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Spawning, Overwintering and Summer Feeding Habitats Used by Anadromous Arctic Char (*Salvelinus alpinus*) of the Hornaday River, Northwest Territories, Canada

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ABSTRACT. Radio telemetry and t-bar tagging were used to locate sites used by Hornaday River Arctic char (*Salvelinus alpinus*) for overwintering, spawning, and summer feeding. Thirty char, 21 in August 1995 and nine in July and August 1999, were captured, radio-tagged, and released back into the Hornaday River. Tracking was done over 14 months in 1995–96 and over three months in 1999, using either aircraft (10 flights) or snowmobiles traveling on the river ice in winter (7 trips). Of 12 radio-tagged char that were relocated during winter 1995–96 and not caught in the 1995 upstream migration fall fishery, 11 (92%) ultimately overwintered in the reach of the Hornaday between Coalmine and Akluk Creek; three of these did so in consecutive years. This area is characterized by groundwater inputs and deep pools (> 2 m) that do not freeze to the riverbed in winter. Another important overwintering site was found in a similarly deep channel on the west side of the Hornaday River estuary, where half of the char radio-tagged in fall 1999 spent the winter of 1999–2000. Spawning locations were discerned through circumstantial evidence from the movements of three radio-tagged fish over entire annual cycles. The locations that were indicated as spawning habitat were all in the main stem of the Hornaday River, in deep (> 2 m), groundwater-fed pools between Coalmine and Akluk Creek. Fourteen percent of 239 char t-bar tagged at Pearce Point in July–August 1997 were caught at the mouth of the Hornaday River, on average within 25 days of tagging, which indicates that the nearshore area of Pearce Point, characterized by upwelling and enhanced productivity, is an important summer feeding area for this stock. This identification of overwintering, spawning, and summer feeding habitats contributes to an emerging list of areas for which it would be prudent to monitor habitat quality, change, and integrity given contemporary changes in climate and the potential for near-future anthropogenic activities in this watershed.

Key words: Arctic char, Hornaday River, *Salvelinus alpinus*, migration, Northwest Territories, overwintering, spawning, summer feeding, tagging

RÉSUMÉ. La radiotélémesure et les étiquettes en T ont été employées pour repérer les lieux utilisés par l'omble chevalier (*Salvelinus alpinus*) de la rivière Hornaday pour l'hivernage, le frai et l'alimentation estivale. Trente ombles ont été capturés dans la rivière Hornaday, soit 21 en août 1995 et neuf en juillet et en août 1999. Des radio-émetteurs ont été posés sur ces ombles, après quoi ils ont été relâchés dans la rivière. Nous les avons suivis pendant 14 mois en 1995-1996 ainsi que pendant trois mois en 1999, en avion (dix vols) ou en motoneige sur la glace de la rivière pendant l'hiver (sept expéditions). Parmi les 12 ombles dotés de radio-émetteurs qui ont été relocalisés à l'hiver 1995-1996 et n'ont pas été attrapés pendant la pêche de la montaison automnale en 1995, 11 (92 %) ont fini par passer l'hiver dans le passage de la Hornaday situé entre Coalmine et le ruisseau Akluk; trois d'entre eux y sont retournés au cours des années qui ont suivi. Cette aire est caractérisée par des apports d'eau souterrains et des fosses profondes (> 2 m) qui ne gèlent pas jusqu'au lit de la rivière en hiver. Un autre lieu d'hivernage important a été trouvé dans un chenal tout aussi profond du côté ouest de l'estuaire de la rivière Hornaday, où la moitié des ombles dotés de radio-émetteurs à l'automne 1999 ont passé l'hiver 1999-2000. Les lieux de frai ont été discernés au moyen de preuves circonstancielles à partir des mouvements de trois poissons munis de radio-émetteurs pendant l'ensemble des cycles annuels. Les lieux qui ont été indiqués à titre d'habitat de frai se trouvaient tous dans le tronçon principal de la rivière Hornaday, dans des fosses profondes (> 2 m) alimentées par de l'eau souterraine situées entre Coalmine et le ruisseau Akluk. Quatorze pour cent des 239 ombles auxquels une étiquette en T a été posée à Pearce Point en juillet-août 1997 ont été attrapés à l'embouchure de la rivière Hornaday, en moyenne 25 jours après avoir été étiquetés, ce qui indique que l'aire sublittorale de Pearce Point, caractérisée par une remontée d'eau et une productivité accrue, constitue une aire d'alimentation estivale importante pour ce stock. L'identification des habitats d'hivernage, de frai et d'alimentation estivale s'ajoute à une nouvelle liste d'endroits pour lesquels il serait prudent de surveiller la qualité, la modification et l'intégrité de l'habitat à la

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lumière des changements climatiques contemporains et des activités anthropiques susceptibles de se produire dans ce bassin hydrographique dans un avenir rapproché.

Mots clés : omble chevalier, rivière Hornaday, *Salvelinus alpinus*, migration, Territoires du Nord-Ouest, hivernage, frai, alimentation estivale, étiquetage

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INTRODUCTION

Arctic char (*Salvelinus alpinus*) have a circumpolar distribution and are the most northerly distributed species of freshwater fish (Scott and Crossman, 1973). They occur in clear-flowing rivers and lakes of the Canadian Arctic that are located, with two exceptions, east of the Mackenzie River (Reist et al., 1997; Reist and Sawatzky, 2010). A riverine, anadromous (sea-run) stock of Arctic char spawns and overwinters in the Hornaday River, Northwest Territories, Canada (Fig. 1) (DFO, 1999). The Inuvialuit of Paulatuk, a community of 314 (Northwest Territories Bureau of Statistics, 2013) located approximately 14 km west of the Hornaday River, have harvested char from this system for subsistence since the community was first settled in the early 1940s. The Hornaday is the largest river draining into Darnley Bay, and it supports the largest stock of Arctic char in the area, with the next large stock located 300 km to the east on Victoria Island (Harwood et al., 2013). A test fishery at the Brock River, the other main river draining into Darnley Bay (Fig. 1), confirmed the presence of char in this system, but only in small numbers (MacDonell, 1988).

Arctic char exhibit several life-history types, the most common being lake-resident (freshwater) and anadromous, with spawning and overwintering usually occurring in lakes (Johnson, 1980; Tallman et al., 1996; Beddow et al., 1998). In some cases, where lakes are not available and suitable habitat exists, spawning does occur in rivers (Johnson, 1980). Some of the overwintering sites used by Hornaday char are known through the timing and locations of the under-ice fishery conducted annually by the community on the main stem of the Hornaday: Tourist Camp, Billy's Creek, and Coalmine (PHTC, 1998; Fig. 1). Nothing is known of the overwintering potential of areas farther upstream than the Akluk Creek confluence, because the river is prone to unstable ice conditions and therefore not accessible by snowmobile or fished regularly in winter (Fig. 1). In recent years, char have also been caught in a winter gillnet fishery from the west channel of the Hornaday River estuary under a cut-bank where the river does not freeze to the bottom. We refer to this area as the "Bluffs," and locally it is called *Nuvaqpaluk* (H. Wolki, Paulatuk, pers. comm. 2013; Fig. 1). The area has never been the subject of scientific study of either fish or fish habitat.

Spawning and overwintering habitats used by Arctic char are often in the same locations since they have similar characteristics (DFO, 2004). The choice of specific spawning sites depends on the presence of a satisfactory substratum, the continuous presence of unfrozen and oxygenated water, and low temperatures (Johnson, 1980; Baxter and McPhail, 1999). Areas associated with groundwater springs provide favourable habitat for char spawning, egg survival, and hatching (Heggenes et al., 2010), and such areas are also used for spawning and overwintering by the closely related species Dolly Varden (*S. malma*) (Sandstrom, 1995; Sandstrom and Harwood, 2002; Mochnacz et al., 2010; Stewart et al., 2010) and bull trout (*S. confluentus*) in Canada's North (Baxter and McPhail, 1999; Baxter and Hauer, 2000; Mochnacz et al., 2013).

The precise location of spawning areas used by Hornaday char have not been described, mainly because the river is inaccessible to fishers in September, when the char spawn (Johnson, 1980). The two large lakes draining into the Hornaday River downstream of La Roncière Falls, Rummy Lake and Seven Islands Lake (Fig. 1), are unlikely to provide overwintering or spawning habitat for anadromous char because of their steep, impassible gradients and minimal or non-existent flows in connecting streams at critical times of year (MacDonell, 1996, 1997). While flows in Rummy and Akluk Creeks (Fig. 1) are too low or non-existent during summer and fall to permit the upstream passage of adult char, passage to Seven Islands and Rummy Lakes may be possible during spring freshet in some years (MacDonell, 1997; Babaluk et al., 1998).

In spring, anadromous Arctic char (smolts or first-time migrants and older fish) leave their freshwater overwintering habitats and make annual migrations to the sea for the important summer feeding period (Johnson, 1980). Char are omnivorous, feeding mainly on small fishes and benthic organisms in summer, but their diet is highly variable between locations and seasons (Johnson, 1980). They feed in both inter-tidal and sub-tidal habitats (Spares et al., 2012).

Availability of critical habitats and continued access to them are of paramount importance to anadromous char stocks for their conservation. Northern stocks have especially narrow habitat requirements for spawning, rearing, overwintering (Stewart et al., 2010; VanGerwen-Toyne and Tallman, 2010), and summer feeding (AANDC, 2012). They are particularly vulnerable to habitat fragmentation and disruption, and special management or mitigation measures may be necessary if industrial development or other human activities threaten their habitats. The observations of critical habitats we present here have not been reported previously for this species in this region, and they augment a growing natural history baseline for this stock.

Here we collate results from two radio-tagging projects (1995–96 and 1999) and two t-bar-tagging projects (1987 and 1997) that aimed to identify critical overwintering,

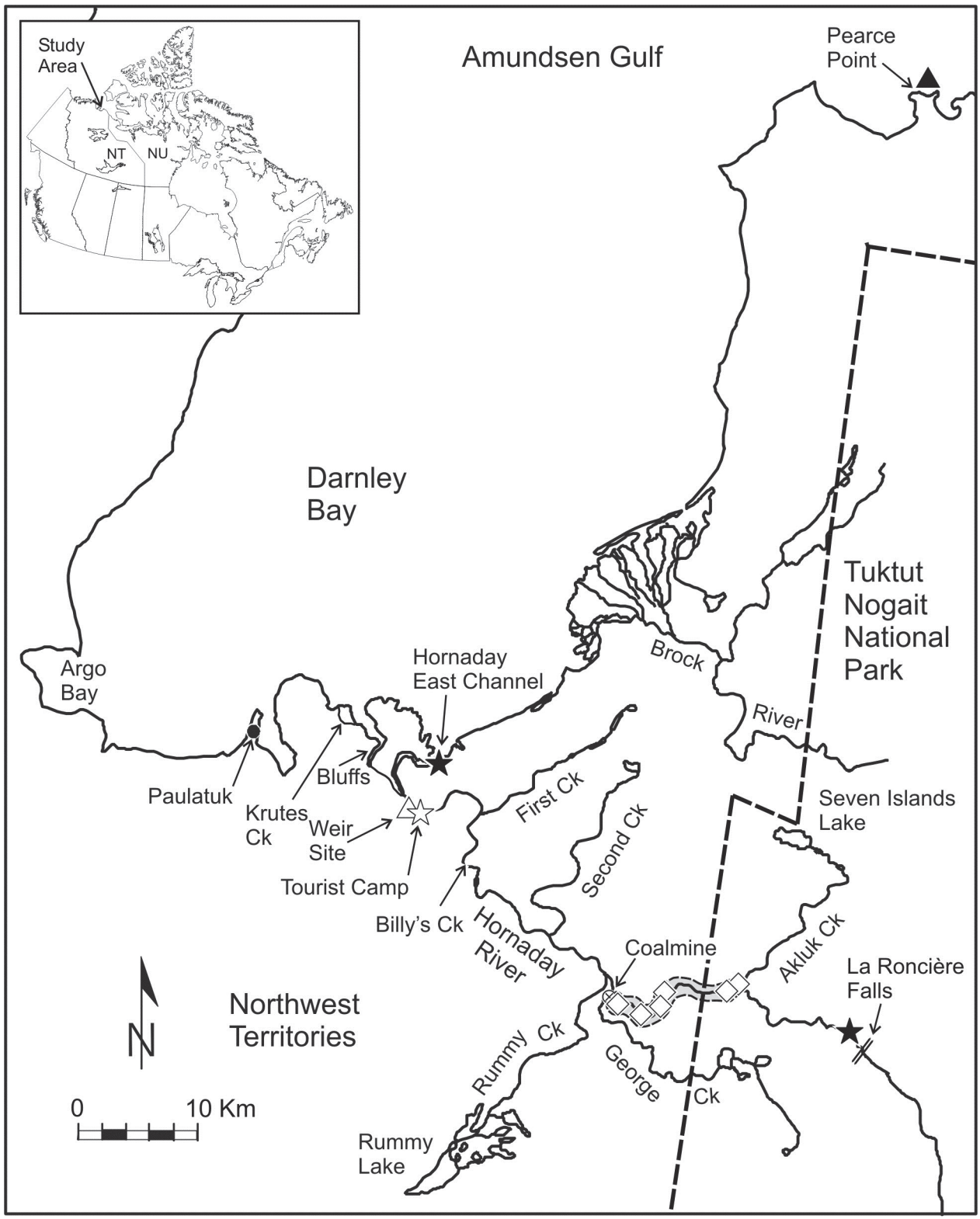

FIG. 1. Map of the Hornaday River area, showing release sites of Arctic char radio-tagged in 1995 (☆) and 1999 (★) and of char t-bar tagged in 1987 (△) and 1997 (▲). Also shown are the Coalmine-Akluk reach (shaded area) and known groundwater sources (◇).

spawning, or summer feeding habitats of the anadromous Hornaday River Arctic char stock. The tagging projects were conducted jointly with the community fishers, the Paulatuk Hunters and Trappers Committee (PHTC), and the Fisheries Joint Management Committee (FJMC). We were able to rely on local expertise and knowledge of subsistence fishers to carry out the research. Those involved recognized how important understanding aspects of char life history is

to ensuring that management initiatives and decisions will conserve the population (PHTC, 1998). One motivation for the tagging projects was to contribute to informed assessment of potential impacts of proposed mineral exploration activities in the watershed near Coalmine (e.g., Jones et al., 1992; Darnley Bay Resources Limited, 2013). Another was the establishment of the Tuktut Nogait National Park in 1996 (Parks Canada, 1996). Understanding the implications of habitat shifts, critical habitats, and general ecology of this stock is also crucial for assessment of the impacts of a changing climate (Reist et al., 2006; Walsh, 2008; Mochnacz et al., 2010; Stewart et al., 2010).

MATERIALS AND METHODS

Study Area

The Hornaday River (69˚19′ N, 123˚48′ W at its mouth) originates in western Nunavut, approximately 100 km north of Dease Arm of Great Bear Lake. It flows in a northwest direction into the Northwest Territories (NT), through Tuktut Nogait National Park, before emptying into Darnley Bay approximately 14 km east of the hamlet of Paulatuk (DFO, 1999; Fig. 1). The river is about 280 km long and drains an area of 13 120 – 14 900 km^2 (Ayles and Snow, 2002). La Roncière Falls (69˚8′ N, 122˚53′ W), located approximately 45 km from the mouth of the river, is 23 m high, forming a barrier to upstream fish migration (Fig. 1).

Downstream of the falls, the river consists of a mainstem channel of rapids alternating with deep pools that do not freeze to the bottom in winter. There the river is between 40 and 100 m wide and 0.5 – 3.0 m deep, with deeper, interspersed groundwater-fed pools in the upper reaches (I. Clark, University of Ottawa, unpubl. data). Preliminary field measurements and reconnaissance in 1999 found the dolomite terrain at the Hornaday to be consistent with other sites where there is continuous discharge of groundwater through the winter, in regions of continuous permafrost between Coalmine and Akluk Creek (Fig. 1) (I. Clark, unpubl. data; Clark and Lauriol, 1997; Clark et al., 2001; Kane et al., 2013). Recharge takes place in carbonate karst, through talik zones. Groundwater springs in the upper reaches of the Hornaday are of typical karst discharge with a Ca(Mg)-HCO_3 facies, similar to the situation that maintains open water throughout the winter at Fishing Branch River, Yukon Territory (Utting et al., 2013).

There are coal deposits along the Hornaday River near the confluences of George and Rummy Creeks, at an area locally known as Coalmine (Fig. 1). The Hornaday River delta is approximately 50 km^2 and has several channels, including a shallow, eastern channel that fishers describe as freezing to the bottom in winter, and a west channel that includes a deep pool under the Bluffs (Fig. 1). The main channel (flow) of the Hornaday River has changed over time; according to fishers, the main flow now favours the west channel over the previously dominant east channel (H. Wolki, pers. comm. 2013). Downstream of the La Roncière Falls, the river provides habitat for anadromous Arctic char and several other anadromous and non-anadromous fish species, including Arctic cisco (*Coregonus autumnalis*), Arctic grayling (*Thymallus arcticus*), broad whitefish (*C. nasus*), burbot (*Lota lota*), longnose sucker (*Catostomus catostomus*), and ninespine stickleback (*Pungitius pungitius*) (DFO, 1999).

Radio Tagging and Tracking

From 15 to 21 August 1995, 21 Arctic char were captured using 127 mm (5-inch) stretched-mesh gillnets near the Tourist Camp site on the Hornaday River (Fig. 1, Table 1). From 29 July to 10 August 1999, eight Arctic char were captured using 127 mm (5-inch) stretched-mesh gillnets in the pool at the base of La Roncière Falls (n = 3) and in the east channel of the Hornaday River estuary (n = 5) (Fig. 1, Table 2). After capture, the char were anaesthetized with benzocaine, measured (fork length, nearest mm), and weighed (nearest 50 g; 1995 only), and where possible, sex was assigned by visually inspecting presence or absence of a developing kype. Subsistence fishers also checked the fish they caught, and in most cases were able to determine sex of the fish.

High-frequency radio transmitter tags (model 2, Advanced Telemetry Systems, Inc., Isanti, Minnesota), compressed cylinders, each of which was 66 mm long, weighed 20 g, and had a unique frequency signal, were mounted on the right side of each fish just below the dorsal fin (Winters et al., 1978; Mellas and Haynes, 1985). Tags were all within the range from 0.4% to 1.1% of body weight, which is below the recommended percent of body weight (Brown et al., 1999). The frequency range for the tags was 48.070 – 48.700 MHz (1995) and 48.674 – 48.764 MHz (1999). The 48 MHz frequency range is commonly used in rivers because of relatively low signal attenuation (Baglinière et al., 1991). These tags are detectable in brackish water, although not useful in the ocean because detection distances decrease with increasing conductivity (salinity) (Shroyer and Logsdon, 2009). The transmitters had a predicted operational life of approximately 365 days.

After tagging, the char were kept for at least 24 h in a traditional, boulder holding pen in the river until they had fully recovered and then released. Our goal was to capture and tag mature fish in spawning condition; however, these occur in such low numbers in the late summer upstream Hornaday River run (< 1%) (Harwood, 2009) that none were caught during the duration of the project. Only mature, resting fish that would not spawn in that particular year, which we refer to as current year non-spawning char, were captured for tagging (size range = 526 to 730 mm, 1750 to 4850 g; Tables 1 and 2). Radio tags were tested with a receiver three times: before application, while the tagged fish were in the recovery pen, and immediately after their release into the river. All radio tags were functioning at the time of release.

TABLE 1. Biological and relocation information of Arctic char radio-tagged at the Hornaday River, 1995–96. Gray shading indicates spawning period (where applicable; i.e., September-October 1996) and overwintering period. Relocation areas: CM = Coastal Marine, HM = Hornaday Mouth (east side of estuary, too shallow for overwintering, probable mortality), TC = Tourist Camp (proximate to Old Weir site), FC = First Creek, BC = Billy's Creek, MS = Main stem, CA = Coalmine-Akluk (upper river), * = caught in subsistence fishery (during interval between surveys), ** = too shallow for overwintering, probable mortality.

Tag site & date	Tourist Camp: 15–21 August 1995																				
Fork length (mm)	720	690	567	605	611	620	540	550	708	698	631	694	650	695	535	593	527	526	730	674	645
Weight (g)	4800	3900	2750	2700	2900	3050	2200	1900	5000	4100	2900	4100	3400	na	1850	2450	2050	1750	4850	3500	3500
Sex	M	M	NA	M	F	F	F	F	M	M	M	M	M	M	M	M	NA	NA	M	M	F
Fish no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Survey date:																					
22 August 1995[1]	HM	HM	TC	HM	MS	FC	TC	FC	HM		FC	TC		TC	CA	CA	BC	FC	BC	FC	
11 October 1995[1]	CA	TC	TC	CA			BC	CA	BC		BC	FC	CA	TC			TC	CA	CA	CA	
		TC*					BC*		BC*		BC*			TC*			TC*	CA*			
28 October 1995[2]	CA		CA	CA	CA			CA				FC	CA						CA	CA	
	CA*																				
23 January 1996[2]			CA		CA			CA				FC	CA			CA			CA		
22 February 1996[2]					CA			CA				FC	CA			CA			CA		
4 May 1996[1]			CA	CA				CA					CA							CA	
										HM**											
12, 19 June 1996[1]				MS	CA			CM*							CM*					CA	
7 July 1996[1]																					
2 August 1996[1]					CA					HM										CA	
24, 25 August 1996[1]				CA	CA							FC								CA	
16 September 1996[1]				CA	CA					HM		FC								CA	
26 October 1996[1]				CA	CA					HM		FC								CA	

[1] air.
[2] ground.

Tracking of radio-tagged Hornaday River Arctic char was conducted from 22 August 1995 to 26 October 1996 and from 1 October to 20 November 1999, using both aerial and ground tracking. Aerial tracking was conducted using a portable receiver from Advanced Telemetry Systems (ATS model R2100) from either a Bell Long Ranger helicopter or a fixed-wing Cessna 206 airplane. Aircraft were equipped with one or two ATS loop antennae attached forward (helicopter) or to both wing struts (fixed-wing airplane). Ten aerial tracking flights were conducted in 1995–96, and each included the Hornaday River from the estuary upstream to La Roncière Falls and Rummy and Seven Islands lakes to the extent that weather and fuel reserves would allow. Aerial flights from June through August 1996 also included all channels in the estuary of the Hornaday River, and, on two occasions, the Brock River as far upstream as its headwater lake (Fig. 1). Tracking was done at altitudes of 100–300 m. After the detection of a radio-tagged char, the tag frequency and location were marked on the field sheet map and GPS coordinates were recorded from the aircraft's navigation system.

Ground tracking was conducted using the same portable receiver from a snowmobile equipped with a single ATS loop antenna. Three ground surveys were conducted in 1995–96 and four in 1999 (Tables 1 and 2). The area encompassed by each ground survey included the Hornaday River from the estuary to near its confluence with Akluk Creek. Tracking was done while traveling on river ice and snow at a low speed (< 10 km/h). After the detection of a radio-tagged char, the char's tag frequency and location were marked on the field sheet map and GPS coordinates were recorded from a hand-held GPS instrument.

Relocations of several radio-tagged char were determined from tagged fish caught in the local subsistence fisheries at the Hornaday River from mid-October to mid-November 1995 and in the subsistence fishery along the eastern coast of Darnley Bay in June 1996.

T-bar Tagging and Recaptures

During 21–24 August 1987, 156 Arctic char were captured at a conduit fence weir trap as they were migrating upstream in the Hornaday River (Fig. 1) (MacDonell, 1988). From 12 July to 6 August 1997, a further 239 Arctic char were captured using 114 mm (4.5-inch) and 127 mm (5-inch) stretched-mesh, nylon, multi-filament gillnets set perpendicular to shore at Pearce Point (69˚47′ N, 122˚40′ W) (Fig. 1). The trap and nets were checked regularly (at intervals of about one hour) to avoid damage to the fish (or mortality). Following capture, the char were removed from the trap or nets and placed in holding tubs or pens containing river water. The char were handled without anaesthetic.

TABLE 2. Biological and relocation information of Arctic char radio-tagged at the Hornaday River, 1999. Light gray area indicates overwintering period. Relocation areas: HM = Hornaday Mouth (east side of estuary, shallow), BL = Bluffs (west side of estuary, deep), CA = Coalmine-Akluk (upper river).

Tag site & date	La Roncière Falls: 29 July 1999			Hornaday River mouth: 2–10 August 1999				
Fork length (mm)	563	568	526	640	620	650	582	NA
Fish no.	22	23	24	25	26	27	28	29
Survey date:								
1 October 1999		BL					CA	
29 October 1999		BL	HM	CA	BL	BL	CA	
14 November 1999		BL						
20 November 1999		BL						

Captured char were measured (fork length, nearest mm), tagged (t-bar anchor tags, Floy Tag & Mfg., Inc., Seattle, Washington), and released. A dead sample of 24 char was taken during the Pearce Point tagging program (for length, weight, sex, maturity). Stomach contents were examined and photographed in the field by the community technicians.

The late summer catches from Hornaday River subsistence fisheries have been enumerated and sampled by community monitors since 1988 (Harwood, 2009), which included recording the capture time and location of any tagged fish. Additional recapture locations and dates were also reported directly to DFO and to the monitors by subsistence fishers between 1998 and 2005.

RESULTS

Seasonal and Individual-Specific Movements of Radio-Tagged Arctic Char

1995–96: Twenty of 21 Arctic char radio-tagged near Tourist Camp from 15 to 21 August 1995 were relocated later in 1995 or during the following year (up to 26 October 1996) (Table 1). The longest tracking period for an individual fish was 436 days (Table 1, Fish no. 21). All relocated (tracking) and captured (subsistence fishery) radio-tagged char were from the Hornaday River proper or from the sea along the coast. No radio-tagged char were relocated or captured in the Brock River system, from any of the Hornaday tributary creeks (e.g., Akluk, George, Rummy Creeks), or in either of the two larger lakes draining into the Hornaday River (Seven Islands Lake, Rummy Lake) (Fig. 1).

During late summer and early fall, the relocated radio-tagged char were found in three general areas in the Hornaday River: 1) in the lower Hornaday River near Tourist Camp (n = 4), 2) farther up the river near an area known locally as "Billy's Creek" (n = 8), and 3) farther upstream on the main river over a 16 km reach between Coalmine and its confluence with Akluk Creek (n = 5) (hereafter called Coalmine-Akluk) (Table 1, Fig. 1).

In late fall and winter, radio-tagged char were also relocated in these three areas of the main-stem of the Hornaday, with most having reached Coalmine-Akluk by this time (n = 10) (Table 1), and a few remaining in the lower reaches near Tourist Camp (n = 4) and Billy's Creek (n = 4). Of 12 radio-tagged char that were relocated during winter 1995–96 and were not caught in the 1995 upstream migration fall subsistence fishery, 11 (92%) were eventually relocated during the winter in the Coalmine-Akluk reach, three of these in consecutive years (Table 1).

In spring and summer, one radio-tagged char was relocated in the main stem of the river approximately 7 km upstream of the First Creek outflow (Fig. 1, Table 1, Fish no. 13). A further two were captured in the coastal, spring subsistence fishery following the out-migration, 8 km east of the Hornaday River estuary (Table 1, Fig. 1). All other relocations in spring and summer (n = 6) were at Coalmine-Akluk.

Of the 21 char radio-tagged, three females were relocated multiple times over a period of 14 months (Table 1). Immediately after tagging, Fish no. 5 (female, 611 mm) moved 5 km downstream, then moved upstream and was next relocated in the Coalmine-Akluk reach on 11 October 1995, and again on 28 October 1995. In spring of the next year (12 June 1996), this fish was relocated within 4 km of Billy's Creek in the main stem of the Hornaday. Approximately 10 weeks later (24–25 August 1996), this fish was again relocated at the Coalmine-Akluk area, where it remained (relocated 16 September and 26 October 1996) (Table 1).

Fish no. 6 (female, 620 mm) was relocated four days after tagging, having moved 30 km upstream to the Coalmine area. Its next relocation, 1 km upstream of the confluence of the Hornaday River and Akluk Creek on 11 October 1995, was the only relocation of a radio-tagged fish farther upstream than the Coalmine-Akluk reach. This fish was then relocated eight times in the Coalmine-Akluk reach (in winter 1995–96, summer 1996, and fall 1996), but was not relocated anywhere else (Table 1).

Fish no. 21 (female, 645 mm) was relocated five days after tagging, having moved 8 km upstream in the Hornaday to the First Creek confluence area (Fig. 1). By 11 October, it was relocated in the Coalmine-Akluk pools, and it was relocated there nine times over winter 1995–96, summer 1996, and as late as 26 October 1996, and nowhere else (Table 1).

1999: Of three Arctic char radio-tagged at La Roncière Falls in late July 1999, one was relocated four times in October and November 1999, downstream of the tagging site in the west channel of the Hornaday River in the deep pool at the Bluffs (Table 2, Fig. 1). Of five char radio-tagged at the mouth of the Hornaday River in August 1999, two moved upstream and were relocated during winter in the Coalmine-Akluk reach, and two were relocated on 29 October 1995 in the west channel of the Hornaday River estuary at the Bluffs (Table 2, Fig. 1).

Movements of T-Bar-Tagged Arctic Char

1987: Twenty-two (14%) of 156 t-bar-tagged Arctic char released at the weir site during 21–24 August 1987 (MacDonell, 1988) were recaptured in the subsistence fisheries over the next two years. Nine were caught returning from the sea during the August 1988 subsistence fishery in the east channel of the Hornaday River estuary (Fig. 2). An additional four were caught in the Hornaday River during the under-ice fishery at Billy's Creek (1988) and Coalmine (1989) (Fig. 2). A further eight were caught in the coastal subsistence fishery in spring 1988 and 1989 at Krutes Creek (Fig. 2) and one tagged char was caught in June 1989 in Argo Bay (Fig. 2).

1997: Of the 239 Arctic char t-bar tagged and released in the sea near Pearce Point between 12 July and 6 August 1997 (mean fork length = 533 mm, range = 358–815 mm), eight were recaptured within one week of tagging at the same location, and re-released. A dead sample consisting of 16 males and eight females had mean fork length 597 mm (range = 437–801). Of 24 char dead-sampled in the field by community technicians, 11 had stomachs containing fish remains; 11 had invertebrate remains; and two had empty stomachs. Where fish remains were present, capelin (*Mallotus villosus*) were purportedly dominant.

Between 6 and 25 August 1997, 34 of the 239 (14.2%) Arctic char t-bar tagged at Pearce Point were captured in the subsistence fishery at traditional fishing sites between the Brock and Hornaday Rivers and at the east channel of the Hornaday River estuary (Fig. 2), approximately 85 km shoreline distance from Pearce Point. These char were at large for an average of 26 days (range = 4–53 days) after tagging. A further 24 tagged char were caught in the same areas and time of year between 1998 and 2001; four were recaptured off the mouth of the Brock River in 1998 and 2004; and one was recaptured at Krutes Creek in the west Hornaday estuary during the spring out-migration in 2005 (Fig. 2). No recaptures of 1997 t-bar-tagged char were reported from any area west of the Hornaday River estuary.

DISCUSSION

Overwintering

Radio-tagging results demonstrated that the anadromous, riverine stock of Arctic char in the Hornaday River uses deep pools in the main stem of the river for overwintering. All char radio-tagged at the mouth of the Hornaday River in August 1995 and two of six tagged at the mouth in August 1999 moved upstream during fall to known winter fishing sites in the Hornaday. Overwintering in rivers is not the most common characteristic among stocks of char found in the Canadian Arctic, which mostly overwinter in lacustrine habitats. The Kellet River, Nunavut, Arctic char stock has the only other known riverine life history (DFO, 2004, 2013).

During late summer and fall, tagged Arctic char were found in the lower regions of the Hornaday River, as this time coincided with the beginning of the upstream migration when the char were actively moving from the sea into the estuary. They were not relocated in any area other than the Hornaday main stem downstream of La Roncière Falls, such as the Brock River system or the Hornaday tributary creeks (e.g., Akluk, George, Rummy Creeks), or in either of the two larger lakes draining into the Hornaday River (Seven Islands Lake, Rummy Lake).

The reach of the Hornaday River from Coalmine to Akluk Creek was identified as particularly important to this stock for overwintering. Of 12 radio-tagged char that we relocated during winter 1995, 11 (92%) overwintered there for one or more winters. Char that overwintered in this reach of the Hornaday used more than one deep pool during the course of the winter, and three fish that we were able to track over an annual cycle used the same deep pool in consecutive years. The overwintering pools on the reach of the Hornaday River from Coalmine to Akluk Creek correspond to locations where there are at least five perennial groundwater-fed deep pools that were sampled in a preliminary study in February and July 1999 (I. Clark, unpubl. data).

Until recently it was thought that anadromous Arctic char overwintered exclusively in freshwater, due to their presumed intolerance of saline conditions at low temperatures (Johnson, 1980, 1989; Berg and Berg, 1993). However, some riverine char populations in northern Norway have been shown to use estuarine waters during the winter (Jensen and Rikardsen, 2008, 2012). Our results also revealed the use of the estuary of the Hornaday River during winter 1999. Of six char radio-tagged in 1999, three were relocated during the winter in the Bluffs area of the west channel of the Hornaday River estuary, and the others, in the Coalmine-Akluk reach described above.

Use of this estuarine habitat by Hornaday River Arctic char in winter is not unknown to the community fishers of Paulatuk, as they have historically (1950s) and more recently (2000s) fished the Bluffs area, with approximately 10 gillnet fishers in the area during the winter (H. Wolki, pers. comm. 2013). As the Hornaday River does not freeze to the bottom at the Bluffs (H. Wolki, pers. comm. 2013), it may be similar to the situation of Lake Herlinveaux in the Northwest Territories—an expansive, essentially freshwater "lake" that forms in the outer Mackenzie River estuary each winter (Carmack and Macdonald, 2002). Lake Herlinveaux has limited or no winter connectivity with the ocean because of the isolating effect of grounded sea ice.

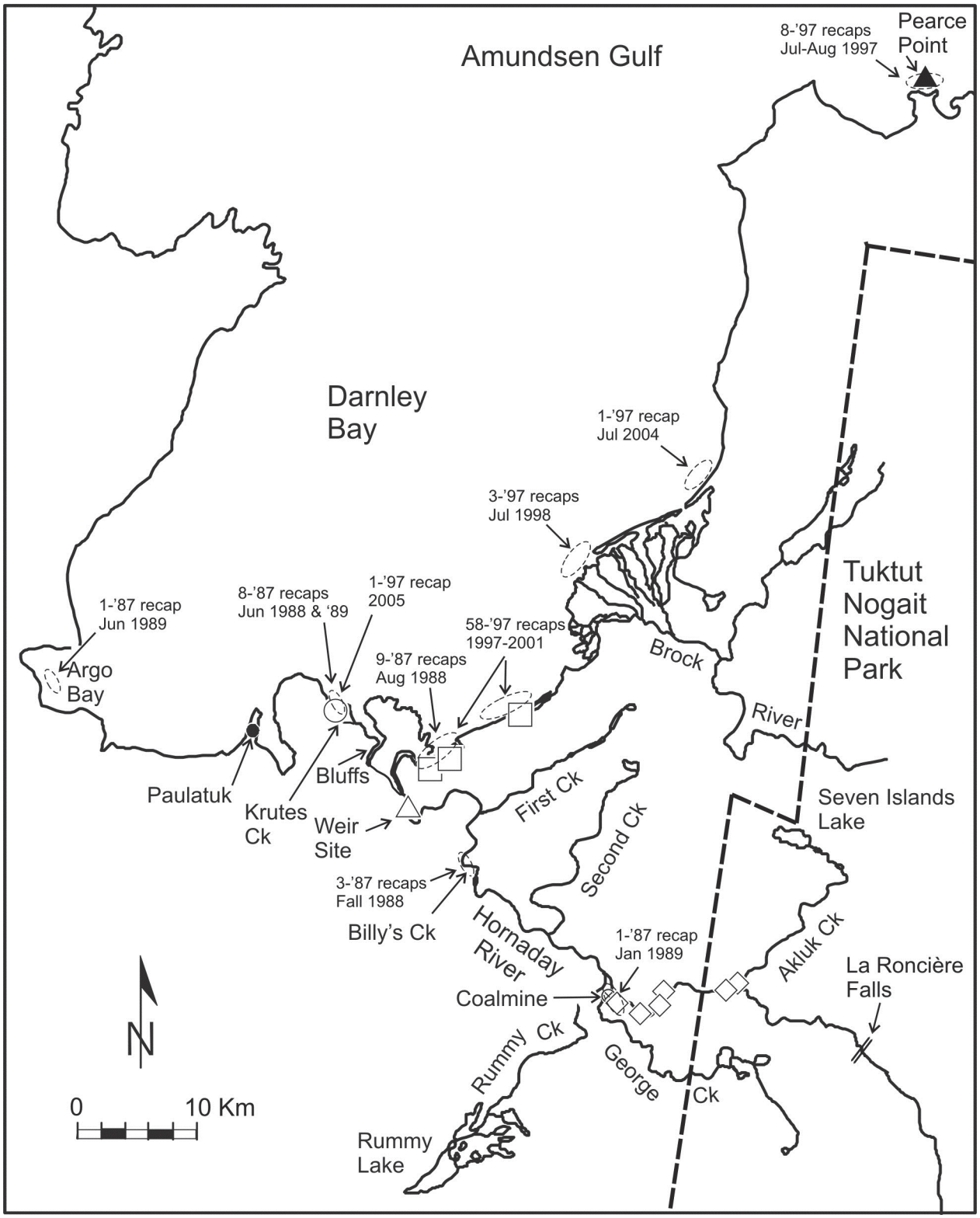

FIG. 2. Distribution of recaptured (recaps) t-bar-tagged Arctic char (dashed-line oval) released at the Weir (△) in 1987 and at Pearce Point (▲) in 1997, indicating the number of recaps and approximate relocation dates. Also shown are major traditional subsistence fishing areas for spring (○) and summer (□) and known groundwater sources (◇).

Our results contrast with the general assumption that Arctic char do not overwinter in marine waters, an assumption on which management of Arctic char in Canada's Arctic has been based (DFO, 2004, 2013; VanGerwen-Toyne and Tallman, 2010). While the majority of anadromous char use freshwater lakes for overwintering, the results from the Hornaday are unique in Canada's western Arctic and most likely reflect the plastic life history that allows char to use

suitable habitats, including estuaries, in certain locations. Investigation of the Bluffs area with scientific fishing and tagging is warranted, along with a study of substrate, depth, salinity, temperature, and oxygen levels, as information of this type is not yet available for this area.

Spawning Sites

One of our study objectives was to determine the spawning locations of Hornaday River Arctic char. Unfortunately, we were unable to deploy radio tags on mature fish in spawning condition, as none were caught during project fishing efforts. They appear to have a life history pattern similar to that described by Johnson (1989) for Nauyuk Lake char: the char ascend the river in fall, and if mature, do not necessarily return to the sea the following summer, but remain in freshwater while their gonads develop. After spawning, the char remain in freshwater for another winter before resuming their feeding migration to the sea the following spring. This life history pattern results in a loss of 30%–40% of their body weight, so they are often in very poor condition when they first return to the sea (Dutil, 1986) and are known as "slinks." The observation of slinks in the Hornaday River estuary catches in the spring (authors' unpubl. data) and the paucity (< 1% annually) of current-year spawners in the upstream migration in August (Harwood, 2009) provide evidence that at least some, and quite possibly the majority, stay in the river during the summer before they spawn.

We have obtained circumstantial but compelling evidence for spawning activity by Hornaday char in the reach of the river between Coalmine and Akluk Creek by examining the relocations of three of the char radio-tagged in 1995. The areas where these char were relocated in mid-September (our tracking dates coincided with the time of spawning according to Johnson, 1980) points to an emerging picture of multiple spawning pools between Coalmine and Akluk Creek. Fish no. 5 showed fidelity to the Coalmine-Akluk overwintering area in fall 1995 and fall 1996, and it used at least one of the same pools in two consecutive winters. Fish no. 6 actually remained in the Coalmine-Akluk area from late August 1995 until it was last relocated on 26 October 1996. Fish no. 21 also did not migrate to sea in summer 1996 (Table 1) and spent what would be considered the spawning period (from 16 September to 26 October 1996) in this area. Specific locations along the Coalmine-Akluk reach that were used by probable spawners were different from each other, suggesting that there are multiple spawning pools in this reach of the river. In particular, we note that the deep pool closest to Coalmine corresponds to the place where a local fisher caught and reported five spent (post-spawning) char in mid-October 1994 (J. Illasiak, Paulatuk, NT, pers. comm. 1994)

MacDonell (1996) caught five char that were current-year spawners, as well as one slink, at the pool at the base of La Roncière Falls in July 1996. Also, in early September 1997, a single female in spawning condition was captured in the pool at the base of the falls, and many more char were observed in the pool at that time (MacDonell, 1996, 1997). None of our radio-tagged fish were relocated in the pool at the base of falls, so we were unable to confirm that this area is possibly used for spawning or overwintering. While this pool may well be a spawning area for Hornaday char, its importance in relation to the Coalmine-Akluk reach remains unknown. Further study incorporating gillnetting, angling, snorkeling or scuba diving, and underwater photography could be undertaken during mid-September by using a helicopter to access the falls area.

The spawning and overwintering habitats of the Hornaday River shown in this study support a large (> 15 000; DFO, 1999), geographically isolated, and unique stock of Arctic char. A small stock of anadromous char uses the Brock River, but its relationship to the Hornaday char stock is not well understood. Tracking flights over the Brock River system during our study were possible on only two occasions, and there were no relocations of radio-tagged char. There is rarely any subsistence fishing activity in the Brock River itself, since there is no flow in the upper reaches in summer and fall (authors' unpubl. data). A test fishery was conducted at the mouth of the Brock River in 1988, and although the size of the stock could not be estimated, the run was described as small (MacDonell, 1988). While there is evidence that reproductive adults return (home) to their natal river (Johnson, 1980; Nordeng, 2009), current-year non-spawning fish (juveniles and resting adults) have been shown to stray between adjacent systems for overwintering (Johnson, 1980; Kristofferson et al., 1984), and this dispersal may be important in maintaining gene flow (Moore et al., 2013). Straying is usually geographically localized, as are char movements at sea, and it occurs mainly among stocks that share a common summer feeding area (Roux et al., 2011a). Evidence suggests that at least some non-spawners move between the Hornaday and the Brock Rivers (Roux et al., 2011b), but the extent of this movement is unknown.

Summer Feeding in the Ocean

In spring, anadromous Arctic char (smolts and older fish) leave their freshwater overwintering habitats and make annual migrations to the sea to feed during the summer (Johnson, 1980). They obtain most of their annual energy requirements from these forays into coastal waters during the short open-water season. The energetic gain from these coastal summer feeding areas is of primary importance (AANDC, 2012), outbalancing both the energetic and physiological costs of migration and the increased risk of predation, by giving the anadromous char access to ample, rich marine food resources for one to three months (McCart, 1980; Johnson, 1980; Gross et al., 1988; Bégout Anras et al., 1999; Rikardsen et al., 2007; Jensen and Rikardsen, 2012). The results of the 1987 and 1997 t-bar-tagging studies provided new information about the locations where anadromous Hornaday char feed during the summer. The paucity

of tag returns on the west side of Darnley Bay (Fig. 1) compared to the east side of Darnley Bay, where fish were recaptured in each year for seven years after tagging, suggested that the summer migrants travel mainly along the east side of Darnley Bay. This result may be biased by unequal sampling effort (e.g., soak times, fishing locations); however, if anadromous char were present in adequate numbers west of Paulatuk, the local fishers would be fishing there. They do not; instead, they generally concentrate coastal fishing efforts to the east of the Hornaday River (PHTC, 1998).

Since 14% of the Pearce Point tagged char were caught within three weeks of tagging near the Hornaday mouth—and nowhere else—it appears that the river mouth is an important Hornaday char feeding area in summer. Fishers from Paulatuk, aware of the abundance of char at this location during summer, provided the original recommendation to conduct the tagging study there. The study's objective was to determine the "home river" of these char that the fishers knew were very abundant there in summer (N. Green, Paulatuk, NT, pers. comm. 1996). Pearce Point is an area of known coastal upwelling (Paulic et al., 2011), which makes it a highly productive marine area during summer.

The field analysis of Arctic char stomach contents suggests that capelin play an important role as prey used by Hornaday River anadromous char in the ocean during the summer months, particularly at Pearce Point. With limited data on summer feeding, we know nothing of annual variability or the extent to which other prey items are used in years of variable capelin abundance. Capelin was also reported as the main marine prey of anadromous char returning from the sea in fall to Nauyuk Lake, where no invertebrates were found in char stomachs at that time (Johnson, 1980, 1989). Further studies are warranted on the location and year-to-year variability of capelin in coastal feeding areas around Pearce Point and other areas of Amundsen Gulf, as well as the energetic value of capelin and other types of potential prey. This information would aid in developing strategies to conserve and protect these important habitats.

In conclusion, the particular habitats in the Darnley Bay area that appear to be of critical importance to anadromous Arctic char are the deep pools in the Coalmine-Akluk reach of the upper Hornaday River main stem, which are associated with perennial groundwater springs (spawning and overwintering), and the rich, marine habitats such as Pearce Point (summer feeding). Potential changes to quality or quantity of groundwater flowing to the main-stem areas and the deep pools that are associated with groundwater springs could be studied in winter using ground-penetrating radar to document their exact locations, size and water depth. Such studies would be useful for future monitoring and protection of these critical habitats. Similarly, the deep-water areas at the Bluffs appear to be of some importance as overwintering habitat, at least in some years, and perhaps increasingly so in recent years. For this area too we require evaluation of salinity, depth, water quality, water quantity, and the extent to which the area is used by Arctic char in other years and in different seasons, as this baseline information is not currently available.

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The cost and challenges of capturing, tagging, and tracking Arctic char in a remote northern system such as the Hornaday River are considerable, and it was only through collaboration with local harvesters and technicians that this study could be successfully conducted. We report on the work of many people. Foremost, we acknowledge four community field technicians, the late Charlie Ruben, Joseph Illasiak, Ruben Ruben, and the late Nelson Green, all of whom worked tirelessly on various aspects of the capture, tagging, and tracking over the years encompassed by this study. Their dedication and skills ensured the successful and safe conduct of the studies. We also acknowledge the late Donovan Dowler (former Vice-Chair Fisheries Joint Management Committee) for his leadership and dedication to the Paulatuk Arctic char programs. We also gratefully acknowledge the char fishers of Paulatuk, for turning in recaptured tags, for sharing their ideas, and for field and administrative assistance with various programs reported in this paper. In particular, we acknowledge Tony Green, Hank Wolki, Noel Green, Peter Green, John Max Kudlak, Steve Illasiak, Pat Thrasher, the late Greg Green, Ryan Green, and Jason Ruben (our sincere apologies to anyone we have missed). We also greatly appreciate the skills and efforts of field camp leaders Paul Sparling (White Mountain Consulting Services, Whitehorse, Yukon) in 1995, and Don MacDonell (North/South Consultants Inc., Winnipeg, Manitoba) for leading t-bar and radio-tagging deployment camps in 1987, 1995, and 1999. From Parks Canada, we gratefully acknowledge the support and assistance of Christian Bucher and from the University of Ottawa, Dr. Ian Clark and Dr. Michel Robin, for conducting groundwater studies on the Hornaday River in 1999. We also acknowledge the directors and staff of the Paulatuk Hunters and Trappers Committee and Fisheries Joint Management Committee for their ongoing support and assistance with these programs. The tagging studies were made possible by funding provided by the Fisheries Joint Management Committee, Parks Canada, Fisheries and Oceans Canada, the Campfire Club of North America, and the Polar Continental Shelf Project of Natural Resources Canada. We thank Steve Sandstrom, Dr. Tom Smith, and three anonymous reviewers for helpful comments that improved this manuscript.

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