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Summer Movements of Radio-Tagged Arctic Charr (*Salvelinus alpinus*) in Lake Hazen, Nunavut, Canada

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ABSTRACT. Radiotelemetry was used to determine whether Lake Hazen arctic charr (*Salvelinus alpinus*) were anadromous and to determine movements of the charr within the lake. In 1995 and 1996, 62 and 55 charr, respectively, were captured, radio-tagged, and released back into the lake. A fixed data acquisition system recorded limited movements of radio-tagged charr in the upper reaches of the Ruggles River, the only outlet from the lake to the sea, in 1995. When movements of radio-tagged charr within Lake Hazen were monitored opportunistically in 1995, most of the relocated charr were found in warmer, more productive waters associated with inflowing streams. No movements of radio-tagged charr in the Ruggles River were recorded in 1996 when the data acquisition system was operated in the lower reaches of the river. These observations supported the conclusions of a study of Lake Hazen charr otolith strontium distribution that Lake Hazen charr were non-anadromous. The Ruggles River may be a detriment to anadromous behaviour because of its length (ca. 29 km), velocity (up to 2.25 $m \cdot s^{-1}$), and the year-round presence of *aufeis* (layered ice buildup). In summer, instead of migrating to the sea to feed, Lake Hazen charr appear to move to feed on abundant prey found in areas where inlet streams enter the lake.

Key words: anadromy, arctic charr, Ellesmere Island, life history, migrations, Quttinirpaaq National Park, radio-tagging, *Salvelinus alpinus*

RÉSUMÉ. On a fait appel à la télémesure pour savoir si l'omble chevalier (*Salvelinus alpinus*) du lac de Hazen est anadrome et pour connaître ses déplacements dans le lac. On a capturé 62 ombles en 1995 et 55 en 1996 qu'on a munis de radio-émetteurs avant de les relâcher dans le lac. En 1995, un système fixe de collecte de données a enregistré les déplacements restreints des ombles munis de radio-émetteurs dans le cours supérieur de la rivière Ruggles, la seule décharge du lac dans la mer. Quand on a pu vérifier les déplacements de ces ombles dans le lac de Hazen en 1995, la plupart des poissons se trouvaient dans les eaux plus chaudes et plus productives associées à des ruisseaux d'arrivée. En 1996, après qu'un système de collecte de données a été installé dans le cours inférieur de la rivière Ruggles, on n'y a enregistré aucun déplacement des ombles munis de radio-émetteurs. Ces observations viennent étayer une étude sur la distribution du strontium otolithique chez l'omble du lac de Hazen, qui concluait que ce poisson n'était pas anadrome. Il se peut que la rivière Ruggles soit peu propice à un comportement anadrome en raison de sa longueur (env. 29 km), de sa vitesse (jusqu'à 2,25 $m \bullet s^{-1}$) et de la présence toute l'année d'un dôme de glace (*Aufeishugel*). En été, au lieu de migrer vers la mer pour se nourrir, l'omble du lac de Hazen semble se déplacer vers les zones où les ruisseaux se déversent dans le lac et qui contiennent des proies en abondance.

Mots clés: anadrome, omble chevalier, île d'Ellesmere, évolution biologique, migrations, parc national Quttinirpaaq, pose de radio-émetteurs, *Salvelinus alpinus*

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INTRODUCTION

The arctic charr (*Salvelinus alpinus*) exhibits considerable phenotypic diversity, and when populations have access to the sea, some fish usually migrate there during the summer to feed in the more productive marine environment (Johnson, 1980). As a result, such charr populations are made up of at least two co-existing forms: a large migratory form (anadromous) and a small resident form that passes its entire life in freshwater (non-anadromous) (Johnson, 1980; Jonsson and Jonsson, 1993). However, the degree of anadromy (i.e., the relative proportions of

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anadromous versus resident individuals) within charr populations that have access to the sea can vary greatly (Kristoffersen, 1994; Kristoffersen et al., 1994).

Arctic charr is the only fish species found in Lake Hazen, located in Quttinirpaaq National Park at the northern end of Ellesmere Island in the Canadian High Arctic. Lake Hazen charr occur in both large and small forms (Hunter, 1960; Johnson, 1983; Reist et al., 1995). The large form grows faster, reaches a greater size, and has lighter coloration and "normal-sized" ventral fins (Reist et al., 1995), resembling the typical anadromous arctic charr of Arctic Canada described by Johnson (1980). The small form of Lake Hazen charr is characterized by slower growth, smaller maximum size, dark coloration, and elongate ventral fins (Reist et al., 1995) and seems to be similar to the non-anadromous arctic charr found throughout the range of the species (Johnson, 1980). Since Lake Hazen is linked to the sea via the Ruggles River, it has been hypothesized that the larger of the two forms of charr is anadromous, and the smaller form is non-anadromous (Hunter, 1960; Johnson, 1983).

Anadromous and non-anadromous arctic charr have traditionally been distinguished through the monitoring of tagged fish migrating to and from the sea (e.g., Johnson, 1989). Recently, otolith microchemistry has been used to identify the environmental histories of fish (e.g., Radtke, 1989; Coutant and Chen, 1993). A study of the distribution of strontium in the otoliths of both large and small forms of Lake Hazen charr provided the first evidence that Lake Hazen charr were not anadromous (Babaluk et al., 1997). Radiotelemetry techniques have been used to analyze various aspects of migratory behaviour in salmonids (e.g., Knight et al., 1977; Bourgeois and O'Connell, 1988; Heggberget et al., 1993; Beddow et al., 1998). As part of an ongoing study of Lake Hazen charr ecology, we conducted a radiotelemetry study to provide 1) further information on whether the fish were anadromous and 2) information on their summer movements within the lake.

MATERIALS AND METHODS

Study Area

Lake Hazen (81°50′N, 70°25′W) has a surface area of 537.5 km^2 (Inland Waters Directorate, 1973) and a recorded maximum depth of 263 m (Deane, 1959; Fig. 1). The lake is fed by glacial meltwater from the ice fields of the Grant Land Mountains to the north (Stewart, 1994), and its drainage basin covers approximately 4900 km^2 (Parks Canada, 1994). The lake retains partial ice cover in most summers (Parks Canada, unpubl. data). The lake is extremely oligotrophic, with no macrophytes and low phytoplankton (Johnson, 1990) and zooplankton productivity (McLaren, 1964). Thirty-four species of benthic invertebrates have been reported from the lake (Oliver, 1963). Lake Hazen drains via the Ruggles River into Chandler Fiord (Fig. 1). The Ruggles River, which drops ca. 157 m in elevation over its course of ca. 29 km (Smith, 1999), is shallow (<1.5 m, Stewart, 1994) and fast flowing (0.47–2.25 m·s^{-1}, M. Jones, Environment Canada, Yellowknife, Northwest Territories, pers. comm. 1998). It has no waterfalls or other obvious barriers to fish movement (Stewart, 1994). However, *aufeis*, the layered ice buildup that occurs when water flows onto a land or ice surface during periods of sub-freezing temperatures (Harden et al., 1977), is present along the lower reaches of the river and on the sea ice of Chandler Fiord (Greely, 1886; Smith, 1999). In most years, the head of the river remains partially open all year (Deane, 1958), but in 1995, low water levels in the lake allowed it to freeze over, the first such occurrence recorded since 1915 (R. Wissink, unpubl. data).

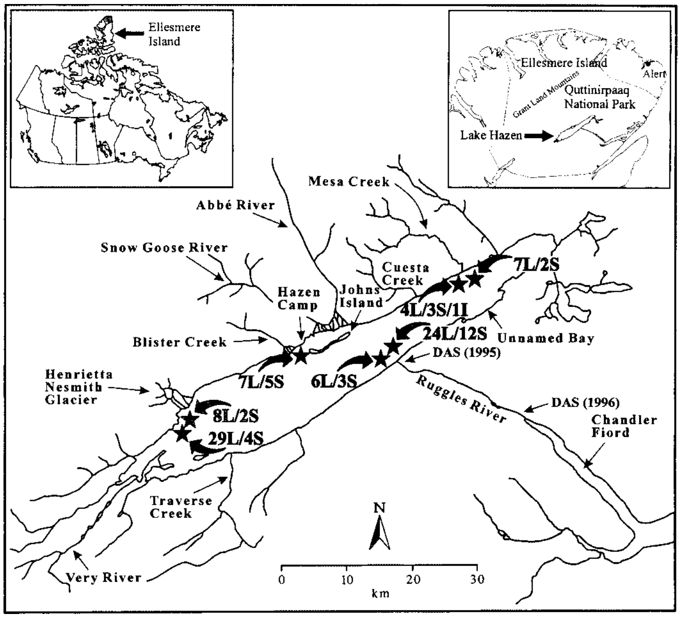

FIG. 1. Map of Lake Hazen. Release sites of radio-tagged arctic charr are shown as black stars for 1995 and grey stars for 1996. Number and form (L = large, S = small, I = indeterminate) of charr tagged at each site are indicated beside each star. Location of the fixed data acquisition system (DAS) is indicated for 1995 and 1996.

Fish Tagging

During 7–13 May 1995, 62 arctic charr (46 large, 15 small, 1 indeterminate form) were captured by angling through the ice at four locations on Lake Hazen, and during 24–27 May 1996, 55 charr (39 large, 16 small form) were captured at three locations (Fig. 1). The 85 large-form charr ranged in fork length from 351 to 685 mm and weighed from 400 to 3100 g; the 31 small-form charr were 305–533 mm long and weighed 260–1370 g; and the one charr of indeterminate form was 423 mm long and weighed 730 g.

Following capture, the fish were held at ambient temperature, anaesthetized with benzocaine (25 ppm, Laird and Oswald, 1975), measured, and weighed. Their form (large or small) was determined using criteria described by Reist et al. (1995). High-frequency (149.32 – 149.80 MHz) radio transmitters (model CFRT-3BM in 1995; model MCFT-3CM in 1996, Lotek Engineering, Inc., Newmarket, Ontario) with a unique, digitally encoded signal were mounted on the right side of each fish just below the dorsal fin (Winter et al., 1978; Mellas and Haynes, 1985). Transmitters used in 1995 and 1996 had a predicted operational life of ca. 260 days. After tagging, the charr were kept in a recovery tank for one hour and then released into the lake. Radio tags were tested three times with a portable receiver: before application, while tagged fish were in the recovery tank, and immediately after their release into the lake. Nonetheless, some tag failure (ca. 10 – 33%) was expected (McLeod and Clayton, 1993; Young, 1996).

Fish Monitoring and Tracking

The fixed data acquisition system (DAS) consisted of a receiver and data logger (Lotek, model SRX-400) equipped with two 4-element Yagi directional antennae. In 1995, the DAS was set up on the north bank of the Ruggles River ca. 1.5 km from the outflow at Lake Hazen (Fig. 1) according to the criteria given by McLeod and Clayton (1993). At this point, the Ruggles River was less than 1.5 m deep and ca. 30 m wide. The antennae were programmed to switch continually to allow identification of upstream and downstream movements of radio-tagged fish (scanning interval = 6.0 s). The expected reception range of this equipment was 550–750 m (McLeod and Clayton, 1993). The DAS operated continuously from 6 May to 8 August 1995. As a system test, an activated reference tag was submerged in the river in the vicinity of the receiver on 6 and 11 May, 14 June, 1 July, and 8 August. In 1996, the same system was set up on the north bank of the Ruggles River near its mouth, ca. 20 km from Lake Hazen (Fig. 1) (scanning interval = 5.5 s). Here, the river was less than 1.5 m deep and ca. 20 m wide. The system operated continuously from 19 May to 12 August 1996. System tests were carried out on 19 and 26 May and 12 August.

Additionally, we searched for radio-tagged charr in Lake Hazen on an opportunistic basis. Most of this tracking was conducted on four days in 1995, using the portable receiver from a helicopter with two 4-element Yagi directional antennae attached to its undercarriage. Although some of the radio-tagged fish may have migrated to deeper areas of Lake Hazen, we concentrated radio tracking on the shallow areas (mainly along the shoreline) for several reasons. First, high-frequency transmitters are not ideal for waters deeper than 3 m (McLeod and Clayton, 1993); second, these were the only areas of the lake with open water; and finally, charr tended to congregate in these areas. The entire shoreline of Lake Hazen was surveyed on 16 June and 2 July 1995, while the shoreline from Hazen Camp around the northeastern end of the lake to the Ruggles River was flown on 9 August 1995 (see Fig. 1). Also, the entire length of the Ruggles River was flown on 16 June, 3 July, and 9 August 1995. Tracking was done while flying at an altitude of ca. 30 m and speeds of 30 – 50 km·h^{-1}. After the initial detection of a radio-tagged fish, additional passes were made at lower altitudes to determine its tag number and obtain a precise location using a Global Positioning System in the aircraft. Manual tracking was done opportunistically on foot from shore or in a collapsible kayak at the mouths of Mesa Creek (2 July 1995), Blister Creek (4 July 1995), the Snow Goose and Abbé Rivers (6 and 8 July 1995), and Traverse Creek (8 August 1995). Although sport fishing on Lake Hazen is extremely limited, all visitors to Quttinirpaaq National Park were asked to release and report any recaptured radio-tagged charr.

RESULTS

Movements of Radio-tagged Arctic Charr in the Ruggles River

In 1995, when the DAS was located near the outlet of the Ruggles River (Fig.1), it recorded only two radio-tagged arctic charr. A small-form charr, tagged near Blister Creek on 10 May, was recorded on the upstream antenna on 25 July (Table 1, fish no. 8) suggesting that the fish moved downstream from the lake to the area of the DAS but not past it. A large-form charr, tagged near the outlet into the Ruggles River on 11 May, was recorded several times by both antennae on 2 August (Table 1, fish no. 10). The fish remained in the area for ca. 45 minutes before apparently returning upstream.

In 1996, when the DAS was located near the mouth of the Ruggles River (Fig. 1), no movements of radio-tagged charr were recorded.

Movements of Arctic Charr in Lake Hazen

In addition to the two arctic charr recorded by the DAS at the Ruggles River, 11 other charr radio-tagged in 1995 were subsequently relocated in the lake and identified (Table 1). Eight of these were relocated during tracking flights; two were caught, released, and reported by anglers; and one was relocated from the kayak. An additional 14 charr radio-tagged in 1995 were relocated on tracking flights, but the signals were too weak to identify the individual fish (Fig. 2). Assuming that all 14 tagged fish with unidentifiable signals were unique, at least 35 of the 62 charr radio-tagged in 1995 were never relocated.

Three of the 55 charr radio-tagged in 1996 were recaptured in subsequent years. One was recaptured by gill net at the mouth of the Snow Goose River on 1 August 1998 (Table 1, fish no. 14). This fish had not increased in length or weight since release, but it had well-developed ovaries and would probably have spawned in autumn 1998. The other two fish were caught by anglers: the second fish at Mesa Creek on 8 July 1999 (Table 1, fish no. 15) and the

TABLE 1. Details of radio-tagged arctic charr relocated in Lake Hazen.

Fish No.	Date Tagged	Location Tagged[1]	Form[2]	Fork Length (mm)	Weight (g)	No. of Times Relocated	Intermediate Location[1]	Date of Last Relocation	Last Location[1]	Minimum Distance Travelled (km)
1	07 May 1995	BC/HC	S	389	520	1	–	02 July 1995	VR	34
2	08 May 1995	HNG	L	550	1670	2	SR	06 July 1995	SR	28
3	08 May 1995	HNG	L	578	1960	2	SR	08 July 1995	AR	29
4	08 May 1995	HNG	L	526	1410	2	AR	10 July 1995	BC/HC	38
5	09 May 1995	MC	L	641	2400	2	MC	02 July 1995	MC	0
6	09 May 1995	MC	L	676	2850	3	MC, MC	25 July 1995	MC	0
7	09 May 1995	MC	S	377	440	1	–	09 August 1995	JI	24
8	10 May 1995	BC/HC	S	372	410	1	–	25 July 1995	RR[3]	19
9	10 May 1995	BC/HC	L	559	1620	2	UN	09 August 1995	UN	33
10	11 May 1995	RR	L	391	540	1	–	02 August 1995	RR[3]	2
11	13 May 1995	HNG	L	542	1500	1	–	16 June 1995	VR	8
12	13 May 1995	HNG	L	552	1800	1	–	02 July 1995	VR	11
13	13 May 1995	HNG	L	685	3100	1	–	08 July 1995	AR	29
14	24 May 1996	RR	L	520	1230	1	–	01 August 1998	SR	10
15	25 May 1996	RR	L	589	1760	1	–	08 July 1999	MC	16
16	24 May 1996	RR	L	624	2250	1	–	13 July 2000	CC	10

[1] AR = Abbé River, BC/HC = Blister Creek/Hazen Camp, CC = Cuesta Creek, HNG = Henrietta Nesmith Glacier, JI = Johns Island, MC = Mesa Creek, RR = Ruggles River, SR = Snow Goose River, UN = unnamed bay, VR = Very River.

[2] S = small, L = large.

[3] Recorded at fixed data acquisition station.

third at Cuesta Creek on 13 July 2000 (Table 1, fish no. 16).

Distance travelled by the fish, including intermediate locations for fish recorded more than once, ranged from 0 to 38 km (Table 1). Two charr were relocated several times in the area where they were tagged and released (fish no. 5 and 6), while fish number 4 was recorded as having moved the greatest straight-line distance (38 km). It was tagged and released on 8 May 1995 in the vicinity of the Henrietta Nesmith Glacier; by 2 July, it had moved to the Abbé River area, and on 10 July, it was angled at Blister Creek. While minimum distance travelled varied, some charr of both small and large forms travelled similar distances within the lake (e.g., fish no. 1 and 9).

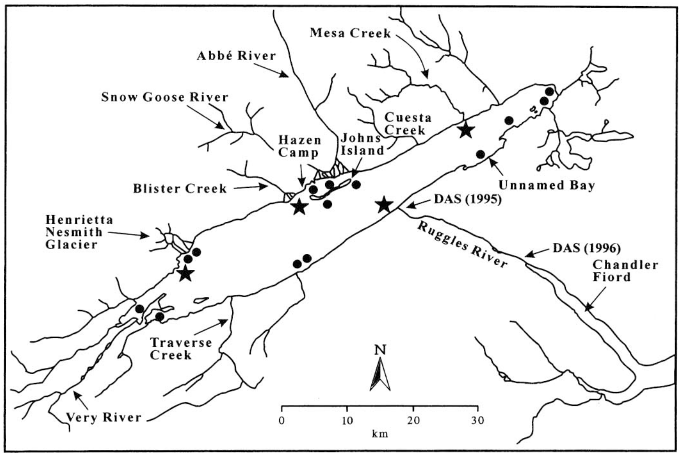

FIG. 2. Distribution of relocated, but unidentifiable, radio-tagged arctic charr (black dots) released in Lake Hazen at various sites (black stars) in 1995.

DISCUSSION

The results of our radiotelemetry study show that both forms of Lake Hazen arctic charr may make brief forays into the upper reaches of the Ruggles River, but there is no evidence that they use the river as a passageway to the sea. Our results complement those of an otolith microchemistry study (Babaluk et al., 1997) and support the conclusion that neither form of Lake Hazen charr is anadromous. Instead of migrating to the sea to feed, Lake Hazen charr appear to move to feed in areas where small inlet streams enter the lake.

Elsewhere, charr tend to congregate in the current below the outflows of rivers into lakes (Lindström, 1954) and move toward the warmer waters of inflowing creeks (Näslund, 1992). Craig and Poulin (1975) reported that juvenile (defined as small) charr moved into small tributary streams that flowed only in spring and summer. The latter movement of small charr has also been observed in the Lake Hazen system (authors, unpubl. data). Näslund (1991, 1992) demonstrated that warmer stream water attracted juvenile charr and triggered an upstream migration. Primary production would be expected to commence earlier in the warmer stream and adjacent lake waters (Näslund, 1992), giving an increased food base for juvenile and small-form charr, which, in turn, would attract the cannibalistic large-form charr (Babaluk et al., 1997).

Several factors may influence the existence of anadromy within fish populations. One such factor is whether the benefits of migration are greater than the costs (Jonsson and Jonsson, 1993). Anadromy has been hypothesized to evolve when migration to the sea results in improved lifetime reproductive potential (Northcote, 1978; Gross, 1987; Gross et al., 1988). Thus, if conditions for feeding, growth, and reproductive development are as good or better in freshwater (i.e., Lake Hazen) than in the sea (i.e., Chandler Fiord), no advantage would be gained by migrating to the sea (Svenning et al., 1992). Babaluk et al. (1997) suggested that the large-form Lake Hazen charr were not anadromous because they were cannibalistic, given the abundant juvenile and small-form charr in the lake.

Anadromous behaviour in arctic charr populations also depends on access to the sea. The Ruggles River has no obvious physical barriers and provides a potential passageway for charr between Lake Hazen and the sea, but because it is long (29 km) and has a high flow rate (0.47–2.25 $m \cdot sec^{-1}$), the river might not be suitable for efficient migrations. Kristoffersen (1994) found negative correlations between anadromous behaviour in Norwegian arctic charr populations and both the length of the outlet river and a migration barrier index (MBI):

$$MBI = (V + C) L$$

where V = mean water velocity ($m \cdot sec^{-1}$); C = 0.25 $m \cdot sec^{-1}$ (estimated optimum swimming speed for a charr of 250 mm length); and L = length of river (m).

Low levels of anadromy were found in cases where rivers were longer than 6.0–7.0 km and MBI values were greater than approximately 4000–5000 (Kristoffersen, 1994). With the exception of riverine, anadromous arctic charr, most lake-dwelling anadromous charr populations in the Canadian Arctic also migrate relatively short distances to the sea (Johnson, 1980). Applying the equation to the Ruggles River yields MBI values ranging from 20 900 to 72 500.

Another potential impediment to seaward migration of Lake Hazen charr may be the *aufeis* present along the lower reaches of the Ruggles River and on the sea ice of Chandler Fiord (Greely, 1886; Smith, 1999). While channels through the *aufeis* would be present during the summer season, enabling downstream passage, upstream migration might be impossible because of the high velocities of water flowing through the constricted channels (Wellen and Kane, 1985).

Kristoffersen et al. (1994) suggested that lake morphology influenced the degree of anadromy: anadromous charr were prevalent in shallow lakes, while non-anadromous charr dominated deeper lakes that had large profundal zones. Lake Hazen, with a maximum recorded depth of 263 m, would be characterized as a deep lake with a large profundal zone and thus may be more suitable for non-anadromous charr. However, while anadromous charr have not been found in Lake Hazen, they have been found in the area. Scanning proton microprobe analysis of strontium in otoliths from charr from Heintzelman Lake (81˚42′N, 66˚56′W, ca. 40 km southeast of Lake Hazen) showed a strontium pattern consistent with that of known anadromous charr (J. Babaluk, unpubl. data). Heintzelman Lake is relatively small (9 km long, 1.5 km wide), shallow (maximum recorded depth = 15 m), and connected to the sea by a relatively short (ca. 10 km), passable river. The river drops ca. 70 m to the sea and has no *aufeis* build-up (Smith, 1999). The Heintzelman Lake watershed most likely meets the criteria for habitat to support anadromous charr as described by Kristoffersen (1994) and Kristoffersen et al. (1994).

In the distant past, Lake Hazen charr were probably anadromous. As a result of isostatic uplift, the land to the south of Lake Hazen has risen more over time than the land in the immediate vicinity of the lake (England and Bednarski, 1986; Smith, 1999). Approximately 6000 years ago, sea level was ca. 72 m higher than it is now. Thus the Ruggles River would have had a shorter length, less gradient, and lower water velocities, making it more conducive to fish migration. As the rising of the land gradually lowered the sea level, the gradient and length of the river would have eventually increased to a point where a critical MBI would have been surpassed, effectively making the river less than ideal for fish migration.

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