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Fish species distribution in relation to water quality gradients in the North Branch of the Moose River Basin

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Abstract. The distribution of fish species in the North Branch of the Moose River (Lake Rondaxe to headwaters of Big Moose Lake) was determined by intensive netting and electrofishing surveys of lakes and streams in the watershed during 1982–83. A chronology of changes in fish species occurrence in the drainage system was reconstructed from earlier published surveys conducted in 1882 and 1931 and unpublished survey data obtained by the NYSDEC during the period 1948–1975. Native species present in 1882 were also collected in 1931. Smallmouth bass (*Micropterus dolomieu*) were introduced in the early 1900's and were present in collections made in 1931. Major changes in the fish community have taken place since 1931. The smallmouth bass and many of the native species found in the earlier surveys were either absent or restricted in occurrence to downstream sites (eg. L. Rondaxe and Moss L. sub-drainage) in 1982. Non-native species introduced after 1931 (yellow perch, *Perca flavescens*; central mudminnow, *Umbra limi*; banded killifish, *Fundulus diaphanus*) are currently widely distributed throughout the drainage system. In particular, the yellow perch is now a dominant species in the larger lakes of the basin. Comparisons of survival rates for caged fish transferred from high to low pH sites in the Big Moose drainage system demonstrated relatively greater acid tolerane of non-native species (yellow perch, mudminnow, killifish) than native cyprinids. Watershed acidity gradients (pH and aluminum concentrations) and relative physiological acid tolerance are major determinants of currently observed fish species distribution patterns in the North Branch of the Moose River. Differences in age and size structure of fish populations inhabiting acidic and non-acidic lakes of the drainage system were apparent, but difficult to interpret without additional information on population size and potential density dependent parameters such as age specific growth and survival rates. Differential hatching success was observed for yellow perch eggs reciprocally transferred between acid (Big Moose) and neutral (Moss L.) lakes. Eggs transferred from Moss L. to Big Moose L. exhibited poor hatching success as a result of alterations in egg membrane structure that inhibited normal egg expansion and the hatching process. This effect was not evident in eggs from the same parents reared in Moss Lake nor in eggs from the Big Moose parents reared in both lakes. These experimental observations suggested possible genetic adaptation to acid stress by the yellow perch population inhabiting Big Moose Lake.

Introduction

Several regional surveys of water quality and fish population status have been conducted in potentially acid sensitive areas of the United States (Schofield, 1976; Pfeiffer and Festa, 1980), Canada (Harvey and Lee, 1982), and Scandinavia Muniz and Leivestad, 1980). Apparent relationships between fish species occurrence (both present and historical) and surface water quality (eg. pH, Ca. and Al concentrations), derived from these surveys constitute the primary evidence of acidification induced impacts on fish populations. Observations of fish species occurrence or disappearance at particular lake pH levels are often misconstrued as species specific dose-response functions or uncritically taken as measures of relative species tolerance to acidification. Attempts to verify these field derived relationships by laboratory bioassay have not been entirely satisfactory and conflicting observations appear to have been the rule, rather than the exception. Experimental work in the laboratory has proven useful for identifying physiological and organismal level responses to specific toxicants found in acidic waters, but dose-response functions have been developed for relatively few species and have limited field application (Baker, 1984; Haines, 1981). Clearly, new approaches are required to establish the contribution of changes in water chemistry to fish population perturbations in areas impacted by acidification.

The calibrated watershed approach has been successfully employed to elucidate and quantify geochemical acidification processes (eg. Hubbard Brook, ILWAS, and SNSF projects). However, the concept of the watershed as an experimental unit has not been fully exploited to examine acidification effects on fish populations. The field surveys described above have generally treated fish and water quality samples from lakes and streams as independent, isolated observations. In regions dominated by closed basins (eg. Seepage lakes of N. Wisconsin) this approach is reasonable. However, in the more mountainous, glacial areas of the eastern United States where open drainage lakes are prevalent these survey data should not be treated as discrete observations. Opportunities for emigration/immigration by fish populations and re-distribution to habitats offering suitable water quality for survival must also be considered when assessing fish species distribution in relation to acidification. The integrated effects of differential physiological tolerances to acidification and behavioral regulation of environmental quality were examined in this study by determination of fish species distribution patterns in relation to the spatial acidity gradients (see Driscoll et al., 1986) observed in the North Branch of the Moose River basin (NBMR). In the NBMR, acidic water chemistry is characterized by low pH-values, low alkalinity, low concentrations of basic cations (principally calcium), and elevated concentrations of aluminum (Driscoll et al., 1986). In neutral pH waters, alkalinity and concentrations of basic cations are relatively high while aluminum concentrations are reduced. Therefore, acidic and non-acidic waters encompass a range in the concentrations of several water chemistry parameters that may influence fish survival. Long term records of fish species occurrence in the NBMR were also utilized to reconstruct chronological changes in fish distribution in relation to acidification and other environmental perturbations.

Specific hypotheses addressed in this study were:

1. Observed fish species distribution across acidity gradients in the NBMR reflects the relative physiological tolerances of the species to acidification.

2. Fish populations inhabiting acidified sites, that are within the physiological tolerance zone of the species, acquire increased tolerance through selective pressures on the most sensitive life history stages. Both hypotheses were evaluated experimentally by *in situ* measurement of relative survival rates for species transferred between sites in the NBMR exhibiting divergent acidity levels.

Historical perspective

The record of observations and intensive surveys of fish species occurrence in the NBMR spans a period of 100 years. Mather (1890) provided the first description of the native fish fauna of the watershed from a survey conducted in 1882. A half century later, Greeley and Bishop (1932) conducted extensive surveys of several lakes and streams in the basin. From 1948–1975, the New York State Department of Environmental Conservation performed more than twenty lake and stream surveys to evaluate management efforts directed towards restoration of fisheries in the Big Moose watershed. Baker (1981) sampled Big Moose Lake intensively in 1977–78 to evaluate age and size structure of the yellow perch and white sucker populations. Collectively, these published and un-published records of fish species occurrence provide a chronology of fish distribution in the NBMR.

During the late 1800's and early 1900's, the indigenous fish fauna of the NBMR consisted of sixteen species (table 1). This species complex is typical of the Boreal or Glacial Relict group of the Adirondack Park (George, 1980). Mather (1890) specifically noted the absence of yellow perch from Adirondack upland waters in general and the introduction of smallmouth bass to the lower reaches of the Moose River (below L. Rondaxe) in the mid 1800's. He also gave a detailed description of two spawning populations of dwarf suckers (*C.commersoni utawana* and *C. catostomus nannomyzon*) in Merriam Lake outlet and Pancake Hall Creek. By 1931, the smallmouth bass was well established in the NBMR and Big Moose Lake in particular (Greeley and Bishop, 1932). Yellow perch had recently invaded lower sections of the Moose River, but they were absent from the North Branch. Whitefish stocking in Big Moose Lake was initiated in 1921 and this species was present in collections made in 1931. The original native species complex described earlier by Mather was also still present in 1931. Additionally, Greeley collected spawning dwarf longnose suckers (June, 1931) at the same locality in Pancake Hall Creek sampled by Mather in 1882. With the exception of lake whitefish and

Table 1. Scientific, common, and abbreviated names of fish species recorded for the North Branch of the Moose River basin.

Scientific name	Common name	Abbreviation	Origin	Status
Salvelinus fontinalis	brook trout	ST	Native	Present
Catostomus commersoni	white sucker	WS	Native	Present
Ictalurus nebulosus	brown bullhead	BH	Native	Present
Lepomis gibbosus	pumpkinseed sunfish	PS	Native	Present
Semotilus atromaculatus	creek chub	CC	Native	Present
Notropis cornutus	common shiner	CS	Native	Present*
Phoxinus neogaeus	finescale dace	FSD	Native	Present*
Rhinichthys atratulus	blacknose dace	BND	Native	Present*
Phoxinus eos	redbellied dace	RBD	Native	Present*
Salvelinus namaycush	lake trout	LT	Native	Extinct
Prosopium cylindraceum	round whitefish	FF	Native	Extinct
Rhinichthys cataractae	longnose dace	LND	Native	Extinct
Couesius plumbeus	lake chub	LC	Native	Extinct
Culaea inconstans	stickleback	SB	Native	Extinct
Cottus cognatus	slimy sculpin	SC	Native	Extinct
Catostomus catostomus	longnose sucker	LS	Native	Extinct
Perca flavescens	yellow perch	YP	Exotic	Present
Notemigonus crysoleucas	golden shiner	GS	Exotic	Present
Fundulus diaphanus	banded killifish	KF	Exotic	Present
Umbra limi	central mudminnow	MM	Exotic	Present
Micropterus dolomieui	smallmouth bass	SMB	Exotic	Present[1]
Ambloplites rupestris	rock bass	RB	Exotic	Present*
Salmo salar sebago	landlocked salmon	LLS	Stocked	Absent
Salmo gairdnerii	rainbow trout	RT	Stocked	Absent
Onhchorynchus nerka	sockeye salmon	SS	Stocked	Absent
Coregonus clupeaformis	lake whitefish	WF	Stocked	Absent
Micropterus salmoides	largemouth bass	LMB	Stocked	Absent
Stizostedium vitreum	walleye pike	WE	Stocked	Absent
Pomolobus pseudoharengus	alewife	AW	Stocked	Absent
S. fontinalis x S. namaycush	splake	SP	Stocked	Present[1]

* Present only in restricted, high waters of the basin.
[1] Only one specimen collected in L. Rondaxe.

smallmouth bass introductions, the fish community of the NBMR was essentially unchanged during the period 1882–1931.

In 1948, an unpublished survey by the New York Conservation Department revealed the presence of both yellow perch and banded killifish in Big Moose Lake. The absence of smallmouth bass and round whitefish was also noted in this survey. Complaints by anglers of poor fishing for brook trout and lake trout in Big Moose Lake in the late 1940's led to a series of extensive surveys, beginning in 1950, and a variety of changes in management policy, directed towards restoration of the fisheries in the Big Moose drainage. Attempts to control the expanding yellow perch population in Big Moose Lake by removal netting and spawn destruction in the spring were conducted from 1951–1960. The longnose sucker and lake whitefish were present in the Big Moose collections made from 1948–1953, but both species were absent from subsequent surveys conducted from 1955 to the present study. The golden shiner first appeared in samples obtained after 1955. The poor condition and declining catch of lake trout in Big Moose Lake in the early 1950's led to a program of experimental stocking of marked fingerling and yearling lake trout from 1950–1953. In 1957, 97% of the survey lake trout catch consisted of marked fish from the experimental stocking. Poor growth and condition of these stocked fish were also observed. No lake trout have been captured by survey netting in Big Moose Lake since 1966. Similar results were obtained with experimental brook trout and splake stocking programs (Pearce, 1958). In a sample of 132 brook trout obtained by angling and survey netting in 1957, 94% were marked fish of hatchery origin. A further breakdown of the recoveries revealed that 127 (96%) trout originated form a spring 1957 planting of yearlings. Less than 10% of the catch originated from previous plants of fingerlings, stocked during the period 1954–56. During the period 1960–1964, unsuccessful attempts were made to re-introduce smallmouth bass and also establish largemouth bass by stocking. Several other stocked species listed in Table 1 were also never established in Big Moose Lake. Finally, after a long succession of failures, all stocking programs in Big Moose Lake were terminated in 1975. Baker (1981) noted that the predominant species remaining in Big Moose Lake during 1977–78 were the yellow perch, white sucker, and brown bullhead. Only four brook trout were captured during two years of intensive netting. No spawning populations of either dwarf sub-species of the white and longnose sucker were observed at historical spawning sites in Pancake Hall Creek or Merriam Lake outlet during investigations conducted in 1977–78 and 1982–83.

Methods

Fish surveys

Lake and stream sites sampled for determination of fish species occurrence within the NBMR, from Lake Rondaxe to the headwaters of Big Moose Lake, are illustrated in Figure 1. Surveys were conducted during the ice-free seasons of 1982–83. Several sites were also sampled by the New York State Department of Environmental Conservation during the same period, using the same protocol described below.

Graded mesh (38–102 mm stretch) experimental gill nets (50 m long, 2 m deep), seine (7.6 m., 4.8 mm mesh), baited minnow traps (5 mm mesh), and Oneida Lake style trap nets (1.2 m. diameter car, 1.3 cm. mesh) were utilized for lake fish collections. Gill nets and minnow traps were fished for

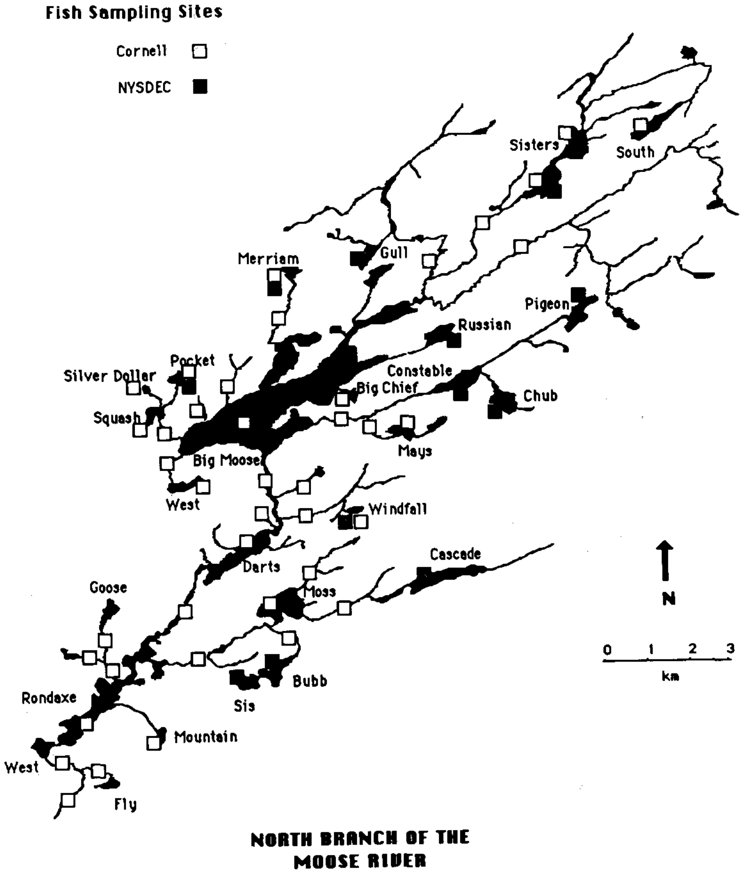

Figure 1. Locations of lakes and streams in the NBMR sampled by Cornell (this study) and the New York State Department of Environmental Conservation (NYSDEC) for determination of fish species distribution.

24 hour periods in each lake sampled. The number of nets utilized in each lake was scaled to lake surface area, in accordance with standardized survey procedures utilized by the New York State Department of Environmental Conservation. Historical (pre-1960) gill net sampling utilized cotton mesh nets of various, un-specified mesh sizes. Although sampling effort was comparable to the current protocol, the effects of different gear efficiencies and size selectivity on relative catch and size distributions could not be adequately evaluated. Shore seining for cyprinids and young-of-the-year was conducted at the same localities sampled during earlier surveys of Big Moose, Darts, and Rondaxe Lakes (Greeley and Bishop, 1932). Trap nets were employed in Darts, Big Moose, and Moss Lakes only.

Streams were sampled quantitatively by electrofishing (Portable battery operated and gasoline D.C. generators were employed.) 30 m. sections at 3–7 sites from the mouth to headwaters of each stream. Blocking seines were used to enclose each section, which was fished by removal 2–3 times in succession. Qualitative, spot checks were conducted by electrofishing additional stream sections to evaluate species presence/absence.

Field processing of fish collected during the stream and lake surveys included measurements of total length (mm) and weight (g), notation of sex and maturity, and removal of scale samples and/or pectoral fins for age determination. Pectoral fin ray sections were used for age determinations of white suckers (Beamish, 1974). Representative species collections from each site were preserved and archived in the Cornell University Fish Collection.

In situ *Bioassays*

Young of the year yellow perch and adult fish of several other species were collected by seining and electrofishing in the Moss Lake drainage system during July, 1983. Specimens collected were held in live cages for two days in Moss Lake Inlet, prior to transfer to other sites. Replicated lots of 10–20 fish per species were subsequently transferred to upstream sites of lower pH in the NBMR and additional lots of each species were held in Moss Lake as controls. The experimental fish were held in plastic mesh minnow traps, with the entrance funnels sealed. Fish survival, water temperature, and water chemistry were monitored for 30 days or until mortality in the controls exceeded 10%.

Fertilized yellow perch eggs were obtained from Moss and Big Moose Lakes on 4/28/83 and 4/29/83, shortly after ice-out and the initiation of spawning by the perch populations. Only recently deposited egg strands (<8 hours old) were collected by submerging shoreline brush and tree limbs in shallow water and allowing the perch to deposit eggs on these "collectors". The egg strands were then removed in water and sectioned into segments containing 100–200 eggs each. each segment was placed in an individual incubation chamber (Figure 2). Six replicate segments (from two females in each lake) were incubated near the site of collection in each lake at a depth of ~ 1 meter. An additional six replicates were reciprocally transferred between the two lakes and incubated at the same sites. For measurements of egg diameter, one replicate from each group was removed at the eyed stage of egg development and another was removed just prior to hatching. Remaining replicates were removed following completion of hatching for estimation of survival. Egg and fry samples were fixed in 10% formalin, washed, and cleared in serial glycerol dilutions up to 80% final glycerol concentration (Galat, 1972). Egg diameters and fry lengths wre obtained from fixed and cleared specimens using a dissecting microscope with an ocular micrometer (Measurements to the nearest 0.01 mm).

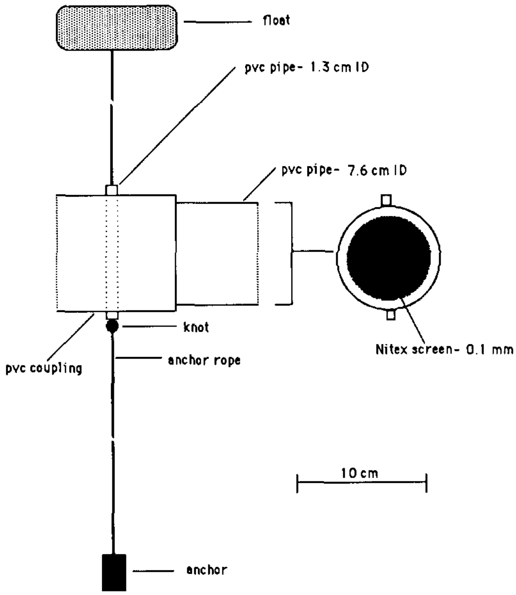

Figure 2. Design of chambers used for *in situ* incubation of yellow perch eggs.

Water analyses

In addition to the analyses obtained by Driscoll et al. (1986) for sites in the NBMR, additional samples were collected at all stream and lake sites where fish samples were obtained or bioassays conducted. Laboratory measurements of pH, alkalinity, aluminum, calcium, and specific conductance were performed as described by Driscoll et al. (1986). Vertical temperature and oxygen profiles were measured at sites netted during the lake surveys.

Results

Fish species distribution in the NBMR

Lake and stream surveys conducted during 1982–83 revealed the presence of sixteen species of fish in the NBMR (Tables 1–3). Nine of the original sixteen native species are included in the current community. Seven of the original native species were not found anywhere in the drainage system and were classified as extinct (Table 1). Six of the remaining seven "new" species that make up the balance of the current fish community are exotics and one (A single splake captured in L. Rondaxe) is a remnant of an experimental stocking program in Big Moose Lake. A comparison of

Table 2. Comparisons of fish species occurrence in the three largest lakes of the NBMR, from survey data collected in 1931 and 1982–83. (+) indicates present, (1) indicates one specimen collected.

	Rondaxe		Dart		Big Moose	
Species	1931	1982	1931	1982	1931	1982
Lake trout			+		+	
Brook trout	+	+	+		+	+
Whitefish					+	
Frostfish					+	
Smallmouth bass	+	+ (1)	+		+	
Rock bass		+				
Pumpkinseed	+	+	+	+	+	+ (1)
Yellow perch		+		+		+
White sucker	+	+	+	+	+	+
Longnose sucker			+		+	
Brown bullhead	+	+	+	+	+	+
Killifish		+		+		+
Stickleback	+					
Sculpin					+	
Lake chub			+			
Creek chub	+	+	+		+	
Common shiner	+	+	+			
Golden shiner		+		+		+
Blacknose dace	+				+	
Redbellied dace	+				+	
Finescale dace	+			+		
Longnose dace					+	
Total No.	11	11	10	7	14	7

Table 3. Fish species collected in lakes of the NBMR surveyed during 1982–83. (See Table 1 for species abbreviations.)

Lake	Surface area.ha.	pH	Species collected	Total no.
Big Moose	520.5	5.1	YP, WS, BG, PS, GS, KF, ST	7
Dart	144.0	5.4	YP, WS, BH, PS, GS, KF, FSD	7
Rondaxe	91.7	6.2	YP, WS, BH, PS, GS, KF, ST, CS, CC, RB, SMB, SP	12
Moss	45.0	6.4	YP, WS, BH, PS, GS, ST, CS, CC	8
Cascade	40.0	6.5	YP, WS, BH, ST, CS, CC	6
Upper Sister	33.6	4.9	YP, WS, BH, PS, GS	5
Lower Sister	33.6	4.8	YP, WS, BH, PS, GS	5
Constable	22.7	5.2	YP, BH, ST	3
Bubb	20.5	6.1	YP, WS, BH, ST, CC	5
Pigeon	18.2	4.6		0
Chub	15.4	5.3	ST, CC	2
Mays	13.0	5.6	ST, BH, CC	3
Sis	10.5	6.1	YP, WS, BH, ST, CC	5
West	10.5	5.1	BH	1
South	10.5	4.9		0
Merriam	7.8	4.5		0
Mountain	6.0	4.7		0
Squash	3.9	4.6		0
Windfall	1.6	6.8	ST, RBD, FSD, BND, WS, CC, BH	7
Pocket	1.2	4.3		0
Big Chief	1.2	4.8		0
Silver Dollar	0.5	4.3		0

species composition changes in the three largest lakes of the drainage system between 1931 and 1982 is presented in Table 2. New occurrences common to all three lakes are the yellow perch, killifish, and golden shiner. Progressive upstream losses of species between 1931–1982 are also evident from these data: four losses in L. Rondaxe, seven in Darts L., and nine in Big Moose Lake. The total numbers of species captured at lake and stream sites in the NBMR are illustrated in Figure 3. The apparent trend of increased species loss in an upstream direction is also reflected by the current longitudinal gradient in species richness for all lakes and streams of the basin. Seventeen headwater lakes and streams, primarily those tributary to Big Moose Lake, were devoid of fish. The number of species collected was greatest in the Cascade-Moss-Rondaxe branch of the drainage system. The general pattern of species numbers parallels the basin gradients of water chemistry and hydrologic differentiation noted by other invesitgators (Driscoll et al., 1986; Peters and Driscoll, in press; Newton

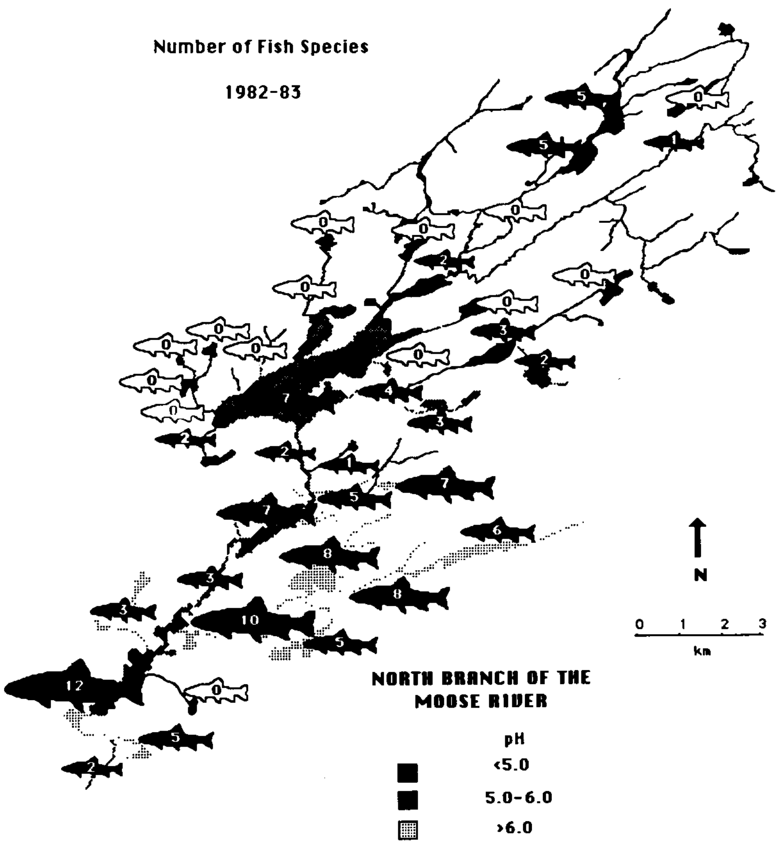

Figure 3. Numbers of fish species encountered at lake and stream sites in the NBMR during 1982–93.

et al., 1986). Most of the native cyprinids encountered in this survey had very restricted distributions, located only at the higher pH sites (eg. Windfall Pond, Cascade-Moss system). Similarly, reproducing brook trout populations were found only in streams having the highest pH levels and greatest relative ground water contributions (Newton et al., 1986) to base stream flow (Figure 4).

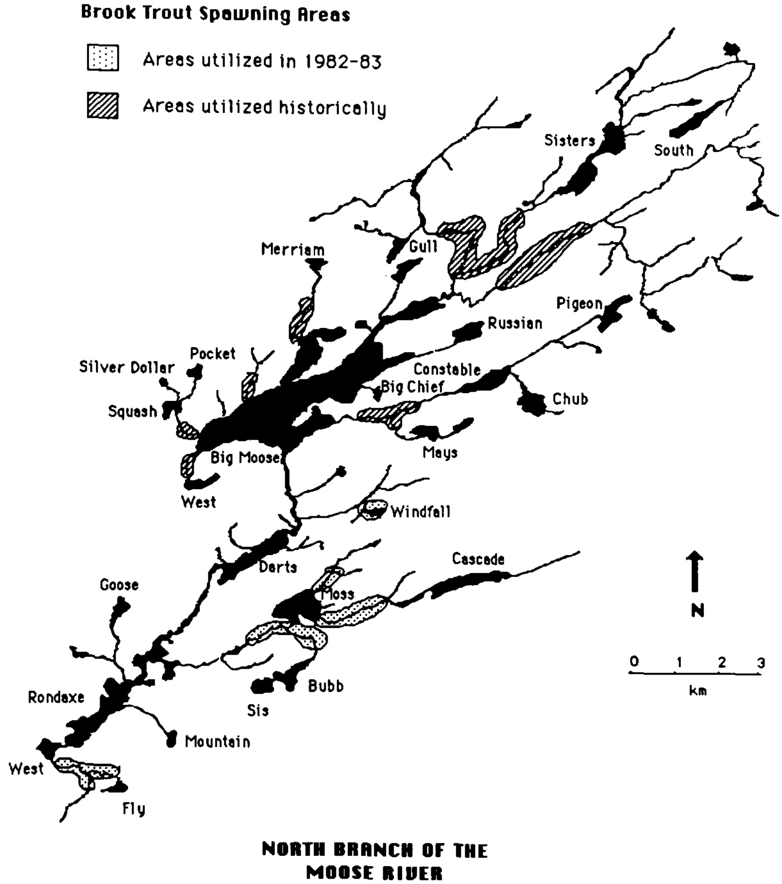

Figure 4. Stream sites in the NBMR where young of the year brook trout were collected during the summer of 1982, where brook trout redds were observed in the fall of 1983, and areas utilized historically (1950's).

Both size (surface area) and pH contributed significantly to variation in species numbers observed in lakes of the NBMR ($R^2 = 0.707$). However, the partial regression coefficient for pH exhibited a higher level of significance (Table 4). Larger lakes offer a greater diversity of potential habitats,

Table 4. Multiple regression analysis of fish species numbers collected in NBMR lakes in relation to summer epilimnetic pH and LOG surface area (LA).

R^2 = 73.5% R^2 (adjusted) = 70.7%
s = 1.96750 with 22 − 3 = 19 degrees of freedom

Source	Sum of squares	DF	Mean square	F-ratio
Regression	203.904	2	101.952	26.34
Residual	73.5503	19	3.87107	

Variable	Coefficient	s.d. of Coeff	t-ratio
Constant	−13.8310	3.02521	−4.57
pH	2.77858	0.594670	4.67
LA	2.43475	0.627335	3.88

thus lakes in the size class of Big Moose would be expected to harbor a greater number of species than are currently present (seven as opposed to fourteen species in 1931). Stream pH and size (average width) were also significantly correlated with species numbers (R^2 = 0.680). However, the contribution of stream size to the regression was relatively small (Table 5). Comparisons of species occurrence in high and low pH streams of the NBMR (Table 6) indicated that streams with summer base flow pH > 6 supported greater numbers of species than streams with pH < 6 (t.05 = 4.96, 22 df). Differences in average density between streams with pH < 6 and pH > 6 were not significantly different (t.05 = 1.70, 22 df). In terms of species occurrence, only killifish and mud minnows were found to occur more frequently in the lower pH streams. Overall, the mud minnow was the most common species in streams of the drainage system. This species was not reported in any of the earlier surveys discussed previously.

Table 5. Multiple regression analysis of fish species numbers collected in NBMR streams in relation to summer base flow pH and average stream width (SW).

R^2 = 70.6% R^2 (adjusted) = 67.9%
s = 1.49834 with 24 − 3 = 21 degrees of freedom

Source	Sum of squares	DF	Mean square	F-ratio
Regression	113.479	2	56.7397	25.27
Residual	47.1456	21	2.24503	

Variable	Coefficient	s.d. of Coeff	t-ratio
Constant	−10.2091	1.86966	−5.46
pH	2.03989	0.293744	6.94
SW	0.424115	0.207193	2.05

Table 6. Comparison of average densities and fish species collected during electrofishing surveys of streams in the NBMR having summer base flow pH levels above and below 6.

	pH < 6	pH > 6	Total
Number of streams	14	10	24
Number without fish	5	0	5
Number with species:			
Brook trout	2	7	9
White sucker	0	7	7
Brown bullhead	2	4	6
Yellow perch	3	6	9
Creek chub	3	8	11
Common shiner	0	1	1
Golden shiner	1	1	2
Blacknose dace	0	5	5
Redbellied dace	0	1	1
Finescale dace	0	1	1
Common sunfish	0	1	1
Killifish	2	0	2
Mud minnow	9	7	16
Average number species (Range)	1.6 (0–5)	5.1 (2–10)	3.0 (0–10)
Average density (No./ha.) of all fish (Range)	200 (0–1180)	7187 (130–51130)	3111 (0–51130)

In situ *bioassays*

The observed species distribution pattern in the NBMR, relative to acidity gradients in the system, suggested a tentative classification of species tolerance to acidification (Table 7). "Sensitive" species were defined as those found only at sites with pH > 6. "Tolerant" species were collected at sites with pH < 5 and the "Indeterminants" were found in both low and high pH waters. This classification was tested by *in situ* transfer of representative species in each category from high to low pH sites in the drainage basin, during the summer of 1983.

Water chemistry at the control (Moss Lake inlet) and treatment (Merriam Lake outlet) sites during the bioassay period is given in Table 8.

Table 7. Apparent species tolerance to acidification, based on observed distribution in lakes and streams of the NBMR.

Sensitive	Indeterminate	Tolerant
Blacknose dace	Brook trout	Mud minnow
Redbellied dace	white sucker	Killifish
Common shiner	Creek chub	Brown bullhead
Smallmouth bass	Pumpkinseed sunfish	Golden shiner
Rock bass	Finescale dace	Yellow perch

Table 8. Water quality in Moss Lake inlet (control site) and Merriam Lake outlet during *in situ* bioassays conducted during July–August, 1983.

Parameter	Moss Lake inlet	Merriam Lake outlet
Temperature	17.5 (12.7–21.1)	15.8 (13.9–18.3)
pH	6.86 (6.5–7.1)	4.58 (4.4–4.8)
Al mg/l (Total monomeric)	0.021 (0.005–0.073)	0.354 (0.296–0.499)

Table 9. Relative survival of seven fish species transferred from the Moss Lake drainage to Merriam Lake outlet (July–August, 1983). Duplicate cages containing 10 fish per species.

Species	Median survival time (days)	% Survival after 28 days
Blacknose dace	2.7	0
Common shiner	3.8	0
Redbellied dace	5.2	0
Creek chub	9.5	0
Banded killifish		53
Yellow perch		72
Mud minnow		100

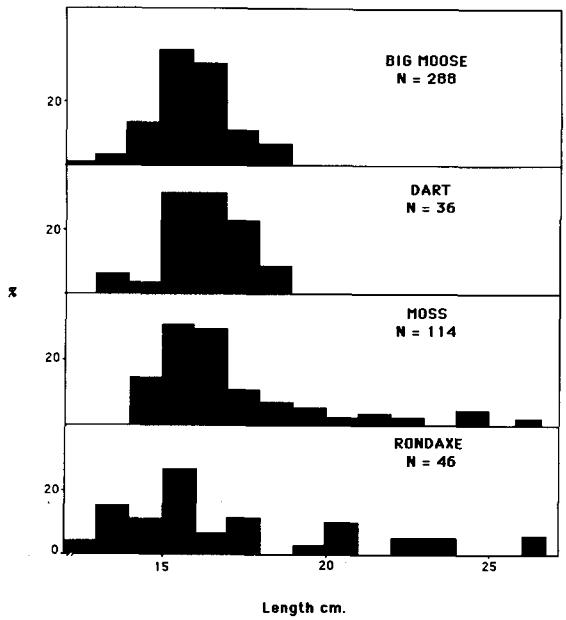

Figure 5. Length frequency distributions for yellow perch obtained by gillnetting in major lakes of the NBMR.

Species in the sensitive (blacknose dace, redbellied dace, and common shiner) and indeterminate (creek chub) groups exhibited high mortality rates during the first week of exposure to Merriam Lake water and none survived the duration of the experiment (Table 9). No mortality was observed for these species at the control site during the first three weeks of the experiment. Johnson et al., in press, also observed high mortality for early life history stages and adults of the creek chub and blacknose dace in their more extensive *in situ* bioasays in the NBMR. Species in the tolerant group (killifish, yellow perch, and mud minnow) experienced

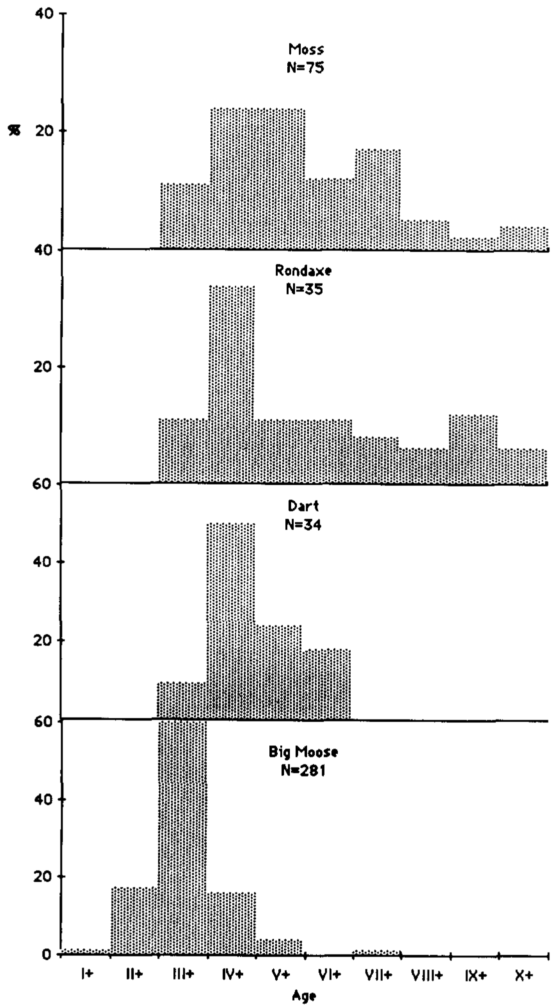

Figure 6. Age frequency distributions for yellow perch obtained by gillnetting in major lakes of the NBMR.

comparatively low mortality in Merriam Lake outlet. None of the mud minnows died during the 28 day exposure and survival of killifish and yellow perch was 53% and 72%, respectively.

Fish population age and size structure

The two most abundant species of fish in lakes of the NBMR are the yellow perch and white sucker (Baker, 1981). A comparison of length frequency distributions for yellow perch in the larger lakes of the basin (Figure 5) reveals an absence of larger perch in Big Moose Lake and Darts Lakes and wider size distributions for the populations in Moss and Rondaxe Lakes. Corresponding differences in age structure of the populations (Figure 6) are apparent, with an absence of older age classes in Darts and Big Moose Lakes. Length frequency distributions for yellow perch obtained during earlier surveys of Big Moose Lake show an apparent trend of decreasing average size after 1955 (Figure 7). The larger average size of perch in the mid 1950's may reflect the effects of the perch removal program discussed previously. The white sucker populations exhibited somewhat opposite spatial and temporal trends in size distributions (Figures 8 and 9). Larger suckers are currently prominent in Big Moose Lake, compared to a smaller mean size in 1953. The Sister Lakes were the lowest pH lakes (pH 4.8–4.9) where white suckers were obtained in this survey.

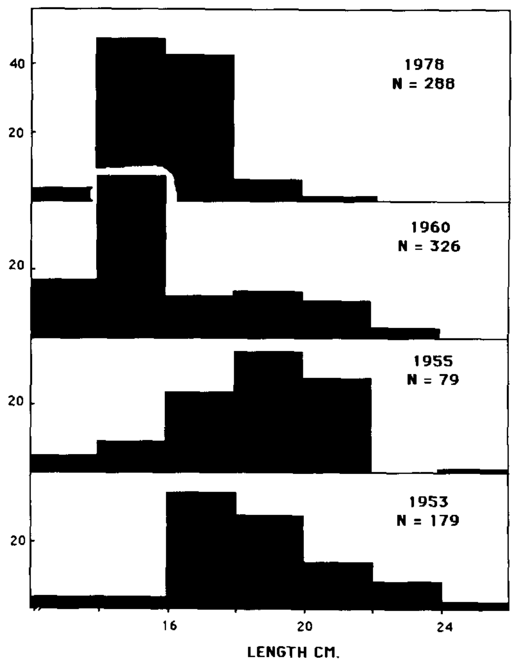

Figure 7. Length frequency distributions for yellow perch obtained during gill net surveys of Big Moose Lake, 1953–1978.

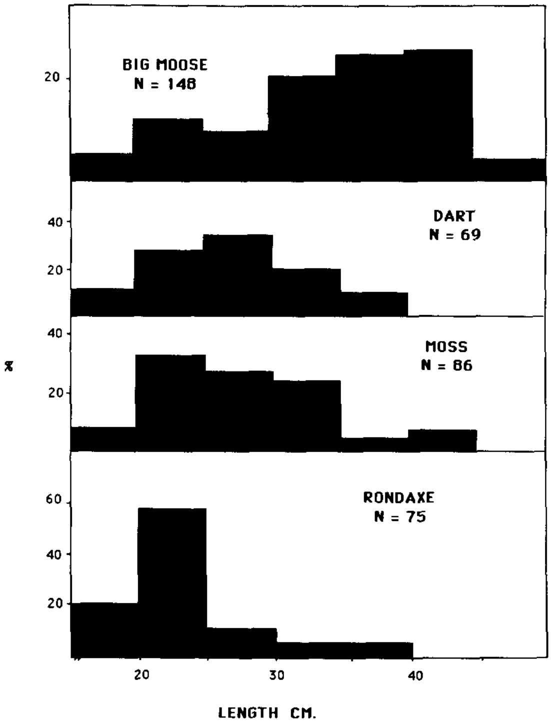

Figure 8. Length frequency distributions for white suckers obtained by gillnetting in major lakes of the NBMR

Only four large suckers (37.0–44.4 cm) were captured in 1983. Previous surveys in 1958 and 1970 produced larger numbers of white suckers with a wider range in size (1958- N = 40, 15.0–40.6 cm; 1970- N = 113, 18.5–39.4 cm).

Yellow perch egg-fry in situ *bioassays*

The yellow perch is currently a dominant species in lakes of the NBMR, occurring in waters at pH levels below 5. Laboratory and field studies of European perch (*Perca fluviatilis*) egg hatchability in acidic waters suggested that reproductive success would be impaired at pH levels of 5.0–5.5 (Runn et al., 1977). We hypothesized that yellow perch inhabiting acidic lakes in the NBMR might exhibit relatively greater acid tolerance, at early life history stages, than populations present in the higher pH lakes. This hypothesis was tested by *in situ* reciprocal transfer of fertilized perch eggs between Big Moose and Moss Lakes during the spring of 1983.

Average temperature, pH, and total monomeric Al concentrations

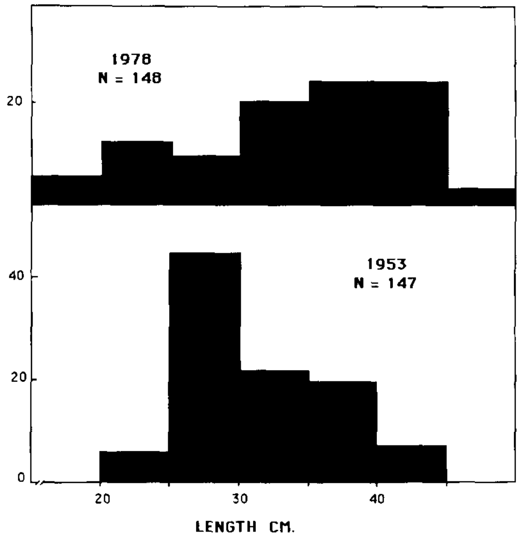

Figure 9. Length frequency distributions for white suckers obtained during gill net surveys of Big Moose Lake, 1953 and 1978.

observed in Big Moose and Moss Lakes during the egg incubation period are presented in Table 10. Although the mean temperatures for the period were similar in both lakes, Moss Lake warmed more rapidly during the intial period of incubation than Big Moose. Thus, comparisons of development rates for eggs in the two lakes were based on cumulative degree days exposure, rather than absolute time. Eggs incubated in Moss Lake reached the eyed stage of development on day 15 at $78\,\Sigma\,^{\circ}D_5$ (cumulative degree days above 5 °C). Eggs in Big Moose eyed on day 19 at approximately the same level of cumulative heat ($68\,\Sigma\,^{\circ}D_5$). Initiation of hatching started on day 23 ($121\,\Sigma\,^{\circ}D_5$) in Moss and day 29 ($139\,\Sigma\,^{\circ}D_5$) in Big Moose. Hatching was complete by day 34 ($220\,\Sigma\,^{\circ}D_5$) in Moss, whereas in Big Moose hatching was still incomplete on day 40 ($250\,\Sigma\,D_5$) when the remaining un-hatched eggs died. The mean percent hatch of eggs obtained from both Big Moose and Moss parents was significantly lower in Big Moose Lake than eggs from the same parents hatched in Moss Lake

Table 10. Water quality at egg incubation sites in Big Moose and Moss Lakes, 4/28–6/7/83.

Parameter	Big Moose	Moss
Temperature °C	10.3(7.0–14.5)	10.9(8.0–15.0)
pH	5.03(4.9–5.2)	6.58(6.5–6.6)
Al mg/l (Total monomeric)	0.212(0.19–0.23)	0.017(0.00–0.03)

Table 11. Mean percent hatch and average length at hatching for yellow perch eggs obtained from and reciprocally incubated in Big Moose and Moss Lakes. Two way ANOVA for Arcsin transformed % hatch in relation to egg source and incubation site.

Incubation site	Egg source	
	Big Moose	Moss
Big Moose		
% Hatch (Range)	43.5(25–75)	3.8(0–9)
Length mm(Std. dev.)	5.43(0.43)	5.25(0.27)
Moss		
% Hatch (Range)	77.0(68–88)	86.2(80–94)
Length mm(Std. dev.)	6.02(0.15)	5.66(0.29)

Analysis of variance for Arcsin % hatch

Source	DF	SS	MS	F	Prob
Egg source	1	695.6	695.6	8.41	0.0133
Incubation site	1	6597.5	6597.5	79.79	0.0001
Interaction	1	1614.0	1614.0	19.52	0.0008
Error	12	992.2	82.7		
Total	15	9899.4			

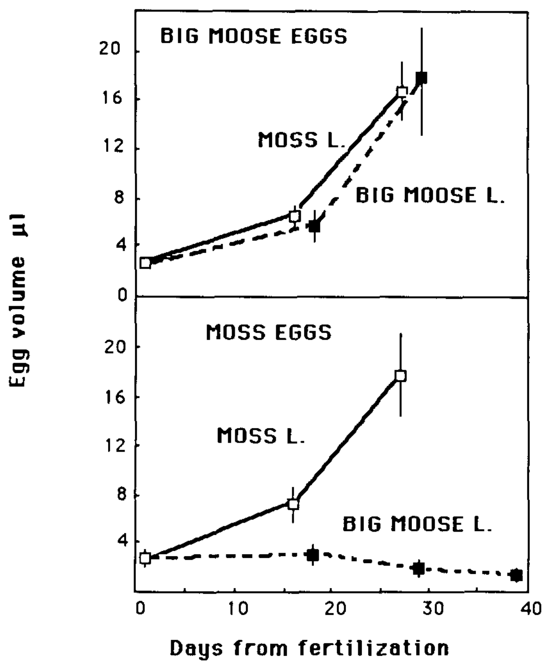

Figure 10. Changes in mean chorion volume (error bars ± 1 standard deviation) of yellow perch eggs obtained from and reciprocally incubated to hatching in Big Moose and Moss Lakes.

(Table 11). Fry hatched in Big Moose Lake were slightly smaller than those hatched in Moss Lake, but size differences were not significant ($P > 0.10$). The extremely low hatch of Moss Lake eggs in Big Moose Lake was apparently related to alterations in chorion structure that inhibited normal egg expansion during development (Figure 10). This effect was not evident in eggs from the same parents incubated in Moss Lake, nor in eggs from Big Moose parents reared in both lakes.

Discussion

Dramatic changes in the composition of the fish communities inhabiting the NBMR first became apparent during the 1940's, following a long period of relative stability from 1882–1931. The poor condition of Big Moose lake trout observed during the 1950's was probably the result of earlier declines of potential forage species, such as the sculpin, round whitefish, and longnose sucker. The average condition factor for 20 lake trout netted during the summer of 1950 in Big Moose Lake was 0.94 (± 0.19) (NYSDEC, unpublished file data). A similar pattern was observed during the experimental acidification of Lake 223. Lake trout condition in Lake 223 dropped dramatically following decline in forage species abundance to levels similar to those observed in Big Moose (Mills et al,. 1986). Recruitment failure in the Big Moose lake trout population during the late 1940's was evident from the marking experiments conducted by the NYSDEC, which demonstrated a predominance of stocked lake trout in the catch. The apparent acidification of Big Moose Lake during this same time period (Charles et al., 1986) suggests that acid stress on the population may have been responsible for the subsequent decline. Mills et al., 1986 observed a series of recruitment failures in the Lake 223 lake trout population when pH levels dropped below pH 5.6. Charles et al. (1986) suggest that a rapid decline in pH from ≈ 5.8 prior to 1950 to $<$pH 5 occurred during the period of lake trout recruitment failure. Bioassays conducted by Johnson et al., in press in Big Moose Lake demonstrated high mortality of lake trout fry at pH levels near 5. Two other factors that could have contributed to the decline of the lake trout population and other species inhabiting Big Moose Lake include the application of DDT to tributary streams for blackfly control and the introduction of yellow perch. Burdick et al., 1964 documented the effects of DDT on lake trout reproduction in Lake George. Although DDT inhibition of reproduction in the Big Moose lake trout may have occurred, there is no documentation of this effect. Further, the heaviest applications of DDT in the watershed were made in the mid 1950's, after recruitment failure had already been observed in the lake trout population. Increased predation by yellow perch on lake trout eggs and fry could also have been a potential source of increased mortality, however no documentation for this effect has been found.

Irrespective of the mechanisms involved in the decline of fish species in Big Moose Lake and other waters in the basin, it seems clear that current species distribution patterns are strongly influenced by existing acidity gradients in the watershed. The working hypothesis proposed at the beginning of this study, that species distribution across acidity gradients reflects the relative physiological tolerances of the species to acidification, is supported by the observed species distributions and their measured tolerances to acidity. The extreme sensitivity of many of the native cyprinid species is well documented from similar field studies in Wisconsin (Rahel and Magnuson, 1983), the observations of species declines in Lake 223 (Mills et al., 1986), and the recent *in situ* bioassays conducted in the NBMR by Johnson et al., (in press). Although isolated reservoirs of these sensitive species still exist in the higher pH waters of the NBMR (mainly in the Moss-Cascade sub-drainage), the opportunity for recolonization of the main drainage system is severely limited by acidity levels that exceed their zones of physiological tolerance.

At the opposite end of the sensitivity spectrum, the most tolerant species in the basin are represented primarily by exotics, such as the yellow perch, mud minnow, and killifish. All of these species are widely distributed in the basin and they are currently the most abundant fishes in acidic areas of the watershed. Differences in age and size structure of both yellow perch and white sucker populations inhabiting acidic and non-acidic lakes in the basin were observed, but difficult to interpret without additional information on population size and potential density dependent parameters such as age specific growth and survival rates. Reasons for the truncated age distributions of yellow perch in Big Moose and Darts lakes are not readily apparent, but could have resulted from higher post-spawning mortality rates in these acidified lakes, errors in ageing, and/or decreased availability of larger prey items.

The yellow perch egg transfer experiment suggested possible genetic adaptation to acid stress by the population inhabiting Big Moose Lake. Although this experiment tends to support our second hypothesis of acquired acid tolerance through selective pressure on early life history stages, additional field and laboratory experiments would be required for validation. The observed failure of Moss Lake eggs to expand during development in Big Moose Lake, at low pH and high Al concentrations, was also observed in field and laboratory experiments with European perch conducted by Runn et al., (1977) in Sweden. However, their experiments did not entail reciprocal transfer of eggs obtained from populations inhabiting both acidic and circumneutral lakes. Runn et al., (1977) also noted that increased rigidity of the chorion jelly layer and loss of elasticity inhibited normal egg expansion during development. Although the embryos developed normally, compaction and deformity was observed at later stages of development prior to hatching. The inability of the larvae to rupture the dense chorion, either because of strucutural changes or inhibition of the hatching enzyme, led to eventual mortality.

The concurrent acidification and inadvertent introductions of exotic, acid tolerant fish species in the NBMR has produced a dilemma and challenge for fisheries rehabilitation. Restoration of water quality, either by large scale watershed neutralization or reductions in acidity sources may be technologically feasible. However, the prospect of restructuring entire fish communities appears less viable at the present time.

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