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MIDWINTER DISTRIBUTION AND PLASMA FREEZING RESISTANCE OF SELECTED FISHES FROM WEMINDJI, JAMES BAY, QUEBEC

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ABSTRACT

The winter distribution and blood chemistry parameters of fishes along an estuarine gradient leading into James Bay, Northern Quebec, and of brook char from an adjacent bay initially believed to be saline, were investigated. Gadids and sculpins were strongly freeze-tolerant, and plasma electrolytes and glucose were well equilibrated despite cold temperatures. Cortisol levels were high, but this was probably related to the stress of capture. Gadid and cottid winter distributions were probably not limited at this site by cold temperatures. By contrast, the cisco (*Coregonus artedii*) changed its distribution between summer and winter, to occupy a winter area where freezing risk was minimal. Brook char were not overwintering in sea water, and were poorly equipped to cope with winter temperatures at this site.

Key words: northern fishes, winter distribution, freezing resistance, blood chemistry

1. INTRODUCTION

Fishes of arctic and subarctic areas of North America face the stress of a prolonged (8–9 month), cold (minimum air temperatures < –50° C) winter. Those living in the sea or in estuaries must cope with subzero water temperatures. This occurs because the water's high salt content permits its chilling to temperatures below 0° C without freezing (supercooling) (Gordon et al. 1962). The less salty body fluids of fish also supercool, and contact with ice crystals while in a supercooled state can cause them to freeze and die (Gordon et al. 1962; VanVoorhies et al. 1978). Cold temperatures can also fatally disrupt the ability of salmonids in salt water to regulate body salt content (Audet, Claireaux 1992; G. Claireaux, C. Audet, unpublished data).

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** Order of authorship determined by proximity to the 50° C isotherm during the field portion of the study.

Some fishes have coped with the supercooling danger by evolving antifreezes which depress their freezing point (e.g. Van Voorhies et al. 1978; DeVries, Eastman 1981). Others may search out water layers of favourable temperatures, or those where ice crystals are absent, thereby reducing the risk of the initiation of freezing.

Habitats and resources of the north of Canada have recently become subject to much debate. They are critical to the way of life of native peoples, and are being altered by hydroelectric developments (e.g. Anon. 1992). In addition, Canada's aquaculture industry is searching for cold hardy stocks of salmonids which can resist cold winters (Fletcher et al. 1988a). Species in northern areas may have evolved greater cold tolerance than conspecifics from more southern areas. Despite these interests, logistical difficulties and great costs have impeded research on northern fishes in winter. Our work in Wemindji, Quebec (Fig. 1) studied environmental correlates of fish distribution in winter. Our objectives were to:

1) Document winter distributions and abundances of fishes along an estuarine gradient,

2) Determine environmental conditions along this gradient (temperature and salinity), and link them to fish plasma freezing resistance and plasma chemistry (ionic composition, glucose and cortisol levels),

3) Investigate reports from our Cree guides of the occurrence of brook char (*Salvelinus fontinalis*), in costal areas of Moar Bay (a marine site) in winter. This species is of great interest to Quebec's aquaculture industry, which would like to culture it in the St. Lawrence estuary, which supercools in winter. Laboratory studies with hatchery stocks suggest that the brook char is neither particularly cold hardy (Fletcher et al. 1988b) nor capable of maintaining its salt balance at cold temperatures (G. Claireaux, C. Audet, unpublished data). If Moar Bay contained a cold hardy stock capable of osmoregulation in seawater at very low temperatures, it could have great economic benefits.

2. MATERIALS AND METHODS

Sampling was conducted within the estuary of the Maquatua River, and in Moar Bay (Fig. 1). Estuarine fish were captured in winter 1989 and 1990 by fishing with an experimental gill net (50 m panels of 25, 39, 51, 64, 77, 102 mm mesh size set on the bottom). All fish caught were identified, and counted. Numbers caught were expressed as catch per 24 hours of fishing effort (CPUE). The brook trout were jigged with baited hooks from stations in Moar Bay. Vertical profiles of temperature and salinity at each site were made with a Beckman STD recorder. The instrument was packed in hot pads when not in use. Ambient air temperatures ranged from –30 to –50° C during the field work.

Blood samples were taken in 1990 and could only be collected from live fish, which limited our sample sizes. We had also planned one more winter sampling campaign; however the closure of Arctic Biological Station (Dunbar 1992) eliminated our logistical support and prematurely terminated the work.

Living fish brought to the surface were rapidly placed in a cooler filled with water from the site where they were captured, and transported by skidoo to our field base at Wemindji. There they were killed, measured, weighed, and a blood sample collected from the caudal vein. The sample was centrifuged to separate out the plasma, then frozen for transport south to our laboratories. There, plasma ionic composition (Na^+ by atomic adsorption spectrophotometry; Cl^- by a Corning model 925 chloride analyzer) and freezing point depression (by total osmolarity (Wescor vapor pressure osmometer or an Advanced Micro-Osmometer 3MO) where 1000 mosm/l = 1.86° C depression of the freezing point below 0° C) were determined. Plasma glucose and cortisol were measured with standard commercial kits (Sigma procedure No. 16W and Kallestad radio-immunoassay procedure No. 825 respectively). Unfortunately, the volume of blood we obtained from some fish did not permit us to run all the analyses.

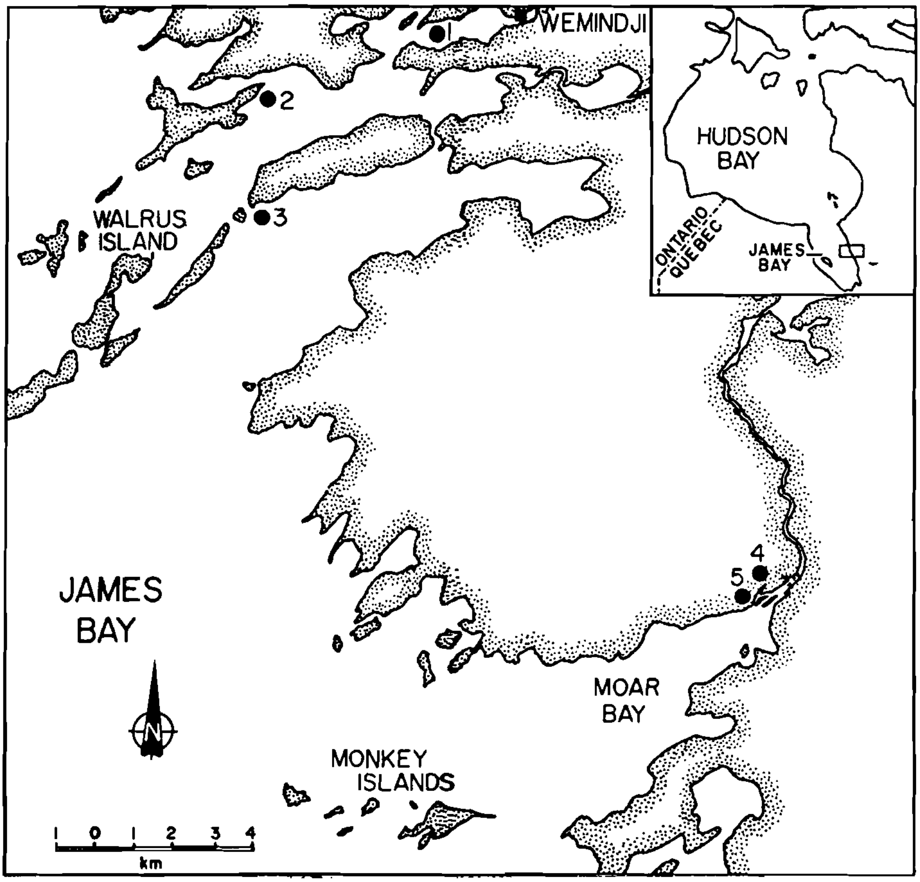

Fig. 1. The study site

For the brook char, stomachs were preserved in formalin and otoliths removed for ageing. The liver (an energy storage organ) was weighed for calculation of hepato-somatic indicies (HSI = liver weight/body weight × 100). Condition factors (K) were also calculated as $K = W \times 100/L^3$, where W is body weight (g) and L is fork length (cm). Values of $K < 1.0$ generally indicate fish are in poor shape. Stomach contents were analysed to the lowest possible taxon, to determine if marine prey were being consumed. Livers and samples of epaxial musculature were freeze dried to calculate tissue water content, and their lipid (energy stores) contents determined with a Labconoco Goldfisch fat extractor.

3. RESULTS

Winter catches at all estuarine stations were dominated by Greenland cod (*Gadus ogac*, Table I). At the warmest, least saline station (station 1), cisco were the next most abundant fish. By contrast, two sculpins (the fourhorn *Myoxocephalus quadricornis* and the shorthorn (*M. scorpius*) were the next most

Table I. Experimental gill net. Mean (±SD) catch per unit effort (number of fish caught per 24 h) at the three stations in summer 1988 and winter 1989. Data from Morin (1990) and Morin et al. (1991)

Species	Station					
	1		2		3	
	Summer	Winter	Summer	Winter	Summer	Winter
G. ogac	2.4 (3.2)	9.7 (5.0)	4.3 (3.8)	5.5 (0.7)	10.4 (5.4)	3.5 (0.7)
M. quadricornis	3.6 (5.5)	0.8 (0.8)	9.9 (6.5)	1.0 (1.4)	2.8 (2.4)	0 (0)
M. scorpius	0 (0)	0 (0)	0.6 (0.7)	0.5 (0.7)	5.0 (3.0)	1.5 (0.7)
C. artedii	7.4 (18.4)	4 (2.5)	8.2 (9.9)	0 (0)	12.2 (8.6)	1 (1.4)

abundant fishes at the colder, more saline stations (stations 2 and 3). CPUE's of all species were higher in summer than in winter.

Brook char were captured in inshore areas of Moar Bay. Ice thickness was 90 cm, and there were about 30 cm of free water between the under-ice surface and the mud bottom. Our thermistor/salinometer was not functioning at this site, but surface water temperatures in the holes were –0.9° C, and the water was fresh to taste. Five trout were captured (mean fork length 26.7 cm, 3.0 cm S.D., range 24.3–31.7 cm; weight 168.51 g, 55.3 g S.D., range 118.7–170.5 g). All char were aged 2+. Condition factors were poor (mean K = 0.86, 0.05 S.D.); hepatosomatic indices were low (1.04, 0.12 S.D.), and no visceral fat (the principal fat storage area for salmonids) was present. Mean lipid contents were 1.99% (0.54 S.D.) for muscle and 9.7% for livers (a single pooled sample from all fish). Water contents were 78.8% (0.8 S.D.) and 73.2% (3.1 S.D.) for the same organs. Stomach fullness values ranged from 0 to 100%. Prey items were exclusively freshwater or terrestrial in origin, and included snails (*Physa gyrina gyrina*), corixids, the trichopteran (*Ceraclea annulicornis*) larvae, and adult insects. Overall the data suggest that the char are limited to freshwater areas, and are suffering from a winter food shortage.

G. ogac and *M. scorpius* had the highest freezing point depressions (capable of tolerating temperatures of –1.86° C), followed in order by *M. quadricornis*, *C. artedii* and *S. fontinalis* (Table II). The values for *M. quadricornis* are calculated only from the concentrations of sodium and chloride in the plasma and hence are conservative. Only the brook char appeared to be supercooled and at risk of freezing at the sites where it was found.

The plasma ion and hormone data show that all species were well equilibrated to the sites where they occurred despite the cold temperatures (Table II).

Table II. Plasma freezing points and chemistry parameters of the captured fishes. The number of fish analyzed in each test is given in parentheses, and was determined by the availability of sufficient quantities of plasma

	G. ogac	*M. scorpius*	*M. quadricornis*	*C. artedii*	*S. fontinalis*
Station captured	1	3	3	1	4, 5
Average daily min. station T (° C)	−0.74±0.10	−1.26±0.03	−1.26±0.03	−0.74±0.10	−0.9*
MOSM/L	>1000 (8)	>1000 (2)	No data	411.0±41.2 (3)	305.0±11.0 (4)
Plasma freezing (° C)	<−1.86 (8)	<−1.86 (2)	<−0.85** (2)	−0.74±0.11 (3)	−0.56±0.02 (5)
Na^+ (meq/L)	214.3±14.6 (10)	264.9±93.5 (3)	221.6±13.1 (2)	165.7±21.3 (4)	151.3±11.8 (4)
Cl^- (meq/L)	207.5±20.9 (11)	214.6±27.4 (3)	231.0±2.8 (2)	143.4±13.6 (3)	137.3±2.2 (4)
Glucose (mg/100 ml)	160.4±99.7 (13)	31.7±26.6 (2)	65.0±22.3 (2)	231.0±79.2 (4)	97.0±26.2 (4)
Cortisol (mg/100 ml)	18.1±12.7 (15)	11.8±7.4 (6)	37.2±14.9 (2)	8.0±4.6 (7)	5.8±1.7 (5)

* Surface temperature in fishing hole; ** Based on Na^+ and Cl^- concentration alone.

4. DISCUSSION

The species captured during our winter sampling periods were also the most common found during our summer sampling (Morin 1990; Morin et al. 1992). CPUEs for all species were lower in winter than in summer, which probably reflects a lower activity on the part of these poikilotherms due to cold temperatures and a consequent reduced probability of their encountering a gill net. The sculpins maintained the same distribution pattern in winter and summer, and their plasma chemistry indicates they were well adapted to cope with winter conditions (Holmes, Donaldson 1969). The shorthorn sculpin is known to produce an antifreeze (Gordon et al. 1962), and we suspect that the other sculpins do likewise. We also note that winter water temperatures were relatively mild at this site (minimum of −1.26° C) compared to those of Labrador (−1.81° C) and Antarctica (−1.9° C; DeVries, Eastman 1981). This may be due to the warm freshwater inflow from the Maquatua river.

By contrast, the cisco and Greenland cod showed major changes in distribution between the seasons. Cisco were caught at the warmest, least saline station in winter, whereas they were abundant at the other stations in summer. The cisco's winter plasma freezing point depressions were identical to the temperatures at the site where they were caught, suggesting that they moved to this area to avoid freezing. Greenland cod catches were most abundant at Station 1, and declined subsequently at stations 2 and 3 in winter. By contrast, cod catches at the same stations in summer demonstrated exactly the opposite pattern. Van Voorhies et al. (1978) showed that the Greenland cod produced an antifreeze which depressed freezing points below –2° C, and our data confirm that the observed habitat shift is not due to osmoregulatory or temperature constraints in winter. It may be associated with spring spawning in brackish water (Vladykov 1972; Morin et al. 1991).

The short summer growing season, limited food resources in freshwater and relatively abundant food in marine environments have favoured the development of anadromy in populations of Arctic salmonids (Morin et al. 1980; Morin, Dodson 1986). Some populations of brook char successfully overwinter at sea (e.g. Power 1980), which presumably permits them to feed on marine resources for most of the year. However, most show a seasonal migration, descending to the sea in spring and returning to fresh water to overwinter (Power 1980; Doyon et al. 1991). Our char were not residing in the marine environment in the winter. Blood parameters were typical of winter-adapted freshwater char (Audet, Claireaux 1992), and this population actually had less freezing resistance than populations from more southern areas (Fletcher et al. 1988b). Their energetic reserves were depleted compared to summer char (Cunjak, Power 1987; Doyon et al. 1991), and we found them in areas where they were probably supercooled, and at risk of encountering ice surfaces. How they avoid freezing in these circumstances is unknown. The cisco, another salmonid, moved into areas where they were thermally protected. Curiously, a member of the mainly tropical wrasse family (Labridae) has colonized northern waters, shows antifreeze activity, and hence is more cold tolerant than the salmonids (Valerio et al. 1990).

5. SUMMARY

Distributions of Greenland cod and sculpins along the Maquatua River estuary in winter were not determined by their ability to resist freezing in sub-zero water temperatures. By contrast, cisco shifted their distribution in winter compared to summer, to occupy an area where plasma would not freeze. Brook char appeared to occur at sites where they became supercooled, and at risk of freezing. Electrolyte and blood glucose levels of all species were well equilibrated, despite the cold.

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