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Overwintering Locations, Migrations, and Fidelity of Radio-Tagged Dolly Varden in the Hulahula River, Arctic National Wildlife Refuge, 2007 – 09

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ABSTRACT. Essential overwintering habitats for anadromous Dolly Varden *Salvelinus malma* on Alaska's North Slope appear to be limited to a small number of perennial springs, primarily in eastern Brooks Range drainages. Because future petrochemical development in the region continues to be a possibility, and development would require large quantities of freshwater, we sought to identify and document the overwintering areas used by Dolly Varden in the Hulahula River, eastern Brooks Range. In August 2007, we implanted 52 Dolly Varden with multi-year radio transmitters at a known overwintering area in the lower Hulahula River. Other wintering areas were located during 11 aerial surveys conducted over the next 2.5 years. A stationary receiver located in the lower Hulahula River provided migration timing information. Radio-tagged Dolly Varden used four discrete areas with perennial springs for overwintering in the Hulahula River drainage. The springs, totaling approximately 12 km in stream length, were located between river km 40 and 105. Radio-tagged Dolly Varden migrated downstream on their way to the Beaufort Sea in early June. Most tagged fish known to have survived the summer at sea returned to the Hulahula River during late July and August, but seven fish overwintered in other North Slope drainages. Within the Hulahula River drainage, 15 fish overwintered in more than one area during the three winters of the project, but only the four identified perennial spring areas were used. These data clearly indicate that the perennial springs in the Hulahula River are essential overwintering habitats for Dolly Varden.

Key words: Dolly Varden, *Salvelinus malma*, Alaska, Beaufort Sea, Hulahula River, North Slope, radiotelemetry, overwintering, migration

RÉSUMÉ. Les aires de concentration hivernales essentielles du Dolly Varden *Salvelinus malma* anadrome sur la North Slope de l'Alaska semblent limitées à un petit nombre de sources pérennes, principalement dans les bassins hydrographiques de l'est de la chaîne de Brooks. Puisqu'il est toujours possible qu'il y ait des aménagements pétrochimiques dans la région et que ceux-ci demanderaient de grandes quantités d'eau douce, nous avons tâché de déterminer les aires de concentration hivernales du Dolly Varden dans la rivière Hulahula faisant partie de l'est de la chaîne de Brooks, et nous les avons répertoriées. En août 2007, nous avons installé des émetteurs radio pluriannuels sur 52 poissons Dolly Varden dans une aire de concentration hivernale connue faisant partie de la rivière Hulahula inférieure. D'autres aires de concentration hivernales ont été repérées grâce à 11 levés aériens effectués au cours des 2,5 années qui ont suivi. Un récepteur fixe situé dans la rivière Hulahula inférieure nous a permis de relever des données sur le moment de la migration. Les Dolly Varden dotés d'émetteurs radio ont utilisé quatre sources discrètes où se trouvent des sources pérennes pour passer l'hiver, dans le bassin versant de la rivière Hulahula. Les sources, qui s'étendent sur une douzaine de kilomètres de longueur, étaient situées entre les kilomètres 40 et 105 de la rivière. Les Dolly Varden munis d'émetteurs radio ont migré en aval, en route vers la mer de Beaufort au début juin. La plupart des poissons avec émetteur ont survécu l'été à la mer et ont regagné la rivière Hulahula vers la fin de juillet et en août, mais sept poissons ont passé l'hiver dans d'autres bassins versants de la North Slope. Dans le bassin versant de la rivière Hulahula, 15 poissons ont passé l'hiver dans plus d'une aire au cours des trois hivers visés par le projet, mais seules les quatre sources pérennes déterminées ont été utilisées. Ces données indiquent clairement que les sources pérennes de la rivière Hulahula sont des aires de concentration hivernales essentielles pour le Dolly Varden.

Mots clés : Dolly Varden, *Salvelinus malma*, Alaska, mer de Beaufort, rivière Hulahula, North Slope, radiotélémétrie, aire de concentration hivernale, migration

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INTRODUCTION

Activities associated with petroleum development in Arctic environments require large volumes of water for drilling as well as for the construction of ice roads (Clough et al., 1987; Sibley et al., 2008). On the North Slope of Alaska, water for industrial purposes is typically withdrawn from lakes, which are present at greater densities west of the Sagavanirktok River than east of it (White et al., 2008; Arp and Jones, 2009). Petroleum development has not been permitted on the coastal plain of the Arctic National Wildlife Refuge in northeastern Alaska, although the possibility of future development is continually being discussed. These discussions have focused in part on potential sources of water to support industrial activities and create ice roads if development were eventually approved. Clough et al. (1987) suggested that water could be withdrawn from rivers if it did not prevent fish passage or measurably degrade aquatic habitat. Elliott and Lyons (1990), however, estimated the volume of winter water from several rivers of the eastern Arctic region of Alaska and contended that it was not sufficient to support petroleum development. Trawicki et al. (1991) provided similar estimates of winter water availability from lakes on the coastal plain in the Canning River delta and farther east. They demonstrated that more winter water was available from lake sources than from river sources, but suggested that it was still insufficient to support industry needs. Despite the low volume of water potentially available for industrial use, discussions over petroleum development on the coastal plain of the Arctic National Wildlife Refuge continue.

Dolly Varden *Salvelinus malma* is a common anadromous species in the Alaskan Arctic (Craig, 1989a) and an important subsistence resource for residents of the region (Craig, 1989b; Pedersen and Linn, 2005). After rearing for two or more years in their natal streams, anadromous Dolly Varden follow an annual pattern of migration, traveling to marine environments each spring to feed and returning to freshwater environments by fall to spawn and overwinter (McCart, 1980; Underwood et al., 1996; Fechhelm et al., 1997). Conventional anchor tagging and genetic studies have shown that Dolly Varden migrate widely along the Beaufort Sea coast during summer feeding periods (Craig, 1984; Krueger et al., 1999), but suggest that their fidelity to their natal drainages for spawning and overwintering is fairly high (Furniss, 1975; McCart, 1980; Everett et al., 1997; Crane et al., 2005). Overwintering habitat in North Slope drainages appears to be limited to a relatively small number of spring-fed areas that maintain flow throughout the winter (Craig and McCart, 1974, 1975; Craig, 1989a). Overwintering habitat is therefore considered to be a limiting factor for anadromous Dolly Varden in northern Alaska.

Dolly Varden overwintering habitats have been identified, through visual surveys from aircraft and ground-based sampling activities, in many North Slope drainages, including the Hulahula River (Craig and McCart, 1974; Daum et al., 1984; West and Wiswar, 1985; Viavant, 2005). Additionally, a small number of radiotelemetry studies have been conducted to locate spawning and overwintering areas and document winter migrations in a few North Slope drainages, including the Anaktuvuk (Bendock, 1981; Viavant, 2005), Sagavanirktok (Viavant, 2005), Canning (Smith and Glesne, 1983), and Hulahula (West and Wiswar, 1985) Rivers. Three overwintering areas, referred to as Fish Holes 1, 2, and 3 (FH1, FH2, and FH3), were identified on the Hulahula River using one or more of these methods, although it was not certain that these represented all overwintering areas. All 29 transmitters in the radiotelemetry study were deployed at a previously identified overwintering area in mid-September, and the study was not designed to identify additional overwintering areas (West and Wiswar, 1985). Additionally, because the visual survey and ground-based sampling methods of habitat identification are most effective with relatively large aggregations of fish, it was possible that additional, unidentified overwintering areas existed in the drainage. In this study, we used radiotelemetry methods to test the hypothesis that the three previously identified overwintering areas were the only three in the drainage. In addition, we present our observations of overwintering habitats and qualitative information on migration, fidelity to overwintering areas within the Hulahula River drainage, and interdrainage exchange.

STUDY AREA

The Hulahula River is a fourth-order (Strahler, 1957), glacially influenced, mountain stream that flows for approximately 150 km from its origin in the Brooks Range to the Beaufort Sea in northeastern Alaska (Fig. 1; Craig and McCart, 1975; Rabus and Echelmeyer, 1998). In this region, average high air temperature in mid-summer approaches 20˚C, and average low temperature in mid-winter approaches −35˚C (Shulski and Wendler, 2007). Annual precipitation averages 10 to 15 cm, most of which falls during the summer. Summer flow levels are influenced primarily by melting snow and rainfall (Lyons and Trawicki, 1994), although during warm periods meltwater from Romanzof Mountain glaciers produces turbid flow in the Hulahula River as well (McCart, 1980). All surface flow ceases during winter, so aquatic habitat becomes limited to a few perennial springs (Craig and McCart, 1975; Childers et al., 1977; Kane et al., 2013). The springs have stable groundwater sources recharged by precipitation across porous limestone regions of the Brooks Range to the south (Hall and Roswell, 1981; Yoshikawa et al., 2007; Kane et al., 2013). Because of the stable groundwater flow during the extended winter season, aufeis areas develop downstream from each perennial spring, and the size or mass of each aufeis area is proportional to the flow volume of the associated spring. While the habitat qualities described above pertain to the Hulahula River specifically, they are similar for all of the north-flowing rivers originating in the eastern Brooks Range.

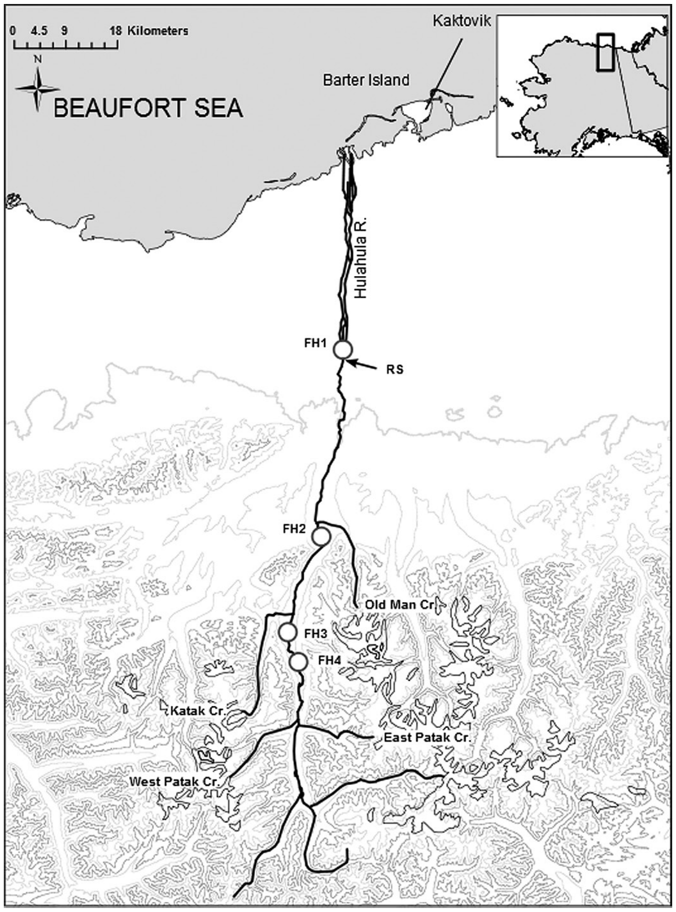

FIG. 1. The Hulahula River drainage with major tributaries. Circles indicate Dolly Varden overwintering locations FH1 to FH4. RS is the location of the remote radio station near FH1. Outlines of mountain glaciers are also shown.

METHODS

Sample Selection and Tagging Protocol

Anadromous Dolly Varden were captured by angling and radio-tagged at FH1 on the lower Hulahula River, approximately 40 river km (rkm) from the sea, between 17 and 22 August 2007. This tagging period was selected because previous sampling activities in the Hulahula River drainage had indicated that large numbers of anadromous Dolly Varden returned to freshwater during the second half of August (Daum et al., 1984). The river was a single channel at the capture location and braided in multiple channels from there downstream to the sea. Fishhole 1 is also the location of the farthest downstream perennial spring in the drainage (Craig and McCart, 1974; Childers et al., 1977) and was therefore the first location where all fish migrating upstream to spawn and overwinter would potentially be available for capture. Following capture, Dolly Varden were evaluated for tagging suitability.

Radio transmitters were surgically implanted in Dolly Varden using methods known to be appropriate and effective for salmonid fishes (Winter, 1996; Wagner et al., 2000; Jepsen et al., 2002). Transmitters weighed 10 g in air, were approximately 6 cm long and 1 cm in diameter, and trailed a whip antenna 40 cm long. Transmitters were designed to emit signals every 3 seconds for approximately 2.5 years, which permitted fish tracking during three overwintering periods. Using Brown's (2008:32) predictive linear regression equation of length and weight data for Beaufort Sea Dolly Varden ($r^2 = 98.5\%$), we calculated that Dolly Varden approximately 38 cm fork length (FL) or larger would weigh more than 500 g. Use of such fish would be consistent with Winter's (1983) recommendation that transmitter weight in air should not exceed 2% of fish weight. Winter's (1983) recommendation is now considered to be a conservative guideline, and others have demonstrated that transmitters weighing as much as 12% of fish weight can be used effectively in some circumstances (Brown et al., 1999). In any case, we considered all captured fish sufficiently large, and we tagged the first 52 uninjured Dolly Varden. After capture, Dolly Varden were placed in an anesthetic solution composed of 40 mg•L^{-1} Aqui-S, an effective concentration that was consistent with the experimental findings of Stehly and Gingerich, (1999), Iversen et al. (2003), and Bowker et al. (2006). Anesthetized fish were placed in a V-shaped cradle and water was delivered to their gills during surgery. An incision approximately 2 cm in length was made through the body wall into the peritoneum anterior to the pelvic girdle and just to the fish's left of center, as suggested by Winter (1996). The antenna was routed through a hole posterior to the pelvic girdle with a hypodermic needle and a grooved director in a modified shielded-needle procedure (Ross and Kleiner, 1982). The transmitter was placed into the peritoneum through the incision and closed with three monofilament sutures using a simple interrupted suture pattern (Wagner et al., 2000). After surgery, fish were held in freshwater to recover and released when they were able to swim away vigorously.

Radio-tracking

Eleven aerial survey flights were conducted to locate radio-tagged Dolly Varden in the Hulahula River and eight other North Slope drainages (Table 1). Radio-tagged fish were identified with unique digital codes, and records were logged in our radio receivers. Each identification record included global positioning system coordinates. Multiple records of each fish were recorded as the aircraft flew overhead, and our best estimate of the actual location of each fish was based on the record with the greatest signal strength. Early and late winter aerial survey flights were designed to identify overwintering locations and determine whether any winter migrations between sites occurred. During the first winter, aerial survey flights were limited to the Hulahula River. All flights along the river followed the main stem from its headwaters to the delta. Subsequent winter flights also included other North Slope drainages from the Anaktuvuk River in the west to the Firth River in the east (Table 1; Fig. 2). Pre-defined index areas were flown on the Anaktuvuk, Sagavanirktok, Canning, and

TABLE 1. Date and season (early winter, late winter, and summer) of aerial survey flights (indicated by x) along North Slope rivers with previously identified perennial springs and Dolly Varden overwintering areas.

Date	Season	Anaktuvuk	Sagavanirktok	Kavik	Canning	Hulahula	Aichilik	Egaksrak	Kongakut	Firth
3 October 2007	Early					x				
1 May 2008	Late					x				
17 May 2008	Late					x				
2 July 2008	Summer					x				
19 September 2008[1]	Early	x	x		x	x				
2 October 2008	Early					x	x	x	x	
28 April 2009	Late		x		x					
29 April 2009	Late					x			x	x
2 July 2009	Summer					x				
1 October 2009	Early					x	x	x	x	
7 October 2009	Early		x	x	x					

[1] Flight conducted by T. Viavant, Alaska Department of Fish and Game, along specific index areas defined in Viavant (2009).

Hulahula Rivers on 19 September 2008 (Viavant, 2009). Other winter flights covered all of the perennial springs and the Dolly Varden spawning and overwintering areas within specific drainages identified by Craig and McCart (1974, 1975) and McCart (1980), as well as main-stem stream reaches from river deltas upstream to headwaters, including major tributaries. An exception to this relatively comprehensive coverage was the Firth River flight, in which the survey was limited to Joe Creek and the upper Firth River main stem. We limited this survey partly because of logistical issues related to the flight, but also because all overwintering habitat in the drainage was thought to be in that region (Glova and McCart, 1974). July aerial survey flights were limited to the Hulahula River drainage and were designed to identify radio-tagged Dolly Varden that overwintered in the Hulahula River but failed to migrate to the sea in early summer.

In addition to aerial surveys, a remote radio receiving station was established near the upstream limit of FH1, approximately 40 rkm from the sea, to record the timing of fall upstream and spring downstream migrations along the Hulahula River. We expected that Dolly Varden in the upper reaches of FH1 would be recorded by the receiving station, but those in the lower reaches would be out of range. Therefore, receiving station records were used only to identify migration timing of fish overwintering farther upstream in the Hulahula River. As in the aerial surveys, passage times were based on the records with the strongest signal strengths. Data recorded by the station were retrieved in July of 2008, 2009, and 2010.

Overwintering areas were identified as geographic sites where one or more radio-tagged fish were located during winter aerial surveys. Migration to the sea or other evidence of life following winter was considered to be confirmation that fish actually survived in a particular overwintering area, thus verifying the habitat classification. Evidence that a radio-tagged fish was alive included downstream or upstream migration records past the receiving station for fish overwintering upstream from FH1; the absence of radio-tagged fish in the drainage during aerial surveys the following summer; harvest in a coastal fishery; migration into other drainages; or a return migration into the Hulahula River following a summer absence. Fish that failed to migrate to the sea and were identified in the Hulahula River during July aerial surveys were presumed to be winter mortalities.

RESULTS

Overview

Fifty-two Dolly Varden were captured and radio-tagged in the lower Hulahula River in August 2007. Five additional fish were injured during capture and were subsequently sacrificed. Fork length of radio-tagged Dolly Varden averaged 50 cm (range: 37–67 cm). Of the 52 radio-tagged fish, 35 were silver and lacked distinctive spawning coloration, and their sex could not be determined with confidence (Fig. 3a). Seventeen fish, 5 males and 12 females, exhibited distinctive spawning characteristics such as body and fin pigmentation in both sexes and lateral compression and a hooked kype in males (Fig. 3b). The five sacrificed fish included one pre-spawning male with distinctive spawning color and morphology and four that were silver in color. The four silver fish ranged from 37.5 to 59.0 cm FL and were classified on the basis of internal examination of their gonads, as described by Lisac (2006), to be two non-spawning males, one pre-spawning male, and one pre-spawning female. One radio-tagged fish was never relocated, indicating either that it exited the Hulahula River shortly after tagging or that its transmitter malfunctioned. Total sample size was therefore reduced to 51 fish during the first winter. Two fish were reported to have been harvested along the Beaufort Sea coast by residents of Kaktovik during summer 2008. Aerial survey conditions for all 11 flights were considered to be optimal, with strong signal reception from all transmitters out to 5 km or more. There was no evidence of any missed fish between early and late winter aerial surveys or between aerial surveys and receiving station records in the Hulahula River.

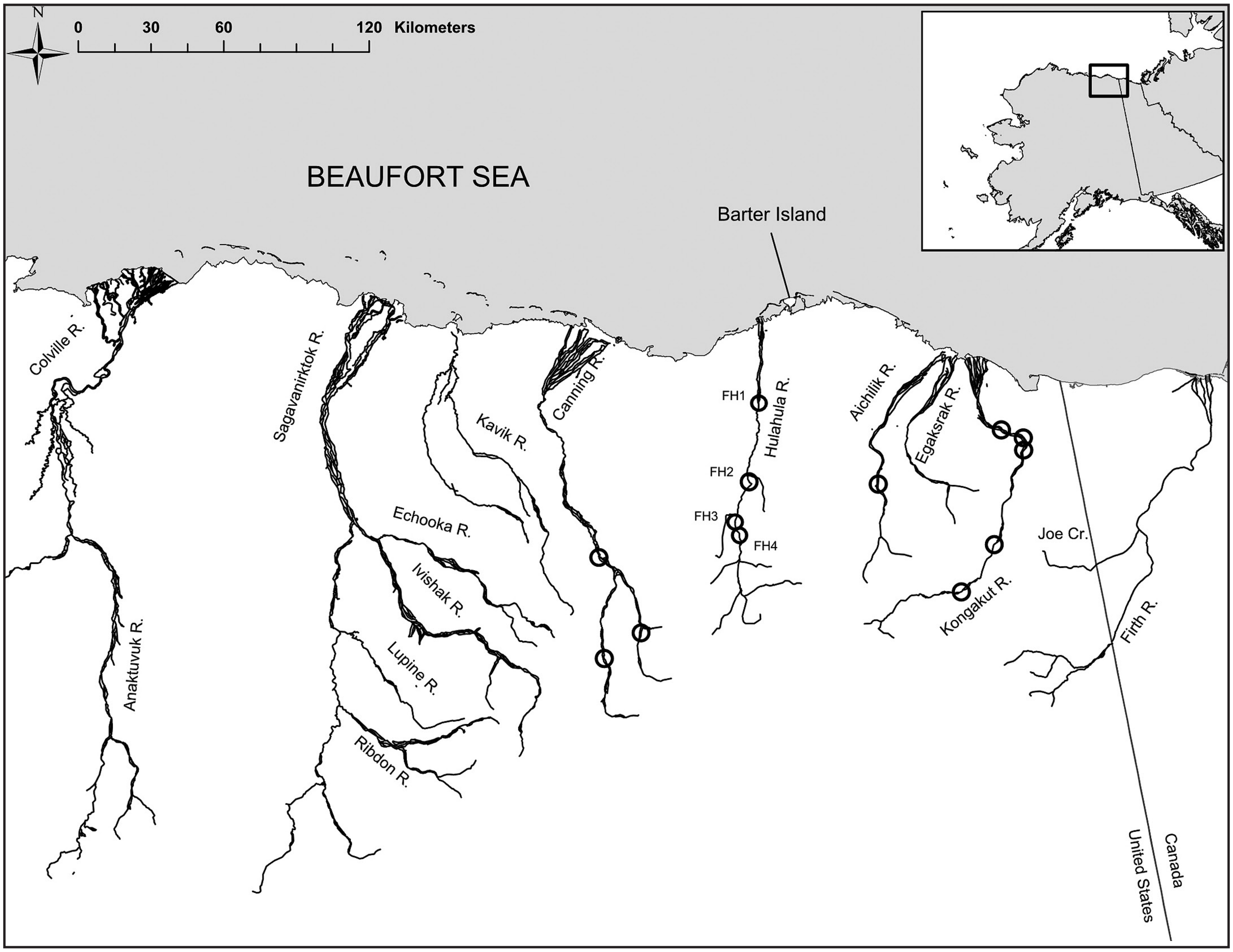

FIG. 2. Map showing selected rivers that drain the North Slope of the central and eastern Brooks Range in Alaska and Yukon Territory. Circles on the Hulahula River show the Dolly Varden overwintering sites (FH1 to FH4) identified in this study. Circles in the Canning, Aichilik, and Kongakut Rivers mark other overwintering locations used by Dolly Varden that were initially tagged in the Hulahula River.

Overwintering Areas

Fifty-one radio-tagged Dolly Varden overwintered in the Hulahula River drainage during winter 2007–08 (first winter), 27 during winter 2008–09 (second winter), and 11 during winter 2009–10 (third winter). Overwintering fish were distributed among four distinct overwintering areas, FH1 to FH4, located approximately 40, 78, 99, and 105 rkm from the sea, respectively (Table 2; Fig. 1). Open flowing water was observed at all four overwintering locations and along other reaches of the river during the early winter flights in October, suggesting that fish could migrate along the river during that season. The Hulahula River valley was unique among the North Slope drainages flown during this project in that the snow appeared to have been blown from the valley, leaving the tundra and the riverbed nearly free of snow during late winter (Fig. 4). This phenomenon gave us a clear view of stream reaches with flowing water, aufeis areas, ice confined to the riverbed, and rocky substrate with no ice or water at all. During the late winter flights in April and May, when the cumulative effects of winter were greatest, we observed reaches of flowing water with associated aufeis areas only at the four overwintering areas. It did not appear that fish migration between overwintering areas was possible at that time. Despite the possibility of migration between overwintering areas in early winter, all radio-tagged fish ended winter in the same locations where they started winter. Only three of 51 fish, two in FH1 and one in FH2, appeared to have died during the first winter and were located in those sites during every subsequent survey of the Hulahula River. One fish remained in FH3 during the first winter, the next summer, and the second winter, but migrated to the sea during the second summer. On the basis of these radiotelemetry and observational data, we concluded that four discrete Dolly Varden overwintering areas exist in the Hulahula River drainage, instead of three, as we originally hypothesized.

FIG. 3. (a) Dolly Varden without spawning colors, referred to as silver: neither sex nor spawning condition could be reliably determined for silver fish. (b) Dolly Varden with dark coloration that clearly revealed pre-spawning condition of both males and females. The sex-specific morphology of males was definitive in pre-spawners. Scale bars are in cm.

Overwintering Distribution and Site Fidelity

More fish overwintered in FH1 than in the other three sites during all three winters of this project (Table 3). Fish classified as pre-spawners in August 2007 overwintered that year in FH1 (n = 15), FH2 (n = 1), and FH3 (n = 1). Fifteen fish used more than one overwintering area within the Hulahula River drainage during the three winters of this project. For example, 19 fish that had overwintered in FH1 during the first winter returned to the Hulahula River during the second winter and were distributed among all four overwintering locations (13 in FH1, 2 in FH2, 3 in FH3, and 1 in FH4). Similarly, some fish from each of the other three overwintering groups occupied different overwintering areas during the second or third winters. These data indicate that Dolly Varden routinely occupy different overwintering areas within the drainage from one year to the next.

Interdrainage Exchange

During the second and third winters of the project, we flew aerial surveys for radio-tagged Dolly Varden in eight North Slope rivers, from the Anaktuvuk River in the west to the Firth River in the east (Table 1; Fig. 2). During the second winter, seven fish were located overwintering in North Slope drainages other than the Hulahula River; three in the Canning River, one in the Aichilik River, and three in the Kongakut River (Table 3). None of these seven fish had been classified as pre-spawners when originally tagged in the Hulahula River, so their natal origins were unknown. During the third winter, we located two radio-tagged Dolly Varden in the Kongakut River. One had overwintered the previous year in the Canning River, and the other in the Aichilik River. These two Dolly Varden had overwintered in three different drainages in the three winters of the study.

TABLE 2. Geographic characteristics of the four overwintering areas identified in the Hulahula River and the nine locations of the seven fish that migrated to other North Slope drainages during the second and third winters. Reach length calculated for the four Hulahula River areas was consistent with our late winter observations of open flowing water at each site.

Drainage	Area[1]	N Latitude[2]	W Longitude[2]	River km[3]	Reach (km)[4]
Hulahula	FH1	69.758°	144.158°	40	4
Hulahula	FH2	69.472°	144.376°	78	3
Hulahula	FH3	69.329°	144.580°	99	3
Hulahula	FH4	69.278°	144.553°	105	2
Canning	C1	69.264°	146.021°	136	
Canning	C2	68.965°	145.687°	178	
Canning	C3	68.887°	146.090°	188	
Aichilik	A1	69.389°	143.058°	80	
Kongakut	K1 (C1)[5]	69.509°	141.701°	38	
Kongakut	K2	69.464°	141.492°	49	
Kongakut	K3 (A1)[6]	69.418°	141.513°	55	
Kongakut	K4	69.090°	141.987°	102	
Kongakut	K5	68.938°	142.405°	128	

[1] Areas are numerically ordered by river kilometer.
[2] Decimal degrees in WGS84 datum.
[3] River km (distance upstream from the sea) refers to the center of distribution of overwintering fish at each site for the four Hulahula River areas, but to individual fish locations for the other drainages.
[4] Distance between the farthest upstream and farthest downstream locations assigned to overwintering fish.
[5] This fish spent the second winter at C1 and the third winter at K1.
[6] This fish spent the second winter at A1 and the third winter at K3.

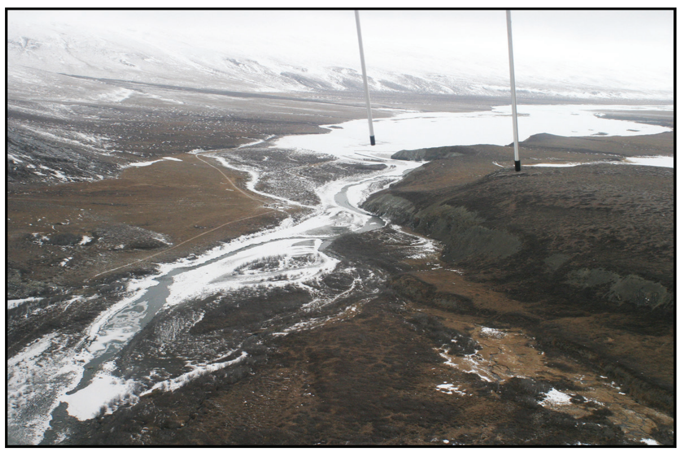

FIG. 4. Looking down the Hulahula River valley on 1 May 2008, over the perennial spring of FH2 and across the large aufeis field below (note the two antenna elements visible in the upper part of the image). The valley is blown relatively clear of snow, a phenomenon observed during both years in which late winter surveys were flown. Air temperature on this date was approximately −30˚C, and there was no indication that any thawing had taken place. In all four overwintering sites, the strongest signals from radio-tagged Dolly Varden were in the open water reaches upstream from aufeis.

TABLE 3. Distribution of radio-tagged Dolly Varden among overwintering locations within the drainages of the Hulahula, Canning, Aichilik, and Kongakut Rivers during (a) the first and second winters and (b) the second and third winters of this study. Location details are shown in Figure 2. Column 2 shows the overwintering distribution of tagged fish in (a) the first winter and (b) the second winter. Column 3 shows the number of these that migrated to sea and returned to freshwater to overwinter again. Columns 4 to 10 show the distribution of these returning fish the following winter.

a)	Distribution	*n* returned	Distribution during 2nd winter						
Location	1st winter	2nd winter	FH1	FH2	FH3	FH4	Canning	Aichilik	Kongakut
FH1	28	19	13	2	3	1			
FH2	11	6	2		1		2		1
FH3	9	7	1	1	2[1]		1	1	1
FH4	3	2				1			1
Total	51	34	16	3	6	2	3	1	3

b)	Distribution	*n* returned	Distribution during 3rd winter						
Location	2nd winter	3rd winter	FH1	FH2	FH3	FH4	Canning	Aichilik	Kongakut
FH1	16	7	6		1				
FH2	3	0							
FH3	6	3	2		1				
FH4	2	1	1						
Canning	3	1							1
Aichilik	1	1							1
Kongakut	3	0							
Total	34	13	9		2				2

[1] One of these two fish remained at FH3 through summer 2008 and migrated to sea in summer 2009.

Migration Timing

During 2008 and 2009, the receiving station recorded the downstream migration timing of 29 radio-tagged Dolly Varden in spring and the subsequent upstream migration timing of 11 radio-tagged Dolly Varden in late summer. The station recorded 21 fish on their downstream migration in 2008, on dates ranging from 5 to 16 June (mode = 10 June), and eight fish in 2009, seven on 2 June and one on 3 June. Nine fish were recorded on their upstream migration in 2008, on dates from 28 July to 26 August, and two fish in 2009, one each on 25 and 30 August (Fig. 5). The absence of these migrant fish in the drainage during summer aerial surveys was considered to be evidence of migration to the sea, although the exact times of sea entrance and exit were not recorded because the receiving station was located 40 rkm upstream.

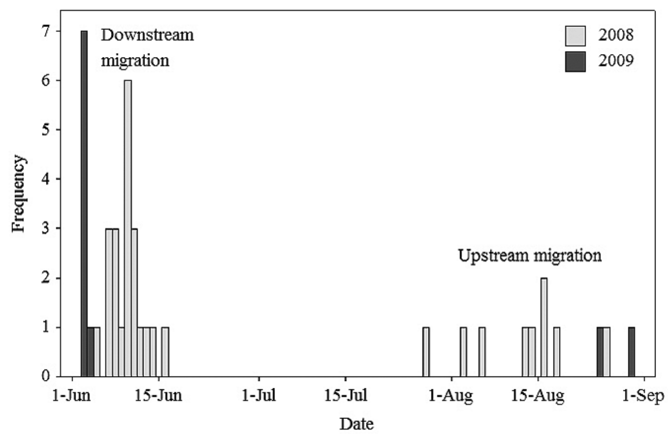

FIG. 5. Timing of downstream and upstream migration of radio-tagged Dolly Varden past the fixed station in the Hulahula River during the summer in 2008 and 2009. Data represent fish that were migrating from or to upstream overwintering sites (FH2, FH3, and FH4).

DISCUSSION

Overwintering Areas

The four Dolly Varden overwintering areas located in the Hulahula River appear to represent all overwintering habitat in the drainage (Table 2; Fig. 1). We observed that each overwintering area consisted of a reach of flowing water followed by an aufeis area downstream (Fig. 4). No other similar habitats were observed in the drainage. Additionally, during the course of the project there were 15 events in which a radio-tagged Dolly Varden overwintered in a different location within the Hulahula River drainage during the second or third winter than in a previous winter, but only the four identified locations were used. Perhaps juvenile Dolly Varden overwinter in smaller, less visible aquatic habitats within the drainage. However, sampling studies that have examined the demographic composition of overwintering Dolly Varden in North Slope rivers have identified small juveniles in the same overwintering areas as large individuals (Glova and McCart, 1974; Furniss, 1975; Craig, 1978; West and Wiswar, 1985). It is therefore possible that all overwintering habitat in the drainage is contained within the four perennial springs identified here, totaling approximately 12 km in stream length.

Overwintering Site Fidelity

Everett et al. (1997) presented evidence of drainage-specific genetic structure among Dolly Varden collected within eastern North Slope rivers in Alaska and Yukon Territory, indicating strong spawning site fidelity for these populations. Additionally, they identified three rivers, including the Hulahula River, in which distinct genetic structure was observed among two or more collections within drainages, suggesting multiple spawning populations. Their baseline samples for anadromous populations were small juvenile fish collected prior to first migration to sea. Observing distinct genetic structure between the lower and upper collection locations within the Hulahula River drainage suggests that juveniles of two or more populations segregate along the river, perhaps remaining in the vicinity of their respective spawning locations. We therefore considered the possibility that larger individuals from these same populations might exhibit fidelity to their spawning sites for overwintering, whether they were in non-spawning or pre-spawning condition. While it is not possible to comment on spawning site fidelity, our data indicate that Dolly Varden do not exhibit strong fidelity to overwintering areas within the drainage (Table 3).

Interdrainage Exchange

When we began this research, we expected that Dolly Varden from the Hulahula River would exhibit strong fidelity to the drainage for overwintering, with few or no fish from our small sample migrating to other drainages. This expectation was supported in part by Furniss (1975) and McCart (1980), who reviewed anchor tagging and recovery data from several North Slope Dolly Varden projects and concluded that interdrainage exchange occurred but was not common. Additionally, Crane et al. (2005) conducted mixed-stock analyses on what they classified as predominantly immature (20–40 cm FL) and predominantly mature (> 40 cm FL) Dolly Varden overwintering in the Sagavanirktok River. They found evidence of interdrainage exchange only among the immature size group and similarly concluded that interdrainage exchange was rare. In our study, seven (20.5%) of the 34 Dolly Varden known to have survived into the second winter changed drainages (Table 3). The seven migrant fish from our sample averaged 44.6 cm FL (range: 40–48 cm FL), which places all except one within the “predominantly mature” size group defined by Crane et al. (2005). If our small sample was representative of the larger population of overwintering fish in the Hulahula River, then interdrainage exchange would have to be classified as a relatively common rather than a rare occurrence.

Future Research

Modern radiotelemetry technology is a powerful tool for locating essential habitats, describing migration timing, mapping geographic distributions, and estimating biological parameters of fish populations (Adams et al., 2012; McKenzie et al., 2012). In this relatively simple study, we used small, long-duration transmitters to clarify our understanding of overwintering habitats used by anadromous Dolly Varden within the Hulahula River drainage, and to describe seasonal migration patterns, annual use of overwintering habitats, and the distribution of radio-tagged fish among drainages. Not all our information was new, but the study added important details and clarity to the existing body of literature that will be useful if petrochemical development becomes a reality in the region. Similar or more complex radiotelemetry research in other Arctic rivers in the eastern Brooks Range would undoubtedly improve our understanding of fish habitats, migrations, and distribution in those drainages as well, enabling more informed conservation measures in the future.

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