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Whitefish Biology, Distribution, and Fisheries in the Yukon and Kuskokwim River Drainages in Alaska: a Synthesis of Available Information

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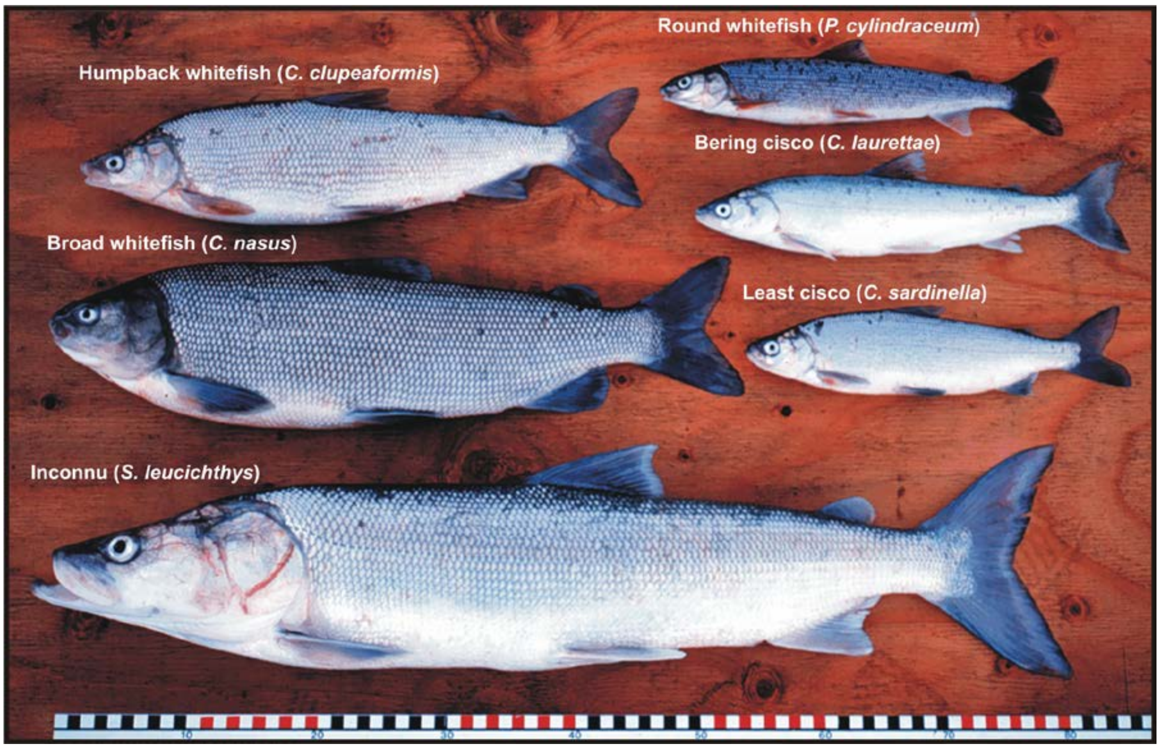

Fairbanks Fish and Wildlife Field Office
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Cover: Six common whitefish species in the Yukon and Kuskokwim River drainages in Alaska (photo credit: R.J. Brown, USFWS).

Whitefish Biology, Distribution, and Fisheries in the Yukon and Kuskokwim River Drainages in Alaska: a Synthesis of Available Information

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Abstract

Whitefish species in Alaska are subject to intensive subsistence fisheries everywhere they occur, commercial fisheries in certain places, and limited sport fisheries. Our understanding of whitefish biology comes primarily from studies of the same or similar species in other places, although some biological studies have taken place locally. Whitefish fisheries in the Yukon and Kuskokwim River drainages in Alaska have been documented in numerous anthropological and social science publications and in subsistence harvest surveys, but usually without species distinctions. Scientific sampling work since the 1960s has been reasonably effective at describing the species that are present and their distributions within the two drainages, but our understanding of populations, migrations, and demographic distribution among habitats is poor. We are just beginning to understand that major spawning migrations into upstream reaches of the drainage occur each summer and fall, juvenile and non-spawning fish dominate the lower reaches of both rivers and the coastal areas, and mature and spawning fish dominate the upper reaches. A small number of whitefish spawning areas have been identified in gravel substrate reaches of main-stem and tributary rivers in both turbid and clear water. Genetics work with whitefish species has focused more on taxonomy and biogeography issues than for management applications. With two exceptions in the entire Yukon and Kuskokwim River drainages, population abundance data are absent. Our ability to protect essential habitats for whitefish populations is growing with the improved understanding of their spawning destinations and life histories. Our ability to monitor whitefish population trends and to make effective harvest regulations, however, is very limited at this point.

In the following manuscript we provide an overview of the whitefish and whitefish fisheries in the Yukon and Kuskokwim River drainages in Alaska. The geography and aquatic habitat qualities of the two drainages are explored in detail. The taxonomy of whitefish species present in the drainage is discussed. We introduce a selection of important biological qualities of whitefish species, as

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documented in the literature. The nature of the many fisheries on whitefish species is described based on individual community studies and regional harvest surveys. Threats to whitefish populations, as identified in two meetings of delegates from a wide range of experience with whitefish harvest, research, and management, are critically examined. These include threats that may arise from overharvest of fishery resources, from habitat destruction that may occur during development activities, and from natural environmental changes. We then review the current state of knowledge of whitefish populations, distribution, and life history within the study area. Information that would improve our ability to protect essential habitats, monitor the abundance of whitefish populations, obtain harvest estimates, and establish reasonable and effective harvest regulations are identified. Finally, a general approach to research of whitefish populations is outlined and a number of specific research concepts and project ideas are recommended for the four species we thought most likely to be impacted by human activities.

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Introduction

Large-scale fishing, development, and transportation activities around the world have negatively impacted many fish populations in marine and freshwater environments (Hilborn et al. 2003; Pauly et al. 2005). The collapse of marine fish populations is most commonly attributed to overfishing (Myers et al. 1997; Hutchings and Reynolds 2004; Mullon et al. 2005), while the collapse of freshwater fish populations is most commonly attributed to habitat degradation (construction of dams, channelization of rivers, water withdrawals, pollution) and introductions of non-native aquatic species (Miller et al. 1989; Ricciardi and Rasmussen 1999; Duncan and Lockwood 2001). A recent status review of marine fish in North American waters identified 82 species that were at least vulnerable to extinction, including 35 species classified as endangered or threatened (Musick et al. 2000). A similar status review of North American freshwater and diadromous fish species identified 700 imperiled species, which is more than a third of the described freshwater and diadromous species on the continent (Jelks et al. 2008). Of the 700 imperiled species, 470 were classified as threatened or endangered and 61 species were considered to be extinct. Previous status reviews of North American freshwater and diadromous fish species indicate that there has been a distinct rise in the number of imperiled species during the last 30 years (Deacon et al. 1979; Williams et al. 1989). For example, the number of species considered to be endangered has risen from 78 in 1979 (Deacon et al. 1979) to 280 in 2008 (Jelks et al. 2008), and during the same time interval 16 species are thought to have gone extinct. Many Pacific salmon and anadromous trout *Oncorhynchus* spp. populations have seen dramatic declines in the western United States because of the construction of large dams and subsequent flow control on numerous rivers, logging activity in many drainages, and chemical and biological pollution from agricultural areas, mining regions, and urban centers (Nehlsen et al. 1991). In addition to habitat degradation in many western rivers, Pacific salmon populations have been exploited in intensive commercial and domestic fisheries. Nehlsen et al. (1991) found that of 214 natural Pacific salmon spawning populations in the western United States, 101 were at high risk of extinction. Human activities have clearly had profound effects on fish populations.

More than half of the native freshwater and anadromous fish species present in the Yukon (*n* = 29) and Kuskokwim (*n* = 27) River drainages are members of the family Salmonidae, and nearly half of the salmonid species are members of the subfamily Coregoninae, the whitefishes (Table 1). An explanation of the evidence or reasoning for species inclusion in this fish list can be found in Appendix A1. None of the salmonids or other freshwater or anadromous fish species within the Yukon or Kuskokwim River drainages are considered to be threatened or endangered at this time, although Jelks et al. (2008) point out that for many species there is insufficient information with which to make a status determination.

Whitefish species (Family: Salmonidae, Subfamily: Coregoninae) have been, and continue to be, important fishery resources for people in northern circumpolar regions of the world (Bodaly 1986; Fleischer 1992; Reshetnikov 1992; Andersen et al. 2004; Georgette and Shiedt 2005). In Alaska and northern Canada they provide a dependable subsistence food base for people and their dogs, and in many places they are available when other sources of fish or wildlife are not (Andersen 1992; Brown et al. 2005; Georgette and Shiedt 2005).

Table 1. Native freshwater and anadromous fish species present in the Yukon and Kuskokwim River drainages (references in text). Taxonomy is consistent with Nelson et al. (2004) except where indicated.

Family	Common name	Species
Catostomidae		
	Longnose sucker	*Catostomus catostomus*
Cottidae		
	Slimy sculpin	*Cottus cognatus*
Cyprinidae		
	Lake chub[1]	*Couesius plumbeus*
Esocidae		
	Northern pike	*Esox lucius*
Gadidae		
	Burbot	*Lota lota*
Gasterosteidae		
	Ninespine stickleback	*Pungitius pungitius*
	Threespine stickleback	*Gasterosteus aculeatus*
Osmeridae		
	Pond smelt	*Hypomesus olidus*
	Rainbow smelt	*Osmerus mordax*
Percopsidae		
	Trout-perch[1]	*Percopsis omiscomaycus*
Petromyzontidae		
	Arctic lamprey	*Lampetra camtschatica*
	Alaskan brook lamprey[1,2]	*Lampetra alaskense*
Salmonidae		
Subfamily: Coregoninae		
	Inconnu	*Stenodus leucichthys*
	Bering cisco	*Coregonus laurettae*
	Broad whitefish	*Coregonus nasus*
	Humpback whitefish	*Coregonus clupeaformis*[3]
	Least cisco	*Coregonus sardinella*
	Pygmy whitefish	*Prosopium coulterii*
	Round whitefish	*Prosopium cylindraceum*
Subfamily: Salmoninae		
	Arctic char	*Salvelinus alpinus*
	Dolly Varden	*Salvelinus malma*
	Lake trout	*Salvelinus namaycush*
	Chinook salmon	*Oncorhynchus tshawytscha*
	Chum salmon	*Oncorhynchus keta*
	Coho salmon	*Oncorhynchus kisutch*
	Pink salmon	*Oncorhynchus gorbuscha*
	Sockeye salmon	*Oncorhynchus nerka*
	Rainbow trout[4]	*Oncorhynchus mykiss*
Subfamily: Thymallinae		
	Arctic grayling	*Thymallus arcticus*
Umbridae		
	Alaska blackfish	*Dallia pectoralis*

[1]Known from the Yukon River drainage only.
[2]Taxonomy follows Mecklenberg et al. (2002).
[3]Taxonomy follows McDermid et al. (2007).
[4]Known from the Kuskokwim River drainage only.

Additionally, they congregate during certain seasons of the year to feed (Brown 2006; Harper et al. 2007), spawn (Andersen 2007; Wuttig 2009), or overwinter (Crawford 1979; Savereide 2002; Moulton and Seavey 2004), and can be harvested at those times and places in very large numbers. Commercial fisheries for whitefish species have developed in many places in North America, most commonly in large lake systems such as Great Slave Lake (Kennedy 1953; Roberge et al. 1982), Lake Winnipeg (Kennedy 1954; Davidoff et al. 1973), or the Laurentian Great Lakes (Fleischer 1992; Gorman and Todd 2007; Mohr and Ebener 2007). Occasionally, however, commercial fisheries take place in rivers or estuaries as in the multispecies fisheries in the Mackenzie River delta in northern Canada (Corkum and McCart 1981; Treble and Reist 1997; Howland et al. 2001b) and the Colville River delta in northern Alaska (Moulton and Seavey 2004; Hayes et al. 2008), the broad whitefish *Coregonus nasus* fishery in the Anadyr River of eastern Russia (Shestakov 2001), the inconnu *Stenodus leucichthys* fishery in northwest Alaska (Soong et al. 2008), and the relatively new experimental fall fishery for Bering cisco *C. laurettae* in the Yukon River delta (Hayes et al. 2008). Despite the widespread use of whitefish resources in domestic and commercial fisheries, management has rarely been informed regarding stock status, harvest levels, or critical life history variables (Corkum and McCart 1981; Bodaly 1986; Tallman and Reist 1997), and has often been ineffective at preventing stock collapses of heavily exploited populations (Fleischer 1992; Gorman and Todd 2007). The persistence of many exploited populations is undoubtedly due more to resilient life history qualities than to management design.

With a few exceptions, subsistence or personal use whitefish fisheries in the Yukon and Kuskokwim River drainages in Alaska are unregulated (Hayes et al. 2008; Whitmore et al. 2008). Legal fishing gear through most of the region include set and drift gill nets, beach seines, traps and weirs, fishwheels, dipnets, spears, and hook and line methods. Poisons and explosives are prohibited. Sport fisheries for inconnu have daily harvest limits that may vary from 1 to 10 per day (Burr 2004; Lafferty 2004; Brase 2008). Maximum gill net length is regulated in Whitefish Lake on the lower Kuskokwim River (USFWS 2010a). A spear fishery for spawning aggregations of humpback whitefish *C. clupeaformis* and least cisco *C. sardinella* in the Chatanika River, a tributary of the Tanana River, is currently limited to a certain number of participants, a one month open season, and a seasonal harvest limit for each participant (Wuttig 2009; Brase 2010). Whitefish species harvested incidentally in commercial salmon fisheries may be sold (Hayes et al. 2008; Whitmore et al. 2008). Commercial fisheries specifically for whitefish have routinely been permitted by the Alaska Department of Fish and Game in various locations within the Yukon and Kuskokwim River drainages. Most whitefish harvested in commercial fisheries are sold in local markets, but a recently initiated commercial fishery for Bering cisco at the Yukon River mouth, which is limited to a total annual harvest of approximately 4,500 kg (10,000 lb), is being marketed in New York City (Fabricant 2008; Demarban 2010). The only whitefish fishery that is regulated based on population abundance information is the spear fishery in the Chatanika River (Wuttig 2009; Brase 2010). In practice, most people living within the Yukon and Kuskokwim River drainages are free to harvest as many whitefish of any species as they want, at any season of the year, and with almost any gear they wish to use.

There has been an interest in the last few years in improving our understanding of whitefish populations in the Yukon and Kuskokwim River drainages in Alaska with the eventual goal of managing these important fisheries for sustainability. Most of the whitefish research that was conducted prior to 1995 was descriptive, documenting the presence of species in particular locations and sometimes presenting length, age, or sex ratio data (Pearse 1976a; Alt 1977b; Wiswar 1994b). Often whitefish data were collected during general fisheries surveys of all species (Craig and Wells 1975; Kramer 1976a; Daum 1994). Rarely did early research elaborate on more difficult aspects of population biology such as reproduction, migration patterns, abundance, or demographics. The geographic distribution of whitefish species within the Yukon and Kuskokwim River drainages began to be reasonably clear by the early 1980s, as portrayed in the general freshwater fishes books of McPhail and Lindsey (1970) and Morrow (1980a), but very few whitefish spawning areas had been identified, migrations of species other than inconnu were unknown, and there was virtually no understanding of populations or how they worked. Since 1995 there have been a number of whitefish research projects that have sought to identify spawning habitats and migration patterns of some species in some reaches of the Yukon and Kuskokwim River drainages (Brown 2000; Harper et al. 2007; Carter 2010). These and other similar projects have begun defining specific populations and identifying their distributions within drainages, prerequisites to any sort of effective management efforts. Because of the large geographic region encompassed by the Yukon and Kuskokwim River drainages in Alaska, along with the large number of whitefish species under consideration, there is a need to identify the most pressing issues within the region and focus research efforts to address those issues. The purpose of this manuscript is to present our current understanding of the taxonomy, distribution, and biology of whitefish species within the Yukon and Kuskokwim River drainages in Alaska, describe whitefish fisheries, consider possible threats to whitefish populations, and suggest priority research and monitoring concepts that will advance us towards effective management strategies for whitefish species. It is our hope that this manuscript serves as a resource for scientists and a strategic guide for future research of whitefish species within the Yukon and Kuskokwim River drainages in Alaska.

Study Area

Our study area encompasses the Yukon River drainage within Alaska and the entire Kuskokwim River drainage, a combined area of approximately 625,000 km^2 (241,000 $mile^2$), along with a coastal region extending from southern Kuskokwim Bay to northern Kotzebue Sound (Figure 1). The entire region extends from approximately 60° to 68° north latitude, and 141° to 168° west longitude. There are about 130 communities within the study area (70 in the Yukon River drainage, 27 in the Kuskokwim River drainage, and 33 in the coastal area), with a combined population of approximately 121,000 people as of 2008 (Appendix A2; U.S. Census Bureau 2010; City-data 2010). The Fairbanks urban area is composed of about 10 neighboring communities and two military bases and has a combined population of about 71,000. Approximately 50,000 rural residents live in the other 119 communities, most of which are isolated from the road system.

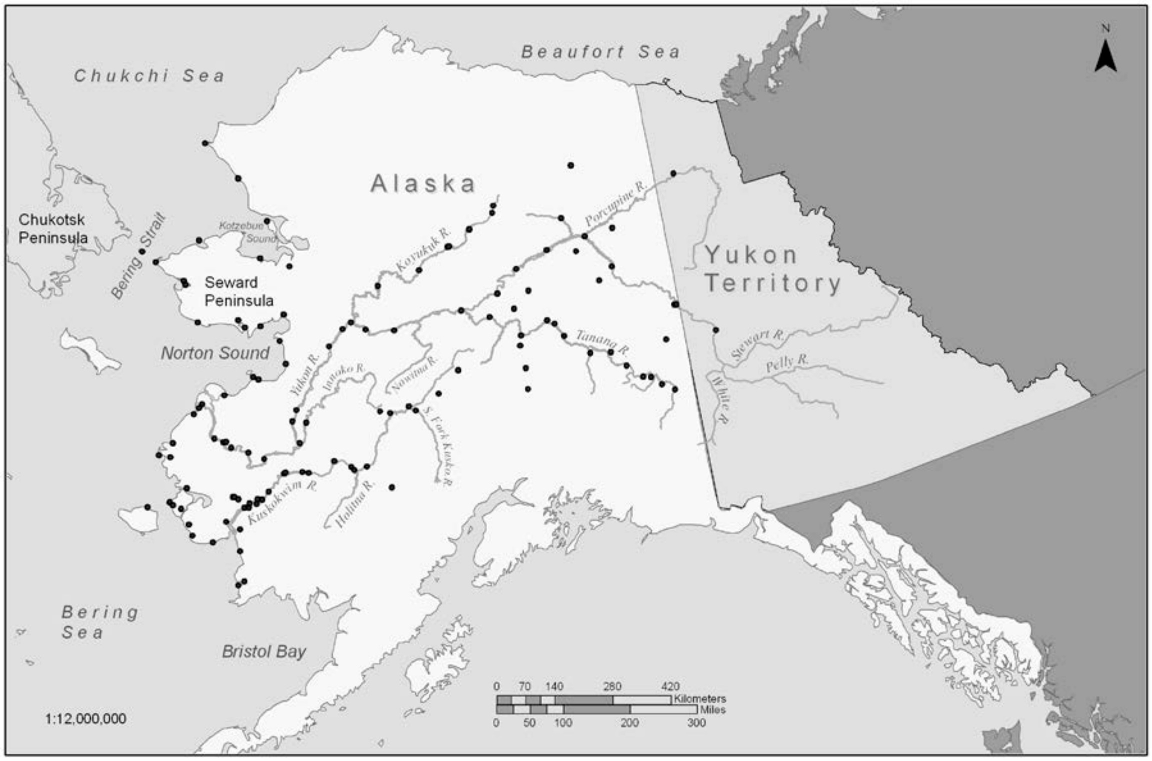

Figure 1. The Yukon and Kuskokwim River drainages in Alaska and Yukon Territory. Some major tributaries are included and the 130 communities within the study area, along with two communities in Canada, are indicated with icons (•).

The Yukon River is the largest drainage in Alaska and the fifth largest in North America (Revenga et al. 1998). It drains an area of more than 850,000 km^2 (328,000 $mile^2$), approximately 500,000 km^2 (193,000 $mile^2$) of which is in Alaska (Brabets et al. 2000). It flows more than 3,000 km (1,860 miles) from its headwaters in northern British Columbia, Canada, to its mouth at the Bering Sea. Average annual flow near the Yukon River mouth is approximately 6,400 $m^3 \cdot s^{-1}$ (226,000 $feet^3 \cdot s^{-1}$) although peak flow in early summer averages about 20,000 $m^3 \cdot s^{-1}$ (706,000 $feet^3 \cdot s^{-1}$) and extreme flow during flood conditions could exceed 25,000 $m^3 \cdot s^{-1}$ (883,000 $feet^3 \cdot s^{-1}$; Curran et al. 2003). There are six major tributaries in the Yukon River drainage (tributaries that contribute 5% or more to the total drainage area and 5% or more to the total flow) including the Pelly, White, and Stewart rivers in the Yukon Territory, and the Porcupine, Tanana, and Koyukuk rivers in Alaska. The White and Tanana rivers originate in the heavily glaciated Wrangell St. Elias and Alaska Range mountains, and are the primary sources of suspended sediment in the Yukon River (Brabets et al. 2000). The Tanana and Porcupine rivers, the two largest tributary systems in the Yukon River drainage, are approximately equal in drainage area, 114,737 km^2 (44,300 $mile^2$) and 116,550 km^2 (45,000 $mile^2$) respectively. The Tanana River, however, contributes approximately 20% of the total flow in the Yukon River drainage while the Porcupine River contributes less than 10%. In addition to main-stem habitats and the major tributaries in the Yukon River drainage, there are many hundreds of smaller tributaries and streams that range from low-gradient, tundra-stained, meandering waterways that flow slowly over mud or other soft substrates, high-gradient, clear-water streams that flow swiftly over cobble and gravel substrates, to a selection of highly turbid rivers that seasonally cascade from Wrangell

Mountains and Alaska Range glaciers (see Appendix A3 for a selection of the larger tributaries within the drainage). Nearly all of these habitats in the drainage are utilized by one or more whitefish species.

The Kuskokwim River is the second largest drainage in Alaska, draining an area of approximately 125,000 km^2 (48,000 $mile^2$; Kammerer 1990; Revenga et al. 1998), which is less than 10% larger than the Tanana or Porcupine River drainages (Brabets et al. 2000). It flows for more than 1,500 km (930 miles) from the headwaters of the North Fork Kuskokwim River to its mouth in Kuskokwim Bay (Appendix A4). Average annual flow near the Kuskokwim River mouth is approximately 1,900 $m^3 \cdot s^{-1}$ (67,000 $feet^3 \cdot s^{-1}$; Kammerer 1990; Dynesius and Nilsson 1994). Despite the similarity in drainage areas, the average annual flow in the Kuskokwim River is 1.5 times that of the Tanana River and 3.0 times that of the Porcupine River. Many of the southern tributaries of the Kuskokwim River drainage, from the Stony River upstream, originate in glaciated regions of the western Alaska Range. These drainages contribute a substantial quantity of suspended sediment to the Kuskokwim River during the summer months. Numerous smaller tributary and stream habitats, similar to those in the Yukon River drainage, are also present in the Kuskokwim River drainage (Appendix A4).

Six major lake districts have been identified in the Yukon and Kuskokwim River drainages in Alaska (Arp and Jones 2009). Lake districts are large, distinctive landscapes with high lake densities (Figure 2). The lake districts identified in our study area include: the Yukon Flats in the upper reaches of the Yukon River in Alaska, encompassing 21,006 km^2 (8,110 $mile^2$); Tetlin and Minto Flats in the Tanana River drainage, encompassing 1,867 km^2 (721 $mile^2$) and 2,787 km^2 (1,076 $mile^2$) respectively; Kanuti and Koyukuk flats in the Koyukuk River drainage, encompassing 3,410 km^2 (1,317 $mile^2$) and 14,658 km^2 (5,659 $mile^2$) respectively; the Minchumina region bridging the Tanana and upper Kuskokwim River drainages, encompassing 3,232 km^2 (1,248 $mile^2$); and the Yukon Kuskokwim Delta region, encompassing 72,831 km^2 (28,120 $mile^2$). The Yukon Kuskokwim Delta is the largest lake district in Alaska. It extends up the Yukon River to include the flatlands of the Atchuelinguk and Innoko rivers and up the north and south sides of the Kuskokwim River valley to about the mouth of the Aniak River. Lake districts in our study area are dominated by shallow, flatland lakes that may be closed or open to nearby river systems (Glesne et al. 2011). Shallow lakes, as defined by Scheffer (1998), are those that are shallow enough, usually <3 m (10 feet) deep, that they normally don't become thermally stratified. Many of these lakes freeze to the bottom or become anoxic in the winter and are thus unable to support overwintering whitefish. A relatively small number of upland lakes are present in the Yukon and Kuskokwim River drainages in Alaska as well. Upland lakes are usually surrounded by hills or mountains (Figure 3) and may be very deep compared to flatland lakes. As examples, Alt (1977b) reported the maximum depth of Aniak Lake, an upland lake in the headwaters of the Aniak River, Kuskokwim River drainage, as 38 m (124 feet), and Pearse (1978) reported the maximum depth of Iniakuk Lake, an upland lake in the upper Koyukuk River, Yukon River drainage, as 61 m (200 feet). Appendix A5 identifies and presents certain physical and biological data from a selection of flatland and upland lakes in our study area. Many of the upland lakes are capable of supporting fish during all seasons of the year. Similar to flatland lakes, upland lakes may be closed or open to nearby river systems. Both flatland and upland

Figure 2. Photographs of the Kanuti lake district in the upper Koyukuk River drainage (left), and in the Yukon Kuskokwim Delta lake district (right) illustrating the distinctive landscape qualities of the lake districts in Alaska. Photos by USFWS staff.

Figure 3. Two examples of upland lakes: Helpmejack Lake in the upper Koyukuk River drainage (left), which is approximately 2.5 km (1.5 miles) long, and unnamed lakes in the recently burned foothills of the White Mountain in the southern Yukon Flats (right). The lake in the foreground is approximately 2 km (1.25 miles) long. Photos by R.J. Brown, USFWS.

lake habitats are essential or important habitats for whitefish species in our study area and will be discussed in that context later.

We included the coastal waters of the Bering and Chukchi seas in our study area primarily because many whitefish populations migrate into brackish or marine water to rear, feed, and overwinter and some species make extended coastal migrations. Alt (1977a), for example, reported that an inconnu tagged in the Holitna River, approximately 523 rkm (325 miles) up the Kuskokwim River, was recaptured five years later 770 rkm (478 miles) up the Yukon River, which required a coastal migration of approximately 500 km (310 miles). Rearing Bering cisco are captured in lagoons and estuaries along the Bering and Chukchi seas, and occasionally as far north as the Colville River delta along the Beaufort Sea coast, but in western Alaska they are known to spawn only in the Yukon and Kuskokwim rivers (Alt 1973a; Bickham et al. 1997; Georgette and Shiedt 2005). Yukon and Kuskokwim River populations are clearly dispersing very widely along coastal habitats for rearing.

The marine environment in the eastern Bering Sea is influenced by currents, tides, ice cover, wind, and river flow levels. Marine currents in the eastern Bering Sea flow north into Norton Sound, along the south coast of the Seward Peninsula, and through the Bering Strait (Stabeno et al. 1999; Woodgate et al. 2005). Tidal amplitude in the region can be as great as 4 m (13 feet) in Kuskokwim Bay, 2.5 m (8 feet) in the central delta, 2 m (6.5 feet) near the south mouth of the Yukon River, and 1.5 m (5 feet) near the north mouth of the Yukon River (McDowell et al. 1987; Kowalik 1999; NOAA 2010). Tidal influence extends over 100 km (60 miles) upstream in the Kuskokwim River. The community of Bethel, for example, experiences tides as great as 1 m (3 feet; NOAA 2010). Tidal amplitude is much smaller in the lower channels of the Yukon River delta and tidal influence does not extend as far upstream (McDowell et al. 1987). Surface salinities in the eastern Bering Sea range between 31 and 33 practical salinity units (psu; Luchin et al. 1999), although, near the mouths of large rivers the salinity environment becomes very dynamic and will stratify both vertically and horizontally based on tides, wind, and river flow. Martin et al. (1987), for example, showed that at a distance of 20 km (12 miles) offshore from the south mouth of the Yukon River the surface water could range from <5 to >15 psu while the water on the bottom, 10 m (33 feet) down, ranged from about 15 to >25 psu depending on conditions. While the Bering Sea does not maintain any permanent ice, annual ice forms each winter and at a minimum extends south to entirely cover Kuskokwim Bay and often a substantial proportion of Bristol Bay (Niebauer et al. 1999). Sea water under ice drops to -1.7°C (29°F) or colder (U.S. Navy 1958; De Vries and Steffensen 2005), which is considered to be lethal for fishes in the family Salmonidae (Brett and Alderdice 1958; Fletcher et al. 1988; De Vries and Cheng 2005). These lethal marine temperature conditions force all of the whitefish overwintering in coastal regions to remain in warmer brackish water environments near river mouths or in fresh water. The Mackenzie River in northern Canada forms a large freshwater plume under the Beaufort Sea ice during winter, extending as much as 100 km (62 miles) offshore and 400 km (250 miles) along shore (Carmack and MacDonald 2002). Similar freshwater plumes must extend from the Yukon and Kuskokwim rivers north along the Yukon Kuskokwim Delta and into Norton Sound during winter, providing an extensive region of nearshore, brackish water habitat for overwintering whitefish.

There are two basic climate regions in our study area: the western coastal region, which includes the Bering Sea coastal area and the Yukon Kuskokwim Delta to a distance of approximately 200 km inland; and the interior region, which includes the rest of the Yukon and Kuskokwim River drainages in Alaska (Shulski and Wendler 2007). The western coastal region contains vast areas of treeless tundra, is underlain mostly by continuous permafrost, and experiences a cold maritime climate. The interior region lies within the boreal forest ecological zone (Hultén 1968), is underlain mostly by discontinuous permafrost, and experiences a continental climate (Shulski and Wendler 2007). Annual temperature extremes are similar in both regions, ranging from -40°C (-40°F) or colder in the winter to +25°C (+77°F) or warmer in the summer, although the interior region tends to have warmer average temperatures in the summer and colder average temperatures in the winter than the western coastal region. Annual precipitation averages between 25 and 50 cm (10 and 20 inches) in the western coastal region and between 20 and 40 cm (8 and 16 inches) in the interior region. Freezing temperatures prevail throughout the two climate regions from October through April and rivers and lakes are generally ice-free from late May through September.

Methods

The development of this manuscript required four different processes including: reviews of biological, ethnographic, and general public literature related to whitefish species and fisheries; convening two meetings of a diverse group of delegates with experience relevant to whitefish fisheries in the Yukon and Kuskokwim River drainages; preparation of a draft written synthesis of information that was sent out for editorial and content review; and a final product that incorporated or reconciled review comments. The Alaska Resources Library and Information Services was our primary source for literature, but we also took advantage of other online abstract search engines, Google Scholar, agency websites, newspapers, and personal contacts. We examined a wide range of literature including newspaper accounts of certain events, agency reports for whitefish occurrence, distribution, and other similar information, and formal journal articles for more technical scientific information. We expanded our horizons and included pertinent literature from Europe, Asia, and elsewhere in North America, where whitefish research has been going on for many decades. Biological literature that did not identify whitefish to species was generally not included. Similarly, preliminary documents that were later synthesized in a final version were often excluded. Misidentification of whitefish species is a common problem and if it was suspected in a particular document, we did not use that information. While not exhaustive, we attempted to make this review comprehensive of the major issues and reflect the current state of knowledge of whitefish biology, distribution, and fisheries.

We convened two meetings in the winter of 2008–2009 with a group of delegates with experience in fish biology, anthropology, and fish management, as well as representatives from fishery user groups in the Yukon and Kuskokwim rivers region (Appendices A5 and A6). Transcripts of the meetings were professionally prepared for later reference. Our main goals for the delegate meetings were to get substantive feedback on content, perspective, and approach from a wide range of people involved in some way with whitefish and whitefish fisheries in the study area. The group of delegates reviewed preliminary documents that introduced numerous issues related to whitefish taxonomy, biology, fisheries, and management. They then discussed biological and social issues related to whitefish fisheries, introduced data gaps in existing information, and considered appropriate methods and data needs for assessment, research, and management. The delegates debated criteria for assigning relative priority levels among resource issues such as fisheries, species, user-groups, research objectives, and management options. Finally, high priority issues were identified in a discussion-based forum using previously developed rating criteria. These high priority issues are presented and addressed in this manuscript.

This manuscript is primarily a review of previous biological, ethnographic, and management literature related to whitefish species, fisheries, and management. Additional information in the form of photographs and various fishery data is also included to illustrate certain points of discussion. Photographs illustrating fish species, biological phenomenon, particular types of habitats, fisheries, development activities, and other items of interest are presented to improve readers' understanding of certain situations. While fisheries data were not collected specifically for this project, some previously collected fisheries data is presented to illustrate certain qualities of whitefish populations. When used, the sources of these data were identified.

While we intend this to be a scientific document following the standards and conventions of the American Fisheries Society (2010) as closely as possible, we chose to present both metric and U.S. standard units of measure in most cases, the metric first followed by the U.S. standard in parentheses, because of the wide range of our potential readership. We wanted this document to be accessible to non-scientific readers who have an interest in the fish and fisheries discussed within, but may find a strictly metric document to be difficult.

Taxonomy

We recognize six common and one uncommon whitefish species, along with two hybrid forms, in the Yukon and Kuskokwim River drainages in Alaska. The six common species include inconnu *Stenodus leucichthys* (locally referred to as sheefish), broad whitefish *Coregonus nasus*, humpback whitefish *C. clupeaformis*, least cisco *C. sardinella*, Bering cisco *C. laurettae*, and round whitefish *Prosopium cylindraceum* (Figure 4). Pygmy whitefish *P. coulterii* have been identified in four lakes in the Yukon Territory portion of the Yukon River drainage (Lindsey and Franzin 1972; Lindsey et al. 1981) but have not been identified in the Alaska portion. Russell (1980) identified pygmy whitefish in Two Lakes, an upland lake in the Upper Stony River within the Kuskokwim River drainage, during a fisheries inventory of the waters of Lake Clark National Park and Preserve. Russell's (1980) finding represents a range extension for the species that has not yet been incorporated into the formal literature. The two hybrid forms (Figure 5) reported in our study area include one that is thought, based on general appearance and intermediate morphometric and meristic data, to be a cross between inconnu and humpback whitefish (Alt 1971a; Brown 2009), and the other between humpback whitefish and least cisco (Brown and Fleener 2001; K.C. Harper, USFWS, unpub. data). These two parental crosses were the most common hybrid forms identified in northern Canada by Reist et al. (1992) analyzing genetic and morphometric data. Hybrid forms are thought to occur accidentally when closely related whitefish species are spawning at the same time and place. A number of taxonomic issues related to inconnu, humpback whitefish, and Bering cisco have been under consideration in recent years and will be briefly discussed below.

The validity of the genus *Stenodus* has recently been called into question. Classical taxonomic affinities among species within the subfamily Coregoninae have been analyzed with cladistic morphological analyses (Smith and Todd 1992) and with several different genetics techniques including allozymes (Bodaly et al. 1991b), mtDNA (Bernatchez et al. 1991; Lockwood et al. 1993), and SINEs (Hamada et al. 1998). Most of the current genus and species designations were supported with these analyses, but the validity of the genus *Stenodus* was not. These analyses and others, as summarized by Stott and Todd (2007), indicated that inconnu were sufficiently closely related to species within the genus *Coregonus* that they should appropriately be placed within that genus. The American Fisheries Society (Nelson et al. 2004) is considering the adoption of this genus name change but will retain inconnu in the genus *Stenodus* until certain additional genetic evidence is published. It is possible that inconnu will eventually be classified as *Coregonus leucichthys*.

The taxonomic relationship between the Bering cisco and Arctic cisco *C. autumnalis* in Alaska was unclear until McPhail (1966) addressed the issue with a sampling and meristic analysis. He argued that Bering cisco and Arctic cisco in North America were both valid

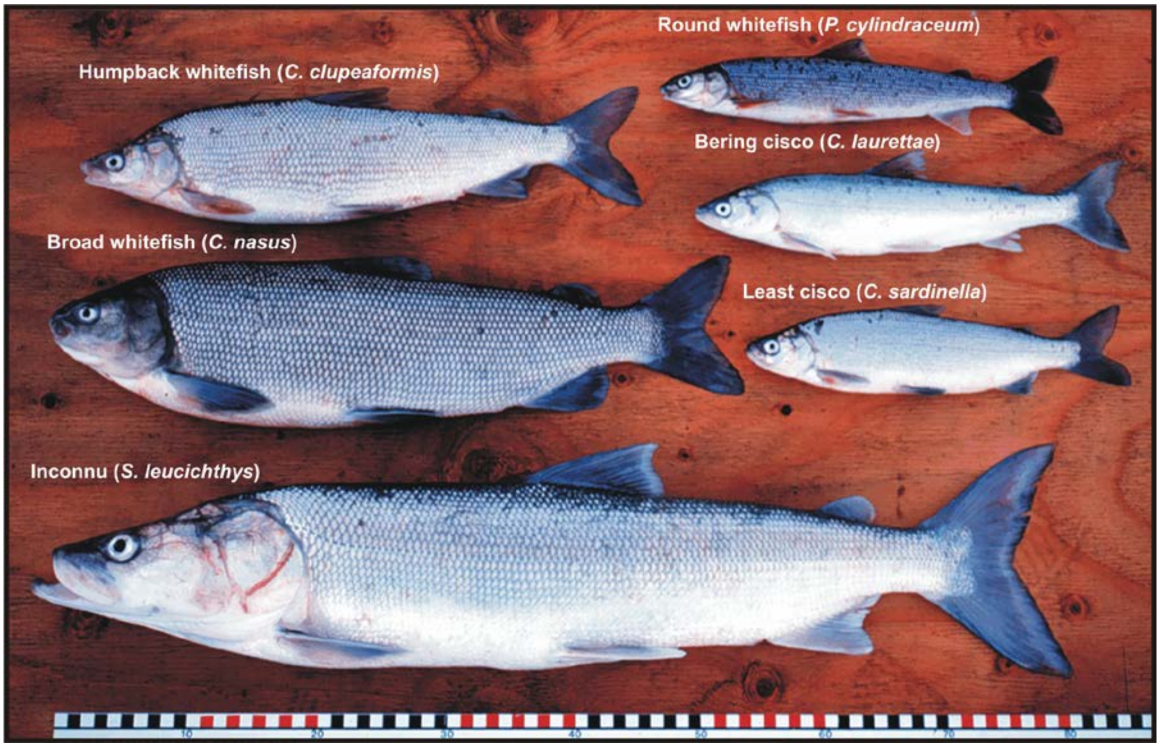

Figure 4. We recognize six common whitefish species in the Yukon and Kuskokwim River drainages in Alaska; inconnu (known locally as sheefish) *Stenodus leucichthys*, broad whitefish *Coregonus nasus*, humpback whitefish *C. clupeaformis*, least cisco *C. sardinella*, Bering cisco *C. laurettae*, and round whitefish *Prosopium cylindraceum*. Scale bar is in cm (30 cm ≅ 12 inches). Photo by R.J. Brown, USFWS.

species based on the distinct geographic distributions of the two similar forms differentiated by low (*C. laurettae*) and high (*C. autumnalis*) gill raker counts, and because of the lack of intergrading of the two forms where their ranges overlapped. Alt's (1973a) gill raker count data from his collections of western Alaska forms were consistent with McPhail (1966). In his dissertation, however, Dillinger (1989) asserted that the distribution of low and high gill raker forms were not as geographically distinct as McPhail (1966) had suggested, and argued that Bering cisco and Arctic cisco should be considered a single species. Dillinger's (1989) work was not particularly convincing and his recommendation was never embraced. Recent genetics evidence presented by Bickham et al. (1997), Turgeon and Bernatchez (2003), and Politov et al. (2004) has provided support for McPhail's (1966) assessment that both Bering cisco and Arctic cisco are valid species, that the Arctic cisco in North America is synonymous with the Arctic cisco in Asia, and that the low gill raker form present in the waters of western Alaska is the Bering cisco.

Humpback whitefishes, the '*Coregonus clupeaformis* complex' (McPhail and Lindsey 1970), include three forms; *C. clupeaformis*, *C. pidschian*, and *C. nelsonii*, the last two of which are reportedly present in our study area in Alaska (Morrow 1980a; Mecklenberg et al. 2002). Specific identification of these three forms, however, is based on population-specific differences in modal gill raker counts from the first gill arch (McPhail and Lindsey 1970). As a result, it is virtually impossible to distinguish between these forms in riverine environments where they occur together. In response to this identification hurdle, Alt

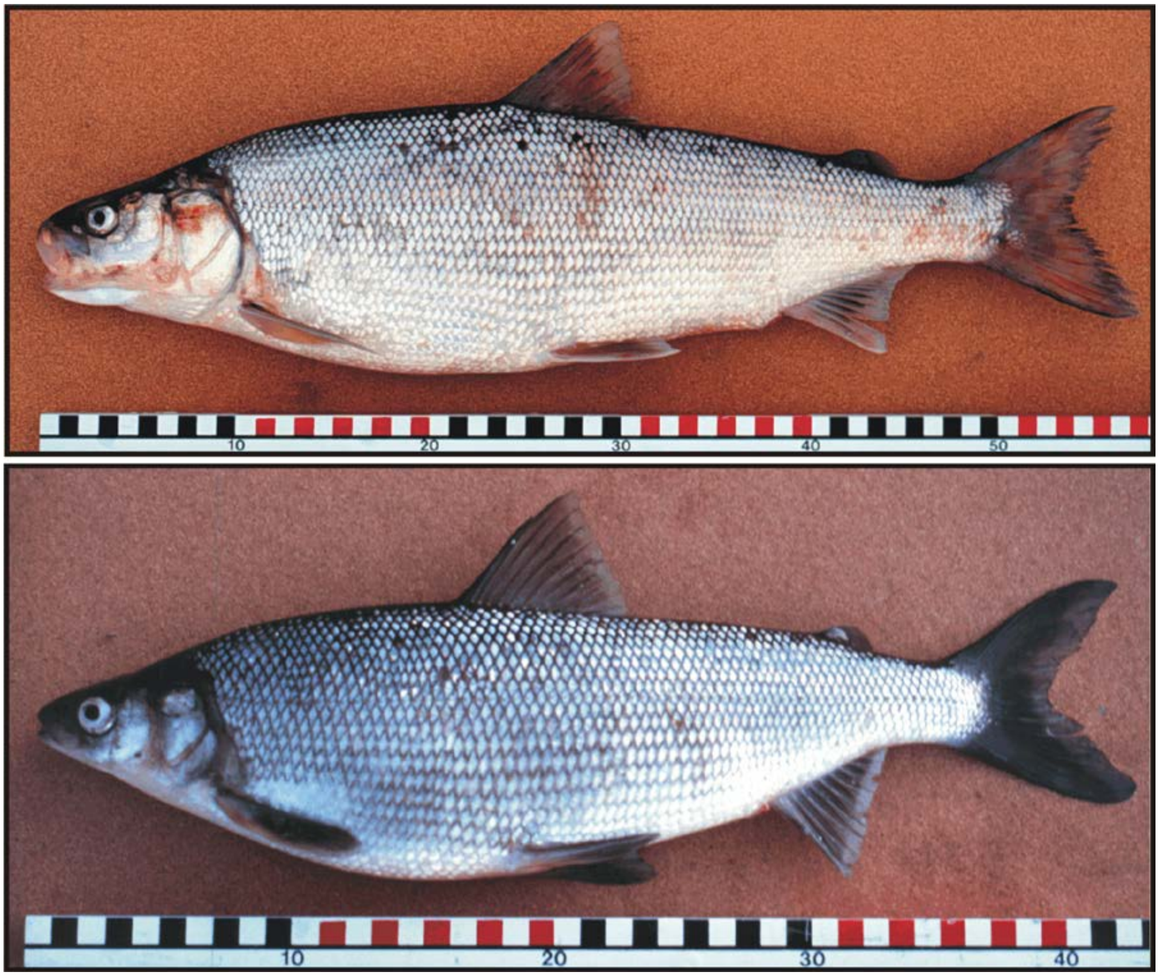

Figure 5. Hybrid whitefish forms from the Yukon River drainage in Alaska that are thought to be from accidental cross breeding of humpback whitefish and inconnu (top) and humpback whitefish and least cisco (bottom). Scale bars are in cm (30 cm ≅ 12 inches). Photos by R.J. Brown, USFWS.

(1979a) recommended that all humpback whitefish in Alaska be referred to as *C. pidschian*, which most fisheries biologists in Alaska have followed. A recent meristic, morphometric, and genetics analysis of the three humpback whitefish forms across North America recommended that the complex should be considered a single species, *C. clupeaformis*, differentiated at the subspecies level (McDermid et al. 2007). Bernatchez and Dodson (1994), however, had previously conducted mtDNA analyses with numerous humpback whitefish forms collected in Europe, Asia, and North America and concluded that all populations around the world were so similar in morphology and genetics qualities that they should be considered a single species, *C. lavaretus* by precedence, a taxonomic possibility recognized by McDermid et al. (2007). Taxonomic name changes come slowly though, and neither recommendation has been formally adopted. None-the-less, McDermid et al. (2007) make a convincing case for a single North American species of humpback whitefish. Therefore, in this manuscript we retain the common descriptive name of humpback whitefish, per McPhail and Lindsey (1970), and follow the species recommendation of McDermid et al. (2007), *C. clupeaformis*.

Biology and Life History

The six common whitefish species found within the Yukon and Kuskokwim River drainages in Alaska share a number of biological and life history qualities but are unique in many ways as well. All species are present as riverine populations that spawn in upstream, gravel-substrate reaches of rivers in fall and rear and feed in downstream reaches of rivers, open lake systems, and estuaries. Three species are known to maintain populations entirely within lake systems. The feeding ecology and preferred foods are different among species in the group, as are qualities such as age and size at maturity, fecundity, and longevity. The size at maturity, various aspects of morphology and ecology, and the timing of biological events such as spawning tend to be similar among river spawning populations of a particular species but can be quite different between river and lake populations. Many of the basic biological and life history qualities of the six common whitefish species of the Yukon and Kuskokwim River drainages in Alaska are tabulated in Table 2 and detailed in the following sections.

Table 2. Select life history qualities of the six common whitefish species in the Yukon and Kuskokwim River drainages in Alaska. Abbreviations for each life history quality are explained in the first column. The numbers within parentheses indicate the source of presented information and correspond to numbered references in Table 3.

Life history quality	Inconnu	Broad whitefish	Humpback whitefish	Least cisco	Bering cisco	Round whitefish
Spawning	Riverine form:	Riverine form:	Riverine form:	Riverine form:	EO–MO (1;20)	Riverine form:
season	MS–LS (30;57)	LO–EN (90;91)	LS–EO (7;22;24)	LS–EO (8;63)		LS–EO (34)
S=Sept	LS (3)	LO–EN (100)	LS–EO (63;91)	EO (25)		O (102)
O=Oct	LS–MO (43;44)	EN (28;29)	Lake form:	Lake form:		Lake form:
N=Nov	LS–MO (93;98)	EN (90;94)	EN (41;52)	normal form:		N (27)
D=Dec	MO–LO (20)	N–ED (85)	N–D (27;41;66)	LS–EO (71)		D (53;80)
E=early	Lake form:	Lake form:	N–D (68;86)	dwarf form:		
M=middle	MO–LO (57)	EN (51)	MO–LD (14)	MS–LS (72)		
L=late			LO–LN (10)			
Fecundity	26–265 (82)	10–96 (99)	5–20 (14)	Normal form:	20–34 (36)	1–12 (12)
(range in	40–350 (56)	14–51 (94)	5–28 (54)	8–19 (71)		2–9 (80)
thousands	42–153 (100)	18–69 (94)	8–65 (33)	10–94 (8;63)		3–11 (75)
of eggs)	45–270 (56)	21–87 (85)	9–90 (62)	12–101 (77)		3–25 (102)
	80–420 (30)		10–80 (64)	12–112 (33)		4–19 (34)
	91–180 (17)		11–44 (77)	14–78 (37)		7–17 (46)
	106–230 (6)		12–74 (100)	Dwarf form:		
	175–250 (38)		12–108 (37)	0.22–0.67 (72)		
			25–80 (14)			
			32–122 (66)			
			35–77 (99)			
			43–111 (55)			
Spawning	Riverine form:	Riverine form:	Riverine form:	Riverine forms:	F-GS (1;20)	Riverine form:
habitat	F-GS (3;20;30)	F-GS (28;51;90)	F-G (7;9;22)	F-GS (8;9;24)		F-GS (34;102)
F=flowing water	F-GS (44;57)	Lake form:	F-G (24;50)	Lake form:		Lake form:
L=lake water	F-GS (93;98)	F-G (51)	Lake form:	no data		F-GM (27)
R=rocks	Lake form:		L-GSM (10;14)			L-RGM (27;53)
G=gravel;	F-G (55;57)		L-GSM (27;52)			L-RGM (80)
S=sand;			F-GM (27)			
M=mud or silt			F-RG (41)			

Table 2 continued.

Life history quality	Inconnu	Broad whitefish	Humpback whitefish	Least cisco	Bering cisco	Round whitefish
Pearl tubercles P=present NP=not present	P (101) NP (4;25) NP (40;45)	P (35) P (49;74)	P (21;22;27) P (41;49;52) P (68;101)	NP (4;76)	NP (25)	P (27;80;102)
Minimum length at maturity (cm FL) m=male f=female	54:62 (m:f; 82) 54:66 (m:f; 30) 57:55 (m:f; 56) 58:69 (m:f; 56) 59:68 (m:f; 48) 61:71 (m:f; 20) 62:71 (m:f; 44) 68:73 (m:f; 95) 68:77 (m:f; 67)	38 (49;85) 39 (28;90) 44 (32) 45 (21)	Normal form: 31 (7;75;31) 32 (33) 33 (22;42) 33 (54;63) 35 (49;52) 40 (59) Dwarf form 13 (31) 15 (16) 22 (15)	Normal form: 21 (72) 26 (42) 27 (71) 28 (21;33) 29 (63;77) 30 (49) Dwarf form: 9 (71)	31 (1;5;24)	20:18 (m:f; 61) 21:20 (m:f; 70) 22 (81) 24 (81) 25 (46) 28 (79[1];80[1]) 29 (102)
Minimum age at maturity (years)	5 (56) 6 (40;56) 7 (20;95;100)	5 (28;100) 6 (24;32) 7 (32;99) 8 (21;78)	4 (49;75) 6 (24;100) 11 (77)	Normal form: 3 (24;26;50) 5 (21;72;78) 6 (73;100) 7 (77) Dwarf form: 3 (71;72)	4 (26)	4 (61) 8 (34;46)
Longevity (years)	24 (56) 25 (24) 27 (95) 28 (20) 31 (56) 35 (60) 37 (100) 41 (25)	16 (28) 20 (49;97) 22 (99) 23 (32) 24 (100) 27 (21;32) 29 (78) 35 (19)	17 (75) 23 (100) 24 (77) 25 (24) 26 (22) 27 (21) 29 (39;49) 34 (59) 36 (13) 57 (84)	Normal form: 14 (39;49) 15 (71) 16 (19;21) 17 (24) 23 (72) 25 (71;77) 27 (78) Dwarf form: 14 (72)	13 (26)	12 (75) 18 (73) 22 (34) 25 (83) 32 (46) 33 (25)
Spawning frequency A=some annual S=some skip	A (48;95;98) S (3)	A (94) S (21;85;94)	A (22;24;47) S (22;24;77)	A (21;47;71) S (71;74)	A (1)	A (34;61;75) S (46;61;100)
Food preferences	primarily fish with some invertebrates (2;3;42;82)	primarily benthic invertebrates: crustaceans insects mollusks (18;19;23;69) (78;85;90)	primarily benthic invertebrates: crustaceans insects mollusks (18;19;23) (74;89)	primarily zooplankton: crustaceans aquatic insects some benthic invertebrates and small fish (8;18;19;71)	primarily zooplankton: crustaceans aquatic insects some small fish (5;25;88)	primarily benthic invertebrates: crustaceans insects mollusks (11;34;46;75) (83;92;102)

[1]Converted from total length to FL using equation in Haymes and Kolenoski (1984).

Table 3. Citation list for biological data presented in Table 2.

Reference no.		Reference no.		Reference no.	
1	ADFG (1983)	35	Daum, D. (USFWS, pers. com.)	69	Lugas'kov and Stepanov (1989)
2	Alt (1965)	36	Dillinger (1989)	70	Mackay and Power (1968)
3	Alt (1969a)	37	Dupuis (2010)	71	Mann (1974)
4	Alt (1971a)	38	Dyubin (2007)	72	Mann and McCart (1981)
5	Alt (1973a)	39	Edenfield (2009)	73	McCart et al. (1972)
6	Alt (1978a)	40	Esse (2011)	74	McPhail and Lindsey (1970)
7	Alt (1979a)	41	Fenderson (1964)	75	Morin et al. (1982)
8	Alt (1980a)	42	Fleming (1996)	76	Morrow (1980a)
9	Alt (1983)	43	Fuller (1955)	77	Moulton et al. (1997)
10	Anras et al. (1999)	44	Gerken (2009)	78	Moulton et al. (2007)
11	Armstrong et al. (1977)	45	Gerken, J. (USFWS, pers. com.)	79	Mraz (1964)
12	Bailey (1963)	46	Gudkov (1999)	80	Normandeau (1969)
13	Barnes and Power (1984)	47	Hallberg (1989)	81	Peck (1964)
14	Bidgood (1974)	48	Hander et al. (2008)	82	Petrova (1976)
15	Bodaly (1979)	49	Harper et al. (2007)	83	Plumb (2006)
16	Bodaly et al. (1991a)	50	Harper et al. (2009)	84	Power (1978)
17	Bolotova and Bolotov (2002)	51	Harris and Howland (2005)	85	Prasolov (1989)
18	Bond (1982)	52	Hart (1930)	86	Price (1940)
19	Bond and Erickson (1985)	53	Haymes and Kolenosky (1984)	87	Reshetnikov et al. (1975)
20	Brown (2000)	54	Healey (1984)	88	Runfola (2011)
21	Brown (2004)	55	Howland (1997)	89	Scott and Crossman (1973)
22	Brown (2006)	56	Howland (2005)	90	Shestakov (2001)
23	Brown (2007a)	57	Howland et al. (2000)	91	Stein et al. (1973)
24	Brown (2009)	58	Howland et al. (2001a)	92	Stewart (2007)
25	Brown, R.J. (USFWS, unpub. data)	59	Howland et al. (2001b)	93	Stuby (2010)
26	Brown et al. (2012)	60	Howland et al. 2004	94	Tallman et al. (2002)
27	Bryan and Kato (1975)	61	Jessop and Power (1973)	95	Taube and Wuttig (1998)
28	Carter (2010)	62	Kennedy (1953)	96	Townsend and Kepler (1974)
29	Chang-Kue and Jessop (1997)	63	Kepler (1973)	97	Treble and Reist (1997)
30	Chereshnev et al. (2000)	64	Kratzer et al. (2007)	98	Underwood (2000)
31	Chouinard et al. (1996)	65	Lawler (1961)	99	VanGerwen-Toyne (2001)
32	Chudobiak (1995)	66	Lawler (1965)	100	VanGerwen-Toyne et al. (2008)
33	Clark and Bernard (1992)	67	Letichevskiy (1981)	101	Vladykov (1970)
34	Craig and Wells (1975)	68	Lindsey (1963b)	102	Zyus'ko et al. (1993)

Spawning season

Spawning seasons for whitefish species have been identified by simultaneously capturing ripe and spent individuals at known spawning locations (Bidgood 1974; Mann 1974; Anras et al. 1999), observing eggs in the water or substrate at spawning sites (Bryan and Kato 1975; Zyus’ko et al. 1993; Gerken 2009), identifying whitefish eggs consumed by other fish captured at spawning sites (Normandeau 1969; Kepler 1973; Brown 2006), capturing spent fish downstream from spawning reaches (Stein et al. 1973; Howland et al. 2000; VanGerwen-Toyne et al. 2008), and identifying post-spawning downstream migrations of radio-tagged fish (Chang-Kue and Jessop 1997; Howland et al. 2000; Brown 2006).

Spawning seasons vary somewhat among populations within species, most dramatically between riverine and lake populations for species that sustain populations in both environments. Inconnu spawning seasons commonly occur between late September and mid-October (Alt 1969a; Underwood 2000). Inconnu in the Anadyr River in eastern Russia and the Arctic Red River in northern Canada apparently spawn somewhat earlier, in mid to late September (Chereshnev et al. 2000; Howland et al. 2000), and those in the main-stem Yukon River spawn somewhat later, in mid to late October (Brown 2000). We are aware of lake populations of inconnu in the Great Slave Lake system of the upper Mackenzie River in northern Canada (Fuller 1955; Howland et al. 2000) and in the Caspian Sea in western Russia (Letichevskiy 1981; Dyubin 2007). In both of these lake systems inconnu make spawning migrations up rivers flowing into the lakes and are not known to spawn in the lakes themselves. In the Great Slave Lake system, spawning occurs in the Slave River during mid to late October (Howland et al. 2000). Caspian Sea inconnu made spawning migrations up the Volga River prior to the construction of a large hydroelectric dam in the lower drainage, which blocked their spawning migration and the impoundment behind the dam inundated their spawning habitat (Letichevskiy 1981; Dyubin 2007). That population has been propagated artificially for several decades so the spawning season is no longer a natural process. Broad whitefish spawning season has usually been identified in early November (Chang-Kue and Jessop 1997; Shestakov 2001; Carter 2010). However, both Stein et al. (1973), in the Arctic Red River, and VanGerwen-Toyne et al. (2008), in the Peel River, Mackenzie River drainage in northern Canada, captured spent broad whitefish in late October indicating they began spawning earlier. Prasolov (1989) reported that broad whitefish in the lower Ob River drainage in northern Russia spawned somewhat later, beginning in November and continuing into early December. The only example of a lake resident broad whitefish that we are aware of is in the Travaillant Lake system in the lower Mackenzie River drainage in northern Canada (Chudobiak 1995; Harris and Taylor 2010b). This population apparently remains within the lake system without migrating out to the Mackenzie River. Harris and Howland (2005), using radio telemetry techniques, found that Travaillant Lake broad whitefish spawn in rivers flowing into and between lakes during early November similar to riverine populations. Riverine populations of humpback whitefish are most commonly reported to spawn in late September and early October (Stein et al. 1973; Alt 1983; Brown 2006) and in some cases as late as mid-October (Harper et al. 2009), while lake resident populations spawn considerably later and over a longer time period. For example, Bidgood (1974) reported that spawning occurred in Pigeon and Buck lakes, eastern Canada, from mid-October through December. Many others have similarly identified spawning seasons for lake resident populations of humpback whitefish extending from early November through mid-December or later (Hart 1930; Bryan and Kato 1975; Anras et al 1999). Riverine populations of least cisco appear to spawn between late September and early October (Kepler 1973; Alt 1980a). Lake resident populations of least cisco occur as normal-size fish, which are similar in size, age, and spawning season to riverine populations, and dwarf fish, which mature younger and at a much smaller size than normal least cisco (Mann 1974; Mann and McCart 1981). Dwarf populations appear to spawn from mid to late September, slightly earlier than normal least cisco. There are three known populations of Bering cisco, all riverine and all in Alaska (Alt 1973a; ADFG 1983; Brown et al. 2007). Spawning seasons of Bering cisco in the Susitna and Yukon rivers appear to extend from early to mid-October (ADFG 1983; Brown 2000). A late September sampling expedition into the Bering cisco spawning area in the Kuskokwim River in 2010 suggested a similar spawning season for that population also (M. Thalhauser, Kuskokwim Native Association, pers. com.). Riverine populations of round whitefish reportedly spawn between late September and early October (Craig and Wells 1975) or between early and late October (Zyus'ko et al. 1993). Lake resident populations spawn during November (Bryan and Kato 1975) or December (Normandeau 1969; Haymes and Kolenosky 1984). Spring spawning populations of various cisco species have been documented in Lake Superior (Todd and Smith 1980), Lac des Écorces in southern Quebec (Hénault and Fortin 1991), and in a few Scandinavian and European lakes (Svardson 1988; Schulz and Freyhof 2003), however, spring spawning has never been documented for any whitefish species or population in Alaska.

Fecundity and egg biology

Whitefish species produce large numbers of eggs and provide no parental care for the eggs or larvae, which experience high levels of mortality. Fecundity, the number of eggs per female fish, ranges widely among individuals within populations but is strongly correlated with size for all whitefish species (Healey and Nicol 1975; Clark and Bernard 1992; Tallman et al. 2002; Howland 2005). Inconnu fecundity may range from low values of 26,000 to 100,000 eggs for small females in a population to high values of 200,000 to 400,000 eggs for large females (Petrova 1976; Chereshnev et al. 2000; Howland 2005; VanGerwen-Toyne et al. 2008). Broad whitefish fecundity ranges from low values of 10,000 to 25,000 eggs for small females to high values of 50,000 to 96,000 eggs for large females (Prasolov 1989; VanGerwen-Toyne 2001; Tallman et al. 2002). Small humpback whitefish may have as few as 5,000 to 10,000 eggs while large humpback whitefish may produce as many as 40,000 to 100,000 eggs or more (Healey 1984; Clark and Bernard 1992; Moulton et al. 1997; Dupuis and Sutton 2012). Small least cisco produce as few as 8,000 to 12,000 eggs while large least cisco produce as many as 100,000 eggs or more (Mann 1974; Clark and Bernard 1992; Moulton et al. 1997; Dupuis 2010). Mann and McCart (1981) reported the fecundity of females from a dwarf population of least cisco in northwest Canada to be extraordinarily low, ranging from 223 to 672 eggs per female. Dillinger (1989) counted the eggs of seven Bering cisco collected in the Yukon River and reported fecundity ranging from 20,210 to 34,166 eggs. To our knowledge these are the only fecundity data for this species. Round whitefish fecundity ranges from low values of 1,000 to 7,000 eggs for small females within populations to high values of 9,000 to 25,000 eggs for large females (Bailey 1963; Normandeau 1969; Zyus'ko et al. 1993). Population specific fecundity data for the six whitefish species we are concerned with (Table 2) suggest that each population experiences unique environmental conditions that lead to population-specific growth and reproductive qualities that may be similar or very different (Mann and McCart 1981; Healey 1984; Tallman et al. 2002).

Eggs of most whitefish species are reported to be from 2.3 to 3.0 mm (~0.1 inch) in diameter at spawning time (Hart 1930; Price 1940; Normandeau 1969; Alt 1969a; Bidgood 1974; Craig and Wells 1975; Howland 2005). Least cisco eggs are apparently somewhat smaller, ranging from 1.5 to 1.7 mm in diameter (Mann 1974; Alt 1980a). Eggs are broadcast over substrate composed predominantly of gravel, sand, or rock in both lake (Hart 1930; Normandeau 1969; Anras et al. 1999) and river (Alt 1969a; Zyus'ko et al. 1993; Brown 2006; Gerken 2009) environments. Whitefish eggs are negatively buoyant and non-adhesive

(Price 1940; Teletchea 2009). They sink to the substrate and become entrained in cracks and crevices (Hart 1930; Normandeau 1969; Bryan and Kato 1975) where they remain during development. Direct exposure to moving water, whether flowing or upwelling, is required for egg respiration (Fudge and Bodaly 1984). Other fish species are known to gather in whitefish spawning areas and eat eggs (Hart 1930; Alt 1969a; Normandeau 1969; Brown 2006). It has been suggested that eggs deposited over silt or sand are more vulnerable to predation than those hidden in the cracks and crevices of gravel and other rocky substrate (Hart 1930; Alt 1969a; Bidgood 1974; Letichevskiy 1981). Hydrologic qualities of spawning reaches, such as flow, upwelling, and dissolved oxygen concentration, are known to influence egg development and survival as well (Brooke and Colby 1980; Fudge and Bodaly 1984; Nasje et al. 1995).

The incubation time for fertilized eggs of whitefish species is inversely correlated with temperature (Price 1940; Colby and Brooke 1973; Brooke 1975). The eggs of most species require somewhere between 330 to 450 degree days to complete development (Eckmann 1987; Næsje and Johsson 1988; Howland 2005; Teletchea 2009; Cingi et al. 2010), which in northern, riverine spawning environments requires approximately 150 to 200 days. Shortly after spawning, eggs experience water temperatures slightly greater than 0°C. In most riverine environments in Alaska, these water temperatures are thought to persist from early October until mid-April or so. The rate of egg development is very slow during the cold period and increases rapidly as water temperature rises in the spring (Colby and Brooke 1973; Bidgood 1974; Luczynski and Kirklewska 1984). Hatching and larval emergence into the water column occurs during or shortly after ice breakup in late April or May and this timing provides a mechanism for downstream dispersal of larvae (Shestakov 1991; Bogdanov et al. 1992; Næsje et al. 1986, 1995). Whitefish larvae hatch with a small amount of residual yolk, as illustrated by Hart (1930) and Sturm (1994), which delays the requirement for exogenous feeding for a few days (Hart 1930; Bidgood 1974; Næsje and Jonsson 1988) and allows dispersal to optimal feeding habitats downstream. Juvenile whitefish are abundant in river deltas, estuaries, and nearby coastal environments of rivers that support whitefish populations (Shestakov 1992; Bond and Erickson 1985; Martin et al. 1987), indicating that spring dispersal of whitefish larvae down large rivers is a common life history strategy.

Spawning areas

Until recently, few whitefish spawning areas had been identified in the Yukon and Kuskokwim River drainages in Alaska. Those that were identified were almost always in clear streams of moderate to small size. The Chatanika River spawning reach in the Tanana River drainage was identified early on because the river is small and clear, it is in a location that experienced a tremendous human presence during the placer gold mining days of the early 1900s (Webb 1985; Spence 1996), and when the Elliott Highway was constructed in the 1950s it crossed the Chatanika River in the midst of the whitefish spawning reach. Numerous fisheries investigations have shown that inconnu, humpback whitefish, least cisco, and round whitefish all spawn in the Chatanika River (Alt 1971a; Kepler 1973; Riffe 1992). Residents in the upper Koyukuk River drainage near the mouth of the Alatna River traditionally fished for inconnu and other whitefish species that migrated to the area each fall (Marcotte and Haynes 1985; Andersen et al. 2004). Their harvests of inconnu led Alt (1968,

1970) to the region where he sampled, tagged fish, flew aerial surveys, and eventually identified the upper Koyukuk and Alatna rivers as spawning destinations for inconnu. Andersen (2007) subsequently evaluated traditional accounts of fishing in the upper Koyukuk River drainage and Brown (2009) conducted biological assessments on other whitefish species and together they established the Alatna River as a major spawning destination for broad whitefish, humpback whitefish, least cisco, and round whitefish as well. Alt (1983) discovered a spawning reach used by humpback whitefish and least cisco in a clear water section of the upper Innoko River during a multi-year survey effort of that drainage. Multiple years of sampling in the Nowitna River drainage let to the discovery that pre-spawning inconnu were migrating into the Sulukna River, an upper drainage tributary (Alt 1985). The actual spawning reach was later identified with radio telemetry methods (Brown, R.J., USFWS, unpub. data) and some of its habitat qualities were subsequently described by Gerken (2009). Alt (1972) found spawning inconnu at the mouth of Highpower Creek in the upper Kuskokwim River after two years of sampling and aerial surveys in the drainage. Almost 10 years later he located a second Kuskokwim River inconnu population spawning in the Big River (Alt 1981a), which is a turbid glacial river. Most spawning reaches in large or turbid rivers can not be located by sampling or visual surveys and they remained undiscovered until radio telemetry methods were sufficiently refined for whitefish applications.

Successful application of radio telemetry technology to identify whitefish spawning migrations and destinations began in the early 1980s. Chang-Kue and Jessop (1983) deployed radio tags on pre-spawning broad whitefish in the lower Mackenzie River and successfully tracked them to their spawning destinations approximately 630 rkm (392 miles) from the Beaufort Sea. Underwood (2000) described the upstream and downstream bounds of the inconnu spawning reach in the Selawik River in northwest Alaska by tagging pre-spawning fish during summer in downstream reaches of the river and following them by airplane and boat to their farthest upstream destinations in the late fall. Similarly, Brown (2000) used a gonadosomatic index to establish that inconnu captured approximately 1,176 rkm (731 miles) up the Yukon River in August and September were all mature fish preparing to spawn and then deployed radio transmitters on over 70 inconnu to locate the spawning reach of the main-stem population. Harper et al. (2007) tagged broad whitefish, humpback whitefish, and least cisco in Whitefish Lake in the lower Kuskokwim River during early to mid summer and located several spawning areas by tracking radio-tagged fish to gravel substrate reaches upstream. By tagging fish in feeding habitats, Harper et al. (2007) could not determine whether tagged fish would spawn that fall or not. Therefore, spawning reaches were suspected when radio-tagged fish migrated upstream in late summer, arrived at swiftly flowing, gravel substrate reaches by late September or early October, remained in the reach for two or three weeks, and then migrated back downstream. Subsequent sampling projects in the suspected spawning reaches were required to verify the presence of spawning whitefish. Many other whitefish spawning reaches have been similarly identified in the Yukon and Kuskokwim River drainages in Alaska and these will be discussed later. Knowledge of these spawning areas allows us to consider whitefish as populations rather than just individuals, and permits the collection of population specific information such as abundance, age and size at maturity, genetic qualities, migration timing, spawning frequency, mortality rate, and other descriptive parameters.

Maturity and spawning readiness

Whitefish species are known to be iteroparous; capable of spawning more than once (McPhail and Lindsey 1970; Morrow 1980a; Reist and Bond 1988). Mature and immature individuals from most whitefish species and populations coexist in freshwater environments, and for anadromous populations, in coastal environments (Bond and Erickson 1985; Lambert and Dodson 1990; Moulton et al. 1997). In addition, not all mature individuals spawn every year (Alt 1969a; Mann and McCart 1981; Brown 2004). By contrast, Pacific salmon species are semelparous; spawning only once and then dying (Groot and Margolis 1991). In addition to being semelparous, most populations of Pacific salmon are fully anadromous, with all individuals in a population going to sea prior to reproduction. It is, therefore, very easy to identify Pacific salmon as mature when they return to fresh water from the sea. Identifying mature from immature individuals within whitefish populations, however, requires directed biological sampling, which is most effective during the few months before and during spawning season.

Mature whitefish have most commonly been identified by measuring egg diameter or weighing egg skeins of females as they approach spawning season. Other methods involve observing residual or atretic eggs within females (Figure 6; Alt 1969a; Normandeau 1969; Mann 1974; Lambert and Dodson 1990), verifying that they had spawned previously, observing pearl tubercles (Vladykov 1970), small bumps on the heads and lateral scales that only occur on spawning fish of some species (Figure 6), and the observation of milt or eggs expressed from fish during handling, verifying readiness for spawning (Mann 1974; Fleming 1996; Brown 2006). Lambert and Dodson (1990) described the difference in seasonal energy content of the gonads and other tissue among spawning and non-spawning lake whitefish and cisco *Coregonus artedii* in a Hudson Bay drainage in eastern Canada. They found that the energy content of the egg tissue in spawning individuals of both species began to increase in early to mid-summer and became recognizably greater than non-spawning individuals by July or August. The energy content in egg tissue of spawning individuals continued to increase through the fall attaining maximum levels 20 to 50 times greater than non-spawning individuals at spawning time. The energy content in the eggs of non-spawning individuals remained at low levels throughout the year. A similar seasonal pattern of energy accumulation was observed for spawning males of both species, although the magnitude of the difference between non-spawning and spawning males was relatively small, a factor of 5 to 10, which is why male gonad weight is rarely used in field studies to determine maturity.

Gonadosomatic indices (GSI) are commonly used to distinguish between mature females preparing to spawn and immature or non-spawning mature females (Bond and Erickson 1985; Moulton et al. 1997; Brown 2004). The GSI is usually calculated as egg percentage of whole body weight: $GSI = (\text{gonad weight} \cdot \text{whole body weight}^{-1}) \cdot 100$. In the spring and early summer, all females that are mature or approaching maturity have small egg masses, usually less than 3% of whole body weight (Bond 1982; Brown 2009). The egg masses of mature females preparing to spawn increase dramatically over the course of the summer to maximum levels up to 20 to 35% of whole body weight (Figure 7; Brown et al. 2007).

Figure 6. Residual or atretic eggs in a gravid female Bering cisco are hard, yellow, and opaque compared to developing eggs that are soft, orange, and translucent (top image). The presence of residual eggs confirms a previous spawning event and verifies maturity. Pearl tubercles on a humpback whitefish preparing to spawn appear as white bumps on the head and lateral scale rows (bottom image). Pearl tubercles verify spawning intent and maturity but are present for only a few weeks prior to spawning for certain species. Photos by R.J. Brown, USFWS.

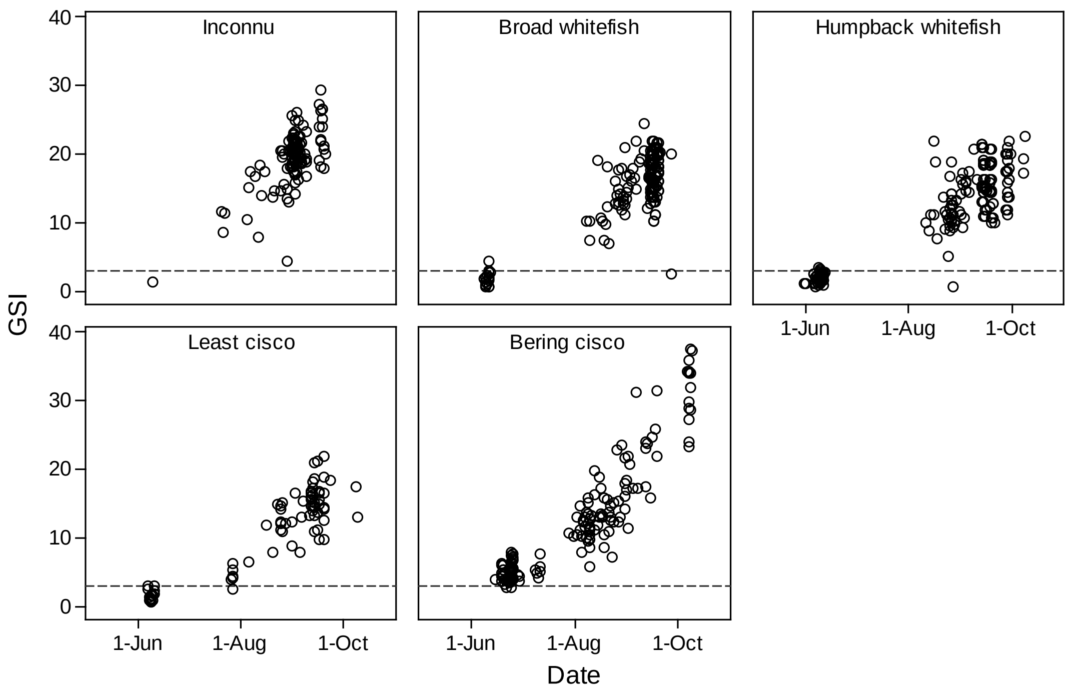

Figure 7. Gonadosomatic indices (GSI) for female whitefish sampled throughout the summer in the upper Yukon River 1,176 rkm (731 miles) or more from the Bering Sea. Female fish with GSI values greater than 3 (horizontal dashed lines) in the late summer and fall are mature and preparing to spawn. Note that nearly all female whitefish encountered in the river during late summer and fall had elevated GSI values indicating preparation for spawning.

Consistent with Lambert and Dodson (1990), the egg masses of non-spawning females remain small through the summer and fall (Figure 8; Brown 2004). When late summer or fall GSI data are plotted against associated age and length data they provide strong evidence for minimum age and length at maturity (Figure 9).

Egg diameter has occasionally been used to identify female whitefish preparing to spawn or that have previously spawned (Alt 1969a; Normandeau 1969; Mann 1974; Lambert and Dodson 1990). It is generally thought that when meiosis occurs all eggs that will be spawned at the next event are created. The observed seasonal increase in egg mass, as identified in GSI data (Howland 1997; Brown 2000; VanGerwen-Toyne et al. 2008) and energy (Lambert and Dodson 1990), is the result of vitellogenesis, the deposition of nutrients into each existing egg in the form of yolk, and not the production of additional eggs (Yaron and Sivan 2006). Alt (1969a), for example, reported that egg diameter of most female inconnu he examined in June in northwest Alaska ranged between 1.2 and 1.5 mm, and a smaller fraction had egg diameter of less than 1.0 mm. In late September, egg diameter of spawning females averaged 2.5 mm. Craig and Wells (1975) conducted similar work with round whitefish and measured egg diameter in May at 0.9 to 1.2 mm, in August at an average of 2.0 mm, and in September at 2.2 to 2.9 mm. Mann (1974) worked with least cisco and measured egg diameter in July that ranged from 0.7 to 0.8 mm, in August at about 1.0 mm, and in late September at about 1.5 mm. These data provide an alternative means to GSI of identifying

Figure 8. Egg skeins of female inconnu preparing to spawn (image on right) become very enlarged in the late summer and fall, often making up more than 25% of the total body weight of the fish. Egg skeins are also present in female inconnu that are not preparing to spawn (image on left) but usually remain less than 3% of total body weight. Photo on right by R.J. Brown, USFWS. Photo on left by A. Behr, ADFG.

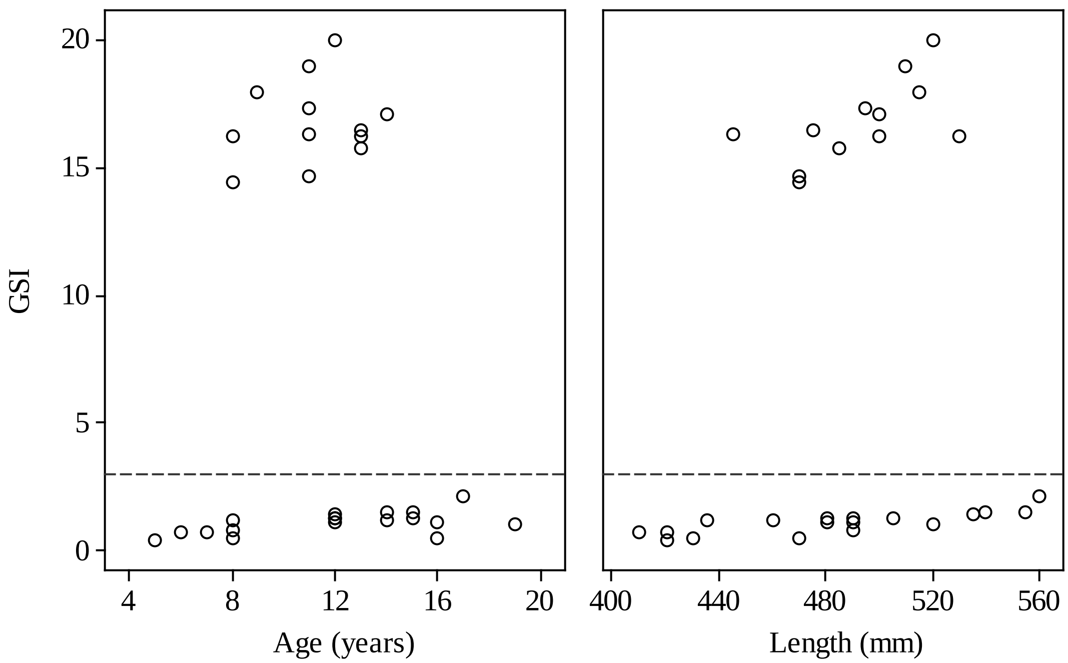

Figure 9. Gonadosomatic index values from broad whitefish harvested in the Selawik River delta in September plotted against age and length (from Brown 2004). The sample included a mix of demographic groups including immature, non-spawning mature, and mature fish preparing to spawn. Values below GSI = 3 (dashed line) come from non-spawning fish. Non-spawning fish age 8 or less and 450 mm or shorter are probably immature while those age 10 or older 480 mm or longer are probably non-spawning mature fish.

females preparing to spawn, although measuring egg diameters would probably not be as sensitive as a GSI to small changes. Alt (1969a) examined two female inconnu in late September that had apparently finished spawning, and found 70 and 200 eggs, respectively, that had not been expelled, along with two new skeins of minute eggs created for the next spawning event. Residual eggs become hard and opaque and can be readily distinguished from newly developing egg skeins in the body cavity, providing evidence of maturity during non-spawning seasons of the year (Figure 6). Yaron and Sivan (2006) contend that residual eggs are eventually degraded enzymatically in a process known as atresia. The time required for atresia in whitefish species is not known, but Lambert and Dodson (1990) observed residual eggs in female lake whitefish in the spring, approximately six months after spawning, and the residual eggs observed in the prespawning Bering cisco featured in figure 6 had persisted at least a full year, indicating that atresia is a lengthy process.

Pearl tubercles are small, rough bumps that form on the heads and lateral sides of some whitefish species during spawning season (Figure 6; Vladykov 1970). They are much more pronounced and widespread on males than females. Vladykov (1970) contends that they facilitate essential contact between individuals during spawning. Only mature fish preparing to spawn display pearl tubercles, so they are a definite indicator of maturity. Of the six species we are concerned with, pearl tubercles are known with certainty to occur on broad whitefish (Harper et al. 2007; Daum, D.W., USFWS, pers. comm.), humpback whitefish (Hart 1930; Fenderson 1964; Brown 2006), and round whitefish (Bryan and Kato 1975; Normandeau 1969; Zyus'ko et al. 1993). Pearl tubercles are reportedly present on spawning inconnu in Russia (Valdykov 1970), but Alt (1971a) stated that inconnu do not have pearl tubercles. Neither Alt (1969a) nor Brown (2000), both of whom handled spawning inconnu in Alaska, made any mention of them. More recently, Gerken (2009) and Esse (2011) handled numerous inconnu during and after spawning season on the Sulukna River spawning reach, Yukon River drainage, and failed to notice pearl tubercles. Scott and Crossman (1973) indicated that they do not occur for inconnu. We also found no mention of pearl tubercles on spawning least cisco (Mann 1974; Alt 1980a; Mann and McCart 1981), and Alt (1971a) and Morrow (1980a) both stated that least cisco do not develop pearl tubercles during spawning. Brown (USFWS, unpub. data) examined ripe inconnu in the Yukon River drainage and ripe Bering cisco in the Yukon and Susitna River drainages in Alaska and noticed subtle ridges along several lateral scale rows in both species that were not noticed during other seasons. These ridges may be analogous to the more distinct pearl tubercles of some other species. It appears that pearl tubercles are useful, non-lethal indicators of maturity and spawning readiness for broad whitefish, humpback whitefish, and round whitefish but not for inconnu, least cisco, or Bering cisco.

Minimum length at maturity

The length at maturity for a population of fish can be a useful tool for evaluating the demographic qualities of an unknown sample. Length data are easy to obtain and do not require lethal sampling. Fork length (FL), measured from the most anterior point on the snout or jaw of the fish to the fork of the tail, is the conventional measure for whitefish species, although some have used standard (Dyubin 2007) or total length (Fenderson 1964; Normandeau 1969; Doyon et al. 1998), which require empirical conversion equations to compare with FL data. Characterizing the length at maturity for a population requires a relatively large sample of fish known to be mature. Brown (2006), for example, sampled over 200 spawning humpback whitefish in the upper Tanana River drainage to establish the length distribution of that spawning population. He established that they were all mature through non-lethal means by identifying the presence of pearl tubercles on all individuals and noting that all males were expressing milt when handled. He compared the length distribution of known mature fish with a larger sample of unknown maturity individuals from the region to show that immature individuals were rare in the upper Tanana River drainage. In another case, Mann and McCart (1981) identified sympatric populations of normal and dwarf least cisco in Trout Lake, northwestern Canada, in part by characterizing the length distributions of mature individual from both populations. They identified mature individuals by examining the egg skeins of females and measuring the egg diameters. Using this method, mature fish could be distinguished from immature fish by late summer or fall. Once they could identify individuals from the two populations, based on the non-intersecting length distributions of mature fish, they were able to establish differences in age at maturity, longevity, fecundity, and other population qualities. Morphometric and meristic qualities of the normal and dwarf least cisco in Trout Lake were similar enough that non-spawning individuals smaller than the largest dwarf least cisco could not be identified as members of either population.

The minimum length at maturity among whitefish populations varies to some extent, particularly between dwarf and normal populations (Mann and McCart 1981; Bodaly et al. 1991a) and sometimes between lake and riverine populations (Jessop and Power 1973; Zyus'ko et al. 1993). Of the six whitefish species we are concerned with, inconnu exhibit the greatest degree of sexual dimorphism for length with the smallest mature females being as much as 10 cm (4 inches) longer than the smallest mature males. Bering cisco (Alt 1973a; Brown, R.J., USFWS, unpub. data) and round whitefish (Mackay and Power 1968; Jessop and Power 1973; Zyus'ko et al. 1993) exhibit more subtle sexual dimorphism for length. No sexual dimorphism for length has been reported for broad whitefish, humpback whitefish, or least cisco. Minimum lengths at maturity for male and female inconnu were, respectively, 54 and 66 cm (21 and 26 inches) in the Anadyr River, eastern Russia (Chereshnev et al. 2000), 58 and 69 cm (23 and 27 inches) in the Arctic Red River, Mackenzie River drainage (Howland 2005), and 61 and 71 cm (24 and 28 inches) in the Selawik River, northwest Alaska (Hander et al. 2008). Minimum length at maturity for broad whitefish has reportedly been as small as 38 or 39 cm (~15 inches) in various Alaskan (Harper et al 2007; Carter 2010) and Russian (Prasolov 1989; Shestakov 2001) populations, and as large as 44 or 45 cm (~18 inches) in populations of northwest Alaska (Brown 2004) and Canada (Tallman et al. 2002). Minimum reported length at maturity for humpback whitefish populations has ranged from 31 cm (12 inches) in northern Alaska (Moulton et al. 1997), 33 cm (13 inches) in interior Alaska (Brown 2006), 35 cm (14 inches) in the Kuskokwim River (Harper et al. 2007), and 40 cm (16 inches) in the Mackenzie River in northwest Canada (Howland et al. 2001b). Minimum length at maturity of dwarf populations of humpback whitefish has been reported as small as 13 cm (5 inches) in Lac de l'Est, Quebec (Chouinard et al. 1996), 15 cm (6 inches) in Como Lake, Ontario (Bodaly et al. 1991a), and 22 cm (9 inches) in Little Teslin Lake in the Yukon River drainage in Yukon Territory (Bodaly 1979). Minimum length at maturity for least cisco has been reported as small as 21 cm (8 inches) in Trout Lake in northern Canada (Mann and McCart 1981), 28 cm (11 inches) in northwest (Brown 2004) and interior (Clark and Bernard 1992) Alaska, 29 cm (11 inches) in northern Alaska (Moulton et al. 1997), and 30 cm (12 inches) in the Kuskokwim River drainage in Alaska (Harper et al. 2007). Mann and McCart (1981) reported the minimum length of maturity of a dwarf population in Trout Lake, northwest Canada, as only 9 cm (3.5 inches). Minimum length of maturity for Bering cisco has been measured at 31 cm (12 inches; Brown, et al.

2012) and 32 cm (13 inches; Alt 1973a) from the Yukon River spawning population, and at 31 cm (12 inches) from the Susitna River population (ADFG 1983). Alt (1973a) reported that a small sample (*n* = 10) of Bering cisco from the Kuskokwim River spawning population ranged from 32 to 41 cm FL (13 to 16 inches), suggesting a similar minimum length of maturity. Minimum length of maturity for round whitefish have been reported as small as 18 to 20 cm (7 to 8 inches) in Quebec (Mackay and Power 1968; Jessop and Power 1973), 25 cm (10 inches) in eastern Russia (Gudkov 1999), 28 cm (11 inches) in Lake Michigan (Mraz 1964) and Newfound Lake in New Hampshire (Normandeau 1969), and 29 cm (11 inches) in the Lena River drainage in Arctic Russia (Zyus'ko et al. 1993). Mraz (1964) and Normandeau (1969) used total length so their measurements were converted to FL with an empirical conversion equation developed by Haymes and Kolenosky (1984). Minimum length at maturity for a whitefish population would be expected to vary slightly over time because of natural variation of environmental conditions and other factors affecting growth and maturity. Large sample sizes of mature fish would be more likely to produce the smallest estimates.

Aging, minimum age at maturity, and longevity

For many years scales were erroneously thought to provide accurate age estimates for whitefish species through life. This perception was supported in part because Van Oosten (1923) and Hogman (1968) validated annual growth increments in scales of relatively young reared whitefish of known ages, which led to many decades of scale aging for whitefish species around the world. Otolith preparation and aging techniques, however, have improved significantly during the last 50 years or so (Chilton and Beamish 1982; Stevenson and Campana 1992) and age validation studies with many fish species using fluorescent markers (Beamish and Chilton 1982; DeCicco and Brown 2006), atomic bomb radiocarbon signatures (Kalish 1995; Campana 1997), ratios of radioactive decay products (Campana et al. 1990; Andrews et al. 2002; 2009), and other methods have repeatedly shown that major increments visible on sectioned otoliths of fishes in the class Osteichthyes, the bony fishes, reflect annual time periods. Experiments comparing whitefish age data derived from scales and otoliths have demonstrated that scales consistently produce younger estimates of longevity within populations, sometimes by 10 to 20 years or more, and age distributions that are shifted to the younger age classes compared to those derived from otoliths (Power 1978; Mills and Beamish 1980; Morin et al. 1982; Bond and Erickson 1985; Barnes and Power 1984; Howland et al. 2004). Jessop (1972) suggested that the observed differences in scale and otolith derived age estimates for round whitefish were small and only an issue for the oldest individuals. Jessop (1972), however, prepared otoliths in sagittal section, which was shown to be inadequate for aging older lake whitefish (Power 1978). Power (1978) prepared lake whitefish otoliths in transverse section and identified a phenomenon he referred to as capping (Figure 10); when lateral growth of the otolith stopped and all successive annuli were deposited only on the proximal surface of otoliths on either side of the sulcus. Sagittal sections only expose annuli in the lateral plane and, similar to scales, are unable to reveal the presence of many annuli from older fish. The consequences of systematically under-aging

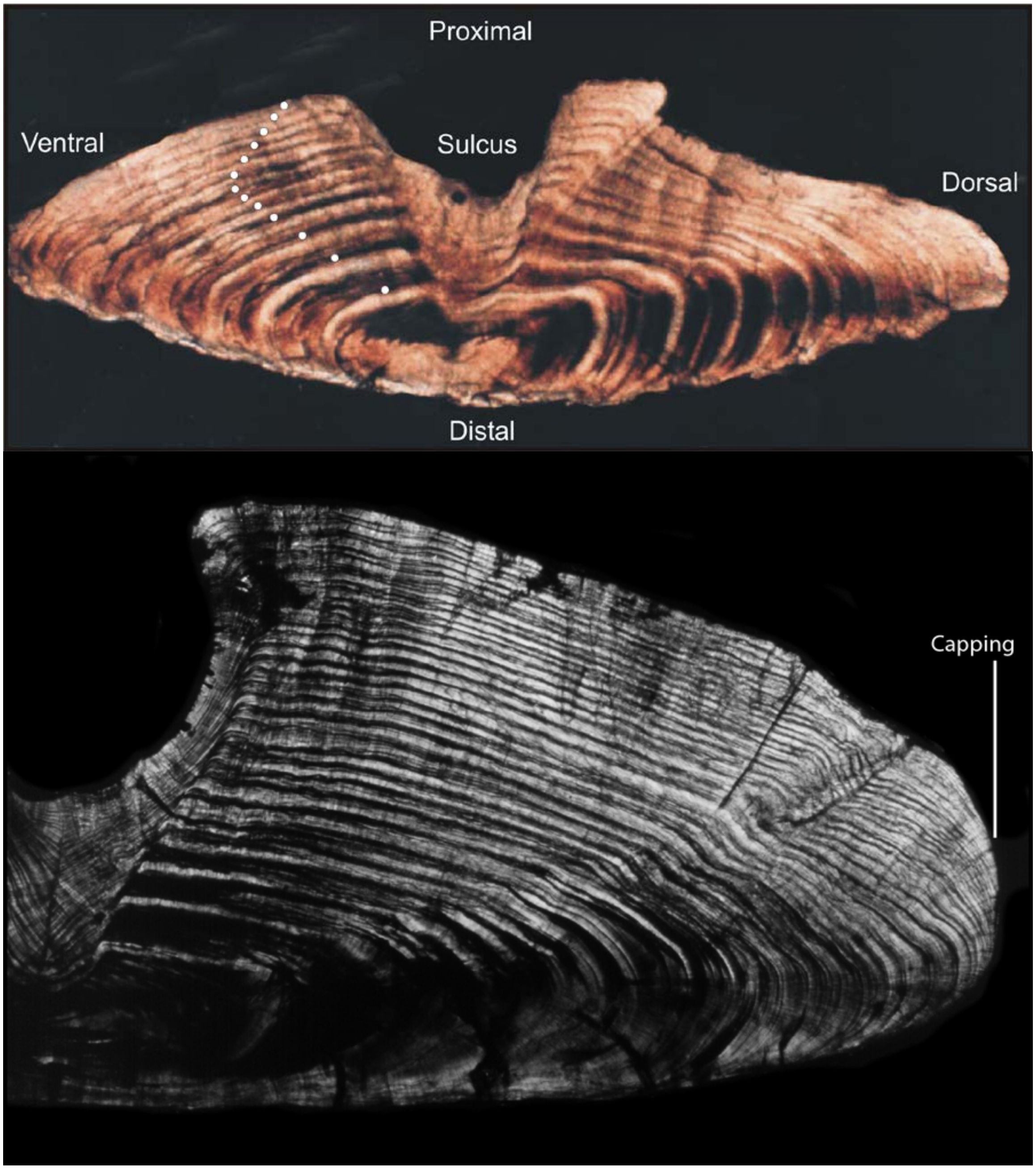

Figure 10. Microscopic image of a transverse sectioned otolith from a round whitefish estimated to be age 13 (top image). White spots on the ventral side of the sulcus illustrate how annuli are counted. Capping occurs in older fish when lateral growth stops and subsequent annuli fail to extend around the lateral tip (bottom image). Photos by R.J. Brown, USFWS.

older fish are that longevity is underestimated and growth rate is overestimated (Power 1978; Mills and Beamish 1980; DeCicco and Brown 2006), which can lead to harvest management decisions that over-exploit the resource. While we acknowledge that scale aging methods may produce comparable age data to otolith methods up until age at maturity, when whitefish growth slows dramatically, we limited our discussions and comparisons of age related issues, in most cases, to those publications that used appropriate otolith methods of aging.

The minimum age at maturity within a population represents the age at which the most precocious individuals attain maturity. Because whitefish within a population mature at a range of ages, only a small fraction of individuals are actually mature at the minimum age at maturity. Some biologists, therefore, prefer to describe age of maturity as the age class in which 50% of individuals are mature (Kennedy 1953; Fenderson 1964; Healey 1975). In practice, it is only possible to determine the 50% age of maturity when representative samples of mature and immature groups are available for sampling at a season when mature individuals can be identified. Riverine whitefish populations commonly stratify among habitats allowing sampling of mature individuals preparing to spawn or non-spawning individuals, but usually not both (Reist and Bond 1988; Chereshnev et al. 2000; Shestakov 2001; Brown et al. 2007). Therefore, estimating the 50% age of maturity can only be accomplished with populations that are isolated in lake systems and that spawn annually once mature to guarantee that all mature fish are identified. Both Healey (1975) and Lambert and Dodson (1990) discuss these and other challenges to first identifying mature individuals, and then age at maturity values that are comparable to other data in the literature and useful as descriptive biological parameters. Minimum age at maturity is a value that is commonly presented in the literature in text or figure form, permits an understanding of the time required for rearing, and is the value we use here to characterize population qualities of the six common species in the Yukon and Kuskokwim River drainages in Alaska.

Minimum age at maturity varies to some extent among populations of the six common whitefish species found in the Yukon and Kuskokwim River drainages in Alaska. Minimum age at maturity for inconnu has been identified as young as 5 years for a spawning population in the Slave River, within the Mackenzie River drainage (Howland 2005); 6 years for spawning populations in the Sulukna River, a tributary of the Yukon River (Esse 2011), and the Arctic Red River, a tributary of the Mackenzie River (Howland 2005); and 7 years for populations in the main-stem Yukon River (Brown 2000), the Peel River, a tributary of the Mackenzie River (VanGerwen-Toyne et al. 2008), and the Kobuk River in northwest Alaska (Taube and Wuttig 1998). Minimum age at maturity for various broad whitefish populations has been reported to be 5 years for a population in the Yukon River in Alaska (Carter 2010); 6 years for populations in the Arctic Red River, lower Mackenzie River (Chudobiak 1995), and upper Koyukuk River, Yukon River drainage in Alaska (Brown 2009); 7 years for populations in Travaillant Lake, lower Mackenzie River drainage (Chudobiak 1995), and the Peel River (VanGerwen-Toyne 2001), and 8 years for populations in northern (Moulton et al. 2007) and northwestern Alaska (Brown 2004). Minimum age at maturity for humpback whitefish populations has been reported to be 4 years for riverine populations in southern Hudson Bay, eastern Canada (Morin et al. 1982), and the Kuskokwim River (Harper et al. 2007); 6 years for riverine populations in the Peel River, lower Mackenzie River drainage (VanGerwen-Toyne et al. 2008), and the Koyukuk River, Yukon River drainage in Alaska (Brown 2009); and 11 years in an anadromous population in northern Alaska (Moulton et al. 1997). Minimum age at maturity for least cisco populations has been reported to be 3 years for riverine populations in the Yukon and Kuskokwim River drainages (Harper et al. 2007; Brown 2009); 5 years for lake and coastal populations in northwestern Canada and Alaska (Mann 1974; Brown 2004); 6 years for a riverine population in the Peel River, lower Mackenzie River drainage in Canada (VanGerwen-Toyne et al. 2008); and 7 years for an anadromous population in northern Alaska (Moulton et al. 1997). Minimum age at maturity for Bering cisco has been identified as 4 years for the Yukon River spawning population (Brown et al. 2012). Recent sampling and aging work with Kuskowim and Susitna River populations suggest minimum ages of 3 years for mature fish (R.J. Brown, USFWS, unpub. data). Minimum age at maturity for round whitefish has been reported to be 4 years for a riverine population in Quebec, eastern Canada (Jessop and Power 1973), 8 years for a riverine population in northern Alaska (Craig and Wells 1975), and 8 years for a lake population in eastern Russia (Gudkov 1999). It is possible that scale derived estimates of minimum age at maturity would be equivalent to those derived from otoliths (Jessop 1972; Barnes and Power 1984) but we do not include those data here.

Most whitefish species are capable of surviving for many years following maturity, allowing multiple opportunities to spawn. Longevity estimates for inconnu have ranged from 28 years in the main stem Yukon River in Alaska (Brown 2000), 35 years in the Arctic Red River in the lower Mackenzie River in Canada (Howland et al. 2004), to 37 years in the Peel River in the lower Mackenzie River in Canada (VanGerwen-Toyne et al. 2008). The oldest inconnu that we are aware of is one from the Selawik River in Northwest Alaska that was aged with a transverse sectioned otolith at 41 years (Figure 11; W. Carter, USFWS, unpub. data). Longevity estimates for broad whitefish have ranged from 16 years for the main stem Yukon River in Alaska (Carter 2010), 20 years in the Kuskokwim River in Alaska (Harper et al. 2007), 24 years in the Peel River in the Mackenzie River drainage in Canada (VanGerwen-Toyne et al. 2008), 27 years in the Selawik River in northwest Alaska (Brown 2004) and in Travaillant Lake in the lower Mackenzie River drainage in Canada (Chudobiak 1995), to a maximum reported age of 35 years for a fish collected in the Mackenzie River delta (Bond and Erickson 1985). Longevity estimates for humpback whitefish have ranged from 17 years for fish captured in the Grande River in southern Hudson Bay (Morin et al. 1982), 23 years in the Peel River in the lower Mackenzie River in Canada (VanGerwen-Toyne 2008), 27 years in the Selawik River in northwest Alaska (Brown 2004), 30 years in the Black River in the Yukon River drainage in Alaska (Brown and Fleener 2001), 36 years from collections in western Labrador in eastern Canada (Barnes and Power 1984), to a maximum reported age of 57 years from collections taken in northern Quebec in Canada (Power 1978). Longevity estimates for least cisco range from 14 years in the Kuskokwim River in Alaska (Harper et al. 2007), 16 years in the Selawik River in northwest Alaska (Brown 2004), 25 years in northwest Canada (Mann 1974) and northern Alaska (Moulton et al. 1997), to a maximum reported age of 27 years in Teshekpuk Lake in northern Alaska (Moulton et al. 2007). Longevity of a dwarf population of least cisco in Trout Lake in northwest Canada was reported to be 14 years (Mann and McCart 1981). The oldest Bering cisco in a sample of approximately 160 aged fish from the Yukon River population was found to be 13 years old (Brown et al. 2012). Longevity estimates for round whitefish have ranged from 12 years for an anadromous population in the Grande River in southern Hudson Bay in eastern Canada (Morin et al. 1982), 22 years in the upper Chandalar River in the Yukon River drainage in Alaska (Craig and Wells 1975), 25 years for a sample from the Ugashik Lakes in southwest Alaska (Plumb 2006), to 32 years in a lake population in eastern Russia (Gudkov 1999). The oldest round whitefish we are aware of was collected from the Pilgrim River on the Seward Peninsula in western Alaska. It was aged from a transverse sectioned otolith at 33 years (Figure 11; Brown, R.J., USFWS, unpub. data). Whitefish populations may each experience unique environmental conditions and harvest pressures, both of which influence the

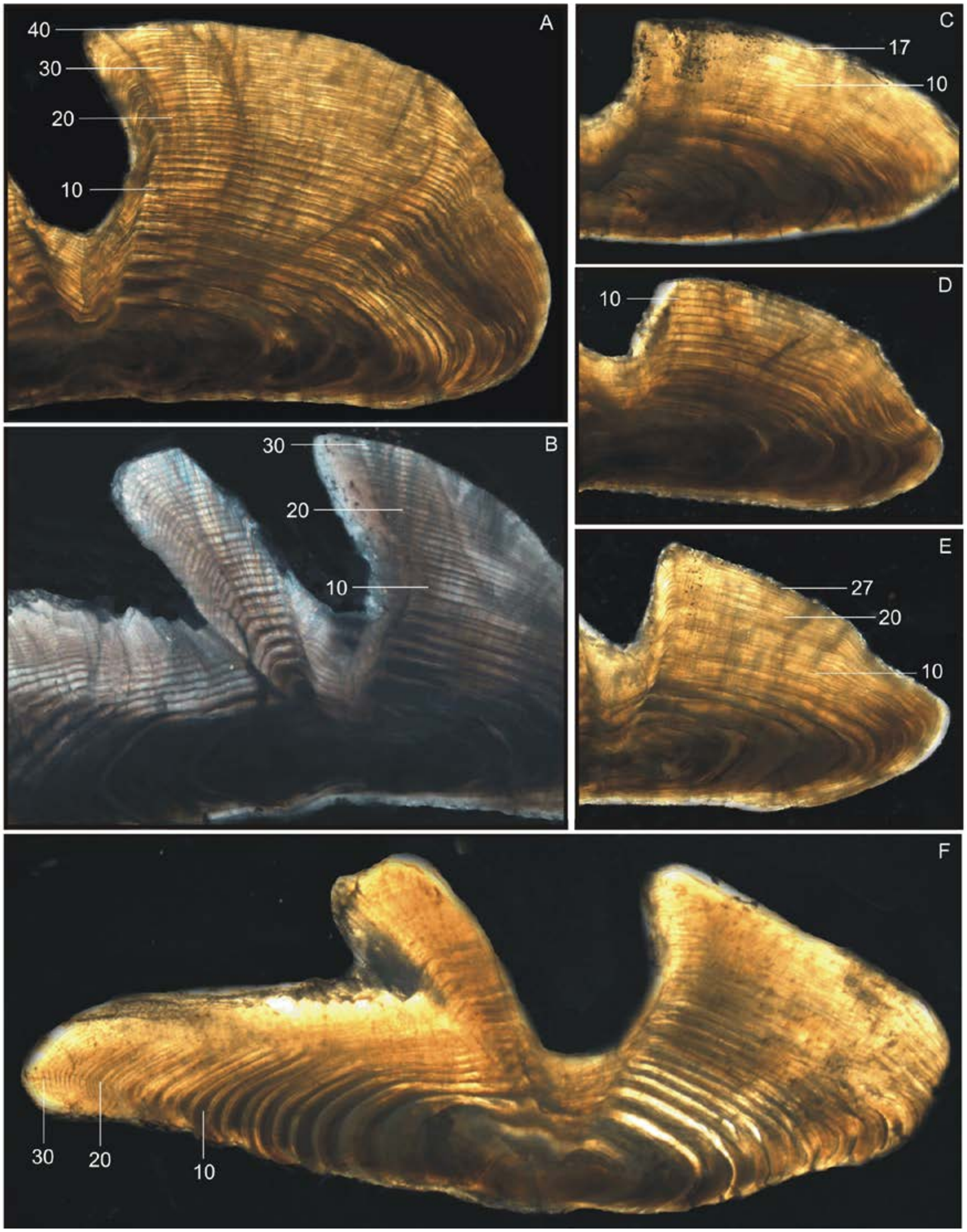

Figure 11. Transverse sectioned otolith images from some of the oldest individual whitefish observed in Alaska including an inconnu aged at 41 years (A), a humpback whitefish aged at 31 years (B), a least cisco aged at 17 years (C), a Bering cisco aged at 13 years (D), a broad whitefish aged at 27 years (E), and a round whitefish aged at 33 years (F). Ten year time intervals or less are indicated to illustrate the way growth increments were interpreted. Photos by R.J. Brown and W.K. Carter, USFWS, and V.R. von Biela, USGS.

probability of survival to advanced age. These factors are probably responsible for the wide range of longevity estimates presented above for most whitefish species.

Spawning frequency

All six common whitefish species in the Yukon and Kuskokwim River drainages are capable of spawning more than once, although spawning frequency is not well understood and may be different for each species and for each population within a species. It has usually been assumed that northern whitefish populations were not capable of spawning during two successive years (Alt 1969a; Reist and Bond 1988; Lambert and Dodson 1990). Lambert and Dodson (1990) examined the annual energetic requirements for spawning lake whitefish and cisco populations in a river in southern Hudson Bay and concluded that they could not obtain enough nutrition to spawn two years in succession and had to skip spawning for at least 1 year after each year in which they spawned. Evidence for the occurrence of skip spawning of individual fish is strong for most whitefish species. Alt (1969a), for example, observed two stages of gonad development in mature female inconnu (maturity presumably based on large size) in northwest Alaska during summer and concluded that those with larger eggs would spawn that year and those with smaller eggs would not. Brown (2004) plotted GSI values against age and length from a sample of 30 female broad whitefish captured in September in the Selawik River delta in northwest Alaska. He showed that approximately half of the sample that were older and larger than minimum age and length at maturity had low GSI values (<3%) and would not spawn that fall (Figure 9). Moulton et al. (1997) used similar data to argue that approximately half of the mature humpback whitefish and least cisco sampled in Dease Inlet in northern Alaska would not spawn that fall. Mann (1974) found a portion of mature size least cisco in his sample lakes in northern Canada whose gonads did not enlarge as spawning season approached and concluded that some mature individuals skipped spawning sometimes. No similar data exist for Bering cisco. Jessop and Power (1973) classified round whitefish from the Leaf River in Quebec as mature or immature based on a qualitative assessment of their gonads and determined that 23 of 147 mature females in their sample (16%) would have skipped spawning that year. Additional evidence of skip spawning is available from a number of additional sources in the literature for most of these species (Table 2). Despite the sampling evidence that some mature whitefish of most species skip spawning some years, the prevalence of skip spawning in populations or through the lifetime of individual fish is largely speculative.

The occurrence of annual spawning for the six common whitefish species in the Yukon and Kuskokwim River drainages has been documented with tagging studies in spawning reaches and sampling to infer proportional composition of demographic groups. For example, in northwest Alaska, numerous spawning inconnu with anchor tags were located in upstream spawning reaches of the Kobuk (Taube and Wuttig 1998) and Selawik (Underwood 2000; Hander et al. 2008) rivers during two consecutive spawning seasons. Extensive sampling in these spawning reaches had demonstrated that only spawning fish were present, thus, a fish's presence in the spawning reaches during two consecutive spawning seasons indicated annual spawning. In addition to the anchor tag evidence, 9 of 26 spawning inconnu equipped with radio tags in the Selawik River were present in the spawning reach during two consecutive spawning seasons (Hander et al. 2008). Tallman et al. (2002) concluded that there was a high incidence of annual spawning for broad whitefish of the Travaillant Lake population in the lower Mackenzie River based on a high sampling proportion of fish preparing to spawn (248 of 273 sampled fish). The Travaillant Lake broad whitefish population is thought to remain in the lake system so the sample was considered to be representative. Hallberg (1989) documented the consecutive year recoveries of numerous anchor-tagged humpback whitefish on the Chatanika River spawning reach in the Tanana River drainage, establishing that at least some individuals spawn annually. Brown (2006) argued that a high proportion of humpback whitefish in the upper Tanana River drainage in Alaska spawned annually based on two lines of evidence. In the first case, 71% (131 of 185) of humpback whitefish that were opportunistically tagged in several feeding habitats in early summer subsequently migrated to spawn in the fall. If annual spawning was rare or did not occur the spawning fraction of the sample should not have been greater than 50%. In the second case, radio tags that would last through two spawning seasons were deployed on a sample of 32 humpback whitefish in the early summer. Eighty-three percent (25 of 30 surviving fish) migrated to spawning areas the first fall and 67% of the surviving spawners (16 of 24) migrated to the spawning areas again the second fall. Similar to the fall surveys in the Kobuk and Selawik River spawning areas discussed above, all mature size humpback whitefish examined in upper Tanana River spawning areas were in spawning condition (Brown 2006). Brown (2004) found that all female least cisco age 5 and older and 275 mm (11 inches) FL or longer that were sampled in the Selawik River delta in September (n = 19) were preparing to spawn. The absence of non-spawning females in the sample led him to suggest that mature least cisco in the Selawik River delta spawned annually. Mann (1974) examined size and age of least cisco in northern Canada to judge maturity and gonad size to classify them as spawners and non-spawners. He observed a consistently small fraction of non-spawners in his sample of mature fish from several locations and concluded that annual spawning was more common than skip spawning. Hallberg (1989) documented the consecutive year recoveries of several anchor-tagged least cisco on the Chatanika River spawning reach in the Tanana River drainage, providing even stronger evidence of annual spawning. The Alaska Department of Fish and Game (ADFG 1983) documented the recovery of a single tagged Bering cisco in the spawning reach in the Susitna River, south-central Alaska, on two consecutive spawning seasons indicating that the species is capable of annual spawning. More recently, residual eggs were documented in a pre-spawning Bering cisco (Figure 6) collected in September 2010 in the South Fork Kuskokwim River (M. Thalhauser, unpub. data, Kuskokwim Native Association), providing clear evidence of repeat spawning and possible annual spawning. Craig and Wells (1975) state that most round whitefish in the upper Chandalar River in Alaska spawn annually, but provide no specific evidence supporting the statement. Jessop and Power (1973) implied that annual spawning was common for round whitefish in the Leaf River in Quebec because 74% of mature females in their sample (124 of 147) were preparing to spawn. All annual spawning evidence discussed above that was based on sampling proportions of mature females that were in spawning versus non-spawning condition depends on representative sampling of the populations, which, as discussed earlier, is unlikely. The strongest evidence for the occurrence of annual spawning in Alaska whitefish species is therefore, the multiple-year anchor tagging and radio telemetry data collected from inconnu spawning populations in northwest Alaska (Taube and Wuttig 1998; Underwood 2000; Hander et al. 2008), for humpback whitefish spawning populations in the Tanana (Hallberg 1989; Brown 2006) and Koyukuk (Brown 2009) River drainages, and for the Chatanika River least cisco population (Hallberg 1989). While the prevalence of annual spawning within whitefish populations is not well understood, it is clear that some individuals in at least some populations are capable of spawning during at least two consecutive seasons.

Food preferences

All six common whitefish species in the Yukon and Kuskokwim River drainages have feeding preferences that have been identified through diet studies and can be inferred by examining their specialized mouth parts (Figure 12) and gill rakers (Figure 13). By understanding food preferences we can also understand habitat associations for the different whitefish species during feeding periods. The large, superior mouth of inconnu, the lower jaw extending beyond the upper jaw, and the long, stout gill rakers are all specializations for capturing and swallowing large, swimming prey. Inconnu feed predominantly on fish of many species and they are also known to consume pelagic crustaceans and large aquatic insects (Alt 1965, 1969a; Fuller 1955; Petrova 1976). The mouths of broad whitefish, humpback whitefish, and round whitefish are oriented in an inferior position, the lower jaw being shorter than the upper jaw, maximizing their ability to pick prey items off the substrate below them. These three whitefish species feed primarily on benthic invertebrates including crustaceans, insect larvae, and mollusks (Craig and Wells 1975; Armstrong et al. 1977; Bond 1982; Bond and Erickson 1985; Gudkov 1999; Shestakov 2001; Plumb 2006; Brown 2007a). Gill raker number and morphology suggest that broad whitefish and round whitefish are more specialized for benthic feeding than humpback whitefish. Least cisco have small, superior mouths that are optimal for taking swimming prey above or in front of them in the water. Least cisco opportunistically feed on a wide range of zooplankton including crustaceans, aquatic insects, and small fish (Alt 1980a; Bond 1982; Bond and Erickson 1985; Mann 1974). Bering cisco have a terminal mouth, both jaws equal in length, that is ideal for taking swimming prey in front of them. Bering cisco feed on zooplankton, including invertebrates and small fish (Alt 1973a; Runfola 2011). Runfola (2011) examined stomach contents of 82 Bering cisco from a coastal sampling site on the Yukon Delta, 65 of which had food in their stomachs. Most feeding fish had eaten ninespine *Pungitius pungitius* and threespine *Gasterosteus aculeatus* sticklebacks and a smaller fraction had consumed a selection of pelagic invertebrates. These feeding data, as well as similar data from other studies, indicate that most whitefish species feed opportunistically on a variety of prey species, and that their diets are dominated by prey they are morphologically specialized for.

Figure 12. Mouthparts of whitefish species are good indicators of their primary feeding strategies: inconnu (A) have large mouths specialized for eating fish; broad whitefish (B), humpback whitefish (C), and round whitefish (F) have downturned mouths specialized for taking benthic invertebrates; least cisco (D) and Bering cisco (E) have small, upward or forward facing mouths specialized for capturing swimming invertebrates and small fish. Photos by R.J. Brown, USFWS.

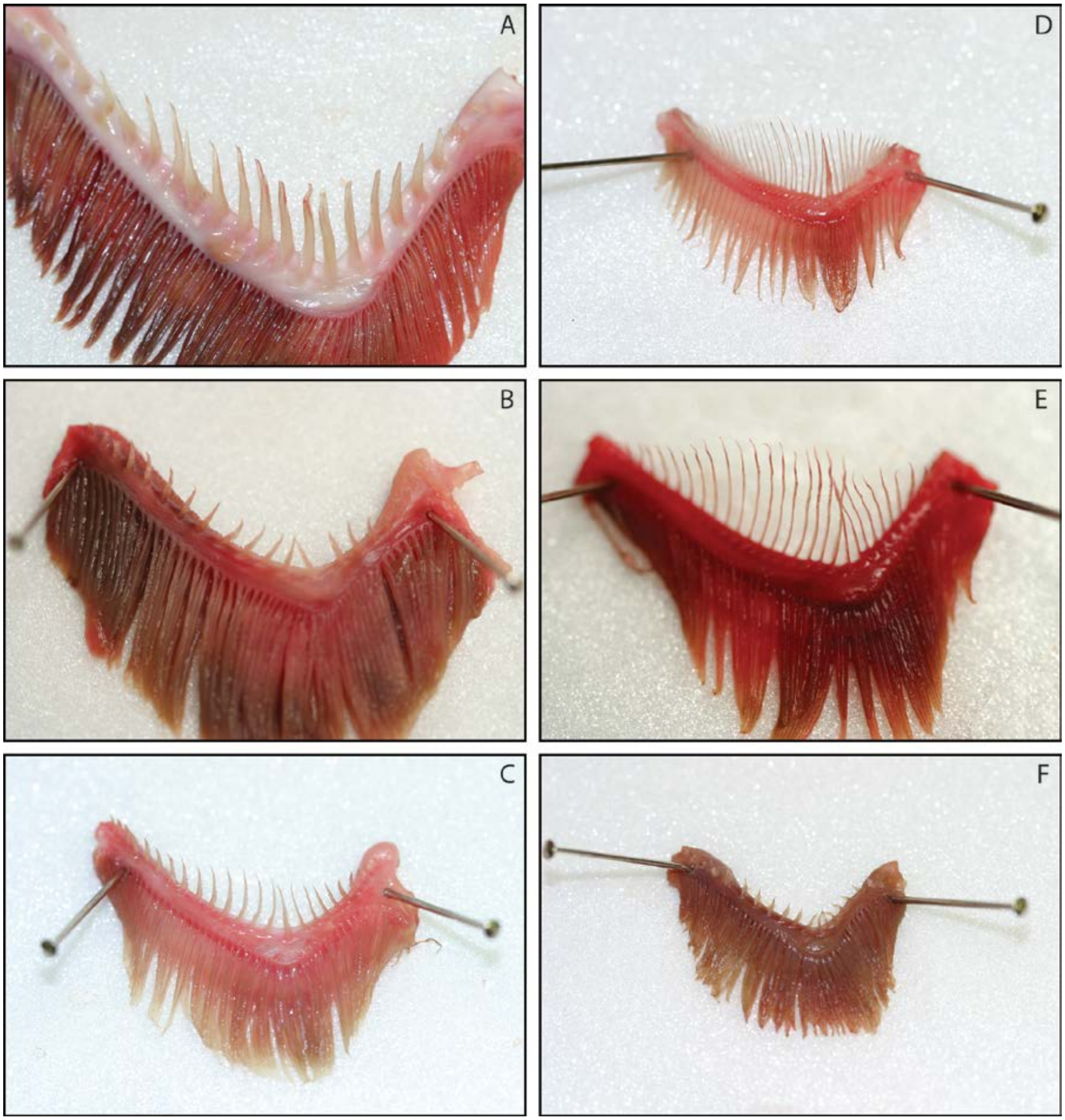

Figure 13. Gill rakers are also good indicators of primary feeding strategies of whitefish species: inconnu (A) have long, stout gill rakers specialized for guiding live fish into their stomachs; broad whitefish (B) and round whitefish (F) have a small number of short, stout, gill rakers that may play a minimal role in their feeding efficiency on benthic invertebrates; least cisco (D) and Bering cisco (E) have numerous long, thin, gill rakers to guide zooplankton and other small pelagic food items into their stomachs; and humpback whitefish (C) appear to have gill raker number and morphology that are intermediate between the benthic and pelagic specialists. Photos by R.J. Brown, USFWS.

Fisheries (Subsistence, Commercial, Sport)

As described earlier, several fisheries, including subsistence, commercial, and sport, occur in the Yukon and Kuskokwim River drainages. While these fisheries have different histories and are managed under different regulatory schemes, they all largely exploit the same populations as these fish migrate through the larger drainage systems. Indeed, the combination of complex population and migratory structures with overlapping harvest systems is a large component of why whitefish species present significant challenges to effective management.

Generally, the subsistence fisheries occurring in the study area are the most significant in terms of magnitude and timing (history of occurrence and seasonality). Continuing beyond the reaches of living memory, subsistence harvests of whitefish species have constituted a significant component of the seasonal round of most rural, primarily Alaska Native, villages in Alaska. Many whitefish species are available at all seasons, providing a stable food base for people and their dogs and are valued as a source of fresh meat during the winter months when other resources are limited or absent (Andersen et al. 2004; Brown et al. 2005). Localized studies over the last 25 years have pieced together broad, drainage-wide pictures of whitefish traditional knowledge, harvest, and use in Alaska (Wolfe 1981; Nelson 1983; Brelsford et al. 1987; Coffing 1991; Andersen and Fleener 2001; Williams et al 2005; Georgette and Shiedt 2005). Here, we provide a general description of the subsistence fisheries, leaving their specific details to the geographical chapters below.

Local fisheries range the length of both rivers but depending on the time of year and distribution of particular species, these fisheries may target only a subset of whitefish species. For example, the Koyukuk River communities rely heavily on whitefish harvests, except for Bering cisco which do not appear to travel up the Koyukuk River (Andersen 2007), though these smaller fish are heavily harvested in other fisheries within their distribution along the Yukon main stem (Brown et al. 2005). In another example, while most of the whitefish species are present in the Tanana River, fishermen there target primarily humpback whitefish due to their abundance in critical area habitats (Case 1986). Patterns of whitefish harvest and use have also shifted through time in most regions of the study area. Perhaps the most significant of these changes was the introduction of the snowmobile, which quickly replaced the use of large dog teams. Maintaining dog teams required significant harvests of whitefish species, in addition to salmon, both during the summer and also in the late winter and early spring when food stores ran low (Andersen et al. 2004). With some notable exceptions in both drainages, whitefish are largely harvested for human use now and existing ethnographic data suggests that historic whitefish harvests may have been larger to feed more working dogs.

Harvesting gear has also changed over time. While some whitefish species can be harvested all year in many places, fishermen throughout both drainages tend to target their harvest during spring and fall migrations and also under the ice during winter months. Seasonal timing of harvest and targeted species dictate gear type. Historically, most whitefish species, especially inconnu, broad whitefish, and humpback whitefish, were harvested with traps (Nelson 1983; Brown et al. 2005). Large, in-river funnel traps were approximately 3 to 4 m (10 to 12 feet) in length and were usually constructed of split spruce with a removable panel of wood or canvas in the back to facilitate fish removal. Funnel traps were designed to target smaller whitefish species although they also caught some larger species and other non-salmon fish species (Andersen et al. 2004). Funnel traps might be used in conjunction with weirs or fish fences to help direct fish towards the funnel opening of the trap. Small basket style traps were used in lakes and slough systems, especially in the spring under the ice and in the fall at specific sites as fish migrated out of lake habitats. Traps were used most heavily up until the 1940s and 1950s. In most areas for which we have documentation, willow-bark gill nets were also used before eventually giving way to the improved technology of cotton twine, and later, nylon nets such that contemporary nylon nets have completely replaced traps as the primary means of harvest. Today, gill nets are constructed with various mesh sizes and lengths, depending on the species targeted and harvest area. They can be used in open water or set under the ice. Other historical harvest methods that continue today include dip-netting in particular areas such as the middle Yukon and upper Tanana rivers, seining, fishwheels, hook and line, and jigging through the ice.

Harvest data are a critical component of any management regime. However, accurate, species-specific harvest data are limited in the Yukon and Kuskokwim drainages. Early harvest estimates were single-year snap-shots and did not differentiate between species, except for “large” (primarily broad whitefish and humpback whitefish) and “small” (primarily least cisco, Bering cisco, and round whitefish, but also juveniles of any species) whitefish. More recent attempts to estimate harvests have paid more attention to reporting by species but have remained single year estimates which do not lend themselves to understanding harvest trends (Andersen et al. 2004; Brown et al. 2005; Brown et al. *in prep.*; Ray et al. 2010). The exception to these single year data sets is the Yukon River post-season survey, which has documented selected non-salmon fish harvests since approximately 1993 (Holder and Hamner 1998). Designed to collect information primarily about summer salmon harvests, it too suffers from a lack of species differentiation in the harvest estimates. More recent, single-year, species-specific harvest estimates (ranging from 2002 to 2007) exist only for the interior region, encompassing much of the Yukon River excluding the lower reaches, and for three communities on the lower Kuskokwim River. If we consider these snapshot harvest estimates to be normal annual values, and we combine the whitefish harvest estimates from all interior communities and for all species, an order-of-magnitude scale estimate of the annual harvest of all whitefish species combined for the interior region of Alaska might be as high as 156,000 kg (344,000 pounds) (Table 4).

Table 4. An order-of-magnitude scale estimate of annual whitefish subsistence harvests in interior Alaska communities in thousands of kg (thousands of pounds).

Inconnu	Broad whitefish	Humpback whitefish	Least cisco	Bering cisco	Total
26 (57)	55 (121)	55 (121)	6 (12)	5 (11)	156 (344)

Successful harvests rely on close observation of whitefish over time; fishers from most subsistence-based communities in the Yukon and Kuskokwim River drainages have developed knowledge of particular locations, timing, and efficient harvest methods based on long-term observations of the life histories and patterned movements of whitefish species in their areas. For example, long term observations of and concerns about regional broad whitefish abundance in the central Kuskokwim area provide critical information both for fishermen and for biologists interested in the life history and health of these populations. However, many of these perspectives are extremely localized and tying these perspectives together is essential to understanding whitefish in the Yukon and Kuskokwim drainages.

While subsistence fisheries are likely the most significant component of harvest both in terms of size and breadth of the fisheries, commercial and sport uses also exist in both drainages. Sport uses of whitefish occur primarily during the summer months at various locations throughout the Yukon and Kuskokwim rivers. Primarily targeting inconnu and taking place in the mouths of clear water tributaries of both rivers, such as the Nowitna, Melozitna, and Innoko rivers within the Yukon drainage, sport fisheries use angling methods rather than gill nets or other capture methods and are characterized by relatively low harvest levels. Harvest data are collected through statewide, voluntary, mail-in surveys, designed to provide estimates of effort, harvest, and catch on a site-by-site basis. However, the survey for the Yukon and Kuskokwim drainages generally yields low response levels. As a result, precise harvest information is not available, though estimates indicate a continued low level of use (Table 5).

Table 5. Estimated sport fishery harvest of inconnu (in numbers of fish) in the Yukon and Kuskokwim drainages, 1996-2008.

Year	Kuskokwim	Yukon
1996	107	837
1997	508	266
1998	119	282
1999	268	247
2000	250	592
2001	124	501
2002	81	630
2003	45	297
2004	182	1,529
2005	1,079	1,477
2006	173	593
2007	435	214
2008	191	545
5 year average	412	872
10 year average	283	663

The Chatanika River, a tributary in the Tanana River basin, supports spawning populations of humpback whitefish and least cisco. During late summer and fall these whitefish migrate upriver to spawn in the vicinity of the Elliott Highway Bridge where they are subjected to a spear fishery that has historically taken place in late September and early October. Both humpback whitefish and least cisco are harvested, as were a small percentage of round whitefish. The fishery became very popular during the 1980s, and harvests peaked to approximately 25,000 fish in 1987 (Brase 2010). Stock assessment during the late 1980s and early 1990s indicated a declining abundance of whitefish, therefore the fishery was closed in 1994, and in 2001 spears were eliminated as a legal sport gear type on the Chatanika River. In 2007, the Alaska Board of Fisheries added spears again as a legal gear type in the personal use whitefish fishery. Currently a limited number of permits are issued annually that designate the dates, fishing area and household limits for this fishery. Two hundred permits were issued in 2009 and approximately 750 whitefish were harvested.

Limited commercial fisheries for whitefish species also take place in both the Yukon and Kuskokwim drainages. Small commercial opportunities have been permitted on the Yukon River since 1978, except between 1995 and 2004 (Hayes et al. 2011). Between 1980 and 1988, harvests ranged from approximately 900 to 5,450 kg (2,000 to 12,000 pounds). Beginning in 2005, a commercial whitefish fishery began in the lower Yukon River, at first targeting any whitefish species with a harvest limit of about 4,500 kg (10,000 pounds), the limit based on a 1980-1990 historical commercial harvest of inconnu and other whitefish species in the lower Yukon area. This fishery typically occurred in September and October. In 2005 and 2006, stretch-mesh gill nets up to 15 cm (6 inches) were allowed. Mesh size was restricted in 2007 to 10 cm (4 inches) when the fishery was shifted to target Bering cisco. In 2009, one permit was issued for a November-December fishery in Y-1 and Y-2 and in 2010, another permit was issued for an April to June fishery, both targeting Bering cisco with a harvest limit of about 2,270 kg (5,000 pounds). This fishery is likely to persist for the foreseeable future.

Commercial fishing opportunities for whitefish species have been permitted on the Kuskokwim River for roughly the same time periods as on the Yukon River. Harvests averaged approximately 1,810 kg (3,993 pounds) of whitefish during years for which there were harvests, which includes 1978-2003 excluding 1983, 1984, 1986, and 1998-2001 (Whitmore et al. 2008). However, this harvest estimate represents all whitefish captured and does not break out species-specific harvests. Since 1992, fishermen have registered for the fishery in the Nelson Island area, the main-stem Kuskokwim from Eek to Bogus Creek, in the lakes in the Eek and Tuntutuliak area, in the lakes south of Napaskiak, the Kuskokwim River between Bethel and Kwethluk, the sloughs and main-stem Kuskokwim River near Bethel, and at the mouth of the Gweek River upstream from Bethel (D. Bue, ADFG, pers. com.).

Potential Threats and Concerns

During the second meeting of the Whitefish Strategic Plan Working Group, we asked the assembled delegates, based on their knowledge and experience, to identify specific issues of concern about whitefish populations and fisheries in the Yukon and Kuskokwim River drainages. Additionally, we asked delegates to rank their concerns among risk categories ranging from high to low. We had previously agreed that the high risk category included situations where there was a possibility of losing a species or a population; the moderate risk category included situations where it was possible to lose a fishery or alter the natural distribution of a population; and the low risk category included situations where it was possible to noticeably reduce population abundance. While not all of the identified concerns could be neatly categorized into just one of the risk levels, they were organized into several major categories including; harvest or fishery related issues, development issues, and natural environmental issues. Several delegates suggested that a lack of biological and harvest information could threaten fish populations in situations where fisheries were permitted to take place without sufficient data for effective management. It was generally agreed that nearly all whitefish fisheries in the Yukon and Kuskokwim River drainages were data deficient. Some delegates suggested that useful biological data included the locations of whitefish spawning grounds and other critical habitats, migratory characteristics, spawning frequency, and other life history qualities. Many delegates considered the development of genetics baseline data to be important for management of commercially fished species. Species-specific harvest information was considered by some delegates to be a critical component of any management plan. Development projects could pose threats to whitefish populations at all risk levels. The group of delegates was specifically concerned about potential oil and natural gas drilling in the Yukon Flats region, placer mining and other development projects in the Innoko River drainage and the Yukon Kuskokwim Delta, the Alaska Railroad extension up the Tanana River, contamination resulting from various ongoing and planned mining projects, and other more localized effects from road construction, the use of culverts, and more. Delegates also expressed concerns about natural environmental changes and their effects on fish populations and habitats. Some delegates, for example, were concerned about the effects of abandoned beaver dams in some lake systems and extensive drift piles in certain rivers on fish distribution and habitat quality. The habitat effects of erosion following forest fires, natural drying of lakes, and changes in river flow patterns were also introduced as environmental issues of concern. This section on threats and concerns regarding whitefish populations and fisheries is based on the issues introduced by the delegates of the Whitefish Strategic Plan Working Group with additional information from the literature.

Harvest and fishery related issues

Overfishing is thought to be the cause of whitefish population declines in many of the large lakes in North America and has the potential to threaten whitefish populations in the Yukon and Kuskokwim River drainages in Alaska. For example, the collapse of shortjaw cisco *Coregonus zenithicus* populations in lakes Superior, Michigan, and Huron during the 20th century has been attributed primarily to overharvest (Gorman and Todd 2007), although Bronte et al. (2010) suggest that ecological changes may have played a larger role in their decline in Lake Superior. Between 1895 and 2003, there were several periods of high shortjaw cisco abundance that inspired tremendous commercial fisheries. Shortjaw cisco were harvested to satisfy a smoked fish market in the United States, the same market that is currently seeking Bering cisco from the Yukon River mouth (Fabricant 2008; Demarban 2010). The shortjaw cisco fisheries, which harvested more than 500,000 kg (1.1 million pounds) annually during peak harvest periods, would periodically drive the shortjaw cisco populations down to such low levels that the fishery was not economical anymore and it would cease for a decade or more. During these periods of low fishing effort, shortjaw cisco populations would recover, starting the cycle again. At this time, however, shortjaw cisco are thought to be extinct in lakes Michigan and Huron and rare in Lake Superior (Hoff and Todd 2004; Bronte et al. 2010). Bronte et al. (2003) indicated that the shortjaw cisco is being considered for listing as a threatened species. Gorman and Todd (2007) suggest that the ecological niche once dominated by shortjaw cisco is now occupied by other cisco species and there is no indication that shortjaw cisco populations will recover. Thus, the apparent collapse of shortjaw cisco populations in the Great Lakes due to overfishing appears to have taken over 100 years.

Two other whitefish species were similarly driven to very low population levels in the Laurentian Great Lakes due to a combination of overfishing, habitat degradation, and introduced species (Hartman 1972; Fleischer 1992; Ebener 1997). Large commercial harvests of lake whitefish and lake herring (lake cisco) *C. artedii* in Lake Erie during the late 1800s and early 1900s led to the collapse of their populations by the mid-1900s (Hartman 1972). Agriculture, logging, and industrial development activities have affected fish habitats in Lake Erie and its tributaries as well; blocking fish migration up some rivers, ruining known spawning areas through sedimentation, depleting dissolved oxygen levels in various regions of the lake because of organic pollution, and other types of environmental degradation. Introduced and invasive fish species entered Lake Erie during this time period as well, some competing with native species for food and habitat and others preying on them. Hartman (1972) concluded that the commercial fishery was the primary cause of initial declines of lake whitefish and lake herring populations and that the combined impacts of habitat degradation and introduced species prevented subsequent recovery. Similar patterns of population decline during the mid-1900s have affected lake whitefish and lake herring in the other Laurentian Great Lakes as well (Selgeby 1982; Fleischer 1992; Nalepa et al. 2005). Attempts were made between the late 1800s through the mid 1900s to enhance lake whitefish and lake herring populations in the Great Lakes through artificial propagation (Todd 1986). These attempts were unsuccessful at preventing population collapses, possibly because they were not conducted at a sufficiently large scale. Lake herring populations have never recovered from the mid 20th century declines in any of the Great Lakes (Selgeby 1982; Fleischer 1992). Lake whitefish populations, on the other hand, have recovered during the last few decades and currently support fisheries at or near historical harvest levels in lakes Superior (Bronte et al. 2003), Michigan (Schneeberger et al. 2005), Huron (Mohr and Ebener 2005), and Erie (Cook et al. 2005), but remain at low levels in Lake Ontario (Hoyle 2005; Owens et al. 2005). The mid-century declines in lake whitefish populations in the Great Lakes are almost universally attributed to a combination of overharvest, competition and predation by non-native species, and habitat degradation (Ebener 1997; Napela et al. 2005). Recent recoveries of lake whitefish in most of the Great Lakes are attributed to aggressive management actions to reduce harvest levels, reduce population levels of invasive sea lamprey *Petromyzon marinus*, rainbow smelt *Osmerus mordax*, alewife *Alosa pseudoharengus*, and other non-native species, and improve habitat quality.

The story of the commercial lake whitefish fishery in Lake Winnipeg illustrates some of the complex data and analytical challenges involved in identifying overharvest of an exploited fish population. Commercial harvest of lake whitefish in Lake Winnipeg, a large lake in eastern Canada with a surface area of approximately 22,870 km^2 (8,830 $mile^2$), began in the late 1800s and quickly became a major economic enterprise (Kennedy 1954; Hewson 1960). By the early 1940s there were about 150 boats engaged in the commercial fishery. Each boat deployed sinking gill nets with 13.3 cm (5.25 inch) stretch mesh webbing that were 4,572 m (5,000 yards) long. During the mid-1900s, the commercial fishery harvested an average of about 1,361,000 kg (3,000,000 pounds) of lake whitefish annually (Hewson 1959), ranging from 454,000 to 1,814,000 kg (1,000,000 to 4,000,000 pounds; Kennedy 1954). Kennedy (1954) examined annual weather data from Lake Winnipeg and catch rate and age data from the commercial fishery to determine whether there was evidence of lower lake whitefish abundance during low harvest years than high harvest years but his results were ambiguous.

Reliable effort data were not available in part because during periods of exceptionally high catch rates the processing plants could not keep up with the volume of fish so excess harvest was turned away and not counted. Kennedy (1954) also believed that weather conditions could significantly influence effort data (i.e., fewer days fished in stormy summers than in calm summers), which could explain harvest variation. There was no age distribution evidence that low harvest years followed weak year class recruitment, nor that high harvest years followed strong year class recruitment. Catch-curve analyses indicated a relatively stable annual mortality rate during the 20 years for which Kennedy (1954) had data. Based on these findings, Kennedy (1954) suggested that the commercial harvest was a negligible fraction of the lake whitefish population in Lake Winnipeg and that harvest limits might be allowed to increase without adverse effects.

Almost 20 years later, Davidoff et al. (1973) examined harvest trends, catch per unit of fishing effort, size and age data of harvested fish, and regulatory and gear changes in the fishery and concluded that lake whitefish populations were being overharvested in Lake Winnipeg. Improved data records allowed Davidoff et al. (1973) to determine that fishing effort had been increasing significantly between 1944 and 1969 while the catch per day of fishing had been declining precipitously. Annual harvest also declined, although less dramatically than the catch rate, because the decline in catch per day of fishing was partially offset by the increased fishing effort. During this same time period, the age distribution of harvested lake whitefish had changed from fish that were primarily 5, 6, and 7 years old during the 1940s, mature fish of three age classes, to fish that were primarily 3 and 4 years old during the 1960s, a mix of immature and mature fish of two age classes. Average weight of harvested lake whitefish declined from 1.2 kg (2.7 pounds) during the 1940s to 0.8 kg (1.7 pounds) in the late 1960s. Many of the gill nets in the fishery during the later years were using mesh as small as 10.8 cm (4.25 inches) stretched, a reduction from the previous standard of 13.3 cm (5.25 inches). Annual survival rates, calculated using the catch curve method of Robson and Chapman (1961), declined from an average of 0.32 during the 1940s to 0.12 during the 1960s. Environmental and pollution effects to the Lake Winnipeg environment were considered but rejected as major contributing factors in the apparent decline of lake whitefish populations (Davidoff et al. 1973). All the indicators that Davidoff et al. (1973) examined suggested that the lake whitefish populations in Lake Winnipeg were being overharvested and they recommended reduced harvest limits. Napela et al. (2005) provided a recent summary update on the lake whitefish fishery in Lake Winnipeg, indicating that abundance estimates and catch rates had been declining since the early 1980s. They contended, based on long-term environmental and water quality records, that progressive habitat changes in the lake were the most likely cause of the continued decline in the lake whitefish populations. These lines of evidence suggest that both fishery and environmental factors acted together in Lake Winnipeg to cause a decline in fish populations.

Inconnu populations in Great Slave Lake have been severely impacted by commercial fisheries during the last 60 years. Both Dymond (1943) and Fuller (1955) reported that tremendous spawning migrations of inconnu took place in at least five rivers flowing into the south side of Great Slave Lake, including the Hay, Buffalo, Little Buffalo, Slave, and Talston rivers. Traditional subsistence fisheries within these rivers harvested great numbers of inconnu each fall, apparently without depleting them. Commercial fishing in Great Slave Lake began in 1945 (Kennedy 1956; Keleher 1972; Roberge et al. 1982). Inconnu were never more than about 10% of the total commercial harvest, the primary species of interest being lake whitefish and lake trout *Salvelinus namaycush*. While there has been a stable market for inconnu as a smoked fish, their populations are thought to have been seriously depleted by the commercial fishery in addition to existing in-river subsistence fisheries (Cosens et al. 1993; VanGerwen-Toyne et al. 2010). Inconnu spawning populations currently exist in the Slave River, where the population appears to be stable (Tallman et al. 2005), and the Buffalo River, where the population appears to be at risk of extinction (VanGerwen-Toyne et al. 2010). Inconnu populations are thought to have been extirpated from the Hay, Little Buffalo, and Talston rivers, primarily due to overfishing in the commercial fishery. Efforts are underway to minimize inconnu bycatch in the commercial fishery in an attempt to save the two remaining populations.

In his review of the effects of the first 20 years of the Great Slave Lake commercial fishery, Keleher (1972) concluded, based on size and catch rate trend data, that lake trout were more profoundly affected by the commercial fishery than lake whitefish. To protect lake trout populations, he recommended that separate harvest quotas be established for the two primary species instead of the single combined quota that was in place at the time. Because both species were taken in most fishing locations, he considered two possible outcomes: establish separate harvest quotas and close the commercial fishery for both species if the quota for lake trout were reached, leaving some of the more abundant lake whitefish quota un-harvested; or continue the single combined quota for both species and acknowledge that lake trout populations would suffer as a result. Recent harvest records suggest that lake whitefish and lake trout populations have survived more than 55 years of the commercial fishery (Read and Taptuna 2003; Tallman and Friesen 2007). Inconnu are still being harvested incidentally in the commercial fishery at reduced levels, but the apparent extirpation of at least three of the five known river-spawning populations in Great Slave Lake (Cosens et al. 1993; VanGerwen-Toyne et al. 2010) indicates that inconnu populations are casualties of the commercial fishery. It does not appear that the valuable commercial fishery for lake whitefish and lake trout will be stopped to protect the remaining inconnu populations in the Great Slave Lake drainage.

Incidental inconnu harvests in subsistence and commercial salmon fisheries in the Yukon and Kuskokwim rivers in Alaska provide riverine analogs to the plight of inconnu populations in Great Slave Lake in Canada. Inconnu migrate to feeding and spawning areas each summer and fall along the Yukon and Kuskokwim rivers during the same time periods when Chinook *Oncorhynchus tshawytscha* and chum *O. keta* salmon fisheries take place (Alt 1977a; Stuby 2010; Brown et al. 2012). Inconnu are vulnerable to the same gill nets and fish wheels that are set for salmon. The average annual harvest of incidental and subsistence caught inconnu in the Yukon River drainage between 1993 and 2002, estimated from post season interviews of stratified random samples of fishing families, was approximately 15,000 fish (Brase and Hamner 2003). No similar inconnu harvest data are available for the Kuskokwim River. Yukon River inconnu come from six known spawning populations originating in the upper Koyukuk River (Alt 1970), the Sulukna River (Alt 1985; Gerken 2009), the Tanana River main stem (R.J. Brown, USFWS, A. Gryska, ADFG, unpub. data), the Chatanika River (Alt 1969a), the Yukon River main stem (Brown 2000), and the upper Innoko River (R.J. Brown, USFWS, J. Burr, ADFG, unpub. data). Brown et al. (2007) used otolith chemistry techniques to establish that many of the inconnu from the upper Koyukuk, Yukon, and

Tanana River populations were anadromous. Kuskokwim River inconnu come from three known spawning populations originating in the Big River (Alt 1981a), the Middle Fork Kuskokwim River (Stuby 2010), and Highpower Creek (Alt 1972). Incidental and subsistence harvests in both drainages are clearly from multiple populations. Abundance data have only been available from the Sulukna River and Chatanika River populations within the Yukon River drainage. The Sulukna River spawning population was counted with a DIDSON sonar system in fall 2008 and 2009 and found to include approximately 2,100 and 3,500 spawning inconnu respectively (Esse 2011). The inconnu spawning population in the Chatanika River was estimated, using weir and rudimentary mark recapture techniques, to be approximately 100 fish during both 1968 and 1972 (Alt 1969b; Kepler 1973). No recent estimates have been obtained for the Chatanika River population but anecdotal accounts indicated that inconnu are occasionally observed during the fall spawning season (K. Wuttig, ADFG, pers. com.). Tagging and catch rate data suggest that the upper Koyukuk and Yukon River populations are larger than Sulukna or Chatanika River populations (Alt 1977a; R.J. Brown, USFWS, unpub. data), but, the magnitude of these larger populations is unknown. No abundance data are available for Kuskokwim River inconnu populations, although, recent radio telemetry data suggest that most Kuskokwim River inconnu are members of the Big River spawning population (Stuby 2010). To our knowledge, sustainable harvest levels have not been determined for inconnu populations anywhere. In the absence of reliable harvest and monitoring programs it seems possible that Yukon and Kuskokwim River inconnu populations could be steadily overharvested and would be noticed only if a population disappeared entirely, similar to the extinct Great Slave Lake populations that originated in the Hay, Little Buffalo, and Talston rivers.

We found documented evidence of only one case where subsistence or commercial fisheries in rivers or estuaries have had a measurable impact on whitefish populations. The Chatanika River spear fishery for humpback whitefish and least cisco is a riverine fishery with monitoring data suggesting population effects from excessive harvests. The fishery began in the late 1970s and annual population assessments have been conducted off and on since 1986 (Hallberg and Holmes 1987; Timmons 1991; Brase 2010). The fishery takes place in the spawning reach for these species during late September and early October, their spawning season. In the 1980s the fishery was open to Alaska residents and there was no harvest limit. The Chatanika River spear fishery became popular among residents of Fairbanks because it was easily accessible along the Elliott and Steese Highway crossings not far from town. Annual harvest levels rose to a maximum of over 25,000 of the two species combined in 1987, prompting action by the Alaska Board of Fisheries to limit daily harvest in the fishery to no more than 15 fish per person (Fleming 1999; Brase 2010). The two species cannot be reliably identified until capture so harvest limits referred to combined catches. Annual mark and recapture population estimates indicated that both species continued to decline even after the daily harvest limits were imposed. The fishery was therefore closed by emergency order in 1990 and remained closed for most years between 1990 and 2007 (Brase 2010). A fishery management plan for the Chatanika River whitefish spear fishery was developed in 1992. The plan established threshold spawning population levels, based on previous mark and recapture estimates of abundance, of 10,000 humpback whitefish and 40,000 least cisco before the fishery could take place. Fleming (1996) analyzed age structure data and found that the proportion of young, recently recruited fish declined dramatically between the late

1980s and the mid-1990s (Hallberg and Holmes 1987; Timmons 1991). Population theory suggests that overfishing should have had the opposite effect on age structure, reducing the proportion of older fish vulnerable to harvest and having little or no effect on younger fish prior to first spawning (Healey 1980; Mills et al. 1995). These findings led Fleming (1996) to suggest that the observed population declines were more a result of recruitment failures than overfishing. Regardless of the primary cause of the observed population declines of spawning humpback whitefish and least cisco in the Chatanika River, intensive fishing would certainly have exacerbated the situation. After a long hiatus, the Chatanika River spear fishery reopened again as a permit fishery in 2007 with a total harvest limit of 1,000 fish (Brase 2010). One hundred household permits were issued in 2007 for the harvest of 10 fish maximum per household of humpback whitefish and least cisco. Because many of the issued permits were not used in 2007, the Alaska Department of Fish and Game issued 200 permits in 2008 and 2009 for a maximum potential harvest of 2,000 fish per year. Meanwhile, during the 2008 spawning season on the Chatanika River there were approximately 22,000 humpback whitefish, an adequate level to initiate the fishery under the 1992 management plan, and 15,000 least cisco, the lowest estimate on record and well below the 40,000 fish threshold established by the 1992 management plan (Wuttig 2009). While the cause of the observed declines in abundance of Chatanika River humpback whitefish and least cisco is not certain, it is likely that unrestricted fishing would reduce the probability of recovery, particularly for the least cisco spawning population that apparently continues to decline. In light of these data, Wuttig (2009) wisely recommended that the fishery be managed very conservatively to avoid a fishery-caused collapse of the least cisco population.

This lack of documented evidence of fishery impacts on riverine or estuarine whitefish populations may reflect more on the scarcity of adequate fishery and fish population data, or confounding effects of dams blocking spawning migrations, than on the status of any particular whitefish population. Harvest records from commercial whitefish fisheries in rivers or estuaries usually identify the number or weight of fish that were sold, but often fail to identify the species and almost never have an understanding of the contributing populations (Corkum and McCart 1981; Hayes et al. 2008; Whitmore et al. 2008). Commercial whitefish fisheries that have occurred in rivers and estuaries in northern Canada and Alaska have generally catered to limited local markets because of the high cost of transportation to larger markets. The recently initiated Bering cisco fishery at the mouth of the Yukon River appears to be a rare exception with its New York City market (Fabricant 2008; Demarban 2010). In any case, most commercial whitefish fisheries in Alaska have been conducted at a relatively small scale compared to the commercial fisheries in the large, southern lake systems closer to population centers and were not likely to have responded in a significant manner to the exploitation level even if a monitoring program had been in place (Roberge et al. 1982; Fleischer 1992; Treble and Tallman 1997; Hayes et al. 2008).

It is extraordinarily difficult to detect the effects of exploitation on riverine or estuarine whitefish populations in general, and particularly so when migrations are impeded by dams and fish populations are being enhanced with stocking programs. Lehtonen and Jokikokko (2002) and Heikinheimo and Mikkola (2004) contend that anadromous European whitefish *Coregonus lavaretus* in the northern Baltic Sea have responded to exploitation with a reduction of mean size. The spawning migrations for these populations, however, were blocked by dams so the populations were being sustained with compensatory stocking programs. Inconnu populations originating in the Volga and Irtysh River drainages once supported tremendous fisheries prior to the construction of hydroelectric dams blocking their spawning migrations (Petrova 1976; Letichevskiy 1981). Similar to the European whitefish populations in the Baltic Sea, these Asian inconnu populations have been sustained in recent decades with stocking programs and no longer support the tremendous fisheries of the past. These habitat and enhancement features prevent legitimate assessments of fishery impacts to these and many other European and Asian whitefish fisheries.

Dams or other development activities do not appear to have seriously impacted whitefish populations in the rivers of northern Canada and Alaska at this time so it would theoretically be possible to identify fishery impacts to whitefish populations if they were to occur. Harvest records from subsistence fisheries in Alaska, however, are often single-year estimates from a fraction of the fishing families obtained during post-season interviews (Coffing 1991; Brase and Hamner 2003; Andersen et al. 2004). In addition, whitefish species identification in subsistence harvest accounts is rare (Marcotte 1991; Brown et al. 2005; Williams et al. 2005). With these types of data, it would be impossible to identify long-term changes in harvest levels or demographics of an exploited species unless it was actually fished to extinction (i.e., we traditionally captured this species here and it is no longer present). River and estuary fisheries usually harvest multiple whitefish species (Crawford 1979; Corkum and McCart 1981; Moulton and Seavey 2005) and for each species there can be multiple spawning populations present (Reist and Bond 1988; Brown et al. 2007; Harris and Taylor 2010a), both factors that confound biological assessments. Despite these difficulties some scientists have attempted to evaluate the effects of riverine and estuarine fisheries on whitefish populations.

Most riverine whitefish fisheries occur in places other than spawning reaches making population assessments very challenging. Treble and Tallman (1997), for example, attempted to assess the impact of an exploratory commercial broad whitefish fishery in the lower Mackenzie River by comparing catch rate and biological data from five harvest years. They acknowledged many caveats to the assessment including their belief that the commercial harvest was composed of multiple spawning populations. Harris and Taylor (2010a) recently used genetics techniques to verify that at least four spawning populations contribute to the lower Mackenzie River fishery. Treble and Tallman (1997) understood that changes in catch rate could be profoundly influenced by factors other than changes in abundance of contributing populations. They suggested that changes in the timing of migrations or the routes of migrations through the many channels of the Mackenzie River delta could dramatically change annual catch rates at given locations without the population level actually increasing or decreasing. Additionally, the commercial harvest of broad whitefish was considered to be a small fraction of the annual subsistence harvests, for which there were only rough estimates. Biological data they evaluated indicated a mix of immature and mature fish in the harvest with demographic groups distributed differently among main-channel and side-channel habitats in the region (Treble and Tallman 1997). Catch rates were highly variable among sampling periods at given locations but there were no observed trends among fishing sites or among years. Comparisons of annual age, length, and other biological parameter data suggested a relatively stable situation. A similar proportion of older fish among years, with maximum ages exceeding 20 years, led Treble and Tallman (1997) to conclude that the fishery was having a negligible effect on broad whitefish populations in the area. They cautioned, however, that small spawning populations could be overfished in the mixed population environment of the lower river without any noticeable changes in catch rate or biological parameter data. Additionally, while it appeared to them that the commercial harvest level could be increased, Treble and Tallman (1997) could not state how much the harvest could be increased and contended that any increase in harvest level entailed risk of depletion of one or more populations. We expect that the same challenges and uncertainties faced by Treble and Tallman (1997) in their multiple-population broad whitefish assessments in the lower Mackenzie River would be similarly encountered in any whitefish assessments undertaken in the lower Yukon and Kuskokwim rivers in Alaska.

These and other similar accounts of whitefish fisheries and populations indicate that the subfamily of species is very resilient to harvest pressures as long as their essential habitats remain undisturbed and accessible. None-the-less, it is evidently possible to deplete whitefish populations through persistent overharvesting as the histories of the inconnu fishery in Great Slave Lake (Cosens et al. 1993; VanGerwen-Toyne et al. 2010) and the shortjaw cisco fishery in the Laurentian Great Lakes (Gorman and Todd 2007) illustrate. It should also be clear that effective monitoring of whitefish populations is exceedingly difficult, particularly for river spawning populations that distribute widely among river, estuarine, and off-channel habitats (Corkum and McCart 1981; Reist and Bond 1988). Population monitoring and abundance projects for river spawning populations appear to have been effective only when conducted in spawning reaches such as the Chatanika River for humpback whitefish and least cisco (Wuttig 2009; Brase 2010) and the Kobuk and Selawik rivers for inconnu (Taube and Wuttig 1998; Underwood 2000; Hander et al. 2008).

Following their review of commercial and subsistence fisheries in the lower Mackenzie River in northern Canada, Corkum and McCart (1981) made a number of recommendations for improvement of fisheries monitoring and management activities in the region. We believe these recommendations are pertinent for fisheries monitoring activities in the Yukon and Kuskokwim rivers as well so we will explore them in some detail here. Corkum and McCart (1981) estimated that subsistence fisheries accounted for about 80% of the whitefish harvest in the lower Mackenzie River, yet, these fisheries were effectively unregulated and very little biological information from the harvest was available. Subsistence fisheries are similarly unregulated and unstudied in the Yukon and Kuskokwim rivers (Brase and Hamner 2003; Hayes et al. 2008; Whitmore et al. 2008) and almost certainly account for over 90% of the whitefish harvests in the two drainages. The first recommendation of Corkum and McCart (1981) was therefore that studies of the subsistence fisheries be initiated. Priority information should at a minimum include the species, quantity, and life stages (i.e., juvenile, adult, resting, preparing to spawn, etc.) harvested. Additionally, they suggested that fishery impacts on specific populations be evaluated, acknowledging that population specific data were not available at the time. Many studies of subsistence resource use, including fish, have been undertaken in the Yukon and Kuskokwim rivers in Alaska, but, only a small number of recent subsistence fisheries studies have identified whitefish to species, and harvest numbers are estimated in some areas of the drainages from post-season interviews of subsamples of fishing families (Andersen et al. 2004; Brown et al. 2005; Williams et al. 2005). Corkum and McCart (1981) pointed out that there was virtually no information available that could guide management and regulation of commercial fisheries, hence, they recommended detailed studies of potential commercial and other heavily exploited species to enable management.

Their sequential list of priority objectives for these studies included: 1) locate spawning areas; 2) identify migration patterns; 3) describe major life history parameters such as growth rate, age structure, and length distribution of species of interest; and 4) establish a relative abundance index that reflects changes in actual abundance. They contended that this information would be sufficient to decide when and where to fish particular species, demographic groups within species, and to evaluate the effects of a fishery on population abundance and biological parameters. The situation with whitefish species and fisheries in the Yukon and Kuskokwim River drainages is similar in every way to that described by Corkum and McCart (1981) for the lower Mackenzie River, and all of the issues and recommendations they discuss were similarly introduced by delegates in the two Whitefish Strategic Plan Working Group meetings that took place in the early stages of this project. We therefore believe that the research recommendations specified by Corkum and McCart (1981) are valid and appropriate for the Yukon and Kuskokwim River drainages as well.

Development issues

Development of natural resources such as minerals or water, or human infrastructure such as roads or oil storage tanks, may threaten whitefish populations by disturbing essential habitats. Spawning, rearing, feeding, and overwintering habitats are all essential to sustain whitefish populations. Spawning habitats, however, are considered to be the most critical because they are more vulnerable to disturbance than other essential habitats. Spawning habitats in riverine environments are singular geographic regions, often occupying a reach only a few km long, where a large fraction of a population congregates each fall. By contrast, there are many locations used for rearing, feeding, and overwintering that are distributed over the entire range of the population (Brown 2000, 2006; Harper et al. 2007). Disturbing a spawning area by mining the gravel substrate, for example, could destroy a population (Meng and Müller 1988; Brown et al. 1998), while disturbing a rearing channel, feeding lake, or overwintering reach used by members of the population might impact those individuals but would not destroy the entire population. In the following sections we explore some of the development activities taking place in the Yukon and Kuskokwim River drainages in Alaska that have the potential to impact whitefish populations.

Minerals mining

There has been a long history of placer mining for gold and other minerals in Alaska (Boswell 1979; Webb 1985; Spence 1996) and it continues in many regions of the Yukon and Kuskokwim rivers today (Szumigala et al. 2011). Large-scale dredging operations profoundly alter entire valleys (Figure 14) and most certainly impact fish habitat use in those areas. Placer mining physically alters streambed habitats through reorganization or removal of substrate material and releases sediment and dissolved minerals into the waterway (Waters 1995; Spence 1996). These additives increase turbidity, which has been shown to reduce primary production and invertebrate densities downstream from mining activities (Wagener and LaPerriere 1985; Van Nieuwenhuyse and LaPerriere 1986; Lloyd et al. 1987, Reynolds et al. 1989; Milner and Piorkowski 2004). The concentrations of dissolved metals also increase in mined streams, often to levels that can be toxic to aquatic animals (LaPerriere et al. 1985). Significant increases in turbidity from a point source can lead to sedimentation of

Figure 14. An aerial image of the Bear Creek mine in the Hogatza River drainage, Yukon River basin. The streambed was mined with a large floating dredge, rerouting the stream course as necessary. Photo by USFWS staff.

the streambed downstream and subsequent changes in hyporheic flow (Bjerklie and LaPerriere 1985). Large-scale habitat changes caused by mining activities have the potential to impact whitefish populations, particularly if they occur in, or immediately upstream from, essential habitats such as spawning reaches. Round whitefish populations may be more at risk from placer mining habitat disturbance than other whitefish species because placer mining usually takes place in small, upper drainage reaches of streams and rivers.

Streambed gravel mining

Streambed gravel mining has been and continues to be a common way to obtain material for roadbeds, airport runways, and other construction projects across Alaska (Woodward-Clyde Consultants 1980; State of Alaska 2009). In many situations, gravel is mined from rivers using a sling-line bucket dredge (Figure 15). With this technique, the bucket is hurled from shore with a crane and then drawn back to shore full of gravel, which is piled up to drain prior to use. Another common method of mining streambed gravel in rural communities is to simply run a bulldozer or loader onto a gravel bar during low flow periods and scrape gravel off the surface for road, airport, or foundation use. Streambed gravel removal has been shown to change stream channel form, substrate composition, invertebrate and fish communities, surface and subsurface flow patterns, and other physical and biological qualities of rivers (Woodward-Clyde Consultants 1980; Mossa and McLean 1997; Brown et al. 1998; Mas-Pla et al. 1999). The effects of streambed gravel removal may be observed as

Figure 15. Streambed gravel mining with dragline dredges is a common practice in the Yukon and Kuskokwim River drainages. The bucket is slung into the River with the crane and drawn back to the shore full of gravel scraped from the river bottom. This image is of a gravel mining operation in the Tanana River drainage near Fairbanks. Photo by R.J. Brown, USFWS.

much as 1 km (0.6 mile) or more upstream and downstream of the actual mined region (Brown et al. 1998). Streambed gravel removed from whitefish spawning habitats would have a negative impact on spawning activity, as documented by Meng and Müller (1988) for lake spawning populations of whitefish *Coregonus* spp. and Arctic char *Salvelinus alpinus* in Lake Lucerne in Switzerland. Despite the physical and biological changes that follow streambed gravel mining, it is currently permitted on a case-by-case basis by the State of Alaska, Department of Natural Resources. Information on some of the individual sales can be accessed on their website (State of Alaska 2009) with the appropriate Alaska Division of Lands (ADL) case file numbers.

Logging

Large-scale logging activity, including road building into logged areas, can increase surface runoff following precipitation events, accelerate erosion, alter water temperature and chemistry in nearby streams and lakes, and reduce low flow volumes within drainage basins (Hartman et al. 1996; Sahin and Hall 1996; Martin et al. 2000). Habitat effects of logging activities are most commonly identified in small drainage basins in which 20% or more of the basin area has been logged (Stednick 1996). Larger drainage basins appear better able to absorb hydrological changes due to logging without measurable effects (Buttle and Metcalfe

2000). Currently, commercial-scale logging in the Yukon and Kuskokwim River drainages in Alaska is confined to the Tanana River drainage. The Tanana River drainage would certainly be considered a large drainage basin by Buttle and Metcalfe (2000), and the logging activity that occurs there is much smaller in scale than operations in Southeast Alaska or the Pacific Northwest. Logging is therefore not thought to be a major development issue relative to whitefish populations at this time.

Roads

Road building activities, whether for logging or other purposes, often result in channelization of adjacent rivers, with bank stabilization efforts in some places and isolation of off-channel lakes and sloughs in other places (Hesse et al. 1989; Harper and Quigley 2000; Roni et al. 2002). Access to off-channel habitats is essential for many riverine fish species (Junk et al. 1989; Ward and Stanford 1989; Galat and Zweimuller 2001) and the isolation of these habitats has resulted in the collapse of large-river fisheries in many developed regions of the world (Fremling et al. 1989; Hesse et al. 1989; Lelek 1989). In addition to direct environmental changes resulting from road construction, as described above, roads increase human access to previously remote areas, which facilitates increased recreational use of resources by a larger community of people (Wheeler et al. 2005). Substantial environmental degradation commonly occurs following unregulated use of off-road vehicles such as airboats, four-wheelers, etc., along remote roadways in the State (Figure 16; Racine and Ahlstrand 1991; Racine et al. 1998). Environmental impacts due to the construction of new roads are considered to be relatively minor at this point in the Yukon and Kuskokwim River drainages, but impacts are progressive and should be considered during the planning stages of any new road building activities in Alaska. After all, large-scale channelization and isolation of off-channel habitats in other river systems did not happen all at once either (Carlson and Muth 1989; Fremling et al. 1989).

Figure 16. Airboat (left image) and all-terrain vehicle (right image) trails across the Tanana River flats south of Fairbanks. Airboats do not require water so they facilitate access to many otherwise inaccessible places in a river floodplain. They leave behind distinct trails that can drain wetlands, swamps, and ponds they traverse (Racine et al. 1998). Wheeled all-terrain vehicle trails across boreal forest lowlands in interior Alaska become muddy ditches as vegetation is removed and underlying permafrost melts (Racine and Ahlstrand 1991). Photos by USFWS personnel.

Contaminants and hazardous material spills

Spills of petroleum oils and other hazardous substances are common events in the Yukon and Kuskokwim River drainages in Alaska (ADEC 2007). Spilled petroleum products may persist in sediments for decades after release, slowly leaching into aquatic environments. When oil is spilled it can have an immediate, acute, negative effect on fish and other aquatic organisms, killing or impairing them through direct contact that may block oxygen uptake, or ingestion, which may compromise other physiological functions (Law and Hellou 1999; Peterson et al. 2003). Heras et al. (1992) found that Atlantic salmon *Salmo salar* exposed to sub-lethal levels of dissolved petroleum oils became measurably contaminated in laboratory concentration tests and that people could reliably identify contaminated from control fish in taste tests. Oil contamination has a much greater impact on the survival and fitness of eggs, larvae, and juvenile fish than on adult fish, primarily because of their inability to leave contaminated habitats. In a multi-year field study in Prince William Sound following the Exxon Valdez oil spill, Bue et al. (1998) found that there was significantly greater mortality in pink salmon *Oncorhynchus gorbuscha* embryos developing in oiled streams than in non-oiled streams. In a subsequent experimental study, Heintz et al. (2000) found that when developing pink salmon embryos were exposed to very low levels of dissolved hydrocarbon (5.4 ppb) they experienced reduced growth and survival compared to control groups of unexposed fish. Similarly, Meador et al. (2006) reported reduced growth and fitness and increased mortality of juvenile Chinook salmon that were fed invertebrates exposed to low levels of dissolved hydrocarbons compared to a control group of fish that were fed uncontaminated food. These and many other similar studies clearly indicate that oil in the environment is never a positive ecological attribute.

The Alaska Department of Environmental Conservation (ADEC 2007) recorded 4,955 spills of oil and other hazardous fluids within the Yukon and Kuskokwim River drainages in Alaska during the 10-year period between 1995 and 2005. The average spill rate within this geographic region was 496 reported spills per year, which released an average of 330 m^3 (87,100 gallons) of hazardous fluids into the environment every year. There are many ways in which spills occur including rollovers of fuel trucks, train de-railings, overfilling fuel tanks, airplane accidents, equipment failures in tank farms, sabotage, mining accidents, and more. In October 2001, for example, a man shot a hole in the Trans-Alaska Oil Pipeline near the community of Livengood releasing over 1,081 m^3 (285,600 gallons) of crude oil into a tributary basin of the Tanana River (Figure 17; ADEC 2002). Most but not all of this oil was subsequently recovered. In late May 1990 an Alaska Railroad tanker train derailed, spilling about 379 m^3 (100,000 gallons) of diesel fuel in the Goldstream Creek basin, a tributary of the Tanana River (ADEC 2007). In 2004 the U.S. Fish and Wildlife Service and the community of Huslia worked together to recover diesel fuel that had been cached by a mineral exploration company more than 40 years before in 171 barrels on a river bank in Billy Hawk Creek, a tributary of the Koyukuk River (Figure 18; USFWS 2004). Some of the fuel was still contained in the barrels and was recovered but the ground at the site was heavily contaminated with oil from leaky barrels and remains at the site. In February 1995, the Clear hatchery spilled 1,749 m^3 (462,000 gallons) of dissolved sodium dichromate, a hazardous salt solution, in the Nenana River basin, a tributary of the Tanana River (ADEC

Figure 17. Images of the Trans-Alaska Pipeline shooting incident in October 2001 near Livengood, Alaska (left), and one of many dislodged and leaking fuel oil tanks in Eagle, Alaska following the extraordinary breakup of May 2009 (right). Photos courtesy of the Alaska Department of Environmental Conservation.

Figure 18. Aerial images of two common types of industrial fuel spills. On the left is an Alaska Railroad derailment of fuel cars in which a large quantity of fuel was spilled (photo courtesy of the Alaska Department of Environmental Conservation). On the right is a photograph of a cache of leaky fuel barrels on Billy Hawk Creek, a tributary stream within the Koyukuk River drainage. These barrels, which contained diesel fuel, had been left at the site for over 40 years before their discovery in 2002 by residents of Huslia (photo by USFWS staff).

2007). Fuel oil and other petroleum products have been spilled in many rural communities and mining sites throughout our study region. A few examples include: 500 m^3 (132,000 gallons) of diesel spilled from the BIA tank farm in Bethel in 1993; 11 m^3 (3,000 gallons) of aviation fuel spilled at Illinois Creek mine south of Galena in 1981; 17 m^3 (4,500 gallons) of fuel oil spilled in Arctic Village in 1983; 34 m^3 (9,000 gallons) of diesel spilled during a fuel truck accident on the Taylor Highway, Fortymile River drainage, in 1995; 26.5 m^3 (7,000 gallons) of methanol spilled during a truck accident on the Dalton Highway, north of the Yukon River, in 1990; 129 m^3 (34,000 gallons) of fuel oil spilled in Nulato in 1989; 4 m^3 (1,070 gallons) of diesel spilled at the Nixon Fork mine in the upper Kuskokwim River in 2005; 5.7 m^3 (1,500 gallons) of diesel spilled in Kipnuk in 2002; 47 m^3 (12,400 gallons) of diesel spilled in Allakaket during the flood of 1994; 4 m^3 (1,100 gallons) of diesel spilled at the Yukon Delta Fish Coop in Emmonak in 1998; and a substantial but unknown quantity of fuel oil spilled in Eagle during breakup in May 2009 (Figure 17; ADEC 2007, 2009). More petroleum products have been spilled in the Fairbanks area than in rural regions of our study area, probably because more petroleum products are handled and used there (ADEC 2010). Between 1978 and 2005 there were 28 major spills, those releasing 3.8 m^3 (1,000 gallons) or more, originating in the North Pole refinery and other bulk fuel storage facilities in the Fairbanks area. These spills released a combined total of more than 1,022 m^3 (270,000 gallons) of petroleum products into the environment. In 2004, a tanker jet operating out of Eielson Air Force Base dumped 132 m^3 (35,000 gallons) of diesel in the Tanana River drainage. In 2004, a military jet crashed near Eielson Air Force Base spilling 57 m^3 (15,000 gallons) of aviation fuel. In addition to the hundreds of above-ground spills that occur each year in our study area, the Alaska Department of Environmental Conservation (ADEC 2010) has overseen cleanup operations of over 500 leaky underground fuel storage tanks during the last 25 years. Because petroleum products: 1) persist for many years in sediments (Peterson et al. 2003); 2) are harmful to fish in very small concentrations in water or food (Heintz et al. 2000; Peterson et al. 2003; Meador et al. 2006); and 3) are spilled frequently and in large quantities in our study area (ADEC 2007); we consider them to be serious threats to the quality of aquatic habitats and fish populations within the Yukon and Kuskokwim River drainages.

Dams and water control

Fish populations are more profoundly impacted by dams than by any other single development activity (Baxter and Glaude 1980; Rosenberg et al. 1997). Dams impede the free migration of fish (Ebel et al. 1989; Dyubin 2007), reduce the amplitude of a river's high and low flow cycles (Ye et al. 2003; Yang et al. 2004), reduce sediment transport within drainages (Rosenberg et al. 1997), release methylmercury into the food chain (Bodaly et al. 1984a), produce large quantities of greenhouse gasses (Rosenberg et al. 1997), change fish community structure (Ward and Stanford 1989), and reduce the water temperature downstream through hypolimnetic withdrawal (Lehmkuhl 1972; Carlson and Muth 1989; Junk et al. 1989). The changes to a river system following the construction of dams have resulted in dramatic declines in native migratory fish populations, the collapse of many commercial and domestic fisheries (Bodaly et al. 1984b; Ebel et al. 1989), and the replacement of previously dominant species with other species more suited to the new environmental conditions (Carlson and Muth 1989).

There are currently more than 39,000 large dams worldwide, most having been built during the last 60 years (Rosenberg et al. 1997). Large dams, those >15 m (50 feet) in vertical height, have been constructed on most large, northern hemisphere rivers (Dynnesius and Nilsson 1994). Large rivers were defined as those with mean annual flow rates of 350 $m^3 \cdot s^{-1}$ (12,360 $feet^3 \cdot s^{-1}$) or greater. The volume of water impounded in the reservoirs created by these dams, which are concentrated more in the northern than southern hemispheres, have reduced global sea levels by approximately 3 cm (1.2 inches) and caused the earth to rotate faster with a small but measurable reduction in day length (Chao 1991, 1995). Many large North American rivers are encumbered with multiple dams. As of 1998, for example, the Columbia River in the Pacific Northwest had seen the construction of 184 large dams within its watershed (Revenga et al. 1998), which effectively destroyed its world-class anadromous salmonid fisheries (Ebel et al. 1989). Similarly, the Colorado River watershed has seen the construction of 265 large dams (Revenga et al. 1998). Current water usage from Colorado

River reservoirs has reduced flow to such an extent that the river rarely reaches its mouth at the northern end of the Sea of Cortez (Carlson and Muth 1989). The Mississippi River, the largest drainage in North America, has more than 2,000 large dams within its watershed (Revenga et al. 1998). Human population plays a major role in the decision to build large dams on rivers so there are many fewer dams on the northern rivers of Alaska and Canada than on rivers in more populated regions to the south.

There are no large dams in the drainages of the Yukon River in Alaska or the Kuskokwim River, although there have been several small diversion dams constructed in tributary systems. A large, hydroelectric dam, however, was constructed in 1958 across the Yukon River near the community of Whitehorse, Yukon Territory, in the Canadian portion of the drainage (Figure 19; Gordon et al. 1960). The Whitehorse Rapids Dam is an earth and concrete structure approximately 18 m (59 feet) tall that created a lake 30 km (18.5 miles) long. The dam was equipped with a fishway in 1959 to allow salmon and other fish species to pass the barrier. One of the tributary system dams in the Alaska portion of the drainage was constructed in the 1940s on the south fork of Hess Creek (Spence 1996), which naturally drains into the Yukon River approximately 83 river km (52 miles) downstream from the Yukon Flats. The dam created a lake approximately 2.5 km (1.5 miles) long and 0.5 km (0.3 miles) wide. The impounded water was diverted via an underground aqueduct to Livengood Creek, a Tanana River tributary, to provide additional water to that stream for a gold dredging operation. In another case a small dam was constructed in the mid-1920s in the upper Chatanika River, Tanana River drainage, to divert stream water into a 140 km (87 mile) long aqueduct called the Davidson Ditch, which provided water to another mining operation (Figure 20; Spence 1996). That dam was removed in 2002 allowing upstream fish migration again after being a barrier for more than 75 years (Brase 2008). In 1979, a large diversion dam was built on the Chena River, Tanana River drainage, to divert floodwaters from the Chena to the Tanana River, providing protection to the community of Fairbanks (Figure 20; Williamson 1984; Rozell 2003). There was a proposal in the 1960s to construct a large-scale hydroelectric dam across the Yukon River at the Rampart Canyon, approximately 1,176 river km (731 miles) from the mouth (USFWS 1964). The proposed dam would have been 160 m (525 feet) tall and would have created a lake 450 km (280 miles) long and 130 km (81 miles) wide, which would have flooded the entire Yukon Flats and beyond. A similar hydroelectric dam was considered by the U.S. Army Corps of Engineers for the Kuskokwim River near the community of Crooked Creek in the 1950s (Alaska Geographic 1988). If built, these large dams would have compromised the river's fisheries, including those involving Pacific salmon and whitefish species, just as dams have impacted fisheries in every other river system where they have been built (Bodaly et al. 1989; Carlson and Muth 1989; Ebel et al. 1989). Hydroelectric dams continue to be discussed in Alaska despite their negative impacts on fish populations. It would not be surprising to see dam construction proposals resurface for the Yukon or Kuskokwim River drainages at some future time, particularly if the human population in Alaska expands and the price of other sources of electrical power increases.

Development conclusion

Many of the effects from development activities described above would have a minimal impact individually on whitefish populations and whitefish habitats within the Yukon and

Figure 19. The hydroelectric dam on the Yukon River at the community of Whitehorse, Yukon Territory (on left). Photo courtesy of Yukon Energy Corporation. The dam was built in 1958 and is 18 m (59 feet) tall (Gordon et al. 1960). A fish ladder (on right) was completed in 1959 to facilitate fish migration past the dam.

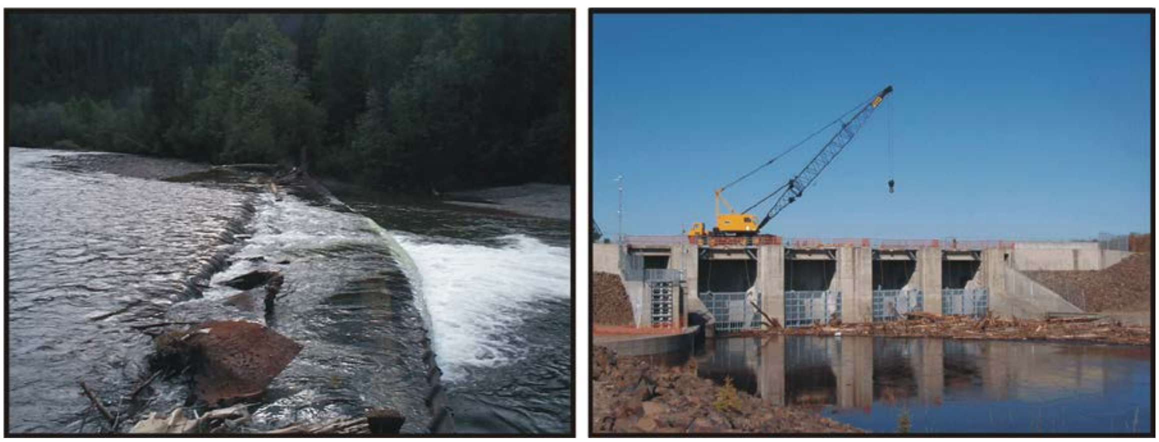

Figure 20. Two dams within the Tanana River drainage. The Chatanika River dam was constructed in 1925 to divert water from the Chatanika River into the Davidson Ditch, a 134 km (83 mile) canal that provided water to mining operations near Fairbanks (Spence 1996). It was later used to produce electricity and was eventually removed from the river in 2002. This photograph of the remnant dam (on left), courtesy of E. Mayer, USFWS, was taken shortly before removal. The Chena River flood control dam (right) was constructed in 1979 to divert water from the Chena River towards the Tanana River during times of exceptionally high flows and prevent flooding in the community of Fairbanks (Rozell 2003). This image, courtesy of M. Osborne, USFWS, is of driftwood removal at the dam shortly after a flood event.

Kuskokwim River drainages. Activities that impede access to, or physically alter essential whitefish habitats, such as dam construction or riverbed mining, would be expected to have the largest impact on whitefish populations. Development effects on fish habitats within river systems are known to be additive, as described by Carlson and Muth (1989) in their historical accounting of over 100 years of water use in the Colorado River drainage, and Limburg et al. (1989) in their account of development history in the Hudson River drainage. A particular development activity, for example, may have a minor effect on fish populations within a drainage, but cumulatively, the sum effects of all development activities, off-channel habitats isolated here, streambed gravel mining there, dikes stabilizing a river along a particular stream reach, a dam in that tributary, a placer mine in another tributary, etc., will profoundly affect fish populations (Brown and Moyle 2005; Hughes et al. 2005; Simon et al. 2005). The Yukon and Kuskokwim River drainages are relatively unaffected by development compared to many large rivers in the lower 48 states and other more developed regions of the world, but they are subject to the same consequences of cumulative development impacts over time. Specific cases of previous, current, and planned development activities will be examined, as they relate to whitefish populations and whitefish habitats, in the sections devoted to regional issues.

Natural environmental issues

Climate change

Human beings have known for several decades that the world was in a warming period that would change certain large-scale aspects of the environment including patterns of precipitation, duration of the growing season, glacier growth and decline, seasonal and permanent sea ice coverage, global sea level, and more (Weart 2008). Many modern societies have supported scientific work attempting to understand the physical basis for the observed warming trend and predict the course of environmental change, which theoretically would enable us to prepare for predicted changes. A small part of the overall climate change research effort has been devoted to the effects of climate change on fish populations and fisheries, which is the focus of this section.

The general effects of climate change on freshwater and anadromous fish habitats and populations have been considered by numerous individuals and organizations. It is generally agreed among those who have examined this issue that the most direct effects of global warming on northern freshwater habitats will be an increase in average and maximum annual water temperatures and an expanded ice-free season (Reist et al. 2006a, 2006b; Ficke et al. 2007). Precipitation patterns may vary in some regions resulting in changes in the timing of stream flow events each year, the proportion of surface versus ground flow, the annual flow volume, and other hydrological qualities (Wrona et al. 2006; Woo et al. 2008; Bryant 2009). Because fish are poikilotherms, their body temperature equalizes with environmental temperature. The warming environment will affect fish directly because many of their physiological processes such as egg development, digestion, growth, and spawning are temperature dependent (Reist et al. 2006a; Ficke et al. 2007). On a continental basis, the southern ranges of cold water fish species are predicted to shift northward as their most southern habitats become too warm. Migration north might be possible for populations in north-south oriented rivers. If temperatures in lake systems and east-west oriented rivers become too warm for cold water fish to thrive, however, their populations would eventually die off and be replaced by species better adapted to warmer water. Alternatively, if a warming trend was gradual enough fish populations might develop genetic adaptations to the new thermal environment. Other possible consequences of climate change that have been considered for northern fish populations include: an increase in riverine sediment loads because of melting permafrost (Wrona et al. 2006; Bowden et al. 2008); an asynchrony in the timing of juvenile fish dispersal and prey abundance (Bryant 2009); increased primary productivity in lakes and rivers experiencing longer solar exposure due to an extended ice-free season (Reist et al. 2006b); increased toxicity to fish of chemical pollutants (Ficke et al. 2007); changes in virulence of disease organisms and infection rates of parasites in warmer environments (Arsan and Bartholomew 2008; Kocan et al. 2009); changes in the marine distribution of fishes as oceanic thermal boundaries move northward (Welch et al. 1998; Mueter and Litzow 2008); and more. In the following section we examine a few of the most direct environmental effects of climate warming in Alaska and discuss some possible responses by whitefishes in our study area.

The climate in interior Alaska has warmed measurably during the last few decades and this warming trend is expected to continue for the foreseeable future (Serreze et al. 2000; Hinzman et al. 2005; Riordan et al. 2006). Effects of this warming trend on the aquatic system in the Yukon and Kuskokwim River drainages include changes in annual river flow patterns (Brabets and Walvoord 2009), reduced duration of ice cover on rivers and lakes (Magnusson et al. 2000), widespread permafrost thawing (Jorgenson and Osterkamp 2005), thicker active layer (Osterkamp 2007), increased subsurface flow volumes (Walvoord and Striegl 2007), reduced surface area and volume of lakes (Riordan et al. 2006), retreating glaciers (Molnia 2007), and other environmental qualities. Two of the most notable changes, as they relate to whitefish populations, are: 1) reduced duration of ice cover resulting from earlier average breakup and later average freeze-up times of rivers and lakes (Magnusson et al. 2000; Burn 2008; Brabets and Walvoord 2009); and 2) widespread permafrost thawing resulting in a thicker active layer (material above the permafrost that freezes in winter and thaws during summer), which has caused many flatland lakes to dry and increased the ground-flow input to rivers (Figure 21; Riordan et al. 2006; Osterkamp 2007; Walvoord and Striegl 2007; Woo et al. 2008).

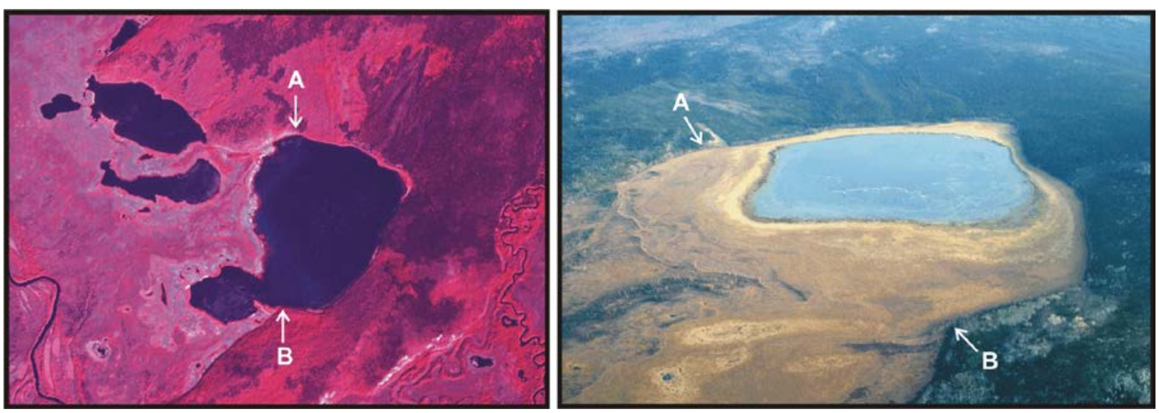

Figure 21. A drying lake in Minto Flats, Tanana River drainage. The image on the left is a high altitude aerial photograph taken in August 1978 and the image on the right is a photograph taken from an airplane in September 2009. Points A and B indicate geographic reference points in the two images, illustrating a significant reduction in lake surface area over the 31 year time interval. The high altitude aerial photo is archived at the GeoData Center at the University of Alaska Fairbanks. The photo on the right is by R.J. Brown, USFWS.

Magnuson et al. (2000) examined long-term trends (up to 150 years) in breakup and freeze-up dates for 39 rivers and lakes in Europe, Asia, and North America and found that breakup averaged 6.5 days earlier and freeze-up averaged 5.8 days later now than they did 100 years ago. Brabets and Walvoord (2009) used long-term records for the Yukon River at Dawson and the Tanana River at Nenana to show that breakup in both locations averaged about 8 days earlier now than they did 100 years ago. Burn (2008) examined several stream flow trends in the upper Mackenzie River drainage in western Canada, including a measure of breakup but not freeze-up, and identified a significant trend during the last 45 years towards earlier breakup timing for most tributaries in that nearby drainage basin. These trends in earlier breakup and later freeze-up dates, which are thought to be occurring throughout the Yukon and Kuskokwim River drainages, would increase the average open water period each year by about 2 weeks compared to 100 years ago. The open water period is the primary feeding time for whitefish species (Alt 1969a; Reist and Bond 1988; Lambert and Dodson 1990) so annual growth should be greater now than it was 100 years ago. If the trend continues, as expected, annual growth should continue to increase. Increased annual growth in whitefish populations should lead to younger ages at maturity. Spawning season for most riverine whitefish populations, as discussed earlier, occurs as water temperature declines towards 0ºC (32ºF), just prior to freeze-up. If the trend towards later freeze-up continues, spawning season will probably also occur later. Howland et al. (2000) presented a latitudinal analogy to this phenomenon in the Mackenzie River drainage, a large north-south oriented river in Canada, when they documented a northern inconnu population spawning 2 to 3 weeks earlier than a southern population. If the trend towards earlier breakup continues as well, egg development time would probably be reduced. Larvae would still be expected to hatch and emerge at or shortly after breakup, whenever it occurs, because of rapid accumulation of degree-days as the water warms just prior to breakup. If prey species are similarly available and predator abundance is not dramatically different for the earlier emerging whitefish larvae, they may be resilient to the timing shift. The current trend towards longer ice-free and shorter ice-covered seasons in the Yukon and Kuskokwim River drainages is likely to have an overall neutral effect on whitefish populations, even though age at maturity may decline and the timing of spawning and emergence may change.

Permafrost thawing across the Yukon and Kuskokwim River drainages is implicated in landscape-scale lake drying events (Riordan et al. 2006), increased groundwater flow (Walvoord and Striegl 2007; Woo et al. 2008), increased winter flow levels in rivers (Brabets and Walvoord 2009), and the increased occurrence of thaw slumps and landslides throughout the north (Jorgenson and Osterkamp 2005; Lipovsky and Huscroft 2007; Bowden et al. 2008). Riordan et al. (2006) analyzed changes in lake surface areas from over 7,000 closed-basin lakes in several interior Alaska lake districts using a chronological series of aerial images from the last 60 years. They found an average reduction in lake surface areas from the different lake districts of 10 to 36%. They attributed these findings to two primary factors: an increased thaw depth of underlying permafrost due to warming climate trends and extensive wildfires (Osterkamp et al. 2000; Jorgenson et al. 2001; Yoshikawa et al. 2003; Lewkowicz and Harris 2005; Lipovsky et al. 2006; Osterkamp 2007), which lowers the water table allowing more water to escape from the lake basins; and a longer and warmer summer season (Serreze et al. 2000; Hinzman et al. 2005), which increases evaporation. Closed-basin lakes within the major lake districts in interior Alaska (see Arp and Jones 2009) are not as likely to support fish as seasonally or permanently open lake systems (Glesne et al. 2011). However, if similar permafrost thawing processes are occurring in the vicinity of open lake systems in river floodplains, and open lakes experience reduced water levels during low flow periods similar to the closed-basin lakes examined by Riordan et al. (2006), then seasonal access to these lakes may become more difficult for broad whitefish, humpback whitefish, and least cisco, species that colonize open lake systems during summer for feeding (Alt 1979a; Brown 2006; Harper et al. 2007). The primary impact of lake drying on whitefish species in the Yukon and Kuskokwim River drainages may therefore be an overall reduction in feeding habitat for the lake-feeding species.

A secondary impact of lake drying may be that fish experience an increased incidence of confinement in seasonally open lake systems and experience mortality events during warm weather if water temperature increases to lethal levels, or during winter if feeding fish are prevented from leaving a lake that can't support overwintering. Beitinger et al. (2000) reviewed the temperature tolerances of over 110 species of North American freshwater fish including nine in the family Salmonidae, although none in the subfamily Coregoninae. The salmonid species they did consider had maximum thermal limits between 25°C (77°F) and 30°C (86°F). Jacobson et al. (2008) empirically identified lethal temperature and dissolved oxygen levels for lake cisco by monitoring 17 lakes in Minnesota during summer mortality events. The lethal oxythermal boundary was a curved function with a greater dissolved oxygen requirement at higher temperatures. For example, mortality events occurred when the temperature increased to 24°C (75°F) if the dissolved oxygen concentration was at saturation level, approximately 8 $mg \cdot L^{-1}$, and at 22°C (72°F) if the dissolved oxygen concentration was 5 $mg \cdot L^{-1}$. Whitefish species in Alaska are likely to have similar or lower maximum thermal limits as lake cisco in Minnesota lakes because of their close taxonomic relationship and the colder Alaska environment.

Shallow lakes that are commonly used as summer feeding habitats by broad whitefish, humpback whitefish, and least cisco routinely warm to lethal or near lethal temperatures in interior Alaska and elsewhere in the boreal forest region. Pienitz et al. (1997), for example, conducted a limnology study on 59 lakes in northwestern Canada, including 17 boreal forest lakes in the Yukon River drainage in Canada. They recorded maximum summer temperatures greater than 20°C (68°F) in 11 of the boreal forest lakes, and two of the lakes reached maximum temperatures of 23°C (73°F). During 21 years of continuous temperature monitoring in the experimental lakes region of Northern Ontario, Canada, Schindler et al. (1996) reported maximum summer temperatures ranging from about 20°C (68°F) to 25°C (77°F). Similarly, Harper et al. (2007) monitored water temperature during the summers of 2002 and 2003 at the outlet of Whitefish Lake in the lower Kuskokwim River drainage and reported maximum temperatures of 24°C (75°F) during both years. The National Park Service has been monitoring physical and chemical parameters in a number of shallow lakes in the upper Yukon River drainage in Alaska and recorded maximum temperatures between 23°C (73°F) and 26°C (79°F) during warm periods in the summer (A. Larson, National Park Service, Fairbanks, pers. com.). By contrast, the larger river systems appear to remain cooler than the shallow lakes and are thought to provide thermal refugia to fishes when lakes become too warm. For example, continuous summer water temperature records from the Rapids Research site on the Yukon River, approximately 1,176 rkm (731 miles) from the sea, revealed annual maximum temperatures during the last 8 years that ranged from 18°C (64°F) to 22°C (72°F; D. Daum, USFWS, Fairbanks, unpub. data). These data indicate that lake-feeding whitefish species are potentially at risk of encountering lethal thermal environments during their summer feeding periods and that stream connections between lake and river systems (Figure 22), as described by Marsh and Hey (1989) and Rowland et al. (2009), would be critical escape corridors during warm periods. If migratory corridors between highly productive foraging lakes and cooler river systems were reduced across the landscape

Figure 22. A lake system in the northern Yukon Flats with a stable connection to the Christian River (left image) and a drying lake in the southern Yukon Flats that no longer maintains a stream connection to Birch Creek (right image). Lakes with stable connections to nearby rivers are optimal summer feeding habitats for broad whitefish, humpback whitefish, and least cisco. Photos by R.J. Brown, USFWS.

due to overall lower water levels, lake-feeding whitefish species could experience an increase in the occurrence of summer mortality events.

Increasing the thickness of the active layer of soil and vegetation across a landscape allows it to hold more water. This phenomenon is considered to be a major factor in recently observed increases in groundwater contribution to streamflow in general, and to winter baseflow specifically in the Yukon River basin (Walvoord and Striegl 2007; Brabets and Walvoord 2009) and in other northern river systems in Canada and Asia (Serreze et al. 2003; Woo et al. 2008). Reist et al. (2006a) suggest that increased groundwater flow may improve overwintering conditions for many northern riverine species. Schreier et al. (1980), however, point out that groundwater usually has lower levels of dissolved oxygen than surface water flowing in stream channels. This generalization was supported by Maclean (2003), who measured groundwater chemistry during summer and winter with piezometers in a chum salmon spawning area of the Chena River, Tanana River drainage. He found that groundwater seeping into the river channel from terrestrial origins, which includes water moving through the active layer, had low dissolved oxygen concentrations, consistently less than 2 $mg \cdot L^{-1}$. By contrast, hyporheic groundwater, stream water flowing through porous gravel within the riverbed, had dissolved oxygen concentrations that were generally greater than 2 $mg \cdot L^{-1}$, which was much more favorable for egg incubation. The dissolved oxygen concentration in ice covered rivers declines dramatically from ice-free levels primarily because the ice prevents atmospheric diffusion (Whitfield and McNaughton 1986; Schreier et al. 1980). Schallock and Lotspeich (1974) measured seasonal dissolved oxygen concentrations in numerous Alaska rivers including several sites within the Yukon River drainage. They discovered that there was a distinct dissolved oxygen depression during winter at all sites and that the depression was most extreme in the lower Yukon River where winter levels dropped to as low as 2 $mg \cdot L^{-1}$. Similar conditions undoubtedly prevail in the lower Kuskokwim River as well. While an increase in the groundwater contribution to Yukon and Kuskokwim River baseflow levels during winter may increase the volume of water in river channels, which may be a positive change for fish, it is also likely to reduce the quality of the overwintering environment for fish because of a groundwater induced depression of dissolved oxygen levels. It is therefore unclear whether an increase in active layer thickness because of permafrost thawing would have an overall positive, negative, or neutral effect of fish.

In addition to increased groundflow, lower water table, and thicker active layer, permafrost thawing across Arctic and sub-Arctic environments has resulted in an increasing incidence of thaw slumps, landslide events, and other thermokarst features, which alter landscapes and may contribute large quantities of sediment into aquatic systems (Figure 23; Jorgenson et al. 2001; Jorgenson and Osterkamp 2005; Lipovsky et al. 2006; Lipovsky and Huscroft 2007; Bowden et al. 2008). Bowden et al. (2008), for example, recently documented 34 permafrost thaw features along the north slope of the central Brooks Range, more than 20 of which were new since 1980 as revealed by a series of aerial photos taken at that time. One of the slumps that began in 2003 in the upper Toolik River drainage has increased the concentration of suspended sediment in the drainage during certain flow conditions by more than an order of magnitude compared to pre-slump levels. Jorgenson et al. (2001) presented evidence based on aerial photographs and radiocarbon data that there has been a progressive degradation of permafrost in the Tanana River flats in interior Alaska since the late 1700s, converting birch forests to thermokarst ponds. They predicted that if the current warming trend continued, the remaining lowland birch forests in the flats would be gone by the year 2100. Lipovsky and Huscroft (2007) analyzed aerial images and conducted an aerial survey of permafrost-related slumps and landslides in the Pelly River watershed in the upper Yukon River drainage in Canada during 2006. They identified 52 slumps and 47 landslides that were caused by thawing permafrost, some of which began after 1980. Eight of the permafrost-related slumps were emitting sediment directly into rivers and streams in the watershed. A similar type thaw slump began emitting sediment into the Selawik River drainage in northwest Alaska in 2004, changing the river in an instant from clear to turbid during the summer months (Hander et al. 2008). Since it began, the Selawik River thaw slump has inundated the gravel-substrate of the inconnu spawning reach downstream with turbid flow throughout the open-water season. Sedimentation of whitefish spawning gravel is known to have a negative effect on egg development and survival (Fudge and Bodaly 1984). The long-term effects of the Selawik River thaw slump on that inconnu population is unclear at this time, but if it continues for decades, as similar thaw slumps have in the upper Yukon River drainage (Burn and Friele 1989), it may ruin that spawning reach. Permafrost throughout the boreal forest region appears to be on a warming trend (Osterkamp and Romanovsky 1999) and given the overall warming trend that has been documented in the north (Hinzman et al. 2005), it is likely to continue degrading, particularly in areas of discontinuous coverage. Permafrost thaw slumps and landslides are therefore expected to continue occurring for the foreseeable future, perhaps with increased frequency. The resulting sedimentation of river systems has the potential to destroy whitefish spawning habitats in the Yukon and Kuskokwim River drainages if the thaw events occur at or in close proximity to spawning reaches.

Beaver dams

Beaver dams in drainage basins alter flow patterns, create lake habitats, and influence fish distribution (Figure 24; Naiman et al. 1988; Collen and Gibson 2001). Dam construction is usually limited to first and second order streams or backwater sloughs. Dams are occasionally washed away and routinely submerged during high flow events. Rivers in Alaska experience high flows each spring as the winter’s accumulation of snow and ice

Figure 23. Sediment flows following natural environmental events. In the image on the left, a mudslide flowed off a hillside and filled the valley floor after a fire burned the organic layer and the underlying permafrost thawed in the Hodzana River, Yukon River drainage (photo courtesy of R. Jandt, Bureau of Land Management). The image on the right is the Kalzas Slide, a large permafrost thaw slump that oozes into the MacMillan River, upper Yukon River drainage. It is expected to release large quantities of sediment into the river for many years (photo courtesy of P. Lipovsky, Yukon Geological Survey).

Figure 24. A beaver dam across American Creek, a small stream in the upper Yukon River drainage in Alaska (left image). Beavers have great difficulty maintaining dams across actively flowing streams such as this. Photo by D.W. Daum, USFWS. Beaver dams such as the one in the right image often block fish passage across waterways in Alaska during low flow periods. High flow periods allow fish passage across most beaver dams within river floodplains. Photo by R.J. Brown, USFWS.

melts, and periodically during the summer and fall following periods of rain (Brabets et al. 2000; Trawicki 2000). Beaver ponds within drainage basins increase water surface area compared to undammed basins, which leads to higher average water temperatures during the summer (Gard 1961; Bryant 1984; McRae and Edwards 1994; Collen and Gibson 2001). Aquatic plant and invertebrate communities shift from those favoring flowing water to those favoring lakes (McCafferty and Provonsha 1983; McDowell and Naiman 1986). Fish exploit beaver ponds and segregate by species and age classes among habitats (Murphy et al. 1989; Schlosser 1995; Collen and Gibson 2001). The tendency of fish to sort by habitat led Snodgrass and Meffe (1999) to characterize many species observed in their study as either "pond fish" or "stream fish" accordingly.

Juveniles of many riverine and anadromous species rear in lake habitats such as beaver ponds. Murphy et al. (1989), for example, found that juvenile sockeye *Oncorhynchus nerka* and coho *O. kisutch* salmon were more abundant and grew faster in beaver ponds and sloughs than in flowing water habitats in the Taku River watershed in southeast Alaska. Schlosser (1995), in the upper Mississippi River drainage, and Snodgrass and Meffe (1999), in the Savanna River drainage, also reported a greater abundance of juvenile fish in beaver ponds than in nearby riverine habitats. In interior Alaska, Brown and Fleener (2001) reported large catches of juvenile broad whitefish, humpback whitefish, least cisco, and northern pike *Esox lucius* in dammed oxbow lakes and none in adjacent riverine habitats in the Black River drainage in the Yukon Flats. Many additional studies of fish habitat use have reported similar findings indicating that beaver ponds are essential habitats for the early life stages of many fish populations (Collen and Gibson 2001).

While beaver dams diversify the aquatic ecology of a watershed, maintain lake habitats within a larger riverine environment, and provide essential rearing habitat for juvenile fish, they can also restrict fish migration, particularly during times of low stream flow. Cunjak and Therrien (1998), for example, observed mature Atlantic salmon gathered below a beaver dam on Catamaran Brook in eastern Canada, apparently unable to migrate to upstream spawning sites. In a tagging study in northern California, however, Gard (1961) showed that three trout species (Salmonidae spp.) routinely ascended and descended a watershed blocked with numerous beaver dams by jumping some dams and by muscling their way through others. Similarly, Bryant (1984) reported that mature coho salmon routinely migrated past beaver dams up to 2 m (7 feet) high in southeast Alaska streams. Also in southeast Alaska, large numbers of tagged juvenile sockeye and coho salmon were shown to migrate over beaver dams directly during high flow periods and through leaky dams during lower flow periods (Murphy et al. 1989). Brown and Fleener (2001) monitored water level in three dammed oxbow lakes in the Black River drainage in interior Alaska and identified several high-flow periods during the summer when fish were able to swim past dams in either direction, thus demonstrating that beaver dams within floodplains are not permanent obstructions to fish migration. None-the-less, some beaver dams may block migration of fish at critical times and prevent fish from reaching spawning reaches, feeding areas, or overwintering habitats. Brown (2006), for example, documented beaver dams on the outlet stream from Mansfield Lake in the upper Tanana River drainage that prevented radio-tagged humpback whitefish from migrating out of the lake in the fall, a migration pattern common to other humpback whitefish in the upper Tanana River. If Mansfield Lake had been too shallow to support overwintering, the trapped fish would have died. Winter fish mortality may occur because a shallow lake freezes to the bottom or because dissolved oxygen levels drop to lethal levels under ice cover (Ficke et al. 2007). Both Fox and Keast (1990) in Ontario, and Hall and Ehlinger (1989) in Michigan, documented winterkill of fish from isolated ponds because of low dissolved oxygen levels. In both studies, however, larger fish experienced greater mortality than small fish. Thus, beaver dams may have positive or negative effects on fish depending on flow levels at critical times of the year and the species or age classes of interest.

Many residents in rural communities of Alaska consider beaver dams to be a serious problem for fish populations. It is clear, however, that beaver dams can provide essential rearing habitat for juvenile fish during the summer and also impede fish migration at times, possibly even killing some trapped fish during winter. In their comprehensive review of the literature on the interactions between beavers, beaver dams, and fish populations, Collen and Gibson (2001) concluded that beaver dams almost always have a positive to neutral effect of fish populations and rarely a negative effect. It is possible that some dams in Alaska trap and kill fish routinely, and their removal might be a good thing for fish in general. However, we have no established way to judge the merits of a beaver dam to determine whether it is more harmful than beneficial to fish or vice versa. Beaver dams are features in the aquatic landscapes of the Yukon and Kuskokwim River drainages. At this time we don't consider them to be serious threats to whitefish populations, particularly when compared to other environmental, development, and harvest threats, as discussed above.

Yukon River Main-Stem Habitat Region

The Yukon River main-stem habitat region extends from the downstream end of the Yukon Flats, near the community of Stevens Village, to the mouth of the Yukon River (Figure 25), a distance of approximately 1,350 km (839 miles). Over twenty tributary rivers join the Yukon River in this region (Appendix A3). Details of the four largest tributaries, the Tanana, Nowitna, Koyukuk, and Innoko rivers, will be dealt with later in separate sections devoted specifically to those drainages. The Yukon River in this region contains high levels of suspended sediment during the summer months and becomes clear during the winter when glacier flow ceases (Brabets et al. 2000). Throughout most of this region the Yukon River flows swiftly over gravel, sand, and silt substrate, but in the delta, essentially the lower 135 km (84 miles) of the river, velocity slows and the substrate is composed almost entirely of silt or mud (Dupré 1980). Islands are common, but the river is not considered to be particularly braided. In the upper reaches of this region the river is commonly 0.5 to 1.0 km (0.3 to 0.6 miles) wide, while in the lower reaches it may be as wide as 2.5 to 5.0 km (1.5 to 3.0 miles). Maximum channel depth increases towards the delta (Brabets et al. 2000). For example, deep channels have been measured at 9 m (30 feet) where the river leaves the Yukon Flats, 14 m (46 feet) near the mouth of the Melozitna River, 938 km (583 miles) from the sea, 18 m (60 feet) near the mouth of the Atchuelinguk River, 203 km (126 miles) from the sea, and up to 30 m (97 feet) near the community of Emmonak in the south channel (McDowell et al. 1987; Brabets et al. 2000). The south channel, Kwikluak Pass, is the largest of many distributaries at the mouth of the Yukon River, passing approximately two thirds of the total flow from the river (Figure 26; McDowell et al. 1987). The middle channel passes about 25% of the total flow and the north channel passes less than 10%. Two much smaller distributaries of the Yukon River enter the Bering Sea considerably south of Kwikluak Pass. The most southerly of these is the Kashunuk River, which leaves the main stem approximately 195 km (120 miles) upstream from the south mouth. It meanders southwest across the delta for about 360 km (225 miles) and enters the Bering Sea in three distributaries of its own between Hooper and Hazen bays, approximately 220 km (137 miles) south along the coast from Kwikluak Pass. These distributaries, the main stem up to the Yukon Flats, and the smaller tributaries along this reach make up the Yukon River main-stem habitat region.

Whitefish species, distribution, and biology

All six common whitefish species are present in the Yukon River main-stem habitat region, although, there are trends in relative abundance within the region based on season, species, and demographics. Martin et al. (1986, 1987) used a wide range of capture gear including gillnets, tow nets, purse seines, fyke nets, and beach seines to conduct a comprehensive sampling program for juvenile salmon and other fishes throughout the Yukon River delta and nearby coastal waters during the summers of 1985 and 1986. Juvenile and adult fishes were captured during 1985 but sampling in 1986 focused primarily on juveniles. Whitefish of all species and demographic groups combined in 1985 made up approximately 64% of the total catch. In 1986, whitefish juveniles represented 14% of the overall catch, a relative abundance exceeded only by ninespine stickleback and smelt species (Osmeridae). Juvenile inconnu, broad whitefish, and humpback whitefish were abundant in nearshore coastal habitats, while least cisco and Bering cisco were abundant in nearshore and offshore

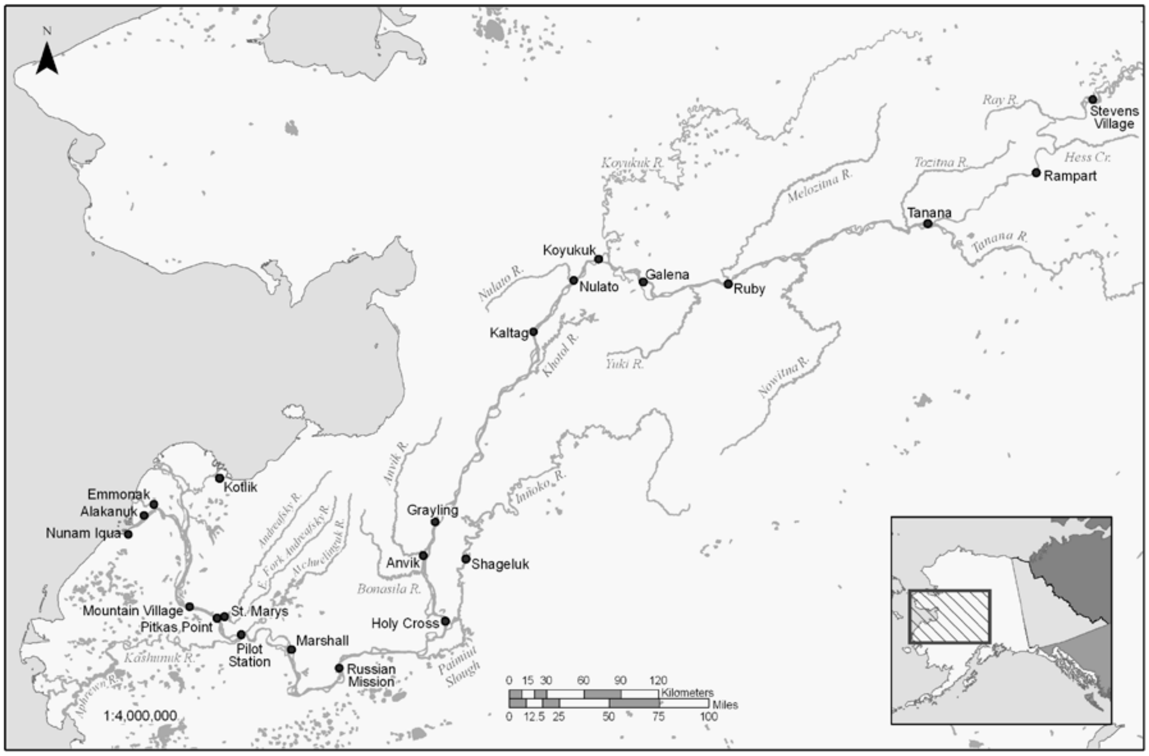

Figure 25. The Yukon River main-stem habitat region including major tributaries and communities.

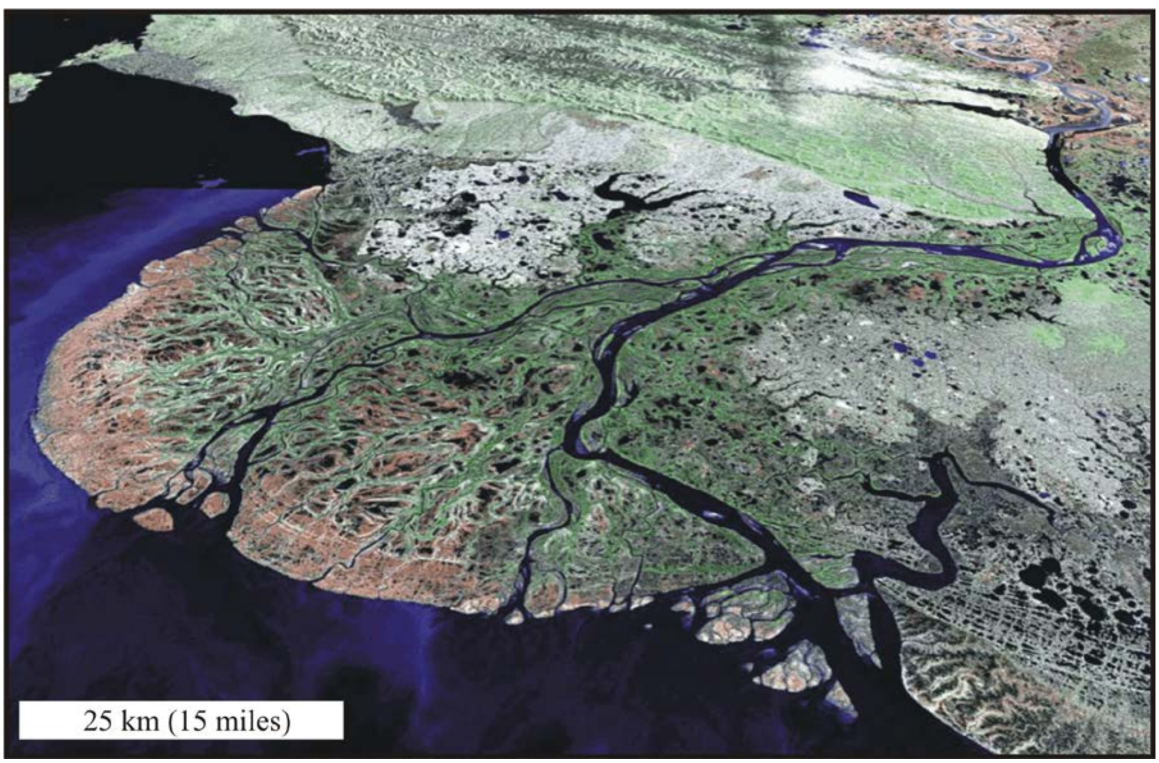

Figure 26. The Yukon River delta illustrating the layout of the major distributaries and landforms. The south mouth of the river, which is the largest channel arcing through the center of the image, is known as Kwikluak Pass. Image courtesy of Dr. W.A. Bowen, California Geographical Survey (geogdata.csun.edu).

habitats as well. Maximum densities of >1,000 to >10,000 juvenile whitefish per km^2 (0.39 $mile^2$) were estimated during July 1986 sampling events, with juvenile least cisco and Bering cisco collectively being about three times more abundant than juvenile inconnu, broad whitefish, and humpback whitefish together. These catch data led Martin et al. (1987) to suggest that July was the peak outmigration timing of whitefish species spawning in upstream reaches of the Yukon River drainage. A single round whitefish was captured in 1985 and none in 1986 suggesting that round whitefish rarely descend into delta or nearshore habitats.

Crawford (1979) surveyed the under-ice subsistence harvests of inconnu and other fish species from lower Yukon River communities from Nunam Iqua to Kotlik in the coastal area upstream to Holy Cross during the winter of 1977–1978. He estimated that over 5,000 inconnu and a similar number of whitefish of three species were harvested, primarily in the early winter and primarily in the coastal communities. Whitefish other than inconnu were not identified to species in the harvest calendars, but, Crawford (1979) observed broad whitefish, humpback whitefish, and Bering cisco during harvest sampling events. Based on length distributions of inconnu and broad whitefish, both immature and mature fish were present. Whitefish species, including inconnu, dominated the under-ice subsistence harvests in communities closer to the coast, while burbot *Lota lota*, northern pike, and Arctic lamprey *Lampetra camtschatica* dominated the harvests in upstream communities. Based on these data, it appears that lower river and coastal environments are favored by whitefish species over upstream, main-stem habitats during winter.

Ken Alt, a fisheries biologist with the Alaska Department of Fish and Game, studied the distribution and biology of inconnu and other whitefish species in Alaska between the early 1960s and the late 1980s. He travelled widely around the Yukon and Kuskokwim River drainages, sampling many rivers and lakes with gillnet and angling methods. He documented his findings in the annual report series of the Alaska Department of Fish and Game, as well as in a number of peer reviewed journal articles. These valuable publications are the foundation of all subsequent whitefish research in our study area. We refer to many of his agency and journal publications in this and following sections, focusing primarily on distribution records, which are very reliable, and secondarily on biological, life history, and migration discussions, which in some cases are speculative.

Fisheries surveys of the smaller tributary rivers in the Yukon River main-stem habitat region have commonly documented the presence of inconnu, broad whitefish, humpback whitefish, and least cisco feeding in the low-gradient, soft-bottom, lower reaches, and round whitefish more commonly observed in the swifter, rocky-substrate, upper reaches. For example, a variable-mesh gillnet and small-mesh beach seine survey of the lower 92 km (57 miles) of the Andreafsky River revealed the presence of broad whitefish, humpback whitefish, least cisco, and round whitefish (Alt 1981b). A floating weir has been in operation approximately 43 km (27 miles) up the East Fork Andreafsky River, the major tributary of the Andreafsky River, for about two months each summer since 1994 (Maschmann 2010). Between 1,500 and 9,000 whitefish have been counted migrating upstream past the weir each year, although, because picket spacing is wide enough to allow smaller individuals to pass without being counted the annual tallies are considered to be less than the actual passage (Tobin and Harper 1996; Maschmann 2009). Whitefish as a species group are counted at the weir but they cannot be identified to species unless they are handled. Over the years, weir personnel have identified a single inconnu (J. Mears and J. Carlson, USFWS, unpub. data), as well as broad whitefish, humpback whitefish, and round whitefish at the weir (Tobin and Harper 1996; Zabkar and Harper 2003). Out of 18 female humpback whitefish sampled at the weir in early to mid-summer 2011, 16 had GSI levels greater than 3%, the average was 5.5% and the maximum GSI in the sample was 8.5% (R.J. Brown, USFWS, unpub. data). These data suggest that humpback whitefish enter the Andreafsky River to feed in the early summer and at least some are preparing to spawn in the fall, although their spawning destinations are not known. No other biological or demographic data are available for whitefish species in the Andreafsky River drainage.

Brief fisheries surveys of the Bonasila, Anvik, Khotol, and Nulato rivers were conducted during summer 1979 (Alt 1980b). A riverboat was used to access these rivers and sampling was conducted with beach seines, angling methods, and gillnets. The lower 65 km (40 miles) of the Bonasila River flows slowly over a soft substrate. Humpback whitefish were captured and inconnu were observed during sampling conducted in the lower 3 km (2 miles) of the river. The lower 161 km (100 miles) of the Anvik River, which included swiftly flowing, gravel substrate reaches upstream and slowly flowing, soft-substrate reaches downstream, were surveyed during a five day period in late June. Broad whitefish, humpback whitefish, and least cisco were present in downstream reaches and round whitefish were common in all reaches. Alt (1980b) reported, based on anecdotal evidence from residents of Anvik, that inconnu were routinely captured in the lower reaches as well. The Khotol River drains the Kaiyuh Flats, an extensive flatland system of lakes and connecting waterways, and flows slowly over a mud substrate into the Yukon River. Inconnu were captured in the lower reaches of the river. Alt (1980b) reported, based on anecdotal evidence from residents of Nulato, that other whitefish species migrated up the Khotol River into the Kaiyuh Flats to feed each summer and returned to the Yukon River in the fall. The Nulato River flows swiftly over a gravel and sand substrate all the way to the mouth. Humpback whitefish and round whitefish were captured near the mouth of the river. Based on these sampling data and anecdotal accounts of area residents, Alt (1980b) proposed that whitefish species other than round whitefish that were encountered in the lower reaches of these tributary streams were present to feed and would spawn and overwinter elsewhere. He allowed that the Anvik River, as the largest and most complex tributary of the four discussed here, might support spawning humpback whitefish, although this has never been investigated.

Fisheries surveys of the Melozitna and Tozitna rivers were conducted on several occasions in the late 1970s and early 1980s (Webb 1983a; Alt 1984). Alt (1984) conducted multi-day raft and boat surveys of the lower 90 km (56 miles) of the Melozitna River using multiple mesh gillnets and angling techniques. Inconnu, broad whitefish, humpback whitefish, and round whitefish were reported in the lower reaches of the river, presumably prevented from migrating into the upper drainage by a narrow canyon with falls between rkm 20 and 40 (rmile 13 and 25). Alt (1984) tagged 13 inconnu in the lower reaches and later recaptured two of them in the Yukon River, one upstream near the community of Rampart, and the other downstream near the community of Anvik. It was his perspective that inconnu and other whitefish species entered the lower reaches of the Melozitna River seasonally to feed but left to spawn elsewhere.

Two different fisheries surveys were conducted on the Tozitna River during 1983. Webb (1983a) floated between rkm 116 and 39 (rmile 72 and 24) during early July using angling and beach seine sampling methods. Alt (1984) surveyed the lower 105 km (65 miles) of the river in late September using angling and gillnet sampling methods. The Tozitna River flows swiftly over a gravel substrate through its entire length and round whitefish were the only whitefish species captured. Alt (1984) contended that inconnu, broad whitefish, humpback whitefish, and least cisco would be expected at the mouth of the river but did not capture them during his survey. The Bureau of Land Management has operated a weir, located approximately 80 km (50 miles) upstream from the mouth, that counted Chinook and chum salmon migrating into the Tozitna River during four summers beginning in 2002 (Post et al. 2007). Species other than Pacific salmon presumably passed the weir but were not identified in their report. These data suggest that round whitefish are common throughout the Tozitna River drainage, while other whitefish species may occur seasonally in the lower few km of the river.

Many different sampling projects have reported whitefish presence and researched whitefish migration and biology along the Yukon River main stem. Research has focused more on inconnu than other species so we understand more about their biology and migrations. Alt (1977a) anchor tagged over 500 inconnu in the lower Yukon River and in spawning reaches in the upper Koyukuk River, including those in the Alatna River. Subsequent recaptures of tagged fish led Alt (1977a) to conclude that many Yukon River inconnu overwintered in the lower Yukon River or its estuary, immature and mature inconnu fed in suitable habitats of the lower Yukon River drainage during summer, and mature inconnu made spawning migrations during late summer and fall into known spawning reaches in the upper Koyukuk River and unknown spawning reaches up the main-stem Yukon River somewhere upstream from the community of Rampart, which is approximately 1,228 km from the sea (763 miles). Inconnu tagged in Koyukuk River spawning reaches during fall were recaptured in under-ice fisheries at the mouth of the Yukon River in November indicating a rapid, downstream migration following spawning in October.

Brown (2000) sampled inconnu at a main stem site called Rapids, approximately 1,176 km (731 miles) from the Yukon River mouth, and used a gonadosomatic index to determine that virtually all were mature and preparing to spawn (Figure 7). Otolith derived ages from 266 mature inconnu from the spawning migration indicated that minimum age at maturity was 7 years, modal ages were 10 years for males and 11 years for females, and the oldest individual in the sample was an age 28 female. Otolith chemistry analyses confirmed Alt's (1977a) contention that most mature inconnu migrating in the main-stem Yukon River reared and overwintered in the sea. Brown (2000) deployed radio tags on over 70 pre-spawning inconnu at Rapids and tracked them to their spawning destination in a braided reach of the Yukon River in the upper Yukon Flats, upstream from the mouth of the Porcupine River, between 1,630 and 1,740 km (1,013 and 1,081 miles) from the sea. Using location data from remote radio receiving stations (Figure 27), as described by Eiler (1995), and aerial survey locations along more than 800 km (500 miles) of river, Brown (2000) found that inconnu migrated upstream to spawn at rates ranging between 16 and 36 $km \cdot d^{-1}$ (10 and 22 $miles \cdot d^{-1}$). Inconnu were present in the spawning reach from late September through mid-October. A receiving station located approximately 35 km (22 miles) upstream from the spawning reach confirmed

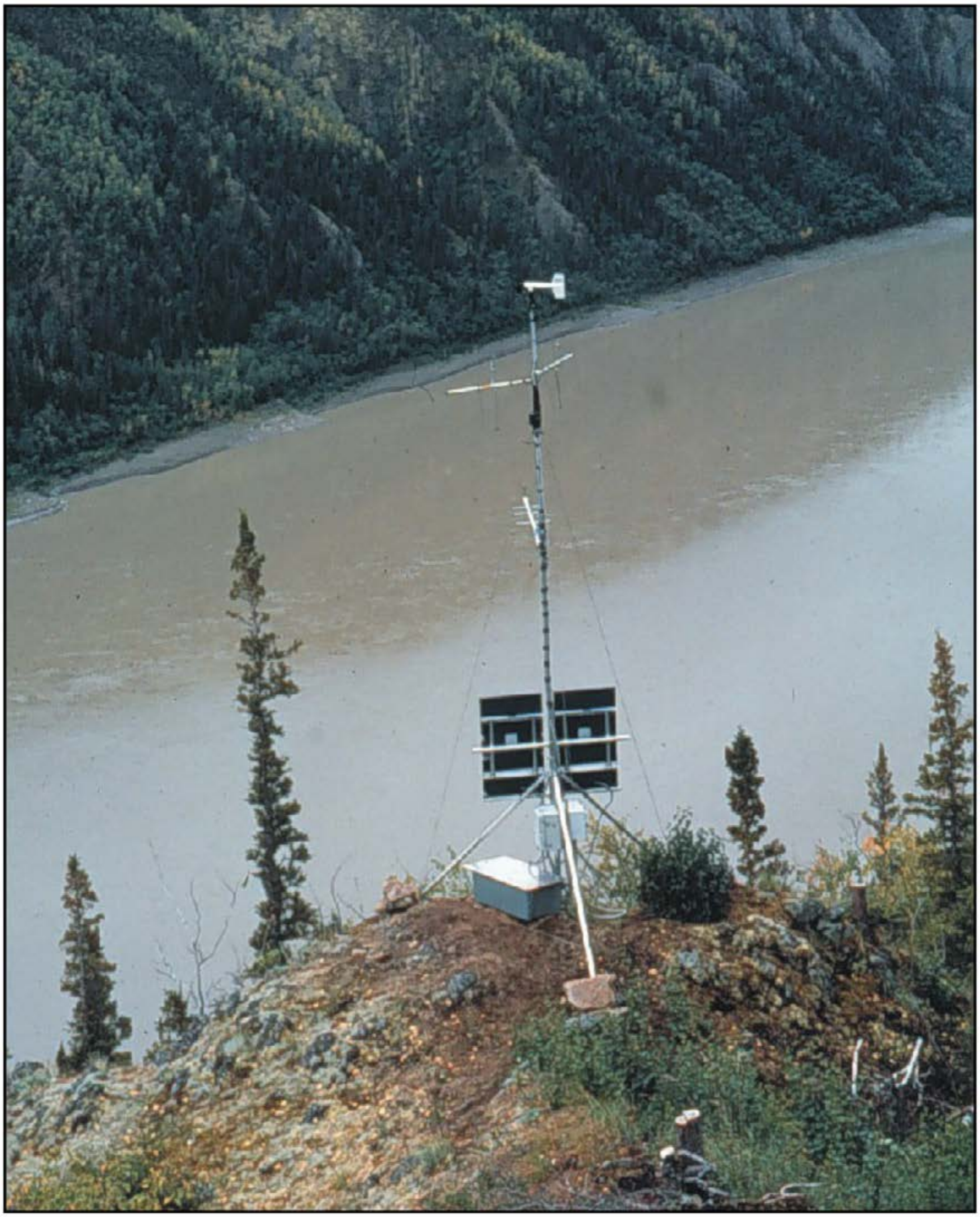

Figure 27. A remote, radio receiving station located high on a bluff along the Yukon River. Solar panels (dark rectangles low on the tower) charge the batteries that power the receiver. Antennas mounted high on the tower point upstream and downstream, allowing the passage direction of radio-tagged fish to be determined based on the strength of the radio signals. In recent years, numerous receiving stations such as this have been deployed around the Yukon and Kuskokwim River drainages to track fish migrations. Photo by J.H. Eiler, NMFS.

that none of the radio-tagged inconnu migrated farther upstream. The post-spawning, downstream migration began in mid-October at rates that ranged between 57 and 197 $km \cdot d^{-1}$ (35 and 122 $miles \cdot d^{-1}$).

Carter (2010) conducted similar research at Rapids focused on broad whitefish. Similar to inconnu, broad whitefish had progressively elevated GSI levels in the late summer and fall (Figure 7) indicating that they were mature and preparing to spawn. Otolith derived ages from 78 mature broad whitefish indicated that minimum age at maturity was five years, modal age in the sample was eight years, and maximum age was 16 years. Otolith chemistry analyses of a subsample of the otoliths indicated that most mature broad whitefish captured at Rapids reared in the sea. Carter (2010) deployed radio transmitters on 41 pre-spawning broad whitefish and tracked them to their spawning destination in the central Yukon Flats, approximately 100 km (62 miles) downstream from the inconnu spawning reach. Based on the timing of downstream retreat from maximum upstream locations, Carter (2010) deduced that broad whitefish spawned in November. Many radio-tagged broad whitefish remained in the Yukon Flats through the winter without the long-distance, post-spawning migration to the lower Yukon River that was observed for inconnu.

Alt (1973b) reported Bering cisco in samples from the Nowitna River mouth to the Porcupine River mouth. He contended that they were all engaged in a spawning migration based on the observation that all the females had greatly enlarged egg masses. He noted that while he occasionally captured large numbers of Bering cisco in gillnets set near the mouths of tributary streams such as Hess Creek, he never captured them in gillnets set farther upstream in the tributaries. Based on these data, Alt (1973b) suggested that Bering cisco spawned in the Yukon River somewhere upstream from the mouth of the Porcupine River. Brown (2000) conducted beach seine sampling in the inconnu spawning reach during early-October and captured spawning inconnu, humpback whitefish, and Bering cisco, indicating that all three species used the habitat.

Humpback whitefish, least cisco, and Bering cisco are also commonly captured at Rapids each summer. Similar to the situation with inconnu and broad whitefish, elevated gonadosomatic indices for these species indicated that nearly all were mature fish preparing to spawn (Figure 7; Brown et al. 2012). Otolith derived ages from mature fish ranged in age from 5 to 22 years for humpback whitefish (n = 65), 2 to 8 years for least cisco (n = 76), and 4 to 13 years for Bering cisco (n = 162). Otolith chemistry analyses indicated that most humpback whitefish, some least cisco, and all Bering cisco reared in the sea (Brown et al. 2007).

A video monitoring system was established on a sampling fish wheel at Rapids in 2001 (Daum 2005). The primary incentive for the development of the video system was to reduce live-box holding times for captured chum salmon because it was suspected that holding fish impacted their subsequent upstream migrations (Underwood et al. 2004), which was eventually confirmed (Bromaghin et al. 2007). The video system took clear photographs of every fish captured in the fish wheel such that the species could be positively identified and then immediately released back into the river without being held captive. Catch rate data and migration timing for all species were obtained by tallying the catch of each species each day throughout the summer, all without harming the fish. The video system has been in

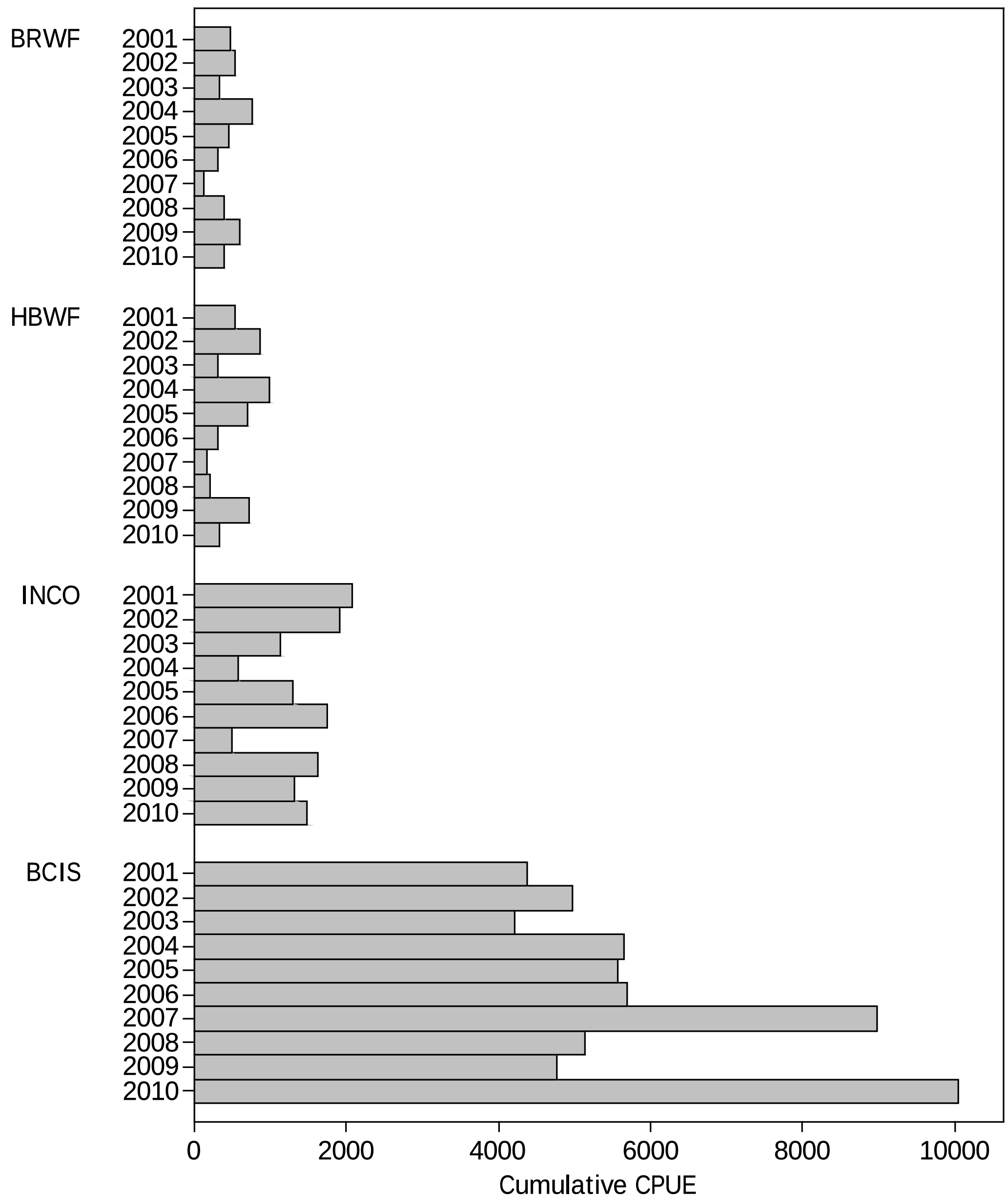

Figure 28. Ten years of cumulative CPUE data for inconnu (INCO), broad whitefish (BRWF), humpback whitefish (HBWF), and Bering cisco (BCIS) at Rapids, a sampling site approximately 1,176 km (731 miles) from the Yukon River mouth, based on a video monitoring system associated with the sampling fish wheel (R.J. Brown, USFWS, unpub. data courtesy of S. Zuray).

operation from mid-June to late September every year since 2001. Cumulative catch data reveal that Bering cisco are more common in the catch than all other whitefish species combined (Figure 28; Brown et al. 2012). The daily catch data, combined with the GSI showing that nearly all whitefish captured at the site were preparing to spawn (Figure 7), have revealed the spawning migration timing for the four most common whitefish species at the site. Least cisco are present at the site but they are not captured in sufficient numbers to identify migration timing. Inconnu have the most distinct migration timing of the four common species. The catch of inconnu reliably increases from 0 to 2 or so fish per day through most of the summer to maximum catches of 60 to 80 fish per day in late August and September, indicating a distinct fall spawning migration up the Yukon River each year (Figure 29). Bering cisco are present in the catch in mid-June when the sampling begins, sometimes at rates of 100 to 200 fish per day, indicating that their migration begins much earlier than for other species. In addition, the Bering cisco spawning migration extends through August usually with several periods of high catch rates suggesting pulses of fish migrating upstream, and tapers off in September when the spawning migrations of inconnu and other species are building up (Figures 29 and 30). The spawning migration of Arctic cisco, a closely related anadromous species that spawns in the Mackenzie River in northwest Canada, also appears to begin early and continue through the summer (Reist and Bond 1988). Reist and Bond (1988) suggested that the extended migration of Arctic cisco in the Mackenzie River may result from longer migrations required by overwintering groups located at greater distances from the river mouth, a distinct possibility for Bering cisco as well. Catch rates of broad whitefish and humpback whitefish have been less than for inconnu and Bering cisco. Catch rates for broad whitefish increase in late August and September to maximum levels of 40 to 50 fish per day, indicating a late fall spawning migration in the Yukon River main-stem habitat region (Figure 30). It is clear from the daily catch data from most years that the migration continues after the fish wheel sampling project stops. Catch rates for humpback whitefish often increase in early to mid-August to maximum levels of 40 to 80 fish per day, while during other years, maximum catch rates of similar magnitudes occur during September. Catch rates of inconnu, broad whitefish, and humpback whitefish during 2007 were very low throughout the summer suggesting that the spawning migrations of these species were either late or relatively poor that year (Figure 29 and 30). Catch rates for Bering cisco in 2007, however, were the second highest of the 10 years in which they were monitored, with a cumulative CPUE of about 9,000 fish (Figure 28), and a maximum daily catch of about 500 fish (Figure 29).

An experimental commercial whitefish fishery has been permitted at the mouth of the Yukon River since 2005 with an annual harvest limit of about 4,500 kg (10,000 pounds; Hayes et al. 2008). During the last few years the fishery has focused on Bering cisco because the buyer in New York City prefers them over the other species (Fabricant 2008; Demarban 2010). The catch has been sub-sampled each year, collecting fork length and otolith derived age data annually, and whole body weight and egg weight of females for GSI calculations during 2009 and 2010 (L. Dubois, ADFG, unpublished data). Comparisons with similar data from mature fish engaged in the spawning migration past Rapids (Brown et al. 2012; R.J. Brown, USFWS, unpub. data provided by S. Zuray, Rapids Research Center) provide demographic information about the harvest. The average lengths of females (35.3 cm, n = 1,091) and males (33.4 cm, n = 961) from the commercial fishery samples were significantly smaller

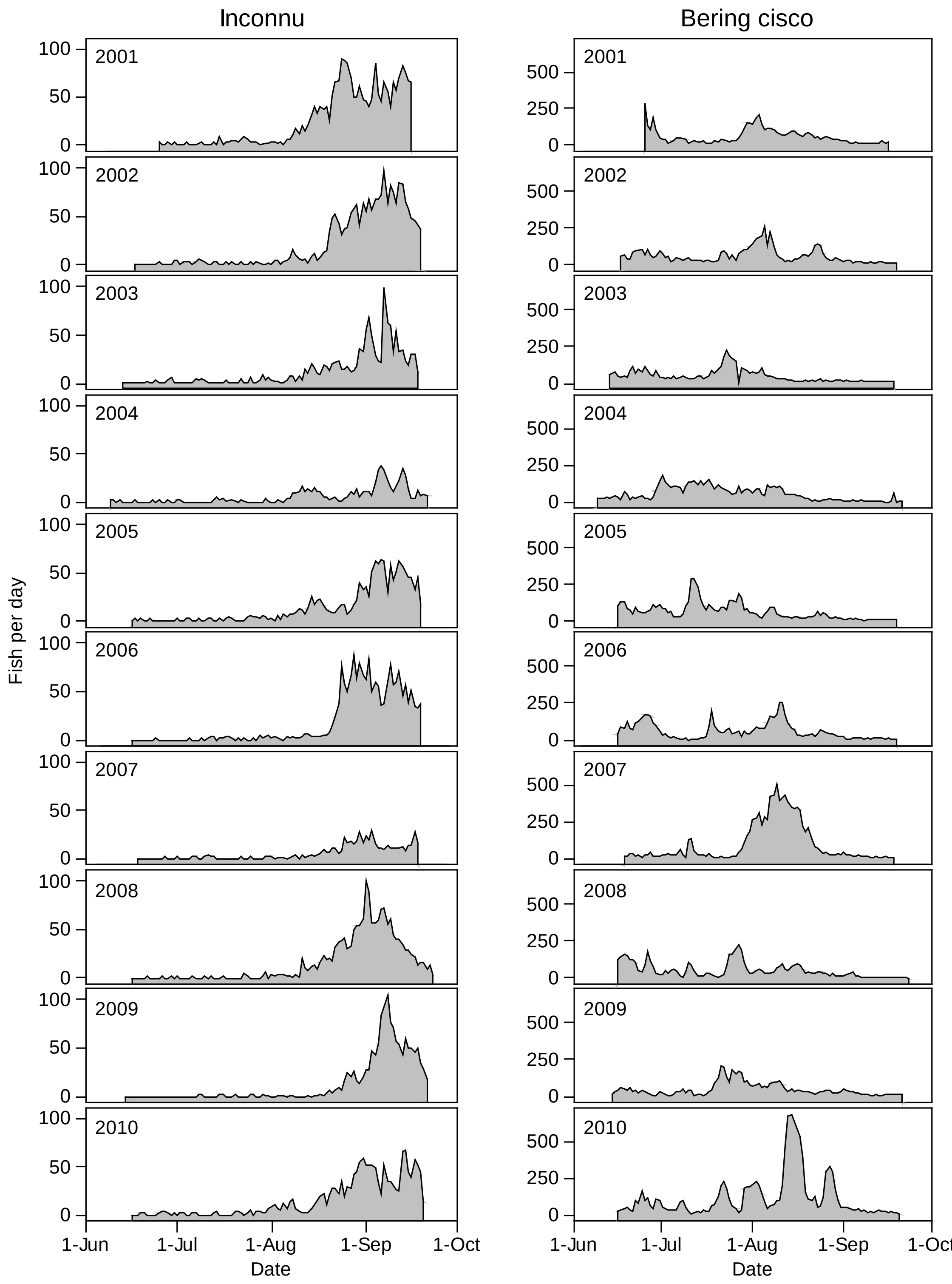

Figure 29. Catch per day of inconnu and Bering cisco during 10 summers of sampling at Rapids revealing annual spawning migration timing (R.J. Brown, USFWS, unpub. data courtesy of S. Zuray).

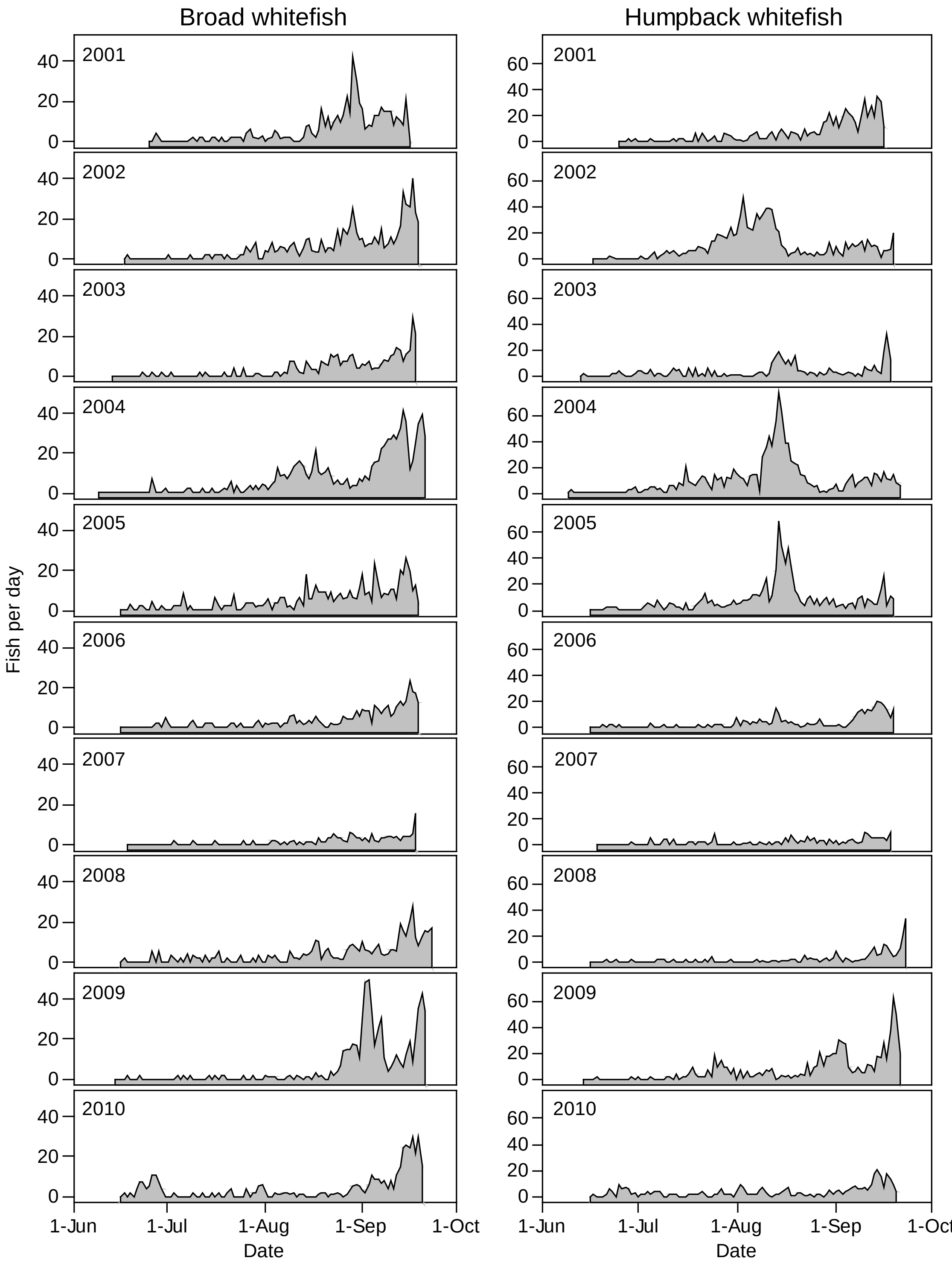

Figure 30. Catch per day of broad whitefish and humpback whitefish during 10 summers of sampling at Rapids revealing annual spawning migration timing (R.J. Brown, USFWS, unpub. data courtesy of S. Zuray).

than mature females (Anova, $P < 0.001$) and males (Anova, $P = 0.001$) respectively (Figure 31). Similarly, the average ages of females (4.7 years, $n = 539$) and males (4.5 years, $n = 397$) from the commercial fishery samples were significantly younger than mature females (6.8 years, $n = 154$; Anova, $P < 0.001$) and males (5.8 years, $n = 106$; Anova, $P = 0.066$) respectively (Figure 32). Gonadosomatic indices of female Bering cisco sampled between June and September during the spawning migration through Rapids, and in October in the upper Yukon Flats where they appear to spawn (Brown et al. 2012; R.J. Brown, USFWS, unpub. data), rise through the season from levels less than 10 in late June to levels as high as 30 or more in early October just prior to spawning (Figure 33). Samples collected from the commercial fishery, which took place in late September, were uniformly low with none at levels that would suggest spawning during the capture year. These three sources of information indicate that the commercial Bering cisco fishery at the mouth of the Yukon River harvests non-spawning fish, most of which are immature.

Most years since 1986, ADFG has operated a sonar project near the community of Pilot Station, approximately 196 km (122 miles) from the sea, designed to estimate the passage of Pacific salmon species migrating to upstream spawning destinations (Carroll and McIntosh 2008). With few exceptions, sonar data do not permit species identification. Species apportionment at the Pilot Station sonar project is done with a complex drift gillnet sampling and analysis program that allocates the total number of fish counted each day among species based essentially on their proportions in the catch (Bromaghin 2005; Carroll and McIntosh 2008). Data presented by Carroll and McIntosh (2008) indicated that inconnu, broad whitefish, humpback whitefish, least cisco, and Bering cisco combined, made up more than 99% of the catch of species other than Pacific salmon. The cumulative passage of these whitefish species at Pilot Station during the 2006 season was estimated to be approximately 875,000 fish, which was second in magnitude to the summer run of chum salmon and approximately 15% of the total passage of fish. Historical data from the years between 1995 and 2006 indicate that this is not an unusual number. These whitefish passage estimates indicate that whitefish are a major component of the fish fauna migrating through the Yukon River main stem habitat region.

Sampling and biological data presented above suggest that the Yukon River main stem is used primarily as a migration corridor for whitefish species between coastal rearing, feeding, and overwintering habitats and upstream feeding and spawning habitats. Spawning areas have not been documented in the region, although, it is likely that round whitefish spawn in many or all of the tributary streams, and it is possible that some spawning occurs in the Andreafsky and Anvik River drainages, as well as in the Yukon River main stem for some of the other whitefish species. Residents in the communities of Tanana and Rampart, for example, have reported catching thousands of whitefish with beach seines in October, just before freeze-up, a traditional practice documented by Case and Halpin (1990) for the community of Tanana. Large aggregations of whitefish in the late fall are typically associated with spawning activity but require biological sampling and possibly radio telemetry work to verify in large river habitat. Recently, USFWS personnel had the opportunity to qualitatively examine 57 whitefish that were harvested in October by beach seine near the community of Tanana and found them to be mostly mature, pre-spawning (based on visual observation of large egg skeins in females and enlarged testes in males) humpback whitefish, broad whitefish, and least cisco along with four fish with immature

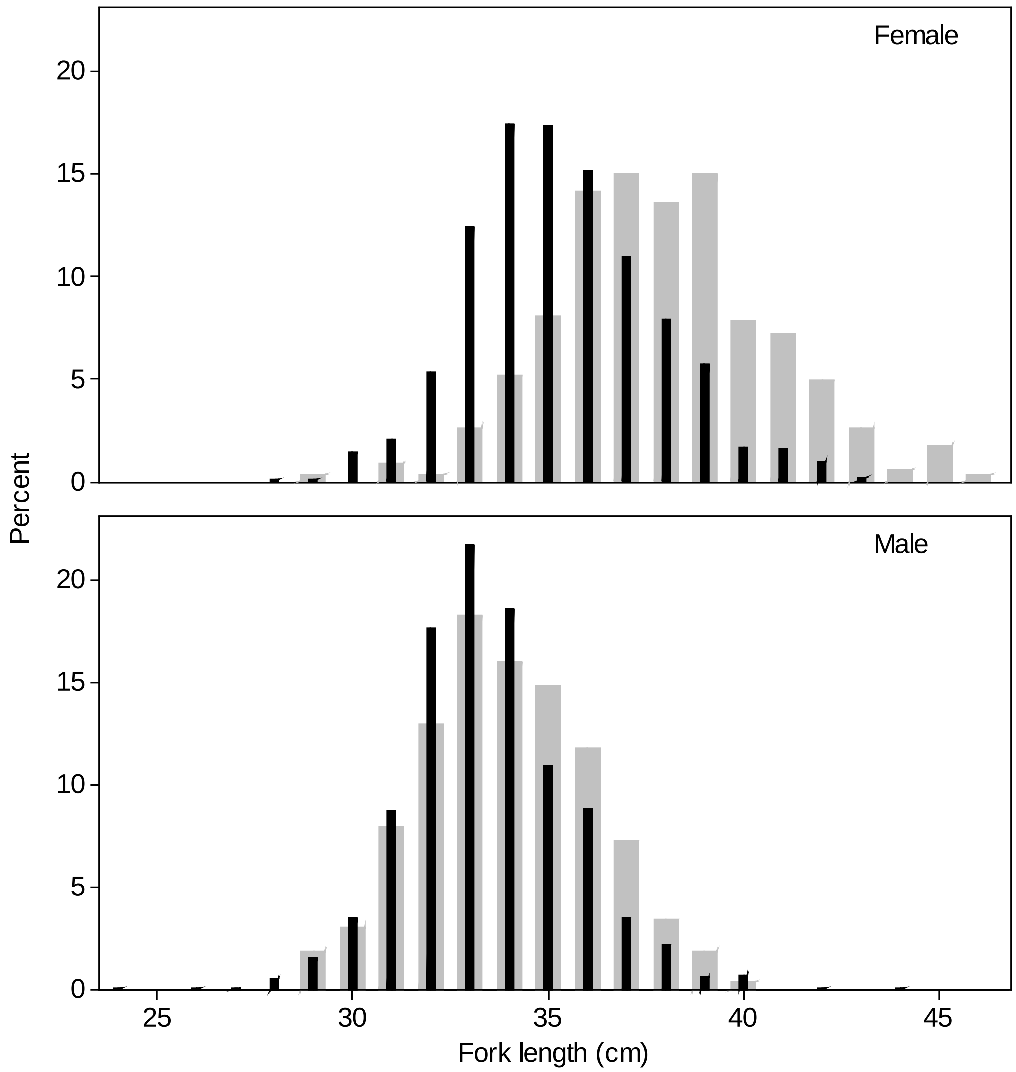

Figure 31. Length distributions of female (top panel) and male (bottom panel) Bering cisco sampled from mature fish in the spawning migration at Rapids (wide grey bars) and the commercial fishery at the mouth of the Yukon River (dark narrow bars). Mean lengths of mature female (37.8 cm, *n* = 347) and male (33.9 cm, *n* = 262) Bering cisco were significantly greater than for females (35.3 cm, *n* = 1,091; Anova, P < 0.001) and males (33.4 cm, *n* = 961; Anova, P = 0.001) sampled from the commercial fishery.

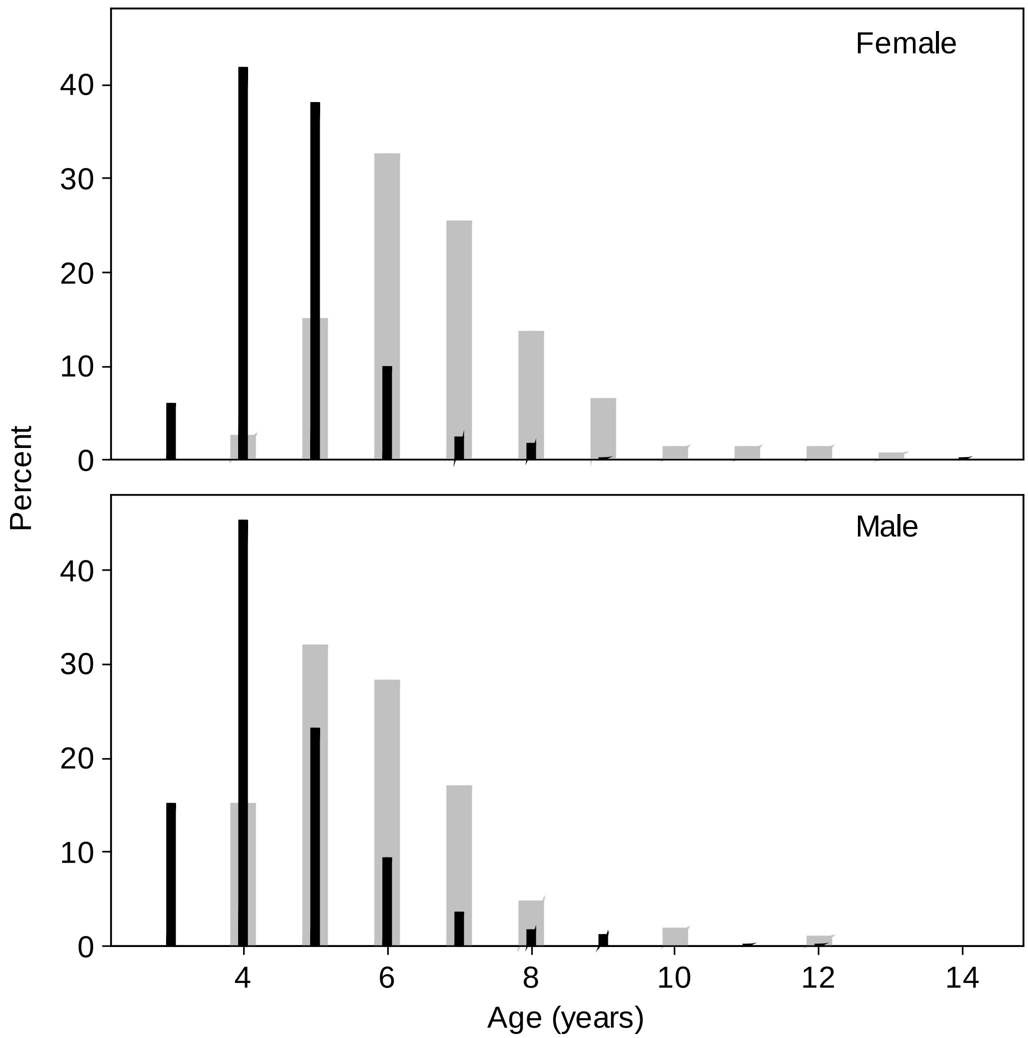

Figure 32. Age distributions of female (top panel) and male (bottom panel) Bering cisco sampled from mature fish in the spawning migration at Rapids (wide grey bars) and the commercial fishery at the mouth of the Yukon River (dark narrow bars). Average ages of mature female (*n* = 154; mean = 6.8 years) and male (*n* = 106; mean = 5.8 years) Bering cisco were significantly greater than for females (*n* = 539; mean = 4.7 years; Anova, P < 0.001) and males (*n* = 397; mean = 4.5 years; Anova, P < 0.001) sampled from the commercial fishery.

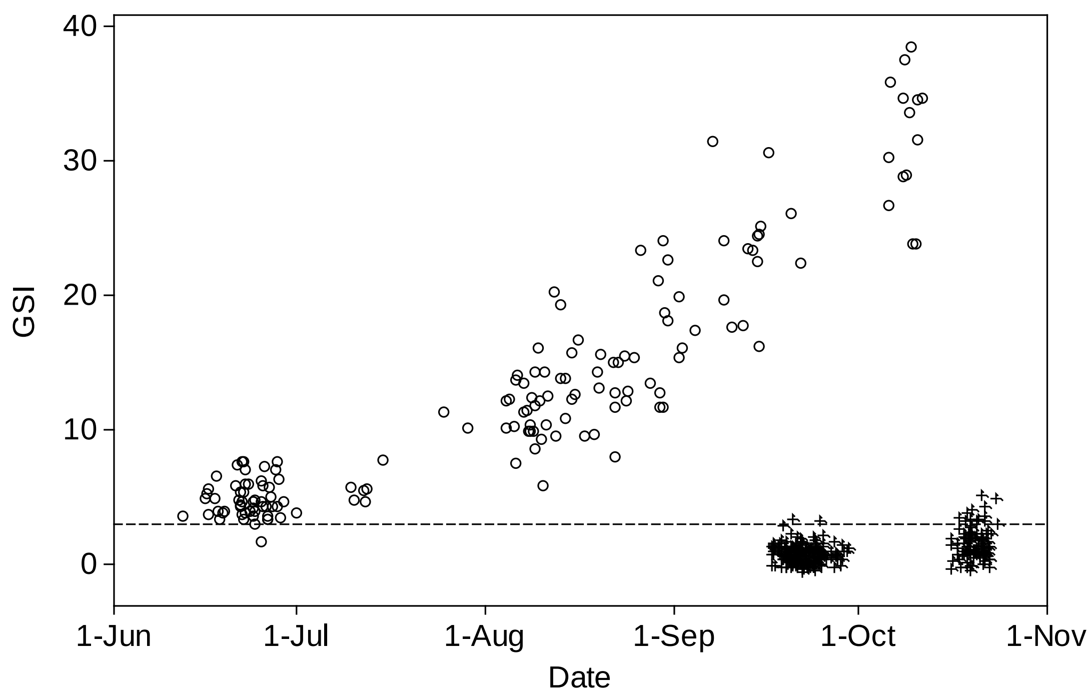

Figure 33. Gonadosomatic indices of mature Bering cisco preparing to spawn (○; *n* = 154), revealing the increasing trend through the season to maximum levels up to 30 or more just prior to spawning in mid-October, and Bering cisco sampled from the commercial fishery at the mouth of the Yukon River (+; *n* = 258), which were clearly too low to spawn during the year of capture. The horizontal dashed line is at GSI = 3, a level that is rarely exceeded by non-spawning fish in late summer and fall.

gonads that were judged to be non-spawning individuals (R.J. Brown, USFWS, unpub. data). No eggs or milt could be expressed from any of these fish, however, indicating that spawning activity was still several days or weeks in the future. It is possible that the pre-spawning fish in these aggregations would migrate farther upstream before spawning. In any case, whitefish spawning habitats have not been identified in the region at this time and it appears that the main stem is used primarily as a migration corridor for whitefish species other than round whitefish.

Fisheries

The Yukon River main stem habitat region is home to 20 active communities and settlements, residents of which all harvest whitefish species on a year round basis. These Yup'ik communities in the lower river and Athabascan communities in the middle and upper river have long histories of relying heavily on whitefish species for personal consumption, dog food, and use in other household products such as fish-skin bags or rendered oil or bait. The Alaska portion of the Yukon River stretches from the mouth at Nunam Iqua and Alakanuk all the way upriver to Eagle at the Canadian border. However, this chapter will deal primarily with the harvest and use of whitefish species in the communities located along the main stem in the lower river (Emmonak, Alakanuk, Kotlik, Nunam Iqua, Mountain Village, St. Mary's, Pitka's Point, Pilot Station, Marshall, and Russian Mission), lower-middle river communities of Holy Cross, Anvik, and Grayling, and the middle river communities of Kaltag, Nulato, Koyukuk, Galena, Ruby, Tanana, and Rampart. The harvest patterns of upper river communities from Stevens Village to the border and of tributary communities are described in other chapters. There is limited published research on the subsistence whitefish fisheries of the Yukon main stem; much of the available data come from several baseline studies conducted in four communities (Wolfe 1981; Pete 1986; Case 1990; Marcotte 1990), two focused studies of local traditional knowledge of non-salmon species (Brown et al. 2005; Brown et al. 2010), and several other reports or ethnographic accounts (Osgood 1940, 1958, 1959; Loyens 1966; Crawford 1979; Fienup-Riordan 1986; Thorsteinson et al. 1989). Additionally, scoping meetings were conducted in May 2008 in Emmonak to investigate existing data gaps, and results suggested that people residing in lower river communities actively harvest several whitefish species over the course of a seasonal round in significant numbers.

Culture and language

An important feature of the lower Yukon seasonal round was that fishing occurred during all seasons and whitefish species figured prominently in this cycle. According to Fienup-Riordan (1986), fall inconnu harvests rivaled the summer subsistence salmon harvest for many delta households in the 1980s. According to Pete (1991), inconnu and other whitefish species were targeted in April/May and September/October, but they were occasionally harvested in other month as well by Russian Mission residents. Russian Mission fishermen recognized several whitefish species including inconnu (*ciiq*), broad whitefish (*kaurtuq* or *akakiik*), humpback whitefish (*cingikegglik*, meaning 'one with a good point'), as well as two types of smaller fish including *neqyagaat* (meaning 'little fish') and *iituliaraat* (meaning 'one with big eyes'). Pete (1991) believed the former term was generally used to refer to Bering cisco while the latter term was typically applied to juvenile whitefish. Russian Mission fishermen made additional linguistic distinctions based on habitat and fish behavior. Inconnu that show up first after break-up in May, for example, were called *kuigpagtat*, or "ocean run", distinguishing them from inconnu caught at other times of the year. Larger whitefish species captured in fall or late winter through early spring were called a*rulailkat*. Broad whitefish are apparently present in isolated lakes in the Russian Mission area, presumably trapped following an unusual flood that allowed them to enter. These fish were referred to as "ones that have stopped move around" and were targeted in early spring because of their high fat content.

The earliest accounts of whitefish use by the Deg Hit'an and Holikachuk Athabascan residents of the lower-middle Yukon River communities of Holy Cross, Anvik, and Grayling date back to the late 1800s (Brown et al. 2005). As Berkes (1999) and Simeone and Kari (2002) note, the vocabulary used to identify and name species is integral to the study of traditional ecological knowledge. The lexical specialization exhibited within a community or language group is one index of the depth and complexity of knowledge about and experience with a species or group of species. According to Brown et al. (2005), Deg Xinag speakers distinguish five species of whitefish, though these species distinctions did not map precisely onto Linnaean classifications (Osgood 1959). While Deg Xinag and Holikachuk terms were identified for most whitefish species distributed throughout in the region, Deg Xinag and Holikachuk speakers also distinguished particular life phases such as juvenile fish (in Deg Xinag, *iłch'eddh* for whitefish fry). The terminology for whitefish species provides one example of increased lexical variation within these two languages (Table 6). Similarly, the words used to describe fish, fishing activities, and harvest locations in the middle Yukon communities offers important insights into understanding Koyukon Athabascan culture and worldview (Brown et al. 2010). As a Koyukon area, these linguistic structures are largely congruent with those described by Andersen et al. (2004) and reproduced in the Koyukuk River chapter of this report, with some notable exceptions allowing for the dialectal distinctions found between Upper Koyukon, Central Koyukon and Lower Koyukon (Brown et al. 2010).

Table 6. Deg Xinag and Holikachuk terminology for whitefish species, adapted from Brown et al. (2005).

English	Deg Xinag	Holikachuk	Literal translation
Whitefish	łegg	łoogg	
little whitefish	Xiłch'edh	K'ithk'ooy	
whitefish fry	Iłch'eddh[1]	iłk'oodh	
Broad whitefish	Tilay		
Lake whitefish	Taghiy	Taghiy	Bottom of water[2] *Tax-* = underwater, submerged
Round whitefish (also a general term for small whitefish)	Xiłting'	Dilmig	
Humpback whitefish	Q'ontoggiy	Q'adiq ney	By and by tomorrow[2]
Inconnu	Sresr	Ses	

[1]From Deg Xinag Stem Dictionary.
[2]Literal translation from Osgood (1958).

Importantly, other cultural and community characteristics appeared to influence the harvest patterns of middle Yukon communities, including the number of dogs, location of community histories, variable adherence to a modified seasonal round, and the demographic structure of the community such as the number of elders (Brown et al. 2010). Additionally, middle Yukon fishermen presented much of their knowledge about fish and fishing practices through the idiom of space using place names. For example, according to Brown et al. (2010), Kaltag residents noted the area across from Four Mile (downstream from the community of Kaltag) where two lakes are named for fishing activities: *Tso Negge,* which means "behind the cache," referring to a place where fish were stored for winter; and *Taaseze Denh*, or "place of broad whitefish." Place name information demonstrates the connections between humans, land, and the animals they harvest and are an important dimension of fishing in most parts of rural Alaska.

Harvest and use

Crawford (1979), Pete (1991), Fienup-Riordan (1986), and Wolfe (1981) provide the basis for much of the existing information about whitefish fisheries in the Yukon Delta. Fienup-Riordan (1986) and Wolfe (1981) offer excellent overviews of the delta fisheries more generally, noting specifics of seasonal and geographical fishing activities by species and community. Local knowledge suggested that environmental conditions such as time of day, tide stage, wind direction, or water level when the river freezes, may affect fishing success. Crawford (1979) focused more specifically on the inconnu fishery in this region, though offers additional information about the harvest of other whitefish species. In general, under ice fishing began in mid October when the ice was thick enough to safely walk on. Effort peaked in November, when 83% of the total winter harvest occurred, and then declined until May when it started up again at lower intensity. Harvest timing varied by location on the river with the more upstream communities in the study area reporting substantial harvests in January, which is somewhat later than in the lower river. The report concludes that while still active, the inconnu fishery has declined in effort and quantity due to the shift away from keeping dog teams and the transition towards a mixed-cash economy where regular employment keeps people from participating in subsistence activities all year long.

Crawford (1979) reported a winter inconnu catch in the lower Yukon River of 3,394 and the expanded figure could be as high as 5,438. Communities near the Yukon River mouth harvested about 85% of the total. Crawford also estimated that 3,562 whitefish were harvested during the fishery, including broad whitefish, humpback whitefish, and Bering cisco. Harvest estimates by season suggest that other whitefish species arrive earlier than inconnu in these lower river communities. During a 2008 baseline harvest survey in Emmonak, fishermen reported harvesting an estimated 2,762 inconnu, suggesting a similar harvest level over time. Harvest estimates for other whitefish species (Table 7) suggest that high levels of harvest and use of whitefish species, including large numbers of least cisco and Bering cisco, continues in lower Yukon River communities. Overall, residents reported that approximately 73% of community households used some whitefish species (Brown *in prep*). Pete's (1991) work in Russian Mission identified the geographical distribution of whitefish harvests in Russian Mission but provided no harvest estimates. Wolfe (1981) provided harvest estimates for select whitefish species for six Yukon Delta communities, however, the selection of interviewees was designed to facilitate the collection of ethnographic data from experienced elders so he may have missed many of the younger, active fishing households. As a result, he may have underestimated fishing effort and harvest levels.

Table 7. Estimated harvest of whitefish species in Emmonak during 2008.

	Households		Weight		No. of fish
Species	use %	harvest %	kg	pounds	harvested
Whitefish (excluding inconnu)	73	55	7,592	16,738	10,856
Broad whitefish	50	39	2,204	4,861	2,430
Humpback whitefish	33	28	1,731	3,816	1,908
Least cisco	29	23	1,256	2,770	2,770
Bering cisco	52	38	2,119	4,671	3,336
Round whitefish	7	6	268	591	394
Unidentified whitefish	1	1	13	29	16

Historically in the lower-middle Yukon River communities of Holy Cross, Anvik, and Grayling (together with Shageluk this area is sometimes referred to as the GASH region), whitefish species were harvested early and late winter with a combination of traps, homemade nets, and hooks. Holy Cross residents sometimes fished the lower Innoko River by placing a weir of willow boughs in the river, guiding fish passage, and then used dipnets to pick whitefish from behind or in front of the weir through troughs cut in the ice. Today, most whitefish species are harvested with nets, hooks, and fishwheels (Brown et al. 2005).

Although the lower-middle Yukon region is known for the quality and size of its northern pike, whitefish species are second only to salmon in terms of harvest and use for the GASH area (Table 8). According to Wheeler (1998) and Brown et al. (2005), broad whitefish and humpback whitefish species are available most of the year, with significant seasonal migrations in the fall and spring. The larger whitefish species begin upstream migrations under the ice in the springtime, heading out of the main river channels and into sloughs and lakes, coincident with river ice break-up. During fall, larger whitefish migrate out of sloughs and lakes and back into the main-stem Yukon River, where most residents believe they overwinter. Inconnu follow similar spring and fall migration patterns, although not into lake systems, and can be found in the Yukon during the winter months. Most of the whitefish harvest occurs during the spring and fall migrations (Brown et al. 2005). Consistent with this, a 2003 survey documented that 94% of the broad whitefish harvest occurred between May and September. Smaller species, *dilmig*, which may include least cisco, Bering cisco, and round whitefish, are most often harvested in fishwheels during the late summer while fishing for chum salmon. In 1990-1991, whitefish species, including inconnu, constituted 16% of the total annual fish harvest for subsistence purposes (Wheeler 1998). In general, whitefish harvests were relatively consistent between 1990 and 2002, while inconnu estimates show more variability between years and communities. Some fishermen expressed concern that whitefish species were generally declining in the area.

Table 8. Estimated harvest of whitefish species in kg (pounds below) by GASH communities in 2003[1].

Species	Anvik	Grayling	Holy Cross	Shageluk	Total
Inconnu	1,028	2,131	20	2,283	5,462
	(2,266)	(4,698)	(44)	(5,033)	(12,042)
Broad whitefish	1,626	4,360	1,159	4,876	12,021
	(3,585)	(9,612)	(2,555)	(10,750)	(26,502)
Humpback whitefish	696	2,874	0	0	3,570
	(1,534)	(6,336)	(0)	(0)	(7,870)
Least cisco	10	0	0	0	10
	(22)	(0)	(0)	(0)	(22)
Bering cisco	3	0	0	0	3
	(7)	(0)	(0)	(0)	(7)
All species	3,363	9,365	1,179	7,159	21,066
	(7,414)	(20,646)	(2,599)	(15,783)	(46,443)

[1]ADFG, Division of Subsistence, unpublished harvest surveys, 2003.

Harvest and use patterns of whitefish species in the middle stretch of the Yukon River, between the communities of Kaltag and Tanana, can be documented back several generations to at least the late 1800s (Zagoskin 1967; Jetté 1911; Loyens 1966). Historically, families used nets, traps, dipnets, and sometimes spears in spring and fall to exploit whitefish during their seasonal migrations, and used fish traps and nets under the ice for a year-round supply of fresh fish. Fishermen in the contemporary communities of Tanana, Ruby, Galena, Nulato, and Kaltag primarily use fish wheels, set nets (open water and under the ice), hook and line, and more rarely fyke nets to harvest whitefish species (Brown et al. 2010).

The middle Yukon communities' use of whitefish species can be characterized over time through high levels of use and distinctly seasonal harvest patterns, largely reflecting seasonal movements of the fish. In 2006, whitefish species constituted 90% (64,193 kg; 141,521 pounds) of the total non-salmon fish harvest across the Middle Yukon, with 60% of the total whitefish harvest comprised of the larger species of broad whitefish (22,383 kg; 49,346 pounds) and humpback whitefish (16,094 kg; 35,481 pounds; Table 9; Brown et al. 2010). Though not necessarily a trend, 2006 harvest estimates are approximately one-fourth of the estimated harvests of all whitefish species in Tanana during 1987 (Case and Halpin 1990). However, both 1987 and 2006 harvest surveys suggest that a significant component of whitefish harvest in the middle Yukon River area is fed to dogs. Harvest surveys were conducted in Galena during 1986 (Marcotte 1990) and again in 2006. Interestingly, the most recent household survey shows an increase in harvest estimates of both inconnu and whitefish species compared to the 1986 survey in Galena. This increase in harvest might be explained by greater percentages of households reporting harvesting both inconnu and whitefish in 2006 than in 1986. For example, 30% of households reported harvesting whitefish in 2006 while 19% of households reported harvesting whitefish in 1986.

Table 9. Estimated harvest in kg (pounds below) of whitefish species by residents of middle Yukon River communities in 2006[1].

Species	Tanana	Ruby	Galena	Nulato	Kaltag	Total
Inconnu	2,271	541	5,394	1,522	562	10,289
	(5,007)	(1,193)	(11,892)	(3,355)	(1,239)	(22,683)
Broad whitefish	4,909	26	16,024	1,426	0	22,383
	(10,822)	(57)	(35,327)	(3,144)	(0)	(49,346)
Humpback whitefish	2,817	406	12,565	306	0	16,094
	(6,210)	(895)	(27,701)	(675)	(0)	(35,481)
Least cisco	215	0	903	10	0	1,128
	(474)	(0)	(1,991)	(22)	(0)	(2,487)
Bering cisco	1,916	0	2,527	0	0	4,443
	(4,224)	(0)	(5,571)	(0)	(0)	(9,795)
Unidentified whitefish	16	48	8,682	323	787	9,856
	(35)	(106)	(19,141)	(712)	(1,735)	(21,729)
All species	12,142	1,020	46,094	3,588	1,348	64,193
	(26,766)	(2,249)	(101,620)	(7,910)	(2,972)	(141,521)

[1]ADFG, Division of Subsistence, unpublished harvest surveys, 2006.

Patterns of harvest would be expected to vary considerably among communities and over time. According to Brown et al. (2010), for example, harvests in Tanana and Galena are largely diverted for dog food, with a relatively small percentage of households harvesting a large percentage of whitefish, while harvests in Ruby, Nulato, and Kaltag have more significant human food components. Additionally, the seasonality of harvest appears to differ between communities. Where one finds significant human food fisheries, harvests occur in more months than in communities that focus their efforts for dog food, which are harvested primarily during the late summer and early fall months. Finally, the harvest areas used by each community vary depending on social and other factors such as whether the community has moved over time, changes in waterways that affect productive sites, and if families continue to travel to seasonal camps and fishing areas.

When asked, local fishermen identified several aspects of local fisheries that concerned them. Lower river fishermen expressed concern about beaver activity in their areas and the extensive drying of lakes complexes in the delta (identified in May 2008 scoping meetings in Emmonak). Lower middle Yukon fishermen also expressed concern about the drying of lakes and sloughs specifically in the area between the main stem and Innoko River (Brown et al. 2005). Middle Yukon fishermen similarly expressed concern about beaver-whitefish interactions, declining quantity and size of inconnu and large whitefish species, and drying lakes and sloughs that affect whitefish habitat and access (Brown et al. 2010). Residents of the Yukon River main-stem habitat region are clearly interested and concerned with factors that may impact their continued use of whitefish resources.

Potential threats and concerns

Overfishing

Twenty communities are located within the Yukon River main-stem habitat region (Appendix A2), with a total population in 2008 of approximately 7,302 residents (U.S. Census Bureau 2010). The farthest upstream community of Rampart is sometimes accessible over an unimproved mining road, but there are no roads linking the rest of the communities. Fishing is a way of life within all of the communities and whitefish species are major components of their harvests during all seasons. During winter 1977-78, for example, Crawford (1979) estimated that as many as 5,000 inconnu and 3,500 whitefish of other species may have been harvested by residents of the delta and lower river communities. Brown et al. (2005) interviewed residents of Holy Cross, Shageluk, Anvik, and Grayling, communities a little farther upstream from the delta, and estimated a combined annual harvest in 2002 of about 2,000 inconnu and over 9,000 whitefish of other species. Residents of Galena harvested more than 500 inconnu and 10,000 whitefish of other species in 1985 and 1986 (Marcotte 1990). Case and Halpin (1990) reported that during 1987 residents of Tanana harvested over 5,000 inconnu and about 25,000 whitefish of other species (Case and Halpin 1990). These rough harvest estimates from this selection of communities throughout the Yukon River main-stem habitat region indicate that the cumulative annual harvest of whitefish species along the river is substantial and may approach or exceed 100,000 fish of all species combined.

Some whitefish populations using the Yukon River main-stem habitat region could be threatened by overfishing now or at some point in the near future. The most likely fisheries threats involve the relatively new commercial fishery for Bering cisco and the incidental harvest of inconnu during Pacific salmon fisheries. The Bering cisco commercial fishery, with its New York market (Fabricant 2008; Demarban 2010), has the potential to expand to unsustainable levels. The fishery is limited to about 4,500 kg (10,000 pounds; Hayes et al. 2008), but, the buyer has requested as much as 18,000 kg (40,000 pounds) or more annually. Without a clear understanding of Bering cisco biology, the populations being exploited, and a monitoring program designed to detect population declines if they occur, the fishery could over-exploit this resource as appears to have occurred for shortjaw cisco populations in the Laurentian Great Lakes (Gorman and Todd 2007). Research is currently being conducted by the U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game to develop genetics baselines for the two known Bering cisco populations in western Alaska, those spawning in the Yukon and Kuskokwim rivers (Alt 1973a), with the objective of conducting mixed stock analysis of the commercial harvest. These data will provide guidance for population assessment and monitoring work in the future. Expanding the commercial harvest without additional information could risk depleting the exploited populations.

The unavoidable, incidental harvest of inconnu in Pacific salmon fisheries in the Yukon River main-stem habitat region is an analogous situation to the incidental harvest of inconnu in the commercial fishery for lake whitefish and lake trout in Great Slave Lake (Roberge et al. 1982; Cosens et al. 1993), as discussed earlier. Inconnu populations that migrate along the Yukon River in the region, and are thus vulnerable to capture in Pacific salmon fisheries, are not monitored such that declines in abundance would be detected. Similar to the Great Slave Lake situation, it would be possible to drive a population to extinction without knowing that it was happening. An argument against incidental harvest in Pacific salmon fisheries being a realistic threat to inconnu populations is that significant gillnet and fish wheel fisheries have taken place along the Yukon River for over 100 years (Pope 1980; Seigel and McEwen 1984) and inconnu are still present. However, it is also possible that additional populations once existed and were extirpated in the early decades of expanded fisheries during and after the initial gold rush periods of the late 1800s and early 1900s (Webb 1985). Understanding the potential influence of the incidental harvest of inconnu in Pacific salmon fisheries in the Yukon River will be possible only with improved population assessment and monitoring activities.

Development issues

Ongoing and potential development projects within the Yukon River main-stem habitat region having the potential to impact whitefish populations include mining, road building, and dam construction. Riverbed gravel mining will probably continue at discrete locations for brief periods of time, but in the absence of known spawning areas in the region, it is unlikely to have a major effect on whitefish populations. Gold mining activities, primarily placer operations, have taken place in the Yukon River main-stem habitat region for many decades and they continue in some locations today. Major placer mining activities in the region have occurred in Kako Creek (Fabich 1993), north of the community of Russian Mission, Stuyahok (Smith 1939), in the upper reaches of the Bonasila River drainage, Grant and Illinois creeks, downstream from the community of Tanana, Morelock Creek, between the communities of Tanana and Rampart, and Minook Creek, near the community of Rampart (L'Ecuyer 1997). Many other smaller or less well documented mining operations have occurred as well. As of 2007, significant placer mining activity in the region was taking place only in the Minook Creek drainage (Szumigala et al. 2008). While placer mining activities disturb stream habitats that may be used by whitefish, as discussed earlier, we are unaware of any new or different impacts in this region that pose a serious threat to whitefish populations at this time.

The Alaska Department of Transportation is considering construction of a major road connecting the existing interior highway system and the Seward Peninsula community of Nome (DOWL HKM 2010). Two alternative routes have been proposed. The northern route follows the Dalton Highway north of the Yukon River and then crosses the upper Koyukuk River drainage and on to the Seward Peninsula. The southern route follows the Elliott Highway towards the community of Manley, west to the confluence of the Tanana and Yukon rivers where a bridge would be constructed over the Yukon River near the community of Tanana, and west from there paralleling the Yukon River on the north side until crossing the Koyukuk River near its mouth and on to the Seward Peninsula. If the proposed road to Nome is eventually built, and if the southern route is chosen, many thousands of people would have easy access to the region. The increased human presence in the region could have a profound effect on fisheries, although perhaps more for those species traditionally captured using angling methods. Few urban visitors would be expected to deploy gillnets or fishwheels in the Yukon River itself, so presumably they would not have a great effect on whitefish species migrating up the Yukon River main stem.

The most destructive potential development project within the Yukon River main-stem habitat region would be the construction of the Rampart Dam, which was studied but rejected about 50 years ago (U.S. Fish and Wildlife Service 1964). It is unlikely that this project will be seriously proposed in the near future, however, if the population in Alaska increases over time and energy costs rise, there may be another push to harness the power of the Yukon River. Rosenberg et al. (1997) point out that large dams continue to be constructed around the world as water and energy needs expand, and that societies routinely sacrifice the resources of free-flowing rivers, which are exploited by relatively few people, for the needs of much larger urban and agrarian populations. The Three-Gorges Dam on the Yangtze River in China, for example, which is currently the largest dam in the world, was constructed during the last 10 years (Kwal-Cheong 1995; Stone 2010). The reservoir behind the dam flooded more than 19 cities and numerous agricultural areas and displaced over a million people. The location was initially identified as a potential dam site by engineers in the 1930s. The dam was being discussed for 40 years before the project was ultimately approved in 1992 (Kwal-Cheong 1995). It started to restrict flow in 2003 and will soon be fully operational (Stone 2010). Because of the ideal geologic setting of the proposed site of the Rampart Dam, proposals to build it may resurface in the future. If the dam is ever constructed, it will profoundly impact the migratory fish populations in the main stem.

Innoko River Habitat Region

The Innoko River is a large tributary of the lower Yukon River, entering the Yukon River approximately 473 km (294 miles) upstream from the Bering Sea (Figure 34). It drains an area of approximately 28,230 km^2 (10,900 $mile^2$), which is approximately 3.3% of the entire Yukon River drainage basin (Alt 1983; Brabets et al. 2000). The Innoko River drainage supports a range of fish habitats which we summarize here based on detailed descriptions by Alt (1983). The Innoko River flows into the Yukon River through its primary mouth in Red Wing Slough and its secondary mouth, Paimiut Slough, 44 km (27 miles) downstream along the Yukon River. In addition, Yukon River water joins the Innoko River approximately 118 and 163 km (73 and 101 miles) upstream from the mouth through Shageluk and Holikachuk sloughs respectively. As a result, the Innoko River downstream from these sloughs flows somewhat turbid during the summer. The river channel is up to 300 m (1,000 feet) wide and 22 m (72 feet) deep in this lower reach, flowing slowly over soft substrate. Within the Innoko River drainage there are two relatively large tributaries, the Iditarod and Dishna rivers, and three, somewhat smaller tributaries, Hather Creek, Mud River, and the North Fork Innoko River. Much of the Innoko River drainage up to the mouth of the North Fork Innoko River, approximately 600 km (373 miles) upstream from its mouth, is lake-rich flatland that is an eastern extension of the Yukon Kuskokwim Delta Lake District (Arp and Jones 2009). Some of the lakes in the Innoko River drainage, of which there are more than 26,000 (USFWS 1993), maintain stream connections to the river on a seasonal or permanent basis, while others are isolated except during irregular high flow events. The Innoko River and its tributaries upstream from Holikachuk Slough and within the Lake District flow very slowly (1.5 to 3 $km \cdot hr^{-1}$; 1 to 2 $mile \cdot hr^{-1}$) over soft substrate, are stained from wetland seepage but not silty (the exception being the Mud River), and are relatively wide and deep (Alt 1983; Figure 35). Gravel or rock substrate is encountered in the upper stream reaches within the Lake District and in the few locations where river channels flow against hills.

The character of the Innoko River changes dramatically just upstream from the mouth of the North Fork Innoko River. It transitions from being a slow, stained, meandering river flowing over a mud or sand substrate to one that flows swift and clear over a gravel substrate for most of its remaining 227 km (141 mile) length (Figure 36). The topography changes from flatland with an occasional hill near the river to one in which the river is bounded between hills and mountains on both banks. Many small streams flow from mountain valleys to join the Innoko River in the upper reaches of the main stem, which headwaters in the mountains just north of the community of Takotna, which is in the Kuskokwim River drainage.

The two, relatively large, southern tributaries within the Innoko River drainage flow north from southern headwater hills into the flats of the Lake District where they join the main stem, while the three, relatively small, northern tributaries flow south from northern headwater hills. The Iditarod River is the largest tributary in the Innoko River drainage. The lower 350 km (217 miles) of the river, up to the abandoned mining community of Iditarod, meanders slowly between mud banks over a soft substrate through the Innoko River flatlands. Hills begin to progressively confine the valley upstream from Iditarod for another 220 km (137 miles) into its headwaters just north of the community of Aniak, which is on the Kuskokwim River. The Dishna River flows swiftly over gravel and sand substrate in some reaches of the main stem but it meanders slowly over a soft substrate through most of its

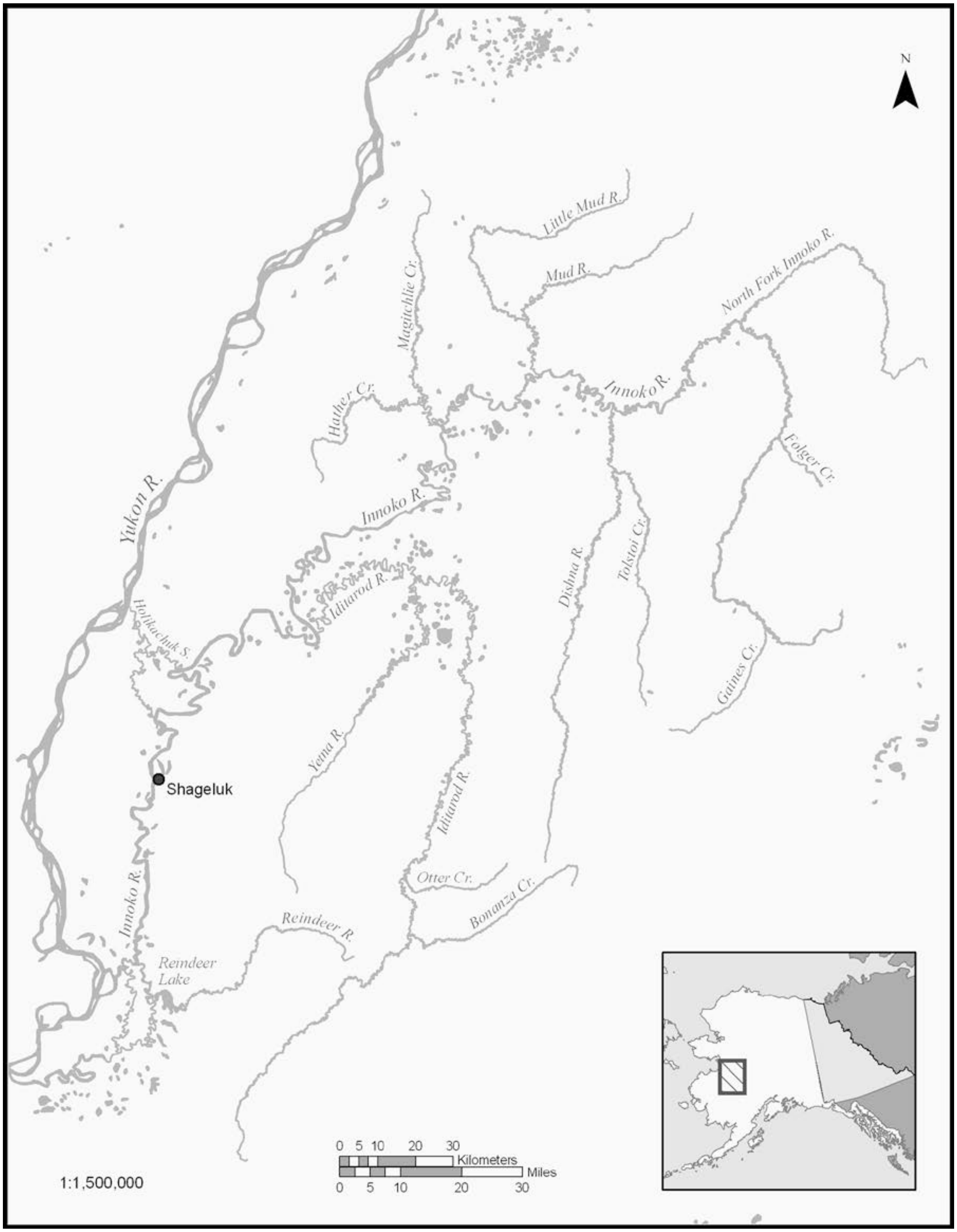

Figure 34. The Innoko River habitat region in western interior Alaska including major tributaries and the one community within the drainage.

Figure 35. Looking upstream at the confluence of the Innoko (left) and Iditarod (right) rivers in the Innoko River flats. The Innoko River at the confluence is approximately 200 m (656 feet) wide and 5 m (16 feet) deep. The Iditarod River at the confluence is about 80 m (262 feet) wide and 7 m (22 feet) deep (R.J. Brown, U.S. Fish and Wildlife Service, unpublished data). Photo by R.J. Brown, USFWS.

length into its southern headwaters, approximately 300 km (186 miles) by river upstream from its mouth. Tolstoi Creek, its one major tributary, flows swiftly over gravel substrate throughout its length. Upland lakes are present in the Innoko River drainage only in a cirque on Beaver Mountain in the headwaters of Tolstoi Creek. Hather Creek, Mud River, and the North Fork Innoko River are the relatively small, northern tributaries. All three are deep, meandering streams that flow slowly over soft substrates from their headwater tributaries, which are small, gravel-substrate streams, to their mouths. The Mud River drainage is extraordinarily turbid from the point where it leaves the headwater streams to its confluence with the Innoko River.

Whitefish species, distribution, and biology

Five whitefish species have been documented in the Innoko River drainage. Alt (1982, 1983) conducted a relatively comprehensive sampling study of fishes in the Innoko River drainage during the summers of 1981 and 1982. He traveled through the drainage by boat during most of the open water season sampling fish in rivers and a few river-connected lakes using angling, gillnet, and beach seine methods. Inconnu, broad whitefish, humpback whitefish, and least cisco were common in low gradient regions of the drainage and round whitefish were present in swifter flowing reaches of the upper drainage. Glesne et al. (2011) sampled 17 oxbow and tundra lakes within the Innoko River drainage (Appendix A5) and found many

Figure 36. Looking downstream into the inconnu spawning reach in the upper Innoko River near Folger Creek illustrating the swiftly-flowing, gravel-substrate river course. Alt (1983) had previously identified this reach as spawning habitat for least cisco and humpback whitefish as well. Photo by R.J. Brown, USFWS.

broad whitefish, humpback whitefish, and least cisco in lakes with stream connections to the river environment. Bering cisco have not been reported in the drainage.

Alt (1983) captured inconnu in riverine habitats up to the mouth of the Dishna River in the main stem, and up to the mouth of the Yetna River in the Iditarod River drainage. He reported that local trappers living farther upstream in the Innoko and Iditarod rivers claimed to have captured inconnu occasionally, suggesting that some inconnu ranged farther into the drainage than his sampling data indicated. Alt (1982, 1983) found few inconnu preparing to spawn during the late summer and fall in the Innoko River drainage and some inconnu he tagged in the early summer were later captured migrating up the Yukon River. These observations led Alt (1983) to suggest that inconnu used the Innoko River drainage as feeding habitat but spawned up the Koyukuk or Yukon rivers. A recent Alaska Department of Fish and Game and U.S. Fish and Wildlife Service radio telemetry project with Innoko River inconnu identified an inconnu spawning area in the upper main stem near the mouth of Folger Creek in the same area where Alt (1983) found spawning humpback whitefish and least cisco (Figure 36; J. Burr, ADFG, R.J. Brown, USFWS, unpub. data). At this time it appears that most but not all inconnu found in the Innoko River drainage originate in spawning areas located much farther upstream in the Yukon River drainage.

Broad whitefish are present in the Innoko River and its major tributaries and river-connected lake systems up to the North Fork Innoko River (Alt 1982, 1983; Glesne et al. 2011). Alt (1982, 1983) found them to be most abundant during summer and fall in the lower Iditarod River drainage leading him to suggest that they may spawn somewhere in the Iditarod River, although, this has never been verified. Brown et al. (2007) and Carter (2010) used otolith chemistry techniques to establish that at least some broad whitefish spawning in the upper Koyukuk River, the Tanana River, and the Yukon Flats reared in marine environments. It is therefore possible that broad whitefish from these upstream populations feed in the Innoko River drainage similar to inconnu. At this time, however, the spawning origins of broad whitefish encountered in the Innoko River drainage are unknown.

Humpback whitefish and least cisco are present in the Innoko River and its major tributaries and river-connected lake systems well into the main stem upstream from the North Fork Innoko River (Alt 1982, 1983; Glesne et al. 2011). Alt (1982, 1983) found both species to be present in riverine habitats in most sampling locations. Similar to his findings with broad whitefish, Glesne et al. (2011) found humpback whitefish and least cisco to be present in most of the river-connected lakes that he sampled in the drainage, which included lakes in the lower Iditarod River drainage and in flatlands beside the Innoko River between the Iditarod and Dishna River mouths. Alt (1983) observed humpback whitefish and least cisco spawning along the main-stem Innoko River upstream from its confluence with the North Fork Innoko River in late September and early October 1981. Ripe least cisco were distributed along a 100 km (62 mile) reach beginning about 25 km (15 miles) downstream to about 75 km (47 miles) upstream from the mouth of Folger Creek (Figure 36). Ripe humpback whitefish were present only in the area downstream from Folger Creek. Alt (1983) described spawning taking place in the evening with pairs of fish breaking the water surface releasing eggs and milt as they did so. Arctic grayling *Thymallus arcticus* captured in the area were eating whitefish eggs. He described the spawning habitat as swiftly flowing water over gravel substrate at depths of 1 m (3 feet) or greater. These observations provide compelling evidence that there are spawning populations of humpback whitefish and least cisco that originate in the upper Innoko River, upstream from the confluence of the North Fork Innoko River. Similar to the situation with inconnu and broad whitefish, Brown et al. (2007) found that many humpback whitefish and least cisco from populations originating farther upstream in the Yukon River drainage had reared in the sea. It is therefore likely that some humpback whitefish and least cisco from other Yukon River populations feed during summer in river and lake habitats of the lower Innoko River drainage.

Fisheries

The Innoko River, a major tributary of the Yukon River, is home to one primarily Deg Hit'an Athabascan community: Shageluk (Figure 34). Historically, inhabitants of the lower-middle Yukon River region followed a subsistence round utilizing seasonal camps until Euroamerican contact and its influences centralized settlement patterns which resulted in the establishment of Shageluk, along with its neighbors on the Yukon main stem, Holy Cross, Anvik, and Grayling. Strong ties remain between these communities, marked by marriage and kinship relations and shared subsistence practices; the Innoko River area is used primarily by residents of Shageluk and also Grayling, who have ties to the Innoko through their residence in the historical village of Holikachuk upriver from Shageluk (Brown et al.

2005). This section provides an overview of the general culture and language, and the harvest and use of whitefish for the community of Shageluk only. Specific information for the communities of Grayling, Anvik, and Holy Cross are covered in the Yukon River main-stem section.

According to Brown et al. (2005) whitefish are the most heavily harvested and used non-salmon fish species for area residents (Figure 37). Historically whitefish were, and continue to be at present, a staple in the annual subsistence harvests and the subsistence lifestyle of the residents. Significant patterns of resource distribution and sharing within and between the four communities in the region continue to characterize this subsistence way of life.

Figure 37. Raymond Dutchman of Shageluk maps important habitat and harvest sites for non-salmon fish species with Caroline Brown. Photo by Melissa Robinson.

Few studies have focused specifically on subsistence fishing, especially of non-salmon species, by residents of the Innoko River Drainage. Specific data on whitefish harvest and use are lacking for the region in general and Shageluk in particular. Information for this chapter draws on two studies: a 1990-1991 study which provides a comprehensive look at non-salmon fish harvest while quantifying actual harvest and use (Wheeler 1993, 1998) and a more recent traditional knowledge study (Brown et al. 2005) that builds on and enhances existing information on lower-middle Yukon River resource use by focusing specifically on the detailed contributions of Athabascan Traditional Ecological Knowledge (TEK) of non-salmon species.

Culture and language

Although both Holikachuk and Deg Xinag Athabascan are spoken by the residents of the Innoko River Drainage, the primary language spoken by the residents of Shageluk is Deg Xinag. Many locals refer to this as “Shageluk” language. According to Brown et al. (2005)

one resident of Shageluk linked the historical relationship between speakers of Deg Xinag and speakers of Holikachuk with the old village of Dishkakat just below the Dishna River in the Upper Innoko. Dishkakat is a historic village that was central to both the middle Yukon area around Nulato and Galena and the Upper Kuskokwim (McGrath and Nikolai area). Conflicts in the area around the mid 1800s and diphtheria outbreaks in 1906 created a depopulation of Dishkakat, and a dispersion of residents (and the language) to other areas.

Although the Holikachuk language is closer linguistically to the lower Koyukon area, its speakers are culturally closer to Deg Hit'an speakers, as demonstrated today by the social interactions and multiple kinship relations within the Innoko River Drainage, than with other people. Despite contemporary efforts at language preservation, Deg Xinag and Holikachuk are spoken by a declining number of people (Brown et al. 2005).

Deg Xinag speakers distinguish five species of whitefish, though these species distinctions did not map precisely onto Linnaean classifications. Additionally, Deg Xinag speakers maintain a rich vocabulary of fish related terms, including fish parts, harvesting tools, processing techniques and other uses (Brown et al. 2005). These linguistic distinctions are outlined more fully in the Yukon River main-stem chapter of this report as well as Brown et al. (2005) and Osgood (1959).

Harvest and use

As for fishermen in most places, knowledge of the fish themselves and the characteristics of their habitat and waterways often determines success in fishing. Shageluk fishermen and others who use the area rely on local knowledge about the Innoko River to shape their fishing practices. For example, local fishermen observed that the Innoko River water is "red" and seasonally "rotten," explaining why there is little wintertime fishing in the Innoko itself. High water in the Yukon often backs up into the lower reaches of the Innoko and in the Holikachuk Slough above Shageluk, a channel of the Yukon that enters the Innoko, causing this stained water to become silty (Robinson 2004). Knowledge of the interconnected system of river, sloughs, and lakes is critical to successful harvesting. Local fishermen utilize the area around Shageluk, such as the Shageluk Slough and the Old Village Slough, as well as downriver to Callign Creek, Layman's, and as far down as Albert's Lake. Fishers from the community of Grayling tend to focus their fishing efforts upriver closer to the historic community site of Holikachuk (Brown et al. 2005).

Historically, fishermen used a combination of traps, handmade nets, hook and line, and dipnets to harvest whitefish species (Figures 38 and 39). Elders remember using dipnets from boats or from the river banks in spring and early summer around the Holikachuk area taking advantage of fish milling about in the mouths of sloughs waiting for the ice to break up and improve the water quality in the Innoko main stem (Brown et al. 2005).

Figure 38. Lucy Hamilton of Shageluk making a net while visiting with a neighbor. Photo by C. Brown, ADFG.

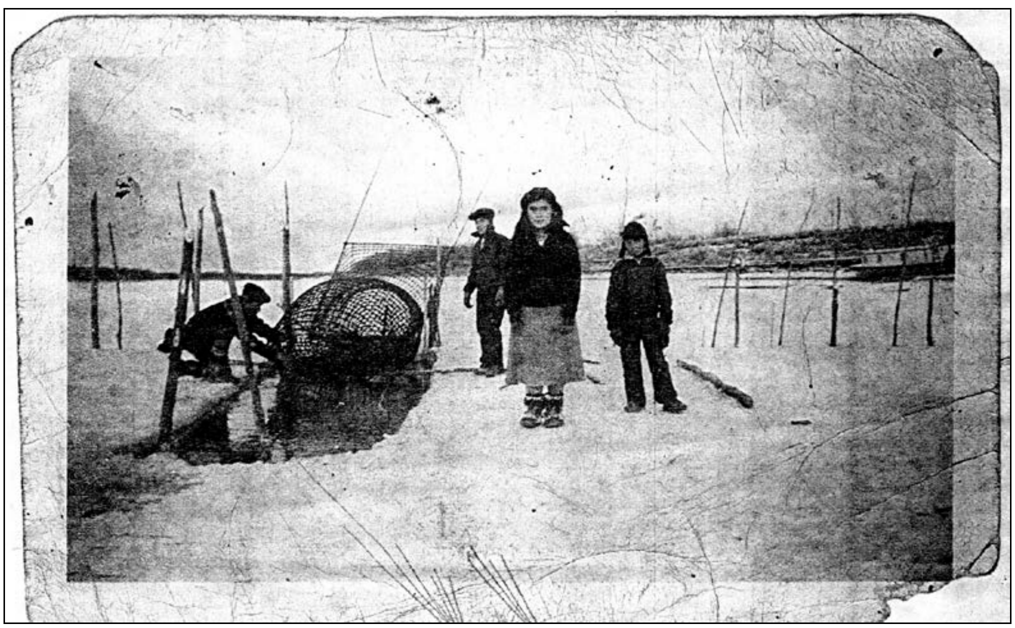

Figure 39. A Shageluk family checks a whitefish trap in front of a fish fence near the village, circa 1940s. Picture courtesy of the late Hannah Maillelle, Grayling.

Current annual subsistence harvests for whitefish and sheefish by Shageluk fishermen occur primarily during two major migrations of primarily humpback and broad whitefish, a spring migration beginning just prior to and immediately after break-up, and a fall migration which is targeted just after freeze-up. One Shageluk elder noted that frogs, or *xiłghiy*, indicate the coming of whitefish in the springtime, their croaking is said to be translated as "the fish are coming" or "*łegg ghilux*." (Brown et al. 2005). Spring migrations appear to coincide with the break-up of river ice.   Fall time marks a second major migration for whitefish species. Shageluk elders describe what they refer to as "shutting down the river," right after freeze-up when the river ice was thick enough to walk on. Fishermen select an area of the river that was not too deep, approximately 3 to 4.5 m (10 to 15 feet) deep and cut a long narrow channel in the ice and insert a fence made of willow brush to block fish passage. Fishers then cut large rectangular holes directly in front of the fence to dip fish out of the river.

Shageluk fishermen also pay attention to these seasonal migrations for traditional management purposes. Local fishermen observe changes in the size distribution within whitefish runs that they argue is linked to abundance; larger fish begin the run with the size of fish decreasing as the run progresses. Fishermen harvest larger fish at the beginning of the run and continue fishing until the size of the whitefish decreases; decreasing size of fish is one possible indicator that fishers have reached a harvest limit and should pull their nets (Figure 40), even if needs have not been met (Brown et al. 2005). Harvest information reported by residents of Shageluk is presented here (Table 10) and is likely comprised almost solely of fish harvested from the Innoko drainage. Portions of the harvests by fishermen from the nearby communities of Holy Cross, Grayling, and Anvik are likely attributable to the Innoko River area, though specific estimates are not available.

Figure 40. Set net by Shagleuk in 2004. Photo by C. Brown, ADFG.

Table 10. Estimated number and weight of whitefish harvested in Shageluk in 2002[1].

Species	no. of fish	kg	pounds
Inconnu	839	4,886	10,771
Broad whitefish	2,688	2,288	5,044
Humpback whitefish	0	0	0
Least cisco	0	0	0
Bering cisco	0	0	0

[1]ADFG, Division of Subsistence, unpublished harvest surveys, 2002.

Potential threats and concerns

Overfishing

Shageluk, with a population 113 in 2008, is the only established community in the Innoko River drainage (Appendix A2). Brown et al. (2005) estimated that residents of Shageluk annually harvested over 800 inconnu and 5,700 broad whitefish and humpback whitefish combined, mostly during the open water season. Our understanding of whitefish use of the Innoko River drainage, as detailed above, suggests that whitefish harvests within the drainage are from multiple populations that originate primarily outside the drainage for inconnu and broad whitefish and both outside and inside the drainage for humpback whitefish and least cisco. Round whitefish have only been captured in the upper reaches (Alt 1982) and may be permanent residents of the drainage. The threat of overfishing to whitefish populations encountered in the Innoko River drainage is impossible to determine without an understanding of the population composition of the harvest, the size of the contributing populations, other harvests within the ranges of those populations outside of the Innoko River drainage, and sustainable harvest levels; none of which are known. If whitefish harvests at levels comparable to those reported by Brown et al. (2005) have been taking place for many decades or more, they may be sustainable without dramatically altering the contributing whitefish populations. Proposals to significantly increase fishery harvests should be considered very carefully. Research into the origins of whitefish captured in the Innoko River drainage could lead to the development of monitoring programs for harvested species.

Development issues

We are unaware of any plans for major development in the Innoko River drainage, other than gold mining, that would have a potential impact on whitefish populations that use the drainage. No new roads, dams, or logging activities have been proposed within the drainage. The potential for fuel spills appears to be limited to accidents related to aircraft or mining, which is a risk common to most of the State. The remoteness of the drainage insulates it from the population centers of the State and the environmental consequences that come with large numbers of visitors.

The Innoko River has figured prominently in the early gold mining history of Alaska (Smith 1939; Brown 1983; Webb 1985) and many gold mining operations continue today throughout the headwater reaches of the drainage. Major placer mining operations have taken place in stream systems in and around Ganes, Ophir, Folger, and Colorado creeks in the upper Innoko River (Figure 41; Brown 1983; Spence 1996; Wendt 2005; Szumigala et al. 2008), Otter and Bonanza creeks in the Iditarod River drainage (Brown 1983; Bundtzen et al. 1992; Wendt 2005), Tolstoi Creek in the Dishna River drainage (Smith 1939; USFWS 1993), and Poorman Creek in the upper North Fork Innoko River (Smith 1939; L'Ecuyer 1993). A major hard-rock mining operation was developed in Illinois Creek during the 1990s, on the flanks of Khotol Mountain in the upper Mud River drainage (Winters 1996), and began production in 1997 (Swainbank et al. 1998). They extracted gold using cyanide heap leach technology for a few years and then the mining company filed for bankruptcy and left the mine site and ore heap in receivership with the State (Szumigala and Swainbank 2000; Szumigala et al. 2001). According to Winters (1996) the Illinois Creek mine was planned as a self contained operation and was never intended to release effluent into the environment.

Figure 41. Heavily mined streambeds in Colorado (left image) and Ophir (right image) Creek valleys in the upper Innoko River drainage. Photos by R.J. Brown, USFWS.

As late as the early 1980s, prior to the establishment and enforcement of turbidity standards for streams in Alaska (Lloyd 1987), Alt (1983) reported muddy effluent from mines in the upper Iditarod and Innoko rivers and suggested that the long period of unregulated mine effluent may have impacted stream habitats used by fish. At this time it appears that small placer mining operations in Innoko River streams maintain settling ponds, in accordance with water quality standards in Alaska (Alaska Administrative Code 1985), to reduce the turbidity of their effluent (R.J. Brown, personal observation). Many of the current mining operations in the Innoko River drainage are in the upper main stem and its small mountain tributaries, which drain through the whitefish spawning habitat that Alt (1983) first identified. Mining activity now is dramatically reduced relative to gold rush times (Brown 1983; Spence 1996), although this is likely to change with the current high price of gold, and mining effluent appears to be much cleaner now than in previous times, so these mines are not thought to be a significant threat to the spawning habitat, which is not being directly disturbed itself. Mining the riverbed gravel of the upper main-stem Innoko River, however, should be avoided because it would certainly impact the inconnu, humpback whitefish, and least cisco populations that spawn there each fall.

Koyukuk River Habitat Region

The Koyukuk River is a major tributary of the Yukon River in the northern interior of Alaska, entering the Yukon River approximately 818 km (508 miles) upstream from the Bering Sea (Figure 42). The Koyukuk River drains an area of approximately 91,000 km^2 (35,135 $mile^2$), with an average annual discharge of 770 $m^3 \cdot s^{-1}$ (27,192 $feet^3 \cdot s^{-1}$), which is approximately 12% of the discharge from the entire Yukon River (Brabets et al. 2000). The Koyukuk River drainage supports a diverse range of fish habitats in interior Alaska. The lower reaches of the river flow relatively slow, smooth, and moderately turbid over a soft substrate of silt, mud, or sand while the upper reaches flow swift and clear over a hard substrate of sand, gravel, and cobble. In the late 1800s and early 1900s, paddlewheel steamboats routinely navigated the river up to the original, now abandoned, site of Bettles at the mouth of the John River (Brown 2007b), approximately 980 km (609 miles) upstream from the Yukon River, and 10 km (6 miles) downstream from the current location of Bettles and Evansville (Figure 42). The Koyukuk River valley downstream from the mouth of the Hogatza River, approximately 437 km (272 miles) upstream from the Yukon River, is an extensive flatland region known as the Koyukuk Lake District (Arp and Jones 2009) where thousands of shallow tundra and oxbow lakes are distributed across the landscape. Many of the lakes are hydrologically connected to the river system, either permanently or seasonally, while others are isolated (Glesne et al. 2011). The lower reaches of the Dulbi and Huslia rivers meander over a soft substrate for many kilometers through this flatland region. The western tributaries, the Gisasa, Honhosa, and Kateel rivers, flow swiftly over a hard substrate almost all the way to their mouths. Rivers farther upstream in the Koyukuk River drainage such as the Kanuti, Alatna, South Fork Koyukuk, John, Wild, and others similarly flow swiftly over a hard substrate through much of their lengths. In contrast with the shallow tundra and oxbow lakes of the flat lands, there are a number of deep, upland lakes in the upper drainage such as Iniakuk and Helpmejack (Figure 3) lakes in the upper Alatna River, Wild Lake in the upper Wild River, and Bob Johnson Lake (sometimes referred to as Big Lake) in the Middle Fork Koyukuk River, that are capable of supporting resident populations of fish throughout the year.

Whitefish species, distribution, and biology

Six whitefish species are present in the Yukon River drainage in Alaska, five of which have been documented in the Koyukuk River drainage, a major tributary of the Yukon River (Brown et al. 2007). Inconnu, broad whitefish, and humpback whitefish are actively sought in subsistence fisheries in the region (Andersen et al. 2004). Least cisco and round whitefish are minor components of the fishery. Bering cisco are present in the Yukon River drainage (Alt 1973a) but are thought to remain in main-stem habitats and have not been identified in the Koyukuk River or other tributary systems (Brown et al. 2007).

Tagging and otolith chemistry studies have shown that four whitefish species found in the Kanuti, Alatna, and South Fork Koyukuk rivers rear in habitats as far away as the mouth of the Yukon River, approximately 1,600 km downstream. Alt (1977a) tagged inconnu in the Yukon Delta and recaptured some of them in the Alatna River, demonstrating that there was a migration between the two locations. Based on a maturity assessment, Alt (1970) determined that inconnu migrated to the Alatna River to spawn. Brown et al. (2007) analyzed otolith strontium (Sr) levels in samples of inconnu, broad whitefish, humpback

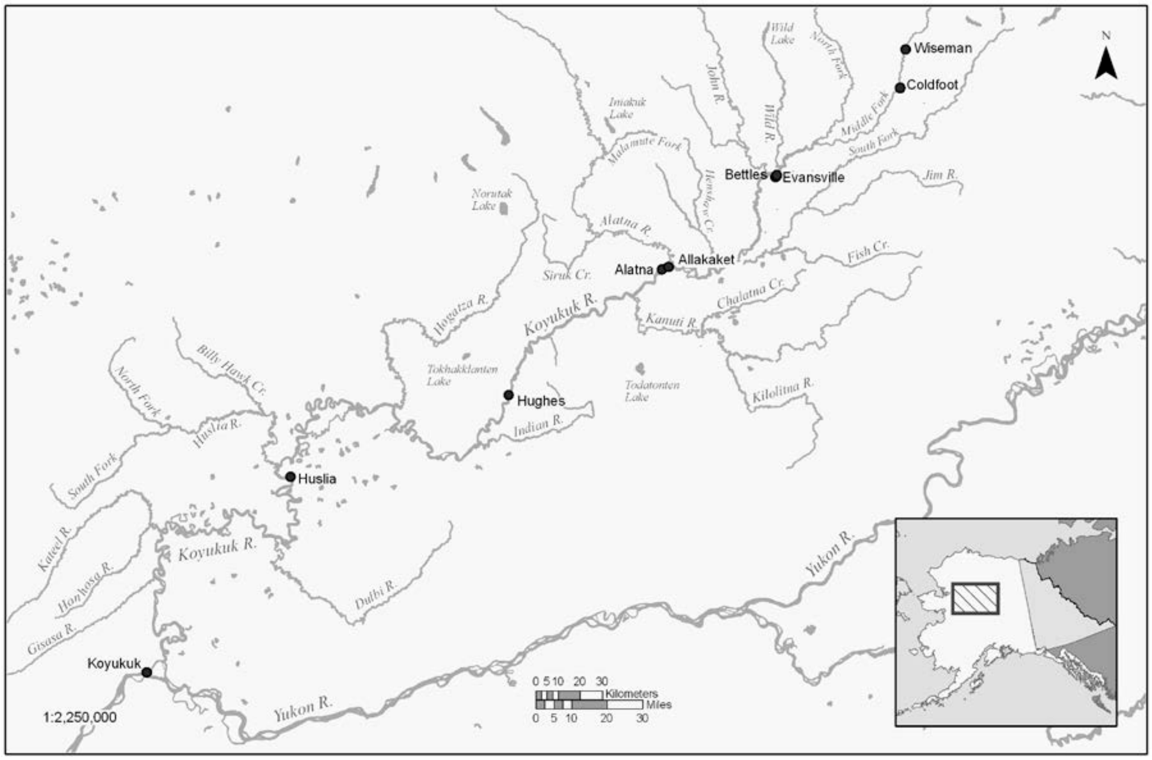

Figure 42. The Koyukuk River habitat region in interior Alaska including major tributaries and communities.

whitefish, and least cisco captured in the Alatna, South Fork Koyukuk, and Kanuti rivers. They found elevated Sr levels in the otoliths of many of the sampled fish indicating that anadromy was a common strategy for all four species. Most inconnu, broad whitefish, and humpback whitefish, and some least cisco that were examined had reared in marine water. These data clearly established that these populations ranged widely though the Yukon River drainage.

Each whitefish species appears to have habitat preferences within the Koyukuk River drainage that may be unique to the species or shared with other species. Sampling data suggest that round whitefish are the only species that prefers the clear-flowing headwater streams. Netsch (1975) and Pearse (1977) conducted extensive fish sampling programs along the proposed oil pipeline route across the upper Koyukuk River drainage during the1970s. They sampled many headwater streams and rivers along the route and found round whitefish to be one of the three most commonly occurring fish species. Both immature and mature individuals were captured. Tag and recapture data in both reports suggested very limited migrations for the species. Of the other four whitefish species present in the Koyukuk River drainage, only a single humpback whitefish was observed by Netsch (1975) and none were observed by Pearse (1977). By contrast, Brown (2009) sampled large river and lake habitats in the Kanuti River flats, the lower South Fork Koyukuk River, the Alatna River, and in the main-stem Koyukuk River between the mouths of the Kanuti and Alatna rivers and captured many humpback whitefish (n = 179), least cisco (n = 100), and broad whitefish (n = 38), but only two round whitefish. Wiswar (1994b) found a similar segregation of whitefish species among habitats during sampling activities in three lower drainage tributaries, the Honhosa River, which flows clear over a gravel substrate, and the North Fork Huslia River and Billy Hawk Creek, which flow turbid over a mud and silt substrate. He found round whitefish in the clear flowing stream and broad whitefish and humpback whitefish in the turbid streams. Glesne et al. (2011) sampled 24 lakes in the Koyukuk Lake District (Arp and Jones 2009), which included oxbow and thaw lakes, most of which were seasonally open to the river through small channels or streams (Appendix A5). He found that broad whitefish, humpback whitefish, and least cisco were encountered in most lakes, inconnu were found in only one oxbow lake adjacent to the Koyukuk River, and no round whitefish were captured. Inconnu are apparently absent from the Koyukuk River drainage during winter. They enter the drainage during early to mid-summer to feed in the lower drainage and migrate upstream as far as the Alatna River to spawn by fall (Alt 1977a, 1978a). Residents of Allakaket contend that inconnu are rarely encountered in the Koyukuk River upstream from the Alatna River mouth (Andersen 2007). Inconnu prefer large river habitat within the Yukon River drainage and are rarely encountered in small streams, headwater reaches, or lakes. Harvest data indicate that the riverine distribution of inconnu, broad whitefish, humpback whitefish, and least cisco is limited to habitats downstream from the communities of Bettles and Evansville (Anderson et al. 2004), approximately 990 km (615 miles) upstream from the Yukon River and 1,808 km (1,123 miles) upstream from the Bering Sea. Round whitefish appear to be the only whitefish species common to headwater streams of the drainage.

Spawning habitats of riverine populations of whitefish in the Koyukuk River drainage have been documented only in gravel substrate reaches of main-stem and tributary rivers between the community of Hughes and the South Fork Koyukuk River. Alt (1970) flew aerial surveys during late fall and observed large spawning groups of inconnu in the Koyukuk River near Hughes, near the mouth of the Alatna River, and approximately 80 km (50 miles) up the Alatna River near the mouth of Siruk Creek (Figure 43). Anderson (2007) reported that residents of Allakaket traditionally travel up the Alatna River in the fall to harvest large groups of pre-spawning inconnu, broad whitefish, humpback whitefish, and least cisco. Brown (2009), using radio telemetry techniques, confirmed that the Alatna River, in the vicinity of Siruk Creek, was used by broad whitefish and humpback whitefish for spawning, and discovered additional spawning habitats in the upper Kanuti and South Fork Koyukuk rivers. Other spawning areas may exist for riverine populations in other suitable gravel substrate habitats in the Koyukuk River drainage but they have not been identified at this time. It seems unlikely that substantial spawning migrations could pass the communities of Bettles and Evansville without being discovered and exploited. Additional whitefish spawning areas, if they exist, are therefore thought to be downstream from these communities.

In addition to the riverine whitefish populations discussed above, isolated or presumed isolated populations of humpback whitefish, least cisco, and round whitefish have been documented in many of the upland lakes in interior Alaska, and one or more of these species occupy most of the upland lakes in the upper Koyukuk River drainage (Roguski and Spetz 1968; Pearse 1978; Glesne et al. 2011; Appendix A5). Four fish species have been documented in Iniakuk Lake, within the Alatna River drainage, including humpback whitefish and round whitefish. Five fish species were documented in Helpmejack Lake (Figure 3), also in the Alatna River drainage, including least cisco and round whitefish.

Figure 43. Late September view of spawning habitat for inconnu and other whitefish species on the Alatna River in the vicinity of Siruk Creek. Photo by R.J. Brown, USFWS.

Six fish species have been reported in Wild Lake, in the headwaters of the Wild River, including least cisco and round whitefish. Five fish species were documented in Bob Johnson Lake, in the upper Middle Fork Koyukuk River, including least cisco and round whitefish. Three fish species were documented in the southern lake of the Twin Lakes, also in the upper Middle Fork Koyukuk River, including round whitefish. Three fish species were documented in Sithylemenkat Lake, in the Kanuti River drainage (Figure 44), including least cisco and humpback whitefish. Sithylemenkat Lake is perched approximately 60 m (197 feet) over the Kanuti River floodplain at a stream distance of approximately 9.5 km (5.9 miles), an average gradient of about 6.3 $m \cdot km^{-1}$ (33 $ft \cdot mile^{-1}$). Pearce (1978) estimated the outlet flow to be <0.03 $m^3 \cdot s^{-1}$ (<1 $feet^3 \cdot s^{-1}$). Least cisco was the most numerous species in the sample catch in Sithylemenkat Lake. Specimens were aged at 2 and 3 years, yet, the largest of 29 least cisco captured was 145 mm (6 inches) FL, suggesting a dwarf population. Dwarf populations of least cisco have been documented in several lakes in northwest Canada (Mann 1974; Mann and McCart 1981) and Alaska, including Harding Lake, an isolated lake in the Tanana River drainage (Clark and Doxey 1988). River spawning populations of least cisco in interior Alaska are commonly mature by age 3 and average over 300 mm FL (12 inches; Fleming 1994; Harper et al. 2007; Brown 2009). These geomorphology and demographic data suggest that the fish populations in Sithylemenkat Lake may be isolated from the river system. Most of the upland lakes in the upper Koyukuk River drainage have outlet streams that could allow fish migration to the river system, however, the apparent absence or scarcity of humpback whitefish and least cisco in the river system upstream from the South Fork Koyukuk River suggests that these species may be residents of the upland lakes where they have been found. More detailed fish demographic studies, to determine if

Figure 44. Sithylemenkat Lake, an upland lake in the Kanuti River drainage, is approximately 3 km (1.9 miles) wide across the longest dimension and is perched approximately 60 m (197 feet) above the flatland lakes of the Kanuti Lake District. Photo by R.J. Brown, USFWS.

all life stages are present in the lakes, or habitat assessments, to determine if fish passage was possible in or out of some of the lakes with minimal outlet streams, would be required to confirm the isolation of these upland lake populations.

Fisheries

Koyukuk River people rely heavily on whitefish species as the salmon runs in the Koyukuk River are less abundant than in other parts of the Yukon drainage (Andersen et al. 2004). Historically, fisheries resources have been one of the most stable and consistent food sources in the Koyukuk River area and significantly, the heavy and long-term participation in these fisheries has helped to shape Koyukon culture and beliefs (Nelson 1983). Today, residents of Bettles and Evansville, Allakaket, Alatna, Hughes, and Huslia harvest whitefish species throughout the year as part of their annual subsistence take (harvest data for the community of Koyukuk were discussed in the Yukon River main-stem section). Literature describing these patterns and levels of use specifically for the Koyukuk River area are primarily limited to baseline harvest surveys (Marcotte and Haynes 1985; Marcotte 1986; Strong and McIntosh 1985), and three ethnographic studies that documented traditional ecological knowledge of whitefish species and their harvest and use (Nelson 1983; Andersen et al. 2004; Andersen 2007). However, together these studies provide a drainage wide picture of whitefish traditional knowledge, harvest, and use.

Culture and language

Koyukon people have a rich collection of terms to describe whitefish species (Table 11). Table 11 is adapted from Andersen et al. (2004) and includes Inupiaq names that are used in the community of Alatna. The Koyukon term for least cisco and Bering cisco appears to be the same, however, it should be noted that the distribution and abundance of Bering cisco in the Koyukon drainage remains unconfirmed by biologists, such that the name may simply be applied to both cisco species if they are not clearly distinguished by residents. Terms such as *telaaye* indicate naming practices that reflect descriptive seasonal conditions and behavior (Andersen et al. 2004). Whitefish are culturally very important, though they are not generally afforded special treatment outside of the usual respect given to all fish and animals used for subsistence. Historically, Nelson (1983) documented a whitefish ceremony after the harvest of the first whitefish in the spring, which symbolized that the people had survived another winter. The first-caught fish was cooked and eaten without disassembling any of the bones, flaking the meat with care, lest there be hard times ahead. If the bones were disturbed, then bad luck would be coming in the next season (Nelson 1983). Much of the Koyukon beliefs about hunting success revolve around the concept of luck such that bad luck was a particularly bad omen and could even mean starvation.

Table 11. Common, Linnaean, Koyukon, and Inupiaq names for whitefish species encountered by residents of the Koyukuk River in interior Alaska.

English	Linnaean	Koyukon	Inupiaq
Inconnu (Sheefish)	*Stenodus leucichthys*	Ledlaaghe or Nedlaaghe	Sii
Broad whitefish	*Coregonus nasus*	Taaseze[1] or Telaaghe/Telaaye[2]	QausriIuk
Humpback whitefish	*Coregonus clupeaformis*	Holehge[3] or Telaaghe/Telaaye	Qaalgiq
Least cisco	*Coregonus sardinella*	Tsaabaaye or Delbege	Saavaayiq
Bering cisco	*Coregonus laurettae*	Tsaabaaye or Delbege[4]	Qauttaq
Round whitefish	*Prosopium cylindraceum*	Hulten'[5]	Quptik

[1] Name translates as "water bear" (Jette and Jones 2000).
[2] Talaaye refers to both species of large whitefish when they are moving upstream in the spring.
[3] Name translates as "it swims upwards" (Jette and Jones 2000).
[4] Delbege is a lower Koyukon term for both cisco species, sometimes used on the upper Koyukuk to refer to any small fish.
[5] Name translates to "sleigh handle", a reference to their round shape.

Harvest and use

Historically, most whitefish species were harvested with traps (*taal'one*), ranging from complex weir systems in the large riverine habitats to small basket style traps in lakes and sloughs (Nelson 1983, Jetté and Jones 2000, Andersen et al. 2004), especially in the spring under the ice and in the fall at specific sites as fish migrated out of lake habitats. Large in-river funnel traps were approximately 3 to 4 m (10 to 12 feet) in length, constructed of split spruce with a removable panel of wood or canvas in the back to facilitate fish removal. Funnel traps were designed to target smaller whitefish species though larger whitefish species and other non-salmon species were welcome additions (Andersen et al. 2004). Funnel traps might be used in conjunction with weirs or fish fences to help direct fish towards the funnel opening of the trap. Traps were used most heavily up until the 1940s and 1950s. Willow-bark gill nets (*taabeel*) eventually gave way to the improved technology of cotton twine and later, nylon nets such that contemporary nylon nets have completely replaced traps as the primary means of harvest. Today, gillnets constructed with various different mesh sizes range from approximately 15 to 30 m (50 to 100 feet) in length. They can be used in open water or set under the ice. The use of seine nets appears to be primarily confined to the upper reaches of the Koyukuk and Alatna rivers "where river conditions and seasonal concentrations of fish are conducive to their use." (Andersen et al. 2004). Seine nets are usually about 46 to 91 m (150 to 300 feet) long, approximately 3 m (10 feet) deep, with 2.5 cm (1 inch) stretch-mesh webbing. Finally, rod and reel or old-style hand lines are also used, though primarily for inconnu during the spring and fall.

Successful harvests rely on close observation of whitefish over time; Koyukon people have developed knowledge of particular locations, timing, and efficient harvest methods based on the life histories and patterned movements of whitefish species in the Koyukuk River drainage. For example, residents of Hughes and Allakaket seine for whitefish along certain gravel bars in their area. According to Nelson (1983), this is most successfully done in dusky light right before freeze-up in lower water. Fish could be easily preserved by freezing on the banks for winter storage. This fishery, while not practiced on a large scale now, was a significant source of human and dog food historically and remains so for those families who continue the practice.

Koyukon fishermen observe that inconnu appear to have a defined geographical distribution in the Koyukuk River; they are mostly observed in the main stem bound for spawning locations in the upper Alatna River. As such, they are rarely observed in the upper Koyukuk River tributaries (Andersen et al. 2004). Residents of Koyukuk, at the confluence of the Yukon River, noted two distinct runs or pulses of inconnu in the Koyukuk River: the first enters the Koyukuk River as early as March and is comprised of larger fish while a second pulse heads upriver in June, approximately two weeks ahead of the Chinook salmon runs. Because the March run is generally only observed by Koyukuk residents, it is speculated that the bulk of this run remains in the Yukon River, unavailable to upstream Koyukuk River communities, who primarily target inconnu in the middle summer and fall months from July to September. Inconnu reportedly mix with other whitefish species on the Alatna spawning grounds in the fall though specific locations are known to produce more of one type of species than another (Andersen 2007).

Other whitefish species, referred to locally as a group as *ts'ol* or *lookk'e* (collective term for fish), constitute one of the most heavily harvested fish resources in the seasonal subsistence round. Similar to inconnu, the larger whitefish species, mostly broad whitefish, move up the Koyukuk River during break-up and into June, shortly before the Chinook salmon run (referred to locally as *betsy yedolggule* which translates roughly as "its grandfather is pushing it along"). However, unlike inconnu, most Koyukon fishermen note that the seasonal movements of whitefish species tends to be less distinct, where various species occupy a variety of habitats seasonally throughout the drainage and are also reported as year round residents of certain lake systems (Andersen et al. 2004). In short, whitefish of the same species, are often observed to do different things, such as migrate or stay in an area year round. Fishing for whitefish and inconnu generally begins in early May after the river ice breaks up, preceding the arrival of salmon, and nets are set in the mouths of sloughs and creeks. Fishing continues through the summer months and into October when fishermen travel to seining spots in the upper reaches for inconnu, whitefish, and other fish species. These harvest periods coincide with times of the year when meat quality is considered prime.

Fishermen identified that humpback whitefish are year-round residents of the lakes in the Brooks Range foothills and smaller whitefish species, such as least cisco and round whitefish, can be found in the Middle Fork near Wiseman in the summer months and around Helpmejack Lake, a small lake system on the upper Alatna River (Andersen et al. 2004). Least cisco were readily identified by Koyukuk River residents while Bering cisco were not readily recognized by many, raising questions about the extent to which Bering cisco are distributed in the Koyukuk River.

Three harvest surveys provide detailed harvest information for Koyukuk River communities: Bettles/Evansville, Alatna, Allakaket and Hughes in 1982 (Marcotte and Haynes1985); Huslia in 1983 (Marcotte 1986); and all communities in 2002 (Table 12; Andersen et al. 2004). However, the earlier two survey efforts only distinguished between inconnu and other whitefish species, thus not providing detailed information by whitefish species. In contrast, the 2002 survey estimated harvest for inconnu and four species of whitefish.

Table 12. Estimated harvest in kg (pounds in parentheses below) of whitefish species in Koyukuk River communities (including Koyukuk) in 2002 (adapted from Andersen et al. 2004).

Species	Koyukuk	Huslia	Hughes	Alatna	Allakaket	Total
Inconnu	1,045	2,454	489	35	3,982	8,005
	(2,304)	(5,410)	(1,078)	(78)	(8,778)	(17,648)
Broad whitefish	1,813	4,407	3,593	272	3,239	13,323
	(3,996)	(9,715)	(7,922)	(600)	(7,140)	(29,373)
Humpback whitefish	65	4,915	4,592	26	1,762	11,360
	(144)	(10,836)	(10,123)	(57)	(3,885)	(25,045)
Least cisco	0	61	2,597	31	830	3,518
	(0)	(135)	(5,726)	(68)	(1,829)	(7,758)
Bering cisco[1]	0	327	15	0	127	469
	(0)	(722)	(32)	(0)	(280)	(1,034)

[1]Note that Bering cisco were most likely misidentified, as discussed by Andersen (2007).

These three surveys are point estimates through time and therefore do not necessarily represent trends in the fisheries. However, several useful comparisons can be made. In 1982, upwards of 80% of Upper Koyukuk households (Allakaket, Alatna, and Hughes) participated in harvesting approximately 6,993 whitefish and 2,771 inconnu. In 2002, approximately 45% of households participated in harvesting an estimated 16,449 whitefish and 1,656 inconnu, a potentially significant increase in the harvest of whitefish species over time by fewer households in these communities. It is speculated that this increase in whitefish harvest may be related to decreases in salmon abundance and harvests experienced by the region over the last 10 years. In 1983, approximately 50% of Huslia households participated in harvesting 873 inconnu and 4,650 whitefish. In 2002, 30 to 50% of Huslia households participated in harvesting 902 inconnu and 6,691 whitefish, respectively, suggesting little change over time in Huslia harvest levels.

Local fishermen have expressed concerns about the overall health and condition of whitefish species in their area. Many believed that fish were not as fat as they remembered in the past; local hypotheses were that changes in the climate have led to melting permafrost, increased siltation, and elevated water temperatures, which together may be limiting feeding opportunity of reducing food quality (Andersen et al. 2004). Future research efforts may eventually address these and other local concerns.

Potential threats and concerns

Overfishing

Eight communities are located within the Koyukuk River drainage (Appendix A2) with a combined total population in 2008 of approximately 530 residents (U.S. Census Bureau 2010). Four of these communities, with a combined population of approximately 440 residents, are located within the region occupied by the riverine whitefish populations (excluding round whitefish), downstream from the South Fork Koyukuk River. In a recent study of non-salmon fisheries in the Koyukuk River drainage, Andersen et al. (2004) estimated that residents of these four communities annually harvest over 33,700 kg (74,000 pounds) of whitefish that is composed of approximately 2,500 inconnu, 6,000 broad whitefish, 8,000 humpback whitefish, and 7,500 least cisco, as discussed above. Gillnet fisheries are directed primarily towards fish migrating in river systems to and from feeding and spawning habitats. Fall beach seine fisheries are directed towards whitefish gathering for spawning in the main-stem Koyukuk River near Hughes and up the Alatna River in the vicinity of Siruk Creek (Andersen 2007). While there are no population data to evaluate the sustainability of this level of harvest, these gillnet and beach seine fisheries have been taking place for many years and are not thought to be an expansion of fishing effort in the region. Whitefish populations originating in the upper Koyukuk River spawning areas are subject to an unknown amount of harvest outside the drainage as well, because a substantial fraction of inconnu, broad whitefish, humpback whitefish, and least cisco rear in marine water near the Yukon River mouth (Brown et al. 2007), and inconnu are thought to overwinter there even when mature (Alt 1977a).

Development

Development impacts to whitefish resources in the Koyukuk River drainage could come in several different forms including mineral extraction, riverbed gravel mining, and roads. Placer gold mining in the drainage began in the late 1800s, primarily in the upper drainage tributaries of the Alatna, John, Wild, North Fork Koyukuk, Middle Fork Koyukuk, and South Fork Koyukuk rivers (Brown 2007b). Miners initially accessed the region by paddlewheel steamboats and other smaller boats during the summer months and overland from the Yukon or Chandalar River drainages using dog teams or on foot in the winter months (Buzzell 2007). Additional large-scale placer mining operations began in the Indian and Hogatza River drainage in the 1930s and 1940s (Smith 1939; Boswell 1979). The Hogatza River placer mine is located in a western tributary named Bear Creek, where a large floating dredge was employed to efficiently mine the entire valley (Figure 14). As recently as the early 1980s, this dredging operation was discharging highly turbid water and impacting the streambed with fine sediments as far as 40 km downstream from the mine, as documented by Webb (1983b). Presumably the mine has improved its settling pond system to bring its water discharges more in line with State water quality standards, as detailed by Lloyd (1987). Numerous placer gold mining operations continue within the Koyukuk River drainage, primarily in the upper reaches of the Middle Fork Koyukuk River drainage and in the Bear Creek region of the Hogatza River drainage (Szumigala et al. 2001, 2008). Despite the unavoidable disruption of stream substrate that occurs with placer mining operations, none are directly threatening known whitefish spawning habitats at this time.

During construction of the Dalton Highway and the Trans-Alaska Oil Pipeline in the 1970s, a large amount of riverbed gravel was removed from upper drainage tributaries of the Koyukuk River including Prospect Creek, Jim River, Middle Fork Koyukuk River, and Dietrich River (Woodward-Clyde Consultants 1980). More recent (1990 to present) riverbed gravel mining operations have taken place in the main-stem Koyukuk River drainage at Allakaket (ADL 415878), Hughes (ADL 414384), and Huslia (ADL 400510). During an aerial survey in late September, which is spawning season for inconnu, Alt (1970) reported seeing spawning aggregations of inconnu in the vicinity of Hughes and Allakaket, as well as up the Alatna River near Siruk Creek. Presumably these inconnu were spawning in these areas. It is possible that streambed gravel removal activities at Allakaket and Hughes have already reduced inconnu spawning habitat in the region. If inconnu spawning activity in the Koyukuk River drainage is as widely distributed as Alt's (1970) aerial survey data suggest, the riverbed gravel removal activities identified above may not have had a serious impact on the population. Riverbed gravel removal from spawning habitats, however, is a potential threat to whitefish populations, particularly if their spawning habitats are more limited in geographic size. We know of no plans to extract gravel from any of the known whitefish spawning habitats, but, these habitats should be considered when planning riverbed gravel extraction projects in the future.

The Dalton Highway crosses several headwater rivers along the eastern part of the Koyukuk River drainage providing road access to the general public. While the Dalton Highway stream crossings provide local sport fishing opportunities for Arctic grayling, as described by Fish (1997), they do not provide reliable boat access to the drainage because the rivers are shallow and rocky near crossing locations and boat launching facilities are marginal. At this time, we are not aware of any plans for road construction in the region. NovaGold Resources Inc. (NovaGold), however, is a large mining company investigating the feasibility of developing a large, hard-rock metals mine in the upper Kobuk River drainage. If that mine is eventually developed, NovaGold intends to ship concentrated ore to an existing processing facility somewhere else (SRK Consulting 2008), similar to the process at the Red Dog Mine in Northwest Alaska. While they do not outline their shipping options in their technical resource report on the project, some residents of the upper Kobuk River believe they are considering two options; a road west to link up with the Red Dog Mine transportation system, or a road east to link up with the Dalton Highway. The road to the Dalton Highway would be the shorter of the two options and would provide substantially improved access to the upper Koyukuk and Kobuk River drainages for rural and urban residents alike.

The Alaska Department of Transportation is considering construction of a major road connecting the existing interior highway system and the Seward Peninsula community of Nome (DOWL HKM 2010). Two alternative routes have been proposed. The northern route follows the Dalton Highway north of the Yukon River and then crosses the upper Koyukuk

River drainage and on to the Seward Peninsula. The southern route follows the Elliott Highway towards the community of Manley, west to the confluence of the Tanana and Yukon rivers where a bridge would be constructed over the Yukon River near the community of Tanana, and west from there paralleling the Yukon River on the north side until crossing the Koyukuk River near its mouth and on to the Seward Peninsula. If the proposed road to Nome is eventually built, and if the northern route is chosen, the Kobuk River mine proposed by NovaGold Resources Inc. would have a road across the upper Koyukuk River drainage to markets and many thousands of people would have easy access to the region.

The environmental effects of road building could impact whitefish populations because of riverbed gravel removal for roadbed construction, culverts on smaller stream and slough crossings could impede free passage of fish into rearing and feeding habitats, and sediments released during construction could change river bottom habitats downstream (Harper and Quigley 2000; Wheeler et al. 2005). In addition to the physical impacts of road building, the increased human presence in the region could have a profound effect on fisheries. Because inconnu are the primary whitefish species captured by hook and line angling methods, they would be the species most likely to be affected by this type of road development, particularly if the road were to cross the Alatna River. This would be an issue to consider if this road is ever seriously considered.

Nowitna River Habitat Region

The Nowitna River is a large tributary of the middle Yukon River, entering the Yukon River approximately 985 km (612 miles) upstream from the Bering Sea (Figure 45). It drains an area of approximately 18,762 km^2 (7,244 $mile^2$), which is approximately 2.2% of the entire Yukon River drainage basin (USFWS 1991; Brabets et al. 2000). The Nowitna River drainage supports a range of fish habitats which we summarize here based on detailed descriptions by Alt (1985) and USFWS (1991). The Nowitna River flows approximately 570 river km (354 river miles) north from its headwaters in the Kuskokwim Mountains, about 60 km (37 miles) north of the Kuskokwim River community of McGrath, into the south bank of the Yukon River. In the lower 150 km (93 miles), downstream from the mouth of the Little Mud River, the Nowitna River flows slowly over a mud or sand substrate, may be as wide as 150 m (490 feet), and as deep as 18 m (60 feet) in some reaches. There are numerous oxbow lakes within the floodplain in the lower reaches of the Nowitna River, many with permanent or seasonal stream connections to the river, and thousands of small tundra and upland lakes, most of which are effectively isolated from the river. Despite the abundance of lakes in the lower reaches of the Nowitna River drainage, it was not classified as a lake district by Arp and Jones (2009). Upstream from the mouth of the Little Mud River, the Nowitna River flows more swiftly over sand, gravel, or rock substrates and becomes progressively more narrow and shallow into the upper reaches of the drainage. Oxbow lakes are present in some reaches of the upper drainage, but, lakes in general are much less common than in the lower reaches.

Within the Nowitna River drainage there are four relatively large tributaries, the Sulatna, Titna, Sulukna, and Susulatna rivers, and two smaller tributaries, the Little Mud and the Big Mud rivers. The Sulatna River flows north into the Nowitna River approximately 119 km (74 miles) upstream from the Yukon River. The Sulatna River flows very slowly over a mud substrate through the lower 300 river km (186 river miles). It can be as wide as 61 m (200 feet) and as deep as 3 m (10 feet) or more throughout the lower reach (Alt 1985), where there are many oxbow lakes within the floodplain. Gravel substrate occurs only in the smaller headwater reaches of the Sulatna River, which are in low hills rather than mountains. The Little Mud and Big Mud rivers drain a relatively low relief region to the east of the main-stem Nowitna River. Similar to their Innoko River counterparts discussed earlier, the Little Mud and Big Mud rivers are extraordinarily turbid throughout their lengths (R.J. Brown, USFWS, personal observations). They are both slow meandering rivers. The Titna River enters the Nowitna River in a large canyon approximately 228 km (142 miles) upstream from the Yukon River. The lower 20 km (12 miles) of the Titna River flows swiftly through a rocky canyon at channel widths as great as 46 m (150 feet), but, the valley opens up beyond that and the river through most of its length flows slowly in large meanders over soft substrate (Webb 1983c). The Sethkokna River, a tributary of the Titna River, is the only substantial reach within the Titna River drainage that flows clear and swift over a gravel substrate (R.J. Brown, USFWS, personal observation). The Sulukna River joins the Nowitna River approximately 288 km (179 miles) upstream from the Yukon River. The Sulukna River may be as wide as 40 m (131 feet) or more and flows clear or stained from tundra seepage over a sand and gravel substrate throughout its length (Gerken 2009). The Susulatna River is the uppermost tributary of the Nowitna River, joining approximately 389 km (242

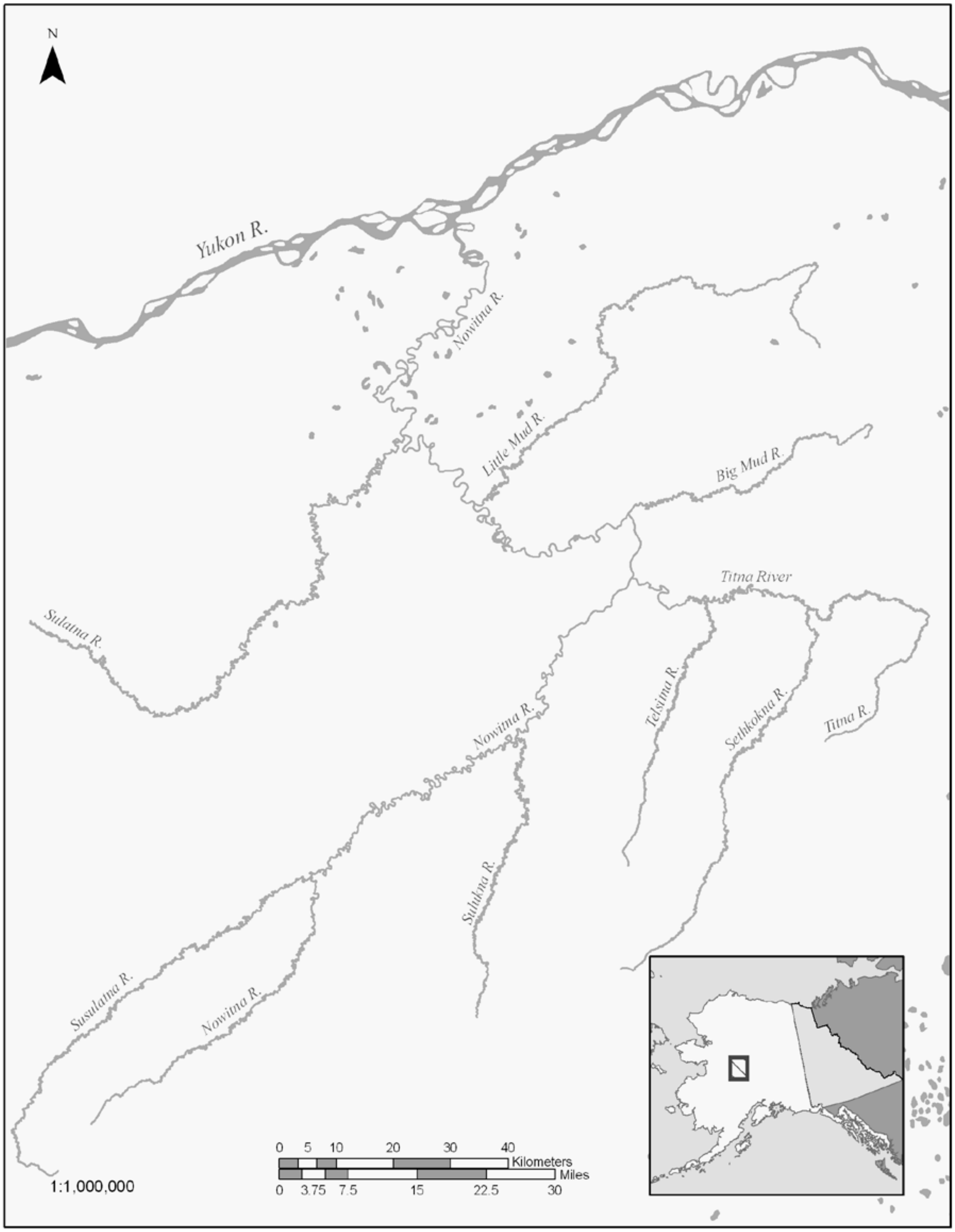

Figure 45. The Nowitna River habitat region in western interior Alaska including major tributaries. There are no communities within the drainage.

miles) upstream from the Yukon River. The Susulatna and main-stem Nowitna rivers upstream from their confluence are similar in size and morphology. Both flow clear and relatively swift over a predominantly sand and gravel substrate.

Whitefish species, distribution, and biology

Six whitefish species have been documented in the Nowitna River drainage. Alt (1985) conducted several fish sampling expeditions in the Nowitna River drainage during the 1970s and 1980s and his summary report is the most comprehensive fisheries study available for the drainage. He traveled throughout the main stem and into the lower reaches of some tributaries sampling primarily with angling methods and multiple mesh gillnet sets. He reported capturing inconnu, broad whitefish, humpback whitefish, and least cisco through most of the slow, meandering, main-stem reaches, round whitefish only in the clear, swiftly flowing upper reaches, and Bering cisco only at the confluence of the Nowitna and Yukon rivers (Alt 1973a, 1985). Webb (1983c) conducted a brief inventory of the Titna River during 1983 sampling with angling methods, multiple mesh gillnet sets, and small mesh beach seines. He captured humpback whitefish and round whitefish in the middle reaches of the drainage and inconnu only at the confluence of the Titna and Nowitna rivers. Wiswar (1994a) sampled the main-stem Nowitna River downstream from the Sulatna River mouth for three weeks in late June and early July and two days in early September, 1993. He was sampling specifically to document the presence of Pacific salmon species so he used large mesh gillnets exclusively. He captured numerous inconnu and broad whitefish, the two whitefish species large enough to be taken with his sampling gear. Glesne et al. (2011) sampled 16 lakes in the lower Nowitna River drainage (Appendix A5), most being oxbow lakes with seasonal or permanent stream connections to the river. He found broad whitefish, humpback whitefish, and least cisco to be common to most lakes with stream connections to the river and inconnu were present in three oxbow lakes near the river.

Perhaps the most important whitefish fisheries discovery in the Nowitna River was that inconnu and humpback whitefish were spawning in the Sulukna River (Alt 1978a, 1985). Alt (1978a, 1985) captured inconnu during early September in the lower Sulukna River and determined that they were preparing to spawn based on his observations of enlarged egg masses in females and the expression of milt in males. He traveled by boat in the lower Sulukna River and observed schools of inconnu throughout the lower 56 km (35 miles) of the river. It was his impression that the greatest concentration of inconnu was in a reach between 40 and 48 km (25 and 30 miles) upstream from the mouth.

A series of more recent studies on the spawning population of inconnu in the Sulukna River have identified the spawning reach within the drainage, described certain spawning habitat qualities, spawning timing, spawning population estimates, and length and age distributions of the spawning population. A radio telemetry project was initiated in 2005 by the Alaska Department of Fish and Game (J. Burr), the U.S. Fish and Wildlife Service (R.J. Brown), and the Bureau of Land Management (C. Kretsinger) to more clearly identify the inconnu spawning reach within the Sulukna River. A 21 km (13 mile) spawning reach between 71 and 92 km (44 and 57 miles) upstream from the Sulukna River mouth was identified based on the farthest upstream locations of radio-tagged fish during multiple aerial surveys in the fall spawning period (R.J. Brown, USFWS, unpub. data). Gerken (2009) subsequently refined the extent of the spawning reach based on a ground survey of spawning inconnu in late September and early October and suggested that it was 20 km (12 miles) in length between 72 and 92 km (45 and 57 miles) upstream from the mouth (Figure 46). Gerken (2009) actually confirmed that inconnu and humpback whitefish were spawning in the reach with underwater video, the observation of inconnu breaking the water surface during the evening while expelling eggs and milt, and egg capture with benthic plankton nets. His data indicated that inconnu would hold in pool habitats during the day and move into runs, which are shallower, gravel substrate reaches with relatively swift current, in the evening to spawn. A DIDSON sonar, a technology that allows the size of passing fish to be estimated reasonably accurately out to about 12 m (39 feet; Maxwell and Gove 2004; Burwen et al. 2007), was deployed in the Sulukna River about 40 km (25 miles) downstream from the spawning reach (Figure 46) in fall 2008 and 2009 (Esse 2011). Primary objectives were to identify the timing and duration of the annual spawning event in the Sulukna River and to count the number of inconnu migrating downstream following spawning. A small number of downstream migrating inconnu were sacrificed to verify that they had spawned. Females were uniformly depleted of eggs except for a small number of residual eggs in the body cavity and males were similarly depleted of milt. Post-spawning inconnu began migrating downstream in late September during both years with the peak outmigration occurring on October 3 in 2008 and October 4 in 2009. Because Esse (2011) operated the DIDSON sonar unit 24 hours each day, he essentially produced a census of the spawning population. He counted 2,079 inconnu in 2008 and 3,531 inconnu in 2009, providing two years of high quality abundance data for the Sulukna River spawning population.

Length and age data for mature inconnu from the Sulukna River spawning population were collected in 2003 (R.J. Brown, USFWS, unpub. data), Gerken (2009) in 2007 and 2008, and Esse (2011) in 2008 and 2009. Mature females tended to be larger than males with minimum fork lengths of 66 and 62 cm (26 and 24 inches) respectively, and median fork lengths of 82 and 72 cm (32 and 28 inches) respectively (Figure 47). The largest female was 93 cm (37 inches) fork length while the largest male was 84 cm (33 inches) fork length. Male inconnu appeared to mature at an earlier age than females with the youngest fish being age 6 and age 9 respectively. Males and females in our sample appeared to be similarly long-lived with maximum ages for both in the mid-20s. These tendencies for female inconnu to mature later and attain greater size than males are also common to other inconnu populations in the Yukon River drainage (Brown 2000) and elsewhere in Alaska (Taube and Wuttig 1998; Hander et al. 2008).

Based on sampling data, Alt (1985) believed that inconnu and humpback whitefish spawned in the Sulukna River and that broad whitefish and least cisco spawned elsewhere in the Nowitna River drainage. Broad whitefish were captured in the Nowitna River upstream from the mouth of the Sulukna River but inconnu and humpback whitefish were not. Alt (1985) considered many of the captured broad whitefish to be preparing to spawn, presumably based on an examination of their gonads, and suggested that they were migrating to spawning habitats in the upper Nowitna or the Susulatna River. Least cisco were most common in the lower Nowitna River and were rarely captured in the upper drainage. As a result, Alt (1985) believed that most were spawning downstream from the Sulukna River. The spawning destinations for broad whitefish and least cisco encountered in the Nowitna River drainage have not been located and it is possible that they use the drainage only for feeding and leave to spawn elsewhere in the Yukon River drainage.

Figure 46. Looking upstream at inconnu spawning habitat in the Sulukna River 75 km (47 miles) upstream from the mouth (top image), and the DIDSON sonar station located about 40 km (25 miles) downstream from the spawning area (bottom image). Post-spawning inconnu were counted as they passed between the end of the orange fence and the cut bank, a distance of 11 m (36 feet). Photos by R.J. Brown, USFWS.

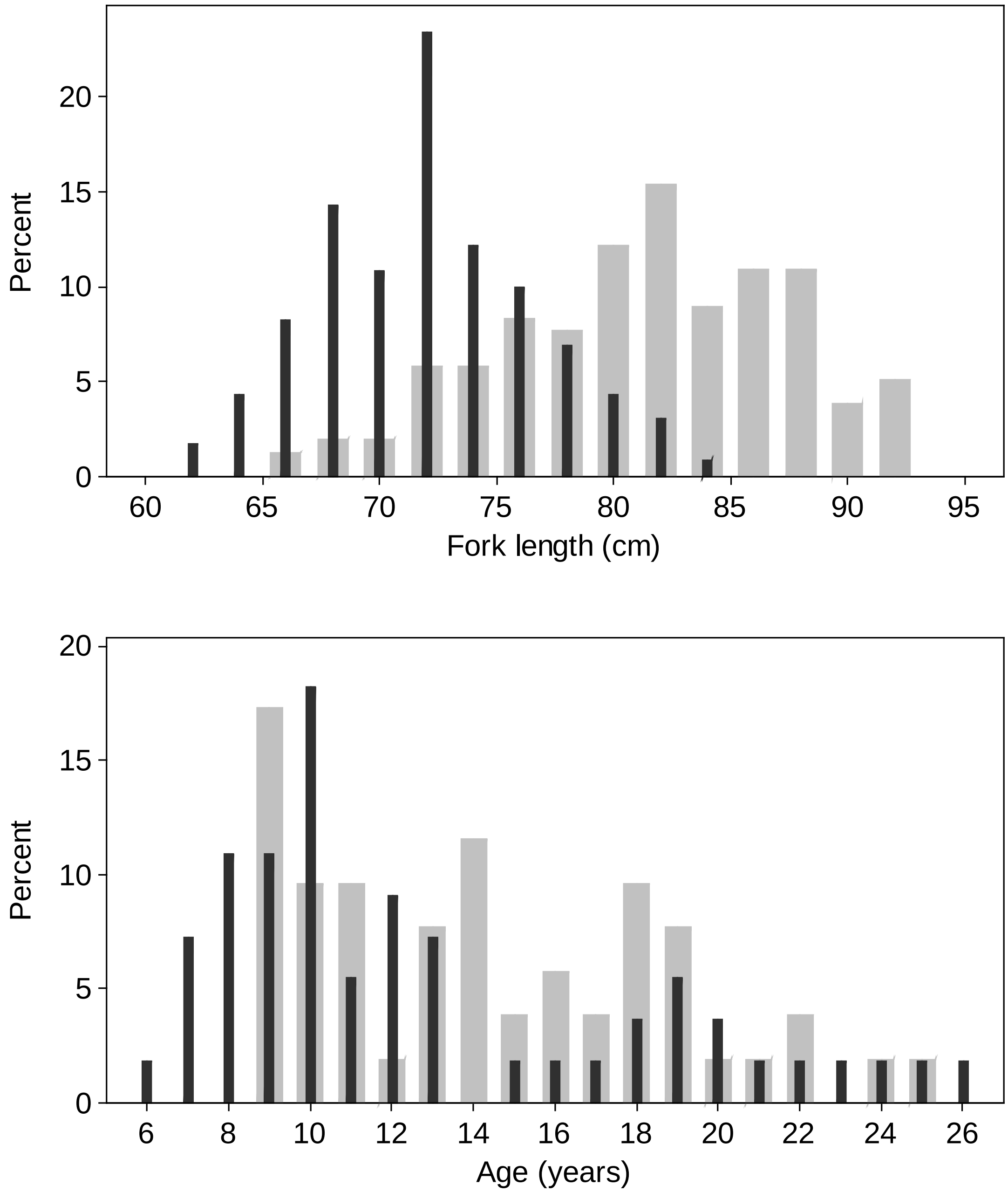

Figure 47. Length and age distributions of mature male (dark narrow bars) and female (wide grey bars) inconnu from the Sulukna River spawning population. Note that larger inconnu tend to be female (*n* = 156) and smaller inconnu tend to be male (*n* = 231). The youngest mature females in this sample (*n* = 53) were age 9 and the youngest mature male was age 6 (*n* = 55), suggesting an earlier age at maturity for males. Maximum ages for both females and males were in the mid-20s.

Fisheries

The Nowitna River drainage was historically used by the ancestors of the contemporary village of Ruby, in the middle Yukon River. It is much less used today for subsistence fishing than in the past. Prior to the establishment of the contemporary village, however, Zagoskin (1967; Hart 1981) documented early Koyukon Athabascan settlements in the Ruby area, including settlements or camps at Mouse Point, downriver from the mouth of the Nowitna on the north bank of the Yukon river and at *Novikaak'at* ("mouth of the Nowitna River"). Neither settlement is currently used for habitation, though both are periodically used for short periods of fishing, especially by Ruby residents who lived or spent time in these places as children. Both areas have been documented as significant use areas for whitefish species by contemporary Ruby residents (Figure 48; Brown et al. 2010).

Figure 48. Caroline Brown maps traditional fishing sites with Martha Wright, Ruby resident born in Mouse Point, in 2007. Photo by L. Kangas, ADFG.

Culture and language

The Nowitna River was a major winter and spring settlement area prior to the 1960s, primarily used by Mouse Point and Kokrines people (most of whom now live in Ruby). Residents of the old settlements in the Nowitna River drainage, as well as contemporary Ruby residents, are primarily Koyukon Athabascan speakers. As such, the linguistic structures surrounding whitefish species and fishing practices is largely addressed in the Yukon main-stem chapter. Families traveled to winter camps up and down the Nowitna River; while these camps were primarily muskrat trapping camps, significant whitefish fishing activities also occurred, primarily jigging for inconnu and setting nets under the ice for other whitefish species. After winter trapping, multiple families travelled to the mouth of the Nowitna River (Figure 49), where they gathered to wait for each other, drying and smoking muskrat and moose meat, and fishing for fresh sources of meat and for dog food. Here they used nets and hooks primarily for inconnu in the spring after ice break up and before floating down the Yukon to other main-stem settlements. The temporary camp provided an opportunity to harvest large amounts of whitefishes as well as other resident species such as northern pike. Men and women worked together to harvest fish and women

Figure 49. Mouth of the Nowitna River, the site of the historical spring gathering after a long winter trapping before returning to Kokrines. Photo by C. Brown, ADFG.

did most of the net repair as well as the setting or checking of nets primarily used to harvest non-salmon fish species (Brown et al. 2010).

Harvest and use

Harvest and use of whitefish species in the Nowitna drainage is largely confined to Ruby residents and residents of other nearby communities who have historical experience in the area. Harvest estimates for whitefish species are presented here for Ruby residents (also in the Yukon main-stem chapter), however, these data are not linked to specific harvest sites. In addition to the Nowitna River drainage, Ruby residents harvest fish from a variety of places, including the old villages at Deep and Big Creeks, the Melozitna River, and Big Eddy (Brown et al. 2010).

Ruby residents report that the spring movements of fish, especially inconnu, were central to their spring fishing practices. They tied these movements to the break up and movement of river ice and many fishermen reported targeting inconnu during spring break-up as a source of fresh meat. Fishermen reported harvesting whitefish species primarily during the open water months, and key respondent interviews in Brown et al. (2010) indicated that fish wheels, gillnets, and hook and line were the primary gear types used for harvest by contemporary residents.

In 2006, Ruby residents reported harvesting an estimated total of approximately 1,238 kg (2,729 pounds) of non-salmon fish species, with the majority of this harvest (82%) comprised of inconnu (541 kg, 1,193 pounds, or 199 fish) and whitefishes (479 kg, 1,056 pounds, or 348 fish). Approximately 38% of Ruby residents reported using inconnu. Only 2 species of whitefish, broad whitefish and humpback whitefish, were reported harvested in 2006, and of these, humpback whitefish were estimated to comprise the largest component by weight (406 kg; 895 pounds). While Ruby fishers reported harvesting an estimated 25 kg (55 pounds) of broad whitefish (14 fish), 48 kg (106 pounds) of unknown whitefishes were also reported harvested.

Potential threats and concerns

Overfishing

There are no communities within the Nowitna River drainage. Fishing in the drainage appears to be limited to opportunistic angling by hunters and trappers living within the drainage (Alt 1985), residents of nearby communities (Case and Halpin 1990), and urban fishers and hunters visiting the river (USFWS 1991). Alt (1985) suggested that harvest levels were probably low compared to many other more populated areas of the drainage. He presented sampling data, however, suggesting that inconnu, broad whitefish, humpback whitefish, and least cisco migrate from main-stem overwintering habitats into the Nowitna River drainage in the spring to feed. Additionally, some inconnu tagged in the Nowitna River have been located elsewhere in the Yukon River drainage (Alt 1973b, 1974, 1975). These data indicate that whitefish encountered in the Nowitna River are vulnerable to harvest in fisheries outside the drainage, although, the geographic distributions of these species within the Yukon River drainage are unknown. Two populations originate in the Nowitna River drainage, inconnu and humpback whitefish, both in the Sulukna River. Other populations of inconnu and humpback whitefish may also visit the Nowitna River to feed, and the population origins of other species are unknown. While Esse's (2011) inconnu abundance data for the Sulukna River spawning population set a baseline for evaluating population trends in the future, they do not allow us to know if the current population level is average, depleted, or high. In any case, there is no evidence at this time that whitefish populations encountered in the Nowitna River drainage are threatened by overfishing.

Development

Placer mining has taken place in the Nowitna River drainage for more than 100 years and it continues today in several tributary streams (Szumigala et al. 2009). Mining and its associated road system is the primary development impact to aquatic environments within the drainage. Mining exploration and production ventures have taken place in several tributaries of the drainage, such as the Titna (Webb 1983c; USFWS 1991) and Sulukna (Eakin 1918) rivers, although, the most extensive operations have occurred in the upper Sulatna River drainage in what is known as the Ruby-Poorman mining district (L'Ecuyer 1993). At its peak in the early 1900s, there were several hundred miners working in the Ruby-Poorman mining district, which included the old mining communities of Long, in the upper Sulatna River drainage, and Poorman and Placerville, in the upper North Fork Innoko River drainage. The entire mining district was accessible by river up the Nowitna and Sulatna rivers, and by trail or road from the community of Ruby on the Yukon River. Dredges, draglines, bulldozers, open pits, and other methods were used in the extensive mining activities in the district. Alt (1985) reported that during September 1984 the lower Sulatna River was very turbid, a condition he attributed to the placer mining operations more than 300 river km (186 river miles) upstream. The Sulatna River has not been identified as important whitefish habitat and there is no evidence that it currently supports spawning for any whitefish species. However, it is possible that the early mining activity, which was much more extensive and unregulated than current activity (L'Ecuyer 1993; Szumigala et al. 2009), could have caused sedimentation of essential habitat for one or more whitefish populations in the Sulatna River drainage and eliminated them. Certainly if a similarly high level of mining, with its removal or disturbance of gravel substrate at the mining site and sedimentation of downstream habitats, were to occur in the Sulukna River drainage, we would expect it to impact and possibly eliminate the inconnu and humpback whitefish populations that spawn there. Given the relatively low level of mining activity in the drainage today, we do not consider mining activity to be a substantial threat to whitefish populations in the Nowitna River drainage.

Tanana River Habitat Region

The Tanana River is the second largest tributary of the Yukon River in drainage area, 114,737 km^2 (44,300 mile^2), and the largest tributary in terms of flow, 1,263 $m^3 \cdot s^{-1}$ (44,600 feet$^3 \cdot s^{-1}$), contributing almost 20% to the total Yukon River flow (Figure 50; Brabets et al. 2000). The southern tributaries of the Tanana River, from the Kantishna River upstream, have glacial origins in the northern slopes of the Alaska Range and the Wrangle Mountains and flow very turbid throughout the open water season each year. As a result, the Tanana River is a major contributor of glacial silt to the Yukon River. The northern tributaries of the Tanana River drain the southern slopes of the Yukon Tanana Highlands, the non-glaciated mountainous region between the Yukon and Tanana rivers. These northern tributaries flow clear except during high flow events during the spring snow melt or following heavy rains during summer. Three lake districts, as discussed earlier, have been identified within the Tanana River drainage; Minto Flats in the Tolovana River drainage, Minchumina, which encompasses part of the upper Kantishna River drainage, and Tetlin in the lower Nabesna and Chisana River drainages (Arp and Jones 2009). In addition to the shallow, flatland lakes of the lake districts, there are many relatively deep, upland lakes in the drainage.

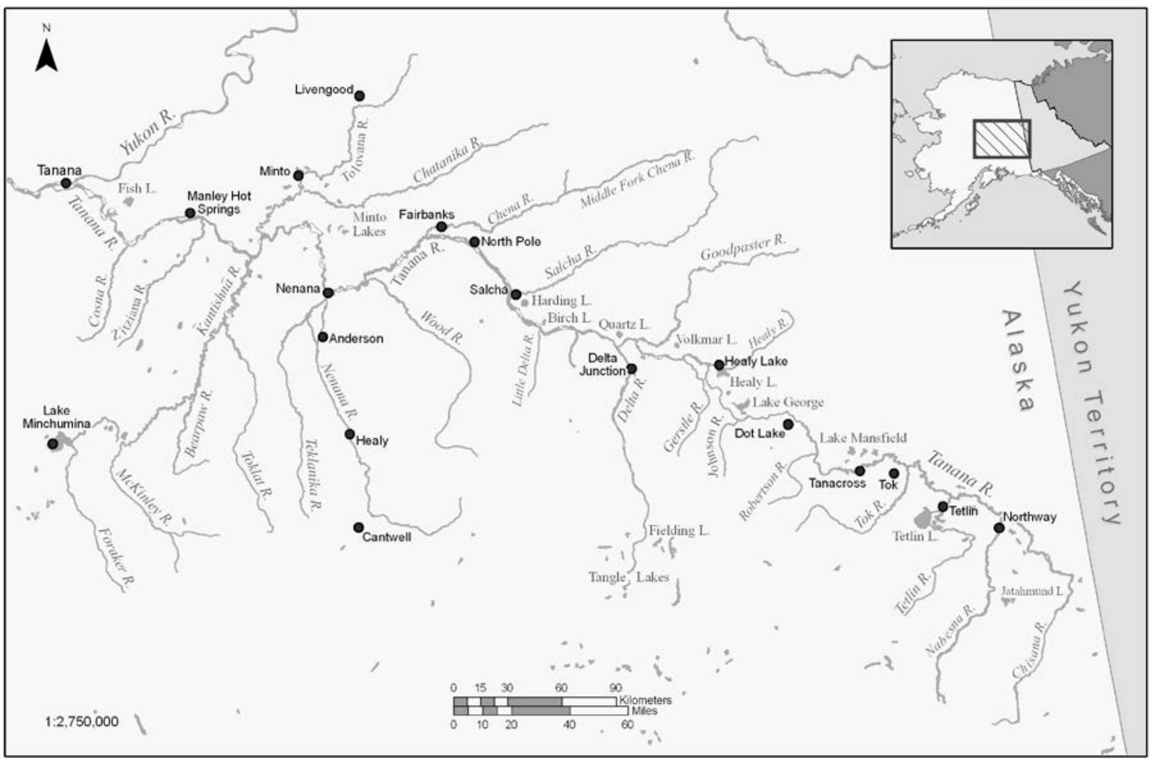

Figure 50. The Tanana River habitat region in interior Alaska including major tributaries and communities.

The main-stem Tanana River flows swiftly for 930 km (579 miles) from its origins at the confluence of the Nabesna and Chisana rivers to its confluence with the Yukon River approximately 1,125 km (699 miles) from the sea. Continually eroding banks and large driftwood piles throughout the main stem illustrate the erosive force of the Tanana River. It flows turbid during the open water season and clear during winter when glacial flow declines (Brabets et al. 2000). Substrate in the lower 260 km (162 miles) of the Tanana River, downstream from the mouth of the Nenana River, is composed primarily of silt and mud with very few areas of gravel or rock. Islands are common in the lower Tanana River but it is not particularly braided (Figure 51). Gravel substrate becomes progressively more common upstream from the mouth of the Nenana River even though there are still many reaches with mud and silt deposits. The 178 km (111 mile) reach between the Chena and Delta rivers, in the mid-Tanana drainage, is extraordinarily swift, shallow, and braided. This reach is dominated by a gravel substrate. River morphology upstream from the mouth of the Delta River is similar to the lower Tanana River but gravel substrate is more common.

Eleven southern tributary rivers flow from glacial origins to the Tanana River. The Kantishna River is the largest of these glacial tributaries and meanders more than 300 km (186 miles) from its mountainous origins to its confluence with the Tanana River. The origins of glacial tributaries farther upstream in the drainage are closer to the Tanana River. Headwater glaciers of some tributaries such as the Delta, Johnson, and Robertson rivers, for example, are close enough that the rivers flow swiftly across glacial outwash gravel directly into the Tanana River. Headwater transfer of fish between the Delta River and the Susitna River is possible at this time through an unusual situation in which the river emanating from the Eureka Glacier splits into two forks along a continental divide (Figure 52). River-connected lake systems are present in many of the glacial river drainages, such as the Minchumina Lake District (Arp and Jones 2009) in the Kantishna River drainage, the Tangle Lake system in the Delta River drainage (Peckham 1976), and the Tetlin Lake District (Arp and Jones 2009) in the lower Chisana River drainage, but, some are simply glacial outwashes with little habitat diversity.

Four northern tributary rivers, the Tolovana, Chena, Salcha, and Goodpaster rivers, flow from the Yukon Tanana Highlands into the Tanana River. These and numerous smaller northern tributaries, flow clear over gravel substrate through much of their lengths. The Minto Flats Lake District (Arp and Jones 2009) lies within the Tolovana River drainage (Figure 53). Fairbanks and its satellite communities lie mostly within the Chena River drainage, which is the most heavily developed tributary within the Tanana River drainage. In addition to the four rivers discussed above, there are numerous open lake systems on the north side of the Tanana River including the Fish Lake drainage in the lower river, and Healy, George, Sand, and Mansfield lakes in the upper river that provide a tremendous diversity of fish habitat that is not influenced by the glacial flow on the south side of the drainage.

In addition to the rivers and lakes described above, there are many unusual riverine habitats present within the Tanana River drainage. For example, there are a number of clear-water, spring-fed streams that emerge on the south side of the Tanana River (Pearce 1974, 1976b; Ridder 1980, 1983; Nelson 1995; Maurer 1999). Underground aquifers coming from the Alaska Range supply a stable volume of clear, cold water for these relatively short drainage systems. As a result, the spring-fed systems are very stable, cold in summer, warm in winter environments for fish. A very different type of habitat is seen in three small, tundra-stained rivers draining the low hills on the south side of the Tanana River downstream from the Kantishna River mouth. These rivers, the Chitanana, Cosna, and Zitziana, appear to meander endlessly through their low-gradient valleys (Figure 54). There are no large gravel reaches

Figure 51. Characteristic images of the lower Tanana River, downstream from the Nenana River (upper image), and the braided reach between the Chena and Delta River mouths (lower image), illustrating the substantial differences in river morphology. Photos by R.J. Brown, USFWS.

Figure 52. Looking north to the Eureka Glacier from approximate location 63.27163 N latitude 146.34725 W longitude. The river emanating from the glacier splits with the west fork (left) flowing into the East Fork Maclaren River, a tributary of the Susitna River drainage, and the east fork (right) flowing into Eureka Creek, a tributary of the Delta River within the Yukon River drainage. Headwater transfer of fish from one drainage to the other is clearly possible at the current time. Photo courtesy of A. Gryska, ADFG.

and no braided regions within these drainages. They maintain vegetated banks that appear to be relatively stable despite the abundance of oxbows within their floodplains. These three drainages are similar in morphology to the upper Tolovana and Tatalina rivers within the Tolovana River drainage on the north side of the Tanana River. These and many other unique habitats are available for fish in the Tanana River drainage.

Whitefish species, distribution, and biology

Five whitefish species have been documented in the Tanana River drainage (Brown et al. 2007). Inconnu, broad whitefish, humpback whitefish, and least cisco are actively sought in subsistence and other fisheries in the drainage (Brown 2006; Brase 2010; Hayes et al. 2008) and round whitefish are occasionally harvested as well (Hallberg et al. 1986). Bering cisco have not been captured in the Tanana River drainage despite numerous biological sampling studies (Alt 1973a; Brown et al. 2007).

Figure 53. Aerial view of the southeast Minto Flats Lake District in the Tolovana River drainage. Photo by R.J. Brown, USFWS.

Inconnu and broad whitefish appear to have the most limited distributions of all the whitefishes within the Tanana River drainage. Brown et al. (2007) conducted an otolith chemistry analysis of both species from samples taken in the main-stem Tanana River and found that some inconnu and most broad whitefish had reared in marine water. Both species are commonly encountered in the Tanana River drainage downstream from the Chena River mouth (Kepler 1973; Townsend and Kepler 1974; Kramer 1975; Alt 1977a, 1979c, 1980a; Borba 2007). Inconnu appear to feed in the lower reaches of clear tributary streams but are rarely encountered in lakes. Broad whitefish are common during summer in open lake systems within the Tolovana River drainage as well as in Lake Minchumina, approximately 317 km (197 miles) up the Kantishna River. Presumably they also migrate into Fish Lake, a large, shallow lake in the lower Tanana River drainage, to feed in summer but there are no species-specific data from that system. Neither inconnu or broad whitefish maintain populations in isolated lakes, however, inconnu were cultured from the late 1960s to the mid-1980s and stocked in several lakes within the Tanana River drainage to enhance sport fishing opportunity, as well as in the Chatanika River in an effort to enhance that small spawning population (Hallberg et al. 1986; Alt 1987; Bentz et al. 1991). None of the inconnu stocked in Tanana River drainage lakes have produced spawning populations and the fate of those stocked in the Chatanika River is unknown. The farthest upstream reports of inconnu include an angler harvest at the mouth of the Salcha River in 1970 and a subsistence harvest somewhere upstream from the mouth of the Delta River in 1972 (Alt 1973b, 1977a).

Figure 54. Aerial view of the central Zitziana River valley (top image), illustrating the low-gradient, meandering nature of the drainage system that continues into the headwaters, and the mixing zone at the river's mouth (bottom image) where the relatively clear Zitziana River enters the turbid flow of the Tanana River in a side channel. These river characteristics are common to the Chitanana, Cosna, and Zitziana rivers. Photos by R.J. Brown, USFWS.

Alt (1972) reported a broad whitefish captured in the main-stem Tanana River about 14 km (8.5 miles) upstream from the Chena River mouth in September, 1971. Dinneford (1978) reported capturing numerous broad whitefish and no humpback whitefish in the Tanana River near the mouth of the Johnson River while many others have reported humpback whitefish but no broad whitefish in that region of the Tanana River (Pearse 1976a; Elliott 1982; Glesne et al. 2011). Van Hyning (1978) suggested that Dinneford (1978) may have misidentified a catch of humpback whitefish, and in the absence of other biological records of broad whitefish in the upper Tanana River, we agree with this assessment. A recent radio telemetry study in the Tanana River drainage has documented a spawning area for several whitefish species, including inconnu and broad whitefish, in the braided main stem between the mouths of the Chena and Salcha rivers (Figure 55; Dupuis 2010; R.J. Brown, USFWS, A. Gryska ADFG, unpub. data), in the same region as Alt's (1972) farthest upstream broad whitefish record. An additional spawning population of inconnu is known to exist in the Chatanika River (Alt 1969b; Kepler 1973), but no other spawning populations of broad whitefish have been identified. The main-stem spawning reach appears to be the normal upstream limit of inconnu and broad whitefish distribution within the Tanana River drainage.

Inconnu are occasionally captured in the Kantishna River and are apparently uncommon in Lake Minchumina. Three fish wheels were operated annually in the Kantishna River drainage during August and September from 1999 to 2007 to estimate the fall chum salmon escapement (Cleary and Hamazaki 2008). The project captured several broad whitefish and humpback whitefish and as many as two inconnu a week in the fish wheel closest to the mouth (P. Cleary, ADFG, pers. com.). Weidner (1972) interviewed a commercial fisherman from Minchumina who claimed to catch inconnu occasionally in Lake Minchumina. More recently, residents of Lake Minchumina, as reported by Holen et al. (2006), claimed to harvest a small number of inconnu in the lake indicating that they are occasionally present. Kramer (1975), however, conducted an extensive gillnet survey of Lake Minchumina in 1974 and captured numerous broad whitefish, humpback whitefish, least cisco, and three other fish species, but failed to capture inconnu. Given the low incidence of inconnu capture in the Kantishna River drainage, it seems unlikely that there is a spawning population there. Instead, it seems more likely that a small number of inconnu distribute widely within the Kantishna River drainage to feed. Demographic sampling to determine maturity and spawning readiness would help clarify this situation.

Humpback whitefish and least cisco are widely distributed in lakes and rivers throughout the Tanana River drainage. Brown et al. (2007) found that some individuals of both species captured in the lower Tanana River had reared in marine water. Humpback whitefish sampled from the upper Tanana River, however, showed no sign of having reared in marine water indicating that both anadromous and freshwater resident populations are present in the drainage. Both species exist as riverine populations, spawning in flowing water over gravel in late September and October (Kepler 1973; Hallberg 1989; Brown 2006), and as lake resident populations with unknown spawning seasons in numerous isolated lake systems (Appendix A5; Kramer 1976a; Pearse 1976a; Hallberg 1984; Glesne et al. 2011). Humpback whitefish are present in riverine environments and open lake systems up to approximately 35 km (22 miles) up the Nabesna River and 107 km (66 miles) up the Chisana River from their confluence (Brown 2006), which is the origin of the Tanana River. Brown (2006) documented two humpback whitefish spawning areas in the upper Tanana River drainage,

Figure 55. Looking upstream into the lower reaches of a newly discovered whitefish spawning area on the Tanana River near the community of Fairbanks (Dupois 2010; R.J. Brown, USFWS, unpub. data; A. Gryska, ADFG, unpub. data). Radio-tagged inconnu, broad whitefish, and humpback whitefish were located during spawning season in this region, which extends from a little downstream of the Chena River mouth to a little downstream of the Salcha River mouth. Sampling during early October revealed that inconnu, broad whitefish, humpback whitefish, least cisco, and round whitefish were spawning in this heavily braided reach. Photo by R.J. Brown, USFWS.

one in a braided region of the Nabesna River and the other in a similarly braided region of the Chisana River near the mouth of Scottie Creek (Figure 56). Several other humpback whitefish spawning areas are suspected, based on fall migration patterns of radio-tagged fish, in the region between Healy Lake and the Robertson River (Brown 2006). Additionally, at least two more spawning populations of humpback whitefish exist in the Tanana River drainage; in the Chatanika River and the main-stem Tanana River (Figure 55; Dupuis 2010).

The Chatanika River humpback whitefish population has been intensively studied for several decades because of a spear fishery that became established on the spawning area during the 1970s and early 1980s (Hallberg and Holmes 1987; Fleming 1996; Wuttig 2009). Kepler (1973) sampled the spawning reach near the Elliott Highway Bridge through the fall of 1972 for ripe and post-spawning fish and provided evidence that humpback whitefish spawn in late September and early October. There is no indication that this basic timing has changed.

Three authors have produced similar estimates of humpback whitefish fecundity ranging from approximately 10,000 to 108,000 eggs per female, with fecundity positively correlated with fish length (Townsend and Kepler 1974; Clark and Bernard 1992; Dupuis and Sutton 2011). Estimates by Clark and Bernard (1992) were the lowest, with maximum fecundity estimated to be approximately 37,000 eggs. However, the lengths of their sample fish were smaller than those examined by either Townsend and Kepler (1974) or Dupuis and Sutton

Figure 56. Looking upstream into a humpback whitefish spawning area in a braided region of the Chisana River near the mouth of Scottie Creek in the upper Tanana River drainage. Photo by R.J. Brown, USFWS.

(2011), which was thought to explain the variation. The minimum length at maturity, with maturity determined by the extrusion of milt or eggs from ripe fish captured in the spawning reach, has been measured at about 33 cm (13 inches) FL (Fleming 1996). The largest humpback whitefish in the spawning population has been measured during various sampling years at between 56 and 58 cm (22 and 23 inches) FL (Fleming 1996; Wuttig 2009; Edenfield 2009). Brown (2006) sampled the Nabesna River spawning population in the upper Tanana River drainage (n = 224) and measured fork lengths ranging from 33 to 51 cm (13 to 20 inches); equal minimum size at maturity and smaller maximum size relative to the Chatanika River population. Minimum age at maturity has not been determined with a combination of otolith aging techniques and a valid method of identifying mature individuals. Edenfield (2009, and pers. com.) found the oldest humpback whitefish in a sample of 118 aged with thin, transverse-sectioned otoliths to be age 29. Hallberg (1988, 1989) reported on spawning humpback whitefish tagged during one season and recaptured in the spawning reach the following year indicating that at least some humpback whitefish in the population are capable of sequential year spawning. Spawning population estimates between 1986 and 2008 have ranged from a low of about 12,000 in 1994 to a high of about 41,000 in 1988 (Wuttig 2009). Fleming (1996) presented age structure data suggesting that spawning population variability was strongly influenced by recruitment and was not a simple consequence of harvest. All age data prior to Edenfield (2009) were produced with scales, which systematically underage fish when growth slows following maturity (Power 1978; Barnes and Power 1984; Howland et al. 2004), and complicate Fleming's (1996) recruitment analysis. Scales, however, should be adequate to evaluate recruitment and the analysis is probably valid. Geographic distribution of the Chatanika River humpback whitefish population during early life stages and seasons other than spawning has not been thoroughly examined.

Least cisco have been encountered in riverine environments and open lake systems upstream to at least Moon Lake, an oxbow approximately 748 km (465 miles) up the Tanana River (Pearce 1976a; Francisco and Dinneford 1977). They have not been captured in gillnet surveys of Mansfield Lake, an open lake system about 20 km (12 miles) farther upstream (Pearce 1976a; R.J. Brown, USFWS, unpub. data), or any of the other upper drainage streams or open lake systems (Pearce 1975; Elliott 1982; Glesne et al. 2011). Lake populations, presumably isolated, are present in several of the large, upper Tanana River drainage lakes including Jatahmund, Takomahto, and East and West Wellesley lakes (Appendix A5; Pearse 1975; Glesne et al. 2011). Presumably least cisco spawn in the Healy Lake and George Lake drainages, and perhaps in nearby braided regions of the Tanana River as well, but no spawning areas have been specifically identified in that region of the Tanana. According to Peckham (1977), populations of least cisco and northern pike existed in Quartz Lake, an isolated lake in the central Tanana River drainage, until 1970 when rotenone was used to kill these species so the lake could be stocked with rainbow trout *Oncorhynchus mykiss* to enhance sport fishing opportunities. At least two riverine spawning populations of least cisco exist in the Tanana River drainage; in the Chatanika River and in the newly-discovered, main-stem Tanana River (Figure 55; Kepler 1973; Fleming 1996; A. Gryska, ADFG, pers. com.).

The Chatanika River least cisco population is certainly the most intensively studied in Alaska. Kepler (1973) sampled the spawning reach near the Elliott Highway Bridge through the fall of 1972 for ripe and post-spawning fish and provided evidence that they spawn in late September and early October. There is no indication that this basic timing has changed. Three authors have produced estimates of fecundity ranging from approximately 10,000 to 100,000 eggs per female, with fecundity positively correlated with fish length (Kepler 1973; Clark and Bernard 1992; Dupuis 2010). Estimates by Clark and Bernard (1992) were the lowest, with maximum fecundity of least cisco estimated to be approximately 50,000 eggs. However, the lengths of their sample fish were smaller than those examined by either Kepler (1973) or Dupuis (2010), which was thought to explain the variation. The minimum length at maturity, with maturity determined by the extrusion of milt or eggs from ripe fish captured in the spawning reach, has been measured at about 26 cm (10 inches) FL (Fleming 1996). Minimum age at maturity has not been determined with a combination of otolith aging techniques and a valid method of identifying mature individuals. The largest least cisco in the spawning population has been measured during various sampling years at between 40 and 43 cm (16 and 16.5 inches) FL (Fleming 1996; Wuttig 2009; Edenfield 2009). Edenfield (2009, and pers. com.) found the oldest least cisco in a sample of 238 fish aged with thin, transverse-sectioned otoliths to be age 14. Hallberg (1988, 1989) reported on spawning fish tagged during one season and recaptured in the spawning reach the following year indicating that at least some least cisco in the population are capable of sequential year spawning. Spawning population estimates between 1986 and 2008 have ranged from a low of about 15,000 in 2008 to a high of about 135,000 in 1991 (Wuttig 2009). Fleming (1996) presented age structure data suggesting that spawning population variability was strongly influenced by recruitment and was not a simple consequence of harvest. All age data prior to Edenfield

(2009) were produced with scales, which systematically underage fish when growth slows following maturity (Power 1978; Barnes and Power 1984; Howland et al. 2004), and complicate Fleming's (1996) recruitment analysis. Scales, however, should be adequate to evaluate recruitment and the analysis is probably valid. Geographic distribution of the Chatanika River least cisco population during early life stages and seasons other than spawning has not been thoroughly examined (Fleming 1999).

Mann (1974) and Mann and McCart (1981) used maturity sampling techniques to identify dwarf populations of least cisco in two lakes of northwest Canada. Mature individuals from these dwarf populations ranged from 8 to 14 cm (3 to 6 inches) FL while the co-occurring "normal" forms ranged from 20 to 34 cm (8 to 13 inches) FL, which is more similar to the range of mature least cisco from the Chatanika River as discussed above. Sampling data suggest that dwarf populations may have evolved in some Tanana River drainage lakes as well, although detailed maturity sampling that would be required to confirm this has not been conducted. In October 1988, for example, Clark and Doxey (1988) sampled the pelagic region of Harding Lake, an isolated Lake in the central Tanana River drainage (Appendix A5), and collected 219 least cisco, many of which they judged to be mature based on their qualitative assessment of gonad condition. The largest individual in the sample was 193 mm (7.5 inches) FL, which is much smaller than the smallest mature least cisco from riverine populations in the Chatanika River (Fleming 1996), Selawik River delta (Brown 2004), or Kuskokwim River (Harper et al. 2007), suggesting a dwarf form. Similarly, Kramer (1975) sampled 287 least cisco in Lake Minchumina, an open lake in the upper Kantishna River drainage, and found no fish larger than 160 mm (about 6.6 inches) fork length. Kramer (1975) acknowledged that larger least cisco could have migrated from the lake, but contended that some females in the sample were gravid indicating maturity at a size consistent with a dwarf population. Fall sampling with a gonadosomatic index component, similar to Mann (1974) or Brown (2004), would be required to confirm the existence of dwarf least cisco populations in Tanana River drainage lakes.

Round whitefish are found throughout the Tanana River drainage, similar to humpback whitefish and least cisco, but they prefer different types of habitats. They are abundant in cold, spring-fed streams (Pearce 1976b; Ridder 1980), common in non-glacial tributary streams (VanHulle 1968; Bendock 1974; Kramer 1976a; Pearce 1976a; Elliott 1982), and rare in flatland lake and riverine habitats (Kepler 1973; Townsend and Kepler 1974; Kramer 1975). Mecum (1984), Ott et al. (1998), and Durst (2001) sampled juvenile fishes in the main-stem Tanana River and various sloughs and streams within the floodplain between the mouths of the Chena and Delta rivers and found small round whitefish to be present nearly everywhere. Mature round whitefish preparing to spawn have been captured in fish wheels in the main-stem Tanana River downstream from the Chena River mouth (Borba 2007; Brown et al. 2007). Otolith chemistry analysis of a subsample of mature round whitefish indicated that they had not reared in marine water, which was consistent with the estuarine sampling work at the mouth of the Yukon River by Martin et al. (1986, 1987) in which round whitefish were absent from estuarine habitats. Recent sampling of the whitefish spawning area between the mouths of the Chena and Salcha rivers (Figure 55) has shown that spawning round whitefish are present with other whitefish species in the area (A. Gryska, ADFG, unpub. data). Because of their wide distribution throughout the Tanana River drainage, round whitefish almost certainly spawn in many other locations as well.

Fisheries

The Tanana River and its tributaries are home to 18 communities that can be culturally divided into roughly four sub-groups (Figure 50). The upper Tanana River drainage communities of Northway, Tetlin, Tok, Tanacross, Dot Lake, and Healy Lake share a language and culturally derived subsistence practices. The mid-Tanana River drainage communities of Delta Junction, Salcha, North Pole, and Fairbanks, along with a few other satellite communities, are larger urban centers located within the Fairbanks Non-Subsistence Area where most fisheries are managed under personal use regulations and subsistence fishing regulations do not apply. These communities have significant non-native populations and do not follow characteristic practices of subsistence economies such as wild resource sharing patterns. The lower Tanana River drainage communities of Nenana, Minto, and Manley share cultural histories of subsistence use. The Alaska Range communities of Lake Minchumina and Cantwell, to the south of the Tanana River floodplain, also maintain rich histories of whitefish harvest and use. The communities found within the Tanana River region are unique in that most are road accessible. The road system complicates harvest estimation because large numbers of people from outside the region may enter to harvest fish within the region and many people living within the region may harvest fish outside the region. Identifying historical harvest records to their correct harvest locations, an essential element to the assessment of exploitation level on a specific fish population, may be difficult or impossible.

This leads to a further comment on the nature of harvest data. Comprehensive subsistence baseline surveys conducted by the ADFG, Division of Subsistence, generally record any harvests made by community residents as part of the annual subsistence harvest for that community, even if the resources were harvested far away from the village itself or outside of traditional use areas documented for that community. Many communities traditionally harvest in areas far from their communities, and even where harvests occur outside of these areas, the resources return to the community and are enveloped in the community's use and distribution networks that are characteristic of subsistence economies. For this reason, harvest surveys may document marine mammal harvests in non-coastal communities, for example, or any other resource not usually found near the community. In the upper Tanana River drainage, this is also the case. Upper Tanana River drainage residents may travel to the Copper River to harvest salmon (Haynes et al. 1984), lacking salmon in appreciable numbers near their villages. Additionally, they may harvest particular whitefish species such as inconnu by traveling down the road to the lower reaches of the Tanana River or to the Yukon River, as inconnu are rarely encountered upstream from the mouth of the Chena River (Alt 1977a). Despite harvest location, these harvests are still protected under Alaska's subsistence statute and are documented in baseline subsistence surveys. Effective management of fish populations, however, requires an understanding of the population being harvested and thus, the geographical location of the harvest. This challenging data situation is not thought to be a large problem for most of the Yukon and Kuskokwim River regions and subsistence harvest survey data may provide a rough measure of harvest level for regional populations of inconnu and other whitefish species that are identified. But, because of the road system in the Tanana River drainage and the ease with which residents can travel to other locations to harvest fish, subsistence harvest data from the Tanana River region are more difficult to interpret for population management purposes.

Whitefish harvest practices of Tanana River drainage residents have been relatively well-documented compared to other Yukon River drainage areas. This can be explained by a few factors. Upper Tanana River communities lack an appreciable salmon fishery and instead, fishermen target whitefish species as their primary fish resource (Case 1986; Marcotte 1991). The importance of whitefish is featured in a significant body of literature in this area, dating back to the 19th century when Lt. Allen first documented local observations of residents in the Upper Tanana River valley (Allen 1887), which was followed by significant ethnographic work by Robert McKennan in 1929-1930 (McKennan 1959). In addition to several ADFG technical reports documenting the subsistence uses of Tanana River drainage residents (Martin 1983; Haynes et al. 1984; Shinkwan and Case1984; Case 1986; Andrews 1988; Marcotte 1991), the subsistence practices of Upper Tanana residents have also been documented in several ethnographies, including McKennan (1959), Guedon (1974), Vitt (1971), and Pitts (1972). The literature on Tanana River drainage fisheries is largely limited to documenting the subsistence practices of rural communities outside of the Fairbanks non-subsistence area primarily in the Upper Tanana River drainage communities with limited information about Minto (Andrews 1988; Marcotte 1995), Cantwell (Williams et al. 2005), and Lake Minchumina (Williams et al. 2005; Holen et al. 2006). Within the Fairbanks non-subsistence area fishermen may harvest whitefish under “personal use” or “sport” regulations. While personal use harvests are well documented through ADFG issued permits, the annual harvest estimate of sport caught fish throughout the Tanana is performed through a survey of select license holders and therefore small isolated harvests of whitefish may be missed.

Historically, fishing has been a significant cultural and recreational activity of inhabitants of the Tanana River drainage. Whitefish species are an important component of the annual subsistence harvest. While many older studies do not distinguish between whitefish species, sampling data indicate that humpback whitefish are the predominant species available in the upper Tanana River drainage (Brown 2006), which is consistent with harvest accounts of many local residents (Robinson 2005). Residents in the lower Tanana River drainage harvest the broader range of species that are available there (see discussion in the fish distribution section). Harvest patterns in this region have changed dramatically over the past century with the development of the road system and a dramatic increase in human population. Residents of Nenana, for example, relied on salmon and whitefish species to feed their dog teams in the early part of the 20th century when dog teams were the primary means of winter transportation (Shinkwan and Case 1984). Increased human activity in the area during that time period was due primarily to gold rush activities and the fur trade, which led to an increased demand for dog teams and fish to feed the dogs. The advent of snow machines reduced the number of dog teams in the drainage and the demand for fish is undoubtedly less now than it was at times in the past.

Culture and language

Whitefish are known commonly by the term, “Luugn” or “Luuk” in upper Tanana River Athabascan (Haynes and Simeone 2007), which is related to the general term for “fish” in many Athabascan dialects. Upper Tanana River drainage speakers also maintain more specific terms for commonly used species such as Xałtįį for broad whitefish and Ługgne for humpback whitefish (Robinson 2005). Marcotte (1995) reports that least cisco are referred to as “shiners” in the Minto area. According to Robinson (2005), there are numerous local terms related to whitefish use as well. For example, whitefish that is cut and dried for human consumption is called “ba,” while whitefish intended as dog food is referred to as “tsalkeey.” Traditional fermented whitefish that is buried in birch bark baskets is known as “dzenaxł.” Fried whitefish stomachs, or ch’itsaan’, was considered a delicacy among residents of Northway. The complexity of the language associated with whitefish fisheries in the Tanana River drainage indicates a long cultural history with these species.

Harvest and use

Historically, the upper Tanana River drainage was populated by nomadic bands of people that followed game populations along seasonal cycles. Most of the bands that traditionally inhabited the area had semi-permanent village sites that were located near fishing weirs built to intercept the summer and fall whitefish runs (Halpin 1987). Many present-day communities are located near these old village sites, including those in the Mansfield area, the Tetlin River area, and the Nabesna-Chisana area. Occasionally, a few local bands would join together, forming regional bands to more efficiently harvest migratory resources such as caribou or whitefish (Haynes and Simeone 2007). McKennan (1959) described one such band, “Mansfield-Ketchumstuck”, which would spend the month of July fishing for whitefish in Mansfield Lake (Haynes and Simeone 2007). In locations such as Mansfield Lake, where large numbers of whitefish could be reliably harvested, large groups of people could live communally during fishing season, working together to catch fish. Communities in the lower Tanana River drainage relied more heavily on abundant salmon runs and gathered along main-stem reaches to fish when those runs were taking place (Shinkwan and Case 1984).

Residents throughout the Tanana River drainage fish for whitefish species year-round, but certain times of the year are considered to be more productive in terms of quantity and quality of fish. Historical harvest patterns and gear types used to catch whitefish provide insight into how people understood seasonal fish cycles. For example, Tanana River residents have historically gone fishing in spring and fall, which correspond with biannual whitefish species migrations, occurring around the time of breakup and freeze-up events (Haynes and Simeone 2007). In June or July, whitefish species migrate from deepwater overwintering habitats, typically rivers and into the shallower streams and lakes. Fishermen began fishing for whitefish this time of year, the fresh fish considered to be a welcome change after winter’s diet of meat and dried fish. In a 1984 study of subsistence practices in Nenana, a resident who lived on the nearby Wood River recalled setting nets during the spring run of whitefish on a slough of the Tanana River (Shinkwan and Case 1984). Later in the summer, residents of Nenana would operate fish wheels to harvest salmon, harvesting whitefish as incidental catch. Marcotte (1995) indicated that humpback whitefish and least cisco were observed to migrate into the Chatanika River during summer and early fall to spawn.

A 1983–84 study in Tetlin documented the harvest of at least two species of whitefish (unspecified) beginning in June and continuing through October (Halpin 1987). The heaviest effort was focused in July, possibly reflecting these historical practices of group fishing. In a 1984 study documenting subsistence harvest patterns in five Upper Tanana communities, Haynes et al. (1984) observed that most whitefish were being harvested immediately in front of the community of Tetlin or in seasonal camps during summer, congruent with its historical use as an important fishing area.

Whitefish species are also heavily harvested during fall and early winter in various streams and lakes during the second migration of the year and as whitefish species migrated back to overwintering habitats. Haynes et al. (1984) reported that in the fall, residents of Northway would spear whitefish as they moved through narrow stream channels to deeper water for over-wintering. Case (1986) confirmed the productive fall fishing efforts by Northway fishers that exploited whitefish species following summer feeding when fish were in their fattest condition of the year. Residents of the Nenana area historically set nets for whitefish in sloughs west of the village during the fall (Shinkwan and Case 1984). A few families fished through the ice using lines after freeze-up. Fishing in small streams or near lake outlets in the upper Tanana River would continue after the first frost, but before ice closed off streams (Haynes and Simeone 2007). Traps, set nets, and spears were used to catch migrating whitefish and other fish species.

Changes in gear types used to harvest whitefish provide important information about area whitefish fisheries and the changes they have experienced. Until quite recently, upper Tanana River fishers used dip nets, gillnets, and less often, fish wheels, to harvest the majority of their catch in rivers and streams (Allen 1887; McKennan 1959; Halpin 1987; Haynes and Simeone 2007). In Minto, traditional fishing gear also included fish fences with traps (khutreth), and occasionally, bows and arrows for whitefish (Andrews 1988; Marcotte 1995). Andrews also reported the use of a long-handled dip net (tanee'oyee) in Minto Flats, which was used to catch northern pike and whitefish by dipping the net into a corral or pen area (Andrews 1988). Fish wheels were used more commonly in the lower river to target salmon, with whitefish considered an incidental, though valued part of the harvest (Shinkwan and Case 1984). Occasionally, gillnets would be set in lakes (Case 1986). McKennan (1959) observed in 1929–1930 the use of a "cylindrical shaped-trap" and the "hoop-shaped dip net," or uu, used in conjunction with the weirs (Halpin 1987). These nets were considered very effective at harvesting fish and were larger than those used to catch salmon. Placed in slow moving water, dip nets' rims were typically 89 to 122 cm (35 to 48 inches) in diameter and filled the opening of the weir (Haynes and Simeone 2007).

By the 1980s, traps were no longer legal, though the weir and hoop net were still in use in the community of Tetlin. One respondent recalled hundreds of whitefish caught within a few hours of the start of a whitefish migration by several men who rotated the operation of two or three nets (Case 1986). He described the scene as follows:

> Fish were cut and hung to smoke and dry at once, children carrying loads of fresh fish to women at family cutting tables until everyone had enough. People smoked and dried their fish at the camps. A portion of the processed fish was carried to a winter camp location. The rest was cached for later retrieval in the fall and winter, for use at camps which served as a winter base of activity, such as Scottie Creek and Fish Camp. (Case 1986: page 26)

The use of commercially-made cotton line and twine in hoop and gillnets was variable in upper Tanana River communities until the 1950s though when this transition from traditional materials such as roots or babiche (rawhide strips) occurred is unclear (Case 1986; Halpin

1987). Today, most whitefish in the upper Tanana River drainage are caught in commercially-manufactured gillnets that allow fishermen to harvest between 100 and 200 fish per day during migrations (Robinson 2005).

Fishing activities in Tanana River drainage households have always involved all or most household members, though specific roles were often based on age and gender. Everyone was responsible for checking nets, but the cutting and hanging of fish was primarily done by women. Men and children would sometimes help by scaling fish or stoking the smudge fire (Halpin 1987). Jigging with hook and line was often done by elderly people and middle-aged women in Minto (Marcotte 1995). In Northway Village, gendered roles were observed, with women primarily responsible for cutting fish. Men would gather wood and drive the boats (Robinson 2005). Elders interviewed for a 1984 study of subsistence activities in Nenana recalled that in the 1920s and 1930s, women ran summer fish camps in the area while men worked for railroad and steamboat companies (Shinkwan and Case 1984).

Participation in upper Tanana River whitefish fisheries is high. A 1984 study in the communities of Tanacross, Tetlin, and Northway documented that approximately 85% of area households participated in harvesting whitefish (Haynes et al. 1984), though household level participation was documented as high as 93% in Northway (Case 1986). Significantly, more households in the upper Tanana River region participated in the whitefish fishery than in any other subsistence activity besides gathering berries and plants (Haynes et al. 1984). The community of Tetlin had an overall 80% household participation rate for any type of whitefish fishing method (Halpin 1987), with approximately 75% of the households using gillnets and 55% using dip-nets during the 1983–1984 time period. In Minto, however, reported harvests of whitefish and household participation in the whitefish fishery were lower than in the northern pike fishery in the area (Marcotte 1995). Several whitefish species are available to residents of Minto and they reportedly harvest humpback whitefish, broad whitefish, and least cisco.

Haynes and Simeone (2007) compared harvest participation levels over time in the communities of Dot Lake, Tetlin, Northway, and Tanacross and found that participation in whitefish fisheries has varied during the past several decades. During the 1987-1988 time period, it was reported that 47 to 70% of households in those communities harvested whitefish. Later, during the 2004–2005 time period, residents of the communities of Dot Lake, Northway, and Tanacross reported participation declines of 3%, 12%, and 35% respectively, while residents of the community of Tetlin reported a participation increase of 25%.

Subsistence harvest levels are an indication of the importance of whitefish species for residents of the Tanana River drainage. In 1988, residents of upper Tanana River drainage communities reported that non-salmon fish, primarily whitefish and northern pike, accounted for an average of 34% of their total annual subsistence harvest (Marcotte 1991). In some communities, whitefish accounted for half of their total annual subsistence harvest. Marcotte (1991) estimated the sum of all whitefish harvests in upper Tanana River drainage communities during his study to be approximately 29,582 kg (65,218 pounds). During the 1983–1984 time period, the mean household whitefish harvest in the community of Tetlin was estimated to be 258 kg (568 pounds), which was a little less than half of the total fish harvest, and approximately 25% of all subsistence foods by weight (Halpin 1987).

Halpin (1987) noted two methods of cutting whitefish: one for human consumption and the other for dog food. Fish were selected for human consumption out of the larger harvest based primarily based on flesh quality; fish intended for human consumption were firmer while soft-fleshed fish were relegated to dog food. Fish cut for humans is called “ba’” and fish cut for dogs is called “tsilalkeiy” (Halpin 1987). Mostly all parts of the fish are used; oil is rendered from boiled intestines, upper intestine and stomach are fried and eaten fresh, and eggs are dried. Residents in the community of Tetlin indicated that whitefish were seldom eaten fresh. Instead, they were eaten dried or stored for the winter. Whitefish were noted to be particularly susceptible to spoilage on warmer days and for that reason, needed to be quickly cut and hung to dry. Other methods of preservation have also been recorded, including fermenting. Historically, Healy Lake residents reported storing whole fish (without their livers) in holes lined with birch bark or caches in the ground (Haynes and Simeone 2007). These fish were later removed and eaten during winter. Traditionally, eggs of whitefish were considered to be a delicacy and made into special dishes (Andrews 1988). A 1992 study of subsistence caught fish for dog food reported that residents in the community of Manley Hot Springs primarily targeted salmon species but used incidentally caught whitefish as well (Andersen 1992). Since whitefish are available in many locations throughout the Yukon River drainage, including along the Tanana, mushers were able to either feed fish fresh to dogs, or allow it to quickly freeze (Andersen 1992).

Subsistence users in the Tanana River region have expressed concern about the status of whitefish populations in the drainage. Some believe that whitefish harvests have declined in recent years when compared with their memories of previous harvests. Residents of the community of Northway have observed some of their traditional fishing sites being increasingly inundated with floodwaters from the glacial Chisana River, causing some lakes to become very shallow because of silt deposition. Some residents believe that the siltation is reducing habitat quality and impacting the health of whitefish in the area. Residents of the community of Tetlin believe that whitefish they harvest have declined in size over the last 15 years. And some residents of the upper Tanana River drainage believe that parasite levels in whitefish they harvest may be greater now than at times in the past (Robinson 2005). It is our nature to be concerned about the status of such an important source of food and cultural activity, as whitefish is for residents of the Tanana River drainage, and perhaps some of their concerns will be investigated further at some point.

Potential threats and concerns

Overfishing

Eighteen communities and nine outlying population centers are located within the Tanana River drainage (Appendix A2) with a combined population in 2008 of approximately 77,500 residents (U.S. Census Bureau 2010; City Data 2010). Fairbanks and its neighboring communities account for about 71,000 residents, with the remaining 6,500 people living in the other 17 communities. Sport fishing with angling gear in the Tanana River drainage is undoubtedly practiced by a much larger fraction of the population than subsistence or commercial fishing with gillnets, fish wheels, or other fishing methods. In addition, an estimated 40 to 45% of sport fishing harvests in the Tanana River drainage were from stocked populations (Parker 2009; Brase 2010), none of which include whitefish species. Inconnu were stocked in some lakes in the past but are no longer thought to be present (Hallberg et al. 1986; Bentz et al. 1991). Commercial whitefish fisheries have taken place during the 1970s and before in Lake Minchumina and Healy Lake, and more recently from Tanana River catches during commercial salmon fisheries (Weidner 1972; Hayes et al. 2008). Subsistence fishing for whitefish species is a major activity for residents in nearly all of the rural communities in the drainage, as described in the anthropology accounts above and in annual management and subsistence harvest reports for the Yukon River drainage (Brase and Hamner 2002; Hayes et al. 2008), but is practiced by a very small fraction of the urban population from Fairbanks and neighboring communities.

With the exception of the Chatanika River spear fishery, harvest levels of whitefish species in the Tanana River drainage are very poorly understood. Because the Chatanika River spear fishery for humpback whitefish and least cisco has been intensively managed since the mid-1980s, there are long-term, species-specific, harvest estimates from those populations (Fleming 1999; Wuttig 2009). Other data sources are flawed in ways that make them unusable for estimating annual harvest levels or long term trends in harvest of any species. Data from the commercial fisheries, for example, identify the number and weight of whitefish sold in various years but don't identify the species (Hayes et al. 2008). Unlikely species such as pygmy whitefish and Pacific halibut *Hippoglossus stenolepis* are identified as components of the subsistence harvest in certain Tanana River communities (Martin 1983; Marcotte 1991) indicating mistaken identification of a harvested species or harvests from outside the Tanana River drainage, both of which make those data unusable. Parker (2009) identifies substantial inconnu harvest numbers in upper Tanana River communities beyond the documented range of inconnu in the drainage suggesting harvests outside the region. Haynes et al. (1984), in fact, documented routine fishing expeditions into the Copper River drainage by many residents of the upper Tanana River. Essentially, the lack of species identification and geographic resolution in the harvest records for most of the Tanana River drainage preclude harvest estimates of whitefish species except for those of humpback whitefish and least cisco in the Chatanika River spear fishery.

While whitefish species are harvested throughout the Tanana River drainage, only the humpback whitefish and least cisco populations from the Chatanika River are known to be at risk of overfishing. This risk has been recognized by the Alaska Department of Fish and Game since the mid-1980s and has inspired many years of population monitoring activities, regulatory actions, fishery closures, and the development of management plans to guide decision making (Fleming 1999; Brase 2010). The spear fishery for humpback whitefish and least cisco takes place in the spawning reach, which is the most critical habitat for any whitefish population, and is road accessible to the large urban population of the Fairbanks area. It is likely that these populations would be overfished to extinction if this fishery were unregulated. It is possible that other whitefish fisheries are taking place in spawning reaches within the Tanana River drainage, but they are almost certainly of a smaller scale and less accessible than the Chatanika River fishery, and therefore, at less risk of depletion. Some of the riverine whitefish harvested downstream from the Chena River mouth are anadromous and are therefore vulnerable to fisheries all the way downstream to the sea (Brown et al.

2007). Substantial population assessment studies will be required before the risk of overfishing to most whitefish populations in the Tanana River drainage can be evaluated.

Development

Whitefish populations are probably threatened more from development activities in the Tanana River drainage than from overfishing or natural environmental factors. Within the drainage there are numerous large, active mineral mines and more planned for the near future (Szumigala et al. 2009), a large coal mine is operating in the upper Nenana River drainage (Buzzell 1994; Szumigala et al. 2009), streambed gravel mining activity is wide-spread and routine (Figure 15; Woodward-Clyde Consultants 1980; State of Alaska 2009), large spills of oil and other toxic materials are common (Figures 17 and 18; ADEC 2007), major new roads and rail lines are being planned (DOWL HKM 2010; HDR Alaska 2010), commercial logging is taking place in many locations (Figure 57; Hermanns 2009; Douse 2010; Joslin 2010), urban areas are expanding into undeveloped lands, stream banks are being cleared and stabilized with levees and riprap to prevent natural erosion patterns (Figure 58; Ihlenfeldt 2006), a major flood control dam is operational on the Chena River (Figure 20; Williamson 1984; Rozell 2003, 2010), and many more habitat altering activities. Few of these development activities threaten whitefish populations by themselves, but, the cumulative result is a steady reduction in the quality of aquatic habitats in the drainage, a process that has impacted fisheries in many other heavily developed watersheds (Brown and Moyle 2005; Hughes et al. 2005; Simon et al. 2005).

Major gold mining operations have taken place in many areas of the Tanana River drainage. Placer mining activities have disturbed streambed habitats more than underground or open pit hard-rock mines and probably represent a more direct threat to whitefish populations. Significant mining regions within the Tanana River drainage include those near Manley Hot Springs (Smith 1939), the upper reaches of the Tolovana River drainage, including Livengood Creek, the upper Chatanika River, and Goldstream Creek (Spence 1996), several upper reaches of the Kantishna River (Bundtzen et al. 1983), the Chena (Spence 1996), Nabesna (Smith 1939; Stanely 2003), and Chisana (Bleakley 1996; Stanely 2003) rivers, and many other smaller operations. Large, floating dredges were operated in many of the Tanana River drainage placer mines (Spence 1996), turning riparian floodplains into mazes of tailing piles (Figure 59). Most floating dredges were operated along streams that are too small to support whitefish spawning areas, although this is not always the case and may not be true for round whitefish spawning areas, which we know very little about. The Cleary Creek mine came close to directly impacting the whitefish spawning area on the Chatanika River, as identified by Kepler (1973), which is less than 2 km (1 mile) from the foot of the dredged region. The Chatanika River spawning reach was subjected to elevated turbidity from smaller placer mines in the upper Chantanika River drainage when they were originally developed in the early 1900s and again when they were reactivated following the deregulation of the price of gold in the early 1970s (Townsend 1987). Drainage from major dredged valleys flow into several lake systems used for feeding by broad whitefish, humpback whitefish, and least cisco. For example, the dredged region in upper Goldstream Creek drains directly into the Minto Lakes, an important whitefish feeding area. Similarly, the heavily dredged region along American Creek, about 28 km (17 miles) west of Manley

Figure 57. A small clear-cut from a logging operation on the hills overlooking Minto Flats within the Tolovana River drainage. Small clear cuts such as this are common on the hills and floodplains of the Tanana River drainage. Photo by R.J. Brown, USFWS.

Hot Springs, drains into Fish Lake, which appears to be another important whitefish feeding area. The long-term impacts of tailings drainage on these important feeding habitats and the whitefish that visit them have not been investigated.

Two major hard-rock gold mines are active in the Tanana River drainage and at least one more is being considered (Szumigala et al. 2009). The Fort Knox gold mine is a large, open-pit facility located in the headwaters of Fish Creek, a tributary of the Chena River (Figure 60). The mine began producing gold in 1996 and was the biggest producer in interior Alaska for many years. Two impoundments downstream from the open-pit and processing facility capture tailings and waste water from the mine. A cyanide heap-leach facility was constructed recently to extract additional gold from lower grade material. The Alaska Department of Fish and Game has been continuously monitoring fish populations in natural and altered habitats downstream from the mine since before its development (Ott and Scannell 1996; Ott and Morris 2010). By all accounts, the mine is containing its waste materials adequately and downstream habitats are not being contaminated. The Pogo gold mine is an underground facility located in the upper Goodpaster River drainage (Staley 2009). According to Szumigala et al. (2009), the Pogo mine began producing gold in 2006 and produced more gold then the Fort Knox mine in 2008. Gold bearing ore is mined from deep underground and milled on the surface (Staley 2009). Gold is extracted from the milled

Figure 58. Four examples of large to small scale bank alterations that are common within the Tanana River drainage. A dike with J-shaped groins has been constructed between the Fairbanks International Airport and the Tanana River to slow erosion in that direction (A). It was recently discovered that this region of the river is a major spawning area for several whitefish species. The mouth of the Nenana River (B) is the upstream terminus of the freight hauling barges in the Yukon River system. As such, it is an industrial site with extensive bank stabilization in the docking area along the Tanana River frontage (the downstream edge of which is seen under the bridge in the lower left), and annual dredging of the Nenana River mouth for fill material and to support other barge activities in the area. Vegetation has been cut and boulders have been dumped along the banks of the lower Chena River to channelize the river course through the community of Fairbanks (C). Riverfronts have been cleared and banks have been stabilized with rocks in front of many riverfront houses in the Tanana River drainage (D). Photos by USFWS staff.

Figure 59. Tailing piles and dredged regions in lower Cleary Creek in the Chatanika River drainage (upper left), Fairbanks Creek in the Chena River drainage (upper right), Goldstream Creak at the community of Fox (lower left), and Ester Creek near the community of Ester (lower right). The dredged region in Cleary Creek is adjacent to a major whitefish spawning area on the Chatanika River (Kepler 1973), which is visible in the lower corners of the image. The dredged region across the Fairbanks Creek floodplain has created an isolated population of Arctic grayling upstream, because the stream now flows subsurface through the extensive tailing piles (Ott and Townsend 1996; Morris and Ihlenfeldt 2008). Photos by R.J. Brown, USFWS.

ore with cyanide leaching methods. Some of the waste material is mixed with cement and injected back into the mine and some is dried and stored on the surface. Wastewater discharge from the mine is constantly monitored to ensure compliance with clean water provisions in their permit. It does not appear that the current hard-rock mines in the Tanana River drainage directly disturb essential whitefish habitats other than those for round whitefish. Exploration is underway on a third, major hard-rock gold prospect located in the upper Tolovana River drainage near Livengood Creek (Szumigala et al. 2009). If eventually developed, the Livengood prospect would become an open-pit mine that would drain down the Tolovana River into Minto Flats, an important whitefish feeding habitat. Presumably an effective containment system would be developed similar to that for the Fort Knox mine. The long-term effects of large hard-rock mines on downstream aquatic habitats are often disastrous, as detailed by Woody et al. (2010) in their analyses of numerous case studies from the continental United States. Perhaps we have learned enough from poorly managed systems to prevent similarly disastrous outcomes here.

Figure 60. Fort Knox, a large, open pit, lode gold mine in the Chena River drainage, a tributary of the Tanana River. Photo by R.J. Brown, USFWS.

Upper Yukon River Habitat Region

The upper Yukon River habitat region includes the entire Yukon Flats and its tributary drainages (Figure 61), and the Porcupine (Figure 62) and Yukon River (Figure 63) drainages up to the Alaska Yukon border. The Yukon Flats is a vast geographic area within the upper Yukon River habitat region spanning approximately 275 km (171 miles) from east to west and 120 km (75 miles) from north to south. The Yukon River arcs through the flats from east to west, flowing swift and turbid through a heavily braided floodplain composed of gravel, sand, and silt (Figure 61). Twelve major tributary rivers join the Yukon River in this region (Appendix A3), the largest being the Porcupine River, which has a drainage area of approximately 114,737 km^2 (44,300 $mile^2$) and contributes almost 10% of the annual flow from the Yukon River drainage (Brabets et al. 2000). Other major tributaries in the Yukon Flats include the Dall, Hodzana, Hadweenzic, Chandalar, and Christian rivers, which flow from the north, and Beaver and Birch creeks, which flow from the south. Major tributaries upstream from the Yukon Flats include the Charley, Kandik, Nation, Tatonduk, and Seventymile rivers. In addition to the many rivers in the upper Yukon River habitat region, there are tens of thousands of lakes, most concentrated in the Yukon Flats where over 37,000 tundra, oxbow, and upland lakes grace the landscape (Arp and Jones 2009). Arp and Jones (2009) classified the Yukon Flats as the second largest lake district within the Yukon and Kuskokwim River drainages, encompassing an area of 21,006 km^2 (8,110 $mile^2$). Many of these lakes maintain permanent or seasonal connections to the river system while others are isolated (Figure 22; Appendix A5; Glesne et al. 2011; Hegland and Jones 2003). A much smaller number of lakes are present outside the Yukon Flats, most being upland lakes on the southern slopes of the Brooks Range (Ward and Craig 1974; Craig and Wells 1975; Pearse 1978). In addition to the riverine and lake habitats identified above, a significant proportion of the drainage areas of the Porcupine (~0.51) and Yukon (~0.35) rivers are in Canada and thus upstream from our upper Yukon River habitat region.

Tributaries of the Yukon Flats flow clear and swift over gravel in their upper reaches and slow and stained or turbid over soft substrate in their lower reaches (e.g., Glesne et al. 1985; Webber and Post 1985; AECOM 2009). Stained or turbid water in the lower reaches of the tributaries is substantially less turbid than the glacially influenced waters of the Yukon River into which they flow (Brabets et al. 2000). Beaver and Birch creeks have extensive lower reaches that each meander for over 250 km (155 miles) across the southern, lake-rich flats (Figure 61). The Dall River in the western flats and the Christian River in the central flats are smaller northern tributaries that also meander slowly across the flats for substantial fractions of their total lengths with many connected lake systems in their floodplain (USFWS 1990; Chythlook and Burr 2002). The gravel substrate upper reaches of the Dall River are distributed among numerous small headwater streams while the Christian River remains a single river course far into its hilly origins. The lower reaches of the Christian River flow exceptionally slow for over 100 km (62 miles) over soft substrate, are permanently connected to many large lake systems in the floodplain, appear to remain entirely within vegetated banks with little variation in water level, and few mud or sandbars are ever exposed. Because the river is relatively narrow in the lower reaches (a large tree can span the width) and the upper reaches are large enough to produce great quantities of drift wood, the lower reaches are subject to massive log jams that extend across the entire river for many km and persist for many years (Figure 64). The Hodzana and Hadweenzic rivers originate in the

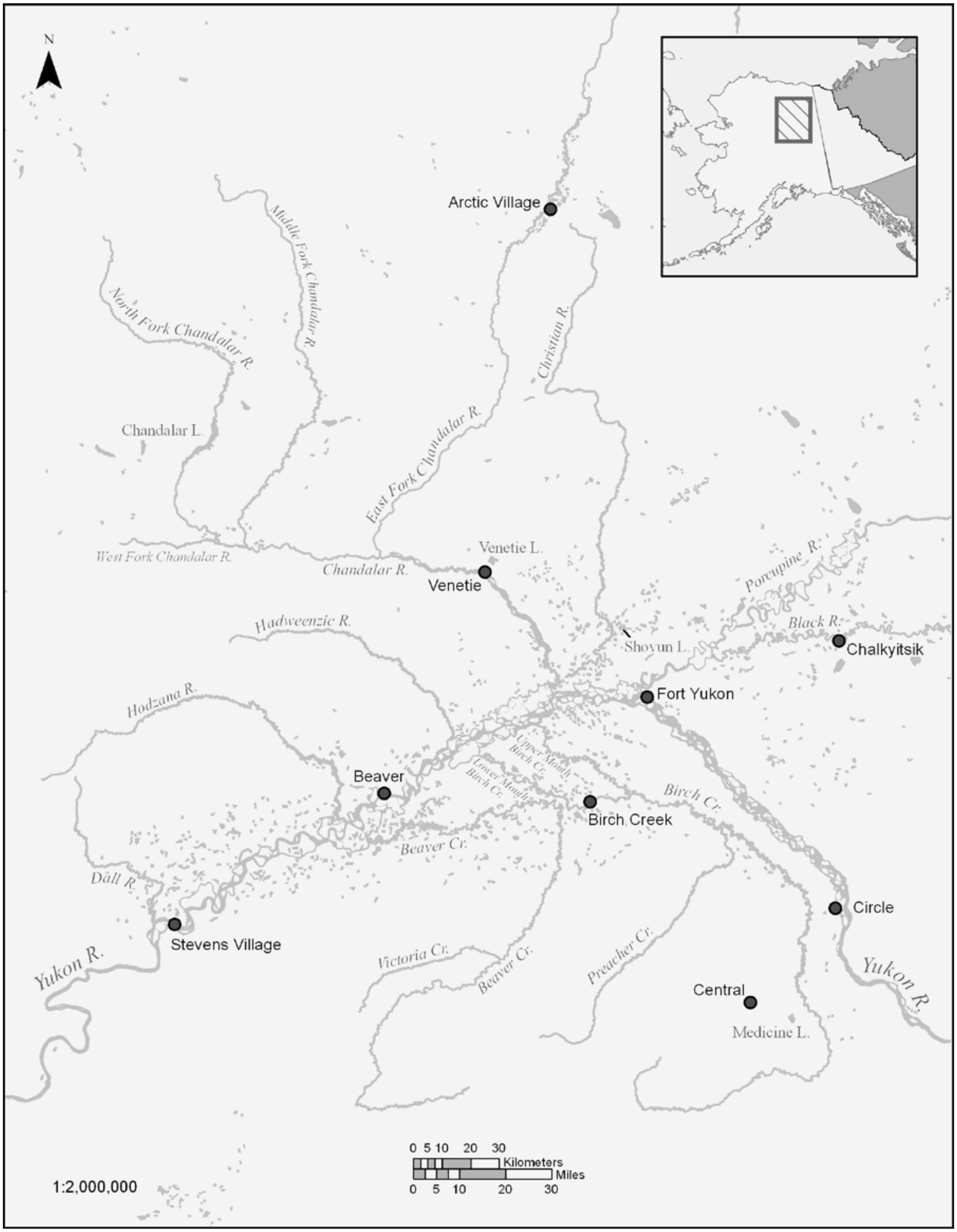

Figure 61. The Yukon Flats within the upper Yukon River habitat region including major tributaries and communities.

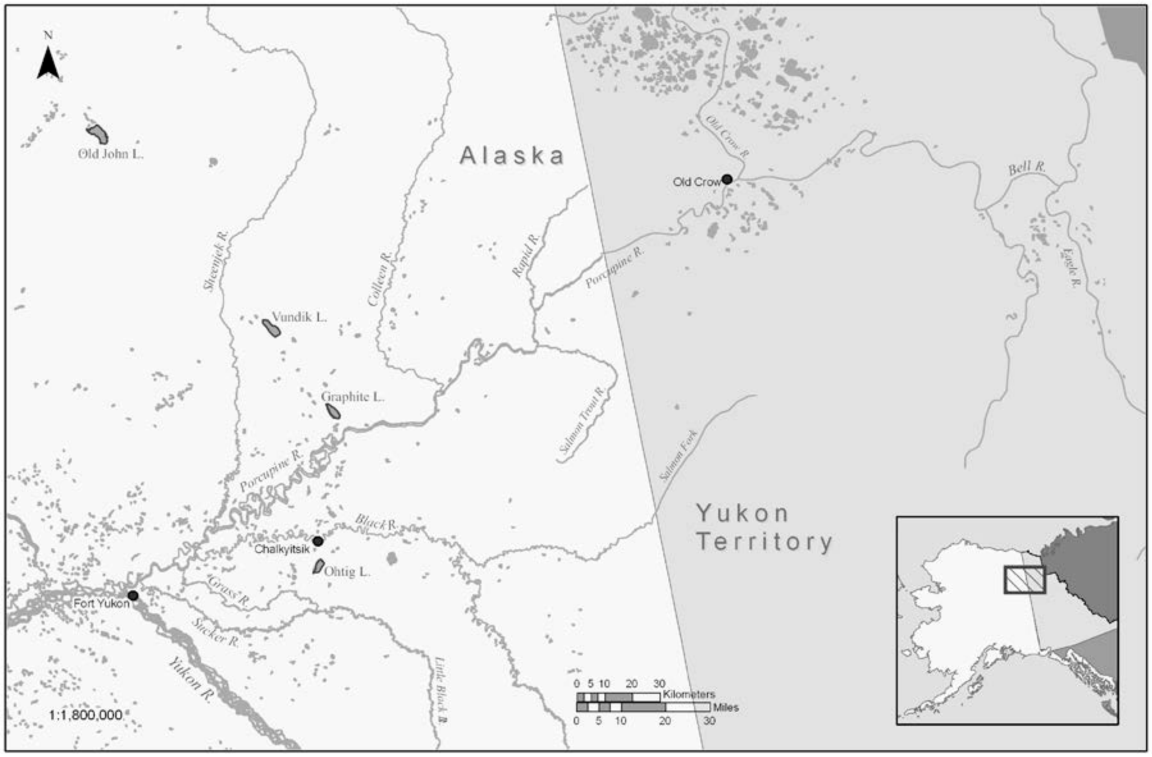

Figure 62. The Porcupine River drainage in Alaska and into neighboring Yukon Territory including major tributaries and communities. The Alaska portion of the drainage is within the upper Yukon River habitat region.

Hodzana Highlands and flow to the Yukon River through the northwestern Yukon Flats (USFWS 1990). Both rivers have similar morphological qualities with upstream reaches flowing clear and swift over gravel and downstream reaches flowing increasingly turbid or stained over small gravel and sand (Figure 65; Glesne et al. 1985; USFWS 1990). The slow flowing lower reaches of the Hodzana and Hadweenzic rivers are relatively short and pass through relatively lake-poor flatlands compared to the extensive meandering reaches of the Dall and Christian rivers, and Beaver and Birch creeks. The Chandalar River is the second largest tributary of the Yukon Flats, encompassing an area of approximately 35,483 km^2 (13,700 $mile^2$) or 4.2% of the entire Yukon River basin (Brabets et al. 2000). It is a dynamic drainage of three major tributaries originating in the Phillip Smith Mountains on the southern slopes of the Brooks Range. There are numerous large, upland lakes in the drainage, some isolated and others with stream connections to the rivers (Appendix A5; Ward and Craig 1974; Craig and Wells 1975; Pearse 1978). The confluence of the Chandalar and Yukon rivers takes place through several distributaries in main-stem and slough habitats with very short, slow flowing, meandering reaches. The lower Porcupine River meanders slowly over a substrate dominated by sand or mud through the northeastern Yukon Flats. Upstream from the flat lands, approximately 195 km (121 miles) upstream from the Porcupine River mouth and 35 km (22 miles) downstream from the Coleen River mouth, the river is bounded by hills and flows more swiftly over a substrate dominated by gravel or sand. Approximately half of the drainage area of the Porcupine River lies in Yukon Territory (Brabets et al. 2000), which includes a major flatland, soft substrate, lake district in the Old Crow River drainage, but is

Figure 63. The upper Yukon River drainage in Alaska and into neighboring Yukon Territory including major tributaries and communities. The Alaska portion of the drainage is within the upper Yukon River habitat region.

Figure 64. Extensive logjams routinely block the lower Christian River in the northern Yukon Flats. Some logjams extend for several km and may last for many years. The two logjams visible in this image were part of a larger blockage for several years and eventually moved to new locations. Logjams in the lower Christian River are not thought to impede fish migration. Photo by R.J. Brown, USFWS.

otherwise dominated by clear flowing rivers over substrate dominated by gravel or sand (Bryan 1973). Major tributaries of the Porcupine River in Alaska include the Black, Sheenjek, Coleen, and Salmon Trout rivers. All of these tributaries except the Black River are clear-water streams flowing swiftly over gravel from headwaters to mouths. The upper reaches of the Black River are clear water streams that flow swiftly over gravel or sand substrate while the lower 100 km (62 miles) or so, downstream from the community of Chalkyitsik (Figure 62), is a tundra stained river that meanders slowly over a substrate dominated by mud or sand. Numerous oxbow lakes bracket the lower reaches of the Black River (Figure 66) and many maintain permanent or seasonal connections to the river (Brown and Fleener 2001). Very few minor tributaries merge with the Yukon River in the Yukon Flats. Most small streams that emerge from the surrounding hills go subsurface or join with the larger rivers described above as they meander across the extensive flatlands.

The Yukon River upstream from the Yukon Flats and downstream from the Alaska Yukon border, a distance along the river of about 243 km (151 miles), is largely confined by hills and mountains, has a narrow floodplain with very few lakes, and flows primarily as a single channel with occasional islands but no substantial braids. The major tributaries in the reach, the Charley, Kandik, Nation, Tatonduk, and Seventymile rivers, flow clear and swift over rocks, gravel, and sand from their headwaters to their mouths (Daum 1994). The mouths of the Fortymile, Sixtymile, and White rivers are in Yukon Territory but at least some of their drainage areas extend into Alaska and are included in the upper Yukon River habitat region.

Figure 65. An aerial view of the lower reaches of the Hadweenzic River in the north central Yukon Flats illustrating the meandering nature of the river and the abundance of young and old oxbows across the width of the floodplain. Substrate in the lower reaches of the drainage appears to be dominated by small gravel and sand. Photo by R.J. Brown, USFWS.

The Fortymile River is a relatively large tributary that flows clear and swift over gravel through nearly all of the drainage, which is mostly in Alaska. An exception to this habitat characterization is the Mosquito Flats, a relatively small flatland area of soft substrate approximately 21 km (13 miles) from east to west and 16 km (10 miles) from north to south in the upper Mosquito Fork of the Fortymile River. Lakes are not abundant, large, or well connected to the river system in the Mosquito Flats. Only small fractions of the upper Sixtymile and White River drainages are in Alaska; the Sixtymile River in the Yukon Tanana uplands and the White River in the northern region of the glacial Saint Elias Mountains. The Yukon River and its tributaries upstream from the Yukon Flats within Alaska are composed almost entirely of riverine rather than lake habitat, and swiftly flowing rather than meandering waterways.

Riordan et al. (2006) used aerial photographs spanning 50 years to identify long term declining trends in lake surface areas of over 2,500 isolated lakes in the Yukon Flats. They found that their study lakes shrunk in surface area by 14 to 18% overall during the time period (Figure 67). They hypothesized the loss was the result of increased evaporation due to warmer summer conditions, and a deeper thawed layer of ground during summer, which increased the depth of the water table allowing lake water to seep out through the soil. Lakes within the Yukon River floodplain are routinely recharged through connecting channels or low relief flats during high flow events and have seasonally variable surface areas as a result (Figure 22).

Figure 66. A satellite image of the lower reaches of the Porcupine and Black rivers near their confluence in the northeast Yukon Flats illustrating the meandering nature of the rivers and the abundance of young and old oxbows across the width of the floodplain. Substrate in the lower reaches of the Porcupine River drainage is dominated by small gravel and sand while mud and sand dominate in the lower Black River. This image, courtesy of Google Earth, spans approximately 32 km (20 miles) from east (right) to west (left).

Whitefish species, distribution, and biology

All six common whitefish species are present in the upper Yukon River habitat region. Similar to other regions, there are trends in relative abundance of each species within the habitat region based on season and demographics. Alt (1969a, 1971b, 1972, 1973b, 1974) conducted many sampling expeditions during spring, summer, and fall into the upper Yukon River habitat region during the late 1960s and 1970s. He used multiple-mesh gillnets in overnight sets as his primary sampling method to catch fish of a wide range of sizes. He found that inconnu, broad whitefish, humpback whitefish, least cisco, and Bering cisco were commonly encountered along the main stem and at the mouths of tributaries throughout the Yukon Flats and farther upstream to the Alaska Yukon border. Within tributaries, inconnu, broad whitefish, humpback whitefish, and least cisco tend to occupy the slow flowing lower reaches (Alt 1974; Glesne et al. 1985; Daum 1994), round whitefish occupy the swifter flowing upper reaches (Craig and Wells 1975; Townsend 1996; Collin and Kostohrys 1998; AECOM 2009), and Bering cisco have not been captured in tributaries and are therefore thought to restrict their migrations to the Yukon River main stem (Alt 1973a; Brown et al. 2007). Broad whitefish, humpback whitefish, and least cisco commonly occupy lakes with permanent or seasonal stream connections to the lower reaches of Beaver Creek, Birch

Figure 67. An aerial view of a region of drying lakes in the south central Yukon Flats. Photo by R.J. Brown, USFWS.

Creek, Christian River, and Black River (Appendix A5; Kramer 1981; Hallberg 1983; McLean and Raymond 1983; Glesne et al. 2011; Brown and Fleener 2001). Some of the upland lakes in the mountain headwaters of the Chandalar and Sheenjek rivers support what appear to be isolated populations of humpback whitefish and round whitefish (Roguski and Spetz 1968; Craig and Wells 1975; Kramer 1976b; Pearse 1978). Population isolation is suspected in some cases because of outlet streams that appear to be too small to support immigration or emigration of mature fish. Broad whitefish have been documented in two upland lakes in the upper Chandalar River drainage, least cisco in only one, a lake they share with broad whitefish, humpback whitefish, round whitefish, and at least five other fish species (Roguski and Spetz 1968; Ward and Craig 1974; Pearse 1978; McLean and Raymond 1983). Both of these lakes maintain permanent stream connections to larger rivers providing no evidence of population isolation for broad whitefish or least cisco. These are the general trends in geographic distribution of whitefish species in the upper Yukon River habitat region.

Directed fisheries surveys in the upper Porcupine (Bryan 1973; Steigenberger and Elson 1977) and Yukon (Walker et al. 1973, 1974; Brown et al. 1976; Walker 1976) rivers in Canada provide similar distribution trends among habitats for the same basic group of whitefish species with two exceptions. While Bering cisco are present in the main-stem Yukon River up to the Alaska Yukon border (Brown et al. 2007), approximately 2,013 km (1,251 miles) from the sea, they appear to be extraordinarily rare in the Canadian portion of the drainage, as evidenced by the single documented case near the community of Dawson, approximately 155 km (98 miles) beyond the border (deGraaf 1981; Edge 1991). In addition, pygmy whitefish have been identified in four lakes in the upper Yukon River drainage in Canada (Lindsey and Franzin 1972; Lindsey et al. 1981) but they have not been identified in the Alaska portion of the drainage. Humpback whitefish, least cisco, and round whitefish appear to maintain both riverine and lake resident populations in the upper Yukon River in Canada (Walker et al. 1973, 1974; Brown et al. 1976; Walker 1976; Bodaly 1979; Lindsey et al. 1981; Lindsey and Kratt 1982) as they appear to do in the Alaska portion of the drainage. These intensive fish survey data from the upper Yukon River in Canada suggest that inconnu and broad whitefish maintain riverine populations only and pygmy whitefish maintain lake resident populations only. Few additional details about whitefish species from the Canadian portion of the Yukon River drainage will be presented here because it is beyond the scope of this review.

Inconnu present in the upper Yukon River habitat region are thought to be from four potential spawning populations (Alt 1988), although spawning locations are known for only one. Brown (2000) conducted an otolith chemistry and radio telemetry study on inconnu captured in the Yukon River upstream from the Tanana River mouth. He was able to show that those inconnu were members of an anadromous population migrating to a spawning destination in the highly braided, upper reaches of the Yukon Flats, upstream from the mouth of the Porcupine River (Figure 68). Sampling in the area with beach seines during early October confirmed that inconnu were spawning in the area and that humpback whitefish and Bering cisco were also present and in spawning condition. Radio tag tracking data from remote receiving stations (Figure 27), aerial surveys, and winter harvest reports revealed that many post-spawning inconnu migrated downstream in mid to late October into the lower Yukon River or Bering Sea to overwinter. The youngest mature inconnu from the upper Yukon Flats spawning population were age 7 or 8, with males tending towards earlier maturity than females, with some surviving for more than 20 years (Figure 69). Mature males in the population tend to be a few cm shorter than mature females and females attain greater maximum lengths, which is common for inconnu populations (Hander et al. 2008).

The other three or more potential inconnu spawning populations in the upper Yukon River habitat region are thought to be freshwater resident forms living entirely within the river system and spawning in the Black River, upper Porcupine River in Yukon Territory, and the upper Yukon River, presumably in Yukon Territory but possibly in the Fortymile River in Alaska also, where they have reportedly been captured in sport fisheries (BLM 1988). Numerous inconnu have been sampled in the Yukon River near the Alaska Yukon border and Brown et al. (2007) found no otolith chemistry evidence of anadromy in a subsample of 10. No maturity data have been collected so minimum length at maturity for that group, if they represent a single population, is unknown. Inconnu have been captured in numerous riverine and large lake habitats in the upper Yukon River drainage in Yukon Territory as far upstream as Lake Laberge (Walker et al. 1974; Brown et al. 1976; Lindsey et al. 1981), downstream from the community of Whitehorse, but we are unaware of any maturity sampling or spawning population work in the upper drainage. Bradford et al. (2008) sampled the main stem shore with a rotary trap near the community of Dawson during the summers of 2002 through 2004. They documented the downstream migrations of age 0 inconnu and other whitefish species, verifying that spawning is taking place in upstream environments somewhere. Alt (1978a) presented sampling evidence of a possible inconnu spawning population in the Salmon Fork of the Black River. Gillnets were fished at two sites in the

Figure 68. Spawning habitat used by inconnu, humpback whitefish, and Bering cisco in the highly braided, gravel substrate, upper reaches of the Yukon Flats. This habitat extends for approximately 138 km (86 miles) along main channels and is 3 to 5 km (2 to 3 miles) wide from main bank to main bank. Photo by R.J. Brown, USFWS.

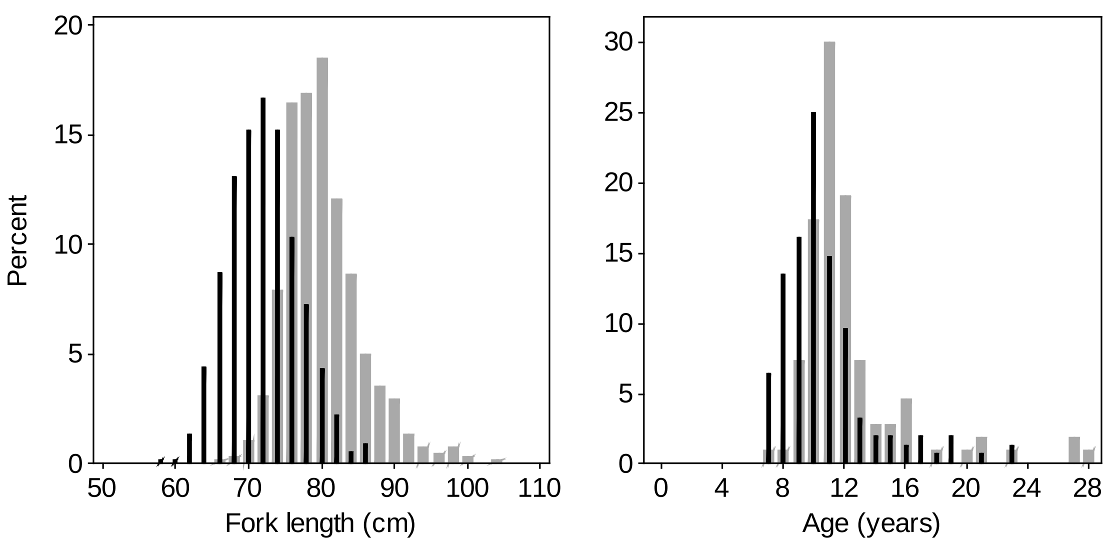

Figure 69. Length and age distributions of mature inconnu from the upper Yukon Flats spawning population. Male inconnu (narrow dark bars) tend to be shorter on average and mature a year or so earlier than female inconnu (wide gray bars), a common phenomena for inconnu populations (Hander et al. 2008).

Salmon Fork of the Black River for a total of 18 nights in late September, 1977. Seventeen inconnu were captured, of which 16 were classified as mature and preparing to spawn because eggs and milt could be easily expressed when handled. Mature inconnu from the Salmon Fork of the Black River appear to reach maturity at a much smaller size than the anadromous populations in the Yukon Flats (Brown 2000) and Sulukna River (Esse 2011), but at a similar size to non-anadromous inconnu migrating into Yukon Territory up the Porcupine River (Brown et al. 2007; Table 13). Because spawning destinations have not been located for pre-spawning inconnu captured in the Black or Porcupine rivers, it is unclear if these represent one, two, or more than two spawning populations. In any case, the reduced minimum length at maturity of these two groups, along with Brown et al.'s (2007) failure to identify any anadromous individuals from the Porcupine River group, indicate that the small-maturing, upper drainage inconnu restrict their migrations to freshwater habitats. Alt's (1978a) report of an inconnu tagged at Hess Creek, downstream from the Yukon Flats, and recaptured three years later in the Black River community of Chalkyitsik, demonstrated that the ranges of anadromous and non-anadromous populations of inconnu intersect at least through the Yukon Flats and perhaps more broadly through the drainage.

Table 13. Length data for mature male and female inconnu from two known populations, Yukon Flats and Sulukna River, and two suspected populations, Black River and Porcupine River, in the Yukon River drainage.

Population or Sample	Sex	*n*	Fork length (cm) Mean (range)	Source
Yukon Flats	Male	156	72 (61–85)	Brown (2000)
	Female	110	80 (71–103)	
Sulukna River	Male	231	72 (62–84)	Esse (2011)
	Female	156	81 (66–93)	
Black River	Male	21	59 (53–67)	Alt (1978a)
	Female	11	67 (59–79)	
Porcupine River	Male	9	59 (50–68)	R.J. Brown, USFWS, *unpub. data*
	Female	8	70 (65–74)	

Individuals from four or more broad whitefish populations inhabit the upper Yukon River habitat region. Carter (2010) used radio telemetry techniques on pre-spawning, anadromous broad whitefish migrating upstream in the Yukon River to identify their spawning area in the middle and lower reaches of the Yukon Flats, approximately 100 km (62 km) downstream from the heavily braided reach used by inconnu. The broad whitefish spawning area (Figure 70) is also braided but the islands are bigger, the channels larger, and the gravel substrate appears to be more stable than in the inconnu spawning reach (Figure 69). Catch rate data indicate that the spawning migration passes Rapids in September and probably continues into October (Figure 30). The most precocious broad whitefish from the anadromous population in the Yukon Flats matured at age 5, the modal age was 8 years, and the oldest fish in a sample of 78 individuals was age 16. The shortest mature broad whitefish was 39 cm (15 inches) fork length and the longest was 64 cm (25 inches). Radio telemetry data showing what appeared to be a post-spawning, downstream migration, similar to that described by

Figure 70. Spawning habitat used by broad whitefish in the braided, gravel substrate, middle reaches of the Yukon Flats. This habitat extends for approximately 270 km (168 miles) along main channels and may be 10 km (6 miles) wide or more from main bank to main bank. Photo by R.J. Brown, USFWS.

Chang-Kue and Jessop (1997) for broad whitefish in the Mackenzie River, indicated that spawning occurred in November. Using long-duration radio transmitters, Carter (2010) was able to show that many broad whitefish remained in the large channels of the Yukon Flats through the winter. In addition, one of these tagged fish was located in a lake within the Yukon Flats the following summer, demonstrating that at least some of the broad whitefish from the anadromous population colonize upstream lakes for feeding rather than returning to the Yukon River delta. Given the great distance between estuarine rearing habitats and upstream spawning habitats, this choice appears to be energetically favorable, although it is unknown whether a large or small fraction of post-spawning fish choose this option.

Sampling data suggest that additional broad whitefish spawning populations may exist in the upper Chandalar (Craig and Wells 1975; Brown et al. 2007), Porcupine (Alt 1974; Brown et al. 2007), Black (Alt 1978a; Brown and Fleener 2001), and Yukon rivers upstream from the Yukon Flats (Alt 1979c; Lindsey et al. 1981; Brown et al. 2007). Brown et al. (2007) obtained broad whitefish samples from subsistence fisheries in the upper Chandalar River, at the community of Arctic Village, and from the Porcupine and Yukon rivers near the Alaska Yukon border. Otolith chemistry analyses from subsamples of broad whitefish from these collections indicated that all were non-anadromous. A sonar project in the lower Chandalar River has conducted beach seine sampling and underwater video monitoring operations in late summer and fall for several years and did not capture or view broad whitefish migrating past (Osborne and Melegari 2006; Melegari and Osborne 2007), suggesting a local population within the Chandalar River drainage. Broad whitefish maturity, length, and age data were collected in fall near the Alaska Yukon border on the Porcupine River during sampling activities associated with Brown et al. (2007). Gonadosomatic indices of 11 females revealed values elevated far above GSI = 3, a level rarely exceeded by non-spawning females (Brown 2004), indicating that the sampled fish were mature and preparing to spawn (Figure 71). Fork length distribution from a sample of 36 males and females ranged from 43 to 59 cm (17 to 23 inches) fork length, which is consistent with mature demographic groups from other populations (Chudobiak 1995; Carter 2010). Age distribution from a sample of 29 males and females indicated that freshwater resident broad whitefish in the Porcupine River matured as young as age 3, which is younger by two or more years than other broad whitefish populations (VanGerwen-Toyne et al. 2008; Carter 2010). Bryan (1973) suggested that broad whitefish may spawn in the upper Old Crow River or in the Porcupine River near the mouth of the Driftwood River but provided no biological data in support. Steigenberger and Elson (1977) documented captured broad whitefish in riverine habitats as far upstream as the mouth of the Fishing Branch River in the upper Porcupine River drainage and Lindsey et al. (1981) captured broad whitefish in Davis Lake, within the Eagle River drainage, an eastern tributary of the upper Porcupine River, but suggested they were rare compared to other species in the lake. Brown and Fleener (2001) captured 27 broad whitefish in the lower Black River, nearly all in oxbow lakes with stream connections to the river. Ages ranged from 1 to 14 years, indicating a mix of immature and mature individuals. A female captured in September had a GSI value of 12 indicating that it was preparing to spawn, but its spawning destination was unknown. Alt (1978a) captured 18 broad whitefish in the Salmon Fork of the Black River during late September but did not comment on maturity or spawning readiness. It is possible that there is a spawning population of broad whitefish in the Black River drainage. Alternatively, broad whitefish from the Yukon Flats or upper Porcupine River populations may utilize the Black River as feeding and rearing habitat. While broad whitefish are present in the upper Yukon River, upstream from the Yukon Flats in Alaska (Alt 1979c; Welp and Ulvi 1986) and Yukon Territory (Walker et al. 1974; Brown et al. 1976; Walker 1976; Lindsey et al. 1981; Selkirk First Nation 2002), sparse capture data suggest that they are not abundant. Brown et al. (2007) conducted otolith chemistry analyses on a sample of eight broad whitefish captured near the Alaska Yukon Border and none were found to have been to sea, suggesting that those upstream from the Yukon Flats were non-anadromous. One or more spawning populations are assumed because of the wide geographic range of occurrence, which extends into headwater reaches in the British Columbia portion of the drainage (McPhail and Lindsey 1970; Brown et al. 1976; Lindsey et al. 1981; Selkirk First Nation 2002), but we could find no information on maturity or spawning locations. In summary, these sampling and distribution data support the concept of one or more freshwater resident broad whitefish spawning populations in several of the upper tributaries of the Yukon River drainage in Alaska and Canada.

Humpback whitefish from multiple populations inhabit the upper Yukon River habitat region in Alaska, and additional populations are present in the Canadian portions of the upper Porcupine and Yukon rivers as well. Brown (2000) captured pre-spawning humpback whitefish in the upper reaches of the Yukon Flats in October while conducting inconnu research, suggesting a main-stem spawning population in the same area used by inconnu and Bering cisco. Subsequent otolith chemistry research indicated that some of the humpback

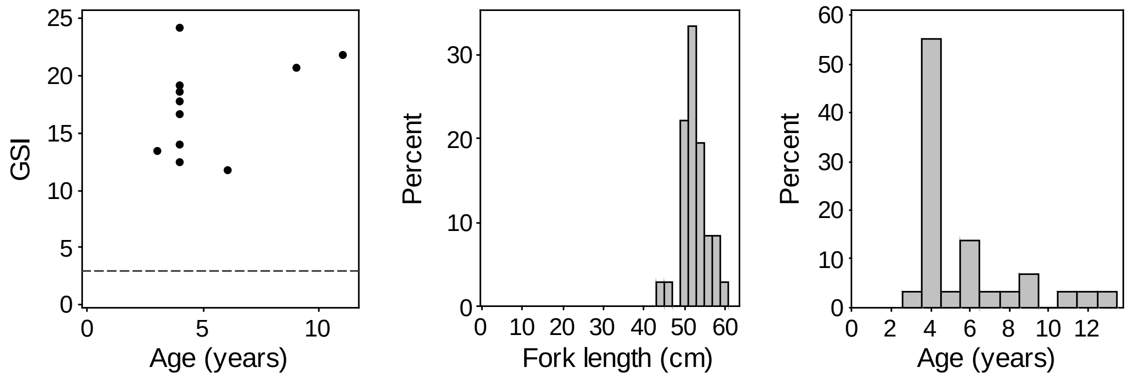

Figure 71. Maturity data and length and age distributions for a small sample of broad whitefish collected in fall near the Alaska Yukon border on the Porcupine River. Gonadosomatic indices of 11 females revealed values elevated far above GSI = 3 indicating that the sampled fish were mature and preparing to spawn. Fork length distribution from a sample of 36 males and females was consistent with mature demographic groups from other populations (Chudobiak 1995; Carter 2010). Age distribution from a sample of 29 males and females indicated that freshwater resident broad whitefish in the Porcupine River matured as young as age 3, which is younger by two or more years than other broad whitefish populations (VanGerwen-Toyne et al. 2008; Carter 2010). These are unpublished data collected during sampling activities associated with Brown et al. (2007).

whitefish spawning in the upper Yukon Flats were anadromous (Brown et al. 2007). Few length, age, or other biological data are available for humpback whitefish from the main-stem spawning population. At least some individuals from this population migrate upstream from the sea and are observed in the video fish wheel located at Rapids, where it appears that the peak of the spawning migration occurs in late August or September (Figure 30). Humpback whitefish sampled farther upstream from the Yukon Flats in the Porcupine and Yukon rivers were found to be non-anadromous.

Humpback whitefish distribution in the upper Chandalar and Sheenjek River drainages appears to be limited to a few large lakes capable of supporting fish during winter. Humpback whitefish are present in Chandalar and Squaw lakes in the upper North Fork Chandalar River drainage (Kramer 1976b; Pearse 1978). Kramer (1976b) sampled Ackerman Lake, a relatively large lake in the Middle Fork Chandalar River, and claims to have visually observed humpback whitefish, although he did not capture them in his gillnets. Pearse (1978) also sampled Ackerman Lake and captured numerous other fishes but did not capture humpback whitefish. It seems unlikely that humpback whitefish would be present in Ackerman Lake and avoid capture in two extensive gillnet sampling surveys so we suspect that Kramer's (1976b) observations may be in error. Humpback whitefish are present in the upper Sheenjek River drainage in Old John (Ward and Craig 1974; Pearse 1978) and Big Fish (Ward and Craig 1974) lakes, and in another unnamed lake in Old Woman Creek (see Appendix A5), an upper drainage tributary. Ward and Craig (1974) initially identified both humpback whitefish and broad whitefish in Old John Lake, and broad whitefish in the other Sheenjek River lakes, but Craig and Wells (1975) claimed this was a mistake and that all fish in the Sheenjek River that were identified as broad whitefish by Ward and Craig (1974) were actually humpback whitefish. No humpback whitefish have been identified in upstream reaches of the Chandalar or Sheenjek rivers (Ward and Craig 1974; Craig and Wells 1975) and few have been captured in test netting operations or observed in underwater video monitoring activities at the sonar project near the mouth of the Chandalar River (Melegari and Osborne 2007). These sampling and observational data suggest that humpback whitefish in the upper Chandalar and Sheenjek River drainages are isolated lake populations.

Humpback whitefish are widely distributed in the Black River drainage from the lower reaches, where they enter oxbow and other connected lake systems to feed during spring and summer (Brown and Fleener 2001), to at least the middle reaches, including the Salmon Fork of the Black River (Alt 1978a). Brown and Fleener (2001) captured 56 mature size humpback whitefish in both riverine and lake habitats in June, none in July, and six age 1 juveniles in lake habitat during September. The seasonal catch of mature size fish indicate a migration passing through the habitat with an unknown destination. The seasonal catch of juvenile fish was probably a result of recruitment to the sampling gear. The presence of juvenile fish rearing in floodplain lake habitat in the lower Black River drainage suggests an upstream spawning location somewhere within the drainage, although it is also possible that the juvenile humpback whitefish were members of a population from outside the drainage and simply migrated in to rear. Alt (1978a) captured 23 humpback whitefish in the Salmon Fork of the Black River during September but did not comment on maturity or spawning readiness. The identification of a spawning population of humpback whitefish in the Black River drainage would require maturity sampling designed to identify spawning readiness followed by a radio telemetry project to determine spawning destination.

Humpback whitefish have been captured throughout the main-stem Porcupine River in early, mid, and late summer (Alt 1971b; 1972; 1974), and near the Alaska Yukon border in fall (Brown et al. 2007). Maturity sampling was only conducted on those humpback whitefish captured near the border in fall, 20 females and 11 males. Gonadosomatic index values of the females averaged 17% and ranged from 11 to 22%, all well above the 3% level that is rarely exceeded by non-spawning fish (Bond 1982; Brown 2004). Males associated with the pre-spawning females were assumed to be preparing to spawn also, although it was not possible to determine empirically. Similar to the pre-spawning inconnu and broad whitefish discussed earlier, pre-spawning humpback whitefish appeared to be migrating upstream to unknown spawning destinations in the Yukon Territory portion of the drainage. Bryan (1973) suggested that they may spawn in the main-stem Porcupine River upstream from the mouth of Lord Creek, about 30 km (19 miles) east of the Old Crow River, although no biological data were provided. Steigenberger and Elson (1977) documented humpback whitefish in riverine environments as far upstream as the Miner River and Lindsey et al. (1981) captured humpback whitefish in Davis Lake, within the Eagle River drainage, an eastern tributary of the upper Porcupine River.

In the Yukon River drainage upstream from the Yukon Flats, humpback whitefish are present as riverine and isolated lake populations (Brown et al. 1976; Alt 1979c; Bodaly 1979; Lindsey et al. 1981). Within the Alaska portion of these upper reaches, humpback whitefish appear to remain almost entirely in main-stem habitats and are not particularly common (Alt 1971b, 1979c; Welp and Ulvi 1986; Daum 1994). Few lakes, which are major feeding habitats for humpback whitefish (Brown 2006; Harper et al. 2007), are present in the area and even fewer are accessible to riverine fish. As a result, most humpback whitefish captured in the area are thought to be migrating through, perhaps from feeding habitats in the Yukon Flats to upstream spawning habitats in the Canadian portion of the drainage. This is speculation, however, because no maturity sampling data are available for humpback whitefish in the area. Sampling data indicate that humpback whitefish are widely distributed in riverine (Brown et al. 1976; Walker 1976) and lake (Lindsey et al. 1981) habitats in the Canadian portion of the upper Yukon River drainage. The identification of benthic and pelagic forms in some lakes (Lindsey 1963; Bodaly 1979) indicate the at least some lake resident populations exist in the upper drainage. These sampling data indicate that humpback whitefish population diversity remains very complex throughout the Yukon River drainage.

Sampling data indicate that least cisco from multiple populations are present in the upper Yukon River habitat region. Anadromous least cisco were identified at Rapids sampling site (Brown et al. 2007), downstream from the Yukon Flats, but least cisco were rare in the catch compared to other whitefish species and it was never clear that an upstream migration of least cisco was occurring. Least cisco are present in the Yukon Flats in main-stem habitats near tributary mouths (Alt 1972), in the lower reaches of tributaries (Glesne et al. 1985; AECOM 2009), and in connected floodplain lakes (Kramer 1981; Hallberg 1983; Glesne et al. 2011; Brown and Fleener 2001). During the Chandalar River chum salmon sonar project, least cisco were captured in a beach seine and observed in underwater video (Osborne and Melegari 2006; Melegari and Osborne 2007). Least cisco were only observed at the sonar site in September and biological sampling revealed that they were mature fish preparing to spawn (Figure 72). Brown et al. (2007) tested 14 otolith samples from this population for chemical signs of anadromy and found no indication that they went to sea. A two year radio telemetry study revealed that their spawning destination was a 20 km (12 mile) braided reach of the Chandalar River approximately 45 km (28 miles) upstream from the mouth (Figure 73; R.J. Brown, USFWS, unpub. data). Following spawning in early October, radio tagged least cisco migrated downstream to the Yukon River. Pearse (1978) and Kramer (1976b) both captured least cisco in Chandalar Lake, a large lake in the upper North Folk Chandalar River. In both cases the maximum size was less than 20 cm (8 inches) suggesting either juvenile fish or a dwarf population (Mann 1974). In either case, their presence in the upper drainage lake suggests a spawning population in the drainage, perhaps a population that remains within Chandalar Lake. Brown (2000) did not find least cisco while sampling in the inconnu spawning area in the upper Yukon Flats. Least cisco are common in connected lake habitats within the Black River drainage (Glesne et al. 2011; Brown and Fleener 2001). Females captured in September (n = 8) had elevated GSI levels ranging from 15 to 17% indicating they were mature fish preparing to spawn (Brown and Fleener 2001). The pre-spawning least cisco, however, were confined at the time in a large oxbow lake and it was unclear if they would spawn within the lake, which did not appear to contain gravel substrate habitats required for successful spawning, or attempt to migrate to the river if given the opportunity. The smallest and youngest mature least cisco in the sample were 31 cm (12 inches) and age 3 respectively. Alt (1978a) captured two least cisco during fall sampling in the Salmon Fork of the Black River but did not comment on spawning readiness. Brown et al. (2007) tested 10 otolith samples from least cisco captured in the Black River for chemical signs of anadromy and found no indication that they went to sea. Least cisco have been captured in numerous locations along the main-stem Porcupine River in Alaska (Alt 1971b, 1974, 1979c). During sampling activities associated with Brown et al. (2007), mature least cisco preparing to spawn were harvested near the Alaska Yukon border suggesting a spawning migration into the Canadian portion of the drainage (unpublished data). Bryan (1973) and Steigenberger and Elson (1977) documented least cisco in riverine and floodplain lake habitats in the Porcupine River drainage up to the mouth of the Driftwood River within the Canadian portion of the Porcupine River drainage but not in riverine habitats farther upstream. Bryan (1973) suspected least cisco spawned in the upper Old Crow River and possibly in the Porcupine River main stem because he captured fry in these locations during summer. Lindsey et al. (1981) captured least cisco in Davis Lake, within the Eagle River drainage, a major tributary, which is the farthest upstream record for least cisco in the Porcupine River. Capture data suggest that least cisco may be rare in riverine environments upstream from the Yukon Flats in Alaska (Alt 1971b, 1979c; Daum 1994) where very few floodplain lakes are available for feeding. Similarly, least cisco are present but rare compared to other whitefish species in riverine environments in the upper Yukon River drainage in Canada (Brown et al. 1976; Walker 1976). Least cisco are present in numerous upper-drainage lakes in Canada (Lindsey et al. 1981; Lindsey and Kratt 1982), which, considering the apparent scarcity of least cisco in upper-drainage riverine environments, may represent isolated lake populations similar to those documented in some large lakes in Bristol Bay, southwest Alaska (Kerns 1968; Heard et al. 1969; Russell 1980). These sampling data indicate that many least cisco populations, both riverine and lake resident forms, exist in the Yukon River drainage upstream from the Yukon Flats.

Bering cisco have only been captured in main-stem habitats, including the mouths of tributaries, but not in their upstream reaches (Alt 1972, 1973a; Brown 2000; Brown et al. 2007). Fisheries surveys in Beaver (Lubinski 1995; Collin and Kostohrys 1998; AECOM 2009) and Birch (Weber and Post 1985; Townsend 1996) creeks, and Hodzana (Glesne et al. 1985), Chandalar (Ward and Craig 1974; Craig and Wells 1975; Kramer 1976b), Porcupine (Alt 1974, 1978a; Brown et al. 2007), Kandik (Alt 1971b; Daum 1994), and other tributaries in the habitat region have routinely reported other whitefish species in upstream reaches of tributaries but never Bering cisco. Brown et al. (2007) collected Bering cisco near the Alaska Yukon border and the farthest upstream record was a single individual captured in the community of Dawson (deGraaf 1981), a community in Yukon Territory approximately 2,168 rkm (1,347 river miles) from the sea. With the exception of deGraaf (1981), sampling studies in riverine and lake habitats of the upper Yukon River drainage in Canada have never reported capturing Bering cisco (Walker et al. 1973; Brown et al. 1976; Walker 1976; Lindsey et al. 1981). Maturity sampling (GSI) throughout the summer season at Rapids, 1,174 km (729 miles) from the sea, and during early October in the upper Yukon Flats, approximately 1,750 km (1,087 miles) from the sea, indicated that all Bering cisco in the upper Yukon River habitat region are mature and preparing to spawn (Figure 33; Brown 2000; Brown et al. 2007). The elevated GSI levels of females in early October, along with easy expression of eggs or milt from all sampled individuals, suggest a mid-October spawning season. The upstream and downstream range of the spawning habitat has not been fully described, but it appears that at least some spawning occurs in the upper Yukon Flats in the same braided, main-stem reach used by inconnu (Figure 68). The limited age distribution of mature Bering cisco (Figure 32) suggests that post-spawning survival is low. No rearing or feeding Bering cisco have been identified in upstream habitats of the Yukon River, so it is likely that survivors migrate back to the Bering Sea following spawning.

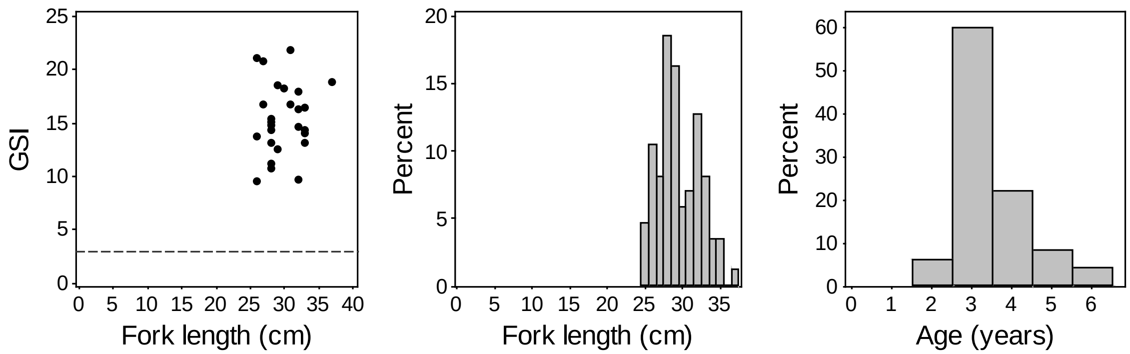

Figure 72. Maturity data and length and age distributions for a small sample of least cisco collected in fall in the lower Chandalar River. Gonadosomatic indices of 26 females revealed values elevated far above GSI = 3, indicating that the sampled fish were mature and preparing to spawn. Fork length distribution from a sample of 86 males and females indicated a minimum length at maturity of 25 cm (10 inches), a few cm smaller than other riverine populations in Alaska (Fleming 1996; Brown 2004; Harper et al. 2007). Age distribution from a sample of 50 males and females indicated that this least cisco population matured as young as age 2 with a mode of age 3, which is younger by one or more years than most other least cisco populations (Mann 1974; Brown 2004; Harper et al. 2007). These are unpublished data collected by R.J. Brown (U.S. Fish and Wildlife Service) during sampling activities associated with the Chandalar River sonar project (Osborne and Melegari 2006; Melegari and Osborne 2007).

Figure 73. Looking upstream (north northwest) into least cisco spawning habitat approximately 45 km (28 miles) up the Chandalar River from the mouth. Photo by R.J. Brown, USFWS.

Sampling data indicate that round whitefish are common in tributary and lake environments throughout the upper Yukon River habitat region but are rare in main-stem habitats, at least during the open-water sampling season. Sampling efforts have identified round whitefish in many tributaries including Beaver (Lubinski 1995; AECOM 2009) and Birch (Durtsche and Webb 1977; Townsend 1996) creeks, and the Hodzana (Glesne et al. 1985), Chandalar (Craig and Wells 1975; Pearce 1978), Sheenjek, Black (Kostohrys et al. 1994), Porcupine (Bryan 1973; Steigenberger and Elson 1977), Charley (Welp and Ulvi 1986), Kandik (Alt 1971b), Nation (Daum 1994), and Tatonduk rivers, as well as many additional locations in the upper Yukon River in Canada (Brown et al. 1976; Walker 1976; Lindsey et al. 1981). Craig and Wells (1975) provided the only convincing evidence of spawning round whitefish within the habitat region. They identified a round whitefish spawning area in the upper East Fork Chandalar River in a highly braided, gravel substrate reach near the mouth of Cane Creek. They sampled a number of round whitefish in late September and found them to be either very ripe, spilling eggs and milt when handled, or partially spawned out at that time indicating that spawning season for that population began in late September and probably extended into October. They found the youngest mature fish to be age 8 and the oldest fish to be age 22. Mature round whitefish ranged from 29 to 44 cm (11 to 17 inches) fork length. At spawning time the eggs were between 2.2 and 2.9 mm in diameter and fecundity estimates from a sample of nine females ranged from 4,200 to 18,700 eggs. It is possible that there are spawning populations of round whitefish in most or all of the tributary rivers throughout the upper Yukon River habitat region, as well as in many of the upland lakes. Migrations of riverine round whitefish are not very well understood, but their scarcity in main-stem habitats during the open water season (Alt 1972; Brown et al. 2007), along with the routine presence of all life history stages within tributary systems (Glesne et al. 1985; Daum 1994), suggests that they have much smaller home ranges than other whitefish species, perhaps remaining in or near natal tributaries throughout life.

Fisheries

The Upper Yukon habitat region is home to 12 communities in the Yukon Flats and farther upstream with a population of approximately 1,539 in 2008 (Appendix A2; Figures 61-63). The communities of Venetie, Beaver, Birch Creek, Fort Yukon, Stevens Village, Chalkyitsik, Circle, Central, and Arctic Village are primarily Gwich'in and Koyukon Athabascan. Of these nine communities, three (Circle, Central, and Arctic Village) lie outside the borders of the Yukon Flats National Wildlife Refuge that encompasses much of the Yukon Flats (USFWS 1990). The Alaska Native people living in Eagle are primarily Han Athabascan. Nearly all communities in the region depend on fishing for at least a portion of their subsistence needs.

Whitefish species are considered to be the most important non-salmon fish resources in the Upper Yukon River habitat region and are an integral part of the subsistence economies of regional communities. Some communities rely almost exclusively on whitefish and other non-salmon species because salmon do not pass near their fishing areas and are available only through sharing and trading networks. As in many other areas of Alaska, whitefish species are available to residents in the Upper Yukon throughout the year, which contributes to their importance (Koskey and Mull 2011). According to Andersen and Fleener (2001) broad whitefish are the preferred or most frequently targeted species of whitefish among

Yukon Flats fishers because of their large size and the high quality of their meat and roe. Round whitefish are rarely mentioned in published ethnographic studies, suggesting that the species may not be as widely available or as commonly targeted as other whitefish species. Historically, fishing areas considered rich in whitefish species played an important role in the original establishment of several Yukon Flats communities. Examples include Arctic Village, Alexander Village (a Christian River community that is no longer occupied), Birch Creek, Chalkyitsik (which in Gwich'in means "fish hooking place"), and Twenty-Two Mile Village (an upper Yukon Flats community that is no longer occupied; Andersen and Fleener 2001; Koskey and Mull 2011).

Culture and language

According to oral history accounts, residents of the Upper Yukon River habitat region harvested and relied on whitefish species long before the presence of Euroamerican traders and settlers in the area. However, the first documented harvest and use of whitefish was in the mid-1800s when explorers and Hudson Bay Company representatives entered the area. On an ethnographic expedition up the Porcupine River in 1936, Osgood (1936) observed that the Kutchin (now Gwich'in) in the Yukon Flats and nearby areas recognized two general types of whitefish; lake whitefish and river whitefish. Geist (1953), on an archaeological expedition in 1952, reported "several species" of whitefish in the Porcupine River, one of which was large and was called "conie" by locals. Geist speculated correctly that this was inconnu.

Whitefish species are known by many residents of the upper Yukon River habitat region by their Gwich'in names (Table 14) as well as a number of other common descriptive names. Most names are commonly understood and used in all villages, but some species have unique localized names. For example, in Fort Yukon, Bering cisco are referred to as "herring" (Sumida and Andersen 1990). The general term in Gwich'in for any whitefish species except inconnu, is *luk daagaii*. Gwich'in speakers also make classifications based on size, such as big whitefish and little whitefish, or habitat preference, such as lake and river whitefish. Juvenile whitefish (up to 20 cm [8 inches] in length) of all species are referred to informally as "sardines" (Andersen and Fleener 2001). The following table listing various terms for whitefish species is adapted from Sumida and Anderson (1990).

Table 14. Terms for whitefish species in the Yukon Flats region.

English	Linnaean	Gwich'in[1]
Inconnu	*Stenodus leucichthys*	Shryah
Broad whitefish	*Coregonus nasus*	Chiishoo or Chihshoo
Humpback whitefish	*Coregonus pidschian*	Neeghan
Least cisco	*Coregonus sardinella*	Ch'ootsik
Bering cisco	*Coregonus laurettae*	Treeluk, luk dohohr'i'
Round whitefish	*Prosopium cylindraceum*	Khalltai'
Unidentified whitefish		Lluk daagai

[1]Sumida and Andersen (1990).

Harvest and use

Whitefish species have been observed and harvested throughout the entire year in lakes and rivers of the Yukon Flats region (Koskey and Mull 2011). Residents have observed that whitefish move along the rivers consistently throughout the summer and are caught under the ice in rivers and lakes during winter as well. Many respondents in a recent study by Koskey and Mull (2011) observed that whitefish could be captured in certain deep lakes throughout the winter. While residents of the Yukon Flats region harvest whitefish species throughout the year, the most intense fishing seems to occur in the late spring and early fall when whitefish are thought to be most actively migrating between river and lake habitats and along the network of sloughs and streams that characterize the area. The consistent presence of whitefish of one species or another in a wide variety of habitats throughout the year testifies to their significance as a subsistence resource in the Yukon Flats.

Each community appears to have its own particular pattern of whitefish fishing based on nearby habitat qualities and the availability of different species. Inconnu are a highly regarded species that are most intensively harvested along the major river systems in the late summer and fall (Koskey and Mull 2011). A study of resource use patterns in Stevens Village in the 1980s indicated that whitefish species other than inconnu were targeted between late May and December while inconnu were specifically targeted between August and early November (Sumida 1988). Residents of the community of Birch Creek, in the southern part of the Yukon Flats, harvest primarily humpback whitefish and to a lesser extent, round whitefish (Koskey and Mull 2011). Fishers in the area described some variation in the physical characteristics of humpback whitefish such as size, coloring, and taste of flesh, however, the particulars of these variations were not discussed in detail. Residents of the community of Chalkyitsik, located in the lower Black River drainage in the northeast Yukon Flats (Figure 62), rely heavily on their local whitefish harvests. Archaeological investigations along the Porcupine River provide evidence of great antiquity in human occupancy and use of the region (Morlan 1975; Dixon and Plaskett 1980). Chalkyitsik elders in the 1970s recalled a highly mobile way of life when they were young, living at the headwaters of the Black River during winter and floating downstream into the lower river to fish during the summer (Nelson 1973). Large numbers of whitefish in the lower Black River provided a very reliable source of food (Caulfield 1983). One of the earliest harvest assessments for the Black River area was a U.S. Fish and Wildlife Service study conducted in 1960, which estimated a whitefish harvest of 4,000 fish by Chalkyitsik residents during that year (USFWS 1964). Arctic Village is a community in the upper East Fork Chandalar River, to the north of the Yukon Flats. It is located upstream from major chum and Chinook salmon spawning areas and residents are therefore very dependent on their harvests of whitefish species (Adams et al. 2005). The Chandalar River near the community is a productive area for broad whitefish, while Old John Lake, located approximately 18 km (11 miles) east of Arctic Village, is a very productive area for humpback whitefish. According to Gustafson (2004), residents of Arctic Village and Venetie traditionally spent several days or weeks each year fishing from seasonal camps at Old John Lake. In recent years, however, the seasonal fishing camps at the lake are used less often. While fishing practices and opportunities vary by community with the region, nearly all take advantage of the whitefish resources available to them.

Fort Yukon is the largest community in the Yukon Flats and appears to harvest more whitefish than all other communities combined (Koskey and Mull 2011). Recent harvest estimates have declined relative to earlier estimates for Yukon Flats communities. In 1986-1987, for example, residents of Fort Yukon reported harvesting more than 23,960 kg (52,823 lb.) of whitefish, including inconnu (Sumida and Andersen 1990), which decreased to 5,352 kg (11,800 lb.) in 2005 (Koskey and Mull 2011). In 1986-1987, inconnu and other whitefish species constituted 8.4% of the total harvest of wild resources (Sumida and Andersen 1990). Harvest estimates gathered in more recent studies provide single-year estimates of whitefish use in some communities (Table 15).

Table 15. Estimated harvest of whitefish species, in kg (pounds), in certain Yukon Flats communities in 2005[1].

Species	Beaver	Birch Creek	Central	Circle	Fort Yukon
Inconnu	196 (432)	33 (72)	85 (187)	14 (31)	974 (2,147)
Broad whitefish	161 (354)	399 (880)	0	0	3,235 (7,131)
Humpback whitefish	138 (306)	68 (150)	0	54 (118)	998 (2,201)
Least cisco	0	0	0	12 (26)	118 (261)
Bering cisco	0	0	0	25 (55)	0
Unidentified whitefish	0	0	5 (11)	0	27 (60)
Total	495 (1,092)	500 (1,102)	90 (198)	104 (230)	5,352 (11,800)

[1]Koskey and Mull (2011).

Capture methods for whitefish species have evolved greatly over time. Traditionally, whitefish were harvested using fish-traps, nets made of willow bark or other materials, hand-jigs, willow-root lassos, and spears (Osgood 1936; Slobodin 1981; Koskey and Mull 2011). Gustafson (2004) recorded Gwich'in terms for some of these gear types, including fish trap (*daahanlee or neegwaatsaii)*, spear (*ch'eedaih)*, fish net (*chihvyaa)*, and two types of fish hooks (*jaŁ and Ła'h)*. The latter type of fish hook is larger (three-inches), and used for angling through ice. Spears thrown from the bank into narrow streams were historically used to catch whitefish. While this practice has been largely abandoned, individuals remain in the Birch Creek region that are skilled at making traditional spears using materials such as carved antler or copper prongs attached to a pole (Koskey and Mull 2011). Today, fishers still use a variety of gear types, many of which are contemporary versions of historic types; however, commercial gill nets are the most widely used gear. Nets set from the shore to midstream began replacing nets at weir sites during the open water season, and nets set under ice continues to be a common fishing method in winter (Caufield 1983; Andersen and Fleener 2001). Gill net mesh size can vary from 2.5 to 20 cm (1 to 8 inch) stretch mesh, though most fishers report using nets with a 10 cm (4 inch) stretch mesh net or slightly greater to target broad whitefish and humpback whitefish (Andersen and Fleener 2001). Hook and line gear continues to be used in both summer and winter. Modern rod and reel equipment is common and some residents also use an older method of "can" fishing, in which a coffee can is used as the reel with the lure cast by hand and retrieved by rewinding the line around the can (Koskey and Mull 2011). Jigging for inconnu and other whitefish species is common in winter months (Sumida and Andersen 1990, Caulfield 1983). Fish wheels are in common use along the main-stem Yukon River, primarily targeting Pacific salmon species but whitefish species are seasonally abundant in their harvests as well. In the community of Circle, for example, inconnu are commonly caught in fish wheels during late summer and fall while fishing for salmon (Koskey and Mull 2011). Function has always been the primary objective in fishing methodologies and the diversity of modern methods represent a logical evolution of technology for subsistence fishers throughout the Upper Yukon River habitat region.

Between 1940 and the late 1960s many families lived seasonally in trapping and fishing camps on the Black and Porcupine rivers. Peter (1979) states that families lived in camps at such places as Shuman House, "Old Village", Ddhahtee, Canyon Village, Burnt Paw, "John Steven's Place", Salmon Village, and Grayling Fork. Today, as in the past, fish camps continue to be focal points for harvesting and socio-cultural activities such as teaching traditional skills and values, sharing resources, and relating oral traditions (Caulfield 1983). Fish camps continue to be occupied seasonally along the Porcupine and Black rivers, and several other tributaries in the Porcupine Drainage. Although now only used in spring and fall, these camps continue to offer a place for families and friends to work together harvesting, processing, and preparing whitefish and other fish species.

With the exception of the advent of refrigeration and freezers, the processing and preservation of whitefish in the Yukon Flats has changed little through the years. Osgood (1936) stated that for Yukon Flats and the surrounding area, dried fish was made in a similar way as that of the Peel River Gwich'in except that the tails are removed. With large fish, the head and backbone was removed and the fish was cut down the stomach leaving two equal slabs of meat held by the tail. These were thrown over a pole to dry. In the case of small fish, the head and backbone are left intact. The head is split open and the backbone cut loose, leaving the head and fleshy parts together joined to the backbone by the tail. This method was thought to be the oldest way of cutting fish as most fish is utilized and fewer cutting strokes were necessary (Osgood 1936). Yukon Flats residents continue to dry whitefish today; however, it is more commonly frozen and stored in freezers for winter use (Koskey and Mull 2011). Birch Creek area residents noted that whitefish provide a sort of "insurance" for declines in the quality and quantity of salmon (particularly Chinook salmon), and are therefore often perceived as a "back-up" food.

One of the most notable changes in Yukon Flat's communities in recent years is the considerable reduction in overall harvest and use of whitefish. Community members in some villages in particular reported that they now harvest less or no whitefish at all compared with a generation ago and instead focus on salmon species. In some cases, this can be attributed to a reduced need because of a decline in the use of sled dogs. A 1960 U.S. Fish and Wildlife Service study reported that whitefish species were used primarily for human consumption, while chum salmon harvests for that year were used for dog food (USFWS 1964). Caulfield (1983) also reported that whitefish species in the Porcupine River drainage were used primarily for human consumption, with food for dogs being a secondary use. However, in Stevens Village, during the 1980s, it was reported that high percentages of harvested whitefish (72%) and inconnu (78%) were fed to sled dogs (Sumida 1988).

Whether human or dog food, whitefish species are part of the regional subsistence economy in the upper Yukon River habitat region.

Local issues and concerns

Residents of the Yukon Flats communities have expressed a variety of concerns about the health and status of whitefish populations in the area. These concerns include the effects of climate change, development issues, changing subsistence use practices, and changing traditional management practices. Many people believe that there are fewer whitefish now than there have been at times in the past, and that the food quality of these fish is reduced, though not to the same degree as the observed decline in quantity and quality of salmon species. Others report more positive observations of whitefish populations. In a 2009 study, for example, residents described inconnu as being "desirable" and the local population was considered to be "healthy" (Koskey and Mull 2011). In another study, however, residents of Arctic Village expressed concerns about declining harvests of whitefish and did not believe that their current harvest levels were sustainable (Adams et al. 2005). In the community of Central, declines in local whitefish harvests were attributed to excess debris in the stream waters as a result of nearby wildfires and earthquakes (Koskey and Mull 2011). A 2004 fire, for example, increased turbidity of Birch Creek, Albert Creek, and Crooked Creek for many months. Some residents from the community of Birch Creek believe that their observations of reduced whitefish harvests and poor food quality may be a result of the extensive mining activity that has historically taken place in the upper Birch Creek drainage. This variability demonstrates the localized differences in fishery experience within the Yukon Flats region.

Residents often cite changing climate as the root cause of an observed drying trend for rivers and lakes in the Yukon Flats. A warmer, drier climate is believed to have reduced flooding in the Yukon Flats, a factor that may be at least partially responsible for the large-scale drying of lakes throughout the region. In the past, the Yukon and its tributaries regularly flooded in the spring, recharging off-channel lakes with water and providing seasonal fish passage between the river and adjacent lakes and sloughs. While seasonal flooding does still occur, many residents of the region believe that it is happening less frequently than in previous times, and at lower intensities when it does happen (Caulfield 1983; Andersen and Fleener 2001; Koskey and Mull 2011), which may limit access for whitefish to off-channel feeding habitats in the spring and prevent those that do reach the lakes in the spring from returning to riverine overwintering habitats in the fall. A few decades ago, Venetie Lake was a major, seasonal feeding habitat for whitefish in the northern Yukon Flats and it historically supported a local whitefish fishery (Figure 74; Caulfield 1983). At this time, however, the connecting stream between the lake and the lower Chandalar River has grown in with sediment and aquatic vegetation preventing fish passage. Venetie Lake is an example of the floodplain drying process discussed above that has resulted in the lake being isolated from the river system, and because it is too shallow to support overwintering fish, it has no fish at all. Thus, the Venetie Lake fishery was apparently lost to an evolving landscape in a changing climate.

As in other locations around Alaska, communities in the Upper Yukon River habitat region have expressed concern about the impact of beaver activity on whitefish populations (Andersen and Fleener 2001). Some residents in the communities of Beaver and Fort Yukon suggested that the number of beaver harvested by local residents has declined in recent times,

Figure 74. Looking north in late fall across the Chandalar River to the partially frozen Venetie Lake, which is approximately 3.5 km (2 miles) across. Note that the community of Venetie is visible on the bank of the river to the left of center. Drainage from Venetie Lake is to the right in this image. The lake once supported a whitefish fishery for residents of Venetie but the outlet stream is now grown in with vegetation to such an extent that fish no longer migrate into the lake to feed during summer (Caulfield 1983). Photo by R.J. Brown, USFWS.

which may have led to an increase in the beaver population within the region. Additionally, many communities had traditions of stream management that included clearing beaver dams from streams so they didn't block fish passage and these traditions are no longer being practiced (Koskey and Mull 2011). Many residents believe that beaver activity is at a very high level now and that it is not a good thing for whitefish populations.

Potential threats and concerns

Overfishing

Twelve communities are located within the upper Yukon River habitat region with a total population in 2008 of approximately 1,539 residents (Appendix A2; U.S. Census Bureau 2010). An additional 1,585 residents reside in the nearby Yukon Territory communities of Dawson (1,330) on the Yukon River and Old Crow (255) on the Porcupine River (Statistics Canada 2010). Some of the Alaska communities are accessible by road but most are not. Fishing is a way of life within most of the communities and whitefish species are important components of their harvests during all seasons (Nelson 1973; Caulfield 1983; Andersen and Fleener 2001). Despite ample evidence that residents of the region utilize whitefish resources, reliable harvest data are lacking. The ADFG has routinely conducted post-season harvest surveys in many of the communities and tabulates their estimates of community harvests of Pacific salmon and other species on an annual basis (Busher and Hamazaki 2005;

Hayes et al. 2008). Inconnu, however, are the only whitefish identified to species. Because the annual surveys involve interviewing subsamples of households within communities, harvest data are expanded statistically based on the fraction of total households surveyed and household harvest variability to estimate total community harvest with an associated 95% confidence interval. These confidence intervals are proportionally very large, often encompassing more than the estimated community harvest. For example, during 2002, an estimated 1,076 (95% CI = 0 – 2,437) inconnu were harvested in Fort Yukon (Brase and Hamner 2003). Similarly imprecise harvest data are observed for all years and they are not useful for calculating exploitation rates from a population or for other management applications. We have no data to suspect overfishing for any population or species in the upper Yukon River habitat region, and only the continued presence of the same whitefish species at the Rapids sampling site (Figure 28) to suggest that populations are sustaining themselves.

Development issues

Historical, current, or potential development projects in the upper Yukon River habitat region include placer gold and streambed gravel mining (State of Alaska 2009; Szumigala et al. 2009), natural gas or oil development in the Yukon Flats (USFWS 2010b), coal (Merritt 1985; Webb 1985) and asbestos (Bundtzen et al. 1984) prospects, and other minor activities. Placer gold mining has been and continues to be the most wide-spread and significant development activity within the upper Yukon River habitat region (Smith 1939; Webb 1985; Spence 1996; Yeend 1996; Szumigala et al. 2009). Virtually all of the southern tributaries in the region, from Beaver Creek to the Fortymile River, have been intensively mined between the late 1800s and the present. The only northern tributary to have seen significant mining activity has been the Chandalar River, primarily in the mountainous Chandalar Mine area to the east of Chandalar Lake (Brosge and Reiser 1972; Buzzell 2007). Large floating bucket dredges have been utilized in many of the southern tributaries, mostly in smaller side streams where they created impoundments to float themselves up valleys running virtually all the gravel in the valley through their sluices (Spence 1996; Yeend 1996). Floating bucket dredges have also been used in the main-stem Fortymile River to some extent, which is an unusually large riverine habitat for dredges. As in other heavily dredged regions, such as Bear Creek in the Koyukuk River drainage (Figure 14), aquatic habitats in the dredged stream valleys of the upper Yukon River habitat region are irrevocably altered. Because round whitefish are the primary whitefish species occupying the stream habitats where substrates have been most disturbed, they are the most likely species to have been impacted by placer mining activity in the region. Small suction dredges have been used in main-stem habitats in the region, which disturbs substrates on a much smaller scale than the larger floating bucket dredges of the old days or the bulldozer operations that are currently active in some of the side streams (Wanty et al. 1999; Szumigala et al. 2009). It is expected, with the current high price of gold, that many of the old placer operations in the southern tributaries of the upper Yukon River habitat region will begin operating again, mostly reworking old tailings with improved methods. Turbidity and sediment flows are the primary regulated factors in placer mining operations, and most of the substrate disturbance has already taken place, so we do not foresee significant additional impacts to whitefish habitats with the expected increase of mining activity in the near future.

Streambed gravel mining has taken place at times in the upper Yukon River habitat region to provide fill material for road and airport runways of some of the isolated communities. Both Chalkyitsik (ADL 413514) and Stevens Village (ADL 415606) have mined streambed gravel in recent years (State of Alaska 2009) and other communities in the region may also choose to do so. It is clear, given the discovery of main-stem spawning inconnu (Brown 2000), broad whitefish (Carter 2010), and other whitefish species in the Yukon Flats, that streambed gravel mining poses a risk to these populations. Inconnu and broad whitefish appear to spawn along a large reach in the Yukon Flats so those populations would probably be resilient to small, discrete streambed gravel extraction events. However, there are many ecological aspects to the main-stem spawning whitefish populations that we don't understand, so future streambed gravel mining proposals should be carefully considered to ensure they don't introduce unnecessary risk to these fish populations.

Three major development projects with the potential to have significant ecological impacts to the upper Yukon River habitat region have been proposed but never realized. These include the Rampart Dam on the Yukon River main stem downstream from the Yukon Flats (USFWS 1964), the Slate Creek asbestos prospect in the North Fork Fortymile River (Bundtzen et al. 1984), and the oil and gas development prospect in the southern Yukon Flats (USFWS 2010b). If constructed, the Rampart Dam would have interfered with fish migration along the river and flooded the entire Yukon Flats and more (USFWS 1964). We may look back at this proposal and suggest that it was foolish because of the profound ecological disturbance it would have created, but there have been over 39,000 large dams constructed on rivers all over the world, with many more being constructed right now, and all of them had similarly profound ecological effects within their drainage basins (Rosenberg et al. 1997). People build dams when the social or political value of a dam outweighs the social or political value of the free-flowing river. It is possible, with an increasing population and rising energy costs, for the Rampart Dam to re-emerge as a potential development project in the future. Therefore, we include it as a potential threat to the migratory whitefish populations along the Yukon River main stem.

The Slate Creek asbestos prospect in the Fortymile River drainage (Bundtzen et al. 1984) would likely have been developed into a large open pit mine if the market for asbestos had not collapsed in the late 1980s when asbestos was recognized as a toxic material and banned for many uses by the U.S. Environmental Protection Agency (EPA 1994). So after many years of exploration and preliminary development, the Slate Creek asbestos prospect closed up shop. It is doubtful that it will be revived in the foreseeable future.

The oil and gas prospect in the southern Yukon Flats was a more recent development that was almost set in motion by a land trade agreement between the U.S. Fish and Wildlife Service and Doyon Native Corporation (USFWS 2010b). Doyon Native Corporation was prepared to trade large amounts of wetland habitat in the central region of the Yukon Flats National Wildlife Refuge to the U.S. Fish and Wildlife Service for a smaller amount of Refuge land with significant oil and gas potential in the southern part of the Refuge. This land trade was ultimately rejected by the U.S. Fish and Wildlife Service following an extensive environmental review (Haskett 2010). If the land trade had proceeded and oil and gas development had taken place, roads would have penetrated many remote regions of the Yukon Flats providing access for a larger population, there would have been an increased risk for oil spills, and water would have been withdrawn from rivers or lakes in the area to support the development. The consequences of such development on whitefish populations in the upper Yukon River habitat region are difficult to evaluate. We are not aware of whitefish spawning areas in the vicinity of the potential oil development lands adjacent to Beaver Creek, although some might exist, but feeding habitats have been documented in off-channel lakes in lower Beaver Creek (Glesne et al. 2011). It would be easy to imagine that a large spill in Beaver Creek or upstream water withdrawals could impact whitefish feeding habitats downstream through direct contamination or by reducing flow levels that could prevent whitefish access to some seasonally accessible lake habitats. Oil development may still take place in the Yukon Flats but we are unaware of any active plans at this time.

Kuskokwim River Habitat Region

The Kuskokwim River habitat region includes river and lake habitats from the mouth of the Kuskokwim River, about 10 km (6 miles) downstream from the mouth of the Eek River, to the headwaters of its many tributaries, which are as far as 1,500 rkm (930 river miles) upstream (Figures 75 and 76; Appendix A4; Whitmore et al. 2008). Parts of two major lake districts fall within the Kuskokwim River drainage: the Yukon Kuskokwim Delta Lake District, which encompasses much of the floodplain downstream from the Aniak River; and the Minchumina Lake District in the upper reaches of the North Fork Kuskokwim River (Arp and Jones 2009). In addition to the numerous, relatively shallow flatland lakes in the floodplains of the drainage, there are a small number of relatively deep upland lakes in the headwaters of the southern tributaries (Alt 1977b; Russell 1980). Many of the south bank tributaries of the Kuskokwim River drainage from the Stony River upstream originate in glaciated regions of the western Alaska Range (Molnia 2007, 2008) and contribute a substantial quantity of glacial sediment to the Kuskokwim River during the summer months. Southern tributaries downstream from the Stony River and all northern tributaries flow clear or tundra stained except during high-flow events. A more detailed description of Kuskokwim River drainage basin, hydrology, and tidal dynamics can be found in the study area section of the introduction.

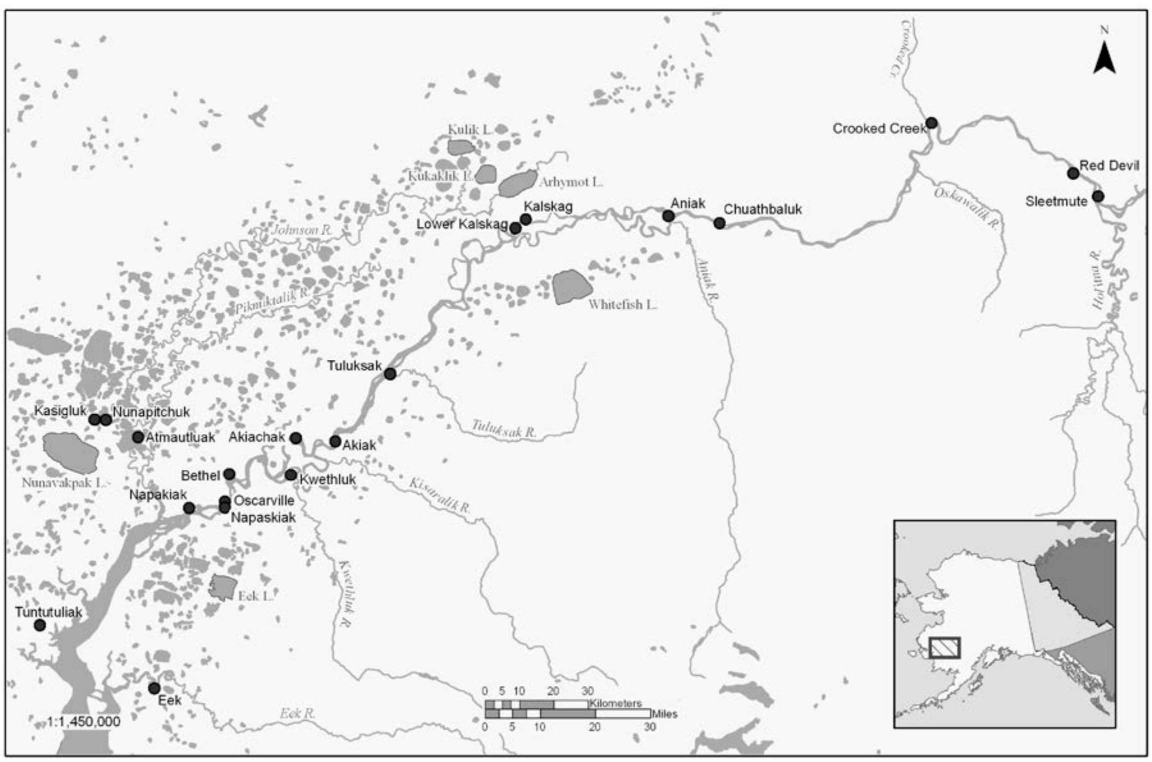

Figure 75. The Kuskokwim River downstream from the Holitna River including major tributaries and communities.

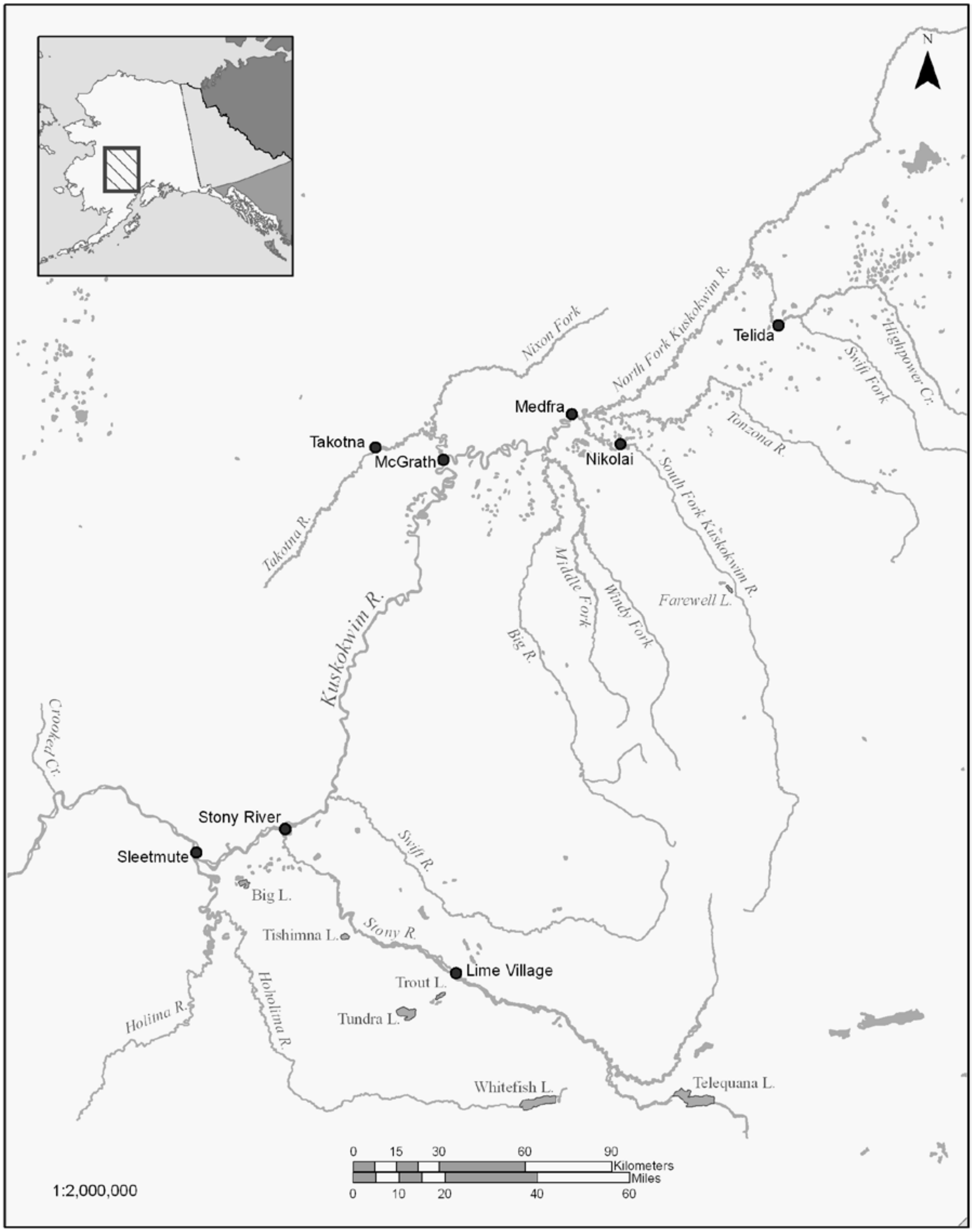

Figure 76. The Kuskokwim River upstream from the Holitna River including major tributaries and communities.

There are a great variety of aquatic habitats in the Kuskokwim River drainage. The main-stem Kuskokwim River is a large, turbid, smooth flowing river through most of its length. The substrate in the lower 307 km (191 miles), up to the mouth of the Aniak River, is predominantly composed of silt or sand. Farther upstream the substrate becomes a mix of material ranging from silt and sand to gravel and rocks, depending on channel morphology and the proximity of the river to source material. While there are many islands in the Kuskokwim River, there are no heavily braided regions of the main stem such as those in the upper Yukon Flats (Figure 68) or in the Tanana River (Figure 51). Glacially influenced tributaries of the Kuskokwim River include the Stony, Swift, Big, Middle Fork, Windy Fork of the Middle Fork, South Fork Kuskokwim, Tonzona, and Swift Fork Kuskokwim rivers. The upper reaches of the glacial drainages flow swiftly over braided, gravel substrate streambeds and transition to slow flowing streams over soft substrate in their lower reaches (Alt 1981a; Ireland and Collazzi 1985a, 1985b). Glacial flow is turbid in summer and clear in winter, similar to the glacial tributaries in the Tanana River drainage (Brabets et al. 2000). Some of the larger non-glacial tributaries entering the south bank of the Kuskokwim River include the Eek, Kwethluk, Kisaralik, Tuluksak, Aniak, Oskawalik, and Holitna rivers. In general, these rivers flow swiftly over a gravel substrate through most of their lengths and transition to slow flow over soft substrate in their lower reaches (Alt 1977b; Alt 1981a). Upland lakes open to river systems are present in the headwaters of many of the southern tributaries rivers (Alt 1977b; Russell 1980). North-bank tributaries include the Kialik, Johnson, George, Takotna, and North Fork Kuskokwim rivers. The Kialik and Johnson rivers are expansive, soft substrate, flatland drainages that lie entirely within the Yukon Kuskokwim Delta Lake District (Figure 77; Arp and Jones 2009). The lower reaches are subject to tidal influence. Fall storm surges that routinely inundate the central Yukon Kuskokwim Delta with marine water (Jorgenson and Ely 2001) may also flood the western lakes of the Johnson River drainage. The George and Takotna rivers, as well as other smaller drainages flowing into the north side of the Kuskokwim River, flow swiftly over gravel substrate through most of their lengths, with relatively short regions of slow flow over soft substrate in the lower reaches of some drainages. The North Fork Kuskokwim River upstream from the Swift Fork, is a low gradient, soft substrate, meandering stream into its headwater reaches (Alt 1972), some of which are included in the Minchumina Lake District (Figure 78; Arp and Jones 2009). These are the basic river and lake habitats available to fish in the Kuskokwim River drainage.

Whitefish species, distribution, and biology

All six common whitefish species are present in the Kuskokwim River habitat region (Figure 4). Additionally, Russell (1980) identified pygmy whitefish that had been eaten by northern pike in Two Lakes, an upland lake in the upper Stony River drainage, establishing the species in the Kuskokwim River drainage (Table 1; Appendix A5). Similar to the Yukon River drainage, there are distinct trends in distribution and relative abundance within the drainage based on species, habitat, season, and demographic factors. Most of the distribution, migration, and life history data presented below come from directed sampling and radio telemetry studies in the drainage. Fish counting weirs have been operated in numerous tributaries including the Kwethluk (Miller and Harper 2010a), Tuluksak (Miller and Harper 2010b), George (Clark et al. 2010), Kogrukluk (Williams and Shelden 2010), Tatlawiksuk (Smith and Shelden 2010), and Takotna (Stewart et al. 2010) rivers. Weir projects are

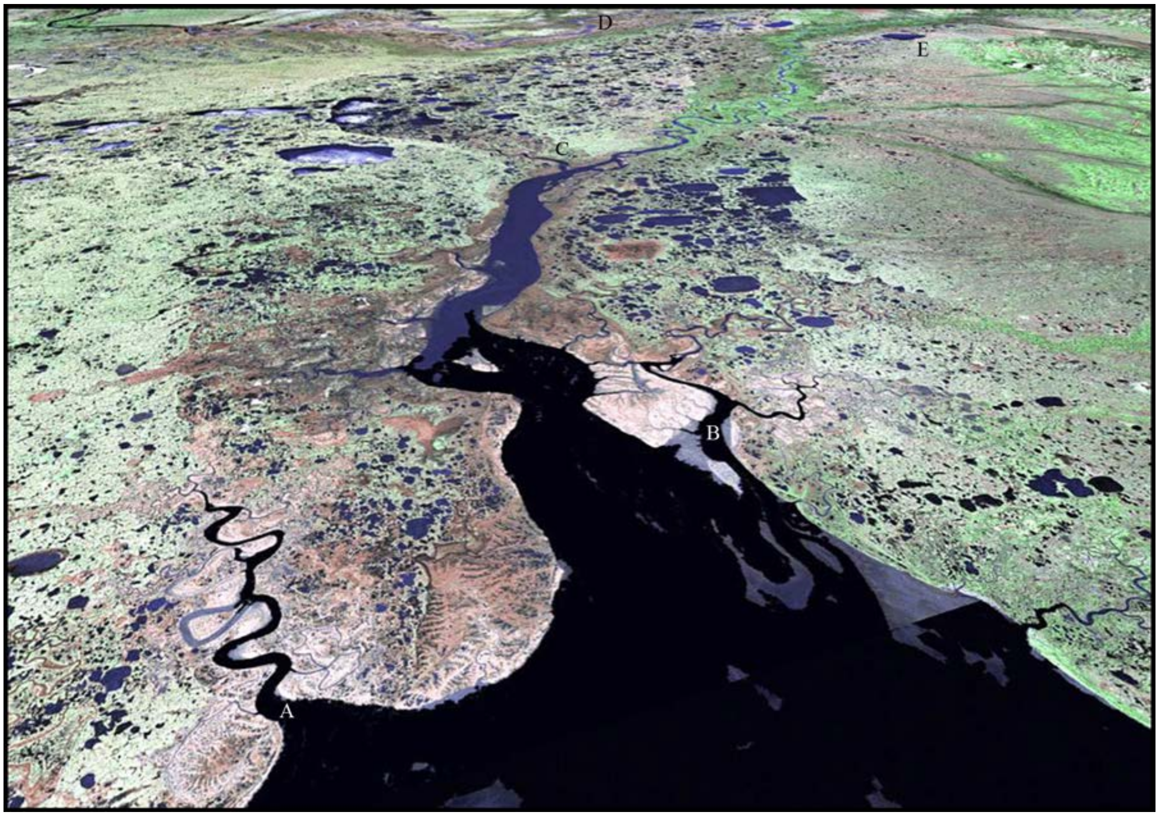

Figure 77. Looking upstream from Kuskokwim Bay into the lower Kuskokwim River valley and the southern part of the Yukon Kuskokwim Delta Lake District. Geographic reference points in this image include the Ishkowik River in the lower left (A), the Eek Channel, which drains the Eek River, just right of center (B), the mouth of the Johnson River drains into the lower Kuskokwim River from the north (C), the Yukon River near the community of Russian Mission in the upper margin (D), and Whitefish Lake is just downstream from the mouth of the Aniak River in the upper right (E). Image courtesy of Dr. W.A. Bowen, California Geographical Survey (geogdata.csun.edu).

always focused on Pacific salmon and are therefore placed on rivers that support salmon spawning habitats. Whitefish species are often counted but rarely identified as they pass through the weirs. Whitefish passage for most weirs are relatively small, often less than 100 whitefish during a three month operation period. For example, Smith and Shelden (2010), counted only 6 whitefish passing upstream through the Tatlawiksuk River weir between June 15 and September 22, 2009, and 273 that were washed up on the weir as they attempted to migrate downstream. The Kwethluk River weir may experience the greatest passage of whitefish in the Kuskokwim River system with over 1,600 whitefish, identified at the time as humpback whitefish and round whitefish, migrating upstream during the 1992 season (Harper 1998). That number has declined in recent years when during the 2004 season, for example, only 423 whitefish migrated upstream through the weir (Roettiger et al. 2005), and during the 2009 season only 151 whitefish migrated upstream (Miller and Harper 2010a). Broad whitefish and humpback whitefish are currently thought to be the primary whitefish species encountered at the Kwethluk River weir based on the identification of those that become stranded on the weir (K. Harper, USFWS, pers. com.). Picket spacing on some weirs is wide enough to allow some whitefish to pass uncounted, and some may pass early in the season before a weir becomes operational, so counts do not necessarily reflect actual

Figure 78. Looking north into the upper North Fork Kuskokwim River valley, about 20 km (12 miles) west of Lake Minchumina. The river meanders over soft substrate through this wide, forested valley with only its uppermost reaches flowing swiftly over gravel. Photo by R.J. Brown, USFWS.

passage of whitefish species. Data available, however, suggest small numbers of whitefish migrating past most weirs in the Kuskokwim River drainage. Without knowing the demographic qualities or species composition of the passage, the most important whitefish information is that there do not appear to be large whitefish migrations into most of the salmon spawning streams. Following are summary distribution and life history data for the six common whitefish species in the Kuskokwim River drainage.

Inconnu are distributed along the Kuskokwim River valley from its mouth in Kuskokwim Bay to the Swift Fork Kuskokwim River, a major tributary of the North Fork Kuskokwim River, about 1,078 km (670 miles) upstream from the sea. Inconnu are known to migrate into the marine environments of Kuskokwim Bay where they have been captured during winter (Alt 1977a). One inconnu tagged in the Kuskokiwm River in 1968 was recaptured five years later in the Yukon River, suggesting that inconnu are not bound within their natal drainages. Most inconnu appear to overwinter from the lower Holitna River to Kuskokwim Bay (Alt 1977a; Stuby 2010). Summer feeding habitats include the slow flowing, lower reaches of numerous tributary rivers from the Kuskokwim River mouth upstream into the North Fork Kuskokwim River (Alt 1977b, 1981a; Maciolek 1986; Stuby 2010). Inconnu avoid lake habitats (Alt 1977b; Maciolek 1986; Harper et al. 2007) and rarely ascend tributary rivers into the swiftly flowing, gravel substrate reaches beyond the Kuskokwim River floodplain (Alt 1977b, 1981a; Stuby 2010). Fall spawning habitats have been positively identified in braided, swiftly flowing, gravel substrate reaches in three glacially influenced tributaries in the upper Kuskokwim River and a fourth spawning area is suspected

(Alt 1972, 1981a; Stuby 2010). Alt (1972, 1981a) used gillnet sampling strategies to locate spawning areas in the Swift Fork of the North Fork Kuskokwim River drainage, which he believed was at the mouth of Highpower Creek, and in the Big River, approximately 66 km (41 miles) upstream from its mouth in a braided reach with gravel substrate (Figure 79). Stuby (2010) deployed 119 radio transmitters in mature-size inconnu captured in numerous locations around the drainage and was able to verify that the Big River spawning area originally identified by Alt (1981a) was the major spawning destination in the Kuskokwim river drainage and another smaller population appeared to spawn in the Middle Fork Kuskokwim River. The inconnu spawning habitats in the Big and Middle Fork Kuskokwim rivers are both in the transition region between the high gradient, heavily braided, gravel substrate, upper reaches of the drainages and the low gradient, non-braided, soft substrate, lower reaches (Ireland and Collazzi 1985b). Stuby (2010) suspected a third population might spawn in the Slow Fork of the East Fork Kuskokwim River near the mouth of the Tonzona River, but that suspicion was based on late fall locations of two fish and has not been verified at this time. None of the radio-tagged fish in Stuby's (2010) study migrated to the Highpower Creek spawning area identified by Alt (1972), suggesting a small population there compared to much larger populations in the Big and Middle Fork Kuskokwim rivers, or that individuals from the Highpower Creek population were less widely distributed and thus less available for tagging. In any case, it appears that inconnu are distributed throughout the main-stem Kuskokwim River corridor from the sea to their upper drainage spawning areas in at least three of the glacially influenced tributary systems, as well as into the lower reaches of many other tributaries and into coastal waters along the Yukon Kuskokwim Delta region.

Riverine populations of broad whitefish, humpback whitefish, and least cisco occupy many of the same habitats within the Kuskokwim River drainage. Sampling and radio telemetry data indicate that all three species rear, feed, and overwinter in the lower drainage and in Kuskokwim Bay (Maciolek 1986; Harper et al. 2007, 2008, 2009). All three species migrate in spring from estuarine or riverine overwintering habitats to feeding habitats in the slow-flowing, lower reaches of tributary rivers or river-connected lake systems (Alt 1977b, 1981a; Harper et al. 2007, 2009). While these three species are commonly encountered in the slow-flowing lower reaches of the tributary rivers, they are rare farther upstream in swiftly flowing, gravel substrate habitats (Alt 1977b). Beginning in mid to late summer, pre-spawning individuals of all three species migrate from feeding habitats to upstream spawning habitats in gravel substrate reaches of the drainage. Radio telemetry data suggest that broad whitefish spawn in two main-stem reaches; one near the mouth of the Swift River, approximately 560 km (348 miles) from the sea, and the other near the mouth of the Big River, approximately 827 km (514 miles) from the sea (Harper et al. 2009). Numerous, pre-spawning broad whitefish were captured in late fall 1971 at the mouth of Highpower Creek, a known spawning location for inconnu (Alt 1972), indicating at least three riverine spawning populations of broad whitefish in the drainage. Harper et al. (2009) followed radio-tagged humpback whitefish to four, gravel substrate spawning destinations including the Big River, in the same area used by spawning inconnu, and the lower Swift River, both glacially influenced southern tributaries, as well as a middle reach of the Holitna River and near the mouth of Ophir Creek, which is the largest tributary to Whitefish Lake in the Kuskokwim River floodplain. Pre-spawning humpback whitefish were captured in late fall 1971 at the

Figure 79. Swiftly flowing, gravel substrate, spawning habitat in the Big River that is used by inconnu, humpback whitefish, and least cisco. Photo by K.C. Harper, USFWS.

mouth of Highpower Creek (Alt 1972), indicating at least five riverine spawning populations of humpback whitefish in the drainage. Radio-tagged least cisco migrated from feeding habitat in Whitefish Lake to spawning habitat in the middle reaches of the Holitna River in the same area used by humpback whitefish (Harper et al. 2009). Sampling evidence indicates that some least cisco spawn near the mouth of Ophir Creek as well. Alt (1981a) captured large numbers of least cisco in the inconnu spawning reach of Big River, which is probably a least cisco spawning area too, although no maturity sampling was done to verify. Additionally, pre-spawning least cisco were captured in late fall 1971 at the mouth of Highpower Creek (Alt 1972), suggesting at least four riverine spawning populations of least cisco in the drainage. Radio telemetry, otolith chemistry, and tag recapture data indicate that following the fall spawning event, most individuals of all three species retreat downstream to main-stem overwintering habitats in the lower reaches of the Kuskokwim River, from the lower Holitna River downstream and into Kuskokwim Bay (Harper et al. 2007, 2009).

Bering cisco appear to limit their distribution in the Kuskokwim River drainage to the main stem and into the South Fork Kuskokwim River (Alt 1973a). Intensive sampling in the drainage revealed that Bering cisco were present in the main stem, an occasional Bering cisco could be capture near the mouths of tributaries downstream from the South Fork Kuskokwim River, no captures were made beyond the immediate mouth regions of these downstream tributaries despite the routine captures of other whitefish species in reaches upstream from the mouths, and no captures of Bering cisco were made upstream from the South Fork Kuskokwim River despite the routine captures of other whitefish species in upstream reaches (Alt 1972, 1977b, 1981a). Further, Alt (1973a) reported that none of the Bering cisco captured in the Kuskokwim River drainage were eating and all had enlarged gonads consistent with a spawning migration. During late September 2010, M. Thalhauser of the Kuskokwim Native Association (unpublished data), sampled a braided region of the South Fork Kuskokwim River (Figure 80) up to about 75 km (47 miles) from the mouth and captured several hundred pre-spawning Bering cisco. Milt could be expressed from all males but eggs could not be similarly expressed from females, indicating that they were not quite ready to spawn. Gonadosomatic index data were collected from nine females from the sample and they averaged 25% of body mass as eggs (range 22 to 31%; Figure 81). These data are consistent with a mid-October spawning time as indicated for the Yukon (Brown 2000) and Susitna River (ADFG 1983) populations. It appears that Bering cisco populations in the Yukon, Kuskokwim, and Susitna River drainages follow very similar life history patterns (Alt 1973a; ADFG 1983; Brown 2000; Brown et al. 2007).

Sampling and harvest data suggest that few isolated lake populations of broad whitefish, humpback whitefish, least cisco, and round whitefish may exist within the Kuskokwim River drainage. Baxter (1973) sampled Whitefish Lake, the large upland lake in the upper Hoholitna River drainage, and identified numerous broad whitefish in his catch. Whitefish Lake is open to the river system allowing fish migration in and out, so simply catching broad whitefish in the lake is not evidence of an isolated population. While broad whitefish are routinely identified in flatland lakes open to riverine habitats, such as Whitefish Lake in the Kuskokwim River floodplain (Harper et al. 2007), Kgun Lake in the central Yukon Kuskokwim Delta (Baxter 1975), and numerous similar lakes in Yukon River lake districts (Glesne et al. 2011), it is very unusual to find broad whitefish in upland, headwater lakes. To our knowledge, isolated lake populations of broad whitefish have only been documented in the Travaillant Lake system in the lower Mackenzie River drainage (Chudobiak 1995; Harris and Howland 2005; Harris and Taylor 2010a), so an isolated population in Whitefish Lake would be a significant discovery. Alt (1977b) sampled upland, headwater lakes in the Aniak, Kisaralik, and Eek rivers finding round whitefish and other non-whitefish species in Aniak Lake, but no round whitefish or other whitefish species in the other lakes (Appendix A5). Both Baxter (1975) and Russell (1980) sampled Telaquana and Two lakes in the upper Stony River drainage, both open to the river system, and found round whitefish in both lakes, least cisco in Telaquana Lake, and Russell (1980) found pygmy whitefish in Two Lakes. Neither broad whitefish nor humpback whitefish were captured in either lake. It is possible that least cisco in Telaquana Lake represent an isolated population simply because it is so far upstream from flatland lake habitats that the species commonly associates with. Residents of Lime Village, a community in the upper Stony River drainage (Figure 76), reportedly harvest broad whitefish, humpback whitefish, and round whitefish as they migrate between riverine and upland lake habitats in the area (Kari 1983), suggesting that these fish are not from isolated populations. Similarly, residents of Telida, a community located on the Swift Fork of the North Fork Kuskokwim River, reportedly harvest whitefish from one or more lakes in the area (Stickney 1980; Stokes 1985). Stokes (1985) reported that whitefish harvests from Lower Telida Lake involved catching fish migrating into the lake in the spring, within the lake during summer, and migrating out of the lake in the fall, demonstrating that those fish

Figure 80. Looking upstream (south) into Bering cisco spawning habitat in a swiftly flowing, gravel substrate reach of the South Fork Kuskokwim River. Photo by R.J. Brown, USFWS.

were not isolated in the lake but were part of the riverine group documented by Alt (1972). While isolated populations of whitefish, including humpback whitefish, least cisco, and round whitefish, appear to be common in upland lakes in the Yukon River drainage, these data suggest that relatively few possibilities exist for isolated whitefish populations in upland lakes within the Kuskokwim River drainage (Appendix A5).

Spawning seasons for riverine populations of inconnu, broad whitefish and humpback whitefish in the Kuskokwim River drainage can be inferred based on the timing of post-spawning migrations of radio-tagged fish. Spawning season for inconnu in other river systems has commonly been documented between late September and mid-October (Brown 2000; Howland et al. 2000; Underwood 2000; Esse 2011). Stuby (2010) monitored post-spawning migrations of inconnu from the Big and Middle Fork Kuskokwim River spawning areas with a remote receiving station and found that most radio-tagged fish left during the first half of October, consistent with a late September to mid-October spawning season. These data are also consistent with Alt's (1972) report of inconnu spawning near the mouth of Highpower Creek beginning on September 30. Spawning season for broad whitefish has been shown to be later than other whitefish species, usually beginning in late October or early November (Shestakov 2001; Tallman et al. 2002; Carter 2010). Radio-tagged broad whitefish in Kuskokwim River spawning areas began downstream migration in early November (Harper et al. 2009), consistent with a late October or early November spawning season. Spawning season for riverine populations of humpback whitefish usually begins in late September or early October (Stein et al. 1973; Alt 1979a; Brown 2006). The post-spawning downstream migration of radio-tagged humpback whitefish from spawning sites in

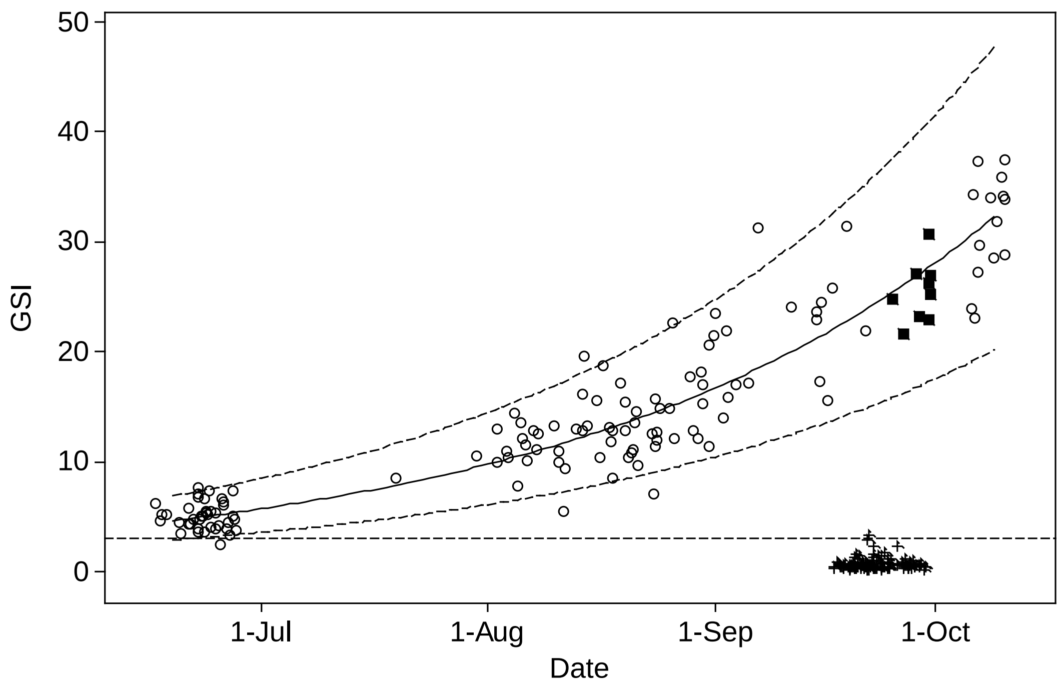

Figure 81. Gonadosomatic indices of mature Bering cisco preparing to spawn (○; *n* = 130), reveal an increasing trend through the season to maximum levels up to 30% or more just prior to spawning in mid-October, Bering cisco captured in the South Fork Kuskokwim River in late September 2010 (■; *n* = 9), demonstrating that they were pre-spawning fish, and Bering cisco sampled from the commercial fishery at the mouth of the Yukon River (+; *n* = 113), which had GSI levels too low to spawn during the year of capture. The solid curved line is fitted to the GSI data from mature Yukon River Bering cisco preparing to spawn and the curved dashed lines describe the 95% prediction interval for spawning Bering cisco. The horizontal dashed line is at GSI = 3%, a level that is rarely exceeded by non-spawning fish.

the Kuskokwim River drainage began in mid-October, consistent with an early October spawning season (Harper et al. 2009). Similar post-spawning migration data are not available for least cisco, Bering cisco, or round whitefish populations in the Kuskokwim River drainage.

Round whitefish have most commonly been found in gravel substrate reaches of non-glacially influenced rivers and in upland lakes (Alt 1977b, 1981a; Russell 1980). They are rarely encountered in the main-stem Kuskokwim River, the swift, turbid waters of the glacial rivers (Alt 1981a), the slow flowing lower reaches of tributaries (Alt 1977b), or the shallow flatland lakes (Maciolek 1986; Harper et al. 2007). This distribution pattern among habitats is consistent with round whitefish distribution in the Yukon River drainage as discussed in previous sections.

Minimum size and age at maturity data have been collected for some humpback whitefish and least cisco in the Kuskokwim River drainage (Harper et al. 2007; K. Harper, USFWS, unpub. data). Some of these data come from collections made in Whitefish Lake in the Kuskokwim River floodplain (Figure 82), which must be considered a mixed population sample, and some come from October collections in spawning reaches located in the Holitna and Swift River drainages, which are population specific data. Samples of humpback

Figure 82. Looking into Whitefish Lake, in the Kuskokwim River floodplain, through the weir established to monitor whitefish migrations at the outlet stream. The dimensions of Whitefish Lake are approximately 12 km (7.5 miles) east to west by 10 km (6 miles) north to south with an average depth of about 1.5 m (5 feet). The 15 km (9 mile) outlet stream joins the Kuskokwim River approximately 268 km (167 miles) from Kuskokwim Bay. Photo by K.C. Harper, USFWS.

whitefish and least cisco were collected through the summer in Whitefish Lake, where they were feeding (Harper et al. 2007). Gonadosomatic indices were calculated for females in an effort to identify mature fish preparing to spawn from those that would not spawn. A scatterplot was prepared with GSI versus FL to illustrate minimum length at maturity for both species (Figure 83). These data were originally presented by Harper et al. (2007). Fish were classified as mature at GSI = 3 or greater based on criteria in Bond (1982) and Brown (2004). Mature female least cisco feeding in the lake ranged between 30 and 41 cm (12 to 16 inches) FL and mature female humpback whitefish ranged between 35 and 50 cm (14 to 20 inches) FL. Pearl tubercles (Vladykov 1970) were present on all humpback whitefish that were collected in early October from the Holitna and Swift River spawning reaches, verifying that they were mature and preparing to spawn. Length and age distributions of these two samples (Figure 84) revealed length at maturity was 36 cm (14 inches) FL for the Holitna River sample (n = 27) and 33 cm (13 inches) FL for the Swift River sample (n = 388). Minimum age at maturity was 5 years for the Holitna River sample (n = 27) and 4 years for the Swift River sample (n = 145). Longevity was estimated at 29 years for the Holitna River sample and 32 years for the Swift River sample. The presence of substantial proportions of older fish in these populations suggests that they are not being overexploited. The much larger sample size from the Swift River population was undoubtedly responsible for the expanded range of length and age data on the tails of these distributions. Adequate length and age at maturity data have not been collected for inconnu, broad whitefish, Bering

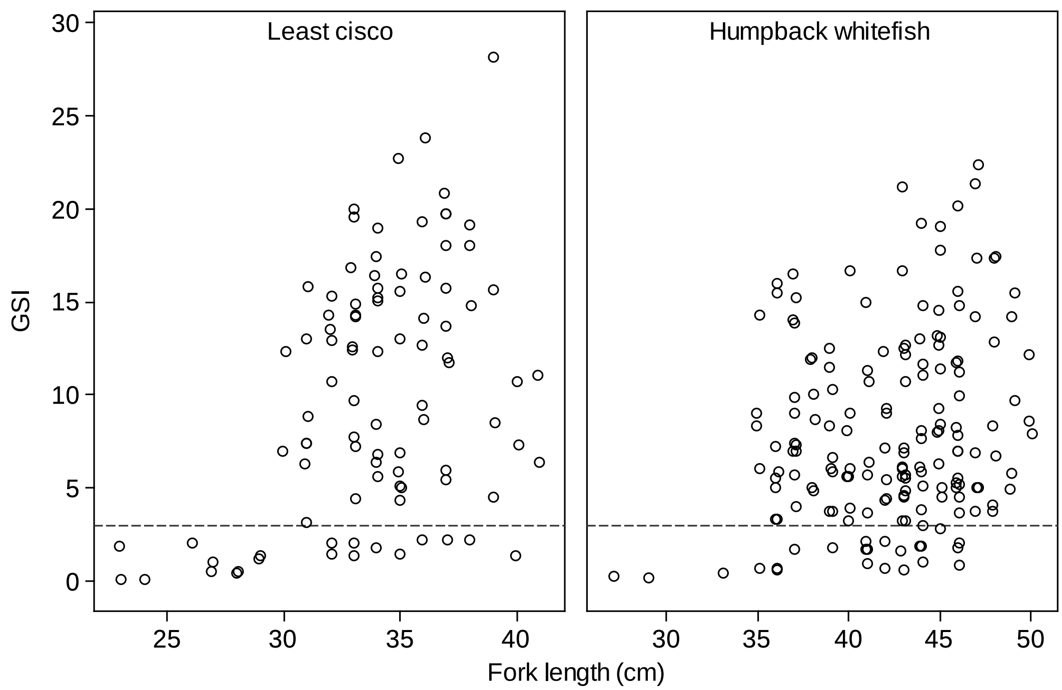

Figure 83. Gonadosomatic indices from samples of female least cisco (*n* = 94) and humpback whitefish (*n* = 167) collected from Whitefish Lake, in the Kuskokwim River floodplain, between May and October 2003. Because radio-tagged fish from Whitefish Lake have migrated to multiple spawning destinations (Harper et al. 2009), these were mixed population samples. Individuals with GSI values exceeding GSI = 3 (horizontal dashed lines) were all mature and preparing to spawn. Lengths of mature females ranged from 30 to 41 cm (12 to 16 inches) FL for least cisco and 35 to 50 cm (14 to 20 inches) FL for humpback whitefish. These data were originally published in Harper et al. (2007) and were provided by K. Harper, USFWS.

cisco, or round whitefish within the Kuskokwim River drainage. Further, least cisco data from Harper et al. (2007), as presented above (Figure 83), only dealt with length at maturity and were not population specific. Our understanding of whitefish populations and our ability to manage them effectively will eventually require length and age at maturity data for populations of the most heavily exploited species.

Fisheries

Home to two distinct cultures and three language groups—Yup'ik, Dena'ina Athabaskan, and Upper Kuskokwim Athabaskan—the Kuskokwim River drainage encompasses 27 established communities, divided culturally into lower, central, and upper drainage groups. Bethel, Aniak, and McGrath serve as the major population hubs for these groups and approximately 13,468 people inhabit the entire area (U.S. Census Bureau 2010). Lower drainage communities include Tuluksak, Akiak, Akiachak, Kwethluk, Bethel, Oscarville, Napaskiak, Napakiak, Atmautluak, Kasigluk, Nunapitchuk, Tuntutuliak, and Eek (Figure 75). The central Kuskokwim region includes the communities of Lower Kalskag, Upper Kalskag, Aniak, Chuathbaluk, Crooked Creek, Red Devil, Sleetmute, and Stony River (Figures 75 and 76). The communities of Lime Village, Takotna, McGrath, Medfra, Nikolai, and Telida lie in the upper Kuskokwim region (Figure 76).

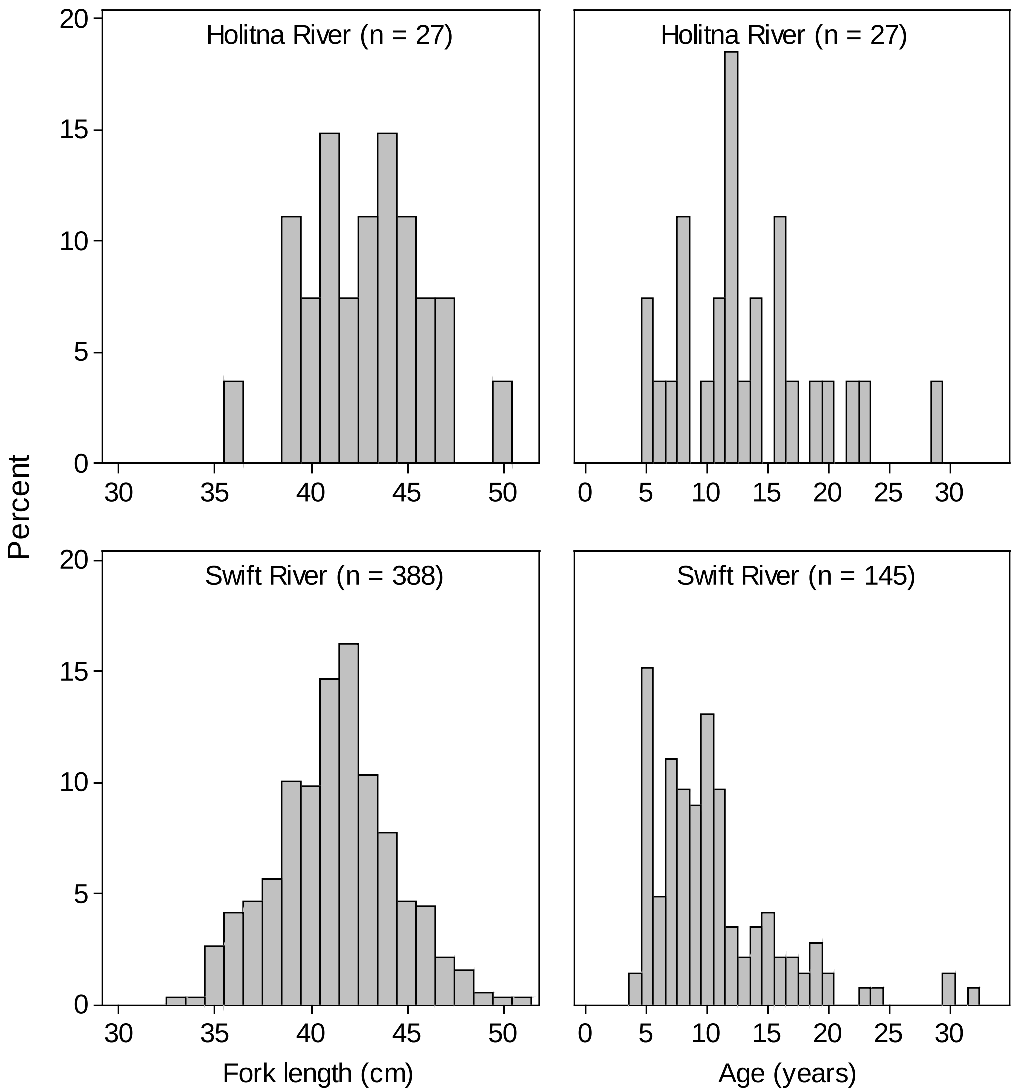

Figure 84. Length and age samples from mature humpback whitefish collected in early October from spawning reaches in the Holitna and Swift River drainages. All males and females exhibited pearl tubercles. Males expressed milt and some females expressed eggs. Gonadosomatic index data from subsamples of females were elevated indicating that they were mature and preparing to spawn. Minimum length at maturity was 36 cm (14 inches) FL for the Holitna River sample and 33 cm (13 inches) for the Swift River sample. Minimum age at maturity was 5 years for the Holitna River sample and 4 years for the Swift River sample. The smaller and younger maturity values of the Swift River sample is undoubtedly a result of the much larger sample size. Note the strong recruitment of age 5 individuals for the Swift River sample. These unpublished data were provided by K. Harper, USFWS.

Historically, whitefish have been a critical part of the overall annual subsistence take of the people of the main-stem Kuskokwim River. While salmon is the primary subsistence fish for Kuskokwim River communities, a great deal of time, effort, and money for gas and gear is dedicated to harvesting whitefish species. Although primarily harvested in the fall and spring throughout the drainage, whitefish species can be taken anytime, making them a stable and consistent food source that can be relied on throughout the year. Residents of the entire region share the traditional values of treating the resource with respect by not wasting, disposing of the remains properly, using traditional food preparation techniques, and sharing with others.

There was a paucity of data available for most Kuskokwim whitefish fisheries until very recently. This section on Kuskokwim River fisheries draws primarily from 14 currently available ADFG Technical Papers concerning subsistence in Kuskokwim River communities dating back to 1979 (Jonrowe 1980; Stickney 1981a; Andrews et al. 1983; Kari 1983; Charnley 1984; Stokes 1985; Brelsford et al. 1987; Coffing 1991; Coffing et al. 2001; Williams et al. 2005; Holen et al. 2006; Krauthoefer et al. 2007; Simon et al. 2007; and Ray et al. 2010). Additionally, two in-progress ADFG reports, an ethnography of Kuskokwim salmon fisheries and research on the comprehensive subsistence harvests of central Kuskokwim communities, also contribute to this section. Finally, we draw on an AVCP report for regional planning (Hooper 2003).

Culture and language

Kuskokwim River residents use a variety of words to refer to whitefish species that draw on various aspects of whitefish species including phenotype, seasonality of harvest, and geographical place names (Table 16). Common names for the different whitefish species along the Kuskokwim main stem are shared by both the lower and the central Kuskokwim River communities. Broad whitefish are referred to locally in English as “broads” or “big whitefish”. Humpback whitefish are referred to as “humpies,” not to be confused with a term also used for a species of salmon. Cisco species and round whitefish are generally referred to as “little whitefish,” and local residents refer to inconnu as “sheefish”.

Table 16. Terms for whitefish in the Kuskokwim River main stem.

Common name	Linnaean name	Dena’ina (Tanaina)[1]	Yup’ik[2]	Upper Kuskokwim Athabaskan[3,4]
Inconnu	*Stenodus leucichthys*	Shish	Cii (Ciiq)	Zidlaghe
Broad whitefish	*Coregonus nasus*	Telay	Akakiik	Tilaya, Taghye
Humpback whitefish	*Coregonus clupeaformis*	Hulehga		Sajila, Tsendude
Least cisco	*Coregonus sardinella*	Ghelghuli	Imarpinraq	Sajila, Dilmije
Round whitefish	*Prosopium cylindraceum*	Hesten	Cingikeggliq	Hwstin

[1](Kari 1983).
[2](Jacobson 1984).
[3](Collins and Collins 1966).
[4](Collins and Petruska 1979).

In the upper Kuskokwim River region, the residents of Nikolai use the generic words sajila and dilmije to denote “common whitefish.” Tiayano’o’ is the word for the month of

September or "whitefish month" likely because of the historical practices of focusing harvest during fall migrations. The community name, Telida, is derived from Tilaya or "lake whitefish"; the community is located in an area known for an abundance of lake bound whitefish locally identified as broad whitefish (Williams et al. 2005). Zidlaghe Zighashno', or "sheefish harvest river", is the local place-name for Big River, a popular fishing location.

Lower Kuskokwim

The subsistence whitefish harvests of many lower Kuskokwim River communities have not yet been fully studied, though a few studies suggest regional distinctions. A traditional knowledge study in the lower river communities of Eek, Tuntutuliak, and Nunapitchuk suggests that area residents have historically relied heavily on broad whitefish, but observed declines have shifted harvest towards humpback whitefish (Ray et al. 2010). The Kasigluk-Nunapitchuk area is renowned for the health and quality of its fish, especially whitefish, which is thought to depend on the annual flooding cycles and drainage of area lakes by several rivers. Commercial sale or barter of whitefish from this region to people on the Bering Sea coast has taken place for many years. Whitefish harvests near Nunapitchuk take place within a large lake and stream region through which the Johnson and Kialik rivers flow. Nunapitchuk residents report elder teachings that suggest that Nanvarpak Lake is the origin of local whitefish. To protect this critical habitat and the whitefish it supports, tribal elders from Kasigluk, Nunapitchuk and Atmautluak adopted a resolution in 1992, prohibiting nets in the lake, especially at the outlet. People not in compliance with the resolution have been issued citations or had their nets confiscated, which has led to controversy about the resolution and its enforcement (Ray et al. 2010). In 1983, Nunapitchuk households caught 2,927 whitefish (3,983 kg; 8,781 pounds) and 3 inconnu (10 kg; 22 pounds). Community harvests from 2005-2006 were substantially higher (Table 17).

Table 17. Estimated harvest of whitefish species by lower Kuskokwim River communities, 2005-2006[1].

Resource	Eek no. fish kg (pound)	Tuntutuliak no. fish kg (pound)	Nunapitchuk no. fish kg (pound)	Total kg (pound)
Inconnu	236 642 (1,415)	372 1,058 (2,333)	53 145 (319)	1,845 (4,067)
Broad whitefish	532 966 (2,129)	1,976 3,585 (7,903)	2,321 4,212 (9,285)	8,762 (19,317)
Humpback whitefish	1,726 2,349 (5,179)	4,335 5,899 (13,004)	3,373 4,590 (10,120)	12,838 (28,303)
Least cisco	20 9 (20)	265 120 (265)	0	129 (285)
Bering cisco	1,598 1,015 (2,237)	467 297 (654)	29 19 (41)	1,330 (2,932)
Round whitefish	0	114 26 (57)	236 54 (118)	79 (175)
All species	4,112 4,980 (10,980)	7,529 10,984 (24,216)	6,012 9,019 (19,883)	24,983 (55,079)

[1]ADFG, Division of Subsistence, unpublished harvest surveys, 2006.

Earlier studies have focused on the nearby communities of Kwethluk (Coffing 1991), Akiachak (Coffing et al. 2001), and Tuluksak (Andrews and Peterson 1983). Although geographically close, these communities display very different whitefish fishing patterns. Kwethluk residents, for example, fish in the main-stem Kuskokwim River and reported harvesting whitefish primarily in the fall between August and November (Coffing 1991). Whitefish are available year-round in the Kuskokwim River near Akiachak, but most fishing for broad whitefish and humpback whitefish in 1998 took place in July and August using salmon nets. Some residents also harvested humpback whitefish with hook and line methods. Cisco species were harvested throughout the year in the Kuskokwim main stem in various locations between Bethel and Aniak. Of these whitefish harvests, a small percentage of broad whitefish and humpback whitefish and all inconnu were harvested while commercial fishing. Between 1980 and 1983, Tuluksak fishers harvested whitefish between May and October and inconnu from September to November (Coffing et al. 2001). Harvest locations near Tuluksak include the Tuluksak River, Otter Creek, Fog River, Little Bogus Creek, Mishevik Slough, and a tributary of Birch Creek (Andrews and Peterson 1983). Other than inconnu, whitefish harvest estimates for Kwethluk were not identified to species while in Akiakchak they were (Table 18).

Table 18. Estimated harvest of whitefish species (no. fish (kg) [pound]) in Kwethluk (1985) and Akiachak (1998)[1].

Resource	Kwethluk, 1985	Akiachak, 1998
Inconnu	2,119 (6,248) [13,775]	205 (606) [1,335]
Broad whitefish	0	4,167 (7,562) [16,671]
Humpback whitefish	0	7,233 (6,562) [14,466]
Unknown cisco	0	353 (120) [264]
Round whitefish	0	422 (288) [634]
Unknown whitefish	9,946 (13,534) [29,839]	0
All species	12,065 (19,783) [43,614]	12,380 (15,136) [33,370]

[1]ADFG, Division of Subsistence, unpublished harvest surveys, 1985 and 1998.

Bethel residents actively catch whitefish in drift and set gillnets in the summer, and with set nets under the ice and by jigging in winter. In 1984, local residents set 83 nets under the ice along a six mile stretch of the Kuskokwim close to Bethel to catch whitefish, northern pike and burbot (Figure 85). In addition, Bethel residents typically catch inconnu in their salmon nets or by hook and line in the summer. Harvest data on whitefish species were most recently collected in Bethel between 2001 and 2004 (Simon et al. 2007). In 2001, Bethel residents harvested an estimated 9,815 fish (14,923 kg; 32,900 pounds), which included inconnu and other whitefish species combined. In 2002, they harvested an estimated 11,375 fish (16,728 kg; 36,880 pounds), and in 2003, 3,838 fish (5,771 kg; 12,725 pounds). The absence of species identification and effort data preclude any understanding of the factors involved in the apparent decline in harvest in 2003.

Throughout the lower Kuskokwim River, fishers generally use 10 to 13 cm (4 to 5 inch) stretch-mesh gillnets, 46 m (150 feet) long for large whitefish and 7 to 9 cm (3 to 3.5 inch) stretch-mesh gillnets for small whitefish. Nets are set in the spring when whitefish species are migrating into lakes, and again in fall when they return to the Kuskokwim River. The fall

Figure 85. Ice fishing in the lower Kuskokwim River. Under-ice gillnets are strung between pairs of sticks visible above the ice. Many nets are deployed in this area. Photo by S.J. Miller, USFWS.

run of whitefish is the preferred fishing season. Inconnu are also caught with nets or by rod and reel in the spring and early summer. According to local residents, round whitefish are occasionally harvested in this region when small-mesh gillnets are used.

Central Kuskokwim

As in the lower river, whitefish species are an important subsistence food source for residents of central Kuskokwim River communities and harvesting can occur throughout the year. A food survey conducted in the region in 1979 (Stickney 1981b) demonstrated that fish, including salmon and whitefish species, and moose were residents' most significant sources of protein. Stony River residents reported particularly high whitefish usage levels during the month of December when other sources of fresh meat were unavailable (Jonrowe 1980). Brelsford et al. (1987) documented information on subsistence harvest areas, seasonal rounds, and general resource use in 1986 for the communities of Aniak, Crooked Creek, and Red Devil. Over the 20 year period covered by the study (1964-1986), the primary and secondary harvest months for whitefish species varied from village to village. In general, whitefish species were harvested from March through October, with the heaviest focus during the fall months. Despite the lack of species specific harvest data, these harvest records establish that whitefish species are important subsistence resources for residents of central Kuskokwim River communities.

Central Kuskokwim River fishers employ a variety of gear to harvest whitefish species, including fish wheels, fyke nets, weirs, drift gillnets, set gillnets, dip-nets, spears, and hook and line gear. During recent ethnographic interviews for the Central Kuskokwim Baseline Subsistence Survey (Brown et al. *in prep.*), one resident of Sleetmute described how he and several other locals harvested broad whitefish and humpback whitefish from area lakes in the springtime using dip-nets and weirs. Another resident of Sleetmute stated that the traditional method of spearing whitefish continues to be used. Red Devil fishers use a “tangle net,” a 30 m (100 feet) long gillnet set so it hangs loose. Residents of the community of Stony River harvest whitefish species with set gillnets, fish wheels, weirs combined with dip-nets, hook and line gear, submerged traps, and spears. Ice fishing with hook and line gear occurs in most villages to some extent throughout the winter (Figure 86).


Figure 86. Ice fishing on the Kuskokwim River near the community of Crooked Creek (left image). Photo by B. Retherford, ADFG. Nikolai resident Nick Dennis making nemaje (right image). Photo by J. Van Lanen, ADFG.

There are many important whitefish harvest locations throughout the central Kuskokwim River region, including the main-stem Kuskokwim River, Aniak River, Whitefish Lake (Figure 82), Holitna River, Hoholitna River, Swift River, and Stony River drainages. Stony River residents use seasonal camps specifically established for catching whitefish. At least five common species of whitefish are harvested from these camps, with humpback whitefish and broad whitefish being the most important species in terms of quantity and nutritional value (Kari 1983, 1985). Stony River fishers observe that inconnu no longer travel up the Stony River in large numbers, such that Lime Village people must now travel downstream to an area around Stony River to harvest them. Fishing for whitefish species occurred throughout what is known locally as the "Great Bend" of the Kuskokwim near Crooked Creek. Red Devil residents fished for non-salmon species including whitefish along the main-stem Kuskokwim River, the mouth of the George River, Eightmile Creek, and the Holitna River (Brelsford et al. 1987). A favorite fishing location for Lower and Upper Kalskag residents is Whitefish Lake (Figure 82; Brown et al. *in prep.*).

Quantitative harvest data are lacking for much of the central Kuskokwim River region, and what does exist is not generally apportioned by species (Table 19). A 2001-2003 study in Aniak and Chuathbaluk revealed that whitefish species were the primary non-salmon fish harvested, accounting for approximately one-third to one-half of the entire non-salmon fish harvest during the study period (Krauthoefer et al. 2007). A comprehensive harvest survey effort by ADFG, Division of Subsistence, is currently taking place in the central Kuskokwim area and will add to our understanding of whitefish harvests from the region.

Table 19. Estimated harvest of whitefish (no. fish (kg) [pound]) in Aniak and Chuathbaluk, 2001-2003[1].

Resource	Aniak 2001-2002	Aniak 2002-2003	Chuathbaluk 2001-2002	Chuathbaluk 2002-2003
Inconnu	808 (2,379) [5,244]	366 (1,079) [2,379]	187 (551) [1,215]	207 (611) [1,346]
Unidentified whitefish	2,477 (3,372) [7,434]	1,649 (2,244) [4,947]	205 (279) [615]	1,295 (1,762) [3,885]
All species	3,285 (5,751) [12,678]	2,015 (3,323) [7,326]	392 (830) [1,830]	1,502 (2,373) [5,231]

[1]Simon et al. (2007).

Upper Kuskokwim

Historically, residents of upper Kuskokwim River communities used traps to catch great quantities of round whitefish or "candle fish" for their large dog teams (Stokes 1985). Other historical fishing gear included weirs, both single and multiple-tined spears with points made of caribou antler (some spear heads were reportedly detachable), dip-nets of thin sinew or willow bark, small nets constructed from moose or caribou sinew with leg bone weights, and hook and line methods. Nikolai elders report the use of fish hooks made from beaver leg bones (Stokes 1985). Inconnu were taken with spears and with beach seines that were drifted along the gravel bars between a man on shore and another in a canoe. Later, the use of fish wheels made catching large quantities of whitefish more efficient. Fish wheels near the Big River Roadhouse on the Kuskokwim River in the early 1900s produced large quantities of inconnu each summer (Stokes 1985). Until the 1960s when traditional fish fences were banned by ADFG, whitefish were often taken in fish fences and traps as the fish moved to and from rivers and lakes. The Little Tonzona River was a favorite location for the use of fish fences in the past (Stokes 1985).

Currently, whitefish species in this region are harvested using a variety of gear both as a target species and as incidental catch while fishing for salmon. Residents of upper Kuskokwim River communities use gillnets and hand lines to capture whitefish through the ice in the winter, and gillnets, spears, fish wheels, dip-nets, and hook and line methods during other times of the year (Holen et al 2006). Similarly, Kari (1983) reported that residents of

Lime Village harvested whitefish of several species with fish wheels, fences, traps, dip-nets, set gillnets, and hook and line methods. According to Ikuta et al. (*in prep.*), residents of Nikolai operated a successful community fish wheel for harvesting whitefish during the last few years. It produced a good quantity of "little whitefish" (possibly Bering cisco).

Fishing locations for whitefish species in the upper Kuskokwim River region vary from community to community. In general, the harvest locations for Upper Kuskokwim residents are almost limitless in the areas surrounding the communities of Telida and Nikolai. Whitefish are harvested from the Kuskokwim River main stem and in many of its tributaries and lakes. Tributaries near the community of Telida that have historically been fished include Highpower Creek and the Swift, Blackwater, Salmon, McKinley Fork, Tonzona, and Big rivers (Holen et al. 2006). Residents of Lime Village harvest whitefish in lakes or in streams connecting lakes and rivers in the Stony River drainage (Kari 1983). Nikolai residents harvest whitefish in several locations during winter and summer (Stokes 1985; Holen et al. 2006). According to one Nikolai resident the best sources of whitefish are some of the small lakes along the North Fork Kuskokwim River. Residents observe that whitefish species travel down the tributaries from these lakes in the fall and head back to the lakes in the spring (Williams et al. 2005).

During the fall, set gillnets are fished in many locations around the upper Kuskokwim River drainage. The importance of the fall harvest of whitefish for Nikolai residents is evidenced by the fact that some fishing sites are located up to 64 km (40 miles) away, necessitating travel by boat on alternate days to check the nets. Residents of Lime Village fish lake outlets of several lakes during the fall, including South Lime Lake to the east and Tishimna Lake to the north, to catch whitefish migrating out of the lakes into the river (Kari 1983). After freeze-up, these sites are also utilized for under-ice fishing with set gillnets and are reached with snow machine (Stokes 1985). In winter, residents of upper Kuskokwim river communities fish on rivers and lakes with under-ice gillnets and with hook and line gear. Stokes (1985) provides a detailed description of traditional under-ice gillnet fishing.

Following break-up in the spring, fishers from upper Kuskokwim River communities harvest whitefish migrating to summer feeding habitats. Residents of Nikolai set gillnets at the confluence of the North and South forks of the Kuskokwim River (Stokes 1985). Fishers from the community of Telida also begin harvesting whitefish shortly after break-up. Specific spring fishing locations for Telida residents include Lower Telida Lake and its outlet, an area near the mouth of Highpower Creek, and at the confluence of the North Fork Kuskokwim and Swift rivers. Residents of McGrath set gillnets for whitefish in the spring near the mouth of the Takotna River. Whitefish are rare in the Takotna River near the community of Takotna (Stewart et al. 2010) so many fishers travel to the Kuskokwim River in spring to harvest whitefish (Stokes 1985). Lime Village residents travel to the lakes near their village from mid to late spring (April-June) to fish for whitefish and other non-salmon species (Kari 1983). Qedeq Vena, Tundra, and Kutokbuna lakes are favored locations for spring fishing. All communities in the upper Kuskokwim River region exploit the spring migration of whitefish.

During summer in the upper Kuskokwim River region, whitefish are usually harvested incidentally while fishing for salmon, however, there are some sites used specifically for the summer harvest of whitefish species. Humpback whitefish and broad whitefish are often taken along the main-stem Kuskokwim River near McGrath (Stokes 1985). Cisco species are often caught by Nikolai fishwheel operators throughout summer. According to Ikuta et al. (*in prep.*), residents of Nikolai utilize the Blackwater Creek (Tlodaleno') and Big River (Zidlaghe Zighashno') areas to specifically harvest whitefish during the summer. Residents of Telida enjoy a summer whitefish fishery in Lower Telida Lake (Stokes 1985). Residents of Lime Village harvest whitefish during summer while fishing for salmon in camps along the Stony River (Kari 1983). While whitefish species are harvested within the upper Kuskokwim River region during summer, it is a minor component compared to the spring and fall harvests.

All communities in the Upper Kuskokwim region prepare and preserve whitefish in a number of ways for human consumption and to a lesser extent for dog food. Residents of Nikolai, for example, describe processing whitefish in the same ways that they process and store salmon; scoring filets and drying it partially or completely (Figure 87; Willams et al. 2005; Holen et al. 2006). Often, a sheet of spruce bark is harvested from a live spruce tree and utilized as a non-slip surface for the fish cutting table (Ikuta et al. *in prep.*). Holen et al (2006), Kari (1983), and Stokes (1985) provide detailed descriptions of fish cutting and processing. Many residents of the region make nemaje, or "Indian ice cream", a delicacy made by mixing together the meat of whitefish, fat of some sort, berries, and sugar (Figure 86). Inconnu eggs are often combined with smashed berries for another type of nemaje (Holen et al. 2006). One Nikolai family related that they liked whitefish stomachs boiled and fried (Williams et al. 2005; Holen et al. 2006). The great variety of preparation and preservation methods for whitefish highlights its cultural importance in the upper Kuskokwim River region.

Figure 87. Nikolai resident Philip Esai brines and prepares cut whitefish for drying at his fish camp on Blackwater Creek (right image). Note the spruce bark mat on the cutting table designed to prevent fish from slipping during the cutting process (left image). Photos by J. Van Lanen, ADFG.

Whitefish harvest data in the upper Kuskokwim River region are minimal. With the exception of inconnu, whitefish harvest data that are available are not species specific. A 1984 survey by the ADFG, Division of Subsistence (unpublished data), estimated a harvest of 2,500 whitefish and 300 inconnu by fishers in McGrath, and a harvest of 167 whitefish and 4 inconnu by fishers in Nikolai. A more recent harvest survey of fishers in Nikolai conducted in 2002 estimated an annual harvest of 386 whitefish and 181 inconnu (Holen et al. 2006). Whitefish harvest estimates for Telida and Takotna are not available. Given the descriptions of whitefish harvest practices in communities in the upper Kuskokwim River region (Stokes 1985; Williams et al. 2005), these harvest data are clearly underestimates of actual harvests.

Potential threats and concerns

Overfishing

Twenty-seven communities are located within the Kuskokwim River habitat region (Figures 75 and 76; Appendix A2), with a total population in 2008 of approximately 13,468 residents (U.S. Census Bureau 2010). Bethel is the largest community in the drainage with a population of approximately 6,468. There are no roads linking Kuskokwim River communities and all access is by aircraft, boats, snow machines, dog teams, and other off-road vehicles. Ice roads between some communities during winter occasionally allow limited car and truck traffic. Fishing is a way of life within all of the communities and whitefish species are major components of their harvests (Kari 1983; Stokes 1985; Andrews 1989; Coffing et al. 2001; Krauthoefer et al. 2007).

Harvest estimates of whitefish species within the Kuskokwim River drainage that are useful for management have not been developed. Intensive subsistence studies have been conducted in many Kuskokwim River communities (Kari 1983; Stokes 1985; Andrews 1989, 1994; Coffing et al. 2001; Krauthoefer et al. 2007) and some of these studies report harvest estimates of whitefish species based on in-person interviews with a sample of community households, which are then extrapolated to estimate community harvest totals (see examples in previous section). While these studies highlight the fact that whitefish species are important subsistence resources in the drainage, most do not identify whitefish to species, annual effort is unknown, the process of interviewing people weeks or months after fishing about the number and species of fish harvested during the previous year is imperfect, and they do not provide adequate time series of harvest estimates with which to develop average annual harvest levels of particular species. Whitmore et al. (2008) present a long-term record of commercial harvest data on whitefish within the Kuskokwim River drainage (Appendix A13, page 161), but no species data are included. Further, there is a note regarding the whitefish category contending that it includes cisco, pike, and blackfish, but does not include catches incidental to the commercial fishery. Burr (2004) and Lafferty (2004) provide long-term records of sport fish catch and harvest data for the upper and lower Kuskokwim River drainage respectively. These data are gathered through the sport fish harvest calendar that is mailed to a subsample of license holders each year and the results are expanded based on the proportion of respondents to all license holders. Burr (2004) and Lafferty (2004) report an average of about 700 inconnu captured each year in the drainage with approximately 400 harvested and 300 released. They do not include inconnu harvested incidentally in salmon fisheries or harvest data on other whitefish species. None of these data are sufficient for developing annual harvest estimates of whitefish species or populations in the Kuskokwim River drainage, or for using as baseline harvest levels from which to measure change. Analysis of length and age distributions of specific whitefish populations, as suggested by Power (1978), Healey (1980), and Mills et al. (1995), and demonstrated by Harper (K. Harper, USFWS, unpub. data) for two humpback whitefish populations in the Kuskokwim River drainage (Figure 84), will be required to identify overexploited whitefish populations in the Kuskokwim River drainage, if they exist.

Development

Potential impacts to whitefish populations in the Upper Kuskokwim region could occur from development activities including mineral extraction, road building, fuel barge traffic on the Kuskokwim River, and urbanization. One of the most pressing development concerns in the Kuskokwim main stem at this time is the development of the Donlin Creek Mine. Gold was first discovered in Donlin Creek near the community of Crooked Creek in 1909. Placer mining, sluice mining, and exploration have been conducted in the area to various degrees since that time (Cady et al. 1955; Brown 1983). The current generation of mineral exploration in Donlin Creek began in 1995 and continues to the present (Szumigala et al. 2009). According to Francis (2008), NovaGold Inc. proposes to construct a hard-rock gold mine 21 km (13 miles) north of the central Kuskokwim River community of Crooked Creek. The Donlin Creek Mine, as planned, would be an open pit mine 3 km (2 miles) long by 1.5 km (1 mile) wide. Construction in the area would include a new airstrip approximately 1.5 km (1 mile) long, located 11 km (7 miles) from the mine. In addition, construction for on-site housing, a port on the Kuskokwim River near the community of Crooked Creek, an on-site power generation plant, a wind turbine farm, a conveyor system, a mill, a water treatment plant, truck shops, labs, a sewage treatment plant, general offices, warehouses, and on-site access roads are planned. Also included would be the construction of a waste rock facility, a fuel farm, a contact water pond, ore stockpiles, a tailings storage facility approximately 3 km (2 miles) long by 1.5 km (1 mile) wide, two freshwater reservoirs, and numerous tailing dams. Power generation and other heavy equipment at Donlin Creek Mine will require approximately 322,000 m^3 (85,000,000 gallons) of diesel fuel annually. This fuel would be hauled by barge along the river. Under current plans, between one and three double-hull river barge tows per day between June and October consisting of four fuel barges pushed by a tug would be traveling on the Kuskokwim River between Bethel and a port at Birch Crossing about 16 km (10 miles) downstream from Aniak. From the Birch Crossing port the fuel would be transported cross-country to the mine via a 30 cm (12 inch) diameter buried pipeline. The pipeline would follow a new 119 km (74 mile) access road from Birch Crossing to the Donlin Mine. A new road connecting the mine to the community of Crooked Creek would also be constructed. In all, the mine property would encompass 127 km^2 (49 $mile^2$) of state mining claims with additional lands leased for mining from Alaska Native Corporations bringing Donlin Creek LLC's total holdings to more than 326 km^2 (126 $mile^2$). The Donlin Creek mining prospect, if it becomes fully developed, will be a significant project within the Kuskokwim River drainage.

The likely effects of the Donlin Creek mine on fisheries or fish populations within the Kuskokwim River drainage are difficult to predict. Local opinions of Crooked Creek residents to the development of a large mine on Donlin Creek fall primarily into two categories; statements of deep concerns about the possible adverse environmental effects of the mine, and opinions that the mine will pose no or little threat to the environment and that it is needed in the area for job creation (Brown et al. *in prep.*). While round whitefish are almost certainly present in the upper Crooked Creek drainage, other whitefish species are likely to be casual visitors if they utilize the drainage at all. The most likely impacts of mine activities on whitefish fisheries or populations, other than local round whitefish populations, would be from accidents that released fuel or other toxic waste into the Kuskokwim River directly.

Several other development projects within the Kuskokwim River drainage have the potential to impact whitefish populations in one way or another. Holitna Energy has proposed a gas-only exploration license on 109 km^2 (42 $mile^2$) of state land. NovaGold and Barrick Gold have expressed interest in obtaining local natural gas for the Donlin Creek Mine should such source be found in the Holitna Basin. However, House Bill 227, currently under consideration by the State legislature, would create a new state reserve, potentially blocking any development access to the area. The bill would create the state's first natural reserve for human-consumptive use of fish and game resources, with an accompanying management plan that emphasizes hunting, fishing, and trapping uses, but would not include a preference for any user group. The Nixon Fork Mine (BLM 2005; Szumigala et al. 2009) is an active hard-rock gold mine within the Takotna River drainage. A fuel spill at the mine in 2005 released 4 m^3 (1,070 gallons) of diesel fuel into the environment (ADEC 2007). The possibility of additional spills of petroleum oils and other hazardous substances from the mine is a concern for area residents. Nyac, a placer mining community in the upper Tuluksak River drainage, has been active since the early 1900s and is currently producing gold (Calista Corporation 2000; Szumigala et al. 2009). A segment of the valley more than 15 km (10 miles) long has been extensively dredged, repeatedly rerouting the natural river course. The river now flows around and through the maze of tailing piles (Figure 88). Any critical fish habitat that may have existed before the mine was active has been irrevocably altered.

A contaminants study designed to determine the impacts of the Nyac mine on aquatic habitats and organisms downstream was conducted for the USFWS in the late 1980s (Crayton 1990). Despite the massive disruption to the floodplain substrate in the upper Tuluksak River, they found no evidence of unusually high dissolved metal concentrations in flowing water downstream from the mine during non-mining periods, but heavy metals had accumulated above background levels in sediments. Fish collected from mining influenced sites had normal levels of accumulated metals in their tissues that were similar to control fish from non-mined stream reaches. Crayton (1990) used Arctic grayling and northern pike for his fish samples, both of which are capable of migrating to or from mining affected reaches. Therefore, there was no guarantee they were exposed to the effluent from the mine when it was operational, or from food organisms that may have become contaminated from living in affected sediments. In any case, it appears that the biggest detectable influence of this mine on fish populations was the physical disruption of the natural habitat.

Urbanization along wild rivers is often a messy affair. It involves stabilizing banks to inhibit natural erosion, mining gravel from the streambed when that is the most economical means of obtaining material, spilling oil and other hazardous materials because large amounts are handled in urban areas and accidents happen, restricting channel flow with culverts to support building projects or roads, sewage treatment and discharge, and more. The consequences of these types of activities on fish populations were discussed in some detail in the introduction. It should be noted, however, that many communities along the Kuskokwim River are in the early stages of modernization and are facing difficult financial choices dealing with many of these issues. Less expensive solutions to problems are often selected out of necessity even if there are long-term consequences. Streambed gravel mining is a

Figure 88. Tailing piles extend completely across the upper Tuluksak River valley at the Nyac mine. A segment of the valley more than 15 km (10 miles) long was extensively dredged beginning in the early 1900s, which repeatedly rerouted the natural river course. The river now flows around and through the maze of tailing piles. Any critical fish habitat that may have existed before the mine was active has been irrevocably altered. Photo by K.C. Harper, USFWS.

common practice for communities along the middle and upper reaches of the Kuskokwim River drainage (State of Alaska 2009). If streambed gravel were mined in whitefish spawning areas it could reduce the quality of spawning habitats or even destroy them (Meng and Müller 1988; Brown et al. 1998). Identifying spawning habitat through radio telemetry projects, as described by Harper et al. (2009) and Stuby (2010), is a first step towards preserving these essential whitefish habitats. Bank stabilization efforts in many rural communities involves piling gravel, rocks, logs, and various old materials in front of eroding banks, hoping it provides some sort of protection from the river. The Bethel waterfront was famous for many years for its selection of cars, barrels, and other debris dumped over its banks (Figure 89), but the community has recently improved their bank stabilization efforts using materials that will not pollute the aquatic environment. Communities everywhere evolve through stages where initially they are too small in population for their development activities to have a substantial effect on the environment and inexpensive solutions to problems work, to being large enough that their activities have a significant effect on the environment and ecologically sound solutions, even if more expensive, become necessary to preserve natural resources. Bethel, being the largest community in the Kuskokwim River drainage, has clearly advanced through the early stages of development and must consider the ecological consequences of their development activities if aquatic resources in the Kuskokwim River drainage are to be maintained. Fish populations depend on unpolluted, naturally functioning aquatic habitats and our development activities must be compatible with their needs if they are to be sustained.

Figure 89. Historical bank stabilization efforts with old cars, waste barrels, and other debris piled over the banks on the Bethel waterfront (top image; photo by J. Barker). Similar situations can be encountered at smaller scales in many rural communities along the Yukon and Kuskokwim River drainages. By contrast, the modern waterfront in Bethel is more effective at preventing erosion and more ecologically sound (bottom image; photo by S.J. Miller, USFWS).

Coastal Habitat Region

The Coastal habitat region extends from southern Kuskokwim Bay, near Goodnews Bay, across the Yukon Kuskokwim Delta, Norton Sound, the Seward Peninsula, and into Kotzebue Sound and the southeast Chukchi Sea (Figures 90 and 91). The shelf habitats of the northeastern Bering Sea and the southeastern Chukchi Sea are about 50 m (164 feet) deep or less in their deepest areas (Drake et al. 1979; Weingartner 1997) and the Bering Sea shelf off the Yukon River delta is less than 30 m (98 feet) deep 100 km (62 miles) from shore (Drake et al. 1979). Tides in this region are greatest in Kuskokwim Bay where the amplitude may be as great as 4 m (13 feet), intermediate near the north mouth of the Yukon River where the amplitude can be as great as 1.5 m (5 feet), and smallest along the Seward Peninsula and southeast Chukchi Sea where the maximum amplitude in most locations is less than 1 m (3 feet) (McDowell et al. 1987; Kowalik 1999; NOAA 2010). Normal high tide levels can be elevated by up to 5 m (3 to 16 feet) during fall storm surges (Kowalik 1984; Johnson and Kowalik 1986; McDowell et al. 1987), which routinely flood freshwater habitats in low lying coastal areas including broad regions of the Yukon Kuskokwim Delta (Jorgenson and Ely 2001). Marine currents in the eastern Bering Sea flow north across the Yukon Kuskokwim Delta, through the Bering Strait, and continue north into the Chukchi Sea and beyond (Overland and Roach 1987; Stabeno et al. 1999; Woodgate et al. 2005). Each year, seasonal ice extends at a minimum from southern Kuskokwim Bay, in the southeast Bering Sea, north across the Bering Sea shelf and encompasses the entire Chukchi Sea and beyond (Muench and Ahlnas 1976; Johnson 1988; Weingartner 1997; Niebauer et al. 1999). At salinities ranging from about 32 to 34 psu, the Bering and Chukchi seas cool under ice to approximately -1.7°C (29°F; McRoy and Goering 1974; Coachman et al. 1975; Woodgate et al. 2005), which is too cold for salmonid fishes (Black 1957; Fletcher et al. 1988; DeVries and Cheng 2005). While the shallow shelf habitats of the northeastern Bering Sea and Chukchi Sea are extraordinarily productive (Grebmeier et al. 2006), the extreme winter water temperatures force salmonid fishes to migrate to warmer habitats (DeVries and Cheng 2005). Pacific salmon species migrate south and west to the Bering Sea shelf break or farther south where sea ice is absent and whitefish species retreat to estuary or freshwater habitats where reduced salinity prevents super cooling of water under ice.

Our interest in this coastal habitat region, as it relates to whitefish, is the narrow coastal band of water freshened by rivers and drawn north by ocean currents. The high abundance of prey organisms in the marine environment is thought to be the primary reason for anadromy of northern latitude fishes (Gross 1987; Gross et al. 1988) and the shallow coastal waters of the eastern Bering and Chukchi seas are extraordinarily productive environments rich in prey organisms suitable for anadromous whitefish species (Grebmeier et al. 2006). Many anadromous whitefish migrate seasonally from their natal drainages to coastal and lagoon environments and take advantage of the abundant food supply. Most whitefish species are thought to be tolerant of brackish environments but not the high salinity level of fully marine environments and thus, appear to restrict their marine migrations to the coastal environments influenced by their natal rivers (Reist and Bond 1988; de March 1989; Howland 2005). The closely related Arctic cisco and Bering cisco, however, are apparently tolerant of marine environments as both species have been captured far from shore in fully marine water (Wolotira et al. 1977; Jarvela and Thorsteinson 1999) and both species have been found rearing at great distances from natal rivers, which required extensive migration through

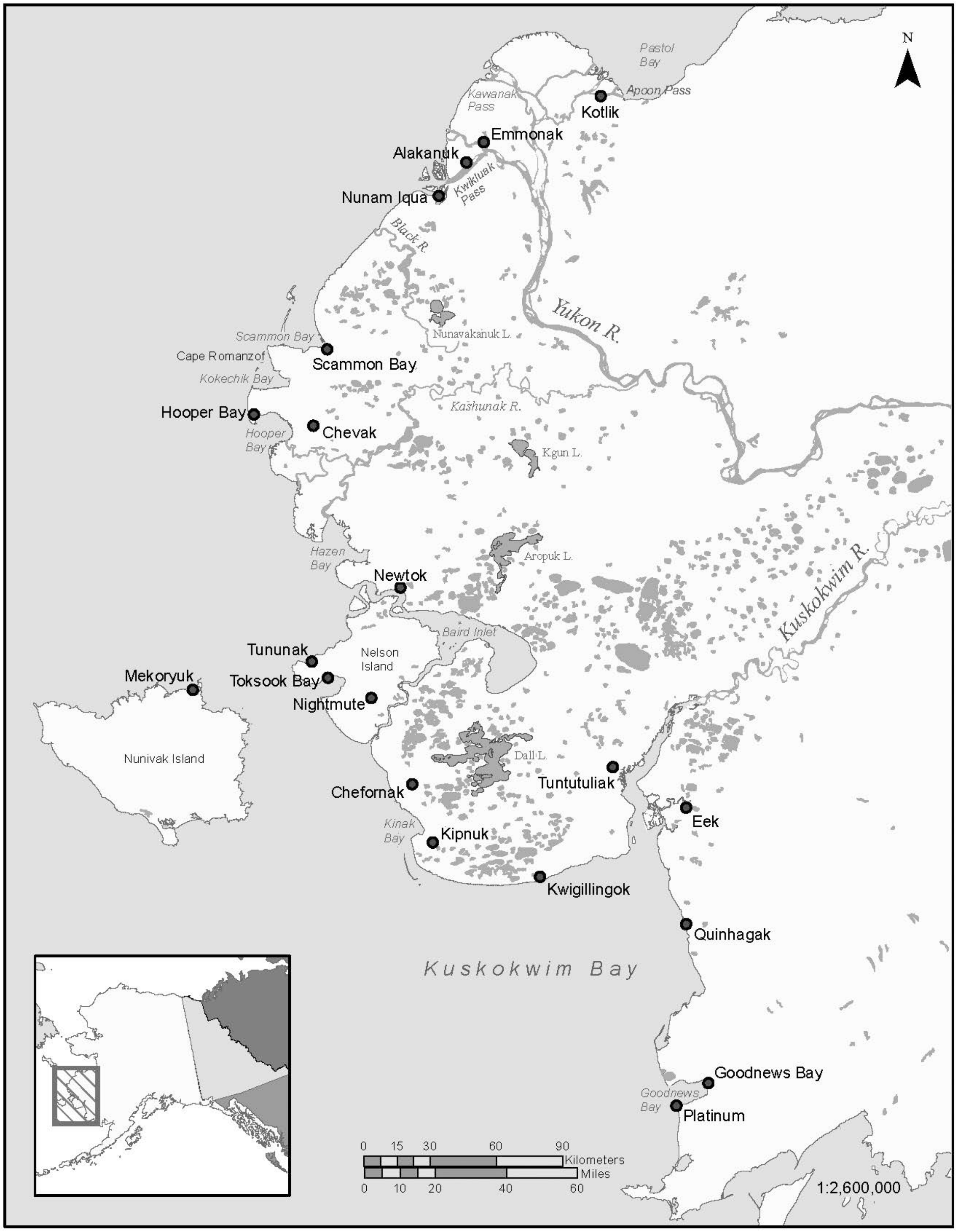

Figure 90. The southern coastal habitat area from southern Kuskokwim Bay, across the Yukon Kuskokwim Delta, to the Yukon River mouth, including coastal communities.

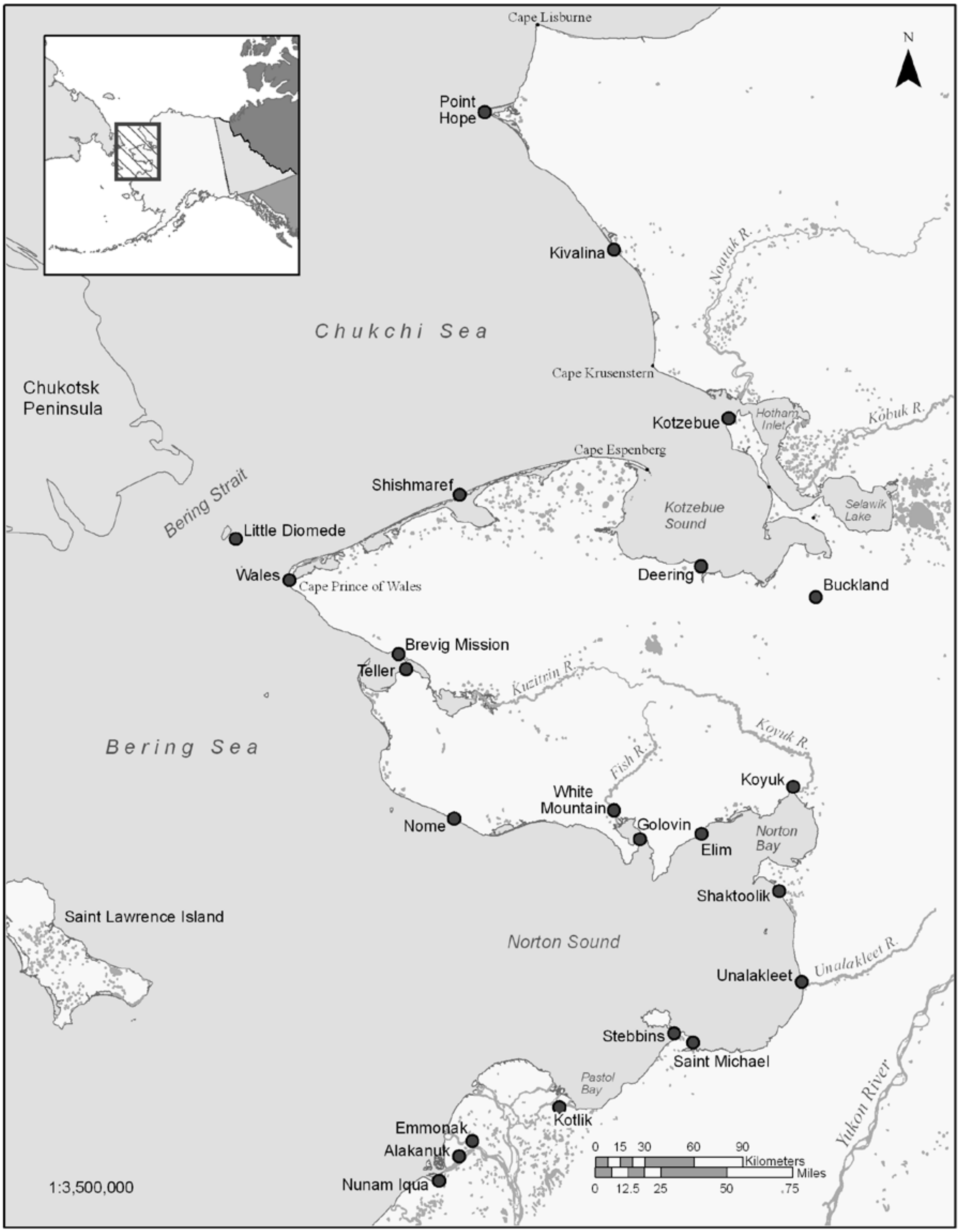

Figure 91. The northern coastal habitat area from the Yukon River mouth, around the Seward Peninsula, to the southeast Chukchi Sea, including coastal communities and some prominent drainages.

marine environments (Alt 1973a; Chereshnev 1984; Bickham et al. 1997; Fechhelm et al. 2007). With the exception of Bering cisco, whitefish species with natal origins in the Yukon and Kuskokwim River drainages are thought to remain in their respective drainages and associated estuaries, while Bering cisco are thought to disperse north from their natal drainages with marine currents, similar to the dispersal of juvenile Arctic cisco from the Mackenzie River (Fechhelm et al. 2007), and occupy coastal habitats throughout the eastern Bering and Chukchi seas.

Whitefish species, distribution, and biology

Five whitefish species are known to be anadromous in western Alaska and have been documented in the coastal habitat region. Martin et al. (1986, 1987) have provided the most comprehensive and systematic sampling data in the Yukon River delta environment that we are aware of and they demonstrated that inconnu, broad whitefish, humpback whitefish, least cisco, and Bering cisco were present in estuary habitats. A single round whitefish was captured in one of the delta distributaries during two summers of sampling revealing that round whitefish avoid the estuary environment, a finding consistent with otolith chemistry data from whitefishes collected in upper reaches of the Yukon River drainage (Brown et al. 2007). They sampled with many different types of gear to ensure all species and all size categories were represented in their catches. Juvenile least cisco and Bering cisco, the pelagic feeding species, were most common offshore in brackish environments along the seaward side of the delta, while inconnu, broad whitefish, and humpback whitefish were more closely associated with near-shore, less saline environments and lower river channels (Martin et al. 1986, 1987).

Less comprehensive sampling data are available for the Kuskokwim River estuary and the broader Yukon Kuskokwim Delta between the two river mouths, which is punctuated by several of the southern distributaries of the Yukon River and many other minor freshwater streams draining the delta platform itself. Baxter (1975) sampled numerous locations from Kuskokwim Bay, near the mouth of the Kuskokwim River, north to Hazen Bay, an estuary region at the terminus of the most southerly distributary of the Yukon River, and reported the presence of broad whitefish, humpback whitefish, least cisco, and Arctic cisco in the area. In his field notes, Baxter (1975) always referred to Bering cisco as Arctic cisco, perhaps because he had not read McPhail's (1966) taxonomic position on the distinction between Arctic cisco and Bering cisco or possibly because he did not accept it. Baxter (1975) reported that many of the whitefish he captured in the delta were of a size consistent with maturity but it was his judgment, based on an inspection of the gonads, that none were preparing to spawn on the year of capture. Runfola (2011) accompanied residents of Scammon Bay, a coastal community on the western margin of the delta, and observed the capture of inconnu, broad whitefish, humpback whitefish, and Bering cisco, Bering cisco being the most abundant and preferred of the whitefish species. Runfola (2011) showed a photo of a gravid female Bering cisco similar to the upper image in Figure 6, to fishers in Scammon Bay to see if there was any indication of spawning activity in the vicinity. The respondents were unanimous that they had never seen a Bering cisco in that condition, which led Runfola (2011) to conclude that Bering cisco were rearing but not spawning in the outer delta. Brown and Eiler (2005) sampled numerous channels and sloughs draining into Hazen Bay with small-mesh gillnets and inspected subsistence harvests in the area and identified broad whitefish, humpback whitefish, least cisco, and Bering cisco. Additionally, they reported that during high tide periods, salinity of up to 10 psu surged up the channels as far as 40 km (25 miles) inland. Stickney (1984) reported on seasonal resource use in two coastal communities; Hooper Bay, in the central region of the delta, and Kwigillingok, on the northern shore of Kuskokwim Bay. Both communities specifically harvested Bering cisco, which was the most commonly harvested whitefish species. Residents of Hooper Bay also harvested small numbers of inconnu, broad whitefish, humpback whitefish, and least cisco, while residents of Kwigillingok apparently did not normally encounter other whitefish species. Seasonal or annual patterns of whitefish distribution and habitat use on the delta are not fully understood, but it is clear from these sampling records that any of the five anadromous species may be found almost anywhere on the delta, and that Bering cisco appear to be the most common species along the brackish margins.

Demographic data for whitefish species captured on the Yukon Kuskokwim Delta is sparse and based primarily on the likelihood of maturity given a certain length for all species except Bering cisco, for which there is also a substantial amount of GSI data. Martin et al. (1986) sampled extensively throughout the Yukon River delta in a wide range of habitats with a variety of gear including multi-mesh gillnets, fyke nets, purse seines, and beach seines from June through September in 1985. They presented length frequency tables for many species including inconnu, broad whitefish, humpback whitefish, least cisco, and Bering cisco. We used those tabulated data to create length frequency histograms to qualitatively compare with length frequencies of samples of mature individuals of the five whitefish species (Figure 92). The mature length frequency data were collected from spawning migrations where GSI data were used to verified maturity and from fall spawning ground collections in the Yukon and Kuskokwim River drainages (unpub. data, R.J. Brown and K. Harper, U.S. Fish and Wildlife Service). These data clearly illustrate that the vast majority of individual whitefish of all five anadromous species present in the delta during summer are immature. Bering cisco is the only whitefish species represented with a substantial mix of small juveniles and larger individuals that could be mature. As discussed earlier, Bering cisco harvested in the commercial fishery in the delta during fall have very low GSI values (Figure 33) and are generally younger than fish sampled from the upstream spawning migration (Figure 32) indicating that they are not spawning on the year of capture and are predominantly immature.

Migration and harvest data for inconnu suggest that the demographic composition of whitefish species in coastal habitats could be different between summer and winter. Alt (1977a) tagged almost 4,000 inconnu in several major drainages supporting inconnu populations in Alaska between 1961 and 1974. Based on seasonal tag returns over the years he inferred that larger inconnu migrated into the river systems to feed during the summer months, to upstream spawning habitats in late summer and fall, and then returned to the lower reaches to overwinter. Winter harvest data compiled by Crawford (1979), who focused primarily on inconnu, demonstrated that mature size inconnu were present in the lower reaches of the Yukon River delta channels during winter. He reported that most fishers used 10 to 18 cm (4 to 7 inch) stretch-mesh gillnets, which would be very selective to larger fish. The juveniles that dominated the catches of Martin et al. (1986) would have been invisible to the large-mesh gear of the fishery so Crawford's (1979) data do not provide

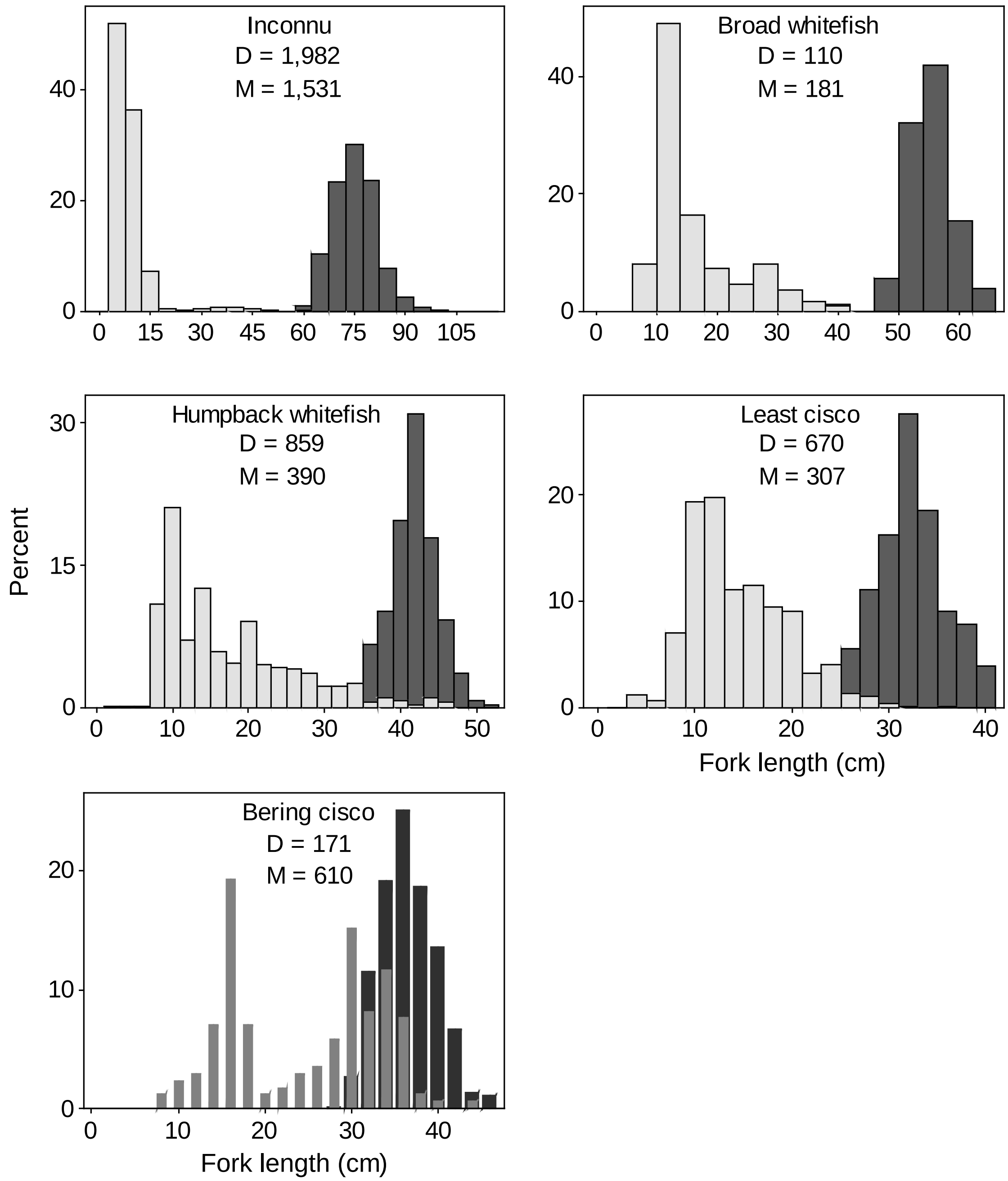

Figure 92. Length frequency histograms of whitefish species captured in the Yukon River delta (light bars), as reported and tabulated by Martin et al. (1986), and of mature specimens collected from spawning migrations or on spawning grounds in the Yukon and Kuskokwim rivers (dark bars). Mature specimen data were from the collections of R.J. Brown and K.C. Harper, U.S. Fish and Wildlife Service. Sample sizes are indicated for delta (D) and mature (M) collections for each species. Note that most of the delta samples for all species were of a size indicating they were immature. Bering cisco appeared to be the only species with a substantial mix of immature and mature size individuals in the delta.

information on the relative abundance of immature and mature demographic groups during winter. None-the-less, these two sources of information support the notion that the demographic composition of whitefish species within the Yukon River delta could be very different during summer than during winter.

Sampling data have shown that all five anadromous whitefish species are present in coastal habitats north of the Yukon River mouth in the Bering Sea and southeastern Chukchi Sea, but spawning populations north of the Yukon River are known only for inconnu, broad whitefish, humpback whitefish, and least cisco. A limited number of inconnu have been captured near the mouth of the Koyuk River, in the northeastern corner of Norton Sound (Figure 91; Alt 1971b), but they have not been reported in coastal or freshwater habitats of the Seward Peninsula despite a tremendous number of intensive, multi-year sampling studies in numerous drainages including the Fish River (Alt 1985; Webb 1987), Nome River (Alt 1984), Imuruk Basin and associated drainages (Alt 1971b, 1980b, 1985), and the Buckland River (Webb 1978). Alt (1988) suggested that an inconnu population may exist in the Koyuk River but it is also possible that the samples he collected were members of a Yukon River population that migrated north in the brackish water plume from the Yukon River. In any case, the next inconnu populations north along the coast are in the Selawik and Kobuk rivers, major drainages in the southeast Chukchi Sea (Alt 1977a, 1988; Taube and Wuttig 1998; Underwood 2000). Inconnu from these populations appear to confine their migrations to their natal rivers and nearby lake and estuarine habitats in eastern Kotzebue Sound.

Broad whitefish, humpback whitefish, least cisco, and Bering cisco appear to be more widely distributed than inconnu in coastal environments north of the Yukon River. All four species have been documented in the Koyuk River (Alt 1971b), Fish River (Alt 1985), Imuruk Basin and associated drainages (Alt 1971b, 1972, 1980b), and the Kotzebue Sound, Hotham Inlet estuary in the southeast Chukchi Sea (Alt 1979b, 1980a). Maturity and harvest sampling data indicate that broad whitefish, humpback whitefish, and least cisco spawn in numerous river systems north of the Yukon River such as the Kuzitrin River in the Imuruk Basin area (Alt 1976, 1979a, 1980a), the Kobuk River (Alt 1979b, 1980a; Georgette and Shiedt 2005), the Selawik River (Brown 2004), and possibly others as well. Fall migrations into upstream spawning reaches have been observed in several drainages and pre-spawning fish are targeted in subsistence fisheries. Georgette and Shiedt (2005) present wonderful descriptive and photographic evidence of this phenomenon for the Kobuk River. By contrast, Bering cisco have not been captured upstream from river mouths and have never been found in spawning condition north of the Yukon River mouth. They are present in virtually every estuary system that has been sampled in the northern Bering Sea and Southeastern Chukchi Sea, appear to be more abundant in saltier regions of estuaries than in fresher regions (Alt 1971b, 1979b), and have never been captured in upstream habitats. Bering cisco are occasionally identified in coastal waters of the Beaufort Sea as far east as the Colville River delta, where they mix with the closely related Arctic cisco (McPhail 1966; Craig 1989; Bickham et al. 1997). Scientists working on Arctic cisco biology had previously discovered that all Arctic cisco present in the Colville River delta were immature, rearing fish with spawning origins in the Mackenzie River drainage, about 600 km (373 miles) to the east (Galloway et al. 1983; Fechhelm et al. 2007). It was therefore, not difficult for those scientists to accept that the few Bering cisco they encountered in the area had spawning origins in the Yukon River drainage, the closest drainage to the south with a documented spawning run (Alt 1973a; Craig 1989; Bickham et al. 1997). There is ample evidence that inconnu, broad whitefish, humpback whitefish, and least cisco maintain spawning populations in river systems north of the Yukon River mouth and that individuals found in those drainages and associated estuaries are not members of populations within the Yukon or Kuskokwim rivers. The sampling and biological evidence for Bering cisco, however, suggests that there are no spawning populations north of the Yukon River mouth and that all individuals found throughout their range in the northern Bering Sea, Chukchi Sea, and western Beaufort Sea are rearing individuals from the Yukon or Kuskokwim River populations, as suggested by Craig (1989) and Bickham et al. (1997).

Fisheries

The Coastal habitat region of western Alaska is home to two distinct Alaska Native language groups; Central Yup'ik in the southern coastal communities and Inupiaq in the northern coastal communities. Because of cultural boundaries and variations in fish habitat, distribution, and other biological factors, the following discussion on fisheries will be organized into two geographic regions; a southern coastal region extending from southern Kuskokwim Bay to the Yukon River mouth encompassing the Yukon Kuskokwim Delta, and a northern coastal area extending from the Yukon River mouth to the southeast Chukchi Sea encompassing Norton Sound, Seward Peninsula, and Kotzebue Sound. The discussion will cover whitefish subsistence harvesting and use practices such as gear type, harvest locations, seasonality or harvest periods, historical and contemporary use, preparation, storage, and local issues and concerns.

Southern coastal area

Culture and language

Fourteen coastal, four lower Yukon River, and two lower Kuskokwim River communities lie within the Yukon Kuskokwim Delta (Figure 90). The six lower Yukon and Kuskokwim River communities are discussed in this section due to their close proximity to the coast and their extensive use of the coastal environment. This large region is home to the Alaska Native language group known as Central Yup'ik.

Whitefish have always been a significant part of the annual subsistence harvest for residents of the delta. According to Wolfe (1981), subsistence whitefish fisheries are the second most important behind salmon fisheries, as evidenced by their language on the species group (Table 20). Bering cisco in particular is known to be an important component of subsistence diets for residents of coastal and lower river communities. Stickney (1984) and Lavine et al. (2007), for example, report that Bering cisco were the most abundant whitefish species available to Bering Sea coastal communities.

Harvest and use

Subsistence use of whitefish species is not well quantified in the southern coastal communities. LaVine et al. (2007) summarized the traditional ecological knowledge of some elders from Quinhagak and Goodnews Bay concerning fish populations in Kuskokwim Bay and combined the elders' knowledge with scientific life history information about each locally harvested fish. The report suggested that Bering cisco were the most heavily utilized whitefish species in that part of the Kuskokwim Bay. Many elders in Quinhagak and Goodnews Bay were not familiar with least cisco. One elder indicated that least cisco were only found out in Kuskokwim Bay. LaVine et al. (2007) reported that round whitefish were occasionally harvested in the Kanektok, Arolik, and Goodnews drainages but in smaller numbers than in the past.

Table 20. Terms for whitefish species in the Yukon Kuskokwim Delta.

English Name	Linnaean Name	Central Yup'ik[1]
Inconnu	*Stenodus leucichthys*	Ciiq
Humpback whitefish	*Coregonus clupeaformis*	Qaurtuq
Least cisco	*Coregonus sardinella*	Kassiaq, Qassayagaq or Neq'yagaq
Bering Cisco	*Coregonus laurettae*	Naptaq or Imarrpinraq
Round whitefish	*Prosopium cylindraceum*	Cauirrutnaq or Uraruq

[1]Stickney (1984).

Residents of Eek and Tuntutuliak, communities near the mouth of the Kuskokwim River, shared information recently on their fisheries with social anthropologists from the Alaska Department of Fish and Game (Figure 93; Ray et al. 2010). In Eek, four species of whitefish dominated their harvest; broad whitefish, humpback whitefish, Bering cisco, and least cisco. Of these species, humpback whitefish comprised the majority of the whitefish harvest, followed by Bering cisco. Six species of whitefish were reportedly harvested by residents of Tuntutuliak; inconnu, broad whitefish, humpback whitefish, least cisco, Bering cisco, and round whitefish. Ray et al. (2010) noted that the residents of Eek and Tuntutuliak historically relied heavily on broad whitefish, but have observed their catches of broad whitefish decline in recent years. As a result, their recent harvests have shifted more towards humpback whitefish.

Stickney (1984) conducted field work in the communities of Hooper Bay, located in mid-delta (Figure 90), and Kwigillingok, located in northern Kuskokwim Bay, comparing the communities' subsistence economies and seasonal harvests (Table 21). She noted some important differences between the Hooper Bay and Kwigillingok fisheries. For example, some whitefish species routinely harvested in Hooper Bay such as inconnu, humpback whitefish, and least cisco, were apparently not available in Kwigillingok. Kwigillingok residents harvested large numbers of Bering cisco during spring in Kuskokwim Bay, near the mouth of the Kwigillingok River, and along several tidally influenced sloughs along the northern coast of Kuskokwim Bay. In Hooper Bay, whitefish species were primarily targeted in the fall, although they were commonly harvested by fishermen while salmon or herring fishing in the summer as well. Residents generally fished for whitefish species in Hooper Bay and in small streams close to their camps. In winter, residents of Hooper Bay joined families from Scammon Bay and Chevak to harvest whitefish, primarily Bering cisco, in the tidal sloughs near the Askinuk Mountains. Bering cisco and least cisco were the most common species harvested in the central delta.

Figure 93. Mapping session with James Charles of Tuntutuliak during recent subsistence surveys. Photo by ADFG staff.

Table 21. Timing of whitefish harvests in Yukon Kuskokwim Delta communities. Header letters indicate the months of the year. Months with major harvest activity are indicated with an "X" and months with minor harvest activity are indicated with a "–".

	J	F	M	A	M	J	J	A	S	O	N	D
Kwigillingok[1]				X	X	–	–	X	X			
Hooper Bay[1]	–	–				–	–	X	X			–
Quinhagak[2]	–	–	–	X	–			X	X	–	–	–
Goodnews Bay[2]	–	–	–	X				X	X	–	–	–
Eek[3]	–		–	–	–	–	–		X	–	–	–
Tuntutuliak[3]	–	–								X	X	–

[1]Stickney (1984).
[2]LaVine et al. (2007).
[3]Ray et al. (2010).

Various methods are used to prepare, preserve and store whitefish by southern coastal communities. In Quinhagak, round whitefish are usually preserved by freezing and then eaten cooked or frozen and raw (LaVine et al. 2007). They may also be eaten raw when freshly caught. Bering cisco, now as in the past, are prepared and eaten fresh in both Quinhagak and Goodnews Bay. Residents of Eek and Tuntutliak report preparing whitefish in a variety of ways, including drying, freezing, and aging underground (Ray et al. 2010). Preservation methods vary depending on the season. Broad whitefish and humpback whitefish are frozen and then eaten raw, cooked, or mixed together with berries, sugar, and oil to make *agutaq*, a delicacy in the delta. One resident described a traditional method used to age whitefish in which fish were cleaned, placed in hand-woven grass baskets, and buried underground.

Later, the fish would be uncovered and eaten without further preparation. Some who still practice this method have replaced the traditional grass baskets with cardboard boxes. Whitefish fat, especially from fall-harvested broad whitefish, may be rendered to make oil. When boiling or cooking whitefish, the oil is skimmed from the water and stored in containers for *agutaq* or other uses. Some have suggested that the taste of whitefish and whitefish oil may depend on where they have been feeding, with some having a sweet flavor and others tasting muddy. In addition to the whitefish meat and whitefish oil, some residents also eat whitefish eggs that are called *agakik*. According to Stickney (1984), spring whitefish harvests in Kwigillingok are prepared fresh or are dried for later use. To dry them, they are first cleaned and gutted, and then braided in long grass ropes to dry. After they are dry, they may be stored in seal pokes or other containers with oil and stored for the winter. In the summer, whitefish harvested from the bay are usually boiled fresh but may occasionally be dried for later use. Some residents observed that cisco harvested at summer berry camps have firmer flesh than those harvested from the bay during the same time of year. As a result, many residents preferred these berry camp fish for summer consumption. These descriptions of whitefish preparation and preservation are just a sampling of how each community in the delta utilizes seasonally available whitefish species to their maximum advantage.

Material technology

Fishing technology and gear types have changed somewhat over the years in the southern coastal area. Historically, people used sinew nets, fish spears, and jigging hooks to harvest Bering cisco in the areas of present day Goodnews Bay and Quinhagak (LaVine et al. 2007). Elders at Tuntutuliak recalled that one of the main ways whitefish were harvested in the past in their area was by using nets made of caribou or seal sinew, or tree bark (Ray et al. 2010). Women would harvest the tree bark, cut it up into tiny strips, and then twist the strips together. The men would then use the twisted bark strips to make the nets. In fact, prior to the availability of modern equipment, all gear in the delta, including the various means of transportation such as dog sleds and boats, was made by hand from locally available materials. Nelson (1900) described a cooperative fishing effort among a small group of people pulling a beach seine for whitefish on a western Alaska beach in the late 1800s. Whitefish species were harvested in the present areas of Hooper Bay and Kwigillingok using nets made of seal sinew (Stickney 1984). Most fishing now is done from skiffs using drift or set gillnets. Whitefish nets are commonly 18 m (60 feet) in length with a stretch-mesh size ranging from 6.5 to 10 cm (2.5 to 4 inches). It was considered to be the women's responsibility to help make and repair the nets and to clean and process the catch. Fishing for whitefish species is often done in conjunction with fishing efforts for other non-salmon species. For instance, methods and gear adapted for whitefish are also used for Pacific herring *Clupea pallasii*. In addition, fishers who use fish traps for other non-salmon species often set whitefish nets and blackfish traps at the same time. Winter fishing gear may include sinking gillnets, ice chisels, augers, and shovels to cut holes in the ice, and poles to set the nets.

Northern coastal area

Culture and language

Moving up the coast from the delta area, the community of Stebbins in Norton Sound marks the southern boundary of the northern coastal area and the community of Point Hope in the Chukchi Sea marks the northern boundary (Figure 91). Nome, located on the southern coast of the Seward Peninsula serves as a regional hub for Norton Sound and Seward Peninsula coastal communities. The community of Kotzebue, in the south eastern Chukchi Sea, serves as the regional hub for communities north of the Bering Strait. The primary Alaska Native language spoken in northern coastal communities is Iñupiaq, though several dialects are used within the region. Whitefish terminology introduced in this section is of the Kotzebue dialect (Table 22). Our main interest in this northern coastal area is in the traditional use of Bering cisco, the only species that is thought to be of Yukon or Kuskokwim River spawning origins, as discussed earlier.

Table 22. English, Linnaean, and common Iñupiaq terms for whitefish species in the northern coastal area.

English	Linnaean	Iñupiaq
Inconnu	*Stenodus leucichthys*	Sii[1]
Broad whitefish	*Coregonus nasus*	Sigguilaq[2] or Qausiluk[2]
Humpback whitefish	*Coregonus clupeaformis*	Qaalgiq[2], Iqalupiaq[2], or Iqalutchiaq[2]
Least cisco	*Coregonus sardinella*	Iqalusaaq[2]
Bering cisco	*Coregonus laurettae*	Tipuk[2]
Round whitefish	*Prosopium cylindraceum*	Quptik[2]
Whitefish (unspecified)		Iqalupiaq[2]

[1] Georgette and Loon (1990).
[2] Georgette and Shiedt (2005).

Harvest and use

Some whitefish species are more widely distributed in the northern coastal area than others. As a result, not all communities have access to the same group of species. Residents of Stebbins and other Norton Sound communities, for example, harvest inconnu and other whitefish species to some extent (Wolfe 1981). Because of their proximity to the Yukon River mouth, Norton Sound fishers probably harvest the same suite of species present in the Yukon River drainage, although their harvests are not identified to species. Residents of Nome harvest several whitefish species in estuaries and streams on the south coast of the Seward Peninsula and in the Kuzitrin River drainage and its estuary, Imuruk Basin, but inconnu are not available there and have not been identified in their harvests (Magdanz and Olanna 1986). The community of Shishmaref is located on a barrier island on the north side of the Seward Peninsula (Figure 91). Whitefish species other than inconnu are harvested throughout the year in the lagoon waters behind the barrier islands (Sobelman 1985). Kotzebue area residents, in eastern Kotzebue Sound including Hotham Inlet, harvest all six of the common whitefish species, including inconnu (Georgette and Shiedt 2005). Similar to other areas of the northern coastal area, Bering cisco were known by local fishers as being a marine or brackish water species not encountered in freshwater, and round whitefish were known as a freshwater species not encountered in brackish water. The other species were harvested in both brackish and freshwater environments. Residents of the community of Kivalina, in northwest of Kotzebue along the Chukchi Sea coast, harvest small numbers of humpback whitefish and Bering cisco, but, prefer the more numerous Dolly Varden *Salvelinus malma* that are available for harvest there (Burch 1985). Least cisco and round whitefish are apparently present in the area (Alt 1978b) but are not sought, and inconnu and broad whitefish have not been identified there. While most harvest surveys have not identified whitefish to species, those that did demonstrated that there were regional differences in targeted species that were consistent with biological survey data discussed above.

Local issues and concerns

When residents of the coastal habitat region have been asked for their thoughts on possible threats to local whitefish fisheries they have responded with three primary themes: environmental changes; issues related to overfishing or competition for fish by different user groups; and environmental consequences of mineral or oil development. Elders in Goodnews Bay and in Quinhagak noted that certain bodies of water have dried up in recent times, reducing available fish habitat (LaVine et al. 2007). The community of Apokak, which is located near Eek, was abandoned in the 1930s due in part to the drying up of area ponds. Elders contend that beaver dams now block many areas of the Arolik River and the Middle Fork of the Goodnews River that were once used by whitefish. Residents of Eek also expressed concern about a growing beaver population and believe that whitefish have subsequently declined in abundance and size. One elder felt that beaver dams contaminate the water and thus kill fish in the area. He explained that taking the beaver dams apart by hand had little effect because the beavers would just rebuild. Trapping activities that historically managed beaver populations are currently practiced by few local residents (Ray et al. 2010). According to Ray et al. (2010), residents in Tuntutuliak consider beaver activity to be a major factor influencing lake drying, which they believe has led to a decline of whitefish abundance. One elder stated that whitefish get trapped behind beaver dams and cannot migrate. Several respondents also suggested that beavers not only change water patterns and affect whitefish habitats, but they also change the navigation routes people use to access their fish camps. Other environmental changes thought to be influencing the abundance or health of whitefish species were; recent warming trends, changing wind and weather patterns, less precipitation in the form of rain and snow in recent years, thinner ice in winter, and erosion (LaVine et al. 2007; Ray et al. 2010).

Delta residents are concerned with the effects of sport and commercial fishing on the fish resources they depend on in the region. According to LaVine et al. (2007), elders remarked on the growing number of outsiders traveling into the region in order to sport fish the Goodnews and Kanektok rivers. There is great concern among residents that the health of fish populations is being affected by sport fishing catch-and-release practices, and that most outsiders take little care when it comes to camping on or around locally known spawning grounds. Catch and release practices are seen as being harmful to fish. Elders see it as “playing with fish” and being disrespectful to the animal that offers itself for harvest. Stickney (1984) reported that residents of Hooper Bay and Kwigillingok were not in favor of introducing additional competition for fish resources such as sport fishing or commercial salmon fishing if either of these would adversely affect subsistence fishing. In Tuntutuliak some elders reported that broad whitefish seem to disappear shortly after the commercial whitefish fishery, but were not sure if this was caused by overfishing considering that humpback whitefish populations did not similarly decline in abundance like broad whitefish (Ray et al. 2010). Coastal residents are keenly aware that there are limits to the abundance of whitefish resources available to them and that their harvest success could decline if other user groups fish the same populations. For this reason they are protective of these fishery resources.

Residents of the coastal habitat region in western Alaska have expressed concern over the environmental effects of two large mines in the region; a platinum mine the southern Kuskokwim Bay, and a lead zinc mine in the eastern Chukchi Sea. The largest mineral development in the Yukon Kuskokwim Delta is the platinum mine on the Salmon River, near the community of Platinum in southern Kuskokwim Bay (Figure 94; Mertie 1976). Platinum has been mined in the drainage since the late 1920s, much of the time with large floating dredges or draglines. Due to the high price of precious metals, the mine is currently in operation reworking old tailings (Szumigala et al. 2011). Over the years the mine has turned most of the Salmon River valley and several of its tributaries into a large network of tailing piles, dramatically changing the original habitat qualities of the drainage. Because the waters from that area drain into the southern part of Kuskokwim Bay, residents of the area are concerned about possible heavy metal contamination of the bay (USFWS 2009). The Red Dog Mine in the eastern Chukchi Sea is a large, hard-rock, open-pit, lead and zinc mine in the upper reaches of the Wulik River (Ott and Morris 2011; Szumigala et al. 2011). It began producing ore in 1989 and is now one of the major zinc producing mines in the world. According to Szumigala et al. (2011), the value of minerals produced at Red Dog Mine in 2010 accounted for almost half of the total value of mineral production in Alaska. Over the years, there have been a number of accidental discharges of metal-rich, settling pond fluids into Red Dog Creek, a tributary of the Wulik River (Ott and Morris 2011). These events have sometimes resulted in fish kills within the river system and residents of Kivalina have become nervous about the effects of the mine on their fisheries and their drinking water, which they draw from the Wulik River (Magdanz et al. 2010). Many smaller mines have been or are active in the region, most notably on the Seward Peninsula where there has been a long history of placer mining (Szumigala et al. 2011).

During public meetings conducted in 1984-1985 by the Yukon Delta National Wildlife Refuge (USFWS 1988), several local residents expressed concern about shore-based oil and gas development in the region. At that time, there was widespread opposition to oil and gas exploration and development. The most common reason cited was the risk of water pollution from oil spills. The most likely areas for future petroleum exploration in the region includes the southern coastal areas between Kuskokwim Bay and Etolin Strait and the coastal areas of the Yukon Delta, but, the potential of a major find was thought to be low.

Offshore oil and gas development are generally considered to be a threat to the local economic base of coastal communities. Stickney (1984) reported that residents of Hooper Bay and Kwigillingok expressed concern about offshore oil and gas exploration and development in the Bering Sea due to the harsh environmental conditions, lack of technology

Figure 94. A 1972 photograph of a large floating dredge working the platinum mine on the Salmon River just south of Goodnews Bay in southern Kuskokwim Bay. It should be noted that floating dredges have worked over most of the Salmon River valley and several of its tributaries, creating a nearly drainage-wide network of tailing piles similar to the image above. Photo by USFWS staff.

to deal with sea-ice conditions, and the potential for spills that could occur from working in these conditions. While potential benefits such as job creation were seen as a positive outcome of exploration and development, the potential for oil spills and water contamination was viewed as too great. A more comprehensive discussion of offshore oil development and its potential threat to whitefish populations in the coastal habitat region will be in the next section.

Possible threats and concerns

Overfishing

There are 33 communities within the Coastal habitat region with a total population of almost 19,000 in 2008 (Appendix A2). Additionally, people from the lower Yukon and Kuskokwim River communities of Nunam Iqua, Alakanuk, Emmonak, Kotlik, Eek, and Tuntutuliak, because of their proximity to and extensive use of the coastal region, contribute approximately 3,000 more people to the population using the coastal environment. Fourteen of the coastal habitat region communities plus the four lower Yukon and two lower Kuskokwim River communities, with a total estimated population of 9,407, are within the Yukon Kuskokwim Delta, a region stretching from southern Kuskokwim Bay to the northern mouth of the Yukon River (Figure 90). The remaining 19 communities in the region, with a total estimated population of 12,625, are north of the Yukon River mouth and include communities in Norton Sound, the Seward Peninsula, and the southeast Chukchi Sea (Figure 91). Numerous anthropology studies of traditional economies and resource use in the region indicate that fishing is a tremendously important activity for virtually all communities and that fish, including whitefish species, provide a major component of annual food supplies (Wolfe 1981; Stickney 1984; Georgette and Shiedt 2005; Runfola 2011).

Current data on biology and demographics indicate that the Yukon Kuskokwim Delta habitat is dominated by immature and non-spawning mature fish of multiple populations that are widely distributed within the expanse of the delta. Documented spawning habitats are all located in upstream, gravel substrate reaches of the Yukon and Kuskokwim rivers and their tributaries. It may be that one or more whitefish populations spawn in the few suitable gravel substrate habitats within the delta, but if so, they have not been documented with appropriate observational or biological evidence. Because whitefish on the delta come from multiple populations and appear to be widely dispersed among brackish and freshwater habitats, we do not perceive any specific threat to whitefish populations from subsistence fisheries in the area. Subsistence whitefish fisheries north of the Yukon Kuskokwim Delta, for all species except Bering cisco, are thought to be exploiting populations with spawning origins that are not in the Yukon or Kuskokwim River drainages and therefore outside the scope of this discussion. Bering cisco across all of western Alaska are thought to have spawning origins in the Yukon or Kuskokwim River drainages. If this is true, all western Alaska harvests are from one or both of these populations. If one or more additional populations exist in western Alaska the spawning migration would have to be identified with appropriate maturity and spawning readiness sampling procedures. In any case, there is no information at this time that subsistence fisheries are threatening or not threatening whitefish populations of any species in the Yukon Kuskokwim Delta or of Bering cisco specifically in western Alaska.

The recently initiated commercial fishery for Bering cisco at the Yukon River mouth has the potential to expand to support what appears to be a large, smoked fish market in New York City (Fabricant 2008; Demarban 2010), which could threaten the contributing population or populations. The Bering cisco commercial fishery appears to be the first in Alaska to establish a reliable market for a whitefish species outside the State. When the commercial fishery began there was only a vague understanding of Bering cisco populations and life history (Alt 1973a; Brown et al. 2007), very little demographic data, no abundance information, and no population monitoring programs. Bering cisco populations were potentially at risk if the fishery had been allowed to expand without additional information. This realization has stimulated numerous projects investigating the demographic and population composition of the harvest. A comparison of length, age, and spawning readiness between fish harvested in the fishery and those sampled from the spawning migration up the Yukon River was conducted to determine the demographic composition of the fishery (R.J. Brown, USFWS, unpub. data; L. Dubois, ADFG, unpub. data). Bering cisco harvested in the fishery were on average smaller and younger (Figures 31 and 32) than mature fish migrating upstream to spawn. The gonadosomatic index (GSI) values of female Bering cisco from the fishery were very low, consistent with values of non-spawning individuals, compared to the high values of mature fish migrating upstream to spawn (Figure 33). These data indicated that the fishery was harvesting non-spawning Bering cisco that were predominantly immature. Because the fishery occurred in rearing habitat near the Yukon River mouth, it was possible that both Kuskokwim and Yukon River populations were present. A genetics project was initiated in 2009 to determine the population composition of the commercial harvest (U.S. Fish and Wildlife Service, Fishery Resource Monitoring Program, Project 10-

209). Baseline genetics samples were collected from the spawning migrations of all three known populations and mixture samples were collected from the fishery. If effective population baselines can be developed, it will be possible to estimate the population composition of the fishery, which would guide the development of a population monitoring program. A migration timing and relative abundance monitoring program for the Yukon River population has already begun, as described in the section on the Yukon River main-stem habitat region, but there is no similar monitoring program for the Kuskokwim River population. Theoretically, if the population composition of the commercial fishery harvest can be determined, and if effective monitoring programs are developed for the exploited populations, harvest levels that would not endanger Bering cisco populations and would not impact subsistence fisheries could be established. Additional information on rearing and spawning distribution, migration dynamics, natural mortality, and reproductive biology of Bering cisco would enhance monitoring and management programs and reduce the risk of population depletion.

Development issues

Perhaps the greatest potential threat to the coastal environments of the Yukon Kuskokwim Delta, northeastern Bering Sea, and southeastern Chukchi Sea would be a large spill from future offshore oil development on the continental shelves of the Bering or Chukchi seas. The threat to marine and coastal ecosystems from offshore oil development was recognized many years ago, which inspired the development and passage of the Outer Continental Shelf Lands Act (OCSLA) by the United States Congress in 1953 (U.S. Congress 1953). The OCSLA has been amended several times but the mandate for environmental studies in offshore areas subject to petroleum development has always remained part of the Act. The environmental studies were mandated to identify the biological resources in a region, predict environmental impacts of development, to design regulatory measures to protect resources, and to provide a baseline from which to measure environmental damage resulting from petroleum development activities, oil spills, or other accidents. Oil exploration activities have taken place on the shallow continental shelves of the Bering and Chukchi seas beginning in the 1960s, leases have been sold in both seas, exploratory wells have been drilled, but full development has not yet taken place (Burden et al. 1985; Minerals Management Service 2009). Over 450 leases were sold in the northeast Chukchi Sea in 2008 (U.S. Department of the Interior 2010, 2011) and exploratory drilling may begin on some of them as early as 2012 (Shell Gulf of Mexico 2011). Initial lease sales took place in 1986 in the North Aleutian Basin, a region of the continental shelf in the southeast Bering Sea that includes Bristol Bay, amid great resistance from Native groups, the fishing industry, the State of Alaska, and environmental organizations (MMS 2009; Alaska Marine Conservation Council 2011). Following the Exxon Valdez oil spill in 1989, these leases were bought back and eventually relinquished in 1995. President Clinton withdrew the region from oil leasing and development consideration in 1998 primarily because of the risk to the vibrant salmon fishery in Bristol Bay. The area was again opened by President Bush to oil leasing and development consideration in 2007, but was subsequently withdrawn in 2010 by President Obama. Offshore leases have been offered in other regions of the Bering Sea during the 1980s including the St. George Basin, which includes the shelf around the Pribilof Islands, the Navarin Basin, which is located in the central Bering Sea near the shelf break, and Norton Basin, located in the north and northeast Bering Sea (Burden et al. 1985). While exploratory wells have been drilled, full development has not been realized, the original leases are no longer active, and following President Obama's withdrawal of the North Aleutian Basin no Bering Sea areas are being considered during the current petroleum lease plan (MMS 2009; U.S. Department of the Interior 2010).

Politics may eventually be in favor of petroleum development on the continental shelf of the Bering Sea, which would increase the risk of a fuel spill that could impact the coastal rearing habitats along the Yukon Kuskokwim Delta. An oil spill in the northeast Chukchi Sea would not impact Bering Sea coastal habitats because of the northerly currents through the Bering Strait. A large oil spill in the southeastern Bering Sea, however, would drift north with the currents, potentially contacting shorelines across western Alaska, which could be devastating to coastal habitats of the Yukon Kuskokwim Delta and the whitefish populations that inhabit them. Smaller development activities near coastal communities such as dredging channels for boat passage or localized spills of sewage, fuel, or other toxic substances, may impact local environments but would be unlikely to impact populations of whitefish because members of populations are so widely dispersed in rearing and feeding environments across the delta. It is our belief that offshore petroleum development in the Bering Sea is the greatest development threat to the coastal habitat region and the whitefish populations that inhabit it.

Research Recommendations

In the final day of the second meeting, the Working Group identified issues of concern regarding whitefish species, populations, and fisheries in the Yukon and Kuskokwim River drainages. Each delegate had an opportunity to introduce up to three issues of concern based on group discussions and their unique historical knowledge. These issues were ranked among priority categories ranging from high to low. The Working Group had agreed that high priority issues were those in which the worst consequences of inaction or wrong decisions might include losing a species or a population; medium priority issues were those in which the worst consequences of inaction or wrong decisions might include losing a fishery or altering the natural distribution of a population; and low priority issues were those in which the worst consequences of inaction or wrong decisions might include reducing population abundance. While not all of the identified issues of concern could be neatly categorized into just one of the priority levels, they were organized into three major categories including; fisheries, development, and natural environmental issues. The Working Group agreed that a lack of biological and harvest information could threaten whitefish populations in situations where fisheries were permitted to take place without sufficient data for effective monitoring and management. It was also agreed that nearly all whitefish fisheries in the Yukon and Kuskokwim River drainages were data deficient. Species-specific harvest information was considered by many delegates to be a critical component of any management plan. Some delegates suggested that useful biological data for exploited whitefish species included the locations of their spawning grounds, migratory characteristics, minimum age at maturity, spawning frequency, age structure, demographic composition of the harvest, and other life history qualities. Many delegates considered the development of genetics baseline data to be a potentially important tool for management of heavily exploited species. These same issues of concern have been identified by others in different river systems as well (Corkum and McCart 1981; Bodaly 1986). These issues of concern were ranked in priority and recommendations were developed for a general order of investigation for any exploited whitefish population. It was recommended that:

1) Exploited species must be identified using appropriate keys when necessary
2) An estimate of the number of fish of each species harvested is essential for population assessment or harvest management studies
3) The demographic composition of the harvest should be investigated
    a. Length composition can help once minimum length at maturity is known
    b. Age composition can help once minimum age at maturity is known
    c. Gonadosomatic index (GSI = (egg weight/whole body weight)•100) will identify mature females preparing to spawn based on established classification criteria
4) Spawning origins of priority species must be located to identify populations
    a. Radio telemetry techniques have proven to be most effective
    b. Once identified, spawning habitats may be protected from development impacts
5) Migration destinations and timing will identify communities that exploit a population
    a. These data would permit an estimate of total harvest of a population
    b. Genetics baseline data may permit the proportional contributions of multiple populations of a priority species in the harvests

6) Once spawning areas are identified, sampling mature component of populations is possible
    a. Baseline genetics collections may be obtained for possible mixed population analyses
    b. Age and length composition of mature component of population may be described
    c. Shifts in age or length distributions may reveal population declines or large recruitment events
7) Abundance of spawning population may enable monitoring the effects of a fishery
    a. Mark recapture techniques possible in some situations
    b. DIDSON sonar possible in some locations
    c. Relative abundance may be adequate if it reflects actual abundance
    d. Prerequisite to fishery effects analysis would be to describe natural variation of annual spawning population abundance, if possible

While all six common whitefish species are unquestionably important from an ecological perspective, it was generally agreed among members of the Working Group that inconnu, broad whitefish, humpback whitefish, and Bering cisco were more directly exploited in fisheries in the Yukon and Kuskokwim River drainages than least cisco or round whitefish and that research should focus on these four priority species. Following is a summary of life history data for each of the four priority species along with some of the more pressing fisheries related issues that were introduced in the Working Group meetings. Issues related to development, habitat, and climate change were also introduced in the Working Group meetings, but, they are not being discussed in this context.

Inconnu

More research has been conducted on inconnu than on other whitefish species and inconnu are routinely identified in subsistence harvest assessments. Documented spawning areas in the Yukon River drainage are in the Alatna River in the upper Koyukuk River drainage (Alt 1977a), the upper Yukon Flats in the main stem of the Yukon River (Brown 2000), the Sulukna River, a tributary of the Nowitna River (Alt 1985; Gerken 2009), and the Chatanika River (Alt 1969a), a tributary of the Tanana River. Recent radio telemetry studies have led to the identification of two additional spawning areas; one in the main-stem Tanana River in the braided region between the mouths of the Chena and Salcha rivers (R.J. Brown, USFWS; A. Gryska, ADFG, unpub. data), and in the upper Innoko River near the mouth of Folger Creek (R.J. Brown, USFWS; J. Burr, ADFG, unpub. data). Sample data suggest that additional spawning populations of inconnu are present in the upper Porcupine River drainage (Bryan 1973; Brown et al. 2007) and in the Upper Yukon River drainage in Canada (Walker et al. 1974; Walker 1976; Bradford et al. 2008), but, these spawning habitats have not been located. Inconnu spawning areas in the Kuskokwim River drainage have been identified in Big River, the Middle Fork Kuskokwim River, and in the lower reaches of Highpower Creek (Alt 1972, 1981a; Stuby 2010). A recent radio telemetry study has identified an additional reach near the confluence of the Tonzona and East Fork Kuskokwim rivers that may also be an inconnu spawning area (Stuby 2010). Radio telemetry data indicate that nearly all inconnu in the Yukon and Kuskokwim River drainages originate in the 10 spawning reaches that have been identified, six in the Yukon River and four in the Kuskokwim River, plus those originating in the upper Porcupine and Yukon River drainage in Canada.

Annual, drainage-wide harvests of inconnu in the Yukon and Kuskokwim River drainages have never been estimated. However, estimates from subsistence surveys of subsamples of fishing families suggest that between 12,000 and 20,000 inconnu are harvested each year in the Yukon River drainage in Alaska (Brase and Hamner 2003), many as incidental harvests during Pacific salmon fisheries. Multiple populations contribute to these harvests but the proportional contributions are unknown. Incidental inconnu harvests in commercial fisheries for lake whitefish and lake trout in the Great Slave Lake in Canada have led to the extinction of three of five known spawning populations in that drainage system because the commercial fisheries continued despite declining numbers of inconnu (Cosens et al. 1993; VanGerwen-Toyne et al. 2010). Inconnu migrate to feeding and spawning areas each summer and fall along the Yukon and Kuskokwim rivers during the same time periods when Chinook and chum salmon fisheries take place. Inconnu are vulnerable to the same gillnets and fish wheels that are set for salmon. Similar to the situation in Great Slave Lake, it is unlikely that the Pacific salmon fisheries within the Yukon and Kuskokwim River drainages would be reduced even if inconnu populations were declining. In practice, however, it would be impossible to detect inconnu population changes within the Yukon or Kuskokwim River drainages because no effective monitoring program is in place for any population.

Abundance data have only been available from the Sulukna River and Chatanika River populations within the Yukon River drainage. The Sulukna River spawning population was counted with a DIDSON sonar system in fall 2008 and 2009 and found to include approximately 2,100 and 3,500 spawning inconnu respectively (Esse 2011). The inconnu spawning population in the Chatanika River was estimated, using weir and rudimentary mark recapture techniques, to be approximately 100 fish during both 1968 and 1972 (Alt 1969b; Kepler 1973). No recent estimates have been obtained for the Chatanika River population but anecdotal accounts indicated that inconnu are occasionally observed during the fall spawning season. Tagging and catch rate data suggest that the upper Koyukuk and Yukon River populations are larger than Sulukna or Chatanika River populations (Alt 1977a; R.J. Brown, USFWS, unpub. data), however, the magnitude of these larger populations is unknown. No relative or absolute abundance data are available for Kuskokwim River inconnu populations. Sustainable harvest levels have not been determined for inconnu populations anywhere. In the absence of reliable harvest and monitoring programs it seems possible that Yukon and Kuskokwim River inconnu populations could be steadily overharvested and would be noticed only if a population disappeared entirely, similar to the extinct Great Slave Lake populations that originated in the Hay, Little Buffalo, and Talston rivers (VanGerwen-Toyne et al. 2010).

Priority inconnu research (relative importance is not implied by order) in the Yukon and Kuskokwim River drainages should include:

1) <u>Collection of high-quality, drainage-wide, annual harvest data.</u> Inconnu are easily recognized so annual harvest data could be collected throughout the drainages, perhaps using fish calendars so estimates are not based on winter memories of summer harvests, a data collection process with limited utility for management or

population assessment purposes. In addition, traditional knowledge studies documenting customary and traditional fishing practices for inconnu should be pursued for management purposes and to improve understanding of the seasonal timing and geographic locations of these harvests, particularly the lower Yukon River and the Kuskokwim River drainage.

2) <u>Development of genetics baselines for the known populations.</u> Adequate genetics baseline samples have been collected from the Yukon River main stem, Sulukna River, and upper Innoko River populations in the Yukon River drainage. Additional genetics baseline samples should ideally be collected for the Alatna, Tanana, and Chatanika River populations in the Yukon River drainage, and from the Big River, Middle Fork Kuskokwim River, and Highpower Creek populations in the Kuskokwim River drainage. Once baseline samples have been collected, development of genetics baselines useful in determining population composition of mixed samples for the various inconnu populations should be pursued within the State of Alaska Gene Conservation Laboratory or the U.S. Fish and Wildlife Service Conservation Genetics Laboratory. High quality harvest data along with mixed population genetics analyses could be used to estimate population-specific harvests and direct research towards the most heavily exploited populations.

3) <u>An update on the status of the Chatanika River and Highpower Creek inconnu spawning populations that were last sampled almost 40 years ago</u> (Kepler 1973; Alt 1972). Estimates of the spawning population in the Chatanika River at the time were extraordinarily small. The Highpower Creek population does not appear to have been represented in a recent drainage-wide telemetry study of inconnu spawning origins in the Kuskokwim River (Stuby 2010), suggesting a similarly small population. The status of these two minor spawning populations should be reexamined.

4) <u>Attempts to locate and confirm other suspected spawning areas in the Yukon and Kuskokwim River drainages.</u> Radio telemetry methods are required to locate spawning reaches and field sampling projects designed to identify spawning readiness will confirm the reaches as spawning areas.

5) <u>Collection of population-specific length and age data.</u> Male inconnu tend to be smaller and mature a year or so earlier than females (Brown 2000; Gerken 2009; Esse 2011), so collections of length and age data should be sex specific. Population specific length and age distributions will change if the exploitation level changes dramatically, so establishing these distributions can be useful.

6) <u>Development of methods to estimate the abundance of inconnu spawning populations.</u>

    a. Relative abundance data such as catch per unit of sampling effort may allow the detection of large changes in abundance if catch rate data actually reflect abundance.

    b. Mark and recapture experiments may be effective with some populations where two capture events are possible. These experiments have been used successfully with inconnu populations in other drainages and provide defensible quantitative estimates with confidence intervals of spawning populations (Taube and Wuttig 1998; Hander et al. 2008). Identifying population increases or decreases of 25 to 50% may be possible with mark and recapture experiments (Seber 2002).

c. A DIDSON sonar system has been used with great effect to count the downstream migration of post-spawning inconnu in the Sulukna River (Esse 2011). The Sulukna River is a relatively small drainage for an inconnu spawning area. Because other species are often present in inconnu spawning reaches, the distance from the sonar transducer to migrating fish has to be relatively short, ideally 10 m (33 feet) or less, to be able to identify inconnu from other smaller species based on size criteria (Burwen et al. 2010). In situations where the DIDSON sonar system is appropriate, it is theoretically possible to count every fish, allowing very small changes in spawning population abundance to be detected. Understanding natural spawning population variability would be essential to attributing observed changes in abundance to changes in exploitation rate. Therefore, one or more long term (ten years or more) DIDSON sonar projects should be considered for appropriate spawning populations.

Broad whitefish

Up until the last 10 years or so, research on broad whitefish within the study region was essentially limited to distribution and growth rate type information (Alt 1976). No spawning locations had been identified until radio telemetry studies focused on the issue during the last decade. Spawning locations in the Yukon River drainage have been identified in the Alatna River in the upper Koyukuk River drainage (Brown 2009), the middle reaches of the Yukon Flats (Carter 2010), and the braided region of the Tanana River between the Chena and Salcha River mouths (R.J. Brown, USFWS, unpub. data). Otolith chemistry analyses indicated that many broad whitefish in these spawning populations were anadromous, rearing in marine water near the mouth of the Yukon River (Brown et al. 2007). Sampling data indicate that there is a spawning migration of broad whitefish up the Porcupine River into Canada (Bryan 1973; Brown et al. 2007), and there are undoubtedly one or more spawning populations in the upper Yukon River drainage in Yukon Territory as well (Walker et al. 1974; Walker 1976), although spawning locations in these upper reaches of the drainage have not been identified. These upper drainage populations appear to be non-anadromous (Brown et al. 2007), remaining in freshwater habitats throughout life. Two spawning locations have been identified in the Kuskokwim River drainage; one in a main-stem reach in the vicinity of the Middle Fork Kuskokwim River mouth and the other in a main-stem reach near the mouth of the Swift River (Harper et al. 2009). Tagging and otolith chemistry studies have shown that many broad whitefish from these populations are anadromous, rearing in Kuskokwim Bay or the Yukon Kuskokwim Delta region (Harper et al. 2007). There are reports of broad whitefish in Chandalar Lake in the upper Chandalar River drainage (Kramer 1976b), Minchumina Lake in the Tanana River drainage (Kramer 1975), and Whitefish Lake in the headwaters of the Hoholitna River (Baxter 1973). Their presence in these upper drainage lakes could be the result of feeding migrations of populations with spawning origins downstream, or it may be that broad whitefish actually spawn within these lake systems and maintain isolated populations there. Isolated populations of broad whitefish within lake systems have only been identified in the Travaillant Lake system in the lower Mackenzie River drainage in Canada (Chudobiak 1995; Harris and Howland 2005), so it would be a significant discovery if isolated populations were documented in Chandalar, Minchumina, or Whitefish lakes. Telemetry data from the Yukon and Kuskokwim River drainages indicate that broad whitefish spawn in large rivers in late October and November (Harper et al. 2009; Carter 2010), which is consistent with similar data from Canada and Russia (Shestakov 2001; VanGerwen-Toyne et al. 2008). Because large rivers are difficult environments to sample during the early winter season, and radio telemetry studies that have been conducted are not comprehensive within the two drainages, it is possible that additional spawning populations exist.

Annual harvest and spawning population abundance data for broad whitefish within the Yukon and Kuskokwim River drainages are very poor. Broad whitefish are usually grouped into a general whitefish category in annual subsistence harvest reports because many people do not distinguish them from humpback whitefish, a related species that is similar in size and shape (Brase and Hamner 2003; Hayes et al. 2008; Whitmore et al. 2008). A small number of recent subsistence research reports have gathered species-specific harvest data for various regions within our study area but none provide a time series (Brown et al. 2005; Andersen 2007). Nearly all of these harvest data, however, have been generated from winter memories of summer harvests, which have limited utility for management or population assessment purposes. There have been no attempts to estimate spawning population abundance for any broad whitefish population within the Yukon or Kuskokwim River drainages. Relative abundance data from a broad whitefish spawning migration have been collected for the last 10 years in the main-stem Yukon River (Figure 30; Brown et al. 2012). These data have been useful in describing the timing of the spawning migration at the sample site but not the actual abundance of the spawning population. Similarly, a weir at the outlet to Whitefish Lake in the lower Kuskokwim River drainage (Figure 82) has counted broad whitefish migrating into the lake to feed during summer and out of the lake as they return to the river to spawn and overwinter (Harper et al. 2007). Many broad whitefish, however, entered the lake before and left after the weir was operational so no reliable estimate of the feeding group has been obtained. Broad whitefish feeding in Whitefish Lake are both mature and immature fish from one or more spawning populations so it is unclear how the abundance of the feeding group relates to the abundance of spawning populations in the Kuskokwim River drainage. Essentially, there are no reliable estimates of subsistence harvests or population abundances of broad whitefish within the Yukon or Kuskokwim River drainages.

Priority broad whitefish research (relative importance is not implied by order) in the Yukon and Kuskokwim River drainages should include:

1) <u>Collection of high-quality, drainage-wide, annual harvest data.</u> Broad whitefish are frequently misidentified, even in biological sampling studies, so obtaining reliable harvest data may be difficult. The development of a fish calendar with clear photographs illustrating distinctive differences among whitefish species may resolve identification problems and allow reliable, in-season harvest data to be collected within both drainages. In addition, traditional knowledge studies documenting customary and traditional fishing practices for broad whitefish should be pursued for

management purposes and to improve understanding of the seasonal timing and geographic locations of these harvests, particularly the lower Yukon River and the Kuskokwim River drainage.

2) Attempts to locate and confirm other suspected spawning areas in the Yukon and Kuskokwim River drainages. Radio telemetry studies should be conducted in the Yukon and Kuskokwim River drainages to confirm suspected spawning populations and locate new spawning populations if they exist. The probability of additional broad whitefish spawning populations may be greatest in the Innoko, Nowitna, Kantishna, Chandalar, and Porcupine River drainages in the Yukon River, and in the Holitna River or upper reaches of the Kuskokwim River in the Kuskokwim River drainage.

3) Investigation of the existence of isolated broad whitefish populations in Chandalar Lake in the Yukon River drainage, Lake Minchumina in the Tanana River drainage, and in Whitefish Lake in the upper Hoholitna River drainage. This would be interesting population research, but to our knowledge, there are no significant fisheries or development threats in these lakes so they are not thought to be particularly high priority issues.

4) Collection of genetics baseline samples from known spawning populations and subsequent development of population baselines capable of distinguishing among populations. Mixed population analyses could eventually be a useful tool to identify heavily exploited populations.

5) Collection of population-specific length and age data. These data, which must be collected from spawning reaches or spawning migrations downstream from spawning reaches, will allow demographic groups to be identified and generation times to be estimated.

6) Development of methods to estimate the abundance or otherwise monitor variation in broad whitefish spawning populations.

    a. Spawning population abundance estimates using mark and recapture techniques may be possible for some populations, although success seems unlikely given the large river spawning sites used by broad whitefish and the lateness of their spawning season. Sonar is unlikely to be effective because of the large river habitats and the size similarity of broad whitefish with numerous other species that may also be in the river.

    b. Relative measures of abundance from a standardized capture operation such as a fish wheel may provide rough indicators of abundance but there are many complicating factors to this approach including capture probabilities that may vary with water level, spawning migration timing that extends through freeze-up, unknown spawning frequency, and more.

    c. Age structure analyses of spawning populations may be the best approach to understanding whether a population is being over-exploited or not. Older age classes tend to be absent in heavily exploited populations of whitefish with relatively constant recruitment (Healey 1975, 1980; Mills et al. 1995). However, a similar age structure may be observed from a sample following a large recruitment event and distinguishing between the two possibilities is not trivial (Hander et al. 2008). In the first case the older age classes are not present in the sample because they are not present in the population. In the latter case the older age classes are not present in the sample because they become a very small fraction of the population following the recruitment of huge numbers of young fish and the probability of sampling them becomes very small. Annual recruitment sampling for young broad whitefish in lower drainage rearing habitats may help interpret age distribution samples of broad whitefish spawning populations.

d. While monitoring broad whitefish populations may be extraordinarily difficult, the first step to any population assessment activities will be to identify the spawning populations and explore options from there.

Humpback whitefish

Many humpback whitefish spawning areas have been documented in riverine habitats of the Yukon and Kuskokwim River drainages. In addition, humpback whitefish are present in numerous upland lakes in both drainages and the species is known to maintain isolated populations in upland lakes (Bodaly 1979; Anras et al. 1999). Known humpback whitefish riverine spawning areas in the Yukon River drainage include three in the upper Koyukuk River drainage (Brown 2009), one in the upper reaches of the Yukon Flats (Brown 2000), at least six in the Tanana River drainage (Kepler 1973; Brown 2006), one in the Sulukna River, a tributary of the Nowitna River (Alt 1978a, 1985), one in the upper Innoko River (Alt 1983), and many more are suspected. Otolith chemistry analyses indicated that many humpback whitefish in riverine spawning populations were anadromous, rearing in marine water near the mouth of the Yukon River (Brown et al. 2007). Sampling studies indicate that a spawning migration takes place up the Porcupine River into Yukon Territory and humpback whitefish are widely distributed in rivers and lakes in the upper Yukon River drainage in Yukon Territory as well (Bryan 1973; Walker 1976), although, to our knowledge riverine spawning areas have not been identified. The upper drainage populations appear to be non-anadromous, remaining in freshwater habitats throughout life (Brown et al. 2007). Documented riverine spawning areas in the Kuskokwim River drainage are in the Holitna, Swift, and Big rivers, as well as in Ophir Creek, a tributary of Whitefish Lake in the lower Kuskokwim River (Harper et al. 2009). Several other spawning areas are suspected including a main-stem reach of the Kuskokwim River downstream from Aniak (Harper et al. 2009), the South Fork Kuskokwim River (M. Thalhauser, KNA, pers. com.), and the Swift Fork of the North Fork Kuskokwim River (Alt 1972), although these have not been verified. Tagging and otolith chemistry studies have shown the many humpback whitefish from Kuskokwim River populations are anadromous and rear or feed in marine water for some period of time (Harper et al. 2007). It is likely that additional humpback whitefish spawning areas will eventually be discovered in the Yukon and Kuskokwim River drainages.

In addition to identifying spawning and rearing habitats, migration timing, spawning timing, reproductive biology, age, and population abundance studies have been conducted with humpback whitefish populations in the Yukon and Kuskokwim River drainages. Humpback whitefish colonize off-channel lakes and low-flow stream and river systems during the spring and early summer each year to feed (Alt 1979a; Brown 2006; Harper et al. 2007). A recent weir project operated in the stream flowing from Whitefish Lake, a large, shallow, feeding lake in the lower Kuskokwim River drainage (Figure 82), has counted as many as 32,000 humpback whitefish leaving the lake from mid to late summer some years (Harper et al. 2007). They apparently migrate into the lake each spring before the ice melts. Spawning migrations may begin as early as late June or July and spawning takes place between late September and mid-October for river spawning populations (Brown 2006, 2009; Harper et al. 2007). Spawning migrations can be very extensive, with some populations migrating more than 1,000 km between feeding and spawning habitats (Brown et al. 2007). Female humpback whitefish may carry as many as 50,000 eggs or more for each spawning event (Clark and Bernard 1992; Moulton et al. 1997; Dupuis and Sutton 2011). Minimum age at maturity for most populations in northwest North America is from 4 to 6 years (Harper et al. 2007; VanGerwen-Toyne et al. 2008; Brown 2009), and the oldest individuals within populations are usually between age 20 and age 30 (Moulton et al. 1997; Brown 2004; Harper et al. 2007). Several abundance estimates have been obtained for the Chatanika River humpback whitefish spawning population, which has ranged from about 12,000 to 40,000 fish during the last 25 years (Brase 2010). A spear fishery was established in the spawning area of this population during the 1980s and its proximity to the community of Fairbanks, with its large urban population, mandated the monitoring effort. A management plan for this fishery, which included least cisco as well, was developed in 1992. The plan established precautionary threshold spawning population levels of 10,000 humpback whitefish and 40,000 least cisco before the fishery could take place. The Chatanika River humpback whitefish fishery is the only one in Alaska that is managed based on population abundance data.

Annual harvest data for humpback whitefish within the Yukon and Kuskokwim River drainages are very poor. Humpback whitefish are usually grouped into a general whitefish category in annual subsistence harvest reports because many people do not distinguish them from broad whitefish, a related species that is similar in size and shape (Brase and Hamner 2003; Hayes et al. 2008; Whitmore et al. 2008). A small number of recent subsistence research reports have gathered species-specific harvest data for various regions within the study area (Brown et al. 2005; Andersen 2007). All of these harvest data, however, have been generated from winter memories of summer harvests, which have limited utility for management or population assessment purposes. Relative abundance data from a humpback whitefish spawning migration have been collected for the last 10 years in the main-stem Yukon River (Figure 30; Brown et al. 2012). These data have been useful in describing the timing of the spawning migration at the sample site but not the actual abundance of the spawning population. A weir at the outlet to Whitefish Lake in the lower Kuskokwim River drainage, which was discussed in the previous section, has counted humpback whitefish migrating into the lake to feed during summer and out of the lake as they return to the river to spawn and overwinter (Harper et al. 2007). Many humpback whitefish, however, entered the lake before and left after the weir was operational so no reliable estimate of the feeding group has been obtained. Humpback whitefish feeding in Whitefish Lake are both mature and immature fish from at least three spawning populations so it is unclear how the abundance of the feeding group relates to the abundance of spawning populations in the Kuskokwim River drainage. Essentially, there are no reliable estimates of subsistence harvests of humpback whitefish within the Yukon or Kuskokwim River drainages and the only reliable population abundance estimates are from the Chatanika River spawning population (Wuttig 2009).

Priority humpback whitefish research (relative importance is not implied by order) in the Yukon and Kuskokwim River drainages should include:

1) <u>Collection of high-quality, drainage-wide, annual harvest data.</u> Similar to the situation with broad whitefish, humpback whitefish are frequently misidentified, even in biological sampling studies, so obtaining reliable harvest data may be difficult. The development of a fish calendar with clear photographs illustrating distinctive differences among whitefish species may resolve identification problems and allow reliable, in-season harvest data to be collected within both drainages. A harvest calendar approach with clear photos should allow humpback whitefish harvests to be collected simultaneously with those of inconnu, broad whitefish, and other species. In addition, traditional knowledge studies documenting customary and traditional fishing practices for humpback whitefish should be pursued for management purposes and to improve understanding of the seasonal timing and geographic locations of these harvests, particularly the lower Yukon River and the Kuskokwim River drainage.

2) <u>Attempts to locate or confirm additional spawning areas in the Yukon and Kuskokwim River drainages.</u> Radio telemetry studies should be conducted in the Yukon and Kuskokwim River drainages to confirm suspected spawning populations and locate new spawning populations if they exist. As with other whitefish species, locating spawning habitats is the first step towards any humpback whitefish population assessment work, genetics collections, or habitat protection activities.

3) <u>Collection of genetics baseline samples from known spawning populations and subsequent development of population baselines capable of distinguishing among populations or groups of populations.</u> The large number of humpback whitefish spawning areas, some in close proximity to others, suggests that it may be difficult to obtain useful genetics baselines for mixed population assessments, although there may be specific exceptions. It may be that regional groups of populations will display identifiable genetics qualities, similar to the regional groupings of Pacific salmon species in the Yukon River drainage (Flannery et al. 2007; Beacham et al. 2008), in which case baseline genetics collections of certain populations may be justified. We would encourage any researchers to discuss their ideas with the Alaska genetics laboratories in the early planning stages of any project to ensure support. Without a way to identify the contributing populations to humpback whitefish harvests in various regions of our study area harvest data would simply be baseline records that may become valuable at a later date.

4) <u>Collection of population-specific length and age data.</u> Minimum length and age at maturity data are available for several humpback whitefish populations in the Yukon and Kuskokwim River drainages. Similar values are observed among populations so this is not seen as high priority, although there may be specific cases where these data would be important. In the absence of spawning population abundance data, which

may be difficult or impossible to obtain from populations spawning in large rivers, age structure analyses may be the best approach to understanding whether a population is being over-exploited or not. Older age classes tend to be absent in heavily exploited populations of humpback whitefish (Healey 1975, 1980; Mills et al. 1995). As discussed in the section on broad whitefish above, however, there are many complicating factors in age structure analyses that may require recruitment sampling or other data to resolve.

5) Investigation of isolated humpback whitefish populations in upland lakes. Lake resident populations have not been studied in the Yukon or Kuskokwim River drainages in Alaska, although they have been intensively studied in Canada (Bodaly 1979; Healey 1980; Anras et al. 1999). Lake resident populations of humpback whitefish, referred to as lake whitefish in Canada, are the most intensively exploited whitefish species in North America supporting huge commercial fisheries outside of Alaska (Bodaly 1986; Fleischer 1992; Tallman and Friesen 2007). Isolated lake populations are relatively easy to sample and monitor compared to riverine populations (Mohr and Ebener 2007). Additionally, there is a large body of literature describing the effects of fishing on recruitment, length and age distributions, and growth rates of isolated lake populations (Johnson 1976; Healey 1980; Mills et al. 1995). There are no known fisheries or development threats in upland lakes within the Yukon and Kuskokwim River drainages in Alaska so they are not thought to be high priority issues, however, it would be valuable to study population characteristics of one or more isolated populations to establish baseline length, age, and recruitment characteristics.

Bering cisco

Research on Bering cisco focused initially on taxonomy and distribution and more recently on life history and migration (McPhail 1966; Alt 1973a; Brown et al. 2007). Bering cisco are commonly found rearing in coastal waters and estuaries of western Alaska from Kuskokwim Bay in the south to Kotzebue Sound in the north (Alt 1973a; Stickney 1984, Georgette and Shiedt 2005; LaVine et al. 2007). They are occasionally encountered as far north as the Colville River delta and there are a few isolated records from Bristol Bay (McPhail 1966; Bickham et al. 1997). Rearing Bering cisco are not found in freshwater habitats beyond river mouths, indicating that the species is fully anadromous. Despite sampling in virtually all the major and most of the minor drainages in south central, Alaska Peninsula, Bristol Bay, western Alaska, and northwest Alaska, spawning migrations have only been documented in three rivers: the Yukon and Kuskokwim rivers in western Alaska (Alt 1973a; Brown et al. 2007; M. Thalhauser, Kuskokwim Native Association, unpublished data), and the Susitna River in south central Alaska (ADFG 1983). Bering cisco have not been identified in Asian Rivers and only two individuals have been documented on the Asian side of the Bering Strait in an estuary on the north coast of the Chukotsk Peninsula (Chereshnev 1984; Chereshnev et al. 2002). Within the Yukon and Kuskokwim River drainages, Bering cisco migrate up the main stems and not into tributaries (Alt 1973a; Brown et al. 2007). They are known to spawn in the upper reaches of the Yukon Flats in the main-stem Yukon River but it is not know how far upstream and downstream from this region spawning occurs. Fishers in the community of Circle, in the upper Yukon Flats, report catching hundreds of Bering cisco in late September. By contrast, fishers in the community of Eagle, about 257 km (160 miles) upstream from Circle near the Alaska/Yukon Territory border, report catching as few as 10 or 20 Bering cisco during fall on a good year. These data suggest that most Yukon River Bering cisco spawn in the Yukon Flats region. Kuskokwim River Bering cisco appear to migrate up the main stem to the confluence of the North and South forks of the Kuskokwim River and then migrate up the South Fork Kuskokwim River to spawn. Sampling in the early 1970s (Alt 1973a) suggested this migration destination and recent sampling in September confirmed that Bering cisco spawn in the South Fork Kuskokwim River (M. Thalhauser, Kuskokwim Native Association, unpublished data). Other spawning destinations in the Kuskokwim River are possible but we have no sampling evidence to support this hypothesis. In the Susitna River in the early 1980s, when fisheries research was being conducted in response to potential hydroelectric development in that drainage, pre-spawning Bering cisco were found migrating up the main stem and did not migrate into tributaries (ADFG 1983). Similar to spawning habitats in the Yukon and Kuskokwim rivers, spawning areas were located in braided habitats of the main-stem Susitna River. These data suggest that Bering cisco are endemic to Alaska and that there may be only three spawning populations.

Bering cisco are specifically targeted in many coastal communities in western Alaska (Stickney 1984; Georgette and Shiedt 2005; LaVine et al. 2007), are incidentally harvested in fish wheel salmon fisheries in the Yukon and Kuskokwim River drainages (Daum 2005; Brown et al. 2007), and are the primary species taken in a commercial fishery at the mouth of the Yukon River (Fabricant 2008; Hayes et al. 2008). Annual subsistence harvest data for Bering cisco have not been collected but there is a good harvest record from the commercial fishery where up to about 10,000 Bering cisco have been harvested each year since 2005 (S. Hayes, ADFG, unpublished data). Coastal harvests are probably mixtures of Yukon and Kuskokwim River populations while upstream harvests are almost certainly population specific.

Population abundance data for Bering cisco are limited to the catch rate data collected recently from the video fish wheel at Rapids Research Site on the Yukon River main stem about 1,176 km (731 miles) from the sea (Figure 29; Brown et al. 2012) and similar data collected during the SuHydro studies on the Susitna River during the early 1980s (ADFG 1983). No other relative or absolute abundance data are available for Bering cisco. The video fish wheel at the Rapids Research Site has run almost every day each summer from about mid-June until late September since 2001. Several high-resolution photographs are taken of every fish captured (Daum 2005). Daily catches of every species are tabulated revealing seasonal patterns of abundance. This 10 year record has revealed a great deal about migration timing but very little about actual abundance. In contrast to other whitefish species, the Bering cisco spawning migration past the Rapids Research Site is underway when sampling begins in mid-June each year with catch rates as high as 100 to 200 Bering cisco per day. Several periods of relatively high catch rates, with maximum catches of 200 to almost 700 Bering cisco per day, are observed each summer (Figure 29). These pulses of Bering cisco are thought to represent the spawning members of groups of fish coming from different rearing habitats. Presumably fish that reared in the Yukon River delta, for example, would enter the river earlier than those rearing in more distant estuaries such as Golovnin Lagoon, Imuruk Basin, or Hotham Inlet. No similar migration data are available for Kuskokwim River Bering cisco.

The recently initiated commercial fishery (fishery) for Bering cisco at the mouth of the Yukon River has stimulated numerous projects investigating the demographic and population composition of the harvest. The fishery appears to be the first in Alaska to establish a reliable market for a whitefish species outside of the State and it has the potential to expand if permitted to do so (Fabricant 2008; Demarban 2010). When the fishery began there was only a vague understanding of Bering cisco populations and life history (Alt 1973a; Brown et al. 2007), very little demographic data, no abundance information, and no population monitoring programs. Bering cisco populations were potentially at risk if the fishery had been allowed to expand without additional information. A comparison of length (Figure 31), age (Figure 32), and spawning readiness (Figure 33) was conducted between fish harvested in the fishery and those sampled from the spawning migration up the Yukon River to determine the demographic composition of the fishery. Bering cisco harvested in the fishery were on average smaller and younger than mature fish migrating upstream to spawn. The gonadosomatic index (GSI) values of female Bering cisco from the fishery were very low, consistent with non-spawning individuals, compared to the high values of mature fish migrating upstream to spawn. These data indicated that the fishery was harvesting non-spawning Bering cisco that were predominantly immature. Because the fishery occurred in rearing habitat near the Yukon River mouth, it was possible that both Kuskokwim and Yukon River populations were present. While a migration timing and relative abundance monitoring program for the Yukon River population has begun, as described above, there is no such information for the Kuskokwim River population. It was clearly important to understand the population composition of the commercial harvest before expanding this fishery. A genetics project was initiated in 2009 to address this issue (U.S. Fish and Wildlife Service, Fishery Resource Monitoring Program, Project 10-209). Baseline genetics samples were collected from the spawning migrations of all three known populations and mixture samples were collected from the fishery. If effective population baselines can be developed, it will be possible to estimate the population composition of the fishery, which would guide the development of a population monitoring program.

Priority Bering cisco research (relative importance is not implied by order) in the Yukon and Kuskokwim River drainages should include:

1) <u>Collection of high-quality annual harvest data, particularly from the coastal fisheries.</u> The Bering cisco subsistence harvest in coastal communities of western Alaska will be important if the commercial fishery is permitted to expand because both fisheries are thought to draw from the same two populations. In addition to numerical annual harvest data, traditional knowledge studies documenting customary and traditional fishing practices for Bering cisco should be pursued for management purposes and to improve understanding of the seasonal timing and geographic locations of these harvests. Harvest records from the commercial fishery are comprehensive but they are lacking from the subsistence fishery. If there is an effort at some point to maximize commercial harvest potential there may be allocation issues between these fisheries and subsistence harvest records will become very important.

2) <u>Sampling a selection of western Alaska rivers to identifying Bering cisco spawning migrations if they exist.</u> Identifying spawning migrations of Bering cisco requires directed sampling activities to catch them in rivers upstream from the estuaries and

then verifying their maturity status and spawning readiness (Brown et al. 2012). Sampling for species presence has been conducted in many western Alaska rivers and Bering cisco have often been identified in river deltas and estuaries but never in upstream habitats except in the Yukon and Kuskokwim rivers (Alt 1971b, 1973a, 1977b, 1979b, 1980b, 1985). These sampling results are the basis for the hypothesis that spawning populations exist only in the Yukon and Kuskokwim rivers in western Alaska. A few rivers including the Goodnews, Koyuk, Fish, Kuzitrin, and Buckland rivers, are large enough to support whitefish populations, have seen minimal sampling activities in the past or whitefish species encountered were not identified, so there is some uncertainty whether Bering cisco enter these rivers to spawn or not. Sampling projects designed to identify spawning migrations of Bering cisco in these rivers would clarify the population status of the species. If additional spawning populations were identified in one or more of these rivers, it would change the dynamics of the Bering cisco fisheries.

3) <u>Delineation of the spawning distributions of Bering cisco in the Yukon and Kuskokwim River spawning areas.</u> Spawning locations in the Yukon and Kuskokwim River drainages are known to be in braided regions of the upper Yukon Flats and the South Fork Kuskokwim River respectively. However, the upstream and downstream limits of these spawning reaches are uncertain. Any attempts to conduct mark and recapture population estimates will require a better understanding of the distribution of spawning fish. Because Bering cisco spawn in large turbid rivers, radio telemetry will likely be the only effective way to identify the extent of these spawning reaches. In addition to the practical utility of this information for designing population sampling activities, the habitats could be protected if streambed gravel mining or other disruptive development projects are contemplated. Therefore, identifying Bering cisco spawning reaches in the Yukon and Kuskokwim River drainage is considered to be a priority.

4) <u>Development of Bering cisco population monitoring programs in the Yukon and Kuskokwim Rivers.</u> Three Bering cisco populations have been identified worldwide. If additional research continues to support this understanding, it will be absolutely critical that a precautionary approach be adopted towards management of the commercial fishery. Bering cisco populations should not be exposed to the elevated levels of risk that may be acceptable for species in which there are many populations. Ideally, monitoring programs in the Yukon and Kuskokwim rivers capable of detecting Bering cisco spawning population changes of 50% should be developed if there were a move to significantly expand the commercial fishery.

5) <u>A relative abundance method such as the sampling fish wheel at the Rapids Research Site (Brown et al. 2012) may be adequate, perhaps augmented with a few seasons of quantitative data for an order-of-magnitude scale relationship between the relative and quantitative measures.</u> Cumulative CPUE data are routinely used in salmon management (Molyneaux 1994; Flynn and Hilborn 2004; Hayes et al. 2008) and similar data from the Rapids Research Site may eventually be useful for Bering cisco (Figure 28). It is not clear whether sufficient numbers of Bering cisco can be captured in Kuskokwim River main-stem fish wheels to produce a similar index of

abundance for that population. If it can be confirmed that there is a single Bering cisco population in the Kuskokwim River drainage that spawns in the South Fork Kuskokwim River, then it may be possible to develop an effective CPUE sampling program within the lower reaches of that river near the community of Nikolai. Ultimately, fishery management plans should be developed that define allowable harvests and open or closed seasons based on precautionary threshold CPUE levels.

6) Quantitative spawning population abundance estimates may be possible with mark and recapture or DIDSON sonar projects, ideally in conjunction with a CPUE project so a relationship between the two might be explored. It seems unlikely that annual funding will be available for long-term application of quantitative methods of population assessment. If Bering cisco migrate near shore up the Yukon or other large rivers, a DIDSON sonar may be able to identify Bering cisco from other species based on size. These possibilities should be explored.

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Appendices A1 Through A7

Appendix A1. An explanation of the evidence or reasoning for species inclusion in the fish list (Table 1): Native freshwater and anadromous fish species present in the Yukon and Kuskokwim River drainages.

Thirty native species of freshwater and anadromous fish are known to occur in the Yukon and Kuskokwim River drainages combined (Table 1; based on Morrow 1980a; McPhail and Lindsey 1970; Lindsey and McPhail 1986; Mecklenburg et al. 2002; and other citations in text). Three species present in the Yukon River have not been documented in the Kuskokwim River (lake chub *Couesius plumbeus*, trout-perch *Percopsis omiscomaycus*, and Alaskan brook lamprey *Lampetra alaskense*) and one species present in the Kuskokwim River has not been documented in the Yukon River (rainbow trout). The Alaskan brook lamprey was originally described by Vladykov and Kott (1978; genus *Lethenteron* initially, *Lampetra* now) and identified in the Chatanika River within the Yukon River drainage. According to Mecklenberg et al. (2002), it has recently been identified in the Chena River as well, near the community of Fairbanks. It is likely that this species is more widely distributed than is currently recognized and may be present in the Kuskokwim River drainage as well. Pygmy whitefish have been identified in four lakes in the upper Yukon River drainage in Canada (Lindsey and Franzin 1972; Lindsey et al. 1981) but not in the Alaska portion of the drainage. More recently, Russell (1980) identified pygmy whitefish in several lakes within the Lake Clark National Park and Preserve includingTwo Lakes, a lake in the upper Stony River in the Kuskokwim River drainage. Only one humpback whitefish species within the "*Coregonus clupeaformis* complex" of McPhail and Lindsey (1970) is included in our species list. An explanation for this can be found in the taxonomy section of the introduction. Morrow (1973, 1980a) proposed an additional *Salvelinus* species in the upper reaches of the Koyukuk River drainage that he named Angayukaksurak charr *Salvelinus anaktuvukensis*, but, it was never embraced by the American Fisheries Society (Mecklenberg et al. 2002; Nelson et al. 2004) and we consider it here to be a Dolly Varden *S. malma*. Residents of the lower Kuskokwim River, up to about 350 rkm (217 miles) from the sea, harvest rainbow smelt during the spring spawning migration each year (Coffing 1991; Coffing et al. 2001; D. Cannon, resident of Aniak, pers. com.). Rainbow smelt are similarly harvested in the spring by residents of the Yukon River delta (Crawford 1979; Wolfe 1981), and have been documented in scientific sampling studies (Martin et al. 1986, 1987; Brown and Eiler 2005), but to our knowledge, they have not been documented beyond the delta channels in the Yukon River. Freshwater resident threespine stickleback are present in several lakes within Bristol Bay drainages (Burgner et al. 1965; Kerns 1968; Heard et al. 1969; Russell 1980) and in Goodnews Lake, within the Goodnews River drainage in southern Kuskokwim Bay (Alt 1977b). No freshwater forms have been identified within the Yukon or Kuskokwim River drainages, but, anadromous or marine forms have been documented from coastal environments of the Yukon and Kuskokwim River delta region (McPhail and Lindsey 1970; Martin et al. 1987). While threespine sticklebacks have not been formally documented upstream from coastal habitats, biologists working in the lower channels of the Yukon and Kuskokwim rivers, as well as residents of the area, contend that they are sometimes found in the lower reaches of both drainages (J. Chythlook, ADFG, pers. com.; J. Akaran, USFWS, pers. com.). It is not clear whether threespine sticklebacks are true native species or marine forms entering by chance with tidal currents, but we have included them in our fish list. Several truly marine fishes are encountered in the lower reaches of both drainages but they are not included in the list. In addition to native fishes, several salmonid species have been stocked in the Yukon River drainage lakes in Alaska, the Tanana River drainage primarily

(Bentz et al. 1991; Skagstad 2001; Behr and Skaugstad 2007), and in Canada (Walker et al. 1973; Brown et al. 1976; Lindsey and McPhail 1986). To our knowledge, only one of the non-native salmonid introductions has developed self-sustaining populations outside of the lakes or waterways where they were originally stocked; rainbow trout that were originally planted in McIntyre Creek near the community of Whitehorse in the Yukon Territory (Fisheries and Oceans Canada 2008). This fish list is as complete as possible given the sampling data available and our current understanding of the taxonomy.

Appendix A2. Communities within the Yukon and Kuskokwim River drainages in Alaska and in the coastal region of the Bering and Chukchi seas. Two Yukon Territory communities near the border with Alaska are also included. Population estimates are from 2006 to 2008 demographic surveys published by the U.S. Census Bureau (2010), City-data (2010), and Statistics Canada (2010). Locations are WGS84 datum.

Drainage or region	Community	Population	N Latitude	W Longitude
Yukon	Alakanuk	711	62.68468	164.65315
Yukon	Alatna	31	66.55292	152.70368
Yukon	Allakaket	85	66.56372	152.64148
Yukon	Anderson	271	64.34550	149.18789
Yukon	Anvik	91	62.65503	160.20395
Yukon	Arctic Village	136	68.12691	145.53540
Yukon	Beaver	75	66.36000	147.39576
Yukon	Bettles	38	66.91690	151.51809
Yukon	Birch Creek	28	66.26147	145.81519
Yukon	Cantwell	215	63.39266	148.94860
Yukon	Central	120	65.57195	144.80231
Yukon	Chalkyitsik	74	66.65378	143.72040
Yukon	Chicken	18	64.07390	141.93754
Yukon	Circle	89	65.82629	144.06202
Yukon	Coldfoot	11	67.25555	150.18728
Yukon	College	13,428	64.84830	147.82719
Yukon	Dawson[1]	1,330	64.06187	139.43164
Yukon	Delta Junction	930	64.03962	145.73137
Yukon	Dot Lake	21	63.66122	144.06445
Yukon	Eagle	145	64.78813	141.20208
Yukon	Eagle Village	75	64.77986	141.11102
Yukon	Eilson AFB	5,400	64.67972	147.08769
Yukon	Emmonak	841	62.77746	164.52727
Yukon	Ester	1978	64.85570	147.97843
Yukon	Evansville	25	66.92446	151.50476
Yukon	Fairbanks	35,132	64.84189	147.71917
Yukon	Fort Wainwright	10,900	64.82605	147.60805
Yukon	Fort Yukon	520	66.56462	145.27001
Yukon	Fox	353	64.95398	147.62833
Yukon	Galena	599	64.73418	156.92653
Yukon	Grayling	170	62.90403	160.06397
Yukon	Harding Lake area	216	64.42043	146.84939
Yukon	Healy	971	63.85697	148.96711
Yukon	Healy Lake	37	64.00038	144.73564
Yukon	Holy Cross	199	62.19918	159.76794
Yukon	Hughes	69	66.04776	154.25633
Yukon	Huslia	257	65.69811	156.39742
Yukon	Kaltag	202	64.32704	158.72193
Yukon	Kotlik	649	63.03282	163.55652
Yukon	Koyukuk	89	64.87940	157.70276
Yukon	Lake Minchumina	28	63.88330	152.31187

Appendix A2 continued.

Drainage or region	Community	Population	N Latitude	W Longitude
Yukon	Livengood	26	65.52374	148.54449
Yukon	Manley Hot Springs	64	64.99962	150.63395
Yukon	Marshall	382	61.87878	162.08481
Yukon	Minto	258	65.15180	149.33960
Yukon	Moose Creek	542	64.71247	147.16113
Yukon	Mountain Village	826	62.08583	163.72561
Yukon	Nenana	344	64.56283	149.09292
Yukon	North Pole	2,212	64.75152	147.35192
Yukon	Northway	105	62.98219	141.95269
Yukon	Nulato	295	64.71945	158.09974
Yukon	Nunam Iqua	164	62.53219	164.84708
Yukon	Old Crow[1]	255	67.56945	139.83550
Yukon	Pilot Station	604	61.93838	162.87737
Yukon	Pitkas Point	135	62.03258	163.28549
Yukon	Pleasant Valley	733	64.88655	146.86608
Yukon	Rampart	40	65.50518	150.16881
Yukon	Ruby	165	64.73952	155.49123
Yukon	Russian Mission	324	61.78489	161.31992
Yukon	Salcha	854	64.47106	146.94098
Yukon	Shageluk	113	62.65755	159.53034
Yukon	St. Marys	548	62.05184	163.17213
Yukon	Stevens Village	78	66.00722	149.09417
Yukon	Tanacross	155	63.37672	143.35285
Yukon	Tanana	268	65.17106	152.08000
Yukon	Tetlin	117	63.13680	142.51698
Yukon	Tok	1,544	63.33658	142.98533
Yukon	Two Rivers	588	64.87002	147.04493
Yukon	Venetie	181	67.01674	146.42124
Yukon	Wiseman	18	67.40986	150.10698
Kuskokwim	Akiachak	624	60.90829	161.42932
Kuskokwim	Akiak	309	60.91142	161.21558
Kuskokwim	Aniak	572	61.57915	159.52917
Kuskokwim	Atmautluak	314	60.86200	162.27290
Kuskokwim	Bethel	6,468	60.79483	161.76398
Kuskokwim	Chuathbaluk	119	61.57119	159.24240
Kuskokwim	Crooked Creek	146	61.86960	158.11284
Kuskokwim	Eek	280	60.21817	162.02380
Kuskokwim	Kalskag	230	61.53690	160.30695
Kuskokwim	Kasigluk	580	60.89417	162.51971
Kuskokwim	Kwethluk	715	60.81127	161.43387
Kuskokwim	Lime Village	6	61.35546	155.43350
Kuskokwim	Lower Kalskag	268	61.51168	160.35949
Kuskokwim	McGrath	351	62.95658	155.59644
Kuskokwim	Medfra	8	63.10614	154.71330
Kuskokwim	Napakiak	353	60.69600	161.95422

Appendix A2 continued.

Drainage or region	Community	Population	N Latitude	W Longitude
Kuskokwim	Napaskiak	391	60.70760	161.76502
Kuskokwim	Nikolai	86	63.01315	154.37404
Kuskokwim	Nunapitchuk	467	60.89659	162.45853
Kuskokwim	Oscarville	61	60.72262	161.76811
Kuskokwim	Red Devil	51	61.76033	157.31331
Kuskokwim	Sleetmute	106	61.70275	157.16959
Kuskokwim	Stony River	65	61.78912	156.58644
Kuskokwim	Takotna	44	62.98845	156.06749
Kuskokwim	Telida	2	63.38378	153.27672
Kuskokwim	Tuluksak	457	61.10142	160.96000
Kuskokwim	Tuntutuliak	395	60.34403	162.66471
Coastal	Brevig Mission	275	65.33293	166.48467
Coastal	Buckland	422	65.97938	161.12445
Coastal	Chefornak	394	60.15897	164.27762
Coastal	Chevak	838	61.52762	165.58534
Coastal	Deering	141	66.07418	162.71176
Coastal	Diomede	146	65.76813	168.90815
Coastal	Elim	313	64.61669	162.25912
Coastal	Golovin	144	64.54427	163.02893
Coastal	Goodnews Bay	230	59.11829	161.58463
Coastal	Hooper Bay	1,109	61.53034	166.10187
Coastal	Kipnuk	688	59.93861	164.03957
Coastal	Kivalina	391	67.72693	164.53554
Coastal	Kotzebue	3,177	66.89794	162.59771
Coastal	Koyuk	296	64.93134	161.15675
Coastal	Kwigillingok	361	59.86418	163.13667
Coastal	Mekoryuk	210	60.38740	166.18547
Coastal	Newtok	342	60.93915	164.62859
Coastal	Nightmute	208	60.47927	164.72275
Coastal	Nome	3,576	64.50040	165.40706
Coastal	Platinum	41	59.01239	161.81803
Coastal	Point Hope	674	68.34979	166.73447
Coastal	Quinhagak	554	59.74951	161.91246
Coastal	Saint Michael	366	63.47888	162.03660
Coastal	Scammon Bay	511	61.84242	165.58252
Coastal	Shaktoolik	230	64.35447	161.19213
Coastal	Shishmaref	560	66.25410	166.07538
Coastal	Stebbins	547	63.51731	162.28444
Coastal	Teller	266	65.26122	166.35990
Coastal	Toksook Bay	534	60.53000	165.10405
Coastal	Tununak	347	60.58486	165.25733
Coastal	Unalakleet	746	63.87432	160.78821
Coastal	Wales	152	65.61057	168.08878
Coastal	White Mountain	203	64.68289	163.40169

[1]Communities in Yukon Territory near the border with Alaska.

Appendix A3. Select tributary rivers within the Yukon River drainage, including the location of the mouth of each tributary (WGS84 datum) and its approximate distance along the river as a fish would swim from the South Mouth of the Yukon River. Distances to major tributary mouths are consistent in most cases with Hayes et al. (2008), Appendix A2. We added approximately 43 km (27 miles) to the main stem distances upstream from the mouth of the Porcupine River. The main-stem Yukon River between the mouth of the Porcupine River and the community of Circle is extraordinally braided. It appeared that Hayes et al. (2008) calculated this distance as a straight line up the center of the river, however, by following the main channels on a 1:63,360 scale topographic map, a path that a fish would swim, we calculated a distance that was approximately 46% greater. Distances to tributaries not included in Hayes et al. (2008) were measured along main river channels on USGS topographic maps of 1:250,000 scale for main-stem reaches and 1:63,360 scale for tributaries. Page 1 of 4.

River mouth	River km (mile)	N Latitude	W Longitude
Yukon River	0 (0)	62.57909	164.98795
Anuk River	101 (63)	62.31325	163.84099
Archuelinguk River	135 (84)	62.12526	163.77831
Andreafsky River	167 (104)	62.02935	163.25028
East Fork Andreafsky River	175 (109)	62.05638	163.10428
Atchuelinguk River	203 (126)	61.96108	162.82372
Kako Creek	362 (225)	61.85760	161.33244
Innoko River	441 (274)	62.18254	159.66966
Shagaluk Slough	571 (355)	62.80187	159.57245
Holikachuk Slough	616 (383)	62.91835	159.47052
Iditarod River	682 (424)	63.03080	158.76702
Yetna River	800 (497)	63.17704	158.26730
Otter Creek	1027 (638)	62.46483	158.23010
Bonanza Creek	1057 (657)	62.33438	158.19607
Magitchlie Creek	838 (521)	63.54030	158.21086
Hather Creek	858 (533)	63.58498	158.29548
Mud River	914 (568)	63.66606	157.69725
Little Mud River	930 (578)	63.80065	157.76139
Dishna River	945 (587)	63.60424	157.28677
Tolstoi Creek	982 (610)	63.45075	157.26260
North fork Innoko	1054 (655)	63.81996	156.62233
Poorman Creek	1144 (711)	63.96488	155.97846
Folger Creek	1123 (698)	63.54632	156.39656
Ganes Creek	1223 (760)	63.09868	156.42972
Bonasila River	492 (306)	62.53280	160.21304
Anvik River	512 (318)	62.68085	160.20505
Khotol River	694 (431)	64.03679	158.72702
Kaltag River	724 (450)	64.33400	158.72635
Nulato River	777 (483)	64.70664	158.14220

Appendix A3 continued.

River mouth	River km (mile)	N Latitude	W Longitude
Koyukuk River	818 (508)	64.92270	157.55639
Gisasa River	908 (564)	65.26160	157.68171
Kateel River	945 (587)	65.45254	157.62838
Honhosa River	958 (595)	65.47311	157.74897
Dulbi River	1064 (661)	65.44709	156.52341
Huslia River	1152 (716)	65.73764	156.54166
Billy Hawk Creek	1238 (769)	65.94449	156.67957
South Fork Huslia River	1358 (844)	65.87621	157.60159
North Fork Huslia River	1358 (844)	65.87782	157.59901
Dakli River	1215 (755)	65.99915	156.24708
Hogatza River	1255 (780)	65.99885	155.39652
Indian River	1374 (854)	65.86875	154.40366
Kanuti River	1505 (935)	66.44617	153.00017
Chalatna Creek	1587 (986)	66.28517	152.30961
Kilolitna River	1640 (1019)	66.20533	152.04457
Alatna River	1539 (956)	66.57007	152.62726
Siruk Creek	1613 (1002)	66.70551	153.30902
Henshaw Creek	1574 (978)	66.55242	152.22569
South Fork Koyukuk River	1587 (986)	66.58157	151.93845
Fish Creek	1619 (1006)	66.60849	151.58963
Jim River	1670 (1038)	66.78962	151.20358
John River	1798 (1117)	66.91367	151.65352
Wild River	1812 (1126)	66.95164	151.47506
Middle Fork Koyukuk River	1836 (1141)	67.04679	151.07259
North Fork Koyukuk River	1836 (1141)	67.04780	151.07903
Yuki River	904 (562)	64.71582	156.12395
Melozitna River	938 (583)	64.76272	155.12112
Nowitna River	985 (612)	64.92630	154.27358
Sulatna River	1104 (686)	64.59720	154.46135
Titna River	1213 (754)	64.37444	153.62686
Telsitna River	1241 (771)	64.33914	153.36940
Sethkokna River	1297 (806)	64.32422	152.98843
Sulukna River	1273 (791)	64.12473	154.04626
Susulatna River	1374 (854)	63.90377	154.77903
Tozitna River	1096 (681)	65.13657	152.41543
Tanana River	1118 (695)	65.16004	151.96278
Chitanana River	1171 (728)	64.92690	151.52784
Cosna River	1183 (735)	64.86120	151.40706
Zitzianaz River	1236 (768)	64.96845	150.50843
Kantishna River	1276 (793)	64.76100	149.96751
Toklat River	1349 (838)	64.45381	150.31349
Bearpaw River	1427 (887)	64.09117	150.69957
McKinley River	1516 (942)	63.86535	151.55852
Foraker River	1596 (992)	63.88965	152.09649

Appendix A3 continued.

River mouth	River km (mile)	N Latitude	W Longitude
Tolovana River	1296 (805)	64.85116	149.83262
Chatanika River	1379 (857)	65.08766	149.30156
Nenana River	1384 (860)	64.56434	149.10654
Teklannika River	1408 (875)	64.47055	149.32211
Wood River	1439 (894)	64.58512	148.68101
Chena River	1481 (920)	64.79529	147.91350
Salcha River	1553 (965)	64.46625	146.98127
Little Delta River	1609 (1000)	64.28070	146.70568
Shaw Creek	1643 (1021)	64.25738	146.12513
Delta River	1659 (1031)	64.15479	145.86007
Goodpaster River	1688 (1049)	64.17052	145.62787
Gerstle River	1704 (1059)	64.05646	145.13616
Healy River	1724 (1071)	64.00684	144.83702
Johnson River	1770 (1100)	63.72042	144.62353
Robertson River	1841 (1144)	63.49099	143.79699
Tok River	1947 (1210)	63.36331	142.84137
Tetlin River	2004 (1245)	63.17209	142.40779
Nabesna River	2055 (1277)	63.04472	141.87001
Chisana River	2055 (1277)	63.04492	141.86223
Scottie Creek	2150 (1336)	62.68418	141.25910
Minook Creek	1228 (763)	65.51789	150.14088
Hess Creek	1270 (789)	65.67199	149.81119
Big Salt River	1307 (812)	65.84808	149.90570
Ray River	1315 (817)	65.87833	149.80450
Dall River	1353 (841)	66.00631	149.26019
Hodzana River	1444 (897)	66.29182	147.77573
Beaver Creek	1465 (910)	66.20448	147.74947
Victoria Creek	1769 (1099)	65.80522	146.64925
Hadweenzic River	1532 (952)	66.46922	146.95013
Birch Creek, Lower Mouth	1545 (960)	66.44577	146.64069
Birch Creek, Upper Mouth	1566 (973)	66.51913	146.15225
Preacher Creek	1754 (1090)	66.12840	144.84325
Chandalar River	1580 (982)	66.60880	146.00666
East Fork Chandalar River	1703 (1058)	67.10231	147.24193
North Fork Chandalar	1764 (1096)	67.16943	148.30721
Middle Fork Chandalar	1764 (1096)	67.17115	148.30383
West Fork Chandalar	1775 (1103)	67.18874	148.51850
Christian River	1601 (995)	66.65983	145.89011
Porcupine River, Lower Mouth	1605 (997)	66.57824	145.42989
Porcupine River, Upper Mouth	1613 (1002)	66.57612	145.31918
Sucker River	1621 (1007)	66.60875	145.21177
Black River	1651 (1026)	66.64430	144.91786
Salmon Fork	1838 (1142)	66.54561	142.59520

Appendix A3 continued.

River mouth	River km (mile)	N Latitude	W Longitude
Sheenjek River	1696 (1054)	66.73925	144.56734
Coleen River	1862 (1157)	67.07125	142.49884
Salmon Trout River	1920 (1193)	67.15919	141.67115
Rapid River	1936 (1203)	67.27719	141.63630
Porcupine River (U.S.-Can. Border)	1962 (1219)	67.41329	141.00005
Old Crow River	2028 (1260)	67.57939	139.79937
Bell River	2174 (1351)	67.28178	137.77943
Eagle River	2216 (1377)	67.29860	137.14017
Charley River	1852 (1151)	65.31684	142.78328
Kandik River	1870 (1162)	65.37428	142.51300
Nation River	1920 (1193)	65.19562	141.70524
Tatonduk River	1952 (1213)	64.99644	141.34182
Seventymile River	1965 (1221)	64.92665	141.30512
Yukon River (U.S.-Can. Border)	2013 (1251)	67.41329	141.00005
Fortymile River	2086 (1296)	64.45442	140.39330
Fortymile River (Can.-U.S. Border)	2120 (1317)	64.31418	141.00002
North Fork Fortymile	2184 (1357)	64.24283	141.75572
South Fork Fortymile	2184 (1357)	64.24192	141.75412
Walker Fork Fortymile	2279 (1416)	64.09846	141.76359
Dennison Fork Fortymile	2390 (1485)	64.05494	141.91179
Mosquito Fork Fortymile	2390 (1485)	64.05429	141.91086
Klondike River	2168 (1347)	64.05640	139.44508
Stewart River	2256 (1402)	63.29202	139.41508
White River	2274 (1413)	63.19204	139.58317
Pelly River	2422 (1505)	62.77688	137.33836

Appendix A4. Select tributary rivers within the Kuskokwim River drainage, including the location of the mouth of each tributary (WGS84 datum) and its approximate distance from Kuskokwim Bay (southern tip of Eek Island). Distances are consistent with Whitmore et al. (2008).

River mouth	River km (mile)	N Latitude	W Longitude
Kuskokwim River	0 (0)	59.99510	162.34768
Eek River	13 (8)	60.08452	162.31005
Tagayarak (Kinak) River	32 (20)	60.24393	162.56832
Kialik River	50 (31)	60.40887	162.42580
Johnson River	77 (48)	60.65327	162.10708
Pikmiktalik River	96 (60)	60.76868	162.24397
Gweek River	135 (84)	60.85563	161.58173
Kwethluk River	131 (82)	60.79522	161.52108
Kasigluk River	150 (93)	60.84517	161.23563
Kisaralik River	151 (94)	60.85747	161.23873
Tuluksak River	192 (119)	61.09708	160.97438
Whitefish Lake outlet	268 (167)	61.47195	160.24127
Aniak River	307 (191)	61.57557	159.52020
Holokuk River	362 (225)	61.53760	158.59342
George River	446 (277)	61.89693	157.71228
Holitna River	491 (305)	61.67960	157.16928
Hoholitna River	538 (334)	61.50937	156.98687
Chukowan River	709 (441)	60.84975	157.85253
Kogrukluk River	709 (441)	60.84848	157.85212
Stony River	536 (333)	61.76925	156.59315
Telaquana River	727 (452)	61.06758	154.41120
Swift River	560 (348)	61.88817	156.30972
Tatlawiksuk River	563 (350)	61.91801	156.24730
Takotna River	752 (467)	62.96313	155.60175
Nixon Fork	777 (483)	63.03443	155.66575
Middle Fork Kuskokwim River	806 (501)	62.98462	154.96830
Big River	827 (514)	62.96413	154.87848
Pitka Fork Kuskokwim River	845 (525)	62.93660	154.74705
Windy Fork Kuskokwim River	906 (563)	62.75932	154.63285
South Fork Kuskokwim River	869 (540)	63.08693	154.64144
North Fork Kuskokwim River.	869 (540)	63.08930	154.64366
East Fork Kuskokwim River	880 (547)	63.10866	154.56533
Tonzona River	1000 (621)	63.18984	153.75930
Swift Fork Kuskokwim River	941 (585)	63.57540	153.49924
Highpower Creek	1151 (715)	63.40829	153.12644

Appendix A5. Lake survey data from the Yukon and Kuskokwim River drainages in Alaska and from the coastal regions of Kuskokwim Bay and the Yukon Kuskokwim Delta. Data include the sub-basin in which a lake is located, the lake name or identifying number, the maximum depth of the lake (if available) in meters (feet), fish species that were present, the location of the lake in north latitude and west longitude (WGS84 datum), and the source of the information. "No Fish Collected" indicates that a lake was surveyed for fish and none were captured. Fish abbreviations are as follows: Alaska blackfish (AKBF), Arctic char (ARCH), Arctic grayling (ARGR), broad whitefish (BRWF), burbot (BURB), Chinook salmon (CHIN), chum salmon (CHUM), coho salmon (COHO), Dolly Varden (DVAR), humpback whitefish (HBWF), inconnu (INCO), kokanee (KOKA), least cisco (LCIS), lake chub (LKCB), lake trout (LKTR), longnose sucker (LNSU), northern pike (NOPI), ninespine stickleback (NSST); pond smelt (PDSM), pygmy whitefish (PGWF), pink salmon (PINK), Rainbow trout (RBTR), round whitefish (RDWF), slimy sculpin (SLSC), sockeye salmon (SOCK), and threespine stickleback (TSST). Underlined abbreviations indicate a stocked species not native to the lake.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Innoko	285-01	2.7 (9)	AKBF, BRWF, NOPI, NSST	63.6234	157.8405	Glesne et al. 2011
Yukon	Innoko	285-02	4 (13)	BRWF, HBWF, LCIS, NOPI	63.5656	157.8595	Glesne et al. 2011
Yukon	Innoko	285-03	1.5 (5)	AKBF, NOPI	63.5418	157.8934	Glesne et al. 2011
Yukon	Innoko	285-04	1.5 (5)	NOPI	63.5188	157.9140	Glesne et al. 2011
Yukon	Innoko	285-05	7.6 (25)	NOPI	63.4296	158.1720	Glesne et al. 2011
Yukon	Innoko	285-06	2.7 (9)	BRWF, HBWF, LCIS, NOPI	63.2340	158.2202	Glesne et al. 2011
Yukon	Innoko	285-07	1.8 (6)	BRWF, HBWF, LCIS, NOPI	63.2164	158.3073	Glesne et al. 2011
Yukon	Innoko	285-08	1.8 (6)	BRWF, HBWF, LCIS, NOPI	63.1741	158.0675	Glesne et al. 2011
Yukon	Innoko	285-09	1.5 (5)	No Fish Collected	63.2217	158.0492	Glesne et al. 2011
Yukon	Innoko	285-10	2.7 (9)	BRWF, HBWF, LCIS, LNSU, NOPI	63.1005	158.2316	Glesne et al. 2011
Yukon	Innoko	285-11	6.1 (20)	BRWF, NOPI	63.6415	158.0161	Glesne et al. 2011
Yukon	Innoko	285-12	7 (23)	NOPI	63.1316	158.8588	Glesne et al. 2011
Yukon	Innoko	285-13	8.2 (27)	BRWF, HBWF, LCIS, NOPI	63.5595	158.1967	Glesne et al. 2011
Yukon	Innoko	285-14	3.4 (11)	AKBF, NOPI	63.5885	157.3565	Glesne et al. 2011
Yukon	Innoko	285-15	0.9 (3)	NOPI	63.6414	157.5361	Glesne et al. 2011
Yukon	Innoko	285-16	0.9 (3)	No Fish Collected	63.5735	157.7406	Glesne et al. 2011
Yukon	Innoko	285-17	1.8 (6)	BRWF, HBWF, LCIS, NOPI	63.6958	157.7875	Glesne et al. 2011
Yukon	Koyukuk	384-01	1 (3)	ARGR, RDWF	66.1208	151.1950	Glesne et al. 2011
Yukon	Koyukuk	384-02 (Sithylemenkat)	12.2 (40)	HBWF, LCIS, NOPI	66.1252	151.3933	Pearse 1978, Glesne et al. 2011

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Koyukuk	384-03	3.4 (11)	No Fish Collected	66.1384	151.8539	Glesne et al. 2011
Yukon	Koyukuk	384-04	1.2 (4)	BRWF, HBWF, LCIS	66.1602	151.7852	Glesne et al. 2011
Yukon	Koyukuk	384-05	1.2 (4)	AKBF, HBWF, LCIS, LNSU, NOPI	66.1493	151.8063	Glesne et al. 2011
Yukon	Koyukuk	385-01	3.7 (12)	NOPI	66.3736	151.9525	Glesne et al. 2011
Yukon	Koyukuk	385-02	5.8 (19)	NOPI	66.3640	151.9731	Glesne et al. 2011
Yukon	Koyukuk	385-03	5.5 (18)	AKBF, NOPI	66.3699	152.0000	Glesne et al. 2011
Yukon	Koyukuk	385-04	1.5 (5)	No Fish Collected	66.1408	151.9202	Glesne et al. 2011
Yukon	Koyukuk	385-05	12.8 (42)	NOPI	66.4998	152.1174	Glesne et al. 2011
Yukon	Koyukuk	385-06	1.2 (4)	NOPI	66.5604	151.6885	Glesne et al. 2011
Yukon	Koyukuk	484-01	9.8 (32)	LCIS, NOPI, NSST	65.3947	156.5800	Glesne et al. 2011
Yukon	Koyukuk	484-02	4.9 (16)	No Fish Collected	65.6404	157.1457	Glesne et al. 2011
Yukon	Koyukuk	485-01	1.5 (5)	AKBF, BRWF, NOPI	65.6790	157.1699	Glesne et al. 2011
Yukon	Koyukuk	485-02	3.7 (12)	AKBF, NOPI	65.2521	157.1198	Glesne et al. 2011
Yukon	Koyukuk	485-03	1.5 (5)	NOPI	65.2226	157.0278	Glesne et al. 2011
Yukon	Koyukuk	485-04	1.5 (5)	AKBF, NOPI	65.2116	156.5546	Glesne et al. 2011
Yukon	Koyukuk	485-05	5.5 (18)	BRWF, HBWF, LCIS, LNSU, NOPI	65.0584	157.3211	Glesne et al. 2011
Yukon	Koyukuk	485-06	4.3 (14)	BRWF, HBWF, LCIS, NOPI	65.0025	157.0936	Glesne et al. 2011
Yukon	Koyukuk	485-07	7.9 (26)	AKBF, LCIS, NOPI	65.4915	157.2236	Glesne et al. 2011
Yukon	Koyukuk	485-08	14.6 (48)	BRWF, INCO, NOPI, NSST	65.3883	157.5816	Glesne et al. 2011
Yukon	Koyukuk	485-09	11 (36)	BRWF, HBWF, LCIS, NOPI	65.4826	157.3345	Glesne et al. 2011
Yukon	Koyukuk	485-10	1.5 (5)	NOPI	65.7931	157.1414	Glesne et al. 2011
Yukon	Koyukuk	485-11	1.8 (6)	BRWF, HBWF, LCIS, NOPI	65.9814	156.8462	Glesne et al. 2011
Yukon	Koyukuk	485-12	5.5 (18)	BRWF, HBWF, NOPI	65.8521	156.6327	Glesne et al. 2011
Yukon	Koyukuk	485-13	6.4 (21)	BRWF, HBWF, LCIS, NOPI	65.8150	156.5900	Glesne et al. 2011
Yukon	Koyukuk	485-14	1.2 (4)	AKBF, NOPI	65.7655	156.8049	Glesne et al. 2011

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Koyukuk	485-15	2.4 (8)	LCIS, NOPI	65.7775	156.8352	Glesne et al. 2011
Yukon	Koyukuk	485-16	4.3 (14)	AKBF, BRWF, LCIS, NOPI	65.6277	156.5666	Glesne et al. 2011
Yukon	Koyukuk	485-17	1.5 (5)	AKBF, NOPI	65.8081	156.1155	Glesne et al. 2011
Yukon	Koyukuk	485-18	1.8 (6)	AKBF, NOPI	65.6946	155.8945	Glesne et al. 2011
Yukon	Koyukuk	485-19	3.4 (11)	AKBF, BRWF, HBWF, LCIS, NOPI	65.5895	156.8699	Glesne et al. 2011
Yukon	Koyukuk	485-20	7.3 (24)	AKBF, BRWF, NOPI	65.6816	155.6699	Glesne et al. 2011
Yukon	Koyukuk	485-21	5.5 (18)	NOPI	65.6993	155.5666	Glesne et al. 2011
Yukon	Koyukuk	485-22	1.5 (5)	AKBF, BRWF, HBWF, LCIS	65.6626	155.3791	Glesne et al. 2011
Yukon	Koyukuk	Agiak		ARCH, ARGR, LKTR	68.0747	152.9532	Bendock and Burr 1985
Yukon	Koyukuk	Bob Johnson (Big)	25.5 (83)	ARGR, LCIS, LKTR, NOPI, RDWF	67.4965	149.3894	Kramer 1976b; Pearse 1978
Yukon	Koyukuk	Helpmejack	25.5 (83)	LCIS, LKTR, NOPI, SLSC	66.9267	153.5467	Roguski and Spetz 1968; Pearse 1978
Yukon	Koyukuk	Iniakuk	61 (200)	HBWF, LKTR, NOPI, RDWF	67.1364	153.2314	Roguski and Spetz 1968; Pearse 1978
Yukon	Koyukuk	Takahula	20 (65)	ARGR, NOPI	67.3508	153.6586	Roguski and Spetz 1968
Yukon	Koyukuk	Tobuk		NOPI, SLSC	67.3008	153.4444	Roguski and Spetz 1968
Yukon	Koyukuk	Twin, South	57.5 (189)	ARGR, LKTR, RDWF	67.5067	149.0689	Kramer 1976b, Pearse 1978
Yukon	Koyukuk	Wild	73 (240)	ARGR, BURB, LCIS, LKTR, LNSU, NOPI, RDWF	67.5064	151.5687	Roguski and Spetz 1968; Pearse 1978
Yukon	Nowitna	584-01	6.7 (22)	BRWF, HBWF, LCIS, NOPI	64.6732	154.4504	Glesne et al. 2011
Yukon	Nowitna	584-02	5.5 (18)	BRWF, HBWF, INCO, LCIS, NOPI	64.5424	154.4067	Glesne et al. 2011
Yukon	Nowitna	586-01	4.3 (14)	AKBF, BRWF, HBWF, LCIS, NOPI	64.7004	154.5298	Glesne et al. 2011
Yukon	Nowitna	586-02	5.2 (17)	NOPI	64.6671	154.6095	Glesne et al. 2011
Yukon	Nowitna	586-03	3.1 (10)	AKBF, BRWF, HBWF, LCIS, NOPI	64.6857	154.5434	Glesne et al. 2011

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Nowitna	586-04	1.5 (5)	No Fish Collected	64.7956	154.5508	Glesne et al. 2011
Yukon	Nowitna	586-05	4.3 (14)	AKBF, NOPI	64.7801	154.6347	Glesne et al. 2011
Yukon	Nowitna	586-06	2.5 (8)	AKBF	64.8819	154.6338	Glesne et al. 2011
Yukon	Nowitna	586-07	2.8 (9)	NOPI	64.8539	154.4413	Glesne et al. 2011
Yukon	Nowitna	586-08	1.8 (6)	No Fish Collected	64.9077	154.0242	Glesne et al. 2011
Yukon	Nowitna	586-09	5.2 (17)	BRWF, HBWF, LCIS, NOPI	64.8012	154.2949	Glesne et al. 2011
Yukon	Nowitna	586-10	5.8 (19)	BRWF, HBWF, INCO, LCIS, NOPI	64.6367	154.5837	Glesne et al. 2011
Yukon	Nowitna	586-11	1.2 (4)	No Fish Collected	64.6889	153.9349	Glesne et al. 2011
Yukon	Nowitna	586-12	3.7 (12)	HBWF, INCO, LCIS, NOPI	64.4241	154.0853	Glesne et al. 2011
Yukon	Nowitna	586-13	4.3 (14)	INCO, NOPI	64.6128	154.3494	Glesne et al. 2011
Yukon	Nowitna	586-14	4.6 (15)	BRWF, NOPI	64.6520	154.4208	Glesne et al. 2011
Yukon	Tanana (lower)	84-01	7.5 (25)	No Fish Collected	64.5219	150.4286	Hallberg 1985
Yukon	Tanana (lower)	84-02	12 (40)	No Fish Collected	64.5964	150.3381	Hallberg 1985
Yukon	Tanana (lower)	84-03	7.5 (25)	NOPI	64.5308	151.0258	Hallberg 1985
Yukon	Tanana (lower)	84-04	8.5 (28)	NOPI	64.4386	151.0072	Hallberg 1985
Yukon	Tanana (lower)	Alma 01	12 (40)	NOPI	64.0387	150.6123	Kramer 1976a
Yukon	Tanana (lower)	Alma 02	18.5 (60)	NOPI	64.0212	150.6037	Kramer 1976a
Yukon	Tanana (lower)	Bear	10 (33)	LCIS, NOPI	64.7867	150.8103	Kramer 1976a
Yukon	Tanana (lower)	Big Long		NOPI	63.5215	152.4488	Markis et al. 2004
Yukon	Tanana (lower)	Black Bear	1.5 (5)	No Fish Collected	64.6616	149.8783	Kramer 1976a
Yukon	Tanana (lower)	Blackfish		AKBF	63.6117	152.6630	Markis et al. 2004
Yukon	Tanana (lower)	Blackfish, East		No Fish Collected	63.6008	152.6173	Markis et al. 2004
Yukon	Tanana (lower)	Brown	1.5 (5)	NOPI	65.4469	148.7103	Roguski and Spetz 1968
Yukon	Tanana (lower)	Caribou		NOPI	63.5537	152.4510	Markis et al. 2004
Yukon	Tanana (lower)	Carlson		NOPI	63.8039	151.9094	Markis et al. 2004

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Tanana (lower)	Castle Rocks		AKBF, ARGR	63.3562	152.1437	Markis et al. 2004
Yukon	Tanana (lower)	Chilchukabena		NOPI	63.9118	151.5079	Markis et al. 2004
Yukon	Tanana (lower)	Deadman	21 (69)	BURB, HBWF, NOPI	64.8420	149.9558	Hansen and Pearse 1995
Yukon	Tanana (lower)	Doghouse		AKBF, SLSC	63.7044	152.4569	Markis et al. 2004
Yukon	Tanana (lower)	Dune	6 (20)	ARGR, RBTR	64.4214	149.8955	Kramer 1976a; Hallberg 1984, 1985
Yukon	Tanana (lower)	Eight-mile	2 (6)	ARGR, RDWF	63.8883	149.2517	Kramer 1979
Yukon	Tanana (lower)	Fish		NOPI	63.5429	152.5021	Markis et al. 2004
Yukon	Tanana (lower)	Fish, East of		AKBF	63.5465	152.4720	Markis et al. 2004
Yukon	Tanana (lower)	Foraker		RDWF, SLSC	63.2108	151.6015	Markis et al. 2004
Yukon	Tanana (lower)	Geskakmina	7.5 (25)	COHO, RBTR	64.6506	150.3111	Kramer 1976a; Hallberg 1984
Yukon	Tanana (lower)	Harding	43 (141)	ARCH, ARGR, BURB, COHO, INCO, KOKA, LCIS, LKTR, NOPI, RBTR, SLSC	64.4199	146.8545	Hallberg 1985; Doxey 1991; Hallberg and Bingham 1991
Yukon	Tanana (lower)	Iksgiza	6.5 (22)	NOPI	64.7522	150.2394	Kramer 1976a
Yukon	Tanana (lower)	KAT 04-19		AKBF	63.9396	151.9077	Markis et al. 2004
Yukon	Tanana (lower)	Kindanina	9 (30)	HBWF, NOPI	64.7575	150.4700	Kramer 1976a
Yukon	Tanana (lower)	Lake 12	8 (27)	NOPI	64.3931	151.1325	Kramer 1976a
Yukon	Tanana (lower)	Lake 13	19.5 (64)	NOPI	64.4191	151.2719	Kramer 1976a
Yukon	Tanana (lower)	Lake 16	5 (16)	No Fish Collected	64.1822	150.5508	Kramer 1976a
Yukon	Tanana (lower)	Lake 18	4.5 (15)	AKBF	64.1697	150.4875	Kramer 1976a
Yukon	Tanana (lower)	Lake 20	11.5 (37)	No Fish Collected	64.2473	150.9885	Kramer 1976a
Yukon	Tanana (lower)	Lake 21	13.5 (44)	BRWF, NOPI	64.2839	151.0066	Kramer 1976a
Yukon	Tanana (lower)	Lake 22	6.5 (21)	NOPI	64.2259	151.1990	Kramer 1976a

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Tanana (lower)	Lake 33	5.5 (18)	NOPI	64.1451	151.4025	Kramer 1976a
Yukon	Tanana (lower)	Mallard	4 (13)	NOPI	65.4369	148.7242	Roguski and Spetz 1968
Yukon	Tanana (lower)	McCleod		BURB, SLSC	63.3728	151.0884	Markis et al. 2004
Yukon	Tanana (lower)	Minchumina	12 (39)	BRWF, BURB, HBWF, LCIS, LNSU, NOPI	63.8868	152.2302	Kramer 1975
Yukon	Tanana (lower)	Mooseheart	11 (36)	HBWF, LCIS, NOPI	64.7650	151.1958	Kramer 1976a
Yukon	Tanana (lower)	Mucha	5 (17)	NOPI	64.2108	150.9061	Kramer 1976a
Yukon	Tanana (lower)	Redland		NOPI	64.6825	152.2958	Kramer 1979
Yukon	Tanana (lower)	Slate		No Fish Collected	63.9292	149.1461	Kramer 1979
Yukon	Tanana (lower)	Spectacle		NOPI	63.5816	152.3883	Markis et al. 2004
Yukon	Tanana (lower)	Square	4.5 (15)	NOPI	64.1870	151.2146	Kramer 1976a
Yukon	Tanana (lower)	Starr		AKBF	63.9476	151.6621	Markis et al. 2004
Yukon	Tanana (lower)	TAN 79-05		AKBF	64.8833	150.7756	Kramer 1979
Yukon	Tanana (lower)	Twin, East	13.5 (45)	HBWF, NOPI	64.4319	150.6458	Kramer 1976a; Hallberg 1984
Yukon	Tanana (lower)	Twin, West	36.5 (120)	BURB, HBWF, NOPI	64.4353	150.8294	Kramer 1976a; Hallberg 1984
Yukon	Tanana (lower)	Wien	33.5 (110)	LCIS, HBWF, NOPI, NSST	64.3536	151.2931	Hallberg 1984
Yukon	Tanana (lower)	Wonder		ARCH, BURB, LKTR, SLSC	63.4725	150.8774	Morrow 1980b; Markis et al. 2004
Yukon	Tanana (upper)	"J"	16.5 (54)	ARGR, LNSU, SLSC	63.8331	145.8339	Peckham 1976
Yukon	Tanana (upper)	"T"	21.5 (70)	BURB, HBWF, LCIS, NOPI	63.7986	143.8811	Pearse 1976; Peckham 1979
Yukon	Tanana (upper)	16.8 Ml	17.5 (58)	ARGR, LKTR	63.0464	145.8811	Peckham 1976
Yukon	Tanana (upper)	784-01 (Fern)	27.4 (90)	ARGR, LNSU	62.7016	142.2960	Peckham 1980; Glesne et al. 2011

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Tanana (upper)	784-02	15.2 (50)	ARGR	62.6533	142.3714	Glesne et al. 2011
Yukon	Tanana (upper)	784-03	27.4 (90)	LCIS, LKTR, NOPI, SLSC	62.6193	142.0277	Pearse 1975; Glesne et al. 2011
Yukon	Tanana (upper)	784-04	9.8 (32)	LCIS, NOPI	62.6022	141.9922	Glesne et al. 2011
Yukon	Tanana (upper)	784-05	3.1 (10)	No Fish Collected	62.8310	141.8118	Glesne et al. 2011
Yukon	Tanana (upper)	784-06	3.1 (10)	No Fish Collected	63.1503	142.2788	Glesne et al. 2011
Yukon	Tanana (upper)	784-07	2.4 (8)	No Fish Collected	63.1542	142.2282	Glesne et al. 2011
Yukon	Tanana (upper)	785-01	7.7 (25)	NOPI	62.7975	141.4563	Glesne et al. 2011
Yukon	Tanana (upper)	785-02	1.5 (5)	NOPI	62.8163	141.7786	Glesne et al. 2011
Yukon	Tanana (upper)	785-03	11.1 (36)	LCIS, NOPI, SLSC	62.6298	142.0967	Glesne et al. 2011
Yukon	Tanana (upper)	785-04 (Takomahto)	35.1 (115)	LCIS, NOPI	62.6190	141.9468	Peckham 1980; Glesne et al. 2011
Yukon	Tanana (upper)	785-05	8 (26)	HBWF, LNSU, NOPI	62.6365	141.1226	Glesne et al. 2011
Yukon	Tanana (upper)	785-06 (American Wellesley)	24.3 (80)	BURB, HBWF, LCIS, NOPI	62.5079	141.2506	Peckham 1980; Glesne et al. 2011
Yukon	Tanana (upper)	786-01 (East Wellesley)	29.2 (96)	BURB, HBWF, LCIS, NOPI	62.4640	141.2713	Peckham 1980; Glesne et al. 2011
Yukon	Tanana (upper)	786-02	24.6 (81)	BURB, LCIS, NOPI	62.4706	141.3237	Glesne et al. 2011
Yukon	Tanana (upper)	786-03	4 (13)	NOPI	62.4822	141.3239	Glesne et al. 2011
Yukon	Tanana (upper)	786-04	11.7 (38)	NOPI	62.5309	142.3887	Glesne et al. 2011
Yukon	Tanana (upper)	786-05	3.4 (11)	ARGR, LKCB, LNSU, SLSC	62.5432	142.2654	Glesne et al. 2011
Yukon	Tanana (upper)	786-06	6.2 (20)	NOPI	62.6533	142.2907	Glesne et al. 2011
Yukon	Tanana (upper)	786-07	5.5 (18)	ARGR	62.6103	142.3312	Glesne et al. 2011
Yukon	Tanana (upper)	786-08	4.3 (14)	No Fish Collected	62.6124	142.3945	Glesne et al. 2011
Yukon	Tanana (upper)	786-09	4.9 (16)	ARGR	62.5966	142.4194	Glesne et al. 2011
Yukon	Tanana (upper)	786-10	2.5 (8)	No Fish Collected	62.6445	142.2796	Glesne et al. 2011

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Tanana (upper)	786-11	24.6 (81)	NOPI	62.6824	142.2747	Glesne et al. 2011
Yukon	Tanana (upper)	786-12	1.2 (4)	HBWF, NOPI	62.8099	141.8665	Glesne et al. 2011
Yukon	Tanana (upper)	786-13	5.8 (19)	NOPI	62.8015	141.9409	Glesne et al. 2011
Yukon	Tanana (upper)	786-14	2.2 (7)	No Fish Collected	62.7796	141.7999	Glesne et al. 2011
Yukon	Tanana (upper)	786-15	4.3 (14)	NOPI	62.7428	141.7099	Glesne et al. 2011
Yukon	Tanana (upper)	786-16	1.2 (4)	NOPI	63.1224	142.2174	Glesne et al. 2011
Yukon	Tanana (upper)	786-17	1.2 (4)	HBWF, NOPI	63.1394	142.2456	Glesne et al. 2011
Yukon	Tanana (upper)	Big	2.5 (9)	ARGR	63.8558	145.8778	Peckham 1976
Yukon	Tanana (upper)	Big Grayling		No Fish Collected	62.5320	143.0754	Markis et al. 2004
Yukon	Tanana (upper)	Bolio	4 (13)	COHO, RBTR, SLSC	63.8933	145.8447	Peckham 1976
Yukon	Tanana (upper)	Chet	11.5 (38)	ARGR, LNSU, SLSC	63.8288	145.8406	Peckham 1976
Yukon	Tanana (upper)	Circle	10.5 (34)	No Fish Collected	63.8319	145.8444	Peckham 1976
Yukon	Tanana (upper)	Clearwater	2 (6)	COHO, HBWF, LCIS, LNSU, NOPI, RDWF	64.0894	145.5964	Pearse 1976
Yukon	Tanana (upper)	Craig	23 (75)	COHO, RBTR	63.7301	144.7172	Pearse 1976
Yukon	Tanana (upper)	Crystal 01	13.5 (45)	ARGR, RBTR	63.1564	145.6453	Peckham 1976
Yukon	Tanana (upper)	Crystal 02	9 (30)	ARGR	63.1514	145.6228	Peckham 1976
Yukon	Tanana (upper)	Deadman	10 (32)	NOPI	62.8833	141.5500	Pearse 1975
Yukon	Tanana (upper)	Donna	9 (30)	RBTR	63.7703	144.9114	Pearse 1976
Yukon	Tanana (upper)	Donnelly	14.5 (47)	COHO	63.7522	145.7992	Peckham 1976
Yukon	Tanana (upper)	Dot	2 (7)	NOPI	63.6642	144.0706	Pearse 1976
Yukon	Tanana (upper)	Downwind	2 (6)	No Fish Collected	63.0769	146.1928	Peckham 1976
Yukon	Tanana (upper)	Dude	16 (53)	No Fish Collected	63.2078	145.7386	Peckham 1976
Yukon	Tanana (upper)	Fielding	22.5 (74)	ARGR, BURB, LKTR, RDWF, SLSC	63.1714	145.6850	Peckham 1976, 1983
Yukon	Tanana (upper)	Fish	20 (66)	ARGR	63.2289	145.9969	Peckham 1976

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Tanana (upper)	Forrest	23 (76)	No Fish Collected	63.4744	144.0281	Pearse 1976
Yukon	Tanana (upper)	Fourmile	4.5 (15)	COHO, INCO	63.3575	142.5744	Roguski and Spetz 1968; Pearse 1975
Yukon	Tanana (upper)	Fourteenmile	12 (40)	RBTR	63.0761	145.8008	Peckham 1976
Yukon	Tanana (upper)	George	11.0 (36)	BURB, HBWF, LCIS, LNSU, NOPI	63.7808	144.5369	Pearse 1976
Yukon	Tanana (upper)	Gillam	13 (43)	ARGR, BURB, LKTR, RDWF	62.4393	142.8196	Peckham 1980
Yukon	Tanana (upper)	Glacier	25.5 (84)	ARGR, BURB, LKTR, RDWF	63.1150	146.2611	Peckham 1976
Yukon	Tanana (upper)	Healy	3.5 (11)	ARGR, HBWF, LCIS, NOPI	63.9775	144.7281	Pearse 1976
Yukon	Tanana (upper)	Island	12 (40)	NOPI	62.7028	141.1144	Roguski and Spetz 1968
Yukon	Tanana (upper)	Jan	14 (46)	COHO, RBTR	63.5650	143.9178	Pearse 1976
Yukon	Tanana (upper)	Jimmy Brown	5.5 (18)	NOPI, RDWF	62.4824	142.5771	Peckham 1980
Yukon	Tanana (upper)	Lake 02	10.5 (35)	No Fish Collected	63.7594	145.8517	Peckham 1976
Yukon	Tanana (upper)	Lake 03	1.5 (5)	No Fish Collected	63.7786	145.8258	Peckham 1976
Yukon	Tanana (upper)	Lake 39	5.5 (18)	No Fish Collected	63.7403	145.8254	Peckham 1976
Yukon	Tanana (upper)	Lake 40	14.5 (47)	LNSU	63.9550	146.1942	Peckham 1976
Yukon	Tanana (upper)	Lake 41	13 (42)	LNSU	63.9433	146.1711	Peckham 1976
Yukon	Tanana (upper)	Lake 42	9.5 (31)	LKCB	64.0125	146.2164	Peckham 1976
Yukon	Tanana (upper)	Lake 43	13.5 (45)	LKCB	63.9192	145.9933	Peckham 1976
Yukon	Tanana (upper)	Lake 45	7.5 (24)	ARGR, SLSC	63.7619	146.0408	Peckham 1976
Yukon	Tanana (upper)	Lake 46	13.5 (45)	NOPI	63.8642	146.0919	Peckham 1976
Yukon	Tanana (upper)	Lake 47	22 (72)	NOPI	63.8439	146.0775	Peckham 1976
Yukon	Tanana (upper)	Lake 48	23 (75)	NOPI	63.8361	146.1114	Peckham 1976
Yukon	Tanana (upper)	Landmark Gap	47 (155)	ARGR, LKTR, RDWF	63.1322	146.0856	Peckham 1976
Yukon	Tanana (upper)	Lisa	8.0 (27)	COHO, RBTR	63.7097	144.6836	Pearse 1976
Yukon	Tanana (upper)	Little Donna	8.5 (28)	RBTR	63.7630	144.8912	Pearse 1976

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Tanana (upper)	Lost	3 (10)	No Fish Collected	64.1993	145.8482	Pearse 1976
Yukon	Tanana (upper)	Mansfield	3.5 (12)	HBWF, NOPI	63.4844	143.4119	Pearse 1976
Yukon	Tanana (upper)	Mark	11.5 (37)	COHO, RBTR	63.8714	145.8644	Peckham 1976
Yukon	Tanana (upper)	Midway	6.5 (22)	No Fish Collected	63.2211	142.2836	Pearse 1975
Yukon	Tanana (upper)	Mile 1238	15 (50)	NOPI	62.7977	141.1878	Pearse 1975
Yukon	Tanana (upper)	Mile 1239	10.5 (35)	No Fish Collected	62.7867	141.3135	Pearse 1975
Yukon	Tanana (upper)	Mile 1239.5	6 (19)	ARGR	62.7867	141.3155	Pearse 1975
Yukon	Tanana (upper)	Mile 1242	5.5 (18)	ARGR	62.8175	141.3522	Pearse 1975
Yukon	Tanana (upper)	Mile 1255	7.5 (25)	NOPI	62.9408	141.6136	Pearse 1975
Yukon	Tanana (upper)	Mineral	3.5 (12)	ARGR, HBWF, NOPI	62.9425	143.3653	Pearse 1976
Yukon	Tanana (upper)	Monte	29 (95)	LKTR, RBTR	63.5050	144.0819	Pearse 1976; Peckham 1983, 1985
Yukon	Tanana (upper)	Moon	2 (6)	ARGR, LCIS, LKCH LNSU, NOPI	63.3764	143.5417	Pearse 1976; Valdez 1976
Yukon	Tanana (upper)	Moosehead	2.5 (9)	No Fish Collected	63.7514	144.5433	Pearse 1976
Yukon	Tanana (upper)	Nickel	11.5 (37)	ARGR, LNSU	63.8278	145.8333	Peckham 1976
Yukon	Tanana (upper)	O. P.	2.5 (9)	ARGR	63.8536	145.9119	Peckham 1976
Yukon	Tanana (upper)	Quartz	13 (42)	COHO, RBTR	64.2146	145.8204	Pearse 1976
Yukon	Tanana (upper)	Rainbow	10.5 (34)	RBTR	64.1294	146.1050	Peckham 1976; Pearse 1976
Yukon	Tanana (upper)	Rapids	7 (23)	RBTR	63.5061	145.8564	Peckham 1976
Yukon	Tanana (upper)	Robertson 02	5.5 (18)	RBTR	63.5056	143.8372	Pearse 1976
Yukon	Tanana (upper)	Rusty		ARGR, LKTR	63.0528	145.8908	Peckham 1976
Yukon	Tanana (upper)	Sevenmile	10.5 (34)	BURB, LKTR	63.1000	145.6225	Peckham 1976
Yukon	Tanana (upper)	Seventeenmile	1.5 (5)	ARGR	63.0428	145.8969	Peckham 1976
Yukon	Tanana (upper)	Tangle, Landlocked	27.5 (90)	BURB, LKTR, RDWF	63.0008	146.0542	Peckham 1976

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Tanana (upper)	Tangle, Long	18 (59)	ARGR, BURB, LKTR, RDWF	63.0978	145.9575	Peckham 1976
Yukon	Tanana (upper)	Tangle, Round	33.5 (110)	ARGR, BURB, LKTR, RDWF	63.0558	145.9900	Peckham 1976
Yukon	Tanana (upper)	Tangle, Upper	20 (65)	ARGR, BURB, LKTR, RDWF	63.0303	146.0606	Peckham 1976
Yukon	Tanana (upper)	Twelvemile	5 (16)	NOPI	63.8603	144.6833	Pearse 1976
Yukon	Tanana (upper)	Twin		ARGR	62.5274	143.2646	Markis et al. 2004
Yukon	Tanana (upper)	Twin, North	13 (42)	LNSU, RBTR, SLSC	63.8664	145.8369	Peckham 1976
Yukon	Tanana (upper)	Twin, South	7 (23)	COHO, LNSU, RBTR	63.8625	145.8383	Peckham 1976
Yukon	Tanana (upper)	Two Bit	20 (65)	LKTR	63.1319	145.6417	Peckham 1976
Yukon	Tanana (upper)	Volkmar	13 (42)	HBWF, LCIS, NOPI, SLSC	64.1205	145.1865	Pearse 1976; Hansen and Pearse 1995
Yukon	Tanana (upper)	Yarger	3 (10)	HBWF, LNSU, NOPI	62.9608	141.6483	Pearse 1975
Yukon	Yukon Flats	82-01	10.5 (35)	NOPI	66.1128	145.6914	Hallberg 1983
Yukon	Yukon Flats	82-02	13.5 (45)	NOPI	66.1097	145.5642	Hallberg 1983
Yukon	Yukon Flats	82-03	20 (65)	NOPI	66.0459	145.4411	Hallberg 1983
Yukon	Yukon Flats	82-04	15 (50)	NOPI	66.0425	145.2405	Hallberg 1983
Yukon	Yukon Flats	82-05	2.5 (9)	BRWF, HBWF, LCIS, LNSU, NOPI	66.1892	145.4400	Hallberg 1983
Yukon	Yukon Flats	884-01	22 (72)	BRWF, LCIS, NOPI	66.0817	146.9404	Kramer 1981; Glesne et al. 2011
Yukon	Yukon Flats	884-02 (Lake 05)	29.6 (97)	LCIS, NOPI	66.1005	146.4113	Kramer 1981; Glesne et al. 2011
Yukon	Yukon Flats	884-03	12.8 (42)	No Fish Collected	66.1256	146.7412	Glesne et al. 2011
Yukon	Yukon Flats	884-04	17.9 (59)	No Fish Collected	66.1216	146.6663	Glesne et al. 2011
Yukon	Yukon Flats	884-05	3.4 (11)	NOPI	66.1722	146.4185	Glesne et al. 2011
Yukon	Yukon Flats	884-06	2.7 (9)	No Fish Collected	66.1857	146.6560	Glesne et al. 2011
Yukon	Yukon Flats	884-07	3 (10)	No Fish Collected	66.3859	146.3609	Glesne et al. 2011
Yukon	Yukon Flats	884-08	4.9 (16)	BRWF, HBWF, LCIS, NOPI	66.2314	146.6373	Glesne et al. 2011

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Yukon Flats	886-01	3.7 (12)	No Fish Collected	66.1726	147.9707	Glesne et al. 2011
Yukon	Yukon Flats	886-02	2.8 (9)	No Fish Collected	66.1679	147.9107	Glesne et al. 2011
Yukon	Yukon Flats	886-03	4 (13)	NOPI	66.1512	147.7341	Glesne et al. 2011
Yukon	Yukon Flats	886-04 (Lake 01)	10.2 (33)	BRWF, LCIS, NOPI	66.0696	147.7151	Kramer 1981; Glesne et al. 2011
Yukon	Yukon Flats	886-05 (Lake 02)	9.5 (31)	BRWF, LCIS, NOPI	66.0764	147.6132	Kramer 1981; Glesne et al. 2011
Yukon	Yukon Flats	886-06	10.8 (35)	NOPI	66.0314	147.5508	Glesne et al. 2011
Yukon	Yukon Flats	886-07	8.6 (28)	BRWF, CHUM, HBWF, INCO, LCIS, NOPI	66.2013	148.0899	Glesne et al. 2011
Yukon	Yukon Flats	886-08	0.9 (3)	No Fish Collected	66.3324	147.9803	Glesne et al. 2011
Yukon	Yukon Flats	886-09	2.5 (8)	No Fish Collected	66.3604	148.5799	Glesne et al. 2011
Yukon	Yukon Flats	886-10	1.8 (6)	BRWF, LCIS	66.2989	148.6746	Glesne et al. 2011
Yukon	Yukon Flats	886-11	9.5 (31)	BRWF, NOPI	66.8888	145.2048	Glesne et al. 2011
Yukon	Yukon Flats	886-12	4 (13)	BRWF, HBWF, LCIS, NOPI	66.8047	145.4153	Glesne et al. 2011
Yukon	Yukon Flats	886-13	9.8 (32)	NOPI	66.8034	145.1168	Glesne et al. 2011
Yukon	Yukon Flats	886-14	2.2 (7)	No Fish Collected	66.8058	144.8954	Glesne et al. 2011
Yukon	Yukon Flats	886-15	5.8 (19)	No Fish Collected	67.1799	144.8003	Glesne et al. 2011
Yukon	Yukon Flats	886-16	2.5 (8)	No Fish Collected	67.2688	144.8165	Glesne et al. 2011
Yukon	Yukon Flats	886-29	10.2 (33)	NOPI	66.8844	145.1551	Glesne et al. 2011
Yukon	Yukon Flats	Burman	29 (95)	BURB, NOPI	66.0613	145.9662	Kramer 1981; Bertram and Person 2005
Yukon	Yukon Flats	Lake 03	13 (42)	NOPI	66.1040	147.5529	Kramer 1981
Yukon	Yukon Flats	Lake 07	18.5 (60)	NOPI	66.1127	145.8731	Kramer 1981
Yukon	Yukon Flats	Lake 08	18.5 (60)	NOPI	66.0605	145.7814	Kramer 1981
Yukon	Yukon Flats	Lake 09, YF 02	6 (20)	NOPI	65.9260	146.6025	Kramer 1981; Bertram and Person 2005

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Yukon Flats	Shovun	11 (36)	BRWF	66.7864	145.3978	McLean and Raymond 1983
Yukon	Yukon Flats	Twentymile	5.5 (17)	No Fish Collected	66.8092	145.5642	McLean and Raymond 1983
Yukon	Yukon Flats	YF 01	30.5 (100)	NOPI	66.0735	146.2681	Bertram and Person 2005
Yukon	Yukon Flats	YF 03	3 (10)	NOPI	65.9921	146.6487	Bertram and Person 2005
Yukon	Yukon Flats	YF 08	9.5 (31)	NOPI	65.9989	146.4691	Bertram and Person 2005
Yukon	Yukon Flats	YF 09	18 (59)	NOPI	66.0112	146.4474	Bertram and Person 2005
Yukon	Yukon Flats	YF 10	5 (16)	NOPI	65.9724	146.5531	Bertram and Person 2005
Yukon	Yukon Flats	YF 14	15 (49)	NOPI	65.9375	146.4828	Bertram and Person 2005
Yukon	Yukon Flats	YF 26	5.5 (18)	NOPI	65.9463	146.0589	Bertram and Person 2005
Yukon	Chandalar	Ackerman	25.5 (84)	ARGR, BURB, HBWF, LKTR, RDWF	67.5305	147.5491	Kramer 1976b; Pearse 1978
Yukon	Chandalar	Arctic Gas 05		ARGR	68.6310	144.8231	Ward and Craig 1974
Yukon	Chandalar	Arctic Gas 08		ARGR	68.5886	144.9024	Ward and Craig 1974
Yukon	Chandalar	Arctic Gas 09		ARGR	68.6068	144.8806	Ward and Craig 1974
Yukon	Chandalar	Arctic Gas 12		No Fish Collected	68.6095	144.8640	Ward and Craig 1974
Yukon	Chandalar	Arctic Gas 18		ARGR, RDWF	68.5568	144.9931	Ward and Craig 1974
Yukon	Chandalar	Arctic Gas 19		ARGR, SLSC	68.6249	144.9057	Ward and Craig 1974
Yukon	Chandalar	Arctic Gas 20		ARGR	68.5444	145.0183	Ward and Craig 1974
Yukon	Chandalar	Arctic Gas 24		ARGR	68.6273	144.6957	Ward and Craig 1974
Yukon	Chandalar	Arctic Gas 36		No Fish Collected	68.1238	145.5419	Ward and Craig 1974
Yukon	Chandalar	Arctic Village Airport	1.5 (5)	NOPI	68.1095	145.5812	Ward and Craig 1974
Yukon	Chandalar	Blackfish	6 (20)	LKTR	68.1955	145.2975	Ward and Craig 1974; Craig and Wells 1975
Yukon	Chandalar	Chandalar	35 (115)	ARGR, BRWF, BURB, HBWF, LCIS, LKTR, LNSU, NOPI, RDWF	67.5167	148.5117	Roguski and Spetz 1968; Kramer 1976b; Pearse 1978

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Chandalar	Junjik		NOPI	68.3016	146.4544	Ward and Craig 1974
Yukon	Chandalar	Loon		BRWF, NOPI	68.1161	145.5569	McLean and Raymond 1983; Ward and Craig 1974
Yukon	Chandalar	Redfish	9 (30)	ARCH, SLSC	68.1742	145.2264	Ward and Craig 1974; Craig and Wells 1975
Yukon	Chandalar	Squaw	13.5 (45)	ARGR, BURB, HBWF, LKTR, NOPI, RDWF, SLSC	67.6072	148.2111	Roguski and Spetz 1968; Kramer 1976b; Pearse 1978
Yukon	Chandalar	Vettetrin		ARGR, NOPI, SLSC	68.5039	145.0865	Ward and Craig 1974; Craig and Wells 1975
Yukon	Chandalar	Vunittsieh	31 (102)	NOPI	67.5433	147.4183	Kramer 1976b; Pearse 1978
Yukon	Porcupine	886-17	2.2 (7)	No Fish Collected	67.3144	143.6653	Glesne et al. 2011
Yukon	Porcupine	886-18	1.5 (5)	No Fish Collected	67.1283	143.6029	Glesne et al. 2011
Yukon	Porcupine	886-19	3.7 (12)	No Fish Collected	67.1905	143.3837	Glesne et al. 2011
Yukon	Porcupine	886-20	2.5 (8)	No Fish Collected	66.9131	143.8796	Glesne et al. 2011
Yukon	Porcupine	886-21	4 (13)	No Fish Collected	66.7040	144.1337	Glesne et al. 2011
Yukon	Porcupine	886-22	18.5 (61)	No Fish Collected	66.4728	142.6834	Glesne et al. 2011
Yukon	Porcupine	886-23	3.7 (12)	LCIS, NOPI	66.3468	142.6272	Glesne et al. 2011
Yukon	Porcupine	886-24	6.8 (22)	BRWF, LCIS, NOPI	66.2985	142.5390	Glesne et al. 2011
Yukon	Porcupine	886-25	7.1 (23)	NOPI	66.2831	142.8858	Glesne et al. 2011
Yukon	Porcupine	886-26	2.5 (8)	BRWF, LCIS, NOPI	66.6226	142.9241	Glesne et al. 2011
Yukon	Porcupine	886-27	2.5 (8)	No Fish Collected	66.6723	142.8766	Glesne et al. 2011
Yukon	Porcupine	886-28	1.8 (6)	No Fish Collected	66.6805	144.3445	Glesne et al. 2011
Yukon	Porcupine	Arctic Gas 23	3.5 (11)	No Fish Collected	68.6069	144.6578	Ward and Craig 1974
Yukon	Porcupine	Arctic Gas 26		ARGR, BURB, RDWF	68.3125	144.2578	Ward and Craig 1974
Yukon	Porcupine	Arctic Gas 27		No Fish Collected	68.3725	144.2050	Ward and Craig 1974

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Yukon	Porcupine	Arctic Gas 28		ARGR, HBWF[1], LNSU, RDWF, SLSC	68.4292	144.2417	Ward and Craig 1974
Yukon	Porcupine	Arctic Gas 30		ARGR	68.3750	144.2290	Ward and Craig 1974
Yukon	Porcupine	Arctic Gas 31		BURB	68.3800	144.2225	Ward and Craig 1974
Yukon	Porcupine	Arctic Gas 32		No Fish Collected	67.9422	142.1683	Ward and Craig 1974
Yukon	Porcupine	Arctic Gas 39	2.5 (8)	No Fish Collected	68.4333	144.3833	Ward and Craig 1974
Yukon	Porcupine	Big Fish		HBWF[1], NOPI	67.9285	144.1083	Ward and Craig 1974; Craig and Wells 1975
Yukon	Porcupine	Grayling	0.5 (1)	No Fish Collected	67.9622	143.1006	Ward and Craig 1974
Yukon	Porcupine	Old John	24 (78)	ARGR, BURB, HBWF[1], LKTR, NOPI, SLSC	68.0745	145.0297	Ward and Craig 1974; Craig and Wells 1975; Pearse 1978
Yukon	Yukon (upper)	Beaver	13 (42)	ARGR, LKTR	62.0389	141.8139	Pearse 1975
Yukon	Yukon (upper)	Carden	3.5 (11)	ARGR, LKCB, SLSC	62.2805	141.1905	Peckham 1980; Markis et al. 2004
Yukon	Yukon (upper)	Cirque, Big		No Fish Collected	64.8148	143.5863	Markis et al. 2004
Yukon	Yukon (upper)	Cirque, Small		No Fish Collected	64.8227	143.5925	Markis et al. 2004
Yukon	Yukon (upper)	Lake 02		No Fish Collected	65.4692	143.6119	Markis et al. 2004
Yukon	Yukon (upper)	Ptarmigan	11 (36)	ARGR, BURB, LKTR, LNSU, RDWF, SLSC	61.8567	141.1639	Pearse 1975; Markis et al. 2004
Yukon	Yukon (upper)	Rock	63 (207)	ARGR, BURB, LKTR, LNSU, RDWF, SLSC	61.7994	141.2579	Pearse 1975; Markis et al. 2004
Yukon	Yukon (upper)	Seymore		NOPI	65.3340	142.0522	Markis et al. 2004
Yukon	Yukon (upper)	YKC 04-25		LKCB	65.3848	143.4564	Markis et al. 2004
Kuskokwim	Aniak	Aniak	38 (124)	ARCH, ARGR, COHO, LKTR, RDWF, SLSC	60.4623	159.1904	Alt 1977b
Kuskokwim	Swift Fork	Big		NOPI	63.5179	152.5252	Markis et al. 2004
Kuskokwim	Swift Fork	Carey		NOPI	63.4049	152.6023	Markis et al. 2004

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Kuskokwim	Eek	Eek	2.5 (8)	NOPI	60.2254	160.3252	Alt 1977b
Kuskokwim	Kisaralik	Gold	58.5 (192)	ARCH, ARGR, LKTR, SLSC	60.2145	159.4650	Alt 1977b
Kuskokwim	Kisaralik	Kisaralik	41 (135)	ARCH, ARGR, LKTR.SLSC	60.3219	159.3460	Alt 1977b
Kuskokwim	Swift Fork	Moose, Northwest		No Fish Collected	63.5925	152.7275	Markis et al. 2004
Kuskokwim	Swift Fork	Sprucefish		NOPI	63.5709	152.7121	Markis et al. 2004
Kuskokwim	Stony	Telaquana	130 (426)	ARGR, CHUM, DVAR, LCIS, LKTR, LNSU, NOPI, NSST, RDWF, SLSC, SOCK	60.9448	153.9100	Baxter 1973; Russell 1980
Kuskokwim	Stony	Two	53 (173)	DVAR, LKTR, LNSU, NOPI, NSST, PGWF, RDWF, SLSC, SOCK	61.1295	153.7800	Baxter 1973; Russell 1980
Kuskokwim	Holitna	Whitefish		ARGR, BRWF, LKTR, NOPI, RDWF	60.9528	154.8700	Baxter 1973
Kuskokwim	Kuskokwim	Whitefish	2 (7)	BRWF, CHUM, COHO, HBWF, INCO, LCIS, LNSU, NOPI, RDWF, SOCK	61.3782	160.0227	Harper et al. 2007
Coastal	Aphrewn	Kgun		BRWF, BURB, CHIN, CHUM, HBWF, LCIS, NOPI, PDSM, PINK	61.5711	163.8120	Baxter 1975; Maciolek 1986
Coastal	Arolik	Arolik	56.5 (185)	ARCH, ARGR, COHO, LKTR, RDWF, SOCK	59.4623	161.1017	Alt 1977b
Coastal	Goodnews	Middle Fork, North		ARCH, LKTR, RDWF, SLSC, SOCK	59.4156	160.5803	Alt 1977b
Coastal	Goodnews	Middle Fork, South	23 (75)	AKBF, ARCH, LKTR, RDWF, SLSC, SOCK	59.4003	160.5583	Alt 1977b
Coastal	Goodnews	Asriguat	23 (75)	ARCH, COHO, LKTR, SOCK	59.5154	160.6269	Alt 1977b
Coastal	Goodnews	Canyon	45.5 (150)	ARCH, COHO, LKTR, RDWF, SOCK	59.4298	161.1731	Alt 1977b

Appendix A5 continued.

Drainage	Basin	Name	Depth m (feet)	Fish present	Latitude	Longitude	Author
Coastal	Goodnews	Goodnews	39.5 (130)	AKBF, ARCH, BURB, CHUM, LKTR, NOPI, RBTR, RDWF, SLSC, SOCK, TSST	59.4926	160.5506	Alt 1977b
Coastal	Goodnews	Kukaktlim	2 (7)	ARCH, LKTR, RDWF, SLSC, SOCK	59.3434	160.4814	Alt 1977b
Coastal	Kanektok	Kagati	51 (168)	ARCH, ARGR, BURB, LKTR, RDWF, SLSC, SOCK	59.8745	160.0667	Alt 1977b
Coastal	Kanektok	Kanuktik	30.5 (100)	ARCH, CHIN, LKTR, RDWF	59.7101	160.3114	Alt 1977b
Coastal	Kanektok	Klak		ARCH, CHIN, LKTR, SLSC	59.7262	160.4603	Alt 1977b
Coastal	Kanektok	Ohnlik	30.5 (100)	ARCH, LKTR, RDWF,SLSC, SOCK	59.7374	160.2632	Alt 1977b

[1]Ward and Craig (1974) initially reported broad whitefish present in this lake but Craig and Wells (1975, pages 77–87, and 100–101) reevaluated the identification and determined that they were actually humpback whitefish.

Appendix A6. List of delegates and guests invited to the November 18-19, 2008 meeting of the Whitefish Strategic Planning Group. Those who were unable to attend are indicated in italics.

Name	Position	Affiliation
Robert Aloysius	RAC Delegate	Yukon Kuskokwim Delta RAC
David Andersen	Subsistence Researcher	Research North
Brandy Berkbigler	Fish Biologist	Tanana Chiefs Conference
Caroline Brown	Subsistence Specialist	Alaska Dept. of Fish and Game
Randy Brown	Fish Biologist	U.S. Fish and Wildlife Service
John Burr	*Fish Biologist*	*Alaska Dept. of Fish and Game*
Richard Carroll, Jr.	*RAC Delegate*	*Eastern Interior RAC*
John Chythlook	Fish Biologist	Alaska Dept. of Fish and Game
Kevin Clark	Kuskokwim Fishery Manager	Alaska Dept. of Fish and Game
Dani Evenson	Yukon/Kuskokwim Res. Man.	Alaska Dept. of Fish and Game
Ken Harper	Fish Biologist	U.S. Fish and Wildlife Service
Russ Holder	Federal Fishery Manager	U.S. Fish and Wildlife Service
Jennifer Hooper	Dir. of Fish. & Forest. Res.	Assoc. of Village Council Pres.
Paul Manumik, Sr.	RAC Delegate	Yukon Kuskokwim Delta RAC
Doug Molyneaux	Kuskokwim Research Man.	Alaska Dept. of Fish and Game
Bill Morris	*Habitat Biologist*	*Alaska Dept. of Fish and Game*
Stanley Ned	Stakeholder	Koyukuk River Representative
Jenny Pelkola	RAC Delegate	Western Interior RAC
Gene Peltola	Yukon Delta Refuge Manager	U.S. Fish and Wildlife Service
Mike Thalhauser	Fish Biologist	Kuskokwim Native Association
Gary Lawrence	*Acting Natural Resources Dir.*	*Council of Athabascan Tribal Gov.*
Jason Hale	Moderator	Yukon River Drainage Fish. Assoc.
Tina Hile	Recorder	Computer Matrix
Richard Cannon	Guest	U.S. Fish and Wildlife Service
Daniel Gillikin	Guest	U.S. Fish and Wildlife Service
Liz Williams	Guest	U.S. Fish and Wildlife Service

Appendix A7. List of delegates and guests attending the April 23-24, 2009 meeting of the Whitefish Strategic Planning Group.

Name	Position	Affiliation
Robert Aloysius	RAC Delegate	Yukon Kuskokwim Delta RAC
Dave Andersen	Subsistence Researcher	Research North
Brandy Berkbigler	Fish Biologist	Tanana Chiefs Conference
Caroline Brown	Subsistence Specialist	Alaska Department of Fish and Game
Randy Brown	Fish Biologist	U.S. Fish and Wildlife Service
John Burr	Fish Biologist	Alaska Department of Fish and Game
Richard Carroll Jr.	RAC Delegate	Eastern Interior RAC
John Chythlook	Fish Biologist	Alaska Department of Fish and Game
Larry DuBois	Fish Biologist	Alaska Department of Fish and Game
Ken Harper	Fish Biologist	U.S. Fish and Wildlife Service
Steve Hayes	State Fisheries Manager	Alaska Department of Fish and Game
Russ Holder	Federal Fisheries Manager	U.S. Fish and Wildlife Service
Jennifer Hooper	Dir. of Fish & Fores. Res.	Association of Village Council Pres.
Paul Manumik, Sr.	RAC Delegate	Yukon Kuskokwim Delta RAC
Doug Molyneaux	Kuskokwim Research Mgr.	Alaska Department of Fish and Game
Laurie Montour	Dir., Natural Resources	Council of Athabascan Tribal Gov.
Bill Morris	Habitat Biologist	Alaska Department of Natural Res.
Stanley Ned	Stakeholder	Koyukuk River Representative
Jenny Pelkola	RAC Delegate	Western Interior RAC
Gene Peltola	Yukon Delta Refuge Mgr.	U.S. Fish and Wildlife Service
Lily Ray	Subsistence Specialist	Alaska Department of Fish and Game
Mike Thalhauser	Fish Biologist	Kuskokwim Native Association
Jason Hale	Moderator	Yukon River Drainage Fish Assoc
Tina Hile	Recorder	Computer Matrix
Audra Brase	Guest	Alaska Department of Fish and Game
Richard Cannon	Guest	U.S. Fish and Wildlife Service, OSM
Dave Esse	Guest	Bureau of Land Management
Dan Gillikin	Guest	U.S. Fish and Wildlife Service
Gary Lawrence	Guest	Council of Athabascan Tribal Gov.
Jeff Olsen	Guest	U.S. Fish and Wildlife Service
Lisa Stuby	Guest	Alaska Department of Fish and Game
Liz Williams	Guest	U.S. Fish and Wildlife Service, OSM