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Some Effects of Physiographic and Biotic Factors on the Distribution of Anadromous Arctic Char (*Salvelinus alpinus*) in Ungava Bay, Canada

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ABSTRACT. Interviews with Inuit hunters and measurements of topographic maps were used to characterize 70 rivers discharging into Ungava Bay in northern Quebec in terms of their ability to sustain runs of anadromous arctic char. Field crews visited 29 of these to verify conclusions and add detail. Anadromous arctic char streams tend to differ from non-char streams in size, gradient and distance to overwintering lakes, but there are no clear distinctions. Shallow boulder-strewn areas with maze-like braided channels were the most common cause of lack of char or problems with fish passage. Inuit hunters reported that low flows in autumn, and associated mortalities among migrating fish, have become increasingly common in recent years. We attribute this, at least in part, to changes in climate and the effect of abundant caribou on vegetation. Both destabilize flow regimes and increase the prevalence and severity of problems for fish migrating upstream. There is considerable opportunity for stream management to ease fish passage and increase production of anadromous arctic char. This is fortunate because the rapidly growing Inuit population is increasing the demand for subsistence harvests, expansion of the sports fishery and initiation of commercial fishing.

Key words: anadromous arctic char streams, Ungava Bay, hunters, stream management

RÉSUMÉ. L'Omble-chevalier arctique anadrome constitue un composant important du régime alimentaire des Inuits. Des enquêtes effectuées auprès des pêcheurs inuits et l'étude de cartes topographiques ont permis de caractériser 70 rivières dans la Baie d'Ungava et de les classer en termes de possibilités de migration de l'omble-chevalier arctique anadrome. Des équipes ont visité 29 de ces rivières afin de vérifier les conclusions émises et d'y ajouter quelques détails. Les rivières à omble-chevalier arctique anadrome se distinguent des autres rivières par leur taille, leur pente et leur distance des lacs hivernaux, mais il est difficile de les séparer nettement. Les zones peu profondes à galets et blocs disséminés et à nombreux méandres expliquent l'absence d'omble-chevalier arctique anadrome ou son incapacité à migrer dans de telles eaux. D'après les pêcheurs inuits, les basses eaux d'automne, et les mortalités des poissons migrateurs qu'elles causent, sont de plus en plus nombreuses depuis quelques années. Ces basses eaux peuvent être partiellement attribuées à des changements de climat et à l'effet de nombreux caribous sur la végétation environnante. Ces deux facteurs déstabilisent le régime des eaux et accroissent la fréquence et la gravité des conditions d'étiage. Les circonstances actuelles favorisent à un aménagement rationnel des cours d'eau qui serait destiné à faciliter la migration des poissons et augmenter la production des ombles arctiques anadromes. Cette situation est d'autant plus favorable qu'il y a une augmentation de la population des Inuits, donc un besoin accru de nourriture de subsistance. De plus, des pressions sont exercées dans la région pour initier une pêche commerciale et développer la pêche sportive.

Mots-clés: rivières à omble arctique anadrome, la Baie d'Ungava, chasseurs, aménagement des cours d'eau

INTRODUCTION

Anadromous arctic char (*Salvelinus alpinus*) is the most important fish available to Inuit hunters, accounting for as much as half of the annual food supply in some traditional communities (Balikci, 1980). In northern Quebec, up to 60% of the total fish harvest and almost 20% of the edible weight of local foods is arctic char (James Bay . . . , 1982), but the proportion varies among communities according to the number of hunters, accessibility of char streams and overwintering lakes and the availability of other fish and wildlife.

In addition to being essential to the subsistence harvest, sports fishing for arctic char is an important source of income for many Inuit, and commercial fishing is viewed as a potentially significant source of revenues. Previous attempts to establish commercial char fisheries in northern Quebec have failed when char stocks quickly collapsed (Power and LeJeune, 1976). If such experiences were repeated over a broader area, they would certainly interfere with subsistence harvests. In contrast, char fisheries in northern Labrador have gradually evolved from a subsistence level through limited commercial development beginning in 1860, to a successful modern fishery accounting for over half of the Canadian commercial char catch in 1980 (LeDrew, 1984). This is cited as an argument in favour of commercial char fishing in Ungava Bay. However, according to some indexes, several areas along the Labrador coast are being overfished (Dempson, 1978) and the total fishing effort may be too high for sustained yields.

Rapid expansion of the Inuit population along Ungava Bay is increasing the demands on the char resource. Robitaille and Choiniere (1985) analyzed Census of Canada data from 1931 to 1981 and estimated the average annual rate of growth of the Inuit population of northern Quebec at 2.8%, which gives a doubling time of about 25 years. Office de planification et de développement du Quebec (O.P.D.Q., 1984) reported a rate of 2.57% for 1976-79, suggesting that while the rate of increase may be declining, it is still very high. Since the Inuit population is dependent on local sources for most of its animal protein, the subsistence demand for arctic char is certain to increase.

While the general biology of arctic char is fairly well known (Moore, 1975a,b; Johnson, 1980; Gillis *et al.*, 1982; Dempson and Misra, 1984; Johnson and Burns, 1984; Dempson and Green, 1985), relatively little information is available concerning freshwater habitats of anadromous populations or the impacts of Inuit subsistence fisheries. An important management question is the feasibility of enhancing char stocks through stream improvement.

The research reported here was undertaken to describe the physical structure of river/lake systems draining into Ungava Bay that support populations of anadromous arctic char and of those systems that do not support such stocks. Information about the status of char in rivers entering Ungava Bay was obtained from local hunters. Many of these hunters expressed a concern that several streams that used to be important fishing areas had deteriorated within living memory. In light of these reports we also considered some of the factors that might contribute to the

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problems most often cited, namely, more difficult conditions for upstream migration in the late summer and autumn.

METHODS

Information about the distribution of anadromous arctic char in river systems entering Ungava Bay was obtained through interviews with 32 Inuit hunters in the communities of Kangiqsualujjuaq, Kuujjuaq, Tasiujaq and Kangiqsuk during July 1984. Hunters were interviewed individually, usually through an interpreter, and at least two independent assessments were obtained for each river system. These assessments included the presence or absence of char, the locations of overwintering and spawning sites, the importance of the fishery to the community and the nature of any barriers to upstream migration or other special features of the system. This information was found to be consistent among hunters within each community and, where hunting areas overlapped, among communities. Non-migratory and anadromous char were easily distinguished, since the Inuit give different names to the two forms. Some difficulties were encountered in describing the degree of obstruction posed by falls, rapids and shallow areas, largely because these assessments were personal and subjective but also because subtleties may have been lost in translation. A particular problem was quantification of intermittent barriers that were reported to occur on some rivers during "dry" years, especially since few hunters visit each local river every year.

In order to gain a clearer impression of the nature of barriers to migration, 29 river systems were inspected by two field crews travelling by boat with local guides during late July and August 1984. One group covered the west coast north of the Koksoak River; the other travelled the east coast north of the George River. These rivers, selected on the basis of information gained from the interviews and from examination of topographic maps, included char rivers of all sizes and non-char rivers with various kinds of barriers. Special attention was given to those streams said to have intermittent barriers. The investigators walked each river from the sea to the first overwintering lake or major barrier to upstream migration, noting the types and degrees of obstruction posed by falls, rapids and shallows. No collecting of fish was attempted.

Rivers were identified by name if they were given on 1:50 000 topographic maps or by the military grid reference for the mouth of the river. The dimensions of each river system described by Inuit hunters were measured on 1:50 000 topographic maps. These included the distance from the sea to the lowermost overwintering area, the average gradient of that section of the river and the area of the drainage basin upstream. Where values were not precisely indicated on the maps, elevations of lakes were interpolated from adjacent contour intervals. River gradients were calculated as the elevation of the overwintering lake (m) divided by the distance to the sea (km), and thus underestimate the slopes of any particularly steep reaches.

Temperature and precipitation data were extracted from the annual summaries of meteorological records from Fort Chimo (Kuujjuaq) of the Atmospheric Environment Service, Environment Canada.

RESULTS AND DISCUSSION

Inuit hunters provided information about the status of arctic char in 70 river systems (Fig. 1): 28 "char rivers" supported important subsistence fisheries, 18 "problem rivers" had partial or complete barriers that limit the extent of upstream migration in at least some years and 24 "non-char rivers" did not support anadromous stocks. Waterfalls were cited as barriers on only 5 otherwise suitable rivers. The commonest form of barriers were shallow, boulder-strewn reaches, which do not afford a clear channel upstream. Other obstacles to migration included remnants of ancient fishing weirs and beaver dams. On problem rivers such barriers are apparent only during summers when rainfall, and hence discharge, is lower than normal, and hunters reported having found dead or stranded char on at least 6 rivers under such conditions. These fish were said to have been trapped by low water during their upstream migration. All hunters indicated that this problem now occurred more frequently and with greater severity than it had 30 years ago.

Direct examination of 29 of these systems (Fig. 1) confirmed the information obtained through interviews and gave us an appreciation of the magnitude of barriers that do or do not block char migration. Five of these were char rivers, ranging in size from very small to very large. Shallow, diffuse channels passing through glacial moraines were found on 16 problem rivers and on 3 non-char rivers. This latter group had been described as being too small for anadromous char even though their drainage basins were well within the size range of char rivers. Five non-char rivers had waterfalls or very steep rapids that block upstream migration.

These shallow barriers to migration occur in glacial end moraines (Andrews, 1970), usually where they plug the ends of valleys to form the lakes used by overwintering char. The outlet streams have removed virtually all sediments finer than pebbles and take the form of broad boulder mazes with few, if any, distinct channels. Much of the flow is subterranean, so that there are many blind channels originating from upwellings among the stones. In most such systems on the east side of Ungava Bay the problem posed by diffuse flow is exacerbated by the steepness of the downstream edge of the moraine. On the west side of the bay, the terrain tends to be flatter, so that moraine reaches are longer and often occur at intervals all along the course of the outlet streams. It is in these boulder mazes that local hunters report increasing numbers of stranded or dead char during dry years. We did not observe this directly, since the summer of 1984 was not particularly dry.

Another possible problem in a few non-char streams, such as LA 4029, LA 2924 and DR 9050, is the lack of any holding or staging pools at the mouth of the river. The significance of this is unclear, but such pools may be crucial to char during the transition from salt to fresh water and the reverse. It is known that anadromous fish may spend 12-40 hours at intermediate salinities while making the transition (Dodson *et al.*, 1972). Arctic char appear to be one of the least tolerant of the salmonids to sea water, so they may be unable to survive direct transfer. (See Johnson, 1980, for a review of what little is known on this subject.)

There were few clearcut distinctions among the stream categories on the basis of their physical dimensions (area of the drainage basin, distance from the sea to overwintering areas, gradient of the outflowing river). Extremely small (<10 km^2 basins) and very steep (gradients >80m·km^{-1}) systems did not have anadromous char (Fig. 2), while all but one of the rivers draining basins of >1000 km^2 were char rivers. The one exception was a problem river flowing through extensive, very flat moraine. Rivers with intermediate gradients (20-70 m·km^{-1})

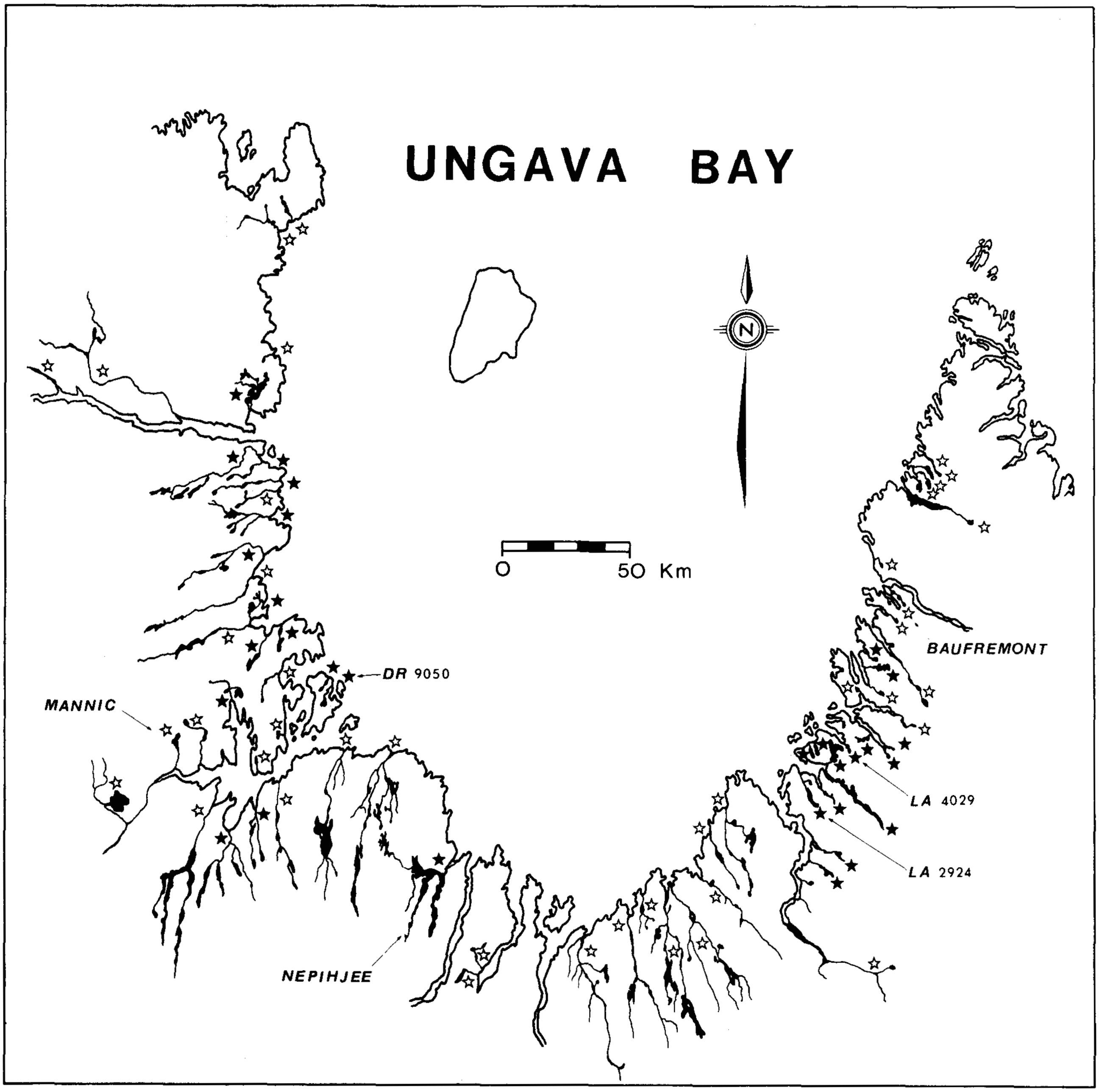

FIG. 1. Map of the Ungava region with the streams mentioned by name in the text identified. Streams about which Inuit hunters provided information are indicated by open stars; those examined in the field are shown by solid stars.

were char or problem systems if the distance from the sea to an overwintering lake was <1 km; longer rivers with intermediate gradients lacked char. There were two exceptions to this generalization: the char rivers Baufremont and Mannic, both of which are long but confined to narrow, evenly sloping valleys with no particularly steep rapids or diffuse reaches.

A similar pattern was observed among low-gradient (<20 $m \cdot km^{-1}$) rivers. All of these draining >150 km^2 had anadromous char, but problem rivers tended to be longer than char rivers. Nearly all of the smaller, low-gradient streams had either complete or intermittent barriers to the movement of anadromous char. Length of the outflowing stream was not much help in discriminating among these systems. On at least two of these rivers, the size or depth of the potential overwintering lake was reported to be insufficient, even though passage to and from the sea should have been possible.

Our observations in the field confirmed that diffuse stream channels are the principal barriers to char migration in Ungava Bay rivers. Are there reasons why char moving upstream through such reaches might be encountering difficulties more frequently in recent years, as was reported by local Inuit? Any factor that would lead to reductions of channel development or depth in late summer could be responsible, if that factor has changed in the past 30 years. Phenomena that might be important, and for which at least some data exist, include post-glacial rebound (uplift), precipitation, temperature and the increase in abundance of caribou in the region. The rate of post-glacial rebound has decreased over time (Andrews, 1970), so unless

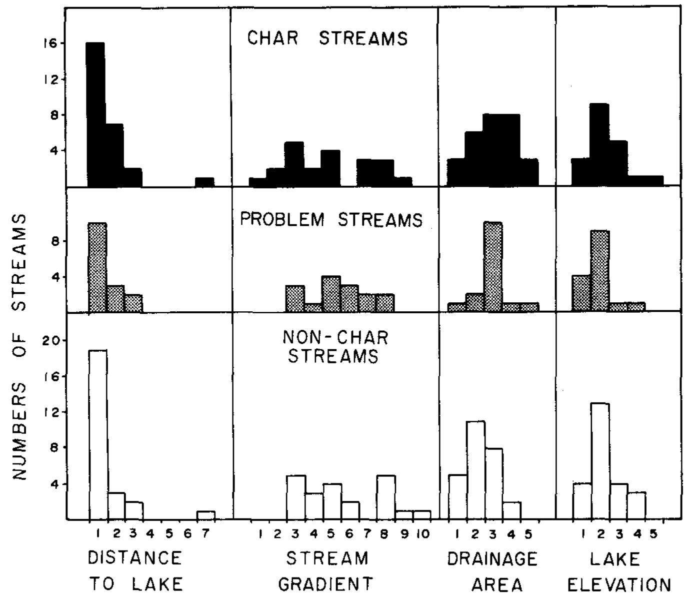

FIG. 2. The characteristics of streams supporting stocks of anadromous arctic char (char streams), those with partial or intermittent barriers to migration (problem streams) and those without anadromous char (non-char streams). All class intervals are logarithmic, with units as follows: distance to overwintering lake (km + 10) and gradient ($m \cdot km^{-1}$) –0.2 log units; drainage area (km^2) – <1.49, 1.5-1.99, 2.0-2.99, 3.0-3.99, >4; lake elevation (m) – <15, 15-50, 51-100, 101-200, >200. Streams with definite waterfalls are not included in the figure; frequencies are not the same in all histograms because data were incomplete in some instances.

there has been some recent aberration, it is unlikely to be significant in the present context.

Precipitation and temperature are the primary factors controlling the amount and rate at which water is discharged by rivers, both directly and indirectly. A change in either of these parameters during the past 30 years could, at least partially, account for the reported increase in problems for char migrating upstream in late summer.

The mean total precipitation at Fort Chimo (Kuujjuaq) from 1948 through 1984 was 484 $mm \cdot yr^{-1}$, most of which fell as snow (Fig. 3). During this period, the general trend was an increase from 1948 through 1964 and a slight decrease in more recent years. A similar pattern is evident for the summer months (July-September), the time when drought could be expected to have the greatest effect on ease of migration. Variation from year to year was large, with drier than average conditions occurring about every third summer.

Few data are available for other parts of the Ungava region. Gray (1983) indicated that average annual snowfall increases from <200 $cm \cdot yr^{-1}$ along the western coast of the bay to nearly 300 $cm \cdot yr^{-1}$ in the east. Since these differences occur over a distance of about 200 km, only small shifts in weather patterns are needed to produce large fluctuations in precipitation from year to year (A. Judge, pers. comm. 1986).

Mean annual air temperature in the Ungava region has also been declining since 1960, by nearly 1°C to about –6°C in 1978, with slightly lower values in the northwest (Gray *et al.*, 1979; Gray, 1983). A great deal of variation is superimposed on this trend, especially during the months of June-September (Fig. 4). Mean temperatures during the warmest months (July and August) have ranged from 7.7° to 14.0°C since 1960. Over the period of continuous records, temperature and precipitation

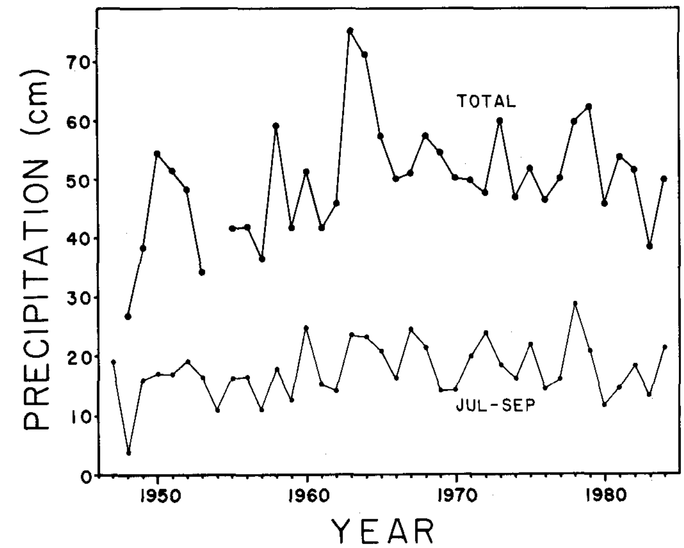

FIG. 3. Mean annual and summer (July-September) precipitation at Kuujjuaq (Fort Chimo), 1948-84, from monthly records, Atmospheric Environment Service, Environment Canada.

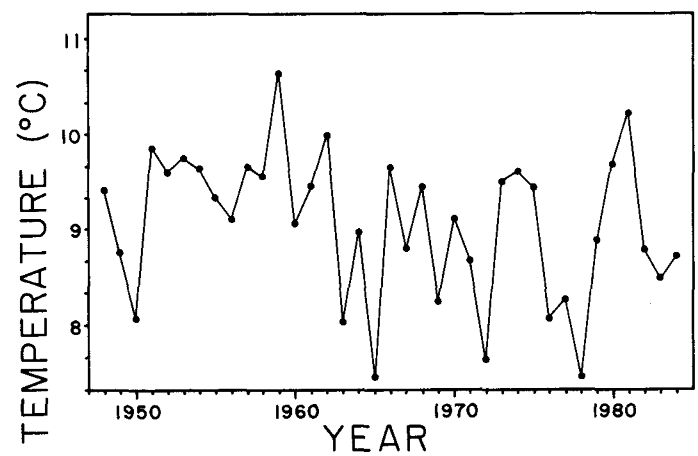

FIG. 4. Mean summer (July-September) temperature at Kuujjuaq (Fort Chimo), 1948-84, from monthly records, Atmospheric Environment Service, Environment Canada.

have been inversely related ($r = -0.48$), so that warm years tend to be dry.

A decline of 1°C in annual mean air temperature can significantly increase the thickness of permafrost (Brown, 1970). This suggests that the observed recent cooling trend could have reduced the thickness of the active layer in summer so that less groundwater is available to maintain stream flows during the time of char migration. In warm summers, the active layer might be deeper, but this is often negated by low precipitation. Taken together, these climatic trends suggest that annual stream discharge may well have declined since 1960. In addition, the general decrease in thickness of the active layer should cause increased frost heave, which would reduce channel development in moraine sections of streams (A. Judge, pers. comm. 1986).

The effects of caribou on arctic char are indirect but may be very significant. These two animals are the most desired available sources of protein for the local Inuit and can substitute for one another as dietary components. Fishing pressure is to some extent inversely related to the abundance of caribou, and vice versa. The two species are also linked through the effects of caribou on terrestrial vegetation, which can profoundly influence the pattern of stream discharge and channel development.

Numbers of caribou in northern Quebec have been increasing rapidly since 1950; the present annual rate of increase of the George River herd has been conservatively estimated at 10% (Audet, 1979). Bergerud (quoted in Audet, 1979) estimated the density of this herd, the largest in northern Quebec, at one animal·0.7 km^{-2}. The impact of such numbers of animals on the local vegetation is obvious even to the casual observer. During the late 1950s, there were few or no traces of caribou in the lower Koksoak, Whale and George River valleys, although ancient trails were still visible from the air. Today, there is widespread evidence of caribou activity, including large areas practically denuded of vegetation, trampled shrubs, windrows of hair along river and lake margins and tracks everywhere, with many hilltops and stream margins having the appearance of cattle yards.

Caribou utilize different habitats at different seasons, often migrating *en masse* between them. For example, Hayeur (1979) reported that the Lac Bienville herd in north-central Quebec grazes *Cladonia* spp. pastures in open spruce taiga in winter; they use reticulated bogs and high ground for calving in spring. Caribou tend to select forage plants that are the highest in protein content and most available, factors that vary seasonally, so that the total diet appears to include virtually all species of plants in the range (Bergerud, 1972). The direct effects of caribou on vegetation have not been studied in northern Quebec, but Helle and Aspi (1983) reported that grazing pressure by semi-domestic reindeer in Finnish Lapland selectively reduced the abundance of large-bodied lichens and shrubs. Total plant biomass decreased with increasing grazing pressure, consistent with the changes observed in the Ungava region since 1955.

Both the amount and species composition of taiga and tundra vegetation can have profound effects on soil moisture and the timing and amount of water discharged by rivers. Finely branching, taller lichen species such as *Cladonia alpestris* act as mulch. The upper levels of the mat dry very quickly, but the lower levels are very resistant to evapotranspiration, and the surficial soil under the mat remains saturated for long periods (Kershaw and Rouse, 1971). Thick-bodied forms resistant to grazing and trampling have relatively little resistance to drying. Evaporation from the dark, peaty soil of the Ungava region would be accelerated by the decreased albedo resulting from reduction of vegetation. The direct effects of such changes in plant cover associated with high densities of caribou would be increased runoff during summer rainstorms and decreased groundwater input during dry periods.

Vegetation also affects the thickness of the snow pack in winter; taller plants tend to trap more snow. In northern Ontario, Larson and Kershaw (1975) reported that when snow depths of approximately 150 cm occurred in spruce forest, nearby sedge meadows had about 30 cm and lichen heaths had as little as 2-5 cm. Insulation of the ground surface from winter temperatures occurs when the thickness of the snow pack exceeds 40 cm (Annersten, 1964), so reduction of vegetation should lead to increased thickness of the underlying permafrost. Unless it is completely eroded away, the peaty surface layer of the soil would dry very quickly in summer, forming a good insulation to help maintain low soil temperatures (Brown, 1970). The net effects on stream discharge and channel morphology would be the same as, and would add to, those resulting from the general decline in mean annual air temperatures discussed earlier.

SUMMARY AND CONCLUSIONS

Inuit hunters provided information about the status of arctic char in 70 rivers entering Ungava Bay. Of the 46 systems supporting anadromous char, 18 were reported to have barriers that prevented fish from reaching overwintering lakes during recent dry years. Direct examination of these rivers revealed that most of the problem areas are shallow, diffuse sections through boulder moraine with no clear channel.

River systems in the Ungava region that support anadromous arctic char drain >10 km^2 above overwintering lakes and have average gradients of <70 $m \cdot km^{-1}$. Rivers with intermediate gradients (20-70 $m \cdot km^{-1}$) have char if the distance to the overwintering lake is <1 km; longer intermediate gradient streams usually lack anadromous char. Low gradient (<20 $m \cdot km^{-1}$) draining >150 km^2 support anadromous populations, but the longer rivers are more likely to have problem sections. Nearly all smaller (<150 km^2) low-gradient rivers have partial or complete barriers to migration.

During recent decades, the increasing frequency of years in which char are reported to have had difficulty returning to overwintering lakes might be attributable to the combined effects of climatic change and a rapidly expanding caribou population on runoff, frost-heave and vegetation. Both mean annual and summer precipitation have declined slightly since 1960, and mean annual air temperature has decreased by about 1°C. Numbers of caribou have risen geometrically since the early 1950s, resulting in changes in terrestrial vegetation. Taken together, these changes would lead to a reduction in the depth of the active layer of the permafrost and an alteration of the pattern of stream discharge. Reduction of free groundwater and destabilization of summer and autumn discharge means that critically low flows are more likely to occur at the time of char migration. Increased frost heave in boulder moraines would further tend to decrease channel development.

The subsistence demand for arctic char is growing with the Inuit population of northern Quebec. If plans for commercial fishing are realized, or if caribou become less available for food, the total demand for char will increase dramatically. This is very likely: there is considerable pressure to develop a commercial fishery, and collapse of the caribou herds is predictable sometime in the future. Since anadromous char have been reported to have difficulty in ascending nearly 40% of the rivers that have traditionally been fished, remedial action is needed to assure the continuing availability of this resource. In a few problem streams Inuit have taken the initiative to clear a channel through the lake end moraine, forming a crude but effective "rustic fishway" to ease the passage of char. It is equally important to consider taking advantage of existing opportunities to increase the number of rivers accessible to anadromous arctic char in northern Quebec. Several major river systems, the Nephijee being a prime example, are blocked by only one set of falls. This work is difficult to promote at the individual level, since it suffers from the so-called "tragedy of the commons" (Hardin, 1968): it does not pay for one person to make the effort when all benefit. It also suffers from another problem in that increasing ease of fish passage in problem streams is tantamount to decreasing ease of capture. To a subsistence hunter, this makes no sense.

Fortunately, recent changes in the social organization in northern Quebec, stemming from the James Bay and Northern Quebec Agreement, have resulted in local hunting and fishing committees being given the responsibility of looking after community common interests. To such committees, management projects on char streams are sensible and consistent with traditional Inuit values. At the 1985 annual meeting of Makivik Corporation and the April 1986 meeting of Anguvigaq representatives in Kuujjuaq, such projects were promoted by several communities around Ungava Bay. In August 1986, channels were cleared through shallow reaches of a river near Tasiujaq by local workers using hand tools, and char were later observed using the new channels (Gillis and Gordon, 1987). While the long-term results of this project remain to be seen, it is clear that such work can be undertaken successfully by the local population with a minimum of equipment and guidance. This may lead to more complex management projects in support of arctic char parallelling those for salmon on the east and west coasts but on a smaller scale. We are hopeful that this scenario will transpire so that anadromous arctic char can continue to be an important component of the Inuit diet.

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