items were more abundant developmental stages (i.e. Diptera pupa) or genera were sometimes specified. Identifications follow Pennak (1978) and Needham and Needham (1962).

3.3 Results

3.3.1 Tusket River

The Tusket River drains a large watershed with numerous lakes and flows into an extensive estuary with many islands. The Annis River, a smaller river, enters the Tusket River in its estuary and is considered here as a tributary of the Tusket. The Tusket River has been found to be very acidic compared to most other rivers in Nova Scotia (Farmer et al., 1980; Watt et al., 1983). While a regular sampling program was not conducted during this study, the water chemistry data collected agree with previous determinations of pH variation throughout the watershed (Table 9). In September, 1983 when river pH's would be close to their annual maximum and Acadian whitefish would be migrating into freshwater, the pH of the Tusket River at Lake Vaughn was 5.23 and the pH of the Annis River just above tidal influence was 6.05. Water samples collected in January, 1984 show lower pH values at these localities which is expected as most rivers in Nova Scotia have pH minimums in midwinter. Thus for the overwintering of adults and the incubation of eggs in 1984/85, the Acadian whitefish would have faced a pH of 4.59 in Lake Vaughn and 5.02 in the Annis River.

Also evident from this table is the high colour of the water reflecting the presence of naturally occurring organic acids and the low alkalinity values. Alkalinity has virtually disappeared in the Tusket River indicating the sensitivity of this river to increased acidification. While alkalinity is still present in the Carleton and Annis tributaries, the values are low and drop to below detection at times.

A list of fish collections from the Tusket River watershed is presented in Appendix 1. Of the 996 fish specimens caught in fresh and brackish water, only two Acadian whitefish were caught. The two specimens were caught in the Annis River and there were no reports of Acadian whitefish from the main branch of the Tusket River despite gillnetting and the operation of a Department of Fisheries and Oceans fish trap on the only functioning fish ladder at the Tusket River dam from October 5, 1982 to November 20, 1982.

The Acadian whitefish specimens were caught moving upstream in a commercial gillnet set overnight in the brackish "basin" near the Annis River mouth and in a hoopnet located in freshwater just above the high tide point on the Annis River. These specimens were caught on October 11 and 12, 1982 respectively. In the 88 hours of gillnet sets in the Annis River "basin" in October of 1982, the Acadian whitefish specimen comprised only 1 % of all fish specimens captured. The hoopnet operated for 210 hours from October 4 to 20, 1982 and the one Acadian whitefish caught comprised only 4 % of all fish specimens caught. A small trapnet which operated for 216 hours just above the "basin" during the same time period failed to catch any Acadian whitefish although eels, mummichogs and tomcods were common.

TABLE 9. Water chemistry data from the Tusket River watershed, Yarmouth Co., N.S. (FOR UNITS OF PARAMETERS SEE TEXT).

LOCALITY	DATE	pH	ALKALINTY	COND.	COLOUR	ACIDITY	HARDNESS
Lake Vaughan	26/9/83	5.23	<0.05	28	120	6.76	4.21
Annis River (Mouth)	"	6.05	0.97	40	60	3.69	6.08
Lake Vaughan	17/1/84	4.59	nil	50	110	-	-
Annis River (Mouth)	"	5.02	nil	61	110	-	-
Lake Vaughan	2/3/85	4.66	nil	46	140	10.81	4.33
Annis River (Mouth)	"	5.15	nil	67	130	9.68	12.71
Annis River (Deerfield)	"	4.65	nil	61	110	10.34	8.77
Tusket River (Kemptville)	"	4.30	nil	63	110	12.03	6.50
Carleton River (Carleton)	"	5.59	1.11	47	110	6.67	8.87
Lake Vaughan	26/8/85	5.12	<0.5	39	100	-	5.1

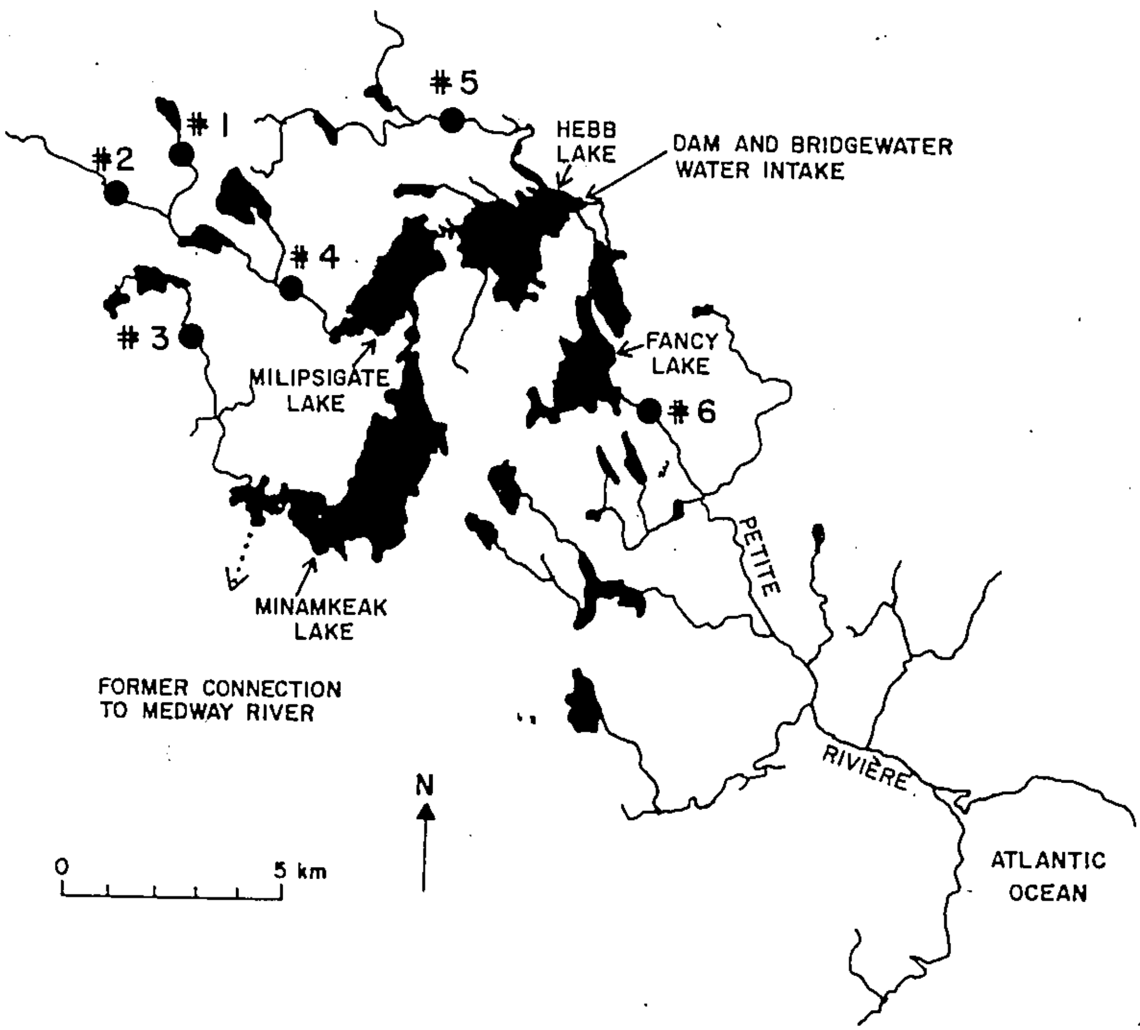
The capture of chain pickerel, *Esox niger*, and brown trout, *Salmo trutta*, in the Annis watershed documented the success of these introduced species. The chain pickerel were caught in Salmon Lake, the first major lake on the Annis River watershed and were also caught in this lake by provincial surveys in 1977. The population of chain pickerel in Salmon Lake is believed to be from the spread of an introduction of the species into the Spectacle lakes system in the 1950's (Gilhen, 1974). One specimen of brown trout was caught migrating upstream at the hoopnet collection site of the Acadian whitefish on October 9, 1982. The specimen was a female 520 mm TL in spawning condition with ripe eggs easily extruded. This species was introduced into the Annis River as early as 1920 (Gilhen, 1974).

3.3.2 Petite Rivière

The Petite Rivière is a rather small watershed with a drainage area of about 90 sq. miles (Figure 20). The watershed occurs in an area of extensive drumlin development giving the landscape a gently rolling nature. There are a number of farms and a few small towns within the watershed although forested areas are still widespread, particularly surrounding the lakes. Also characteristic of the watershed is the abundance of bogs which impart a tea-colour to the water.

Bathymetric maps of Minamkeak, Milipsigate and Hebb Lakes are presented in Figures 21, 22 and 23. These lakes have maximum depths of 13m, 16m and 14m respectively although much of the area of these lakes is more shallow. The lake bottoms are silt in the deep water areas whereas shoals and shoreline areas have a rocky bottom. The shoreline of the lakes is mostly stones although there are sections of sand and weed beds. Because of the protective legislation for the watershed there are no

Figure 20: The Petite Rivière watershed, Lunenburg Co., N.S., showing water chemistry sampling stations (1- St. George brook; 2- Still brook; 3- Frederick Lake outlet; 4- Birch brook; 5- Wildcat creek; 6- Petite Rivière at Conqueral Mills).


#5
#1
#2
HEBB
LAKE
DAM AND BRIDGEWATER
WATER INTAKE
#4
#3
MILIPSIGATE
LAKE
FANCY
LAKE
#6
PETITE
MINAMKEAK
LAKE
FORMER CONNECTION
TO MEDWAY RIVER
RIVIÈRE
N
0
5 km
ATLANTIC
OCEAN

cottages or other lakeshore developments on these lakes. Fancy Lake, which occurs outside of the Protected Water Area, however, has numerous cottages and is subject to a variety of recreational activities.

The data collected on temperature and dissolved oxygen profiles in Hebb Lake is presented in Figure 24. The temperature data shows that while the lake does stratify to a degree during the summer, a typically cold water hypolimnion is not present. The temperature at the bottom of the lake at the begining of stratification in the spring was 14°C and the temperature rose to almost 20°C by August 26, 1983 indicating the warm water nature of the lake. Oxygen concentrations in the lake appear sufficient for fish although bottom readings were quite low in August. An oxygen concentration of only 2 mg/l obtained in the bottom two meters on August 4, 1983 might suggest anoxic conditions resulting from high respiration rates on the bottom or that the oxygen meter probe entered the bottom sediments.

Water chemistry data from the Petite Rivière watershed is presented in Figures 25, 26, 27 and 28. The Petite Rivière shows a trend in seasonal pH variation similar to other rivers in Nova Scotia. PH is high over the spring and summer followed by a fairly quick drop in the fall to a midwinter pH minimum. Also seen in Figure 25 is the wide variation of pH throughout the watershed. While pH is usually above 5.5, rising to 7.0 at times in the lower Petite Rivière at Conqueral, pH is rarely above 4.5, dropping to 4.2 at times, in Still brook, a small darkly coloured brook draining a bog area. The lakes within the Petite Rivière watershed usually have pH's above 5.0 and on a few occaisions above 6.0. During the winter however, pH's have been recorded from Hebb Lake as low as 4.5 and from Minamkeak Lake as low as 4.8 indicating pH fluctuations that could seriously affect aquatic life.

Alkalinity values, indicative of the buffering capacity of the water, show variation throughout the watershed in accordance with pH variation (Figure 26). Some localities

Figure 21: Bathymetric map of Minamkeak Lake, Lunenburg Co., N.S., with fish sampling localities corresponding to collection data in Appendix 2. Depths are in meters.

5
2
10
12
45
46
47
48
49
1 Km
N

Figure 22: Bathymetric map of Milipsigate Lake, Lunenburg Co., N.S., with fish sampling localities corresponding to collection data in Appendix 2. Depths are in meters.

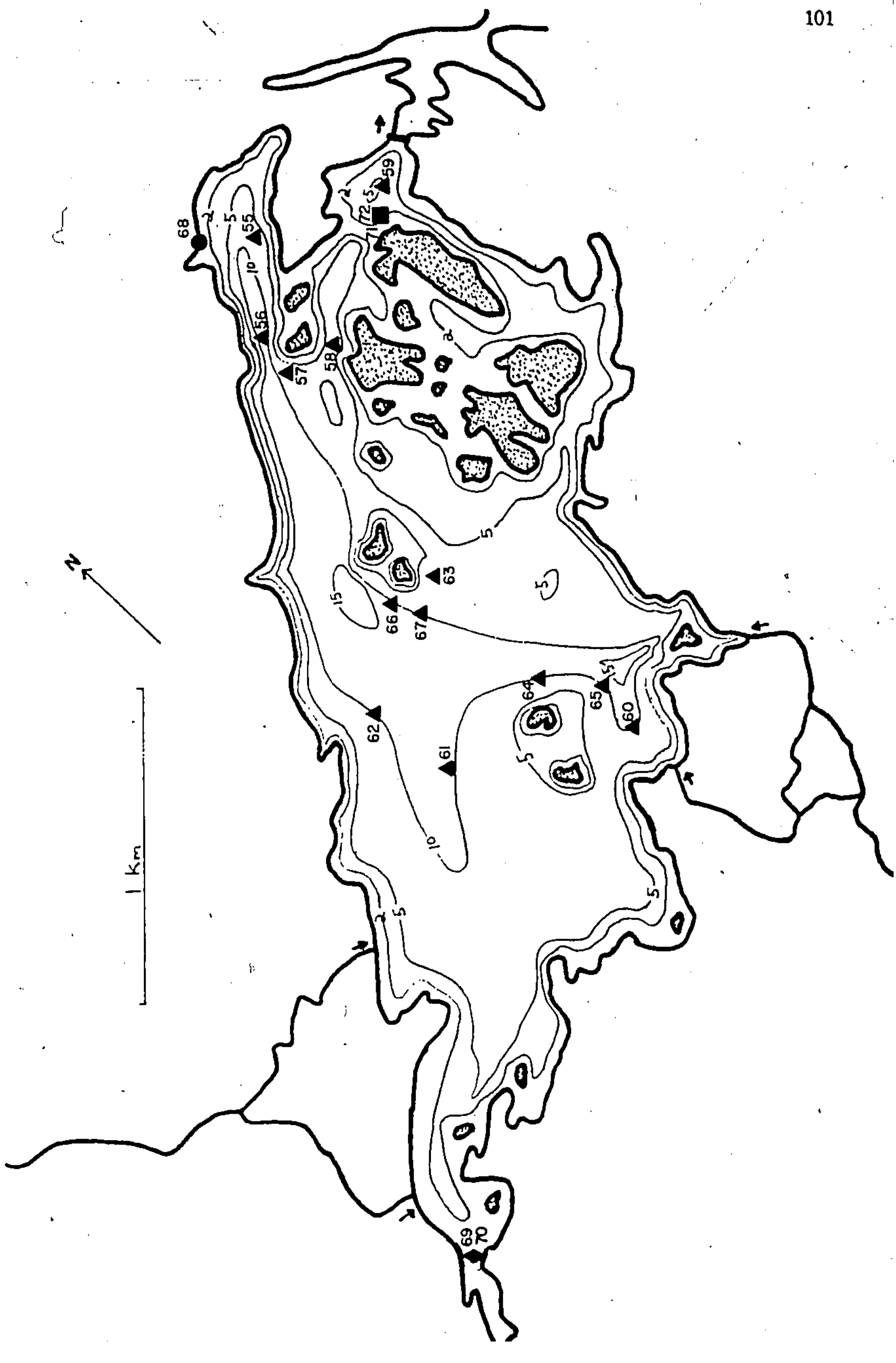

N
1 Km
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
2
5
10
15

Figure 23: Bathymetric map of Hebb Lake, Lunenburg Co., N.S., with fish sampling localities corresponding to collection data in Appendix 2. Depths are in meters.

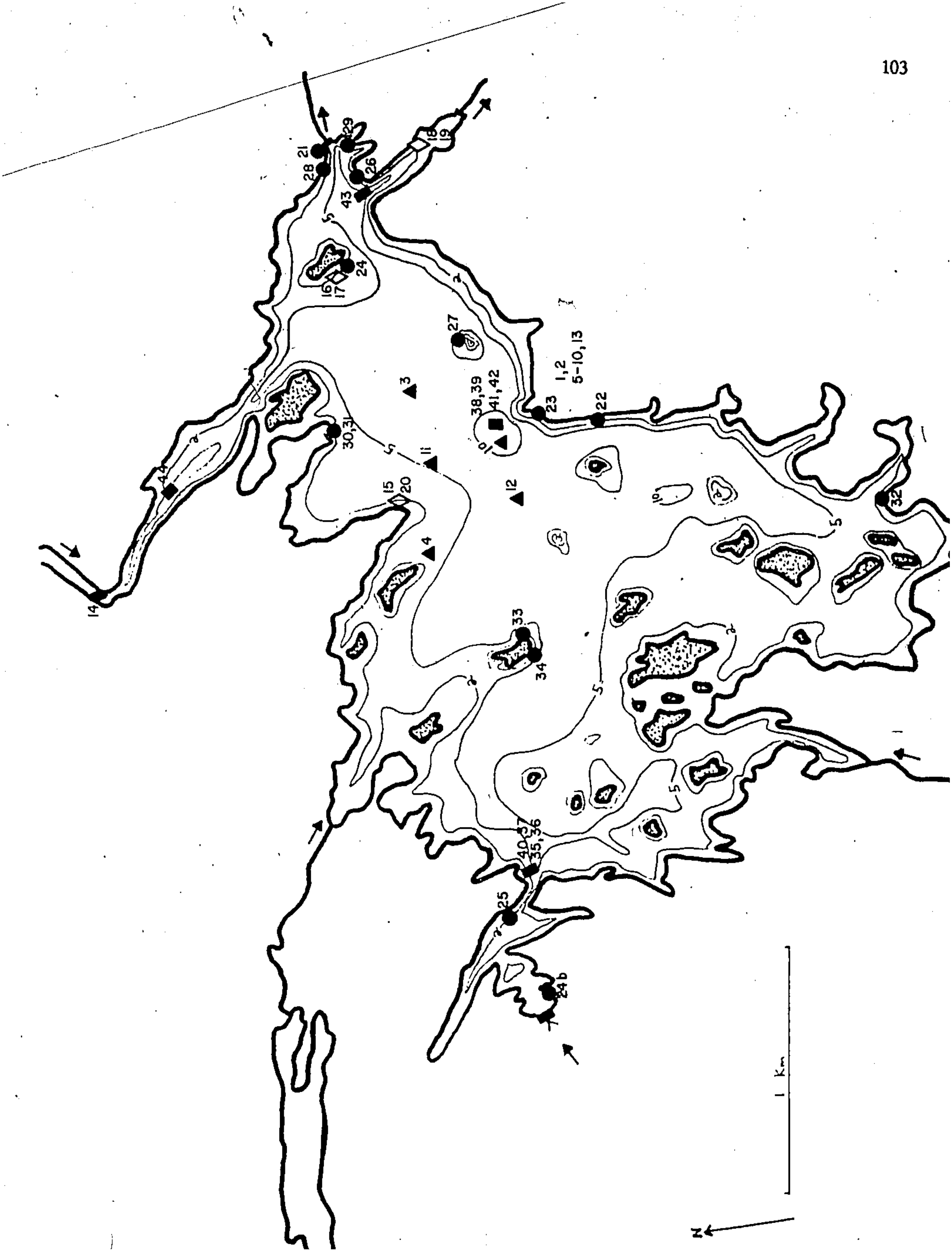

1 Km
N
1,2
5-10,13
3
4
11
12
14
15
16
17
18
19
20
21
22
23
24
24b
25
26
27
28
29
30,31
32
33
34
35,36
37
38,39
40
41,42
43
44

Figure 24: Dissolved oxygen and temperature profiles in Hebb Lake, Lunenburg Co., N.S. (1983).

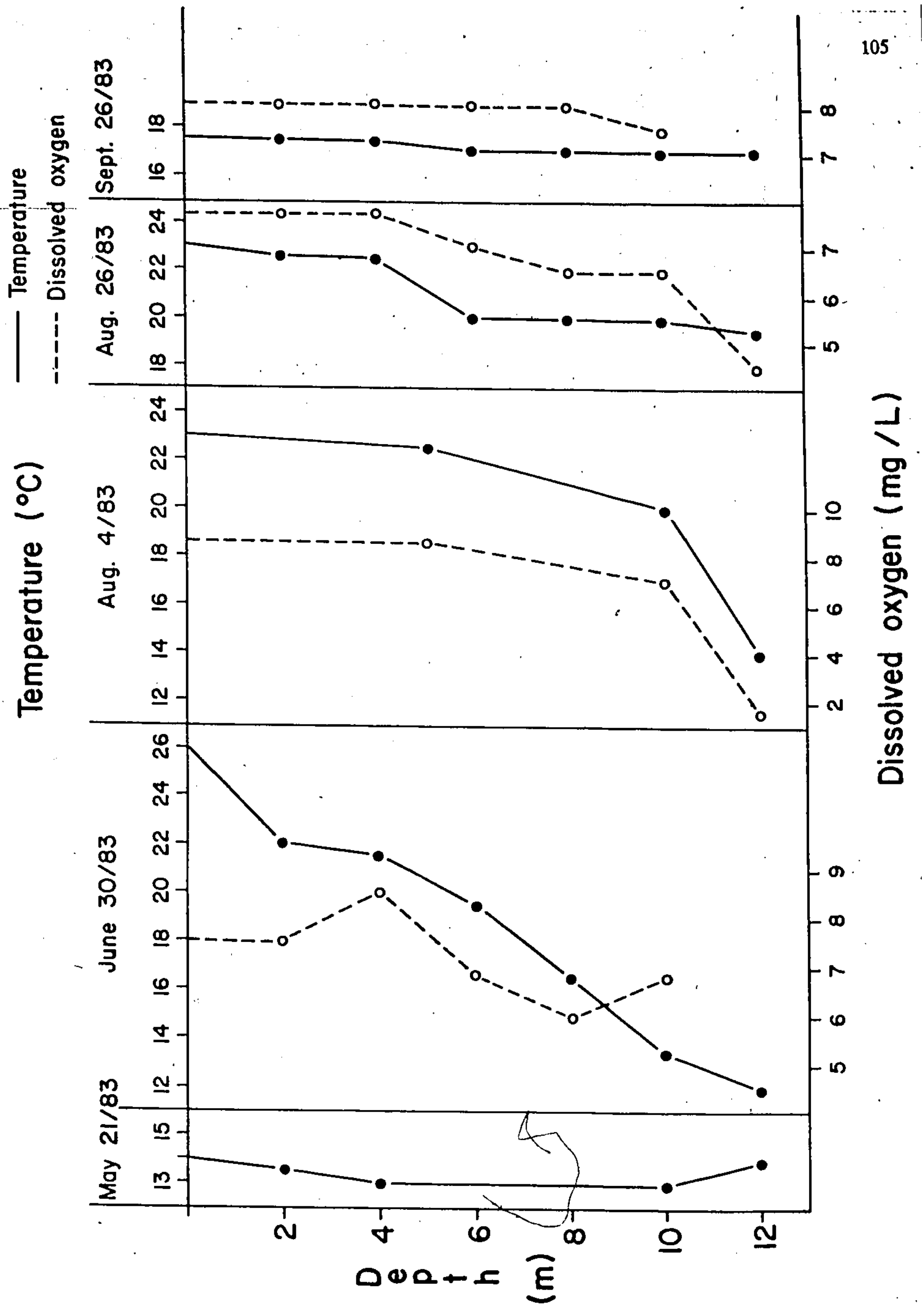

Temperature
Dissolved oxygen
Temperature (°C)
Dissolved oxygen (mg/L)
Sept. 26/83
Aug. 26/83
Aug. 4/83
June 30/83
May 21/83
Depth (m)
2
4
6
8
10
12

Figure 25: Seasonal water pH variation throughout the Petite Rivière watershed, Lunenburg Co., N.S. (1983-85).

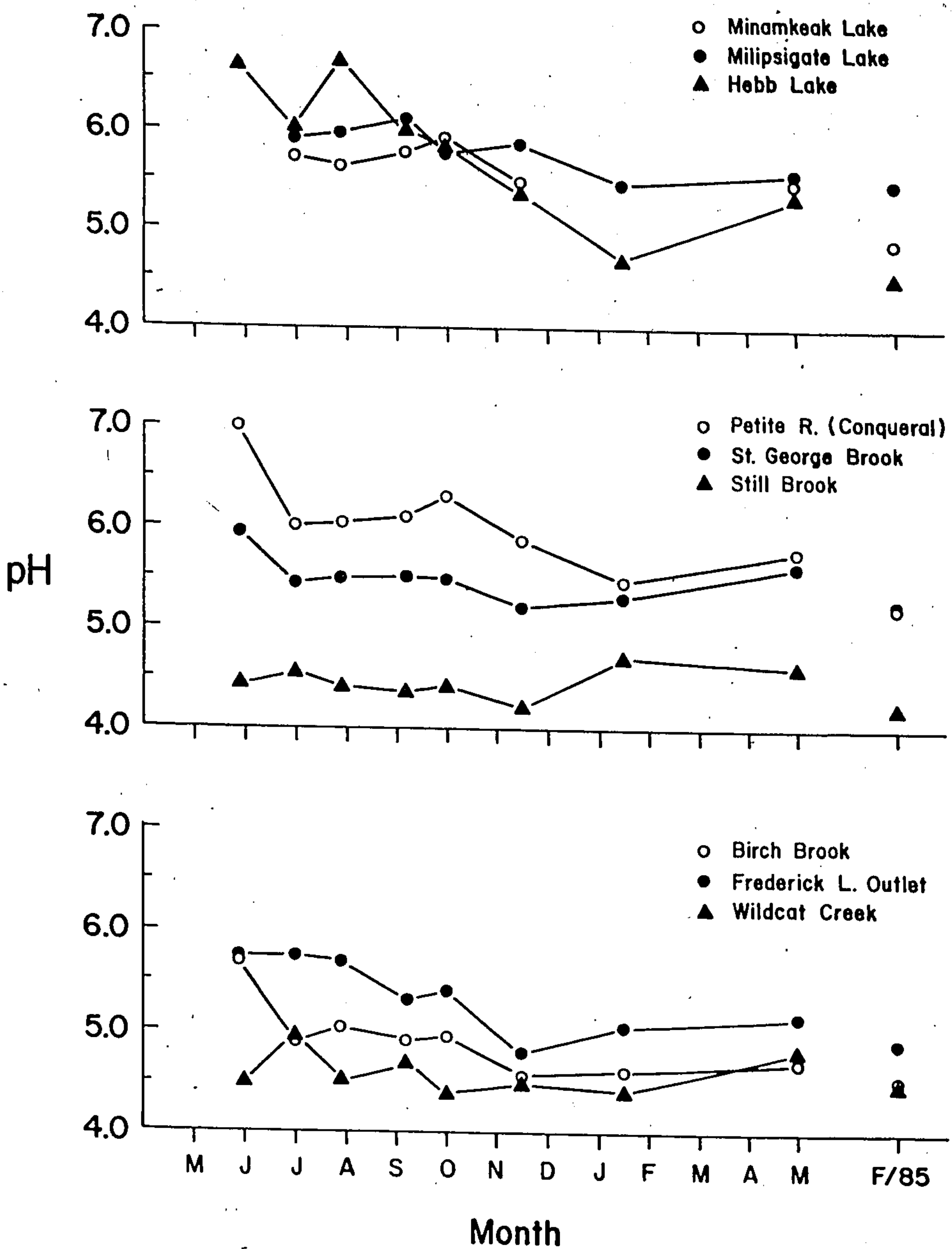
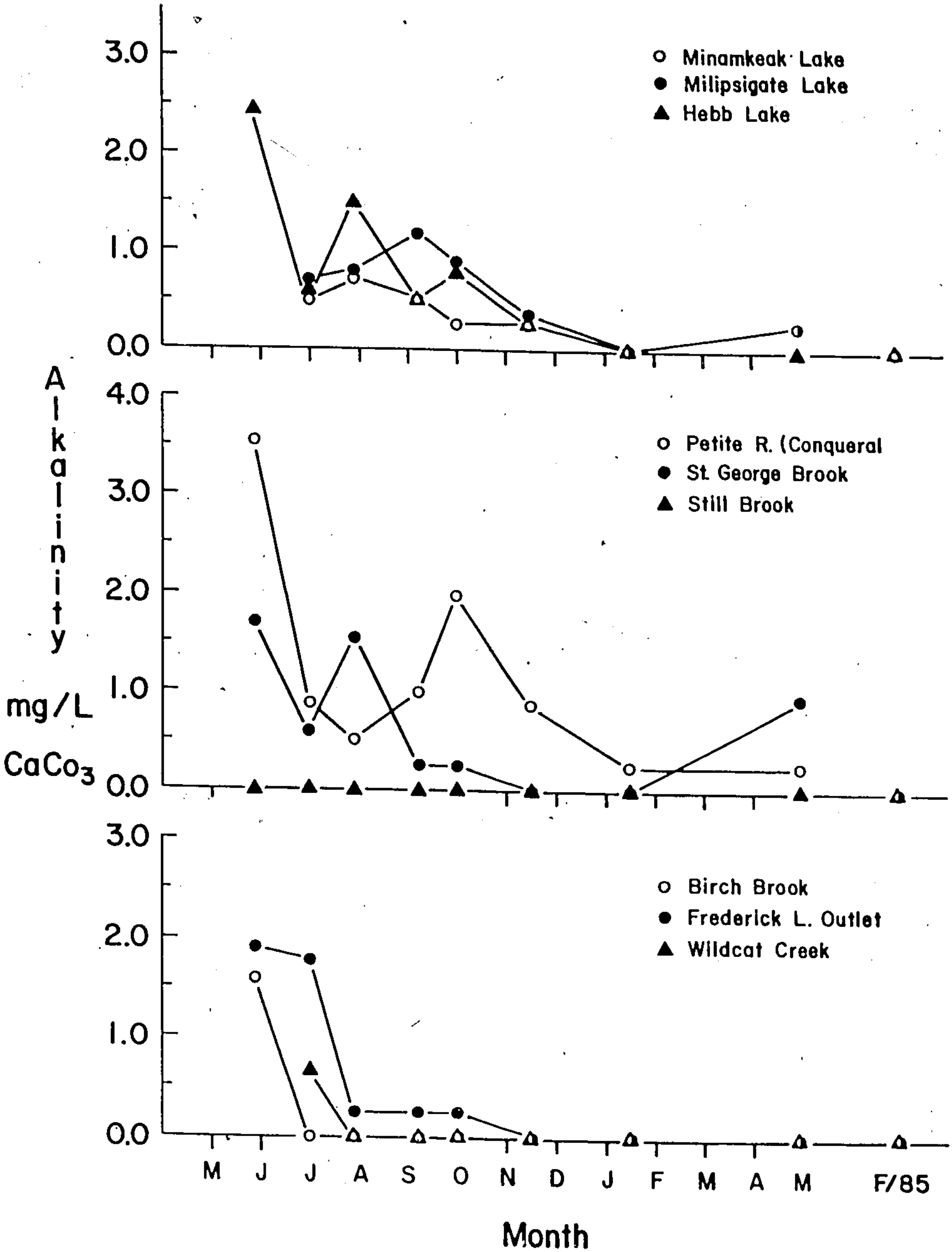

7.0
6.0
5.0
4.0
Minamkeak Lake
Milipsigate Lake
Hebb Lake
7.0
6.0
5.0
4.0
Petite R. (Conqueral)
St. George Brook
Still Brook
pH
7.0
6.0
5.0
4.0
Birch Brook
Frederick L. Outlet
Wildcat Creek
M J J A S O N D J F M A M F/85
Month

Figure 26: Seasonal water alkalinity (mg/l of $CaCO_3$) variation throughout the Petite Rivière watershed, Lunenburg Co., N.S. (1983-85).



3.0
2.0
1.0
0.0
Minamkeak Lake
Milipsigate Lake
Hebb Lake
Alkalinity
mg/L
CaCo3
4.0
3.0
2.0
1.0
0.0
Petite R. (Conqueral
St. George Brook
Still Brook
3.0
2.0
1.0
0.0
Birch Brook
Frederick L. Outlet
Wildcat Creek
M J J A S O N D J F M A M F/85
Month

Figure 27: Seasonal water color (hazen units) variation throughout the Petite Rivière watershed, Lunenburg Co., N.S. (1983-85).

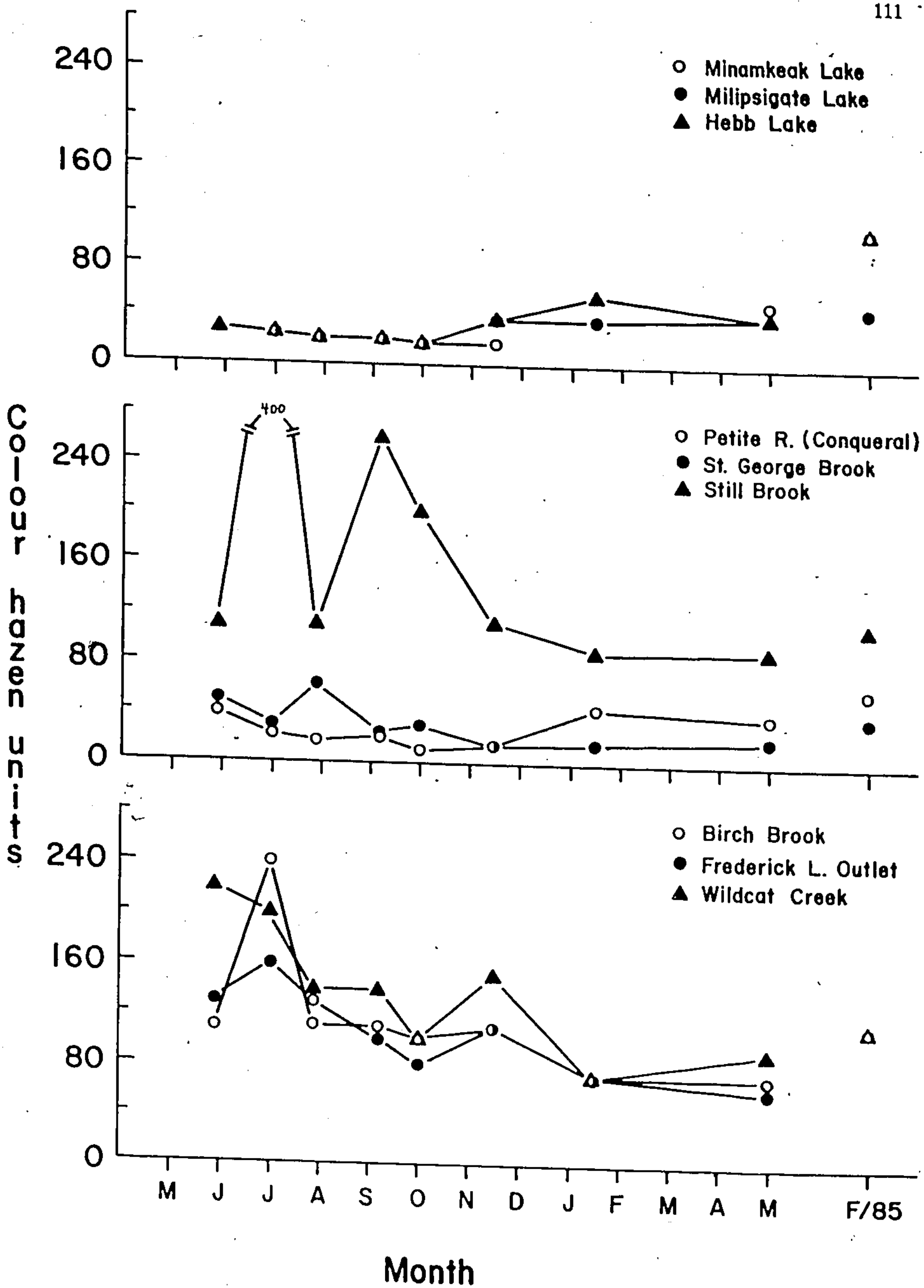
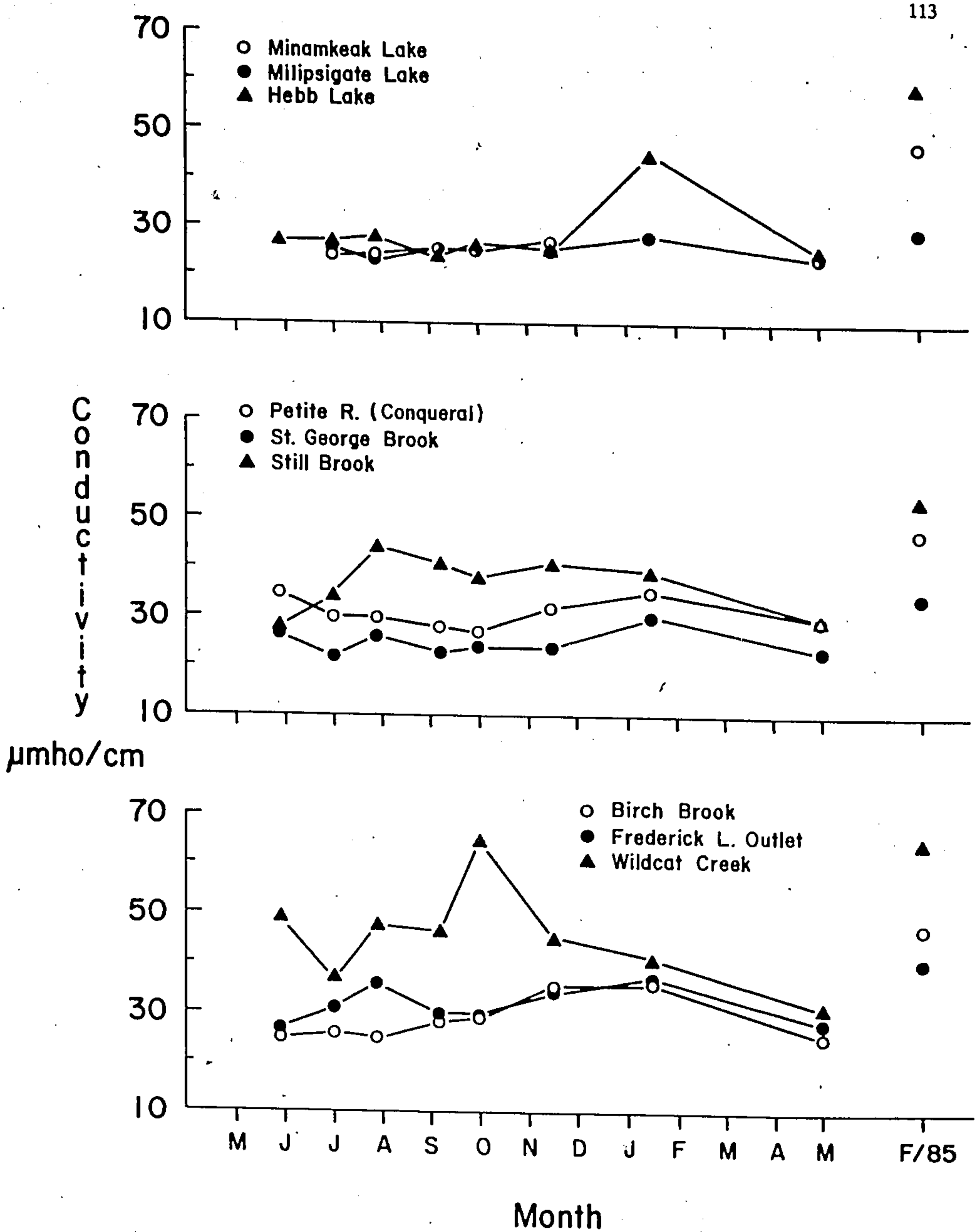

Minamkeak Lake
Milipsigate Lake
Hebb Lake
Petite R. (Conqueral)
St. George Brook
Still Brook
400
Birch Brook
Frederick L. Outlet
Wildcat Creek
Colour hazen units
0
80
160
240
M J J A S O N D J F M A M F/85
Month

Figure 28: Seasonal water conductivity (μohms) variation throughout the Petite Rivière watershed, Lunenburg Co., N.S. (1983-85).


Minamkeak Lake
Milipsigate Lake
Hebb Lake
Petite R. (Conqueral)
St. George Brook
Still Brook
Birch Brook
Frederick L. Outlet
Wildcat Creek
Conductivity
µmho/cm
70
50
30
10
M J J A S O N D J F M A M F/85
Month

such as the Petite Rivière at Conqueral have alkalinity detectable at almost every sampling period whereas others such as Still brook lack any trace of alkalinity at all sampling periods. The Petite Rivière lakes have low alkalinity values, although during the summer months alkalinity values can rise substantially. A source of concern is the decrease and low level of alkalinity and hence buffering capacity of Minamkeak, Milipsigate and Hebb Lakes over the winter months. The most recent readings revealed a lack of measureable alkalinity in Minamkeak and Hebb Lakes in February, 1985.

Water colour also shows considerable variability throughout the Petite Rivière watershed (Figure 27). Colour, indicative of the amount of naturally occurring organic acids in the water, ranges from values usually less than 40 hazen units in the Petite Rivière lakes to Stillbrook where colour values are all above 80 and as high as 400 hazen units. The small brooks, usually draining bog areas, show colour maximums in the summer whereas the lakes and their outflow in the Petite Riviere at Conqueral have colour maximums in the winter.

Conductivity values throughout the Petite Rivière watershed varied between 20 and 65 µmho/cm with values usually highest in the winter (Figure 28). Conductivity readings were mostly below 40 µmho/cm although Hebb Lake had a conductivity of 60 µmho/cm in February, 1985 and the highly coloured Stillbrook and Wildcat Creek showed high conductivities over the summer months.

A summary of fish collections from the Petite Rivière lakes is presented in Appendix 2 and the collection localities are shown in Figures 21, 22 and 23. Acadian whitefish were found in Minamkeak, Milipsigate and Hebb Lakes. Despite four gillnets set overnight in Fancy Lake and two overnight in the Petite Rivière estuary, no Acadian whitefish were collected at these localities. While the capture of an Acadian whitefish by Mr. D. Bell in the Petite Rivière estuary in May, 1986 indicates the presence of the species below Hebb Lake, there is little evidence to date suggesting that a resident population of Acadian whitefish exists in Fancy Lake. Local residents have occasionally reported Acadian whitefish from Fancy Lake however it is possible these reports are of specimens from the upper lakes or anadromous specimens (could be checked by scales) if such a population does exist.

All Acadian whitefish were caught in gillnets and a summary of gillnetting results in the Petite Rivière lakes as well as lakes containing lake whitefish is presented in Table 10. These lakes appear generaly similar in fish species composition and abundance as assessed by gillnetting although Fancy Lake, which is no longer obstructed from the sea, was found to contain Atlantic salmon and lack Acadian whitefish. The lakes show a predominance of white perch, white sucker and yellow perch while Acadian whitefish and brown bullheads were less common. The results also indicate that the Acadian whitefish is not very abundant in these lakes, particularly in Milipsigate Lake where the species accounted for only 2.3% of the specimens caught compared to 68.7% for White perch.

A number of other fishing methods were used in an attempt to sample other habitats in the Petite Rivière lakes and these results are summarized in Table 11. While these methods were successful in catching fish, no adult or young Acadian whitefish were caught. The nets may not have been placed in the proper habitat to capture Acadian whitefish or the species may have been able to elude the nets more easily than gillnets. The capture data indicated that banded killifish, golden shiners, ninespine sticklebacks and young yellow perch were common in shallow waters and eels were found in the deeper portions of the lake. The presence of eels was also indicated by the fact that many Acadian whitefish specimens were mutilated by eels feeding on them in the gillnets.

TABLE 10. Gillnet capture data from lakes found to contain Acadian whitefish and lake whitefish in Nova Scotia. Species values expressed as number of specimens caught and per cent of all specimens caught at each locality.

LOCALITY		GILLNET EFFORT (HRS.)	C. canadensis	C. clupeaformis	S. salar	O. mordax	Alosa sp.	C. commersoni	I. nebulosus	M. americana	P. flavescens	A. rostrata
			SPECIES									
ACADIAN WHITEFISH												
Mimamkeak L.	N	72	5	-	-	-	-	26	4	20	15	-
	%		(7.0)					(36.6)	(5.6)	(29.6)	(21.1)	
Milipsigate L.	N	180	11	-	-	-	-	86	10	329	43	2
	%		(2.3)					(18.0)	(2.1)	(68.7)	(9.0)	(<0.1)
Hebb L.	N	154	21	-	-	-	-	42	2	127	8	-
	%		(10.8)					(21.5)	(1.0)	(62.6)	(4.1)	
Fancy L.	N	72	-	-	1	-	-	15	1	52	32	-
	%				(1.0)			(14.9)	(1.0)	(51.5)	(31.7)	
TOTAL (Excluding Fancy L.)			37	-	-	-	-	154	16	476	66	2
			(4.9)					(20.5)	(2.1)	(63.4)	(8.8)	(<0.1)
LAKE WHITEFISH												
L. George	N	74	-	22	-	-	-	-	-	153	25	1
	%			(10.9)						(76.1)	(12.4)	(<0.1)
Caribou L.	N	28	-	1	-	-	-	9	-	9	6	-
	%			(4.0)				(36.0)		(36.0)	(24.0)	
L. Mushamush L.	N	42	-	2	-	-	-	36	3	39	1	-
	%			(2.5)				(44.4)	(3.7)	(48.1)	(1.2)	
Mira R.	N	47	-	25	1	1	66	8	-	23	-	-
	%			(20.2)	(<0.1)	(<0.1)	(53.2)	(6.5)		(18.5)		
TOTAL	N		-	50	1	1	66	53	3	224	32	1
	%			(11.6)	(<0.1)	(<0.1)	(15.3)	(12.3)	<0.1)	(52.0)	(7.4)	<0.1)

TABLE 11. Fish species capture data from seine, trapnet and minnow trap collections in Hebb lake, Lunenburg Co., N.S.

LOCALITY	EFFORT (HRS.)	*I. nebulosus*	*F. diaphanus*	*P. pungitius*	*P. flavescens*	*M. americana*	*C. commersoni*	*N. chrysoleucas*	*A. rostrata*
SHORELINE									
1) SEINE	(HAULS)								
Minamkeak L.	1	–	–	–	–	–	–	63	–
Milipsigate L.	1	–	16	–	–	–	–	–	–
Hebb L.	15	–	565	6	34	8	6	111	–
Fancy L.	1	–	1	3	2	–	–	1	–
1) MINNOW TRAP	(HRS)								
Hebb L.	168	–	2	1	18	1	–	–	–
LAKE BOTTOM									
1) TRAP NET	(HRS)								
Milipsigate L.	168	14	8	1	7	1	–	–	–
Hebb L.	624	27	4	–	9	22	1	15	6

A breakdown of the gillnet capture data of Acadian whitefish by season and habitat in the Petite Rivière lakes is presented in Table 12. Acadian whitefish were found throughout the water column in the fall and spring when the lakes were isothermal. In July, 1983 when a thermocline was present in Hebb Lake, Acadian whitefish were found in deep water although gillnets were not set in surface waters which could have determined if the species was also found throughout the water column at this time. Using catch per unit effort values (total), Acadian whitefish were caught more than twice as often in surface waters compared to midwater or bottom habitats. This was in contrast to other fish species which were found to be more abundant near the bottom than in surface waters. Acadian whitefish caught at the surface comprised 27 % of the catch of all species whereas midwater and bottom captures comprised 20 % and 2 % respectively. Those Acadian whitefish caught near the bottom were almost invariably caught in the deeper parts of the lakes. Only 7 % of the bottom catches of Acadian whitefish were made in gillnets set on the bottom at a depth of less than 8m. It is notable however, that a gillnet with two 15m panels of 37.5 and 50mm stretched mesh was set overnight across the channel just below the Milipsigate Lake dam outlet on February 17, 1985 and five Acadian whitefish were caught. The fish were caught in an ice-free area near the surface in running water where the water depth was about 3m. Extensive observations at this locality in summer months failed to find any Acadian whitefish and suggests that the species may venture into such shallow areas during the cooler winter months.

A comparison of the abundance of species in surface and bottom gillnets from a number of lakes in Nova Scotia is found in Tables 13 and 14. White perch and yellow perch comprised much of the gillnet captures although Acadian and lake whitefish were also common in some lakes. Acadian whitefish were the most abundant species caught in the surface waters of Hebb Lake and lake whitefish comprised much of the

TABLE 12. Seasonal habitat preferences of Acadian whitefish in the Petite Rivière lakes, N.S., expressed as number of specimens caught.

HABITAT	EFFORT (HRS.)	C. canadensis	C. commersoni	I. nebulosus	M. americana	P. flavescens
		SPECIES				
FALL 1982						
Surface	60	12	-	-	32	12
Midwater	48	3	1	-	6	7
Bottom <8m.	85	1	68	9	129	7
Bottom >8m.	115	8	64	5	270	40
SPRING 1983						
Surface	12	5	-	1	-	-
Midwater	12	2	2	-	4	-
Bottom >8m.	12	3	2	-	5	-
SUMMER 1983						
Bottom <8m.	36	-	10	1	18	-
Bottom >8m.	18	3	7	-	5	-
TOTAL						
Surface	78	17	1	1	32	12
Midwater	60	5	3	-	10	7
Bottom <8m.	121	1	78	10	147	7
Bottom >8m.	145	14	76	5	280	42

surface water captures in Lake George. Although the data is not conclusive, Acadian whitefish appear to be more abundant in surface waters than other species in their respective lakes.

Almost all species appeared more abundant in bottom gillnets except for the Acadian whitefish. Acadian whitefish averaged only .04 specimens per gillnet hour in bottom nets in the Petite Rivière lakes compared to .27 specimens per hour in surface nets. In the same bottom gillnets, white perch averaged 1.29 specimens per gillnet hour. In contrast to Acadian whitefish, lake whitefish appeared more abundant in bottom nets. An average of .30 lake whitefish caught per hour in bottom gillnets was obtained compared to only .13 specimens per hour in surface gillnets for all lake whitefish lakes. The data also indicates that some lake whitefish populations are more abundant in their rerspective lakes than Acadian whitefish. The bottom gillnet catches of .53 and .61 lake whitefish per hour in the Mira River and Lake George respectively, suggest these lakes have relatively high densities of whitefish. The highest abundance of Acadian whitefish was in Hebb Lake where .32 specimens were caught per hour in surface gillnets. The bottom gillnet data also indicates that white perch is the predominant species in many lakes in Nova Scotia and that yellow perch and white suckers are also usually abundant.

Results of the stomach content analysis of whitefish specimens are presented in Table 15. There was considerable variation in the type and quantity of food items eaten by different populations of Acadian and lake whitefishes. This may be due to sampling bias as the individuals from different populations were often caught in different seasons and from different age groups.

Acadian whitefish from Hebb Lake had fed on many flying ants (Hymenoptera) while some specimens from Minamkeak Lake were found to contain mostly plankton (Cladocera). Acadian whitefish from Milipsigate Lake had a more diversified diet,

TABLE 13. Fish species abundance in surface waters of Nova Scotian lakes as assessed by gillnet capture data. Values expressed as number of specimens caught per hour of gillnet set.

LOCALITIES	EFFORT (HRS.)	*Coregonus* sp.	*M. americana*	*P. flavescens*	*C. commersoni*	*I. nebulosus*
ACADIAN WHITEFISH						
Minamkeak L.	18	.22	-	.56	-	-
Milipsigate L.	28	.14	.89	.07	-	-
Hebb L.	28	.32	.25	-	-	.04
AVERAGE		.27	.38	.21	-	.01
LAKE WHITEFISH						
L.George	16	.19	.31	-	-	-
Caribou L.	14	.07	.21	-	.29	-
L.Mushamush L.	-	-	-	-	-	-
Mira R.	-	-	-	-	-	-
AVERAGE		.13	.26	-	.29	-
OTHER LAKES						
Fancy L.	18	-	.33	-	-	-
Herring Cove L.	18	-	-	1.89	-	-
L.Rossignol	18	-	-	-	-	-
Salmon R.L.	16	-	-	.06	.13	-
Raynards L.	16	-	.63	.31	.13	-
AVERAGE		-	.32	.45	.05	-

TABLE 14. Fish species abundance in bottom waters of Nova Scotia lakes as assessed by gillnet capture data. Values expressed as number of specimens caught per hour of gillnet set.

LOCALITIES	EFFORT (HRS.)	*Coregonus* sp.	*S. salar*	*S. fontinalis*	*M. americana*	*P. flavescens*	*I. nebulosus*	*C. commersoni*	*N. chrysoleucas*
ACADIAN WHITEFISH									
Minamkeak L.	36	-	-	-	.50	.08	.11	.72	-
Milpsigate L.	132	.05	-	-	2.30	.31	.08	.64	-
Hebb L.	98	.08			1.08	.08	.02	.41	-
AVERAGE		.04	-	-	1.29	.16	.07	.59	-
LAKE WHITEFISH									
L. George	28	.61	-	-	4.75	.89	-	-	-
Caribou L.	14	-	-	-	.43	.43	-	.36	-
L. Mushamush L.	42	.05	-	-	.93	.02	.07	.93	-
Mira R.	47	.53	.02	-	.49	-	-	.17	-
AVERAGE		.30	.02	-	1.65	.45	.02	.37	-
OTHER LAKES									
Salmon L.	30	-	-	-	2.17	.83	.27	1.3	.07
Silvery L.	54	-	-	.41	-	-	.04	-	.04
Herring Cove L.	36	-	-	-	-	6.06	.08	.36	-
L. Rossignol	36	-	-	-	2.81	1.17	.50	.08	.58
Salmon R. L.	16	-	-	-	-	.31	-	.06	-
L. Doucette	17	-	-	.06	.88	.59	1.18	1.00	.06
Raynards L.	30	-	.03	.13	.37	.83	-	.27	.03
L. Ainsley	35	-	-	.14	1.51	-	-	.06	-
Fancy L.	36	-	.03	-	1.06	.89	.03	.42	-
AVERAGE		-	.03	.19	1.47	1.53	.35	.44	.16

TABLE 15. Stomach contents of Acadian whitefish and lake whitefish from Nova Scotia. Food items expressed as mean number per stomach, standard deviation (in parentheses) and per cent occurrence in all stomachs examined from each locality.

FOOD ITEM

Locality	Sample size	Cladocera	Ostracoda	Isopoda	Amphipoda	Decapoda	Hydracarina	Plecoptera adult	Plecoptera nymph	Ephemeroptera nymph	Odonata nymph	Megaloptera nymph
ACADIAN WHITEFISH												
Hebb L.	8	39.50(54.45) 75%						1 13%			1.17(0.41) 75%	
Milipsigate L.	6	1 17%						9.00(4.24) 33%		1.25(0.50) 67%	1 25%	1 33%
Minamkeak L.	4	3250.00(1767.47) 50%			2 25%		1 25%			1 25%	1 25%	
Maan-	18	1076.83(1864.80) 28%			2 6%		1 6%	5.00(5.66) 17%		1.13(0.18) 28%	1.06(0.10) 50%	1 6%
Tusket R.	10			6 10%	2 10%	1 30%		2.50(2.12) 20%	160.50(153.24) 40%	1 10%		7 10%
TOTAL/MEAN	28	1096.83 18%		6 4%	2 7%	1 11%	1 49%	3.75(1.77) 18%	160.50 14%	1.07(0.09) 21%	1.06 32%	4.00(4.24) 7%
LAKE WHITEFISH												
Mira R.	12	7.36(7.23) 92%	2.50(2.12) 17%		25.83(39.09) 100%		5.00(3.46) 25%					
L. George	14	1.80(1.79) 36%		8.75(15.93) 57%	11.50(11.93) 57%		2 7%			1 14%		
L.Mushamush L.	2										1 50%	
Pringle L.	7	1780.00(580.80) 100%					1 14%					
TOTAL/MEAN	35	596.39(1025.04) 66%	2.50 6%	18.67(10.13) 57%	18.67(10.13) 57%		2.67(2.08) 14%			1 6%	1 3%	

TABLE 15. (cont'd.)

Food item

Locality	Trichoptera nymph	Coleoptera adult	Hemiptera adult	Simuliidae larvae	Chaoborus larvae	Other Diptera larvae	Diptera pupa	Diptera adult	Hymenoptera adult	Sphaeriidae clam	Gastropoda	Fish
ACADIAN WHITEFISH												
Hebb L.		1 13%					1 13%	2 13%	42.00(31.22) 38%			
Milipsigate L.	2.50(2.12) 33%	4 17%	4 17%			1 17%	10.25(10.40) 67%	2 17%				1 17%
Minamkeak L.					2 50%							
Mean	2.50 11%	2.50(2.12) 11%	4 6%		2 11%	1 6%	5.63(6.54) 28%	2 11%	42.00 17%			1 6%
Tusket R.	1.67(1.15) 30%	1 20%	1 10%	463.75(405.94) 40%		6.25(5.32) 40%	10.50(12.08) 60%	1.50(0.71) 20%	2 10%			1 20%
TOTAL/MEAN	2.09(0.59) 18%	1.75(1.06) 14%	2.50(2.12) 7%	463.75 14%	2 7%	3.63(3.71) 18%	8.07(3.44) 39%	1.75(0.35) 14%	22.00(28.28) 14%			1 11%
LAKE WHITEFISH												
Mira R.	1 17%				3.57(4.69) 58%	11.00(9.04) 83%	2.67(2.08) 25%			20.45(29.84) 92%	1.25(0.50) 33%	
L. George	10 7%					12.25(17.26) 86%	3.00(2.45) 29%	10 7%		10.50(12.61) 43%	1.67(1.15) 21%	
L.Mushamush L.					5 50%		2 50%					
Pringle L.						2 29%	1 14%					
TOTAL/MEAN	5.50(6.36) 9%				4.29(1.01) 23%	8.42(5.59) 69%	2.17(0.88) 26%	10 3%		15.48(7.04) 49%	1.46(0.30) 20%	

consuming adult Hemiptera and Coleoptera (*Hydrophilus* sp.), fish (*Fundulus diaphanus*) and a variety of insect larvae and nymphs. Dragonfly nymphs (Odonata) were the most commonly occurring food item in these lake populations while Cladocera, mayfly nymphs (Ephemeroptera) and Diptera pupae were also commonly eaten.

The diet of the Acadian whitefish from the Tusket River differed from the lake populations as some specimens had ingested large numbers of stonefly nymphs (Plecoptera) and blackfly larvae (Simuliidae). Those fish caught in brackish or salt water had been feeding on shrimp (Decapoda), amphipods and fish (*Ammodytes* sp.). Diptera pupae were the most commonly occurring food item for Tusket River specimens with stonefly nymphs, blackfly larvae and other diptera larvae also commonly eaten.

Lake whitefish also showed considerable variation in diet between populations as specimens from Pringle Lake fed almost exclusively on plankton (Cladocera) while those from the Mira River and Lake George were feeding mainly on benthic organisms. The Mira River specimens had ingested many amphipods, sphaeriid clams and Diptera larvae. Similarily lake whitefish from Lake George contained many amphipods, sphaeriid clams, Diptera larvae and isopods. The most commonly occurring food items for whitefish from the Mira River were amphipods although sphaeriid clams, Cladocera and Diptera larvae were also commonly eaten. Diptera larvae were the most commonly eaten food for Lake George specimens with isopods and amphipods also common.

A comparison of the proportion of major food classes consumed by Acadian and lake whitefish is presented in Table 16. While there is considerable variation between populations within a species, there are some notable differences between the two species. Whereas lake whitefish commonly fed on molluscs, Acadian whitefish never fed on this food item in freshwater. Similarily lake whitefish often contained many amphipods and isopods whereas Acadian whitefish very rarely consumed these organisms. Acadian whitefish were found to feed more heavily on insects than lake whitefish, particularily Coleoptera and winged insects characteristic of surface waters. Acadian whitefish were also found to feed on fish unlike lake whitefish. Interestingly specimens of both species were found to be feeding almost exclusively on Cladocera plankton.

TABLE 16. Feeding preferences of Acadian whitefish and lake whitefish from Nova Scotia. Values expressed as a per cent of the number of number of all food items eaten at each locality.

	ACADIAN WHITEFISH				LAKE WHITEFISH		
	Hebb Lake n=8	Milipsigate Lake n=6	Mikamkeak Lake n=4	Tusket River n=10	Mira River n=12	Lake George n=14	Pringle Lake n=7
Cladocera	45.1	2.7	99.8	-	9.1	2.5	99.8
Isopoda	-	-	-	0.9	-	12.2	-
Amphipoda	-	-	0.1	0.3	32.0	15.3	-
Sphaeriid clam	-	-	-	-	25.4	14.6	-
Gastropoda	-	-	-	-	1.6	2.3	-
Fish	-	2.7	-	0.2	-	-	-
Insect larva	-	12.2	0.1	72.7	19.2	30.9	0.1
Insect nymph	1.3	2.7	0.06	24.6	-	1.4	-
Insect pupa	1.1	27.9	-	-	3.3	4.2	0.1
Insect adult	52.4	51.7	-	1.3	-	13.9	-
Other	-	-	0.03	0.1	9.4	2.7	-

3.4 Discussion

Although critical information on the ecology of the Acadian whitefish is still lacking, available information indicates that the species has adapted to two quite different watersheds. The Tusket River is one of the larger rivers in Nova Scotia and it drains an extensive watershed with a number of large tributaries and many lakes. The river flows into a large complex estuary with many islands and extensive mud flats exposed at low tide. In contrast, the Petite Rivière is a small river, draining a series of shallow lakes, that flows into a small estuary without extensive mud flats.

The habitat occupied by the Acadian whitefish within these two watersheds is also quite different. In the Tusket River, the Acadian whitefish is anadromous, inhabiting freshwater only in the winter months and returning to seawater in the spring. Acadian whitefish have been captured extensively in brackish waters of the Tusket River and the species is also known to venture out of the estuary into full seawater. It is not known upstream of Lake Vaughn or much past Pleasant Lake on the Annis River and thus may not migrate more than about 1 km into freshwater. In the Petite Rivière however, the Acadian whitefish has adapted to an entirely freshwater existence in three small lakes. These lakes are landlocked and occur about 15 km from the sea. There may also be a small anadromous population of Acadian whitefish surviving near the mouth of the Petite Rivière.

Because of the many differences between the habitat of the Acadian whitefish in the Petite Rivière and the Tusket River watersheds, it would appear that the habitat requirements of the species are quite adaptable. Acadian whitefish have been caught in full seawater at Hall's Harbour, a considerable distance from the Tusket River, and thus appear to be able to adapt to a completely marine environment unlike most whitefish species. Reports from local residents suggest that when Acadian whitefish went to sea their movements were very similar to Atlantic salmon (W.B.Scott, in litt.).

While lake whitefish have anadromous populations (Dadswell, 1975MS; Morin et al., 1981), these populations are usually confined to estuaries and do not migrate much into seawater. Scott and Crossman (1973) suggested that the Arctic cisco, *Coregonus autumnalis*, was the most sea-going whitefish although the arctic waters frequented by this species are generally less saline than those off southern Nova Scotia.

The Acadian whitefish has also been able to adapt to the small, warm water lakes in the Petite Rivière watershed. Because the lakes are shallow, no thermal stratification forms to maintain a cold hypolimnion throughout the summer months. Typically whitefish are considered cold water fish and those inhabiting lakes normally require a coldwater hypolimnion in which to retire over the summer months. On August 26, 1983, almost the entire water column of Hebb Lake was 20°C or warmer indicating a lack of cold water habitat. There are also extensive areas of shallow water in these lakes which indicates that the volume of cool water habitat available to Acadian whitefish over the summer months is quite small and may be important in limiting population size.

Acadian whitefish in Hebb Lake are found mostly away from shallow water although in winter months they approach close to shore. They occur throughout the water column although they have been found more commonly in surface waters when the lake was isothermal in the spring and fall. In the summer months they probably retire to deeper waters, which although not cold would be cooler than surface waters.

The presence of the Acadian whitefish in surface waters is also reflected in their feeding habits. Many Acadian whitefish had eaten food characteristic of surface waters such as adults of Coleoptera, Hemiptera and flying ants, stoneflies and dipterans which had presumably fallen on the water surface. Acadian whitefish also appeared to feed in the water column consuming Diptera pupae, fish and Cladocera. While insect nymphs were commonly eaten, typically benthic food such as amphipods, isopods and molluscs were rarely consumed. This feeding behavior appears characteristic of an opportunistic predator. This observation is substantiated by the reports of anglers who have caught Acadian whitefish on hooks baited with worms or small minnows and even on a fly (Piers, 1927). The flies were usually taken from two to six inches above the water surface.

Acadian whitefish from the Tusket River also appeared to be opportunistic predators having fed on a variety of active prey including stonefly larvae, shrimp, fish and adults of a variety of insects. Scott and Crossman (1973) reported specimens from Yarmouth Harbour had eaten amphipods, small periwinkles, (*Littorina littorea*) and marine worms although molluscs and marine worms were not found in this study.

A growth study of Acadian whitefish was not done although individuals from the Tusket River indicate that the species can reach a length of at least 507 mm TL (475.35 mm SL). One resident from the Tusket River area recalled seeing specimens as large as 8 pounds (W.B.Scott, in litt., 1975). Acadian whitefish in the Petite Riviere lakes do not reach such a large size and the largest specimen examined in this study was 317 mm TL (270.35 mm SL). Anglers have reported specimens from 7 to 16 inches (175-400 mm) although rare individuals as large as 18 inches (450 mm) have also been caught (Piers, 1927). These anglers also reported that specimens usually ranged from 1¼ to 1½ pounds. All specimens of Acadian whitefish examined in this study were mature except for one specimen from Minamkeak Lake which was the smallest at 147.49 mm SL. The next smallest specimen was a mature male, 177.96 mm SL., from Hebb Lake.

The amount of information available on the spawning behavior and early life history stages is still extremely limited. Spawning in the Petite Rivière lakes probably occurs in late fall or early winter similar to most other whitefishes. Semple (1973) found lake whitefish from Scotch Pond, N.S., started to spawn on December 10 when water temperature had dropped to 5°C. most other whitefishes. Acadian whitefish in Hebb Lake had not spawned as late as November, 13 in 1982 when water temperature was 10°C. The gonads of these specimens were well developed but the fish did not appear ready to spawn for some time. Specimens caught in Hebb Lake on May 22, 1983 when water temperature was 14°C had much smaller gonads indicating spawning had occurred previously.

Similarily, the Acadian whitefish in the Tusket River probably spawns in late fall or early winter. The female specimen caught in the Annis River on October 11, 1982, when water temperature was 12°C had well developed ovaries but was not yet ready to spawn. A specimen caught at the Tusket River dam on November 4, 1967 also had well developed gonads but was not ready to spawn. Specimens caught in the Tusket River on May 24, 1940 and June 24, 1966 had poorly developed gonads indicating spawning had taken place earlier.

With the information gathered on lake whitefish populations in Nova Scotia during this study it is possible to make preliminary comparisons between this species and the Acadian whitefish. Whereas the Acadian whitefish was found throughout the water column and particularly in surface waters in the Petite Rivière Lakes, lake whitefish were more common near the bottom. In keeping with these habitat preferences, the Acadian whitefish was found to be more of an opportunistic predator, while lake whitefish appeared to be more typical benthos feeders. These feeding differences agree with morphological differences in mouth shape noted previously between the species. The Acadian whitefish has a terminal mouth with small but well developed teeth while the lake whitefish has a subterminal, toothless mouth. The different mouth shapes and habitat and food preferences would suggest the Acadian whitefish and lake whitefish are adapted to different ecological niches.

Lake whitefish did not feed much on active prey such as fish or the nymphs and adults of insects. Lake whitefish from the Mira River and Lake George fed mainly on benthic food such as small molluscs, amphipods and Diptera larvae. This diet is similar to that of lake whitefish occuring in the lower Saint John River, N.B., which fed almost exclusively on molluscs with amphipods and insect larvae the next most abundant food items (Dadswell, 1975MS). However, adult lake whitefish have been reported to feed on a wide variety of food including fish and insects from surface waters (Scott and Crossman, 1973) and the lack of such food items in this study may be the result of small sample sizes.

The lake whitefish from Pringle Lake, N.S., were found to consume mainly plankton. The mean gillraker number of these whitefish was 30.9 compared to 25.1 and 22.6 for Lake George and Mira River specimens respectively. Lake whitefish from Pringle Lake also had proportionally longer gillrakers than Lake George and Mira River specimens. The association of more and longer gillrakers with mainly pelagic feeding has been frequently observed in a number of *Coregonus* species (Svardson, 1952, 1965; Lindsey, 1963; Scott and Crossman, 1973; Bodaly, 1979) although exceptions have also been found (Kliewer, 1970). While gillraker number in coregonid fishes can reflect environmental influences, this character is known to have a strong hereditary component (Svardson, 1952; Lindsey, 1981). Populations of lake whitefish such as in Pringle Lake may thus represent populations that have adapted to feeding on available plankton and may be quite genetically distinct from the more widespread low gillraker number, benthic feeding lake whitefish populations. This genetic difference may be significant enough in some cases to suggest the high gillraker number forms of lake whitefish are distinct species (Fenderson, 1964; Kirkpatrick and Selander, 1979; Bodaly, 1979).

Unlike gillraker number, the length of gillrakers seems to be a character more easily modified by environmental influences. The second generation of a transplanted stock of lake whitefish was found not to differ from the parental stock in gillraker number although there was a significant difference in gillraker length (Loch, 1974). Loch felt that only two generations was not sufficient time for natural selection to produce this difference and that environmental factors rather than genetic ones caused the observed difference. In this study, populations of Acadian whitefish and lake whitefish that had fed predominantly on benthic food were found to have shorter gillrakers. Similarily, Kliewer (1970) and Loch (1974) in studies of lake whitefish found a strong negative corelation between gillraker length and the percentage of benthic food eaten which led to hypotheses of shorter gillrakers resulting from mechanical wear on gillrakers during feeding on harder benthic organisms (Loch, 1974) and from a dietary effect on gillraker development (Tretiak, 1975).

It is evident from results presented in this chapter that the Acadian whitefish is not abundant in the Tusket River or the Petite Rivière watershed. Despite extensive netting in the Tusket River watershed during this study, no specimens were caught in the Tusket itself and only two Acadian whitefish were caught in the Annis River. The main Tusket River population may already be extinct as there was no evidence of a fall migration at the Tusket River dam in 1982 and there has been no recent report of an Acadian whitefish from fishermen below the dam. While Acadian whitefish appeared more abundant in the Petite Rivière watershed, few specimens were caught per hour of fishing effort and the specimens represented only about 5% of the specimens of all species caught. These low numbers of Acadian whitefish reported from the Tusket and Petite Rivière watersheds are in marked contrast to the numbers previously occupying these watersheds.

Prior to 1940, Acadian whitefish were abundant in the Tusket River and it was not uncommon for a gaspereau fisherman to accidentally catch 200 specimens in a season (Gilhen, 1977MS). Gilhen also mentions a gaspereau fisherman on the Annis River who said that years ago it was common to catch 50 to 100 Acadian whitefish a year. While there is little information on population size in the past from the Petite Rivière lakes, anglers have reported catching as many as two dozen Acadian whitefish in a days fishing at the Milipsigate Lake dam outlet (E.Mandaggio, personal comm.; E.March, in litt).

The decline of Acadian whitefish appears to have been somewhat different between the Tusket and Petite Rivière watersheds. The abundance of Acadian whitefish in the Tusket River started to drop noticeably in the 1940's, possibly due to the installation of more turbines in the Tusket River dam (Gilhen, 1977MS). The decline of Acadian whitefish in the Petite Rivière watershed is less documented and may not have been as significant. It is likely that the Acadian whitefish was never very abundant in the Petite Rivière lakes as the lakes are small and shallow and have probably never provided an extensive habitat to support large populations of Acadian whitefish.

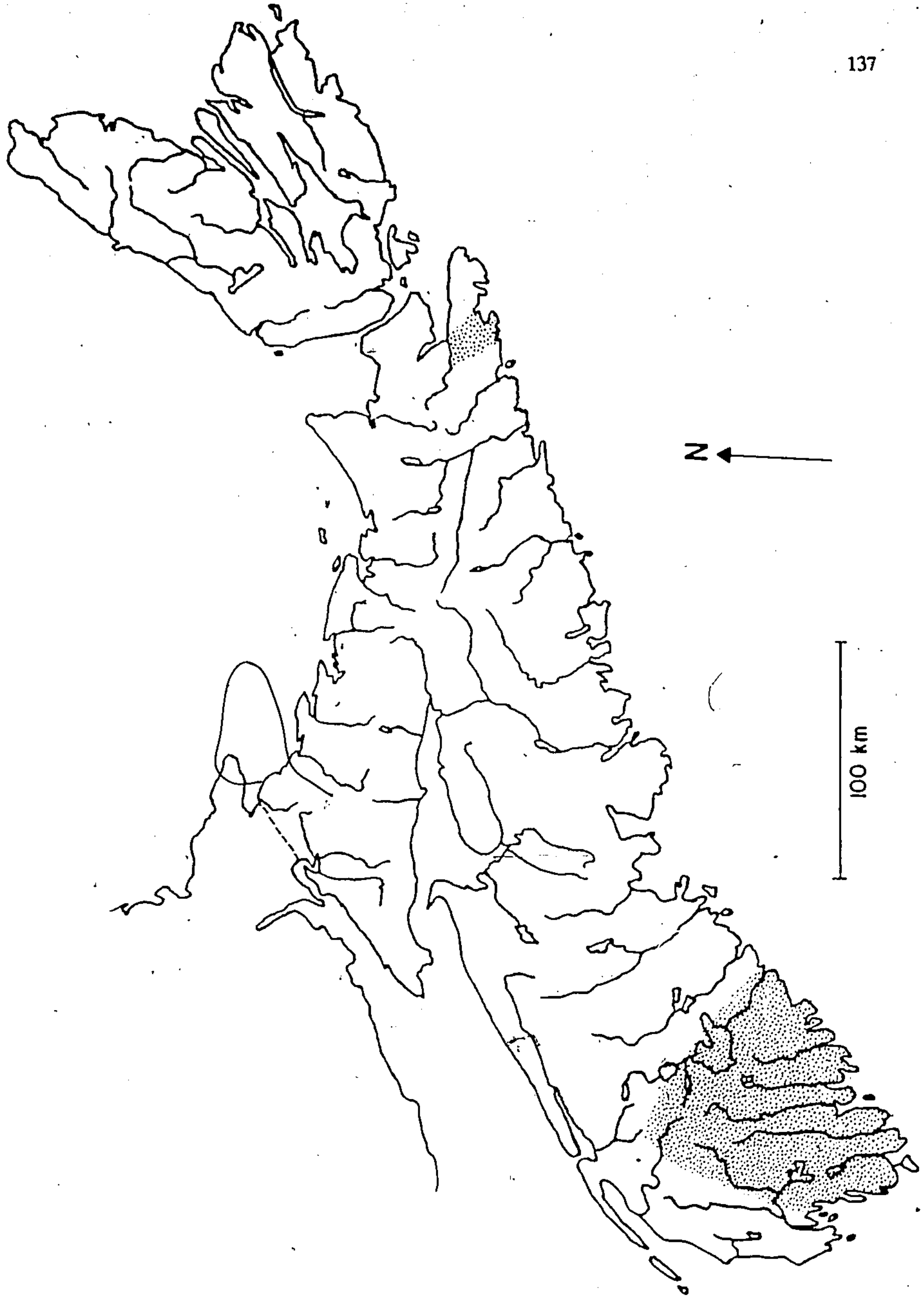
While it is interesting that the decline of Acadian whitefish in the Tusket River took place close to the time of the perceived increase of acid precipitation in Nova Scotia in the 1950's, the impact of acidification on the species is not well understood. Available information would suggest that, as a group, whitefishes are not as sensitive to low pH as other salmonid species. Haines (1981) noted that lake cisco and lake whitefish ceased reproduction or declined in abundance only at pH's from 4.4 to 4.7 and below 4.4 respectively. Beamish (1976) considered the lake cisco to be relatively tolerant to low pH and Kerekes (1982MS) found lake whitefish in Nova Scotian lakes where pH readings were at least as low as 4.9.

Perhaps of greatest concern to the survival of Acadian whitefish is that the acid sensitive stages for the species coincide fairly closely with the time of annual pH minimums. The most acid sensitive stages for most fish species are the early developmental stages and particularily the newly hatched larvae (Farmer et al., 1980; LaCroix et al., 1985). In southwestern Nova Scotia pH minimums occur in midwinter when Acadian whitefish eggs would be incubating and the pH's are still low in early spring when newly hatched larvae of Acadian whitefish would presumably be present. The pH of Hebb Lake in February, 1985 was 4.5 and the pH of the Annis and Tusket Rivers in March, 1985 was 5.15 and 4.66 respectively. While the failure to find young Acadian whitefish in these localities may be due to lack of appropriate fishing gear and habitat sampling, a lack of young could also indicate recruitment failure. Beamish (1974) and Harvey (1980) have found that it is frequently the failure of young fish to be recruited into the population that leads to the loss of a species from a lake rather than the direct toxic effects of acidity on adults.

The recent acidification of waters in southwestern Nova Scotia may also provide information concerning the curiously disjunct distribution of the Acadian whitefish in the Tusket and Petite Rivière watersheds. A map of Nova Scotia is shown in Figure 29 which indicates the acid sensitive areas of the province where river pH's are frequently below 4.7 and many native Atlantic salmon populations are now extinct. It is interesting that the Petite Rivière and the Tusket River (more specifically the Annis and Carleton tributaries) are unique in occurring just at the perimeter of this acid sensitive area. It is possible that acidification of the watersheds between the Tusket and Petite Rivière watersheds caused the extinction of intervening populations of Acadian whitefish although there is no historical record of such populations to substantiate this.

The Petite Rivière may also have provided a unique habitat for Acadian whitefish survival compared to most other watersheds in Nova Scotia. The Petite Rivière lakes have always been relatively free from pollution because their water quality had to be maintained to provide clean water for the Town of Bridgewater. The Petite Rivière watershed is also one of the few in Nova Scotia that has not had introductions of brook trout, *Salvelinus fontinalis*. It is not known what impact there is on native fish popula-

Figure 29: Map of Nova Scotia adapted from Watt et al. (1983) showing areas sensitive to acidification and where mean annual river pH is below 4.7.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100 km

tions resulting from the introductions of brook trout and other species such as Atlantic salmon, rainbow trout or chain pickerel. While these present ecological factors may be important in explaining the distribution of Acadian whitefish, historical factors such as human alterations of habitat or even events associated with the Wisconsin Ice age must also be considered. Why the Acadian whitefish should be confined to only a small part of southwestern Nova Scotia and nowhere else is interesting and will be explored further in a discussion of zoogeography.

Although a considerable amount of information has been gathered on the habitat of the Acadian whitefish, there are still many aspects of the ecology of the species that are poorly known. The paucity of information on the ecological requirements of the Acadian whitefish in the Tusket River is particularly apparent. The migration patterns of the species in the sea and freshwater are poorly known and there is still virtually nothing known about spawning time, spawning grounds or the early life history stages. These aspects of the ecology of the Acadian whitefish in the Petite Rivière lakes are also poorly understood and in need of investigation.

Chapter IV

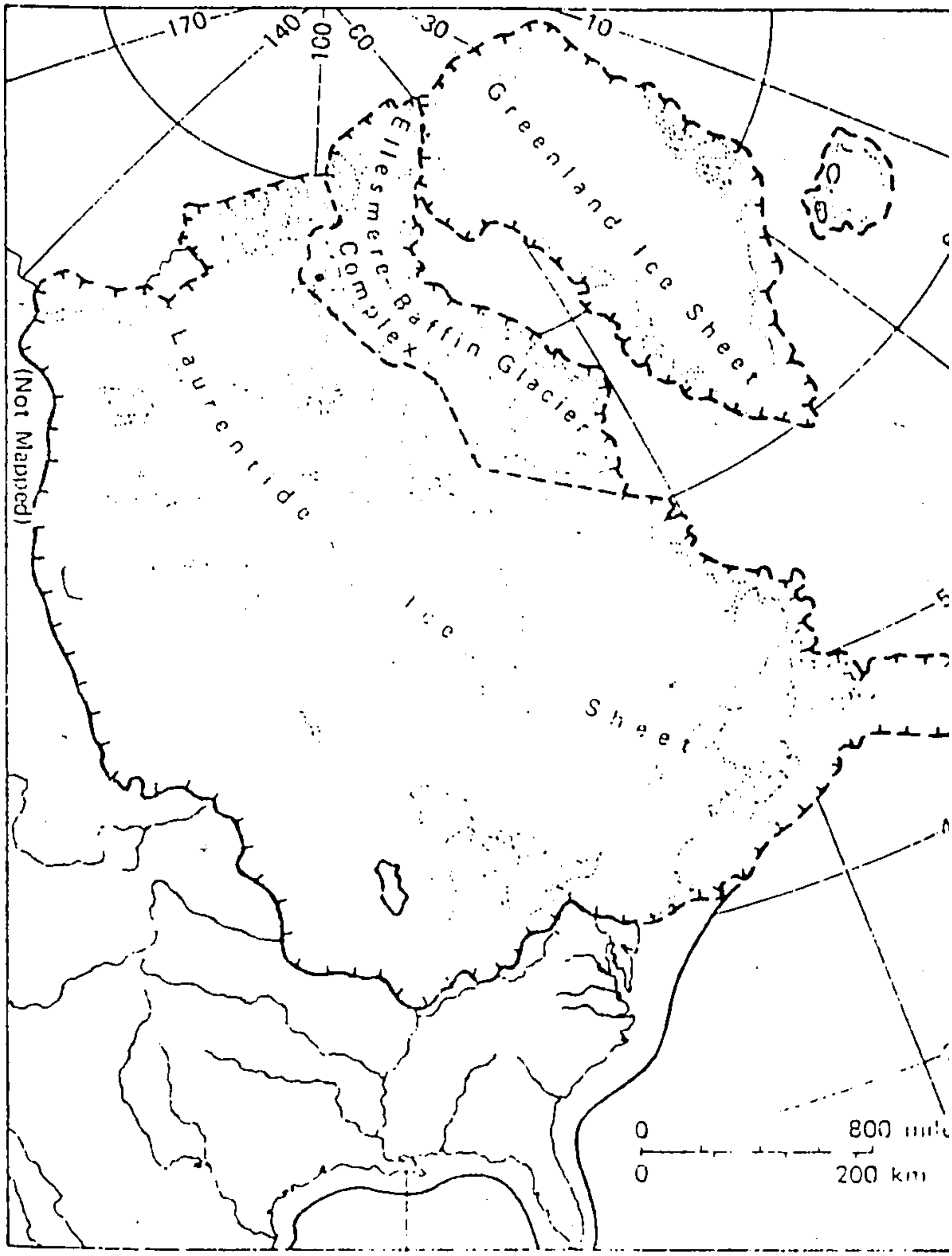
ZOOGEOGRAPHY

The distribution of the Acadian whitefish is curiously disjunct and very restricted. It was suggested that the disjunct distribution of the species could be the result of the acidification of intervening watersheds in the preceding ecological discussion. Why the Acadian whitefish should be restricted to only southern Nova Scotia, however, raises some interesting questions concerning the glacial history of the Maritimes region.

The Maritimes region has been glaciated many times in the past (Piper, 1975). The most recent glacial period, the Wisconsin, is believed to have started 100,000 years ago and consisted of several glacial advances and recessions (Prest, 1970). Interpretation of Wisconsin glacial events has been controversial, particularily concerning the extent of glaciers during the most recent glacial maximum of the late Wisconsin.

Two different models have prevailed on the extent of late Wisconsin glaciers in eastern North America; the Maximum and Minimum models (Ives, 1978; Prest, 1984). According to the Maximum model which has prevailed since the 1940's, the Maritimes region was completely over-riden by the advancing Laurentide Ice sheet which extended offshore well past present coastlines (Figure 30). This model was advanced most strongly by Richard Flint and was perpetuated by publications of a glacial map (Flint et al., 1945) and three text books (Flint, 1947; 1957; 1971). On the basis of the Maximum model, all plants and animals now found in the Maritimes region must have arrived from ice-free refugia outside the region after the retreat of glaciers about 18,000 years BP.

Figure 30: Map of eastern North America showing the maximum extent of Late Wisconsin glaciers according to Flint (1971).

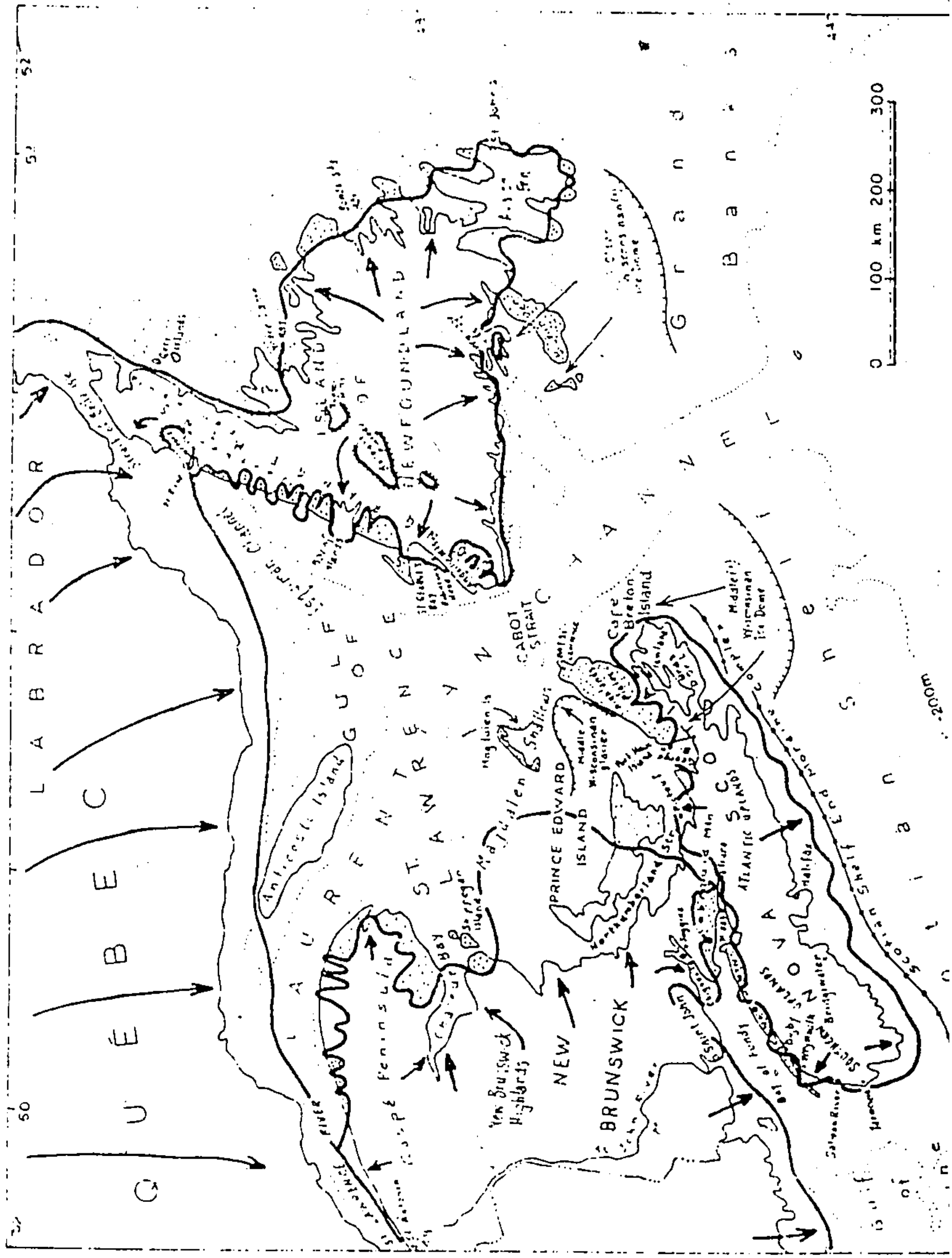

170
140
100
60
30
10
Greenland Ice Sheet
Ellesmere-Baffin Glacier Complex
Laurentide Ice Sheet
(Not Mapped)
0
800 mile
0
200 km

The Minimum model which prevailed prior to 1940, was based upon patterns of weathering and glacial erosion in higher mountain ranges of Labrador and around the Gulf of St. Lawrence (Ives, 1978). Studies of these areas suggested they had not been over-riden by glaciers in the late Wisconsin. While this model lost support following the interpretations of Flint and colleagues, it has recently come to attention again.

One source of support for the Minimum model has come from studies suggesting that the Maritimes Region was not covered by the Laurentide Ice sheet during the late Wisconsin period, but was instead covered by smaller, locally derived ice caps (Prest and Grant, 1969). While these ice caps could have completely covered the Maritimes region and coalesced with the Laurentide ice sheet at some time in the past, their extent during the late Wisconsin maximum about 18,000 years BP is now believed to have been less extensive than previously thought (Prest et al., 1976; Grant, 1977; Alam and Piper, 1977; Ives, 1978; Quinlan and Beaumont, 1982; Grant and King, 1984; Rampton et al. 1984; King and Fader, 1986; Grant, 1987).

Grant (1977) combined evidence from stratigraphic sections, a raised interglacial platform, iceflow indicators and the weathering of terrain to re-interpret Wisconsin glacial events in the Maritimes region. This evidence lead him to suggest that " the Wisconsin stage began with the growth of local ice caps at an early stage, culminated with a relatively early flood of ice over nearly the whole area, then after a widespread withdrawl more than 40-50,000 years BP, readvance with declining vigor at least twice again but only from local midland or lowland sources that were not competent to override much of the area " (p. 251). Grant hypothesized that the late Wisconsin glaciers extended almost to and only slightly beyond the present coastline leaving many upland and highland nunatuks and large areas of emerged shelf as potential ice-free areas (Figure 31).

Figure 31: Map of the Maritime region and surrounding area showing the maximum extent of Late Wisconsin glaciers according to Grant (1977). Bold line- inferred limit of Late Wisconsin glaciers; stippled areas- nunatuks and other extra-glacial areas; arrows- main direction of ice flow; pecked line- speculative limits of earlier ice masses.


QUEBEC
LABRADOR
GULF OF ST. LAWRENCE
ISLAND OF NEWFOUNDLAND
Anticosti Island
Gaspé Peninsula
Chaleur Bay
New Brunswick Highlands
NEW BRUNSWICK
PRINCE EDWARD ISLAND
Magdalen Is
CABOT STRAIT
Cape Breton Island
NOVA SCOTIA
ATLANTIC UPLANDS
Halifax
Bay of Fundy
Saint John
Scotian Shelf End Moraine
Grand Banks
Laurentian Channel
200m
0 100 km 200 300

The Acadian whitefish has been hypothesized to have survived the Wisconsin period on emerged offshore Scotian banks and then dispersed to Nova Scotia following deglaciation (Schmidt, 1986). This hypothesis seems to be based mainly on the Maximum model of Wisconsin glaciation in the Maritimes Region. The Minimum model suggests the Acadian whitefish could have survived at least the late Wisconsin glacial advance in an ice-free refugia in southwestern Nova Scotia rather than on offshore banks. The possibility of such a mainland refugium has also been suggested based on evidence from fossil molluscs (D.E. McAllister, pers. comm.).

The evidence for a late Wisconsin glacial refugium in southwestern Nova Scotia is provided by locally derived surface tills of late Wisconsin age that have been found to terminate at small moraines a few miles inland from the present coastline (Grant, 1977; 1986). Glacial maps have thus shown a late Wisconsin glacial limit just inland of the present coastline near Salmon River, N.S. (Grant, 1977; 1987). This Minimum model suggests an extensive ice-free area could have existed along the coast and on adjacent offshore areas as a result of lowered sea levels at the time.

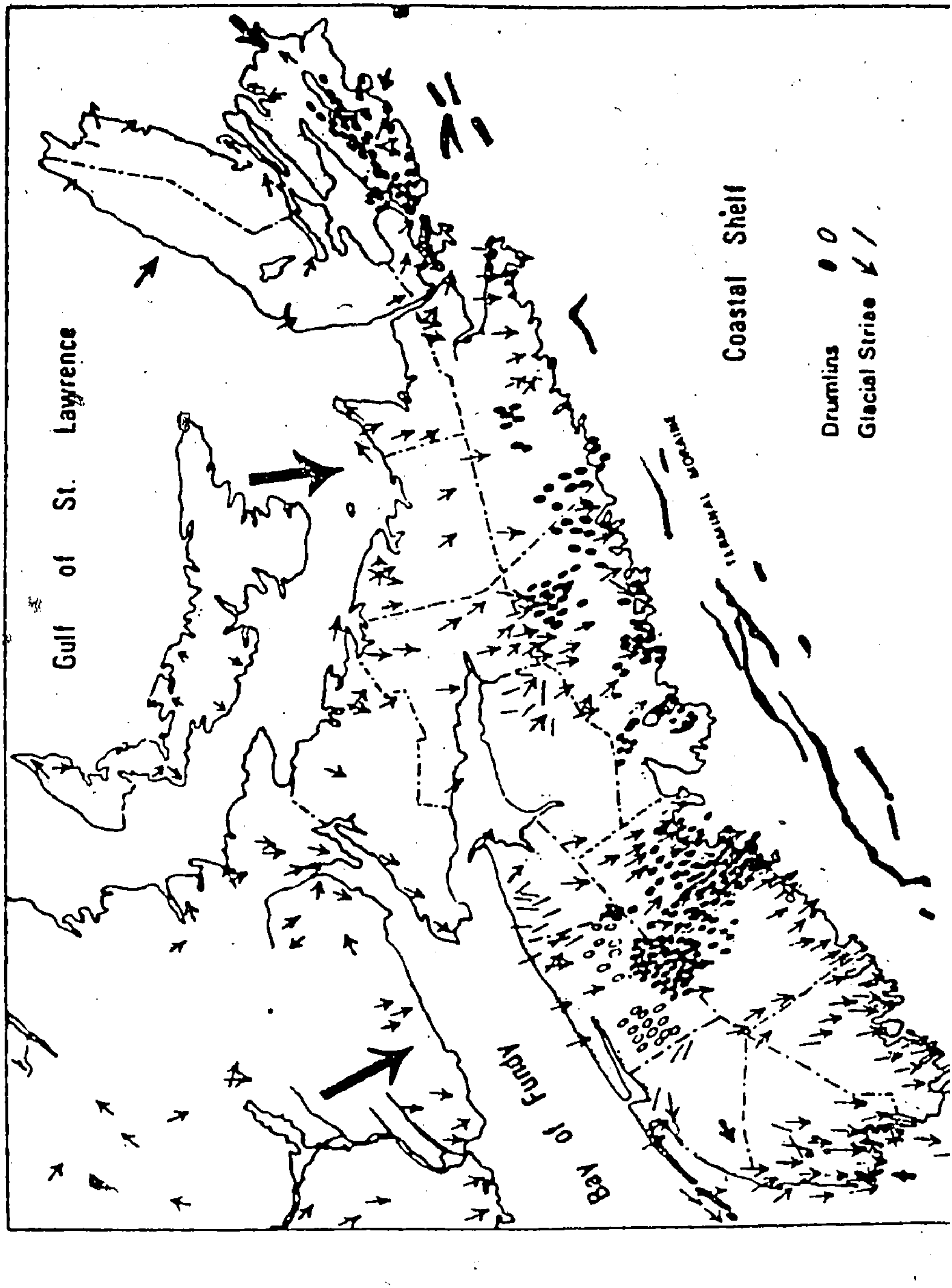
The ice-free area in southwestern Nova Scotia might have served as a glacial refugium for the Acadian whitefish even through the middle Wisconsin period. While an early Wisconsin glacial advance may have extended well offshore onto the Nova Scotian shelf earlier than 40,000 years BP, the extent of glaciers after that advance was less widespread (Grant, 1977; Grant and King, 1984; King and Fader, 1986). Marine shells including an extinct gastropod, *Atractodon stonei*, suggest that parts of southwestern Nova Scotia were ice-free in the middle Wisconsin (King and Fader, 1986). Analysis of these shells has given an average radiocarbon age of 38,600 $\pm$ 1300 years BP, and U-Th ages of 40,000-30,000 years BP (Wagner, 1977). The shell fauna was also found to be indicative of water temperatures comparable to those in this area today (Wagner, 1977). This suggests that the glaciers may not have extended that far offshore during Middle Wisconsin advances and that climatic conditions during this time may not have been too severe for a biological refugia.

To account for warmer temperatures during the Middle Wisconsin, it has been hypothesized that a northward shift of the Gulf Stream may have provided a more hospitable maritime climate in spite of the presence of mainland glaciers (Nielson, 1974; Wagner, 1976). The Gulf Stream might have had a stronger influence in the area as a result of a reduction in the flow of the cold Labrador Current which would have been deflected from its normal inshore path by glacial ice or exposed offshore shelf areas (Bousefield and Thomas, 1975; Alam and Piper, 1983). Whether southwestern Nova Scotia could have provided a refugium for the Acadian whitefish during all glacial advances of the early and middle Wisconsin is still uncertain.

Recent geological data is compatible with the hypothesis that the Acadian whitefish survived at least the Late Wisconsin period in a refugium in southwestern Nova Scotia. Glacial events might thus be important in understanding the present restricted distribution of the Acadaian whitefish. It is interesting that the Acadian whitefish is found only in areas of Nova Scotia with glacial drumlins (Figure 32). Drumlins are sporadically distributed in glaciated areas and have long been used to interpret the direction of flow of former glaciers (Menzies, 1979). The unusually disjunct population of arctic ciscoe in northern Ireland (Ferguson et al., 1978) is also found in an extensive drumlin field. While drumlins are believed to form as a result of subglacial processes, there is still uncertainty about factors determining drumlin development (Menzies, 1979).

The drumlin field occuring in the Tusket River estuary has been reported to be an interesting anomally (Gravenor, 1974). Many drumlins were found to indicate ice flow onshore from the south contrary to expected ice flow from inland sources. While drumlin shape can be variable, it is unlikely that over 50% of the drumlins should indicate a

Figure 32: Map of the distribution of drumlins in Nova Scotia taken from Roland (1982).


Gulf of St. Lawrence
Coastal Shelf
TERMINAL MORAINE
Drumlins
Glacial Striae
Bay of Fundy

reverse ice flow. This apparent onshore ice flow has also been noticed in Cape Breton and could be attributed to pre-Wisconsin glacial events or unique events associated with advances of glaciers from exposed offshore shelf areas (Grant and King, 1984). The geological uniqueness of the Tusket River area is thus an interesting parallel to the biological uniqueness of this river with its populations of Acadian whitefish and disjunct coastal plain plant species (Keddy, 1985).

While the Acadian whitefish could have been restricted to southwestern Nova Scotia by glacial events initially, subsequent ecological factors would also have contributed to its present distribution. Southwestern Nova Scotia has a depauperate freshwater fish fauna as the peninsular shape of the Province has restricted the postglacial dispersal of fishes from New Brunswick (Livingstone, 1953; Gilhen, 1974). This depauperate fauna could therefore provide a less competitive environment for the Acadian whitefish.

The Acadian whitefish does not occur with other salmonid species to any great extent. It is not known to co-exist with the lake whitefish or with the brook charr *Salvelinus fontinalis*. The brook charr is widespread in the Maritimes region and appears to have similar behavioral habits to the Acadian whitefish. The brook charr may occupy a similar niche to the Acadian whitefish and be a superior competitor. The Petite Rivière watershed is one of the few in Nova Scotia that has not had introductions of the brook charr. While the Acadian whitefish occurs in the Tusket River with the Atlantic salmon, the anadromous migrations and freshwater periods of these two species occur at different times.

In summary, recent geological interpretations of the Wisconsin glacial history of northeastern North America support the recognition of a number of Late Wisconsin ice-free areas in the Maritimes region. The geological data does not refute the hypothesis of a Late Wisconsin refugium for Acadian whitefish in southwestern Nova Scotia. The data also indicate a need to review the biogeography of northeastern North America. Early hypotheses of refugia in areas around the Gulf of St. Lawrence for plants (Fernald, 1925) and beetles (Lindroth, 1963) are now better supported by geological evidence (Grant, 1977). Some of these refugia have been a source of controversy for many years (Drury, 1969).

SUMMARY

1. The Acadian whitefish has been readily distinguished from all North American whitefishes except the lake whitefish species complex. The morphological and biochemical data presented in this thesis provide evidence to support the recognition of the Acadian whitefish as a valid species, distinct from the biological variation exhibited by the lake whitefish species complex.

2. Principal component and discriminant function analyses of 10 meristic characters and 43 morphometric characters found Acadian whitefish to be completely distinguished from specimens of lake whitefish from the Maritimes region. The Acadian whitefish was significantly different from lake whitefish for 35 of 53 characters examined ($p < .01$).

3. Acadian whitefish and lake whitefish were best distinguished by vertebrae number. This character completely separated over 99% of Acadian whitefish (64-67, $\bar{X}$=65.3) and lake whitefish (58-64, $\bar{X}$=60.6) specimens. Adipose to caudal length, adipose base length, nare diameter, lateral line scales and the length of the pelvic axillary process also showed highly significant differences between the species. Acadian whitefish were found to have a terminal mouth, a ventral notch in the adipose eyelid of most specimens (82%) and a different arrangement of pearl organs than lake whitefish. The latter species had a subterminal mouth and a ventral notch in the adipose eyelid of only a few specimens (11%).

4. Acadian whitefish were clearly distinguished from lake whitefish in an electrophoretic analysis of eight polymorphic genetic loci. Acadian whitefish and lake whitefish were fixed for alternate alleles at two loci (GPDH-A,B) and had different allele frequencies at three other loci (IDH-A,B, MDH-B). Acadian whitefish were also found to have unique alleles for MDH-B and LDH-skeletal loci not predicted by present genetic models for lake whitefish.

5. The taxonomic position of the Acadian whitefish remains uncertain. While gill raker number suggests the species should be classified as a true whitefish (*Coregonus*), a number of other morphological characters suggest affinities to the ciscos (*Leucichthys*). The biochemical data in this thesis, although not conclusive, found Acadian whitefish to be more similar to Arctic ciscos from the Northwest Territories than lake whitefish from Nova Scotia.

6. Principal component analyses of morphological variation in lake whitefish populations in the Maritimes region found no clearly distinguishable population. However, canonical variate analyses found populations from the Mira River, N.S., and Kerr Lake, N.B. to be completely distinct. These populations had unusually low lateral line scale counts for the species and the gill raker counts for the Mira River population were low for eastern North America.

7. Dwarf whitefish from Square Lake, Me., were not found to be morphologically distinct from the other populations of lake whitefish in the Maritimes region. It had been anticipated that these specimens might have shown a distinctiveness reflecting their prior taxonomic recognition as *Coregonus stanleyi* Kendall, 1903. The lack of distinction using the characters examined in this study does not invalidate the previously established evidence for taxonomic recognition. A thorough taxonomic study of this putative species is still required.

8. The distribution of the Acadian whitefish was found to be very restricted and curiously disjunct. The species is confined to Minamkeak, Milipsigate and Hebb Lakes in the Petite Rivière watershed, Lunenburg Co., and the Annis River in the Tusket River watershed, Yarmouth Co. While formerly abundant in the main branch of the Tusket River, the species now appears extirpated from this locality. Specimens were caught several decades ago in seawater from Hall's Harbour, Kings Co., N.S., Yarmouth Harbour, Yarmouth Co., N.S. and probably from the mouth of the Sissiboo River, Digby Co., N.S.

9. Lake whitefish were found to be more common in Nova Scotia than previously believed. Populations were found where local anglers and government records were not aware of their existence. While lake whitefish were introduced into the Maritimes region around the turn of the century, early natural history accounts suggest at least some of these populations are native to this region.

10. The Acadian whitefish population in the Tusket River watershed is anadromous whereas the lacustrine populations in the Petite Rivière are landlocked. Some evidence suggests a small anadromous population of Acadian whitefish may occur in the lower Petite Rivière. The Petite Rivière lakes were found to be shallow (maximum depths 13 to 16m), and without a coldwater significant hypolimnion in the summer months. Acadian whitefish were not common in these lakes, comprising only from 2.3 to 10.8% of the gillnet catch of all fish specimens in each lake. Acadian whitefish were caught more than twice as often in gillnets set at the surface over deep water as compared to mid-water and bottom sets in these lakes. Despite considerable effort, no Acadian whitefish were caught in seines, minnow traps or a small trap net in the Petite Rivière lakes.

11. Acadian whitefish in the Petite Rivière lakes were found to feed on active prey such as flying and surface swimming insects, dragonfly and mayfly nymphs, zooplankton and small fish. Specimens from the Tusket River had ingested large numbers of stonefly nymphs and blackfly larvae as well as flying insects and fish. Little information was obtained on the spawning of Acadian whitefish although specimens from the Annis River and Hebb Lake had not spawned in 1982 by October 12 and November 17 respectively. The ecology of the Acadian whitefish is still poorly known.

12. Lake whitefish in Nova Scotian lakes were caught more than twice as often in gill-nets set on lake bottoms as compared to mid-water and surface sets. They were found to be feeding on more typically benthic prey such as amphipods, sphaeriid clams and chironomid larvae although specimens from Pringle Lake, N.S., with high gill raker counts, were feeding almost exclusively on zooplankton. Preliminary data, although not conclusive, suggest Acadian whitefish and lake whitefish occupy different ecological niches.

13. The restricted and curiously disjunct distribution of the Acadian whitefish was suggested to be the result of man-made habitat alterations, ecological factors and historical factors associated with the Wisconsin Ice Age. There is now geological evidence for an ice-free area in southwestern Nova Scotia that could have served as a Late Wisconsin refugium for the Acadian whitefish. This geological evidence also suggests a need to review the biogeography of northeastern North America.

14. Acidification of the habitat of the Acadian whitefish threatens the species with extinction. In the winter of 1984/85, Acadian whitefish adults and incubating eggs in the Annis River and Tusket River main branch faced pH's at least as low as 5.0 and 4.6 respectively. While slightly better buffered, the Petite Rivière lakes yielded alkalinity values below detection and pH's as low as 4.5 during the winter of 1984/85. This lev-

el of acidification threatens the survival of Acadian whitefish and the species is classified as endangered.

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APPENDIX 1. Freshwater fish capture data from the lower Tusket River watershed, Yarmouth Co., N.S.. Gear letters are as follows; G- gillnet, H- hoopnet, T- trapnet and effort is expressed in hours. Species refer to: 1- Acadian whitefish, 2- brook charr, 3- Atlantic salmon, 4- brown trout, 5- smelt, 6- chain pickerel, 7- white sucker, 8- brown bullhead, 9- eel, 10- golden shiner, 11- white perch, 12- yellow perch, 13- Alosa species, 14- tomcod.

NMC NO.	LOCALITY	DATE	GEAR/EFFORT	SPECIES 1	2	3	4	5	6	7	8	9	10	11	12	13	14
82-651	Salmon Lake, N.S.	Oct.04/82	G-15						3	35	6			60	22	1	
-652	"	"	"						2	4	2		2	5	3		
-689	Annis River, N.S. (basin)	Oct.12/82	G-12	1													
-691	"	"	G-18					6								12	12
-716	"	Oct.17/82	G-12					14									16
-721	"	Oct.18/82	G-24														1
-722	"	"	"					17									16
-724	Tusket River, N.S. (bridge)	Oct.20/82	G-18					82								3	23
-725	" (narrows)	"	"					10									8
-814	Raynards Lake, N.S.	Nov.16/82	G-15		1			1					1	10	24		
-815	"	"	"					2				1		10	5		
-816	"	"	"		3	1		7						1	1		
82-653	Annis River, N.S.	Oct.4/82	H-14							7		1		1		2	
-655	"	Oct.5/82	H-13							1				1			
-662	"	Oct.7/82	H-24									1					
-668	"	Oct.8/82	"				1										
-675	"	Oct.9/82	H-48							1				1			
-684	"	Oct.11/82	H-15	1													
-690	"	Oct.12/82	H-24		1												
-696	"	Oct.13/82	"			1								1			
-726	"	Oct.20/82	"			2										1	
-663	"	Oct.7/82	T-24					1				3				1	
-669	"	Oct.8/82	"									7				2	6
-676	"	Oct.9/82	T-48					1				35					7
-683	"	Oct.11/82	T-24									9					5
-692	"	Oct.12/82	"									21					11
-714	"	Oct.17/82	"									27					1
-723	"	Oct.19/82	T-48									7					1

APPENDIX 2. Freshwater fish capture data from lakes in the Petite Rivière watershed, Lunenburg Co., N.S. Gear letters refer to: G- gillnet, H- hoopnet, T- trapnet, M - minnow trap, S- seine and effort is expressed in hours. Code numbers refer to Figures 21-23. Species refer to; 1- Acadian whitefish, 2- Atlantic salmon, 3- white sucker, 4- brown bullhead, 5- golden shiner, 6- banded killifish, 7- white perch, 8- yellow perch, 9- nine-spine stickleback, 10- eel.

NMC NO.	LOCALITY	CODE	DATE	GEAR/EFFORT	SPECIES 1	2	3	4	5	6	7	8	9	10
82-805	Hebb Lake, N.S.	1	Nov.12/82	G-16	2		2				19	2		
-806	"	2	"	"	4						7			
-807	"	3	"	"	2						3	5		
-808	"	4	"	"			19				59	1		
83-183	"(day mid-water)	6	May 22/83	G-6			2							
-184	"(day bottom)	7	"	"			2				5			
-188	"(night surface)	8	"	"	5			1						
-189	"(night mid-water)	9	"	"	2						4			
	"(night bottom)	10	"	"	3									
84-1455	"	11	July 12/83	G-18			9	1			12			
-1456	"	12	"	"			1				6			
-1457	"	13	"	"	3		7				5			
84-1446B	"	14	Aug. 4/83	H-96							2			
84-182	"	15	May 22/83	M-24									1	
84-1439	"	16	July 26/83	"								1		
-1440	"	17	Aug. 1/83	"						2		3		
-1445	"	18	Aug.15/83	M-48								2		
-1448	"	19	Aug.16/83	M-24								12		
-1450	"	20	Aug.17/83	"							1			
83-175	"	21	May 9/83	S						24				
-185	"	22	May 23/83	"					1	24		4		
84-1433	"	23	July 15/83	"						15				
-1434	"	24	"	"						7		2		
-1435	"	24b	July 19/83	"			3			6	1	2	1	
-1436	"	25	"	"									1	
-1443	"	26	Aug. 10/83	"			1		56	116	7			
-1443A	"	27	"	"					1	2			1	
-1446	"	28	Aug. 15/83	"					1	10			1	
-1446A	"	29	"	"			1		9	54				
-1449	"	30	Aug. 17/83	"						5				
-1449A	"	31	"	"					17	127				
-1451	"	32	"	"					23	166				
-1453	"	33	July 12/83	"						9		21		
-1454	"	34	"	"			1		3			5	2	
83-180	"	35	May 21/83	T-24					2	1				
-186	"	36	May 24/83	T-72					2	2	8	1		
-189	"	37	May 26/83	T-48			1		11	1		5		
84-1432	"	38	July 15/83	T-72										1
-1438	"	40	July 27/83	T-24					23		11			4
-1440A	"	41	Aug. 1/83	T-120										1
-1444	"	42	Aug. 11/83	T-24					4			3		

APPENDIX 2. (cont'd.)

NMC NO.	LOCALITY	CODE	DATE	GEAR/EFFORT	1	2	3	4	5	6	7	8	9	10
					SPECIES									
-1447	"	43	Aug. 16/83	T-120							2			
-1452	"	44	Aug. 17/83	T-24							1			
82-614	Milipsigate Lake	55	Sept.19/82	G-12	1			1			3			
-615	"	56	"	"			7	4			23			
-616	"	57	"	"	2						24	2		
-618	"	58	Sept.20/82	"							24	3		
-619	"	59	"	G-13			34	1			23	3		
82-620	Milipsigate Lake	60	Sept. 20/82	G-13	2			1			76	2		
-622	"	61	Sept. 23/82	G-14	1						15	1		
-623	"	62	"	"	3						36	10		
-624	"	63	"	"			2	3			14			
-789	"	64	Nov.7/82	"	2						1			2
-790	"	65	"	"							9	10		
-791	"	66	"	"			42				80	2		
-792	"	67	"	"			1				1			
-625	"	68	Sept. 24/82	S						16				
-626	"	69	Sept. 23/82	H-36							2			
-627	"	70	Sept. 24/82	H-24			4				1			1
-793	"	71	Nov. 7/82	T-24				13		3		6		
-794	"	72	Nov. 8/82	"				1		1				
-809	"	73	Nov. 13/82	T-120						4	1	1	1	
-801	Minamkeak Lake, N.S.	45	Nov. 11/82	G-18			13				12	3		
-802	"	46	"	"	4							10		
-803	"	47	"	"	1						2	2		
-804	"	48	"	"			13	4			6			
-800	"	49	Nov. 9/82	S					63					
-796	Fancy Lake, N.S.	–	"	G-18		1	11				24			
-797	"	–	"	"							6			
-798	"	–	"	"			4	1			14	32		
-799	"	–	"	"							8			
-795	"	–	"	S					1	1		2	3	

Appendix 3.

Halifax N.S.
25/5/83.

The Curator,
Museum of Natural Sciences,
Ottawa, Canada.

Re:- THE ACADIAN WHITEFISH.

Dear Sir,-

Early this year on page one of the Halifax Chronicle-Herald (copy enclosed) was an item stating a two-man team under your auspices had discovered a small number of these fish still exist in Millipsigate Lake. In view of the seeming limited knowledge existing about the Acadian Whitefish, the following comments about their former habits and habitat in this watershed may be of some interest or help to your research team.

Although the paper item stated they were thought to be extinct in 1925, for your information I caught several of the whitefish in May of 1934, not in Millipsigate but in the pond below the dam where said lake runs into Hebbs Lake. I am certain of the year and month, and believe the date was on or near May 17th. I have not been back there since.

Years ago, along with my father and brothers, we were very interested in these beautiful little fish. We fished all of the lakes that make up the watershed of the Town of Bridgewater water supply. I have caught them in Millipsigate Lake at the mouth of Birch Brook as far back as seventy years ago. My father who was born in 1871 used to tell us he caught them in the same place when he was a boy, Therefore their existence in that lake certainly dates back well over a century.

However they were never considered really plentiful in that lake. Their main area of concentration was, in my time, and according to my father, in his time, in the ponds between Millipsigate Lake and Hebbs Lake. We always believed this was their spawning area. My father used to tell us that even before the dams were built for the Town of Bridgewater water supply, these whitefish were more numerous in these ponds than anywhere else. Also many of the fish we caught there, particularly during late May and early June contained roe.

Re.- Acadian Whitefish

Many years ago, on a calm day in this area, schools of these whitefish could be seen breaking the surface of the water. On these occasions we could often fill our creel in a short time. I used a very small Silver Doctor fly, not a dry fly. They would take it best just before dark. In early spring they could be caught on a tiny minnow.
To my knowledge these whitefish have never been known to exist in any of the lakes that empty into either Millipsigate lake or Hebbs Lake, i.e. Minamkeak, Andrew, Louis, Garter and Demone Lakes. However I have caught them at the outlet of Hebbs Lake, where it emptied into Fancy Lake. Access upstream for fish there has been blocked off for over a century. I have also caught them at the spillway from the Town of Bridgewater generating plant, where it empties into Fancy Lake. No access upstream has ever been possible for fish at that place. We have also caught a few in the Petite River, at Conquerall Mills. It may be worth noting that inexperienced trout fishermen have been known to wrongly identify these whitefish as salmon parr, although the resemblance was not sufficient to warrant it.
Acid rain and dams are stated as the considered cause for the decline of these fish. While no doubt true, there was, I think, another reason. In the early 1920 s, there were persistent rumors that unscrupulous persons dynamited schools of these fish and gathered them up in nets. If the attached map, taken from a recent copy of The Nova Scotian, is reliable, the outlook for any revival of the Acadian Whitefish in the Tusket area is bleak. However the acid rain menace does not appear to be too serious at this time in the Millipsigate area, and it can be hoped these beautiful little fish may exist there for a long time yet.
Regarding the name "Acadian Whitefish" we never knew them by that name. We often tried to have them identified. We consulted the late Robie Tufts, a well known authority on Nova Scotia wild life, who was unable to help. We also consulted Mr. H. Piers, who was curator at the Nova Scitia Museum. He identified them as a branch of the cisco species.

Re:- Acadian Whitefish

My father, who was a well known artist, (his wildfowl paintings, some sixty of them, life size or to exact scale, are in the Nova Scotia Archives) once made a life size painting of one of these whitefish for Mr. Piers. It seems neither Mr, Piers nor Mr. Tufts had any knowledge of their existencee in the Tusket area, nor did we.

These Acadian Whitefish may well have been by nature an ocean fish, and when trapped in Hebbs Lake by the town storage dam, have acquired the ability of a number of other species to exist in fresh water the year round.

Millipsigate Lake is possibly the only place in Canada and perhaps in the world where these fish now exist. Ihave suggested to Col. L.M. Sebert of the editorial staff of The Canadian Geographic Magazine that this may merit mention in that publication. A copy of this letter is also being sent him.

Yours very truly,

J.E.R.March

cc.- L.M.Sebert