Assessment of Northern Dolly Varden, *Salvelinus malma malma* (Walbaum, 1792), Habitat in Canada

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ASSESSMENT OF NORTHERN DOLLY VARDEN, *SALVELINUS MALMA MALMA* (WALBAUM, 1792), HABITAT IN CANADA

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Mochnacz, N.J., Schroeder, B.S., Sawatzky, C.D., and Reist, J.D. 2010. Assessment of northern Dolly Varden, *Salvelinus malma malma* (Walbaum, 1792), habitat in Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2926: vi + 48 p.

Key habitat for northern Dolly Varden (*Salvelinus malma malma*) is described and quantified for all known populations in Canada from existing literature and field surveys conducted in 2008 and 2009. We define key habitat as an area which, if disrupted or lost, would have serious implications for the survival of existing populations of that taxon. Adult Dolly Varden use areas associated with perennial groundwater springs for spawning and overwintering. Juveniles rear in low velocity side channels and small streams (< 10 m wide) during the summer and join adults at overwintering sites in most areas during the winter. Near shore coastal areas are important feeding grounds for anadromous populations. Winter habitat, which typically corresponds with spawning habitat, is pivotal for survival of all northern Dolly Varden populations. This habitat is comprised of small groundwater-fed pools in isolated headwater reaches, which remain open all winter, whereas most of the remainder of the river freezes to the bottom. Surface area calculations of this habitat ranged from 0.0001 km^2 to 0.1903 km^2 for the rivers that were surveyed. The total amount of known winter habitat available for northern Dolly Varden is estimated to be 0.6315 km^2 for all rivers combined. Appropriate measures should be taken to monitor and protect key winter habitat.

Key Words: Northwest Territories; Yukon Territory; northern Dolly Varden; key habitat; perennial groundwater springs; fish habitat; North Slope; overwintering, spawning, and rearing habitat; *Salvelinus malma malma*.

RÉSUMÉ

Mochnacz, N.J., Schroeder, B.S., Sawatzky, C.D. et Reist, J.D. 2010. Évaluation de l'habitat du Dolly Varden septentrional, *Salvelinus malma malma* (Walbaum, 1792), au Canada. Rapp. man. can. sci. halieut. aquat. 2926: vi + 48 p.

L'habitat clé du Dolly Varden septentrional (*Salvelinus malma malma*) est décrit et quantifié pour toutes les populations connues au Canada dans la documentation actuelle et les études sur le terrain effectuées en 2008 et 2009. Par habitat clé, nous entendons une aire qui, en cas de perturbation ou de perte, aurait de graves conséquences sur la survie des populations existantes de ce taxon. Le Dolly Varden adulte utilise les aires associées aux sources d'eau souterraine pérennes comme zones de frai et d'hivernage. Les alevins grossissent dans les faux-chenaux peu rapides et les petits cours d'eau (< 10 m de largeur) durant l'été et rejoignent les adultes aux sites d'hivernage dans la plupart des régions durant l'hiver. Les zones côtières constituent des aires d'alimentation importantes pour les populations anadromes. L'habitat hivernal, qui correspond habituellement à l'habitat de frai, est crucial pour la survie de toutes les populations de Dolly Varden septentrionaux. Cet habitat se compose de petits bassins alimentés par les eaux souterraines dans des tronçons en amont isolés, qui demeurent ouverts tout l'hiver, tandis que la majeure partie du reste de la rivière gèle jusqu'au fond. Les calculs de l'aire superficielle de cet habitat ont varié de 0,0001 km^2 à 0,1903 km^2 dans le cas des rivières étudiées. La superficie totale d'habitat hivernal connu mise à la disposition du Dolly Varden septentrional est évaluée à 0,6315 km^2 pour toutes les rivières regroupées. On devrait prendre les mesures qui s'imposent pour surveiller et protéger l'habitat hivernal clé.

Mots clés : Territoires du Nord-Ouest; Territoire du Yukon; Dolly Varden septentrional; habitat clé; sources d'eau souterraine pérennes; habitat du poisson; versant Nord; habitat d'hivernage, de frai et de grossissement; *Salvelinus malma malma*.

INTRODUCTION

Species that inhabit Arctic aquatic ecosystems face unique challenges not encountered by more temperate taxa. Distribution, growth, and abundance are limited by prolonged winter seasons where suitable habitat and food are sparse (Power et al. 1999). Activities that disturb key habitats in these ecosystems could have catastrophic results for a given year class and ultimately lead to an overall decrease in ecosystem productivity (Cunjak 1996). Northern form Dolly Varden, *Salvelinus malma malma* (Walbaum, 1792), is a riverine char that is an important subsistence fish for many northern communities in the western Arctic (Papik et al. 2003). However, with increasing global change and development activities in the North, the habitat of Dolly Varden could be at risk. Specific habitat requirements for all life stages (spawning, rearing, and overwintering) make northern populations in Canada highly vulnerable to extirpation as a result of habitat loss, fragmentation, and disruption (Stewart et al. 2010).

We have a basic understanding of the distribution, general biology, and population structure of northern Dolly Varden populations (Stewart et al. 2010). However, very little work has been done to identify, delineate, and quantify habitat. Our objective was to assess habitat for northern Dolly Varden in Canada. Specifically, we intended to 1) describe habitat use for each life stage, 2) determine which types of habitat are pivotal for survival, and 3) quantify the total size of these habitats for northern populations. We define key habitat as an area which, if disrupted or lost, would have serious implications for the survival of existing populations of that taxon (COSEWIC 2010). Areas that are not defined as key habitat are still considered to be important because they are used by individual fish or groups of fish and function to influence population productivity. However, if these areas were lost we assume the impact on populations would not be as severe.

BACKGROUND

Taxonomy

Historically, Arctic Char, *Salvelinus alpinus* (Linnaeus, 1758), has been the taxon thought to be the predominant representative of the *Salvelinus* genus in northern North America (McPhail 1961). Due to morphological and meristic variation, anomalous populations were recognized as a variant of the species and identified as the "western form" of Arctic Char and subsequently grouped in the *S. alpinus* species complex (McPhail 1961; Morrow 1980; Behnke 1980; Reist 1989; Reist et al. 1997). Taxonomic uncertainty of the *S. alpinus* species complex was further resolved using morphologic and meristic analyses, which identified this "western form" as a distinct species - Dolly Varden, *S. malma* (McPhail 1961).

Since 1980, re-examination of the taxonomic status of fishes in north western Canada and Alaska has identified additional taxa present in this geographic range. Fish, previously considered Dolly Varden, occurring south of the Great Bear River are now identified as a discrete species - Bull Trout, *S. confluentus* (Suckley, 1858) (Haas and McPhail 1991; Reist et al. 2002). Chars occurring west of the Mackenzie River have been re-classified as Dolly Varden and those found east of the Mackenzie River (primarily in lacustrine habitats) are considered to be Arctic Char (Reist et al. 1997).

Dolly Varden in North America has also been further revised to include a southern form (*S. malma lordi*) and a northern form (*S. malma malma*) (Behnke 1980). The two sub-groups can be differentiated by gill raker counts, vertebral number, and genetic analyses (Behnke 1980; Phillips et al. 1999). The southern form is distributed along the Pacific coast from Washington to the Gulf of Alaska and the south western Yukon Territory, whereas the northern form can be found from the north side of the Alaskan Peninsula and the Aleutian Islands to the Mackenzie River in Canada (DeCicco and Reist 1999; Figure 1). Further distinction of the northern form into two groups, including an inland group, has been proposed based on biological, distributional, and life history variation; however, this split remains unconfirmed (DeCicco and Reist 1999).

Distribution

Five genetically distinct populations of northern Dolly Varden have been confirmed in river systems from the Beaufort Sea drainage (Reist 1989). Along the Yukon North Slope, populations occur in the Firth River and its major tributary Joe Creek, the Fish River, the Babbage River, and the Big Fish River (Sandstrom et al. 1997; Sandstrom and Harwood 2002). Additional populations are known from the Yukon Territory and Northwest Territories in the Rat River, a tributary to the Mackenzie River Delta (Reist 1989); the Gayna River, a tributary to the central Mackenzie River (Mochnacz and Reist 2007); and the Vittrekwa and Blackstone rivers of the Peel River basin (Evans et al. 2002; Anderton 2006; Millar 2006; Sawatzky et al. 2007). In Alaska, Dolly Varden occur in major rivers draining to the north, central, and southern coasts and it is believed that many inland isolated populations also occur state wide but these are not confirmed (Craig and McCart 1974; Figure 1).

Both inland and coastal populations inhabit high-gradient, mountain streams for 8-9 months of the year (Craig and McCart 1973). Discharge is governed by snowmelt, precipitation, and groundwater sources in the spring, summer, and fall. However, during the winter, flow rates are extremely low and perennial groundwater springs are the only water source in these rivers (Clark et al. 2001; Power et al. 1999). In some systems (e.g., Big Fish River) groundwater may account for 80% of the baseflow in the summer and fall (Clark et al. 2001). Perennial springs originate either in the riverbed itself or from nearby orifices, which are often found at the base of talus slopes. During the winter these rivers are ice-covered downstream of groundwater sources and at some point the ice extends to the river bed (Craig and McCart 1973). Therefore, fish must overwinter in upstream areas associated with perennial springs which are not completely frozen.

Life History

Dolly Varden exhibit both anadromous and freshwater (resident) life history strategies (Armstrong and Morrow 1980). Multiple strategies may be observed within a single river basin and even within a single population. Most adult fish and large juveniles with access to the sea are anadromous, undertaking annual migrations to feed in highly productive coastal waters during the summer and then returning in the fall to their natal streams to spawn and overwinter (Craig 1989; Reist 1989).

A certain proportion of individuals from anadromous populations, known as riverine (residual) fish, remain in freshwater for their entire life and avoid the annual migration to sea. This life history is dominated by precocious males, which are often associated with anadromous spawning pairs and are commonly observed darting into redds to release milt once the eggs have been deposited by the female (Reist 1989). This tactic is known as “sneaking” and is a trait of residual Dolly Varden that appears to aid in the maintenance of genetic diversity within these systems and may promote recovery of anadromous populations that have collapsed (Reist et al. 2001). Residual populations are found in tributaries to the Big Fish and Rat rivers (Sandstrom and Harwood 2002, Stewart et al. 2010), and the Babbage, Firth, and Vittrekwa rivers of the Yukon Territory (Bain 1974; Glova and McCart 1974; Reist 1989; Babaluk and Reist 1996; Millar 2006).

Stream-resident (isolated) life history types typically occur as disjunct populations in headwaters of small streams isolated from anadromous and residual populations by impassable barriers or distance. Isolated fish spend their entire lives in headwaters of small freshwater streams (Reist 1989). These populations are self-sustaining (i.e., both sexes confirmed) and although they may move downstream into areas where anadromous and residual populations are found, this has never been documented (Reist 1989; Stewart et al. 2010). A more detailed description of life history types and stages are summarized in Sawatzky and Reist (2010 in press).

Biology

Dolly Varden are iteroparous, reproducing multiple times during their life but often not over successive years (Stewart et al. 2010). Some populations with shorter migrations to sea may spawn annually (e.g., Rat River (Sandstrom et al. 2009)); however, other populations exhibit spawning in non-consecutive or fewer years (Sandstrom et al. 1997; Sandstrom and Harwood 2002).

Anadromous adults and smolts migrate downstream to productive coastal waters as river ice begins to melt and aquatic connections between habitats emerge, typically in late June and July. The timing of these events is influenced by environmental conditions and can vary annually by several weeks. Feeding occurs in the highly productive coastal waters of the Beaufort Sea during the short summer months and represents the most significant energetic intake by individuals for the entire year (Craig 1989). Evidence suggests that anadromous fish rarely feed during migrations, spawning periods, and throughout the winter (Glova and McCart 1974). Following the coastal migration and feeding period, current-year spawners are typically the first to return upstream to the natal spawning grounds (Glova and McCart 1974; Reist et al. 2001). Upstream migration occurs in early fall, and most Dolly Varden have returned to the spawning and overwintering location by mid-October (Sandstrom et al. 2001). Juveniles in the Rat River, NT have been noted to return significantly later than spawning fish (Sandstrom et al. 2001). Spawning occurs in late August through to the end of October when water temperatures range from 3 to 8°C (Stewart et al. 2010). Emergence occurs seven to nine months post-spawning and is highly temperature dependent as eggs incubated at higher temperatures require less time to develop. Rearing occurs near overwintering habitats with short local movements in the vicinity of these areas (Griffith 1979). Juveniles remain in freshwater habitat until they are capable of surviving in saline environments (i.e., smoltification), often between two and four years, and mature between five and seven years of age (Sandstrom and Harwood 2002).

Anadromous juveniles and adults exhibit a high degree of natal philopatry (i.e., homing) with limited recruitment known from other populations. Genetically distinct populations have been identified across the Arctic coast of Canada and Alaska and limited evidence of genetic exchange between disjunct populations has been observed (Reist 1989). Though some evidence of overwintering in non-natal streams has been observed, these likely represent non-spawning fish, which do not offer a genetic contribution to the local stock (McCart 1980; J. Reist unpubl. data). Strong homing to natal spawning areas with limited recruitment from other populations has significant implications for stock conservation and management, especially for the mixed stock subsistence fishery along the Beaufort Sea coast (DFO 2003a,b,c). Furthermore, populations are highly vulnerable to stochastic events (e.g., winterkill) as eggs, juveniles, and adults are confined to small (e.g., < 2 km), isolated headwater areas during the winter, which may last for 8-9 months. The selection and extended use of small discrete winter habitats by all life stages suggests that these areas are pivotal for long-term sustainability of healthy populations.

METHODS

We assessed the relevance of various habitat types based on use by different life stages. The data examined was classified as spawning, overwintering, rearing, and feeding habitat according to three criteria: 1) life stage present, 2) time of year, and 3) life process/behaviour observed (e.g., spawning, feeding). For example, if adult fish were observed in a stream during the fall and exhibited spawning behaviour (e.g., redd excavation, female/male spawning pairs, defending nest, etc.) we classified this area as spawning habitat. If the behaviour of fish observed in a particular habitat was unknown, we identified these areas as potential habitat based on the life stage present, habitat occupied, and time of year. For example, if adults were found in suitable spawning habitat (i.e., appropriate substrate size) during the spawning period, but no spawning behaviour was observed, we identified this area as potential spawning habitat. The only exception to this was potential winter habitat which was identified based on areas which were clearly not completely frozen to the bottom (e.g., thin ice). Key habitat types were then identified based on the following criterion: if the habitat was disrupted or lost it would seriously affect the survival of an existing population. Our habitat assessment was based on examination of existing data, field surveys, and expert opinion.

Most of the data were gathered and synthesized from existing literature. We calculated the total area (km^2) for each habitat type described in the literature. In instances where the size of the area was not reported, we extrapolated the mean-wetted width and length for the site from 1:50 000 topographic maps or maps from the report. In addition, we surveyed the Rat, Big Fish, Firth, and Babbage River systems to document overwintering habitat in March 2008 and 2009. The total length and mean-wetted width was measured for all open water sections and we documented the presence of fish from bank-side and aerial surveys. Fish were identified to species and assigned a life stage based on size where possible. Data describing habitat use for various life stages are summarized in Table 1, and known and potential spawning and overwintering habitat is quantified in Tables 2 and 3 respectively. The total area is the sum of the known and potential habitat for each location. For winter habitat calculations we assumed that all ice covered sections downstream of aufeis fields were completely frozen to the bottom. The only exception to this was habitat that was covered by thin ice or small isolated ice-free sections, which we documented as potential winter habitat.

COMMON HABITAT FEATURES

A common threat to northern Dolly Varden populations is the onset and long-term persistence of cold temperatures and ice-covered habitat. To succeed in this region, fish have adopted life history strategies to survive in these extreme environments. Though specific habitat use may vary between river basins and among life history stages, common habitats are identified and discussed below, which are important, and in some cases pivotal for survival.

Groundwater

Perennial groundwater springs are found in all freshwater streams that northern Dolly Varden are known to occupy in Canada. Habitat associated with groundwater is pivotal for the long-term persistence of populations because perennial springs maintain overwintering habitat (Craig and McCart 1974; Glova and McCart 1974; Stewart et al. 2010; N. Mochnacz unpubl. data). If winter habitat were lost, it is unlikely that fish would adapt to survive in marine environments and populations would eventually be extirpated. Although groundwater is a vital feature common to all Dolly Varden streams in northern Canada, the proportion of habitat associated with these springs in an given stream is small (e.g., <5% of total habitat available in the Babbage River downstream of the falls). Not only are these areas very important for winter survival, but they are also spatially limiting for northern Dolly Varden and associated species (Power et al. 1999; Sandstrom et al. 2001; N. Mochnacz unpubl. data).

There are three types of groundwater that are common in northern rivers: 1) active layer groundwater, which originates in shallow sediments that freeze and thaw each year, 2) supra-permafrost perennial springs that originate deeper than active layer groundwater, but are not geo-thermally heated (range = 0.5-4.0°C), and 3) sub-permafrost perennial springs, which originate from much deeper in the earth's crust, are warm (range = 8.0-16.0°C), and usually have high total dissolved solid concentrations (Clark et al. 2001). The size of open water areas in rivers during the winter is influenced by the groundwater temperature, snow depth, atmospheric conditions, flow volume and rate, and the stream gradient (Stewart et al. 2010). Perennial groundwater is the only water source in these northern rivers during the winter, which otherwise freeze to the bottom over long stretches (Craig and McCart 1973; Power et al. 1999; Clark et al. 2001). In some river systems groundwater may account for up to 80% of the baseflow during the open water season (Clark et al. 2001).

Habitats associated with perennial groundwater springs are not only vital during winter but also during spawning periods because they create micro-habitats for fish which are conducive to successful spawning. Discrete springs offer relatively constant water temperatures, moderate water flow, and high dissolved oxygen levels, which prevent these areas from freezing during the winter and promote successful egg development and keep waste levels (CO_2) from reaching toxic levels (Sandstrom and Chetkiewicz 1996; Baxter and McPhail 1999). Several studies demonstrate that egg-to-fry survival is higher and development rates are accelerated for salmonids in habitats with groundwater versus those without (Garrett et al. 1998; Baxter and McPhail 1999). Dolly Varden spawn in areas associated with perennial groundwater springs (Stewart et al. 2010; N. Mochnacz unpubl. data) presumably to exploit habitat which is favourable for spawning (i.e., avoid freezing, appropriate temperature, constant flow, and high oxygen content). Similarly, other closely related char selectively spawn directly on or near discrete groundwater springs (e.g., Arctic Char, *Salvelinus alpinus*, Cunjak et al. 1986; Brook Trout, *S. fontinalis*, Curry and Noakes

1995; Blanchfield and Ridgeway 1996, 1997; Bull Trout, *S. confluentus*, Baxter and McPhail 1999).

Aufeis

An aufeis (icing), which is an area of thick layered ice that persists during the spring and often into the summer months, is created by upwelling groundwater being forced out over the ice surface when encountering a frozen river bed (Yoshihara 1973; Craig and McCart 1974; Clark and Lauriol 1997; Clark et al. 2001; Yoshikawa et al. 2007). An aufeis field often forms the downstream boundary of spawning and overwintering areas in northern rivers (Baker 1987; Stewart et al. 2010; N. Mochnacz unpubl. data). The features and extent of the aufeis field vary annually in response to environmental conditions and influence baseflow during the open water season (Sandstrom and Chetkiewicz 1996; Clark and Lauriol 1997; Yoshikawa et al. 2007). Before the aufeis forms in the fall, Dolly Varden migrate upstream beyond the upper boundary of the aufeis to access spawning and overwintering areas. Although there is some speculation that adults may use these braided channels where aufeis forms in the fall for spawning, this has not been confirmed.

Small streams

Small streams are key for survival because they are used by Dolly Varden for spawning, rearing and overwintering (Sandstrom and Harwood 2002). Adults often use the same locations for overwintering and spawning, therefore, the availability and quality of rearing habitat associated with these areas likely influences juvenile recruitment. Furthermore, poor juvenile recruitment will impact population growth. This is supported by Vélez-Espino and Koops (2009), who demonstrated that the growth rate of the Laurentian Black Redhorse (*Moxostoma duquesnei*) was sensitive to juvenile survival rate. Levin and Stunz (2005) found similar results which imply that rearing habitat is key for long-term survival.

Anadromous Dolly Varden have been shown to preferentially occupy slower flowing habitat (e.g., pools) in small streams decreasing energetic expenditure before and after spawning and during winter (Sandstrom et al. 2001). In northern streams, overwintering habitat is limited to open water areas and ice-covered areas that do not freeze to the bed in isolated reaches above aufeis fields (S. Sandstrom unpubl. data). These overwintering areas are vital for survival; however, this habitat is spatially limiting (i.e., small proportion of entire stream available) and likely operates to regulate individual survival and thus population abundance through density-dependent survival.

Coastal areas

Access to key habitat is important for anadromous adults as they move between feeding areas in productive near shore coastal habitats and spawning, rearing, and overwintering habitats in freshwater streams. Areas of upwelling springs and tributaries to main rivers function as feeding grounds for fry, parr, and residuals (Stewart et al. 2010). First-year smolts move into river deltas and estuarine habitats to feed in habitat with higher prey density (Glova and McCart 1974; Stewart et al. 2010). Larger rivers (e.g., Rat River), which typically function as corridors, are important for current-year spawners as they provide a route to productive coastal waters. Dolly Varden feed in these areas until they achieve a suitable fitness level which allows them to return to their natal freshwater rivers to successfully spawn (Craig 1989; Sandstrom et al. 2001). These highly productive feeding areas are important; however, if these habitats were disrupted or lost, fish could feed in freshwater rivers, albeit likely acquiring less energy under such a scenario.

Complete loss of connectivity to coastal feeding areas would eliminate anadromy and prompt an overall shift in population structure dominated by stream-resident fish.

HABITAT USE AND AVAILABILITY

Spawning

Spawning sites are typically associated with perennial groundwater springs that form three main areas: a) the discharge area – the source of the groundwater at the top of the site characterized by open water extending downstream throughout the year; b) the main body – the middle and lower areas of the site, which can be partially ice covered and often associated with filamentous green algae; and c) the aufeis field – occurring at the bottom of the site, characterized by multiple layers of flooded ice, which is often quite expansive (Clark and Lauriol 1997; Clark et al. 2001; Yoshikawa et al. 2007). The top of the aufeis field typically delineates the lower boundary of spawning and overwintering sites. However, in the Big Fish River, fish were observed during the late winter in ice tunnels formed in the aufeis field that were 2 m wide and had water that was 0.5 m deep (DFO 2003a). Formation of these tunnels may be a unique situation resulting from the higher groundwater temperature characterizing this system (DFO 2003a; Clark et al. 2001). Spawning habitat is pivotal for successful recruitment and typically corresponds with overwintering habitat, which is spatially limiting.

Spawning occurs in the early fall between September and October in high-gradient, headwater streams (Stewart et al. 2010). Females excavate redds in shallow (0.2-1.5 m), low velocity areas (mean = 0.40 m/s, range 0.30-0.90 m/s) associated with perennial groundwater source(s), and substrate ranging in size from 16-63 mm (Sandstrom and Chetkiewicz 1996; Stewart et al. 2010; N. Mochnacz unpubl. data). Spawning usually coincides with water temperatures between 3-8°C (Stewart et al. 2010; Table 1).

Although redd densities are high in some areas (e.g., > 250 redds in a 300 m reach of Fish Creek), redd superimposition has not been confirmed in northern streams (N. Mochnacz unpubl. data). This behaviour has been documented in other systems (Kitano and Shimazaki 1995) and is not uncommon for other char species, especially populations that spawn in areas associated with groundwater (Baxter and McPhail 1999). Redd superimposition implies that either habitat is spatially limiting, habitat requirements are very specific, or a combination of both. This phenomenon poses a threat to successful progeny development because re-excavation of existing redds can dislodge eggs sweeping them into unfavourable locations, potentially increasing the risk of predation (Kitano and Shimazaki 1995). Higher egg density in the substrate can also lead to higher mortality as a result of decreased dissolved oxygen and increased incidence of fungal disease (Goodyear 1980). Furthermore, redds constructed by smaller females are more vulnerable to re-excavation and superimposition than those of larger-bodied females as nest depth is positively correlated with fork length (Kitano and Shimazaki 1995).

Firth River

All known spawning habitat in this river system is associated with perennial groundwater springs and used at some point in the year by all life stages (Glova and McCart 1974; DFO 2003c). Three spawning areas are known in the Canadian portion of the Firth River and are closely related to aufeis formation. The first site is approximately 15 km downstream of the Alaska/Yukon Territory boarder, parallel to the mountain formation along the east bank of the upper Firth, immediately above the first aufeis field. It is approximately 500 m in length (Glova and McCart 1974). The second area is 3 km downstream of the Alaskan border and is 300 m in length, and the third is located at the Yukon/Alaska border and is approximately 200 m long (Figure 2).

Kristofferson et al. (1991) observed redds in the main stem immediately below the confluence with Muskeg Creek and in the main stem opposite of the confluence with You Creek. Upstream of the Alaskan border, redds were reported for 14 km in areas of braided channels in gravel plains. Along the right branch of a fork off the main stem, redds were also seen up to 4 km upstream at which point the stream became impassable due to low water levels (Kristofferson et al. 1991). In Joe Creek, redds were observed at the base of a cliff in clear water that was strewn with large boulders (Baker 1987; Kristofferson et al. 1991; Figure 2). Redd sizes ranged from 1.0-1.5 m long and 0.5-1.0 m wide (Baker 1987; Kristofferson et al. 1991). Spawning in the Firth River occurs earlier than Joe Creek, which may be linked to differences in groundwater temperatures observed at each location (Stewart et al. 2010).

During late winter surveys in the Firth River Delta, Mutch and McCart (1974) discovered an area of open water fed by groundwater sources that was approximately 350 m long (Figure 3). Spawning has not been observed at this site, but stomach content analysis of Dolly Varden collected from this area revealed the presence of embryos, indicating that this could be a potential spawning location (Glova and McCart 1974).

The extent of known spawning habitat for anadromous fish in the Canadian portion of the Firth River and Joe Creek is 0.1843 km^2 (184 300 m^2) and 0.0217 km^2 (21 700 m^2) respectively (Table 2).

Babbage River

The upper Babbage River is fairly shallow and flows over a wide flood plain of gravel and crushed rock, which terminates at a waterfall with a drop of 8.3 m (Baker 1987). In the lower river, after the falls, the channel deepens and narrows in a valley of shale cliffs and the rocky substrate is occluded by a heavy deposition of mud and silt (Baker 1987). An isolated stream-resident population occurs above the falls of the main stem and an anadromous population below (Bain 1974; Reist 1989; DFO 2003b). The stream-resident population spawns somewhere upstream of the falls and the anadromous population spawns in the headwaters of the Canoe River and Fish Hole Creek (Figure 4). The extent of spawning habitat for anadromous fish in the Babbage River system (i.e., Fish Hole Creek/Canoe River) is 0.0073 km^2 (7300 m^2) and 0.0189 km^2 (18 900 m^2) for the isolated life history type (Table 2).

Big Fish River

An anadromous population spawns in Little Fish Creek (formerly Cache Creek, McCart and Bain 1974), a tributary to the Big Fish River (Figure 5). Females spawn annually in this system as opposed to other North Slope rivers where fish spawn in alternate years (DFO 2003a). The spawning area consists of a series of pools, runs, and riffles (1-2 m deep, 5-10 m wide) downstream of a 3 m waterfall (Jessop et al. 1974; Gillman et al. 1985). The dominant substrate in this section is gravel to cobble size rock, which is typically 16-63 mm in diameter (Stewart et al. 2010). Similar to other overwintering and spawning locations, this area is maintained by a perennial groundwater source. However, unlike most locations, this spring originates from a sub-permafrost groundwater source. The water chemistry of the groundwater from this stream is very different from groundwater of other “typical” North Slope springs as it is relatively warm (8-16°C), has a high mineral content (2600 ppm), is slightly basic (pH = 7.6-8.1), and has dissolved oxygen levels ranging from 0.2-6.8 ppm (McCart and Bain 1974; Clark et al. 2001; Stewart et al. 2010). Upwelling groundwater can maintain winter water temperatures as high as 16°C upstream of the main falls and produces an open water section below the falls that extends approximately 4 km downstream (McCart and Bain 1974; Jessop et al. 1974; Clark et al. 2001).

Most Dolly Varden populations spawn and overwinter in the same areas, which are usually near discharging groundwater. However, in Little Fish Creek an anadromous population spawns approximately 2-3 km downstream of the groundwater source. This may be due to excessively high temperatures and dissolved solids at the discharge location, which could be detrimental to egg development (Sandstrom 1995; Sandstrom and Harwood 2002). The extent of spawning habitat is 0.0471 km^2 (47 100 m^2; Table 2) for the anadromous population downstream of the falls.

An isolated stream-resident population exists above a waterfall (> 10 m) in Little Fish Creek (Figure 5). The water upstream of the falls is warm (10-16°C during winter), has high total dissolved solids, and very low dissolved oxygen levels (McCart and Bain 1974). This population is significant as it provides insight into the tolerance of this species to environmental extremes (McCart and Bain 1974). The extent of spawning habitat available in this reach is 0.0082 km^2 (8200 m^2; Table 2).

Rat River

The Rat River population spawns in Fish Creek, a small, high-gradient, headwater tributary (DFO 2001; Sandstrom et al. 2001; Figure 6). Spawning occurs upstream of a large aufeis area, which is fed by a number of perennial groundwater sources (4-5°C). The aufeis melts during the ice-free period and exposes the lower portion of the spawning area, which is characterized by a flat gravel field of braided channels (Sandstrom et al. 2001).

Groundwater is derived from supra-permafrost sources that are much cooler (i.e., 3-5°C) than the ones found in the Big Fish River system and may explain why fish spawn earlier in this area (Sandstrom and Chetkiewicz 1996). The presence of multiple groundwater sources and a high proportion of suitable spawning substrate (~ 30% pebble) suggest that Fish Creek may have more spawning habitat than other northern rivers (N. Mochnacz unpubl. data). There is also anecdotal evidence of “shift spawning” (i.e., dual spawning periods in a constant location) but further research is needed to confirm this occurrence (DFO 2001; Stewart et al. 2010). The extent of spawning habitat available for anadromous Dolly Varden in the Rat River is 0.08910 km^2 (89 100 m^2; Table 2). We have not documented spawning habitat upstream in this system; however, suitable habitat associated with perennial groundwater springs (0.0043 km^2 or 4300 m^2) was documented in 2009 (Table 2; Figure 6).

Peel River

Dolly Varden have been observed in the main stem of the Peel River; in Stony Creek in the Northwest Territories; and in the Blackstone, Snake, and Vittrekwa rivers of the Yukon Territory (Stewart et al. 2010; Figures 7, 8, 9). Spawning sites were identified by Anderton (2006) in the Blackstone River, Snake River, and an unnamed creek. Millar (2006) observed spawning activity and documented approximately 20 pools with suitable spawning habitat in Ne’edilee Creek, a tributary to the Vittrekwa River, YT (Figure 8). Each pool was approximately 2 m wide, 5 m long and 1.3 m deep and consisted of gravel substrate with undercut banks that were sheltered by willows. The water was clear and cold (2.7°C in late August; Millar 2006). The total amount of spawning habitat documented was 0.00210 km^2 (2100 m^2) in this reach (Millar 2006; Table 2). Spawning sites have been identified in the Blackstone River and several other unnamed locations within the Peel River system; however, the habitat has not been quantified (Anderton 2006; Reid and Skinner 2008; Figures 7 and 8).

Gayna River

An isolated stream-resident population occurs in the Gayna River (Mochnacz and Reist 2007; Figure 9). This population inhabits an isolated pool, which is approximately 50 m wide and

150 m long (0.0075 km^2 or 7500 m^2; Table 2). Although fish in spawning condition were captured at this site, discrete spawning habitat (i.e., redds) has not been documented (Mochnacz and Reist 2007).

Fish River

Approximately 1000 fish were observed in the upstream reaches of Fish River on October 5, 1972. Both anadromous and residual Dolly Varden in spawning condition were captured at this site but the size of this area was not documented (Craig and McCart 1973; Figure 10).

Overwintering

Dolly Varden spend the entire winter in upstream sections of freshwater streams associated with perennial groundwater sources. These areas often correspond with spawning sites. Winter habitat extends from the most upstream extent of open water, which is created at the main groundwater orifice, downstream to the upper boundary of the main aufeis field. In these areas there is a combination of open water habitat originating at the main groundwater source and ice-covered habitat that is not completely frozen to the bed. Juvenile fish occupy open water areas (N. Mochnacz unpubl. data), whereas adults are typically found in ice-covered habitat (S. Sandstrom unpubl. data). Fish may overwinter in areas downstream of the main aufeis field that do not freeze to the bottom because of flow and depth (e.g., Firth River Delta, Mackenzie Delta); however, this has rarely been documented (e.g., Glova and McCart 1974). Winter habitat is pivotal for survival but is generally restricted to several small isolated sections of headwater streams above aufeis fields (Stewart et al. 2010). All life stages inhabit the same overwintering habitats; however, fish will occupy different niches within these areas based on size and density (Glova and McCart 1974; N. Mochnacz unpubl. data). Large adults occupy deep pools in ice-covered areas above the aufeis field, whereas smaller adults and juveniles typically occupy deep pools in open water areas and shallow channel margins (< 0.30 m) near ice cover (Stewart et al. 2010; N. Mochnacz unpubl. data). There has not been any evidence to suggest that Dolly Varden overwinter at sea (Craig and McCart 1974). Overwintering habitats range in average depth from 0.1-1.0 m; have an ice depth cover of 0.0-2.0 m; dissolved oxygen from 5-13 ppm; and water temperature ranging from 1-11°C (McCart and Bain 1974; N. Mochnacz unpubl. data).

Firth River

In the Firth River system, fish overwinter in two areas: the Firth River and its major tributary, Joe Creek (Baker 1987; Figures 2, 3). All sub-adult life stages (fry and parr) have been found in the lower Firth Delta in late winter (Glova and McCart 1974; Figure 3). Juveniles (i.e., all pre-smolt phases) exploit marginal areas in the vicinity of groundwater sources, which are too shallow for larger adult fish. Smolts and adults aggregate in deeper channels and pools, which is likely a reflection of size segregation (Glova and McCart 1974). Fry and parr were identified from three locations in this system: a) the gravel floodplain of the upper Firth extending upstream of the aufeis, b) the upper reaches of Joe Creek extending above the aufeis, and c) the delta of the lower Firth. All three areas are associated with groundwater sources and may represent overwintering habitat (Kristofferson et al. 1991). The extent of overwintering habitat in the Firth River and Joe Creek is 0.1903 km^2 (190 300 m^2) and 0.0217 km^2 (21 700 m^2) respectively with a further 0.3393 km^2 (339 300 m^2) identified as potential winter habitat (Table 3).

There are also some areas in the Firth River that are ice covered but do not completely freeze to the bottom; these include the main stem at the confluence with Muskeg Creek, the deep pools along the canyon wall of the lower Firth, and areas within the Delta (Glova and McCart 1974; Figures 2, 3). Fry have been observed during the ice-free period in these areas and both juvenile and adult fish have been observed in late October when connectivity to upstream areas was lost (Glova and McCart 1974).

Babbage River

Anadromous and residual Dolly Varden overwinter above the aufeis field in the headwaters of Fish Hole Creek. There is a perennial groundwater spring (4.0°C) just upstream of the confluence with the Canoe River (68° 36’N, 138° 44’W; Figure 4) that maintains open water in this area throughout the winter (N. Mochnacz unpubl. data). As groundwater flows downstream towards the aufeis it cools and starts to freeze, creating ice-covered habitat that does not completely freeze to the river bed. Juveniles (FL=60-300 mm) occupy open water areas during the winter in this system (N. Mochnacz unpubl. data), whereas adults use ice-covered habitat (S. Sandstrom unpul. data). Downstream of the main aufeis fields, in both Fish Hole Creek and the Babbage River, most of the river is completely frozen to the bed during winter with the exception of some isolated deep pools in the Babbage River (Baker 1987; S. Sandstrom pers. comm.; Figure 4). The overwintering habitat available for anadromous fish in the Babbage River below the falls and in Fish Hole Creek/Canoe River is 0.0573 km^2 (57 300 m^2). Above the falls stream-residents have access to 0.0271 km^2 (27 100 m^2) of overwintering habitat and an additional 0.0020 km^2 (2000 m^2) of potential winter habitat (Figure 4; Table 3).

Big Fish River

Dolly Varden overwinter in Little Fish Creek, a tributary to the Big Fish River (Figure 5). The water chemistry and water temperature in this stream are influenced by significant thermal groundwater contributions. A stream-resident population occupies habitat upstream of the falls and anadromous fish use habitat below. Dissolved oxygen levels increase as water flows from the groundwater source above the falls downstream to the primary overwintering location for anadromous fish (Stewart et al. 2010). Fish spend the winter in pools found in open water and ice-covered sections, which extend from the base of the falls to the start of the aufeis field (Fehr and Archie 1989; Sandstrom and Harwood 2002; Stewart et al. 2010). Juveniles (FL=60-300 mm) occupy open water areas during the winter (N. Mochnacz unpubl. data) and adults use ice-covered habitat (S. Sandstrom unpul. data). The extent of overwintering habitat used by anadromous fish is 0.04710 km^2 (47 100 m^2) and 0.00820 km^2 (8200 m^2) for stream-residents. An additional 0.002 km^2 (2000 m^2) has been identified as potential habitat for the anadromous population downstream of the main overwintering area (Figure 5; Table 3).

Rat River

Anadromous Dolly Varden overwinter in Fish Creek, a tributary to the Rat River (Figure 6). Sandstrom et al. (2001) showed that both juveniles and adults overwinter in several deep pools immediately upstream of the aufeis area. However, juveniles arrive at the overwintering location post-spawning. The extent of known overwintering habitat available for the anadromous population is 0.08910 km^2 (89 100 m^2; Table 3). Other areas suitable for overwintering may exist in deeper areas of the lower reaches of the river as well as some adjoining channels in the Mackenzie Delta (Sandstrom et al. 2001). During winter surveys in 2008 and 2009 we observed many small areas (50 m x 50 m) upstream of the aufeis field that were either ice free or not completely frozen to the bottom. We also found a large open water section of river near the headwaters that was 0.0043 km^2 (4300 m^2).

A small open water section spanning 0.0002 km^2 (200 m^2) was also found at Scho Creek, which is a tributary to the Rat River situated just east of Fish Creek (Figure 6). No Dolly Varden have been captured or observed in this stream but the habitat is similar to Fish Creek.

Peel River

Contrary to North Slope populations, which typically use the same areas for spawning and overwintering, preliminary data suggest that populations from the Peel River system may use different areas during the winter (Anderton 2006). Within this watershed, overwintering habitat has been identified in the Peel River, Blackstone River, and Wind River, and it is assumed that lacustrine populations overwinter in Elliot Lake, Horn Lake, and two unnamed lakes (Anderton 2006; Figure 7). Although this watershed has not been surveyed as intensively as systems further north, preliminary data suggest that only stream-resident and lacustrine populations occur in this area (Anderton 2006). Known and potential overwintering habitat have been documented in this watershed, but these areas have not been quantified.

Further north in the Vittrekwa River, fish inhabit the main stem during winter (Millar 2006; Figure 8). The extent of overwintering habitat available is 0.0001 km^2 (100 m^2) with an additional 0.002 km^2 (2000 m^2) identified as potential winter habitat (Table 3).

Gayna River

An isolated stream-resident population occurs in the Gayna River (Mochnacz and Reist 2007) and inhabits an isolated pool, which is approximately 50 m wide and 150 m long (0.0075 km^2 or 7500 m^2; Table 3). We captured one adult Dolly Varden from this pool in February 2009, which confirms that this is indeed viable overwintering habitat (Figure 9). There are many suitable overwintering areas downstream; however, we have no evidence that a self-sustaining Dolly Varden population occurs in this downstream area. Any fish using overwintering habitat downstream of the falls likely represent strays from the upper pool or individuals from a fluvial bull trout population, which has been confirmed below these falls (Mochnacz and Reist 2007).

Fish River

Both anadromous and residual Dolly Varden in spawning condition were located in the upstream reaches of Fish River on October 5, 1972 (Craig and McCart 1973; Figure 10). This site was the only location where the river was not frozen. Very little is known about this population but it is likely that other overwintering sites exist in this system.

Rearing

It has been suggested that post-emergence, the highest densities of fry occur in riffles and peripheral habitats with gravel streambeds (also some finer particles, some cobble and a few boulders) having mean depths between 0.2 and 0.4 m (0.8 m maximum depth) and a surface velocity of 0.1 m/s (Griffith 1979). Alevins need suitable substrate to bury themselves post-emergence and remain under cover until the transition to fry (yolk sac absorbed). Larger substrates, in high flow areas are also important for fry (Griffith 1979).

Rearing habitat has not been well documented in northern streams; however, areas where juveniles have been observed correspond with spawning and overwintering sites (Stewart et al. 2010). During the open water season (i.e., spring, summer, fall), fry tend to occupy shallow waters along stream edges and small side channels (Glova and McCart 1974). Juveniles migrate to deeper pools along undercut banks and on the downstream side of large boulders (Glova and McCart 1974). Both fry and parr are widely distributed in the Firth River and Joe Creek during ice-free periods (Figures 2, 3), yet the greatest densities are typically seen in the vicinity of perennial groundwater sources (Glova and McCart 1974). In the fall of 2008 and 2009 we observed fry and parr at the spawning and overwintering area of Little Fish Creek (Big Fish River system). During a late winter survey in March 2009 juveniles ranging in size from 80-300 mm were observed in the headwaters of Joe Creek (Firth River system) and in pools above and below the confluence of Fish Hole Creek and the Canoe River (Babbage River system). In March 2010 similar sized juveniles were also observed during snorkel surveys in open water areas above the main aufeis field in this system and also in Little Fish Creek. In both instances, fish were occupying deeper areas in ice-free pools and under ice shelves formed near shallow channel margins. Although rearing habitat is important for juvenile recruitment, it does not appear to be spatially limiting in the spring, summer, and fall as a large proportion of suitable habitat is available during this time. It is unclear if juvenile overwintering habitat is limiting, but given the small proportion of open-water habitat available during this season it is conceivable that in low water years habitat availability may constrain juvenile survival.

Feeding

Anadromous Dolly Varden migrate downstream in the spring to feed in estuarine and coastal areas of the Beaufort Sea. Fish disperse both east and west from their natal streams and often remain parallel to shore, within 500 m of the coast. Adults may venture out further but rarely in excess of 1 km offshore (Craig 1989). Seasonal migrations can exceed 300 km and daily movements range from 3-6 km (Glova and McCart 1974).

The downstream migration by anadromous fish to coastal areas of the Beaufort Sea and subsequent time offshore is the only significant feeding period for smolts and adults. It is estimated that fish spend less than 10% of their lives at sea feeding (Stewart et al. 2010). Smolts and adults primarily consume insects and small crustaceans (Armstrong and Morrow 1980). At sea, mysids represent the primary food source, in addition to amphipods and larval fishes (e.g., Fourhorn Sculpin, *Myoxocephalus quadricornis*; Arctic Cod, *Boreogadus saida*), whereas in estuarine areas Dolly Varden rely upon a variety of invertebrates and other small fish. Juvenile and stream-resident fish are opportunistic and will feed on insects, spiders, annelids, molluscs, fish eggs, and other small fish (Stewart et al. 2009). There is little overlap between diets of anadromous and stream-resident fish (Armstrong and Morrow 1980). Fry and parr also consume a range of invertebrates; however, dipteran larvae represent a significant component of their diet (Armstrong and Morrow 1980).

Although annual feeding at sea is important for anadromous fish, it is unclear if they could accumulate sufficient energy stores to successfully spawn if they only had access to freshwater habitats. We hypothesize that if connectivity to more productive marine habitat was temporarily lost, most anadromous fish would adopt a residual life history resulting in a major shift towards a higher proportion of non-anadromy. A major shift towards the residual life history would result in small sizes of individual fish and decreased population abundance.

HABITAT STRESSORS AND RISK FACTORS

Dolly Varden is an important part of the Inuvialuit and Gwich'in subsistence fisheries and is considered a significant traditional food source by the local communities (Byers 1993; DFO 2001). Dolly Varden populations from the Big Fish River and the Rat River have shown serious declines creating concern for long-term sustainability (DFO 2001, DFO 2003a; Sandstrom et al. 2009). Such declines have prompted local communities, co-management boards, and Fisheries and Oceans Canada to re-assess the status of populations along the Yukon North Slope and the Northwest Territories.

Habitat degradation

Any activity that could reduce water levels in freshwater streams and rivers has the potential to negatively impact northern Dolly Varden populations. Overwintering habitat, which is typically limited to several small isolated headwater reaches of freshwater streams, is most sensitive to water fluctuations. A substantial reduction in discharge would significantly decrease the carrying capacity of overwintering habitat and could result in severe winter kill of all life stages. A decrease in discharge could also de-water downstream reaches and isolate these key habitats preventing successful upstream migrations by anadromous fish in the fall. Recent climate change predictions indicate that summer precipitation will decrease and annual air temperatures will increase in the north (Reist et al. 2006). If this occurs, the amount of surface water contributing to these systems could decrease and result in lower water levels during fall and winter. An increase in air temperature could also degrade existing permafrost and promote slumping and infilling of spawning habitat.

Activities, which could directly disturb or destroy spawning or overwintering habitat, also represent a serious threat to Dolly Varden populations as these activities could compromise recruitment and lead to direct mortality during winter. Development activities with the greatest potential for direct impacts are those associated with hydrocarbon exploration and subsequent transport, which include: stream crossing work such as ford crossings, temporary culvert placement, right-of-way clearing, and in-stream work (i.e., pipeline installation using open trench method); seismic exploration; and water removal (Stewart et al. 2010).

Habitat fragmentation

Fragmentation of migratory corridors that provide seasonal access between feeding and overwintering areas could severely damage and possibly extirpate both anadromous and isolated stocks. Activities that could compromise the connectivity between these habitats include access roads for development, causeways to offshore hydrocarbon platforms, and water withdrawals (Stewart et al. 2010). Direct impacts to feeding habitat do not present as significant a risk to populations because this habitat is not considered key or spatially limiting. However, loss of connectivity to marine feeding areas would eliminate anadromy and could prompt an overall shift in population structure dominated by stream-resident fish. This would be a significant shift as local communities target the anadromous populations in subsistence fisheries (Byers 1993).

SUMMARY

During winter, which can span 8-9 months in the north, Dolly Varden populations are confined to upstream reaches of freshwater streams that do not completely freeze because of discharging groundwater. Fields of thick ice (aufeis) build up downstream of the open water where flow can no longer follow the channel and spreads out on top of the ice. These aufeis fields contribute significantly to baseflow during the summer months (Yoshikawa et al. 2007). Habitat associated with discharging groundwater sources is used for spawning, rearing, and overwintering; however, these areas are spatially limiting as they comprise a small proportion of the total habitat available in streams. Overwintering habitat is pivotal for these fish as the carrying capacity appears to be limiting in most northern streams and likely influences population growth. Accurately delineating and protecting winter habitat will be very important for the long-term sustainability of northern populations. All known spawning sites are considered key habitat as they correspond with overwintering habitat, although, unlike overwintering habitat, fish have access to other areas during the spawning period. If spawning habitat is lost, it is unclear if Dolly Varden populations would adapt to spawn in different areas, which are presumably of lower habitat quality. Further work is required to determine if spawning and rearing occur in areas that do not correspond with overwintering habitat.

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Table 1. Habitat use by northern Dolly Varden in Canada.

	Activity		
	overwintering-all life stages	**adults-spawning**	**eggs/rearing/juveniles**
Substrate	Silt, fine gravel, small-large cobble, sparse boulders	Gravel, preferred 25-50 mm diameter (10), pebble 16-64 mm (17), fine gravel (14), cobble (7)	Fine gravel (1), gravel (2), small cobble (3), preferred size 25-50 mm diameter (10), silt to boulders, medium rock preferred (11), downstream side of large boulders (13)
Habitat	Alternating series of pools, runs, and riffles associated with perennial groundwater, variable flow regime (3,14,15, 17)	Alternating series of pools, runs, and riffles associated with perennial groundwater, variable flow regime (3,14,15, 17)	Stream edges, gravel bars, backwaters, braided channels, small streams, river deltas (7,11,12)
Water Depth	1-2 m (2,3), 0.2 m (5) Pools below rapids (1) Spring-fed pools (14)	1-2 m (2,3), 0.2 m (5) Pools below rapids (1), spring-fed pools (14)	0.1-1.5 m (10,11,16)
Water Temperature (°C)	Average 4.0-5.0 at discharge site (4), 16.0 at source (Little Fish River) (13)	3-8 (9,11, 12), 4.0 (5)	Emerge at 1.5C (12), 4-6 (16), 0-8 (1,9)
Water Velocity (m/s)	0.3-0.6 (5,6)	0.3-0.6 (5,6)	0.3-0.6 (5,6)
pH	7.6-8.1	8.0-8.5 (5)	7.5-8.5
Dissolved oxygen	2.6-14.5 mg/L, 0.2 mg/L at Little Fish R (8,13)	2.6-14.5 mg/L, 0.2 mg/L at Little Fish R (8,13)	2.6-14.5 mg/L, 0.2 mg/L at Little Fish R (8,13)
Conductivity	Mean range=120-350 at 25°C (11), 446-540 on Firth, 4800 µmhos/cm at 25°C, Little Fish R (8,13)	Mean range=120-350 at 25°C (11), 446-540 on Firth, 4800 µmhos/cm at 25°C, Little Fish R (8,13)	Mean range=120-350 at 25°C (11), 446-540 on Firth, 4800 µmhos/cm at 25°C, Little Fish R (8,13)
Salinity	-	5-20 ppt (11)	Exclusively freshwater in natal streams, estuarine habitat used for feeding (7, 8)

Numbers in parentheses correspond to:
1) Stein et al. 1973; 2) Craig 1978; 3) Gillman and Sparling 1985; 4) DFO 2001; 5) Yoshihara 1973; 6) DeCiccio 1991; 7) McCart 1980; 8) Sandstrom 1995; 9) Hatfield et al. 1972; 10) Sandstrom and Chetkiewicz 1996; 11) Stewart et al. 2010; 12) Glova and McCart 1974; 13) McCart and Bain 1974; 14) Jessop et al. 1974; 15) DFO 2003a; 16) Armstrong and Morrow 1980; 17) Mochnacz unpubl. data.

Table 2. Estimate of known and potential spawning habitat for northern Dolly Varden in Canada. Area is expressed in square kilometers.

		Yukon North Slope and Northwest Territories (NT)								Upper Mackenzie Mountains (NT)	Peel River Basin (YT)		
		Fish River	Firth River	Joe Creek	Little Fish Creek (Big Fish River)		Babbage River		Fish Creek (Rat River)	Gayna River	Vittrekwa River	Blackstone River	Total Area
Life history[1]		A	A	A	R	A	R	A	A	R			
Spawning Habitat (km^2)	Known	-	0.1843	0.0217	0.0082	0.0471	0.0189	0.0073	0.0891	0.0075	0.0021	-	0.3862
	Potential	-	-	-	-	0.002	-	-	0.0043	-	-	-	0.0063
	Total	0	0.1843	0.0217	0.0082	0.0491	0.0189	0.0073	0.0934	0.0075	0.0021	0	0.3925

1. A = anadromous, R = resident

Table 3. Estimate of known and potential winter habitat for northern Dolly Varden in Canada. Area is expressed in square kilometers.

		Yukon North Slope and Northwest Territories (NT)								Upper Mackenzie Mountains (NT)	Peel River Basin (YT)		
		Fish River	Firth River	Joe Creek	Little Fish Creek (Big Fish River)		Babbage River		Fish Creek (Rat River)	Gayna River	Vittrekwa River	Blackstone River[2]	Total Area
Life history[1]		A	A	A	R	A	R	A	A	R			
Winter Habitat (km^2)	Known	-	0.1903	0.0217	0.0082	0.0471	0.0271	0.0573	0.0891	0.0075	0.0001	0.183	0.6315
	Potential	-	0.3303	0.009	-	0.002	0.002	-	0.0043	-	0.0020	-	0.3496
	Total	0	0.5206	0.0307	0.0082	0.0491	0.0291	0.0573	0.0934	0.0075	0.0021	0.183	0.9810

1. A = anadromous, R = resident
2. This is an estimate from a lacustrine population that inhabits an unnamed lake connected to the Blackstone River

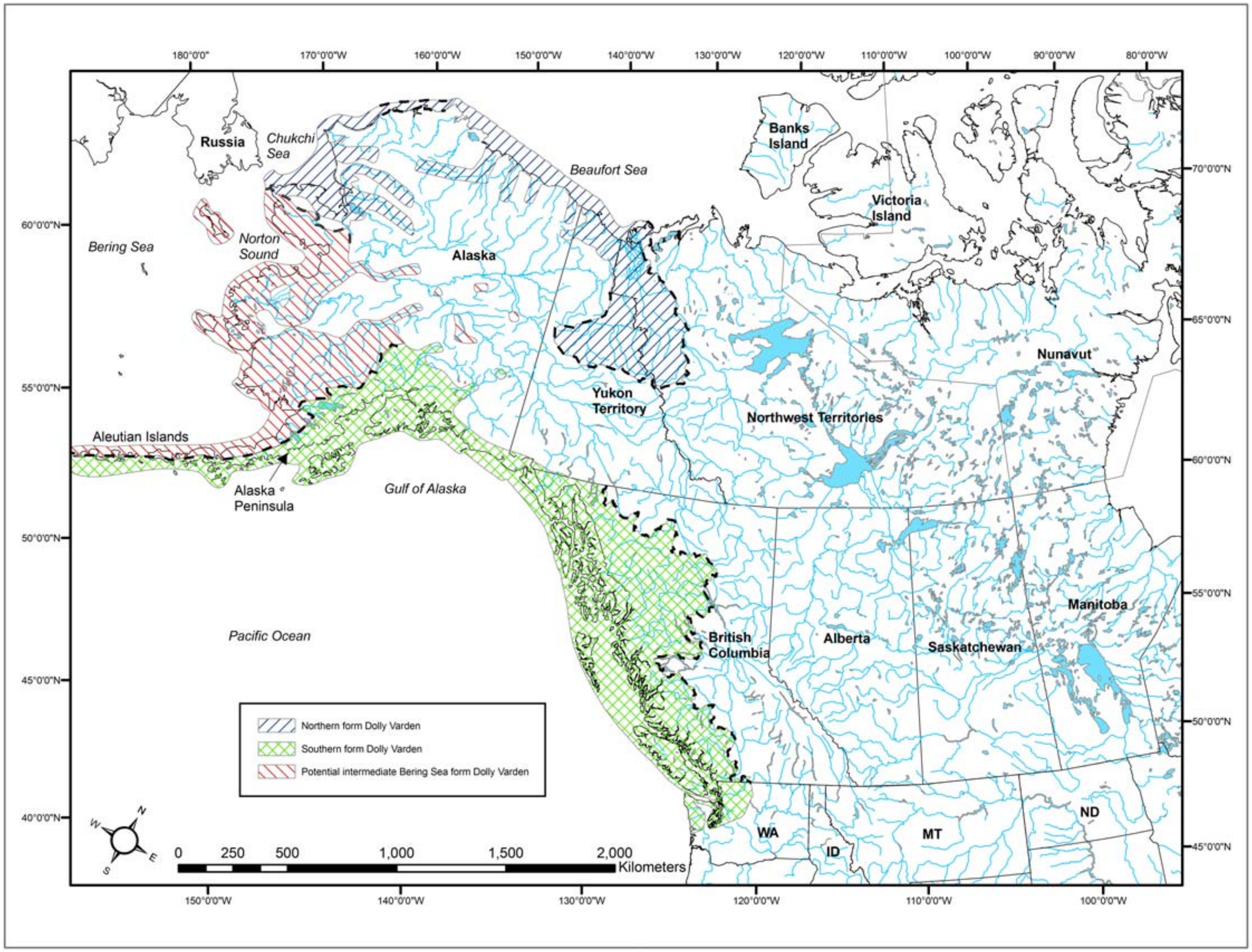

Figure 1. General North American distribution of southern, northern, and possible intermediate Bering Sea forms of Dolly Varden, *S. malma* (Sawatzky and Reist 2010 in press). Dashed lines indicate uncertainty in extent of distribution boundary.

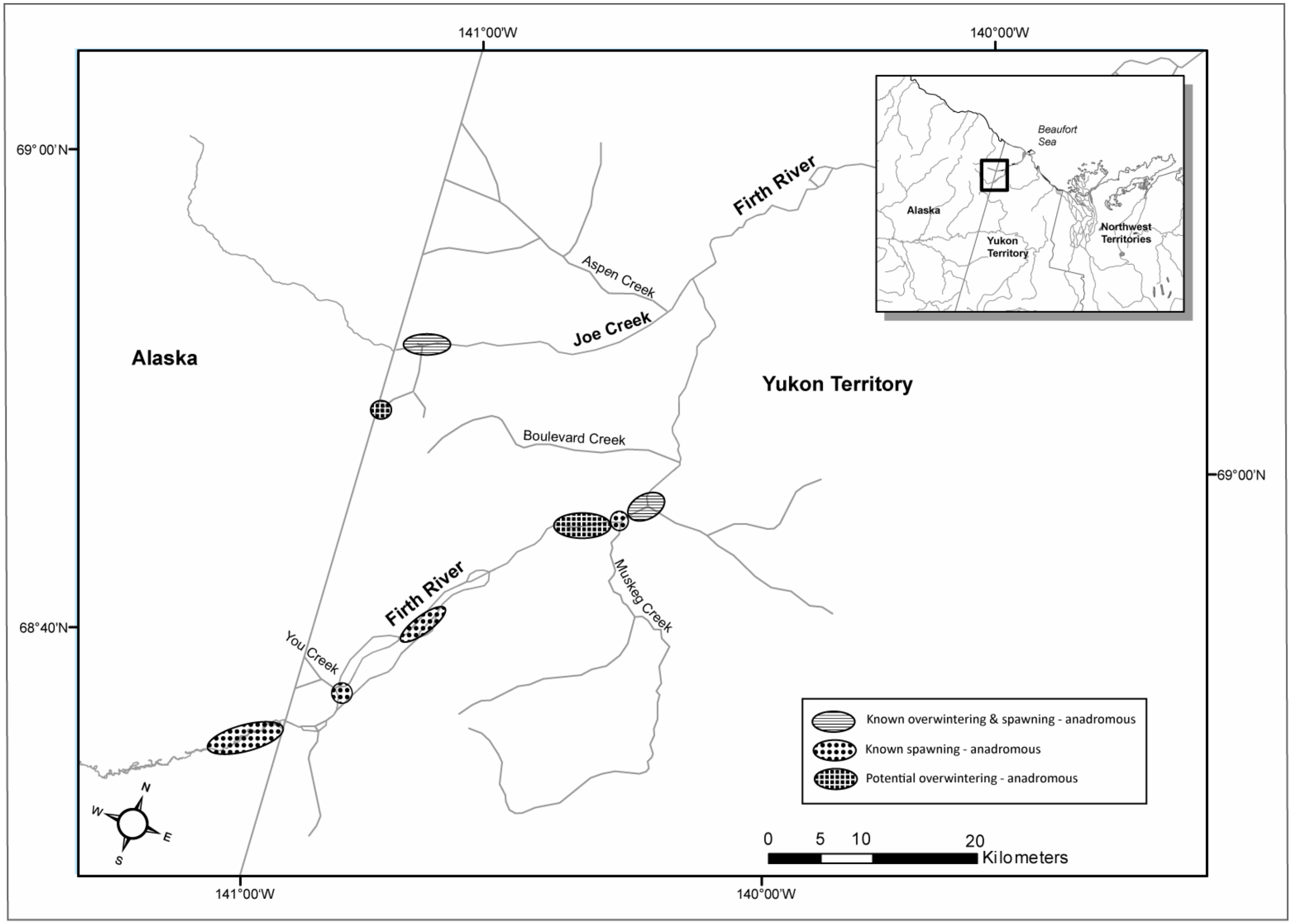

Figure 2. Known and potential Dolly Varden overwintering and spawning areas in the upper Firth River and Joe Creek. Note: spawning and overwintering areas identified on the map are not to scale.

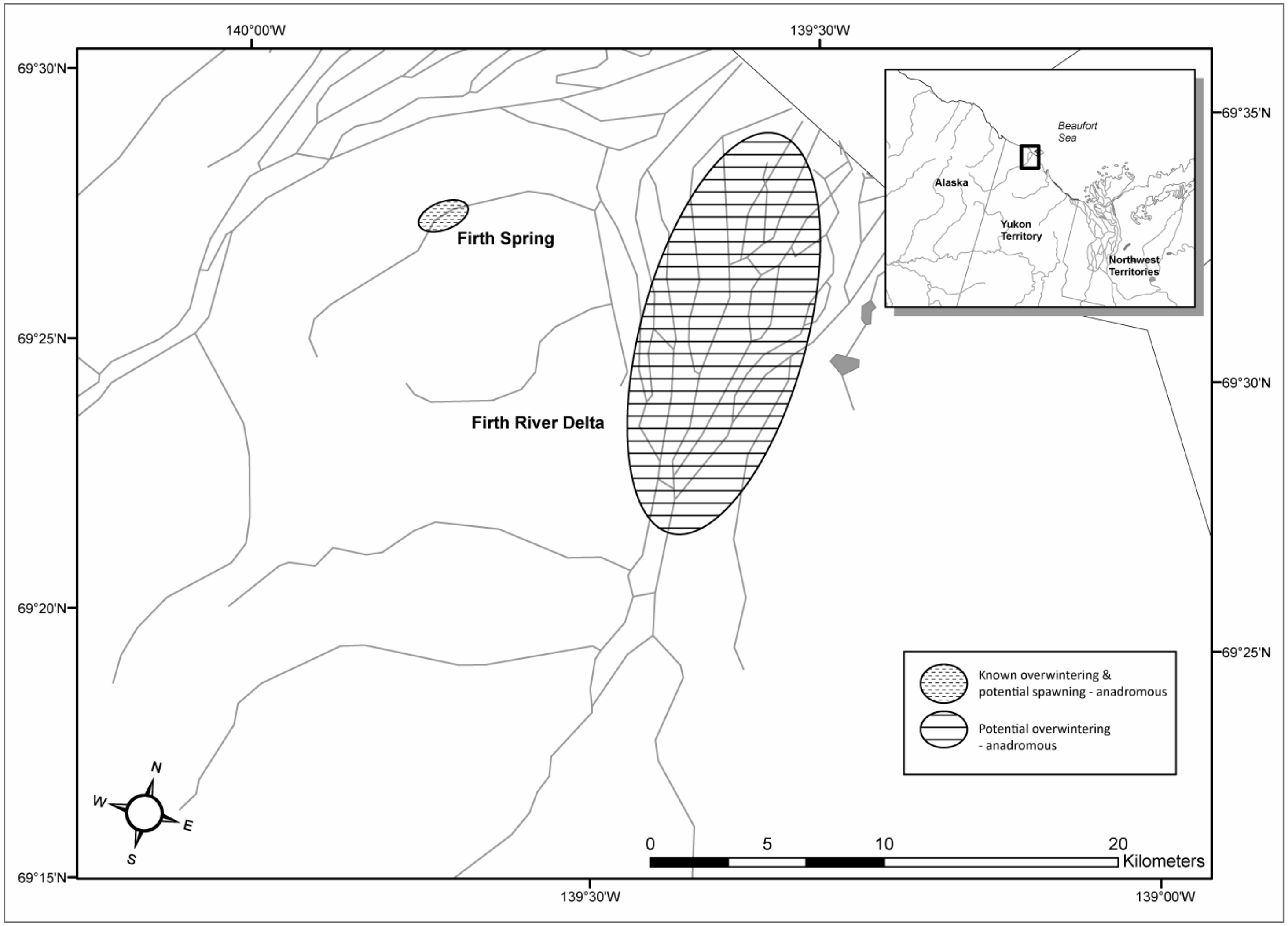

Figure 3. Known and potential Dolly Varden overwintering and spawning areas in the Firth River Delta area. Note: spawning and overwintering areas identified on the map are not to scale.

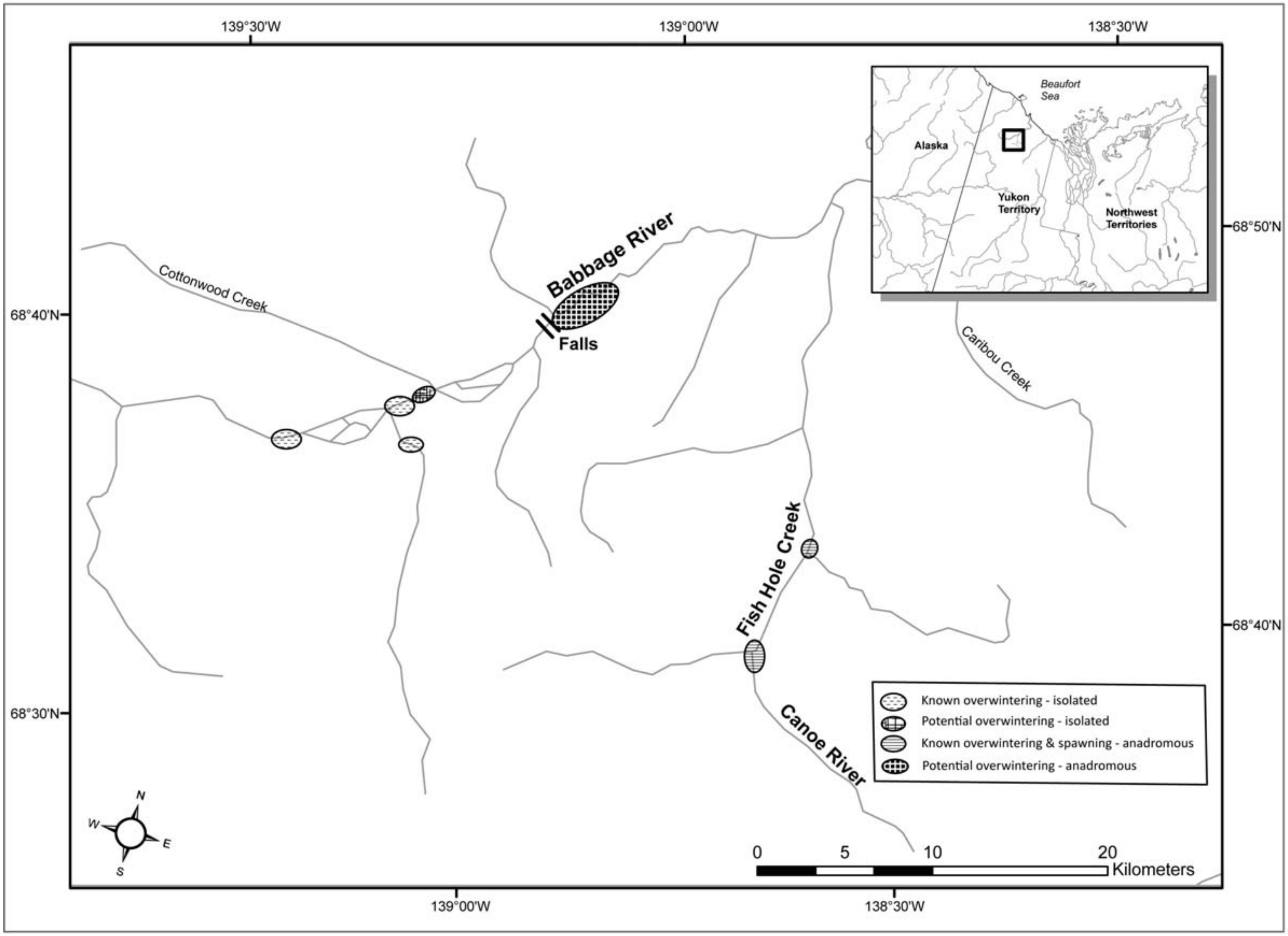

Figure 4. Known and potential Dolly Varden overwintering and spawning areas in the Babbage River system. Note: spawning and overwintering areas identified on the map are not to scale.

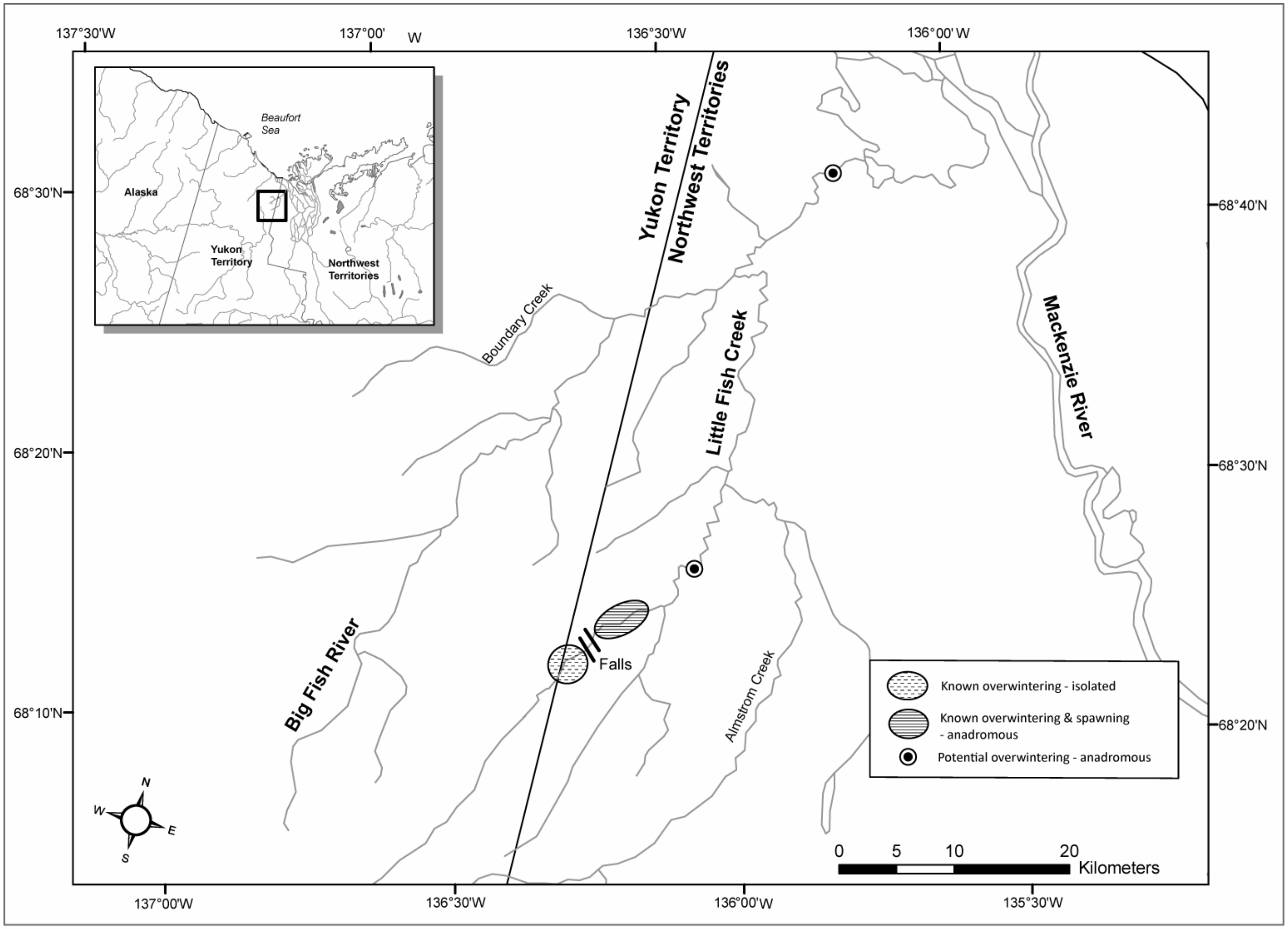

Figure 5. Known and potential Dolly Varden overwintering and spawning areas in the Big Fish River and Little Fish Creek. Note: spawning and overwintering areas identified on the map are not to scale.

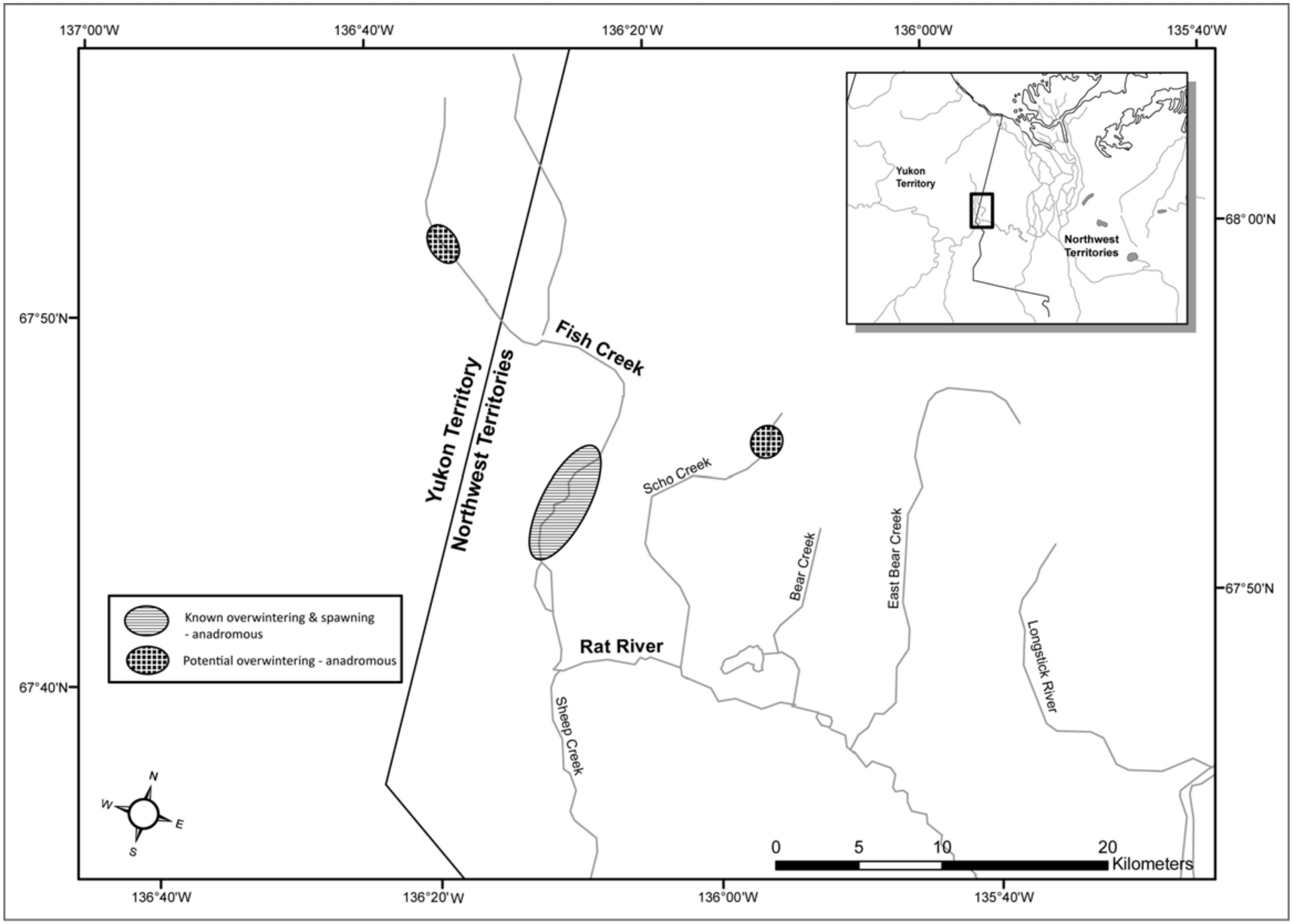

Figure 6. Known and potential Dolly Varden overwintering and spawning areas in the Rat River system. Note: some potential winter habitat may exist in deeper areas of the Rat River main stem. Spawning and overwintering areas identified on the map are not to scale.

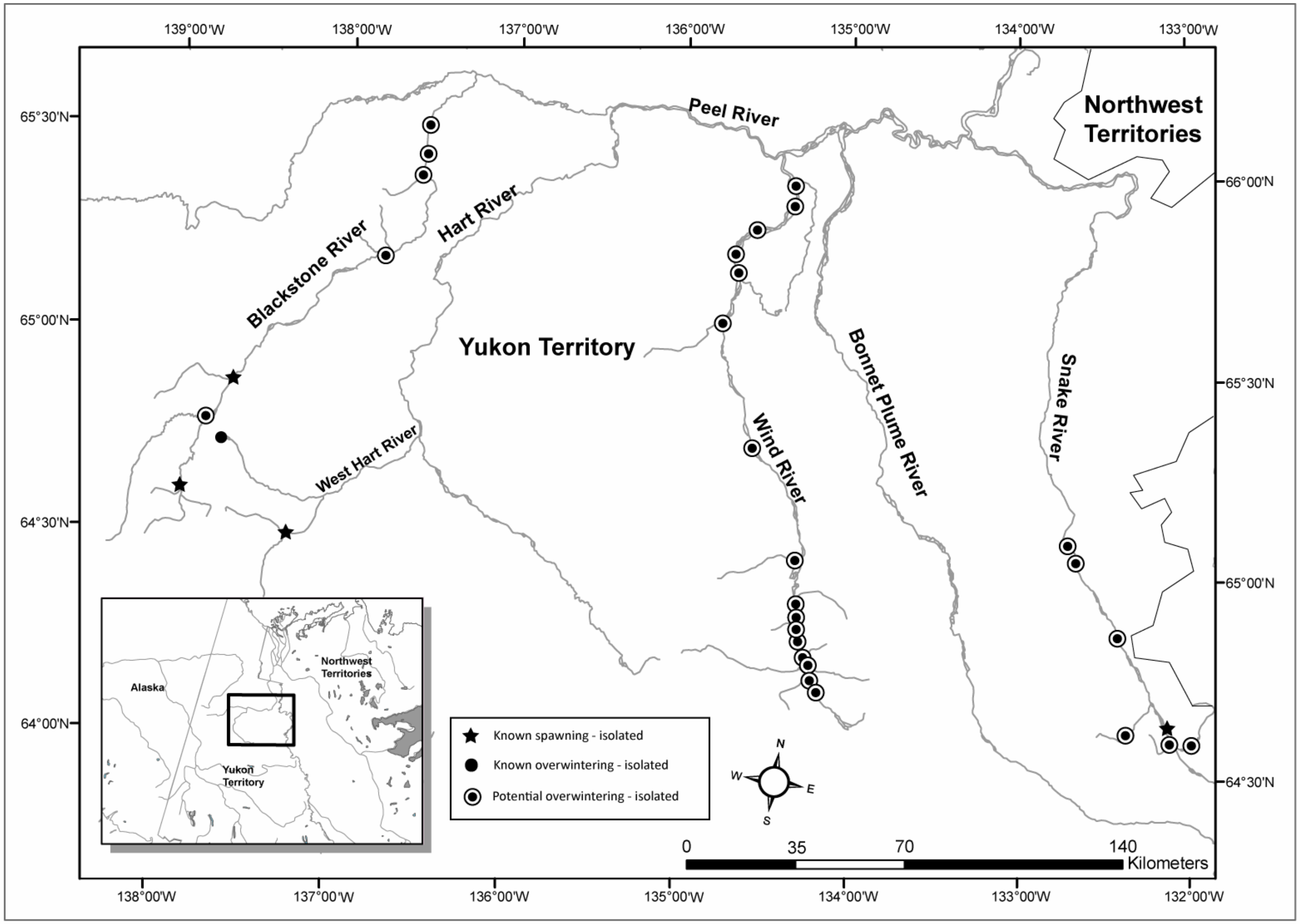

Figure 7. Known and potential Dolly Varden overwintering and spawning areas in the Peel River system (Anderton 2006; Reid and Skinner 2008).

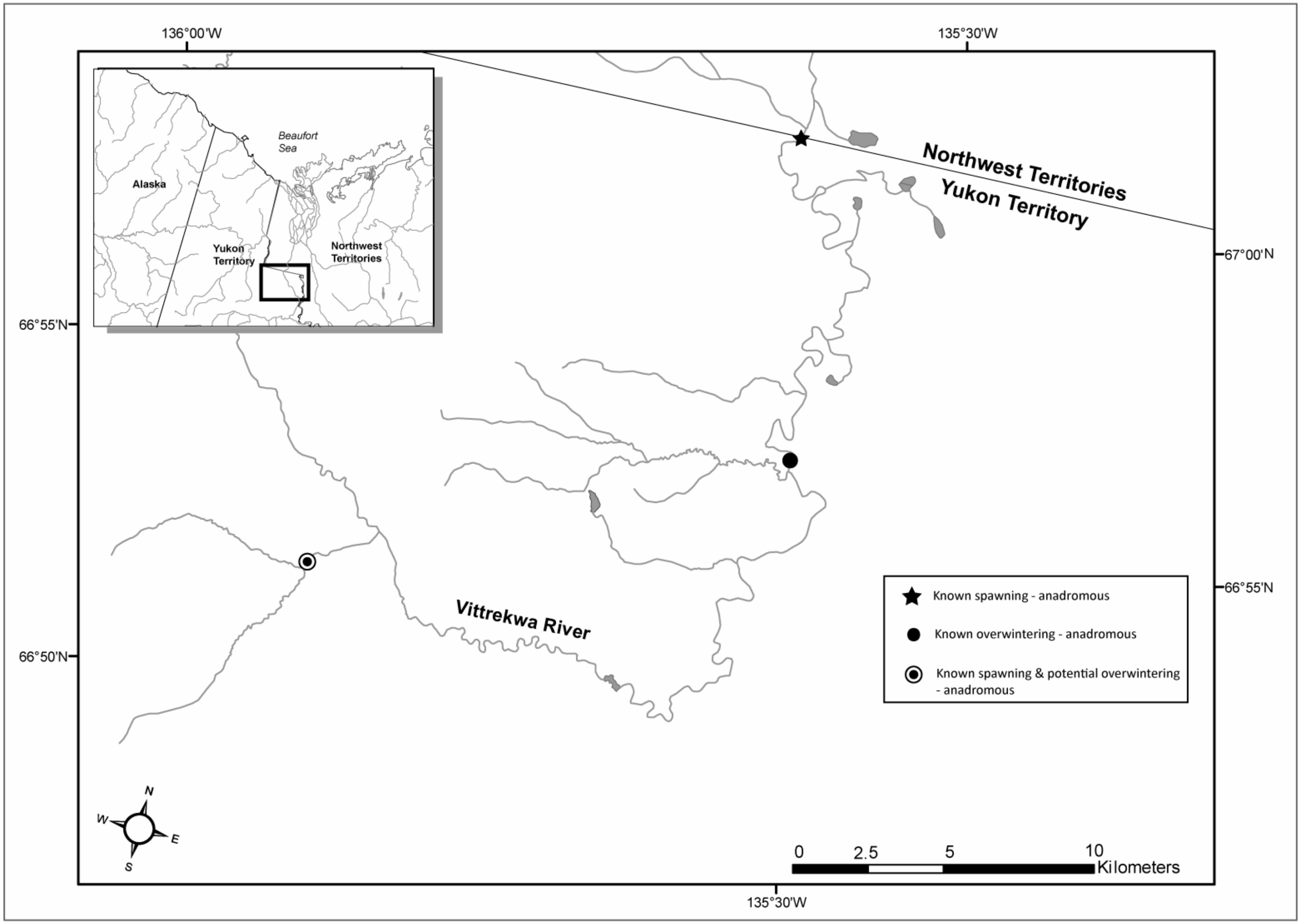

Figure 8. Known and potential Dolly Varden overwintering and spawning areas in the Vittrekwa River (Stephenson 2000; Millar 2006; Reid and Skinner 2008).

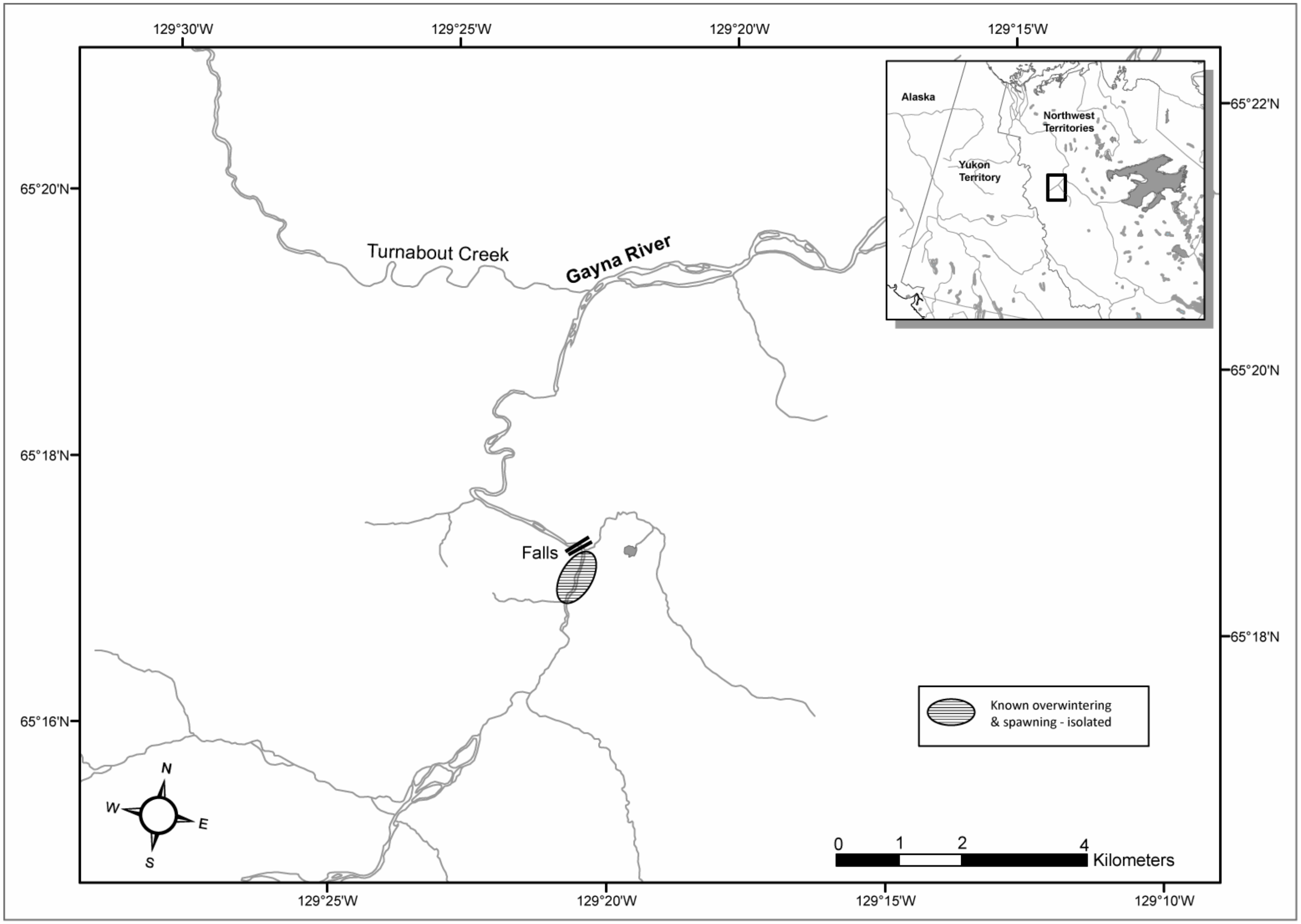

Figure 9. Known Dolly Varden overwintering and spawning area in the Gayna River. Note: spawning and overwintering area is not to scale.

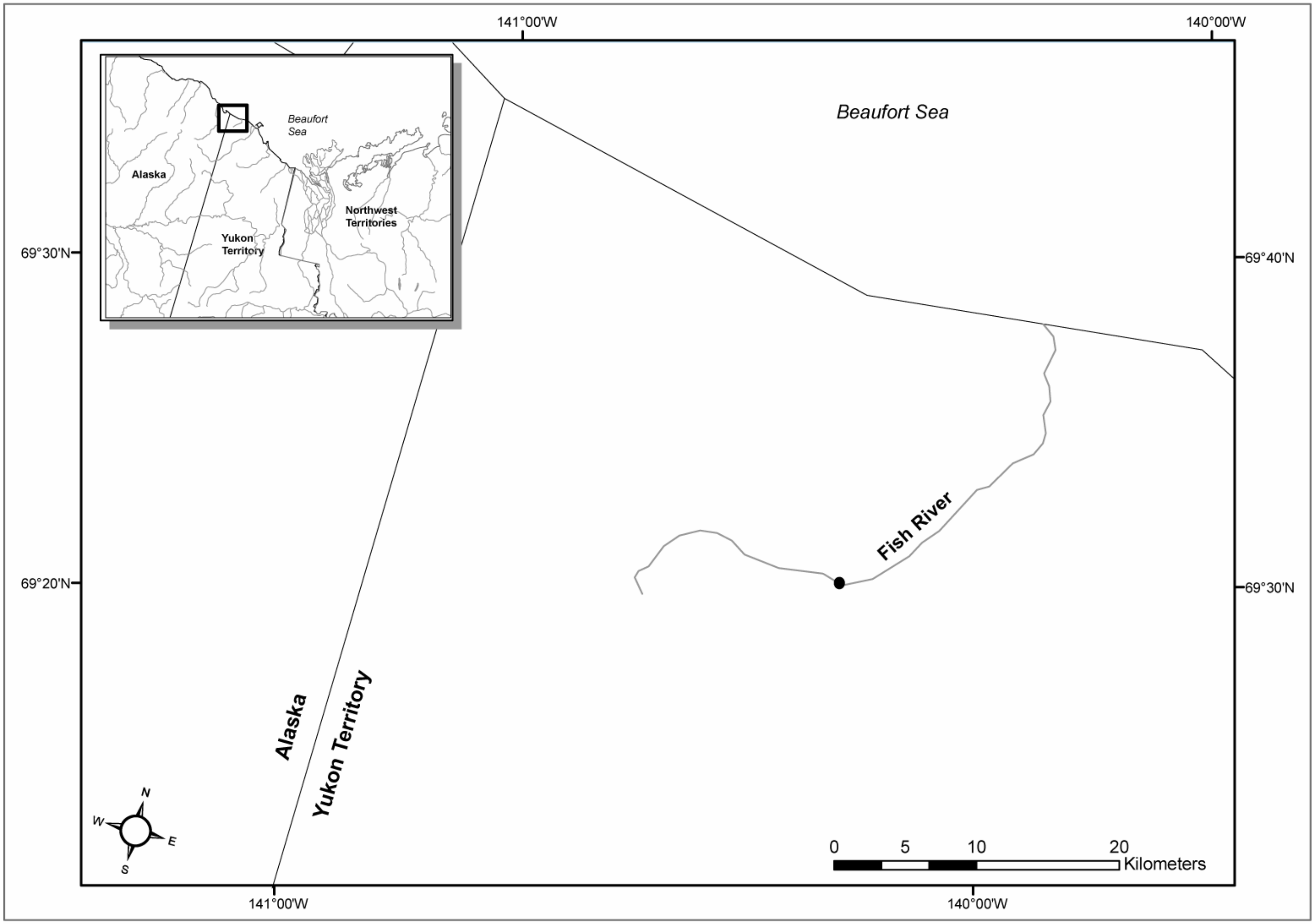

Figure 10. Known Dolly Varden overwintering and potential spawning area (●) in the Fish River.