Fishery Data Series No. 10-47

Spawning Locations, Seasonal Distribution, and Migratory Timing of Kuskokwim River Sheefish using Radiotelemetry, 2007-2009

Final Report for Study 06-305
USFWS Office of Subsistence Management
Fisheries Division

by
Lisa Stuby

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Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	$>$
greater than or equal to	$\geq$
harvest per unit effort	HPUE
less than	$<$
less than or equal to	$\leq$
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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By
Lisa Stuby
Division of Sport Fish, Fairbanks

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1599

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ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

Lisa Stuby,
Alaska Department of Fish and Game, Division of Sport Fish,
1300 College Road, Fairbanks, AK 99701-1599 USA

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ABSTRACT

This study was initiated to expand our understanding of spawning locations, seasonal distribution, and movements of sheefish or inconnu *Stenodus leucichthys* in the Kuskokwim River drainage. During late summer/early fall 2007 and late spring 2008, 119 sheefish were captured throughout the Kuskokwim River drainage and surgically implanted with radio transmitters. Radio-tagged sheefish were tracked using a combination of 8 stationary receiving stations and 3 aerial tracking flights that were conducted annually during July, late September, and mid-October. Through fall 2009, 52 radio-tagged sheefish travelled to 3 spawning areas. The majority travelled to a 7 km section within the Big River, where spawning activity had been previously documented. Much smaller proportions migrated to areas on the Middle and Slow Forks of the Kuskokwim River, previously undocumented for spawning activity. Migratory timing profiles illustrated that sheefish arrived at their spawning areas during late July through mid-September and spawned during late September through early October. Post-spawning outmigration occurred during a 1 to 1.5 week period in mid-October. The majority of sheefish, spawners and non-spawners, migrated downstream to the Lower Kuskokwim River to overwinter. A much smaller proportion of sheefish overwintered in the middle to upper portions of the Kuskokwim River drainage. During the summer, sheefish traveled to and between mouths of major Kuskokwim River tributaries to feed on outmigrating salmon smolt and other species of fish. We will continue to track the radio-tagged sheefish in 2010 and 2011 and to document spawning locations, monitor migrations, and identify summer feeding areas.

Key words: Kuskokwim River, Holitna River, Big River, Middle Fork, aerial tracking flight, sheefish, seasonal movements, spawning areas, *Stenodus Leucichthys*, radio transmitter, stationary receiving stations.

INTRODUCTION

The Kuskokwim River is the second largest drainage in Alaska. From its headwaters in the Alaska Range, the Kuskokwim River drains approximately 130,000 km^2 along its 1,130 km course to the Bering Sea (Figure 1). This drainage supports five species of Pacific salmon as well as numerous resident species, including inconnu *Stenodus leucichthys*, commonly called sheefish in Alaska.

Sheefish are a highly migratory whitefish found in large northern rivers and associated lakes of northwestern North America and northern Eurasia (McPhail and Lindsey 1970). Sheefish, like other whitefish, are known for their high phenotypic plasticity (Behnke 1972). Most sheefish in Alaska are estuarine anadromous, while much smaller numbers belong to local nonanadromous stocks. Sheefish undertake movements and/or migrations related to feeding, spawning, and overwintering, with estuarine anadromous sheefish undertaking the longest migrations (Howland et al. 2000). Prior to this study, documented knowledge of sheefish on the Kuskokwim River is based almost entirely on work by Alt (1987) in the 1970s and early 1980s, and on information from other systems.

Currently and historically, the greatest use of sheefish in the Kuskokwim River drainage has been for subsistence. Between 2002 and 2004, sheefish constituted 787, 346, and 900 of the total non-salmon subsistence harvest of 28,500, 17,693 and 35,430 fish, respectively in the lower river near Bethel (Fall et al. 2003, Brown et al. 2005, Fall et al. 2007). In the middle river near Aniak, sheefish are harvested throughout the year and have constituted 995 and 573 of the total non-salmon harvest of 10,890 and 5,417 for 2001–2002 and 2002–2003, respectively (Krauthoefer et al. 2007). The majority of sheefish are harvested in the lower river during the early spring as the fish migrate upriver and provide a source of fresh fish prior to the salmon runs. The residents of Nikolai and Telida in the upper drainage report that sheefish are one of the first fish to return to the area in early spring. Residents of Nikolai will travel to and harvest sheefish at the mouth of

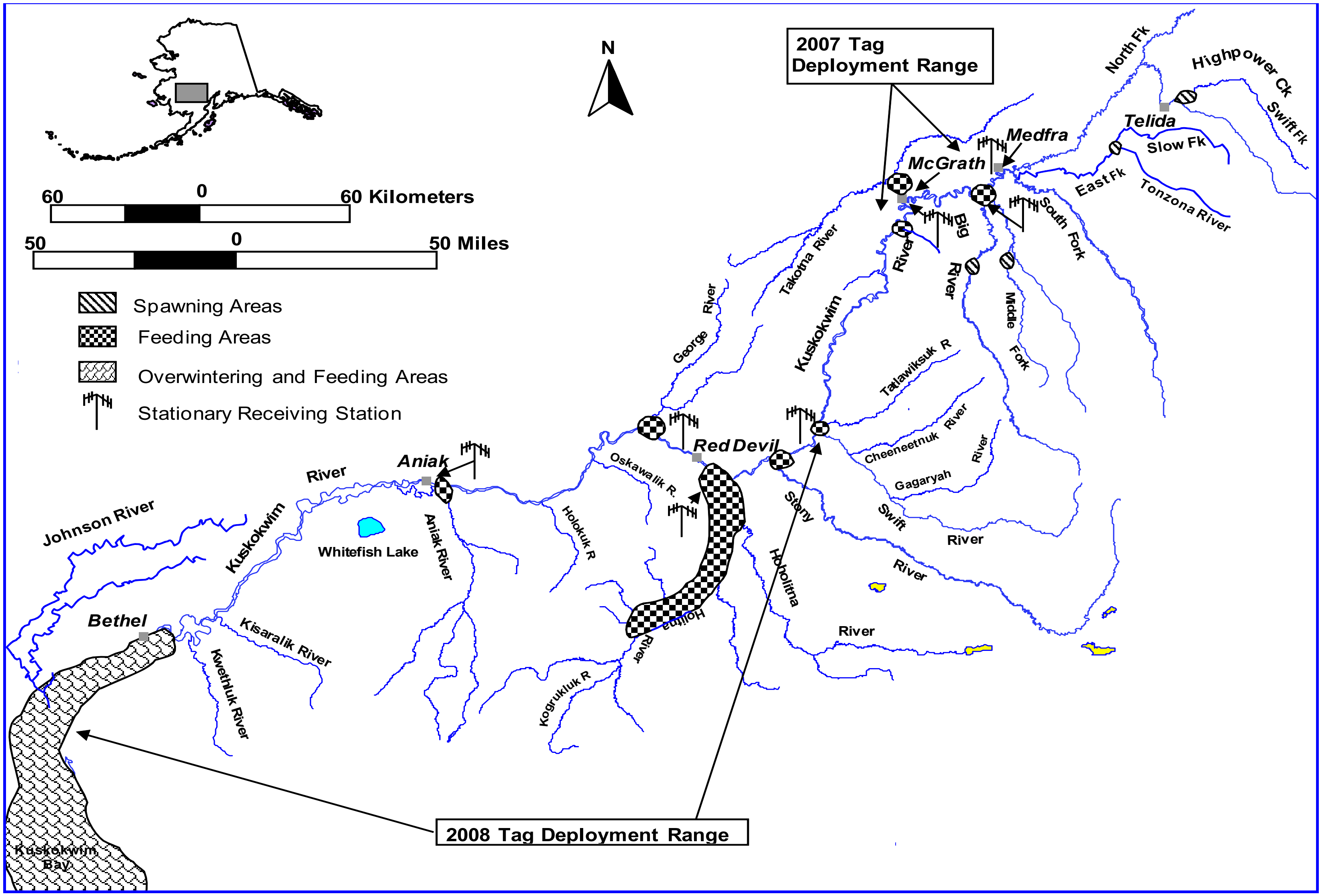

Figure 1.–Map of the Kuskokwim River showing approximate overwintering, feeding, and spawning locations for sheefish as recorded by Alt (1987) and noted in this study. Map includes the locations of stationary receiving stations and the approximate ranges of radio tag deployment for 2007 and 2008.

Big River in June. Present and former (currently living in Nikolai) residents of Telida harvest sheefish in late August and early September at the mouth of Highpower Creek (Williams et al. 2005).

Sheefish are also an important targeted species by sport fishers in streams and tributaries within the Kuskokwim River drainage with the largest fishery occurring in the Holitna River (Chythlook 2009). Between 2005 and 2008, estimated sport harvest of sheefish within the Kuskokwim River drainage varied ten-fold: 997 in 2005, 173 in 2006, 435 in 2007 and 81 in 2008. Sport harvest estimates in the Holitna River drainage were 349 in 2005, 14 in 2006, 0 in 2007, and 81 in 2008, ranging from 0% to 100% of the total estimated sport harvest within the entire Kuskokwim River drainage (Jennings 2009a, 2009b, 2010a, 2010b.).

Alt (1987) documented 2 spawning areas within the Kuskokwim River drainage: 1) in the lower 200 m of Highpower Creek near Telida; and, 2) in a 20 km section of the Big River (Figure 1). Alt did not actually see fish spawning within these mainly occluded tributaries; however, sheefish that were collected from these areas were freely expressing milt and eggs with little pressure. Alt collected these sheefish in late September until October 3 when he had to suspend sampling due to river ice and thus did not determine the post-spawning timing of downriver migrations to their overwintering areas.

Management of the Kuskokwim River sheefish population for long-term sustainability requires a greater understanding of their life history. This three-year study (2007–2009) was initiated to extend our understanding of seasonal habitat use and movements by sheefish in the Kuskokwim River drainage. Incorporating telemetry techniques has allowed for precise observations of sheefish movements and migration timing. The primary purpose of this study was to identify locations of spawning aggregations (stocks). This study has also provided information on migration timing and seasonal distribution of sheefish throughout the entire drainage of the Kuskokwim River (Figure 1). Information gathered may be used to design future studies to investigate the population dynamics of specific spawning stocks, stock abundance, and stock compositions of harvests. The study will be extended through 2011 to further describe and/or locate additional sheefish spawning areas.

OBJECTIVES

The main objective of this study was to:

1. document spawning stocks and spawning locations of sheefish in the Kuskokwim River drainage.

Secondary objectives were to:

1. determine the migratory timing of mature sheefish to their spawning, overwintering, and feeding areas;
2. identify specific summer feeding areas used by known spawning stocks; and,
3. collect tissue samples from all radio-tagged sheefish for future genetic stock identification analysis.

In addition, there was one task to:

1. collect fin rays from 10 sheefish for later thin-sectioning on a Buehler Isomet[1] thin-section precision low-speed saw® for practice using this equipment and to examine the feasibility of collecting, processing, and assigning accurate ages from these structures.

METHODS

STUDY DESIGN

For 2007, this study was designed to capture and mark 30 sheefish in spawning condition in the Upper Kuskokwim River during their spawning migration in late summer/early fall and to track them to spawning areas. For 2008, 89 sheefish of unknown spawning status would receive radio transmitters in the lower and middle portions of the Kuskokwim River. During 2007, capture and tagging took place mainly within the vicinity of McGrath and 9 prespawning sheefish were captured and implanted with transmitters between 14 August and 6 September. In 2008, 110 sheefish of unknown spawning status were implanted with radio transmitters, including the 21 transmitters that did not get deployed in 2007. From fall 2007–fall 2009, we tracked and recorded the movements and migratory timing of all radio-tagged sheefish during the open water period and will continue to do so through 2011.

During 2008, a two-tiered sampling approach was used to distribute radio transmitters to ensure that both migratory and nonmigratory components of the population were tagged. Based on Alt (1987), sheefish predominately overwinter in the Lower Kuskokwim River and Kuskokwim Bay and migrate to upriver summer feeding locations immediately following river ice-out in the spring. In contrast, it is believed that a much smaller portion reside year-round in the Middle and Upper Kuskokwim River (Chythlook 2009). To maximize the probability of locating all spawning areas, an attempt was made to deploy as many transmitters as possible in the Lower Kuskokwim River and its tributaries prior to upstream migration. The remaining tags would then be dispersed into fish captured at their summer feeding areas between Bethel and the Tatlawiksuk River (Figure 1).

Radio transmitters were surgically implanted into captured sheefish and are guaranteed to transmit for a minimum of 3 years. The movements of all radio-tagged fish were recorded by an array of 8 stationary receiving stations located throughout the Kuskokwim River drainage (Figure 1). In addition, sheefish were tracked by small, fixed-wing aircraft during late July, late September, and early October, with the fall surveys providing data on locations and timing of probable spawning activity.

CAPTURE AND TAGGING

A crew of three persons captured and tagged sheefish during 14 August–6 September 2007. From 14 to 31 August, we fished primarily at the following upper river locations: the mouth of the Katlitna River, which is located approximately 36 rkm downriver from McGrath; the mouth of the Takotna River, which is located directly across from McGrath; the mouth of Nixon Fork, which is located at 23 rkm of the Takotna River; and the mouth of Grayling Creek, which is located 43 rkm upriver from McGrath. From 2–3 September we fished near and at the mouth of the Big River (Figure 1).

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[1] Brand names used in this report are included for scientific completeness, but do not constitute product endorsement.

During 2008, fishing for sheefish commenced downriver from Bethel immediately after break up in mid-May as soon as the Kuskokwim River near Bethel became safe to travel. Prior to capture operations, 7 sheefish radiotagged in 2007 were located during an aerial tracking flight of the Lower Kuskokwim River. The locations of these fish were used to guide fishing effort. The upstream migration of these fish also provided information about how long to sample downriver before moving upriver with the spring migration. Because of the uncertainties in timing of the upstream migration, the rate of migration, and where and how much time the migrating sheefish would spend at the mouths of the major tributaries, we were flexible in our approach to fishing locations and how much time was spent at each location.

A total of 5 people on 2 crews were used to capture and tag sheefish at the mouth of the Johnson River and near Bethel during 22–29 May 2008. Once this downriver sampling was complete, one crew of 3 people travelled upriver and attempted to capture and tag sheefish near the mouths of the Kwethluk, Tuluksak, and Aniak rivers for approximately one week. Afterwards, the same crew of 3 people continued upriver to set up a base camp at Barge Slough on the Holitna River. From the base camp, the crew fished the mouths of the George, Holitna, Stony, Swift, and Tatlawiksuk rivers for approximately two weeks.

The mainstem Kuskokwim River is glacially occluded and turbid and water clarity at the mouth of the Johnson River was poor due to tidal and mainstem influences. As a result, gillnets with 6 in mesh size were used to capture sheefish. Upriver fishing was conducted at the mouths of large tributaries such as the George, Holitna, Swift, and Tatlawiksuk rivers and utilized hook-and-line methods. Lures had single, barbless hooks in order to minimize injury. Regardless of capture method, fish were retrieved into the boat with a rubber landing net that was designed to minimize damage to fish during catch-and-release practices. Attempts were made to inflict the least amount of stress and injury to each captured fish. Fish that showed signs of stress and/or injury due to capture (bleeding from hooks, ripped fins, lethargy, etc.) were released without receiving a radio transmitter.

Radio transmitters were surgically implanted following the methods detailed by Brown et al. (2002). For each sheefish that was captured and implanted with a radio transmitter, data collected included: measurement of fish length to the nearest 5 mm FL; gender, location (river mouth, mainstem GPS coordinate), transmitter frequency and code, date of capture, and any notable condition information.

A small pelvic fin clip was collected from each radio-tagged sheefish. Each tissue sample was cleaned and immediately placed in an individually labeled vial filled with 100% ethanol and stored in a cool, dark place. These samples will be added to future collections and used to establish a genetic baseline for sheefish from the Kuskokwim River which may allow for identification of different stocks.

The original study design called for radio transmitters to be implanted into sheefish that were greater than 750 mm FL, as fish of this size were likely to be mature (Brown 2000, Taube and Wuttig 1998). However, achieving this objective was difficult, especially at the downriver fishing locations, so we relaxed our criteria and sheefish as small as 640 mm were tagged. Once daily catches increased markedly in the middle of June, especially on the Holitna River, only sheefish $\geq$750 mm FL were radio-tagged.

Comparisons of length distributions of spawning and non-spawning sheefish were conducted using the Kolmogorov-Smirnov (KS) two sample test (Conover 1980).

RADIO-TRACKING EQUIPMENT AND TRACKING PROCEDURES

Internally implanted radio transmitters were 3V Micro Coded Fish Transmitters that are 1.5 cm in diameter and 7 cm long, with a wire whip antenna about 43 cm long (Lotek[2] model MCFT-3L), and programmed with a 3s burst rate. Transmitters were programmed to operate for 7.5 months (April 15–November 30) and then shut off for 4.5 months (December 1–April 14) in order to guarantee operation for at least 3 years. Each radio transmitter is distinguishable by a unique frequency and encoded pulse pattern. For 2007, all transmitters were programmed with 1 frequency in the 149.200 MHz range with 30 encoded pulse patterns for a total of 30 uniquely identifiable tags. For 2008, transmitters were programmed with 2 frequencies (149.040 and 149.580 MHz), each with 45 codes for a total of 90 uniquely identifiable transmitters. One of the 149.580 MHz transmitters was not deployed and has been used to test receivers that have been downloaded and restarted to ensure proper working ability.

Eight stationary receiving stations (Figure 1) recorded the time and date of the upriver migration to feeding and/or spawning areas and of post-spawning outmigration to overwintering areas. The stationary receiving stations were operated similar to that described by Eiler et al. (2004). Each station consisted of a Lotek receiver powered by either four, 12 V deep cycle batteries or a series of four, 6 V batteries that were charged with a solar array. The components were housed in a water-resistant steel box covered with a fitted rain-proof tarp. Two 4-element Yagi antennas were used to receive the radio signals from the radio-tagged fish. Each antenna was mounted on a mast elevated 2–10 m above the ground depending on the elevation of the site above the river with one antenna aimed upstream and the other downstream. The receivers were programmed to scan through the frequencies at 6 s intervals, and receive from both antennas simultaneously. When a signal of sufficient strength was encountered, the receiver paused for 6 s on each antenna, and then tag frequency, tag code, signal strength, date, time, and antenna number were recorded on the data logger. The relatively short cycle period minimized the chance that a radio-tagged fish would swim past the receiver site without being detected.

Personnel from the U.S. Fish and Wildlife Service (USFWS), Kuskokwim Native Association (KNA), and ADF&G set up the 8 stationary receiving stations during mid-April of 2007 and 2008 and ADF&G and KNA personnel set up the stations during 2009. One receiving station is located near McGrath, another near Medfra, and one was placed on the Middle Fork of the Kuskokwim River at the mouth of Blackwater Creek a few bends below the confluence with the Big River (Figure 1). In addition, a receiving station is located on the mainstem of the Kuskokwim River at Sinka's Landing, which is located just downriver from the mouths of the Swift and Tatlawiksuk rivers (Figure 1). Other mainstem receiving stations are located just downriver from Red Devil and across from and approximately 2.5 km upriver from Aniak (Figure 1). A receiving station is also located on the Holitna River approximately 2 kilometers upriver from the mouth. Lastly, a receiving station is located at the entrance to Whitefish Lake (Figure 1). All 8 receiving stations were programmed with all 2007 and 2008 frequencies prior to tagging efforts in May 2008.

Initially, all 8 receiving stations were equipped with Lotek SRX_400 receivers and at approximate 1-month intervals, the data collected on the receivers were downloaded into a laptop computer. During 2008, the stationary receiving station located near the mouth of Big River was

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[2] Lotek Wireless, Inc., Ontario, Canada.

equipped with a Lotek SRX_600 receiver and a Forest Technology System satellite modem. This setup enabled the project biologist to directly communicate with the receiver using a standard telephone line and download and erase data and change receiver settings at any time. During 2009, an SRX_600 with satellite modem was installed in the receiving station located just above McGrath.

In addition to the stationary receiving stations, aerial tracking flights that encompassed most of the Kuskokwim River drainage were used to locate radio-tagged sheefish. During 2007, flights were conducted between the mouth of the Katlitna River and upriver tributaries during 27 September and 8 October. The USFWS also conducted an aerial tracking flight during 15–18 October 2007 throughout the Kuskokwim River drainage as part of a separate study to locate radiotagged whitefish and located several tagged sheefish. During 2008, flights were conducted during 20–22 July, 23–25 September, and 8–9 October. The USFWS also conducted aerial tracking flights during 14 July and 6 and 20 August. During 2009, flights were conducted during 3–4 July, 9–11 September, and 9–12 October. Aerial tracking flights were conducted with one Lotek SRX_600 receiver/scanner that was actively listened to by the project biologist and one SRX_600 that passively scanned and recorded any sheefish that the project biologist may have missed. The sheefish and whitefish frequencies were loaded into both receivers prior to each flight. Flight altitude ranged from 100–300 m above ground. Two H-antennas, one on each wing strut, were mounted such that the antennas received signals perpendicular to the direction of travel.

Ascertaining whether sheefish located during the fall aerial tracking flights were spawning was subjective because they were difficult to observe from the air in turbid water. In addition, funding and staff were not available to verify spawning activity on the ground. The following criteria were considered to be supportive that a radiotagged sheefish was located in a spawning area: 1) it was located during the likely time of spawning; 2) it was located in habitat consistent with spawning areas described by observations from past research; 3) it was located in close proximity to one or more radio-tagged sheefish, and; 4) it was located among a large aggregation of sheefish that were sighted from the air. The designation of spawning areas will become more definitive if radio-tagged sheefish are located in the same areas during the spawning period in future aerial tracking flights.

Fin Ray, Scale, and Otolith Ages

During 2007–2009, pectoral fin rays, otoliths, and scales from 11 sheefish were collected for thin-sectioning and age assignment. A length was taken, gender noted, and stomach contents examined for each fish collected. Seven of these fin ray and otolith pairs were taken from capture and tagging mortalities in 2007 and 2008. Three fish were collected in 2009 during sport fishing activities on the Holitna River as part of the ADF&G-Anadromous Waters Catalog (ADF&G-AWC) sampling effort and 1 fish was collected from the mouth of the George River. The ADFG-AWC kept one of the otolith pairs for future Strontium (SR) isotopic analysis to examine the frequency of anadromy.

Pectoral fin rays were covered in Epoxy prior to thin-sectioning. A Buehler Isomet thin-section precision low-speed saw® was then used to create the thin-sections which were then adhered to microscope slides. The thin-sectioned fin rays were viewed under a compound microscope under 10X power in a darkened room. To better highlight the annuli, a polarizing filter was used which darkened the background and enabled better viewing contrast of the annuli.

One otolith from each pair was sectioned through the nucleus, encapsulating the distal to proximal edges. The otolith was first ground to the focus using a diamond-grinding wheel, mounted on a glass slide with Crystalbond Thermoplastic, and further ground to a thin section, encapsulating the focus in the transverse plane (Secor et al. 1991). Similar to the fin rays, the thin-sectioned otoliths were viewed at 10X power in a darkened room on the same microscope. A polarizing filter was utilized to provide additional contrast.

Scales were taken from an area located just behind the dorsal fin and approximately 1 to 2 centimeters above the lateral line. Each scale was cleaned, attached to a gummed card, and then impressed into a sheet of acetate. Each scale was then aged using an EyeCom microfiche reader® at 15X power in a darkened room. Each scale, fin ray, and otolith from each fish was read once by the project biologist.

RESULTS

Of the 9 sheefish captured and implanted with radio transmitters in 2007, six were captured with hook-and-line and 3 with a gillnet. Four sheefish were captured and tagged at the mouth of the Katlitna River, 1 at the mouth of the Takotna River, 1 at the mouth of Nixon Fork, and 3 near the mouth of Big River (Figure 1). Of the tagged fish, 3 were identified as gravid females, 1 as a gravid male, and the gender designation of the remaining 5 was uncertain. For the 4 sheefish where gender was positively identified, testes or eggs were easily seen through the incision. The body cavities of the 3 females were swollen with eggs.

In 2008, 110 sheefish were implanted with radio transmitters. Fifteen sheefish were captured and tagged at the mouth of the Johnson River and 6 were captured and tagged near Bethel. We attempted to capture and tag sheefish at the mouths of the Kwethluk, Tuluksak, and Aniak rivers and various locations on the mainstem Kuskokwim River where sheefish had been occasionally captured during past sampling efforts directed at Chinook salmon. After a week of effort, we captured and tagged 1 sheefish approximately 25 rkm below Aniak (Figure 1). Of the remaining 88 radio transmitters, 12 were deployed at the mouth of the George River, 62 at the mouth of the Holitna River, and 14 at the mouth of the Tatlawiksuk River (Figure 1). Because these fish were captured in late spring and early summer, gender could not be discerned because their gonads were insufficiently developed.

Of the 9 sheefish that were captured and radiotagged during August 2007, 2 are presumed to have died as a result of tagging and handling (Table 1). For the 110 sheefish that were tagged in 2008, 14 are assumed to have died as a result of tagging and handling. Through fall 2009, 14 sheefish are known (fisher contacted ADF&G personnel) or assumed (strong tag signal coming from a fish camp or village) to have been harvested in the subsistence fishery (Table 1). Also, as of fall 2009, the fates of 8 radio-tagged sheefish are still unknown but may be discerned with additional aerial tracking flights and stationary receiving data during 2010 and 2011.

SPAWNING LOCATIONS AND TIMING

Radio-tagged sheefish were located in the 20 km section on the Big River that Alt (1987) had noted to be a spawning area (Figure 1, Table 2). One sheefish that was captured and radio-tagged at the mouth of Big River during 2007 travelled to this area after being released and was assumed to have spawned there. In 2008, 33 radio-tagged sheefish migrated upriver to this section of the Big River (Table 2, Figure 2, Appendix A2), 2 of which were tagged during 2007. During 2009, 20 sheefish travelled back to this area, including 7 of which are assumed to have spawned in this area during 2008, 1 fish that was tagged in this area in 2007, and 2 fish that were tagged in the Lower Kuskokwim River in 2008.

A second likely spawning area that was previously undocumented was located on the Middle Fork of the Kuskokwim River near the confluence with Windy Fork. Four radio-tagged sheefish travelled to this area and were detected during the September and October aerial flights during 2008 and 1 fish was detected there during 2009 (Figure 2, Table 2, Appendix A2). During the October 2008 and 2009 aerial tracking flights we were able to fly low and circle this area. The water was clear and we observed aggregations of 100 to 200 sheefish within an approximately 1.88 km section of river. Both the 20 km area on the Big River as well as this location met our criteria for spawning areas. For both these areas, radio-tagged sheefish were generally located farther up the drainages in 2009 than in 2008 (Figure 2, Appendix A2).

Radio-tagged sheefish bound for spawning areas in the Big River and Middle Fork arrived over a two-month period during 2008 and 2009 (Figure 3). During 2008, the earliest date that a sheefish was first detected at the mouth of Big River was 23 July, the latest arrival was on 19 September, and the average arrival date was 25 August. For 2009, the earliest arrival date was 7 August, the latest 14 September, with an average arrival date of 24 August (Figure 3). Many of these sheefish, especially the earlier arrivals, spent weeks swimming back and forth across the receiving station located near the mouth of Big River and within their spawning areas (Stuby 2009). During 18–22 July 2008 a radio-tagged sheefish entered the Big River and/or Middle Fork before heading back out to the mainstem Kuskokwim River. This sheefish was probably feeding because the fish was not present during typical spawning times. Another sheefish entered this area on 1 September 2008 and left on 14 September 2008. It is uncertain whether this sheefish had spawned or was just feeding.

A third location was identified as a potential spawning area. During 2008 one sheefish was detected during the time of spawning at the mouth of Slow Fork, near the confluence of East Fork and Tonzona rivers (Figure 4). In 2009, a different sheefish travelled to the same location during the same time of year (Table 2). The closest receiving station is at Medfra, which is approximately 136 km (84 miles) downriver from the mouth of Slow Fork. The sheefish in question swam past this station on 29 August 2008 and 1 September 2009, respectively. It is unknown how long it took them to travel to the mouth of Slow Fork, but during the 9 September 2009 aerial tracking flight, the sheefish was detected approximately 80 km downriver from the mouth of Slow Fork near the southern tip of East Fork Hills. Given 2 different fish in subsequent years travelled to the same location during the time of spawning, it is likely that this area may be another previously unknown spawning location.

Table 1.–Assigned fates of sheefish in 2009 that were captured and radiotagged during 2007 and 2008.

	Capture and tagging location during 2007					Capture and tagging location during 2008						
	Katlitna River	Takotna River	Blackwater Creek	Big River	Total	George River	Holitna River	Johnson River	Tatlawiksuk River	Mainstem Kuskokwim near Bethel	Mainstem Kuskokwim near Aniak	Total
Number of Sheefish Tagged	4	2	1	2	9	12	62	15	14	6	1	110
Tagging Mortality	0	1	0	1	2	1	7	5	0	0	1	14
Harvested in Subsistence Fishery	0	0	0	0	0	1	7	2	3	1	0	14
Unknown	1	0	0	0	1	0	5	1	0	2	0	8
Detected alive and moving during fall 2009	3	1	1	1	6	10	43	7	11	3	0	74

Table 2.–Spawning location, frequency of repeat spawning, and post spawning behavior of Kuskokwim River sheefish radiotagged in 2007 and 2008.

Spawning Location	Year Tagged 2007	Year Tagged 2008	Repeat Spawning	Post-Spawning Behavior: Spent summer following spawning in the Lower Kuskokwim River[a]	Post-Spawning Behavior: Spent winter of 2008/2009 near McGrath	Post-Spawning Behavior: Spent winter of 2008/2009 in the Holitna River	Post-Spawning Behavior: Spent winter of 2008/2009 in the Lower Kuskokwim River
2007							
Big River	1	-	-	1	0	0	1
Middle Fork	0	-	-	0	0	0	0
Slow Fork	0	-	-	0	0	0	0
Total	1	-	-	1	0	0	1
2008							
Big River	2	31	2[b]	10	3	5	24
Middle Fork	0	4	0	1	0	0	4
Slow Fork	0	1	0	0	0	1	0
Total	2	36	0	11	3	6	28
2009							
Big River	2	18	8	-	-	-	-
Middle Fork	0	1	0	-	-	-	-
Slow Fork	0	1	0	-	-	-	-
Total	2	20	8	-	-	-	-

[a] Lower Kuskokwim River is defined as all waters downstream of the Village of Akiak.

[b] One fish was captured and tagged at the mouth of the Big River during 2007 and then travelled back to the Big River spawning area during 2009. The rest are repeat spawners from 2008.

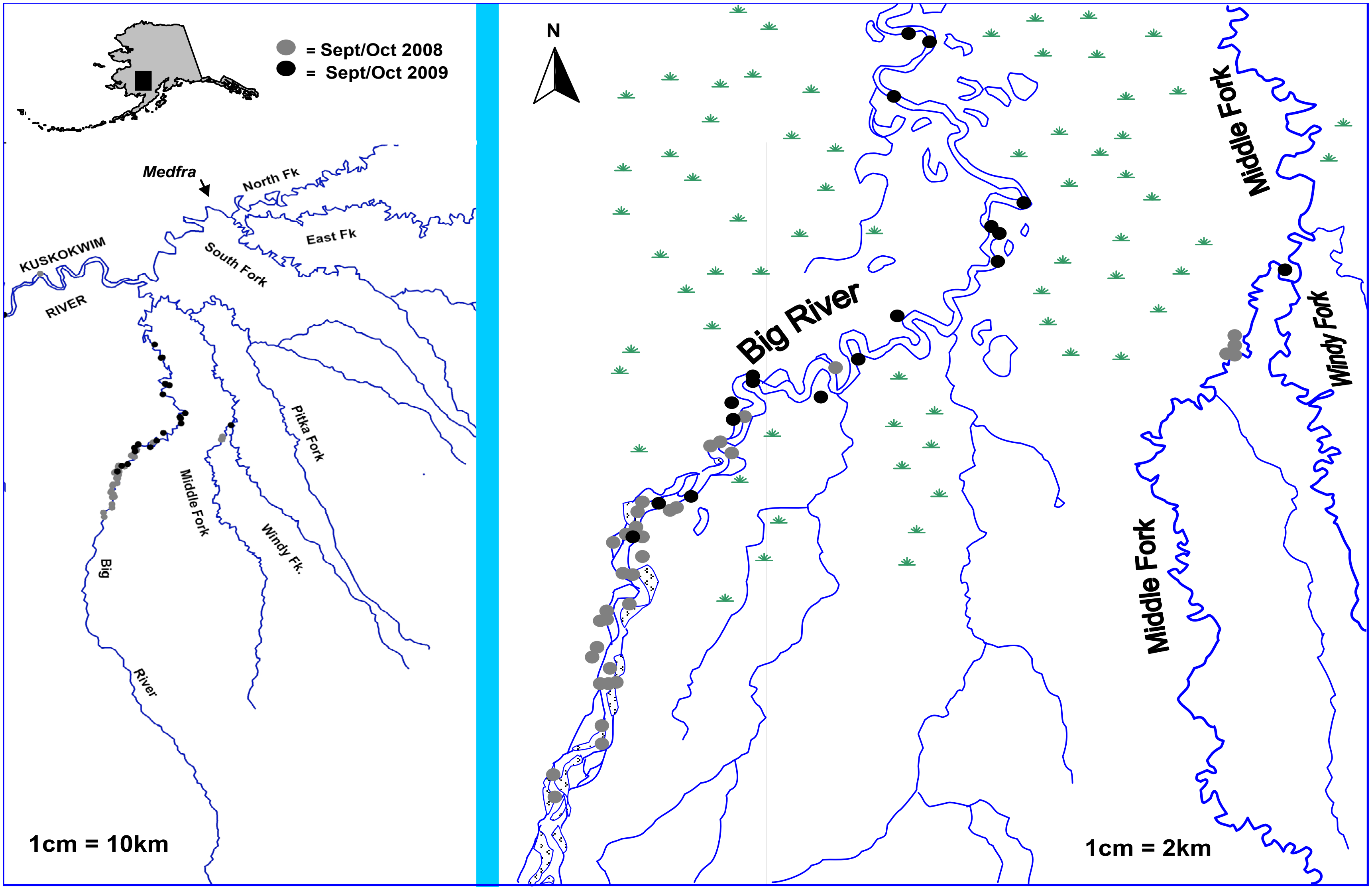


Figure 2.–Locations of radio-tagged sheefish in purported spawning areas on the Big River and Middle Fork of the Kuskokwim River during September and October aerial tracking flights during 2008 and 2009. The map on the right illustrates the spawning areas in 5X more detail.

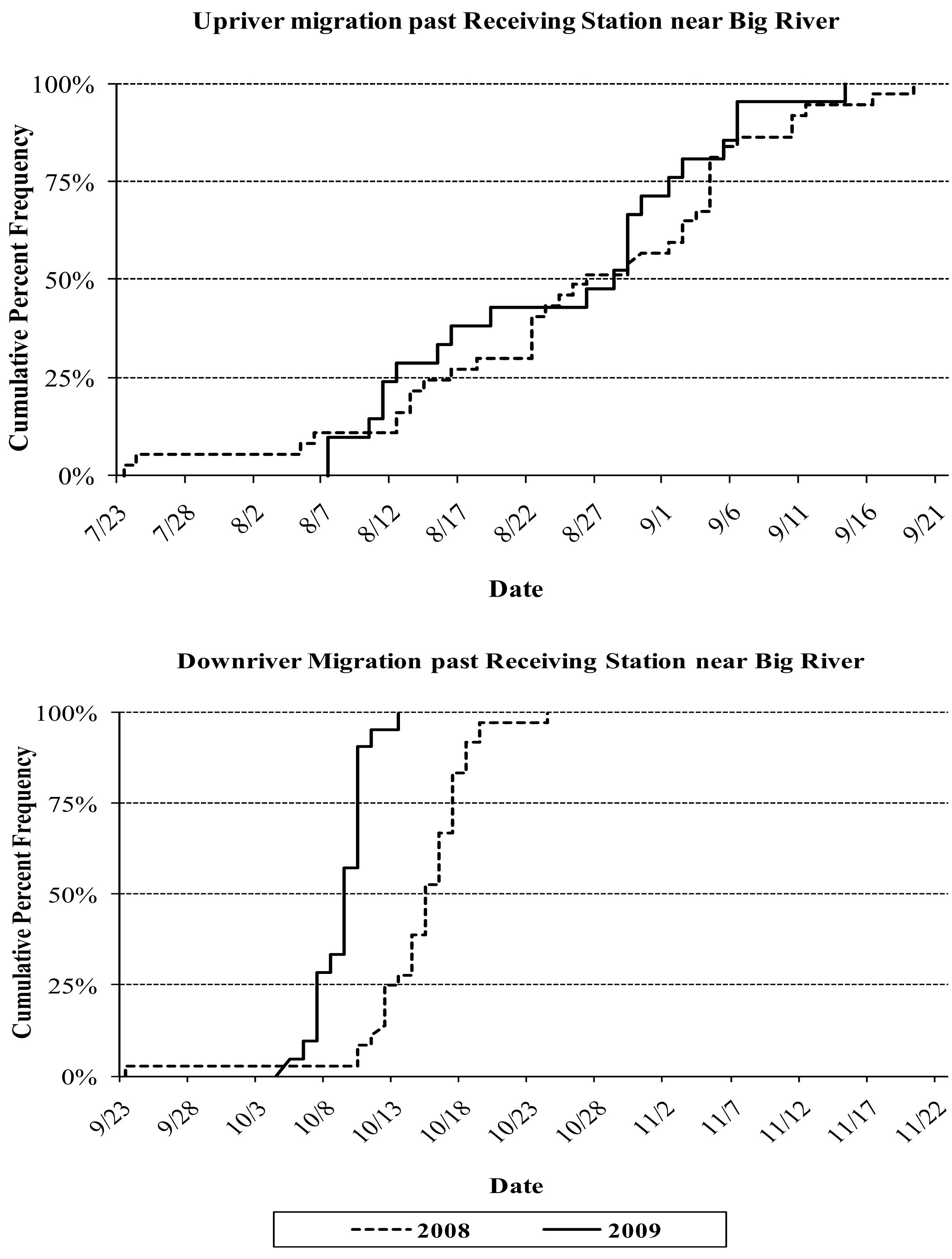


Figure 3.–Cumulative arrival and departure dates for sheefish that migrated to upriver spawning areas on the Big River and Middle Fork of the Kuskokwim River during 2008 and 2009.

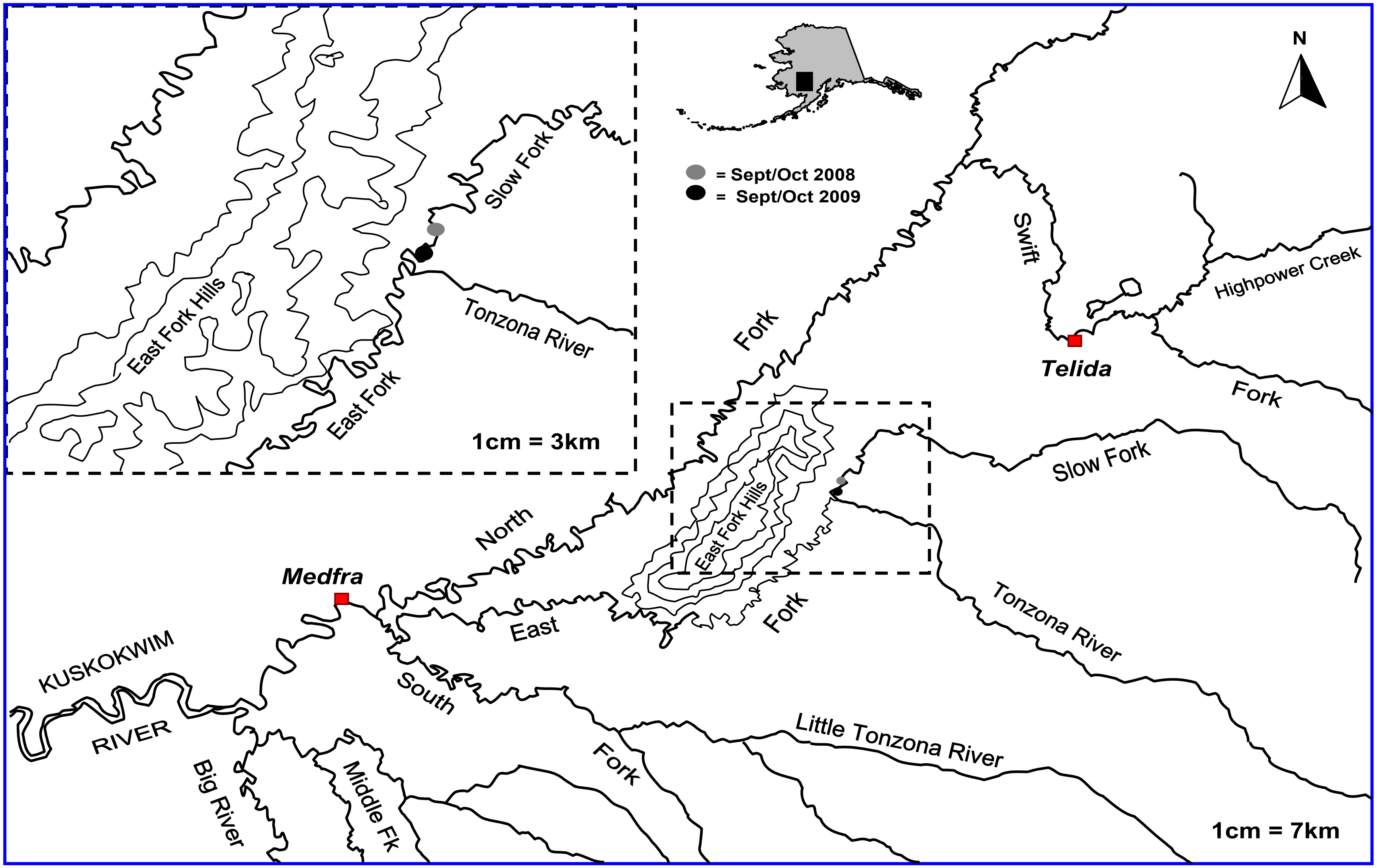


Figure 4.–Map showing locations of two radio-tagged sheefish near the mouth of the Tonzona River and Slow Fork during the September and October aerial tracking flights during 2008 and 2009. The smaller map in the upper left-hand corner illustrates this area in more detail.

None of the radio-tagged sheefish entered Highpower Creek during the 3 years of the study (Appendix A2). Test net activity conducted by Alt (1987) from 19–28 September 1971 revealed the presence of “large numbers” of spawners in Lower Highpower Creek and it was speculated that spawning was occurring there. Due to poor water clarity and windy weather, we were unable to fly low enough to observe sheefish in Highpower Creek during September and October 2008 and 2009.

Downriver migration of post-spawning sheefish was more compressed than the upriver migration prior to spawning (Figure 3). During 2008, one sheefish was recorded leaving the Big River/Middle Fork area as early as 23 September. However, most fish (34) migrated out of the area within a 9-day period between 10 and 19 October. The latest a fish was recorded leaving the area was 24 October. During 2009, radio-tagged sheefish were recorded leaving the Big River/Middle Fork area approximately 6 days earlier than in 2008 but over the same time span (Figure 3). The earliest sheefish left on 5 October, the latest on 13 October with an average departure date of 9 October.

Both spawning and non-spawning sheefish appeared to begin their downriver migration during mid-October. By the middle of October 2008, 34 of the 53 sheefish tagged between the George and Tatlawiksuk rivers that did not travel to spawning areas migrated downstream. Their timing past the tracking station above Aniak was approximately 1week earlier on average than that of post-spawning sheefish (Figure 5). A mistake in downloading the receiving station near Aniak negated getting downriver migration information for 2009. However, during the October 2009 aerial tracking flights, 37 radio-tagged sheefish appeared to be travelling downriver and during mid-October 2007, 7 sheefish were detected by receiving stations travelling downriver. Thus, during fall 2009 the timing of downriver migration of sheefish to overwintering habitat in the Lower Kuskokwim River and/or Kuskokwim Bay was probably similar to 2007 and 2008.

WINTER AND SUMMER DISTRIBUTION AND MOVEMENTS

Most of the radiotagged sheefish spent the winter in the Lower Kuskokwim River and Kuskokwim Bay and travelled upriver soon after spring ice out. The seven sheefish that survived tagging during 2007 spent both winters (2007/2008 and 2008/2009) in the Lower Kuskokwim River (Table 3). In addition, 60 radio-tagged sheefish from 2008 also spent the winter of 2008/2009 in the Lower Kuskokwim area including 28 of 36 sheefish that had travelled to upriver spawning areas (Table 2, Table 3). During an aerial tracking flight on 22 May 2008, 6 of the 7 sheefish tagged during 2007 (the remaining fish spent the summer in the Kuskokwim Bay and in the mainstem Kuskokwim River between the Kialik and Johnson rivers) were detected between Akiak, a village located 55 km upriver from Bethel, and the mouth of the Aniak River. One of these fish was recorded passing the stationary receiving station near Aniak on 10 May 2008, which was the date the Kuskokwim River broke up at Aniak. Near the mouth of the Johnson River the mainstem Kuskokwim River broke up on 14 May 2008, so this sheefish was migrating upriver under the ice. The other 5 radio-tagged sheefish were detected swimming upriver soon after ice out. During 2009, the earliest radio-tagged sheefish detected past the Aniak receiving station was on 16 May 2009 (Figure 6). A sheefish was detected passing the receiving station located downriver from Red Devil on 17 May 2009 but was missed by the station near Aniak. None of the radio-tagged sheefish were detected at the Aniak station before the ice went out on 3 May 2009.

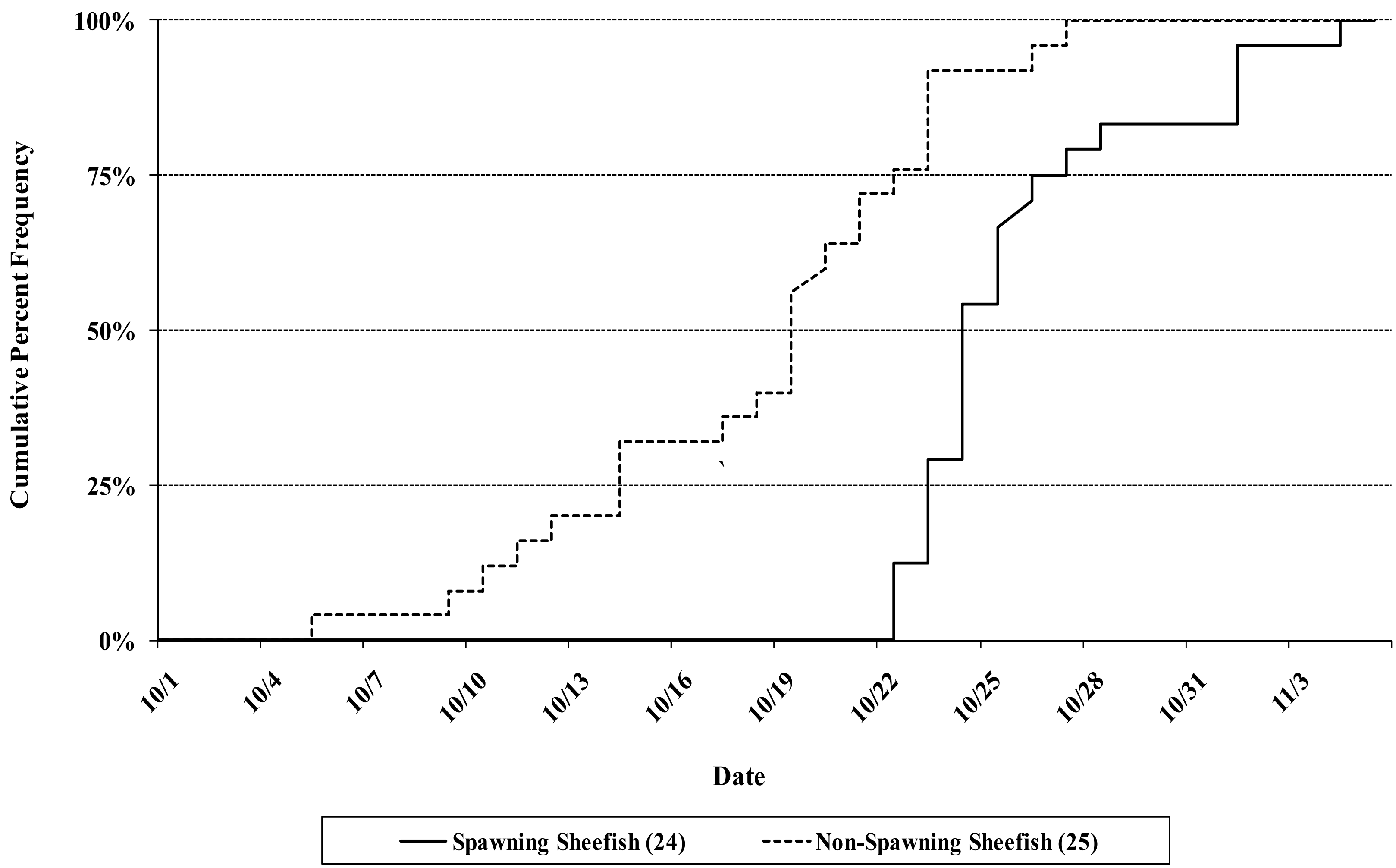


Figure 5.–Cumulative downriver passage dates at the stationary receiving station located near Aniak for spawners and non-spawners during 2008. Numbers in parenthesis are the number of fish recorded.

Table 3.–Overwintering behavior of sheefish by capture location during the winters of 2007/2008 and 2008/2009.

	Capture Location in 2007 (Tributary Mouth)					Capture Location in 2008 (Tributary Mouth)				
	Katlitna	Takotna	Blackwater	Big	Total	George	Holitna	Johnson	Tatlawiksuk	Total
Number captured and tagged	4	2	1	2	9	12	62	8	14	96
Winter 2007/2008										
Recorded past receiving station near Aniak and overwintered in Lower Kuskokwim River	4	1	1	1	7	-	-	-	-	-
Overwintered in or near the Holitna River	0	0	0	0	0	-	-	-	-	-
Spent winter near McGrath	0	0	0	0	0	-	-	-	-	-
Winter 2008/2009										
Recorded past receiving station near Aniak and overwintered in Lower Kuskokwim River	4	1	1	1	7	11	30	8	11	60
Overwintered in or near the Holitna River	0	0	0	0	0	0	14	0	0	14
Spent winter upriver near McGrath	0	0	0	0	0	0	2	0	1	3

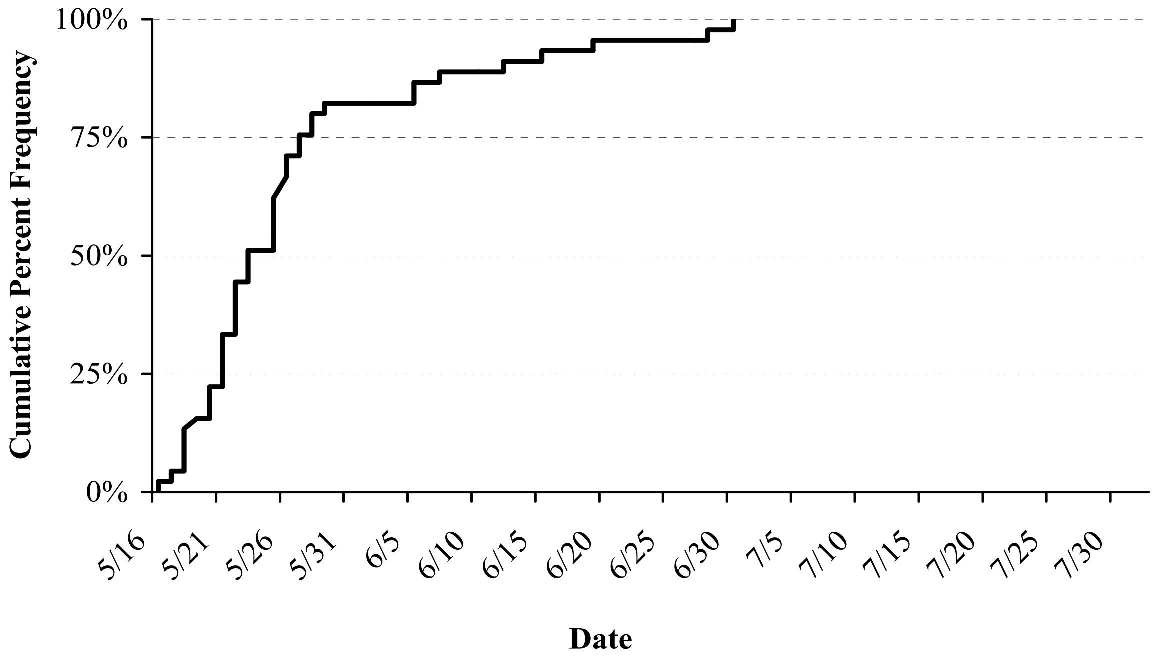
Although the majority of radio-tagged sheefish spent the winters of 2007/2008 and 2008/2009 in the Lower Kuskokwim River, a significant number spent the winter in or near the Holitna River and/or in upper mainstem locations. Based on information from receiving stations and aerial tracking flights, 14 sheefish spent the winter of 2008/2009 in or near the Holitna River and 3 sheefish overwintered near McGrath (Table 3). These fish were among the 62 that were captured and tagged in the Lower Holitna River during early to mid-June 2008. One sheefish that had spent the winter of 2008/2009 in the Holitna River was detected heading downriver toward Lower Kuskokwim overwintering areas during October 2009.

Sheefish showed varying degrees of fidelity to summer feeding areas at the mouths of major tributaries of the Kuskokwim River during 2008 and 2009. Approximately 50% of the sheefish that were radio-tagged during 2007 and 2008 returned to the river mouths where they were captured. Five sheefish that were radio-tagged during 2007 migrated back to their areas of capture in 2008 (Table 4). A fish that was tagged at the mouth of Nixon Fork, a tributary of the Takotna River, moved downriver and overwintered below Bethel during the winters of 2007/2008 and 2008/2009 then travelled upriver during early May 2009 and spent the entire summer back at the mouth of Nixon Fork until mid-October when it began its downriver migration. Other sheefish tagged during 2007 and 2008, in particular those tagged lower in the Holitna River (Appendix A1), showed similar summer site fidelities. However, not all sheefish returned to their areas of capture/feeding. Forty-three sheefish also travelled to other tributary mouths in addition to their capture sites throughout the summer (Table 4).

During 2008 and 2009, most of the sheefish that were tagged at the mouth of the Johnson River and near Bethel spent the summer and fall in the Lower Kuskokwim River. During 2008, the 1 sheefish that was tagged in 2007 and assumed to have spawned in the Big River (Table 5) spent the summer in the Lower Kuskokwim River below Bethel. During 2009, seven sheefish that were captured and tagged at the mouths of the George, Holitna, and Tatlawiksuk rivers during 2008 spent the summer below Bethel. Among these were 5 fish that had travelled to the spawning areas during 2008 (Table 2). Overall, during the summer of 2008/2009, 11 of the 38 sheefish that travelled to the spawning areas during 2008 spent the summer of 2009 downriver of Akiak in the Lower Kuskokwim River.

During 2008, 4 sheefish that were captured and tagged at the mouth of the Johnson River travelled up the Kongeruk River, a tributary of the Johnson River that is located approximately 9 km upriver from the mouth (Figure 7, Table 5, Appendix A2). These fish were detected during the September and October aerial tracking flights. Similarly, during 2009, these 4 fish in addition to the 2 sheefish that had been tagged at the mouth of the George and Holitna rivers in 2008, travelled up the Kongeruk River during late summer/early fall. According to Alt (1987) sheefish are thought to prefer spawning locations with moderately swift to swift current with substrate composed of varying sized gravel, which helps insure that the eggs lodge on the river bottom and are not carried away by the current. From the air, the Kongeruk River, similar to the Johnson River into which it flows, appears to be underlain by fine sediments and have a relatively slow current compared to upriver locations such as the Big River. Therefore, the Kongeruk River is not believed to be a sheefish spawning location.

Upriver Migration Past Receiving Station near Aniak



Upriver Migration Past Receiving Station near Red Devil

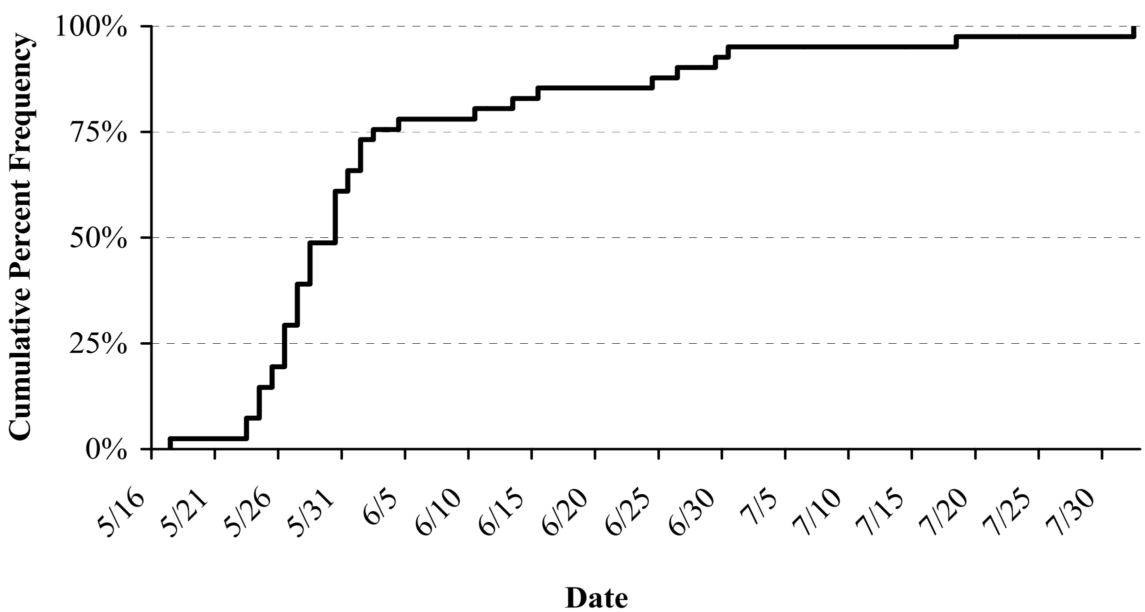


Figure 6.–Upriver migration times of radio-tagged sheefish past the stationary receiving stations located near Aniak and Red Devil during 2009.

Table 4.–Feeding area fidelity for sheefish that were captured and tagged during 2008 and 2009.

	Capture Location in 2007 (Tributary Mouth)				Capture Location in 2008 (Tributary Mouth)				
	Katlitna River	Takotna River	Blackwater Creek	Total	George River	Holitna River	Johnson River	Tatlawiksuk River	Total
Number Captured and Tagged[a]	4	1	1	6	12	62	8	14	96
2008									
Located in same area during 2008	4	1	0	5	-	-	-	-	-
Not Located during 2008	0	0	0	0	-	-	-	-	-
Located in Different Area during 2008	0	0	1	1	-	-	-	-	-
2009									
Located in same area during 2009	0	1	0	1	4	30	5	4	43
Not Located during 2009	4	0	1	5	7	24	3	9	43
Located in Different Area during 2008	2	0	1	3	1	8	1	3	13

[a] Excludes two fish that were tagged near the mouth of Big River during 2007. These fish were in spawning condition and were travelling to spawning areas on the Big River or Middle Fork.

Table 5.–Number of sheefish that spent the summers of 2008 and 2009 downriver of Akiak in the Lower Kuskokwim River by tagging location and year of tagging.

	Summer Location[a]					
	Lower Kuskokwim River		Johnson/Kongeruk Rivers		Kialik River	
Tagging Location (Year)	2008	2009	2008	2009	2008	2009
Big River (2007)	1	0	0	0	0	0
Johnson River (2008)	8	6	4	4	2	1
Kuskokwim River near Bethel (2008)	3	2	0	0	0	0
George River (2008)	0	2	0	1	0	0
Holitna River (2008)	0	3	0	1	0	1
Tatlawiksuk River (2008)	0	2	0	0	0	1
Total	12	15	4	6	2	3

[a] Those sheefish that were not located in the Lower Kuskokwim River or Kuskokwim Bay were located in the Johnson, Kongeruk and Kialik rivers, which are major tributaries in the Lower Kuskokwim River.

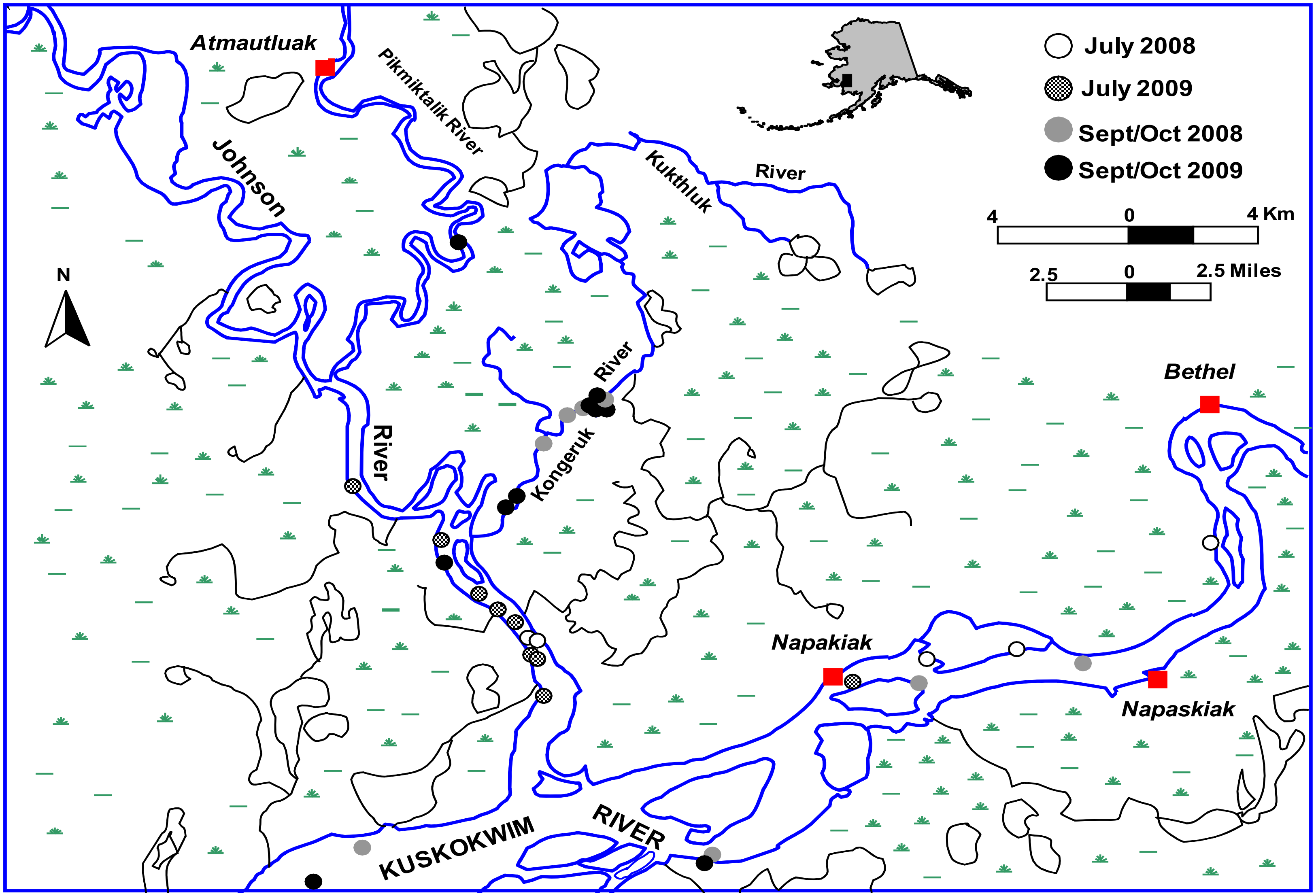


Figure 7.–Map showing sheefish that were located near the mouth of the Johnson River during the 2008 and 2009 July aerial tracking flights and movement of these fish during late summer/early fall up the Kongeruk River as noted during the 2008 and 2009 September and October aerial tracking flights.

LENGTH COMPOSITION

Length compositions of the radio-tagged fish differed among mature and immature fish. The average length of the 21 sheefish that were tagged downriver at the mouth of the Johnson River and near Bethel was 705 mm. The average length of all the tagged fish (119) was 750 mm with a minimum of 640 mm and a maximum of 910 mm. The average length for the 52 sheefish that migrated to upriver spawning areas during 2008 and 2009 was 775 mm, and the average for the remaining sheefish that were assumed to not have spawned was 711 mm. The smallest sheefish that travelled to the spawning areas was 670 mm. Overall, the length composition recorded during the time of capture of the 52 sheefish that travelled upriver to spawning areas during 2007–2009 were significantly different from those that did not travel upriver to spawn ($D=0.51$, $P<0.01$, Figure 8).

FIN RAY, SCALE, AND OTOLITH AGES

Estimated ages based on pectoral fin rays and on scales were compared to otolith ages, where otolith ages were considered the desired standard. Both the pectoral fin ray ages and scale ages were comparable to otolith ages for sheefish up to 10 years of age (Table 6). For the 4 older sheefish, fin rays and scales tended to underage compared to the otolith ages (Table 6). Discerning ages from otoliths was difficult due to the presence of what appeared to be vaterite, a polymorph of calcium carbonate. The vaterite in the otolith made deciphering annuli difficult, particularly in the four fish that were over 10 years of age. Therefore, these fish may be much older than indicated by the minimum ages based on the annuli that could be deciphered (Table 6).

DISCUSSION

Sheefish spawn in very few locations in the Kuskokwim River and it is likely that the same areas are used for spawning every year. To date, only 4 spawning areas have been described for the entire Kuskokwim River sheefish population. Fall locations of radiotagged sheefish in this study have suggested spawning was occurring in sections of the Big River and Middle Fork and potentially in a third area on the Slow Fork. A fourth area in lower Highpower Creek was inferred by Alt (1987), but was not verified in this study. Because sheefish are broadcast spawners, it can be assumed that spawning should take place in a relatively small area within a short time frame. Indeed, the spawning areas on the Big River (~20 km) and Middle Fork (~2 km) are relatively small. Radio-tagged sheefish were located in the Big River spawning area in all years of the study. Furthermore, even though Alt (1987) did not detect spawning activity on the Middle and Slow Forks, it is unlikely that these areas represent new spawning populations that had not existed during the time of Alt's work. Sheefish have specialized spawning habitat needs. In addition to occupying relatively small spawning areas, sheefish prefer habitat with fast-flowing, shallow water (Alt 1987, Howland 2005). These conditions may restrict the establishment of new spawning areas. Even though we didn't actually observe groups of sheefish on the Slow Fork during the 2008 and 2009 October flights, it would be unusual for these fish to have travelled so many miles up a shallow drainage for feeding at this time of the year.

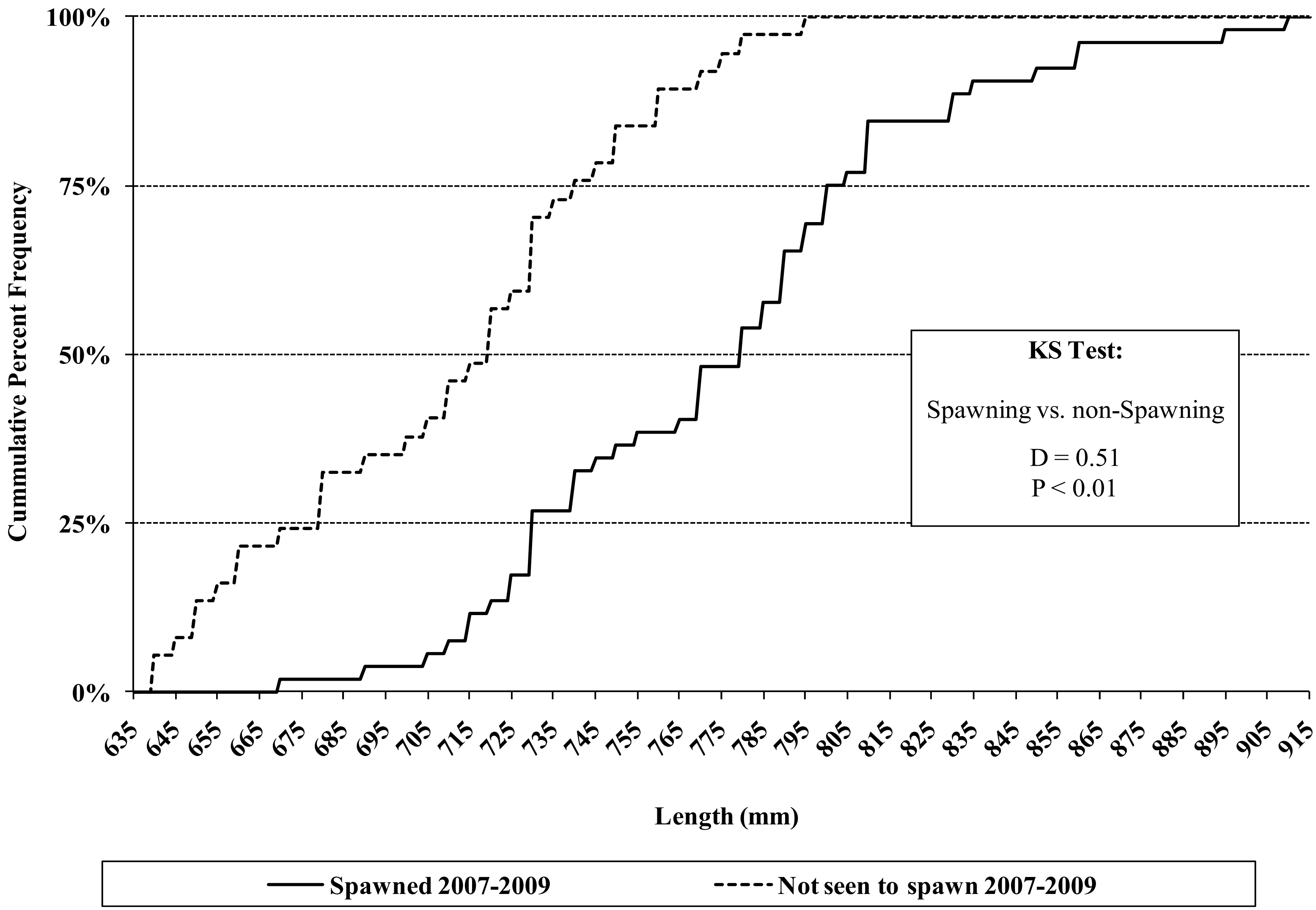


Figure 8.–Cumulative length frequency distributions comparing radio-tagged sheefish that were assumed to have spawned in the Upper Kuskokwim River and those that were assumed to not have spawned during 2007–2009.

Table 6.–Ages from pectoral fin rays, otoliths, and scales taken from 11 sheefish that were captured during 2007–2009 at the mouths of Kuskokwim River tributaries.

				Ages from Structures (years)		
Capture Date	Capture Location	Length (mm)	Gender	Fin Rays	Otoliths[b]	Scales
24 Aug 2007	Katlitna River	650	Male	8	8	8
27 Aug 2007	Katlitna River	805	Male	10	15+	9
22 May 2008	Johnson River	650	Female	6	6	6
12 June 2008	Holitna River	755	Female	11	19+	9
15 June 2008	Tatlawiksuk River	730	Female	7	8	8
15 June 2008	Tatlawiksuk River	755	Female	8	8	8
16 June 2008	Holitna River	715	Male	7	10+	9
21 June 2009	George River	>800[a]	Female	11	13	9
18 Aug 2009	Holitna River	730	Female	6	Unable to age	7
18 Aug 2009	Holitna River	670	Female	7	8	7
18 Aug 2009	Holitna River	520	Male	5	6	5

[a]Specimen delivered to project biologist with its head and tail removed.

[b]Due to vaterite formation obscuring, full ages could not be readily discerned and ages represent minimums.

Radio-tagged sheefish migrated to the vicinity of their spawning grounds approximately 1–2 months before spawning took place, but the post-spawning outmigration was much more abrupt. Howland et al. (2000) noted similar in- and-out migration timing and patterns for sheefish in the Mackenzie River system in the Yukon Territory, Canada. Alt (1987) assumed that spawning occurs sometime during late September to early October. In a 2007 and 2008 study of sheefish on the Sulukna River, a tributary of the Yukon River, the onset of spawning was documented on 23 September and post-spawning migration began on 5 October (J. Gerken, University of Alaska, Fairbanks, personal communication). The last date of in-migration prior to spawning and the first date of the post-spawning outmigration for the radio-tagged Kuskokwim River sheefish was similar to what was noted in Gerken's study.

Through fall 2009, 37 radiotagged sheefish that survived tagging and handling had not yet travelled to an upriver spawning area. It is likely that many of these sheefish were immature at the time they were tagged. This is especially likely for the fish that were tagged in the Lower Kuskokwim River because 17 of 21 fish tagged there were less than 750 mm FL, the length at which most sheefish populations mature (Brown 2000, Taube and Wuttig 1998). All of these fish remained in the lower river during the open water period of 2008 and most remained there during 2009. According to Alt (1969), non-spawning adults and immature sheefish are more likely to remain in the lower reaches of river and estuary systems. Over the next 2 years of this study, it is likely that many of the fish that have not spawned will be located in spawning areas as they grow and mature. It is unknown whether the sheefish that migrated upriver before and soon after ice out and prior to our capture efforts in 2008 were larger in size, more likely to spawn, and more likely to spend the summer in the middle to upper portions of the Kuskokwim River drainage.

It is also possible that tagging affects prevented some of the sheefish from spawning, especially in 2007. Although gender and maturity status could not be determined from fish captured in spring and summer 2008, it was assumed that because they were tagged early in the season their spawning behavior was not compromised. Similar to other Arctic whitefish species, sexual maturation in sheefish takes place during upstream migration (Dodson et al. 1985). Winter (1996) cautioned that gravid female fish are not ideal candidates for surgically implanted transmitters due to the lengthy recovery period before their behavior returns to normal. Hander et al. (2008) noted that 4 of 30 pre-spawning fish that were tagged on the Selawik River during 2005 did not spawn. However, during the following year, 2 of these 4 fish were located in a spawning area. They also assumed that the surgeries may have prevented these 4 fish from spawning soon after tagging. Of the 7 sheefish tagged during late summer in 2007, only one travelled to the spawning area on the Big River. Our tagging efforts during 2008 were approximately 3 months earlier than 2007 and allowed more time for post-surgery recovery prior to fall spawning. The amount of time needed for full recovery from the surgeries and any effect this may have had on spawning success in 2007 and 2008 was unknown.

This study suggests both sequential and non-sequential spawning for male and female sheefish. Sheefish are iteroperous, but it has been noted from past studies that after spawning, females may not spawn again for 2 or more years (Reist and Bond 1988) whereas males are more likely to spawn during sequential years (Underwood 2000). A known female that travelled to the Big River spawning area during 2007 was observed in this location again 2 years later during 2009.

Of the 52 sheefish that travelled to upriver spawning areas, 7 were noted to spawn during 2008 and again in 2009. However, the gender of these 7 sheefish was unknown, but it is likely both sexes are represented. Sheefish studies on the Kobuk River have documented sequential year spawning in radio-tagged females as well as males (Savereide *In prep*). In addition, 2 sheefish (1 female and 1 unknown) that were tagged during 2007 and assumed to be in spawning condition (the one female was swollen with eggs) did not travel to the upriver spawning areas in 2007, but did travel to the Big River spawning area the following year. It is unknown whether these fish would have spawned in 2007 if they had not been handled and if so, would they have spawned again in 2008.

The post-spawning migration of Kuskokwim River sheefish from their spawning areas to downriver overwintering areas tended to be fairly synchronous and abrupt. Similar to what we recorded, Howland et al. (2000) observed that the post-spawning run of sheefish out of the Arctic Red River in Canada lasted 1–2 weeks, with the majority having moved downriver by 15 October. Likewise, Underwood (2000) noted that the post-spawning migration on the Selawik River occurred between 27 September and 19 October, with the peak on 14 October. Tallman et al. (1996) observed that the post-spawning downstream migration of radio-tagged sheefish in the Slave River of Canada occurred between 15 and 30 October. Non-spawning sheefish that were tagged between the George and Tatlawiksuk rivers also began their downriver migrations during a similar time period to the spawning sheefish. The non-spawning fish arrived downriver earlier because they remained near or below the mouth of the Tatlawiksuk River, and thus had less distance to travel to the tracking station near Aniak than the upriver spawning sheefish (Appendix A).

The average date of the post-spawning migration of sheefish occurred approximately 1 week earlier in 2009 than 2008. According to the National Weather Service, Fairbanks Forecast Office (http://pafg.arh.noaa.gov/), the Upper Kuskokwim River area was experiencing record high temperatures and precipitation in 2009 during the time period when radio-tagged sheefish were leaving their spawning systems. Alt (1987) noticed sheefish preferred water temperatures that range from 0.6 to 5.5 ^{o}C for spawning. Howland (2005) noticed similarly that sheefish spawning in the Arctic Red River in Canada preferred temperatures of 2-3^{o}C. It was also noticed that sheefish spawning in the Sulukna River preferred temperatures of 0 to 3^{o}C (J. Gerken, University of Alaska, Fairbanks, personal communication). The exact correlation between air temperature or precipitation and water temperature is not known, but it is very plausible that the warmer, wetter fall in 2009 contributed to warmer water temperatures in the Big River and an earlier outmigration time for sheefish. A temperature data logger was deployed in this area during September 2009 and may provide information on changes in water temperature during October if it is retrievable after break-up in 2010.

Information collected to date indicates that the majority of Kuskokwim River sheefish exhibit a high degree of fidelity to summer feeding areas. With the exception of those sheefish that eventually migrated to the upriver spawning areas, most of the sheefish that were tagged in 2008 at the mouths of the George, Holitna, and Tatlawiksuk rivers remained at those locations for the duration of the summer and either returned back to these areas in 2009 or never left. Unless travelling to a spawning area, sheefish generally did not travel far from the tributary mouths (Appendices A1 and A2). During spring and summer most of the main Kuskokwim River tributary mouths are a good source of outmigrating salmon smolt. During mid-May 2008, one capture mortality had a stomach full of anadromous smelt. An examination of stomach contents of 3 capture mortalities in June 2008 showed the stomachs to be full of outmigrating salmon smolt as well as a few juvenile resident species such as lamprey *Lampetra japonica* and burbot *Lota lota*. During late August 2009, three sheefish were captured on the Holitna during a survey of this drainage by ADF&G-AWC and the project biologist. The stomachs of these fish contained primarily juvenile whitefish and juvenile salmonids. Future aerial tracking flights and stationary tracking station data will further examine the degree of fidelity to feeding areas within the Kuskokwim River drainage.

Although the majority of sheefish spent the winter in the Lower Kuskokwim River and Kuskokwim Bay, 14 spent the winter upriver in the Holitna River and 3 in the mainstem Kuskokwim River near McGrath. During 2008, two sheefish that had travelled to Big River to spawn left the Middle Fork long after the majority had left by mid-October and then spent the winter upriver near McGrath. According to Chythlook (2009) sheefish are caught occasionally through the ice during winter in the Middle to Upper Kuskokwim River. Whether these fish represent a stock that is distinctly different from those wintering in the lower river is doubtful. As sheefish are broadcast spawners and spawn in relatively small locations, it is likely that eggs and milt from fish that overwinter in multiple areas intermix. With 2 additional seasons of aerial tracking flights, we will observe the degree of fidelity these fish have to their overwintering areas.

In contrast to past studies (Howland et al. 2004, Mills and Chalanchuk 2004), ages assigned to fin ray sections substantially underestimated age compared to assignments from otoliths for the 4 sheefish with otolith ages greater than 10 years and more closely approximated the scale ages. Scales tend to underage long-lived, slow-growing individuals due to the decrease in somatic growth in older fish (Chilton and Beamish 1982). Howland et al. (2004) compared the fin ray, otolith, and scale ages of 80 sheefish that were collected from the Arctic Red River, Northwest Territories, Canada and found that the age estimates from pectoral fin rays were similar to those from otoliths, while those from scales were substantially lower at ages greater than nine years. I replicated Howland's (2004) study with a small sample of Kuskokwim River sheefish to determine if similar ages could be deciphered from fin rays and otoliths to provide an accurate and non-lethal method to estimate ages during future projects.

The presence of what appeared to be vaterite in the 11 sheefish otoliths collected was so prevalent in some otoliths that noting each annuli, particularly in fish older than 10 years, was difficult. In general, aragonite is the most common polymorph found in otoliths, but vaterite does occur and has been related to stress, particularly stress associated with hatchery practices (Bowen et al. 1999). The presence or degree of vaterite formation cannot be deciphered without mass spectrometry analysis of the chemical matrix of each annulus in the otolith (Veinott et. al 2009). Although very few otoliths were examined, the apparent high prevalence of this mineral in Kuskokwim River sheefish is curious and warrants further investigation.

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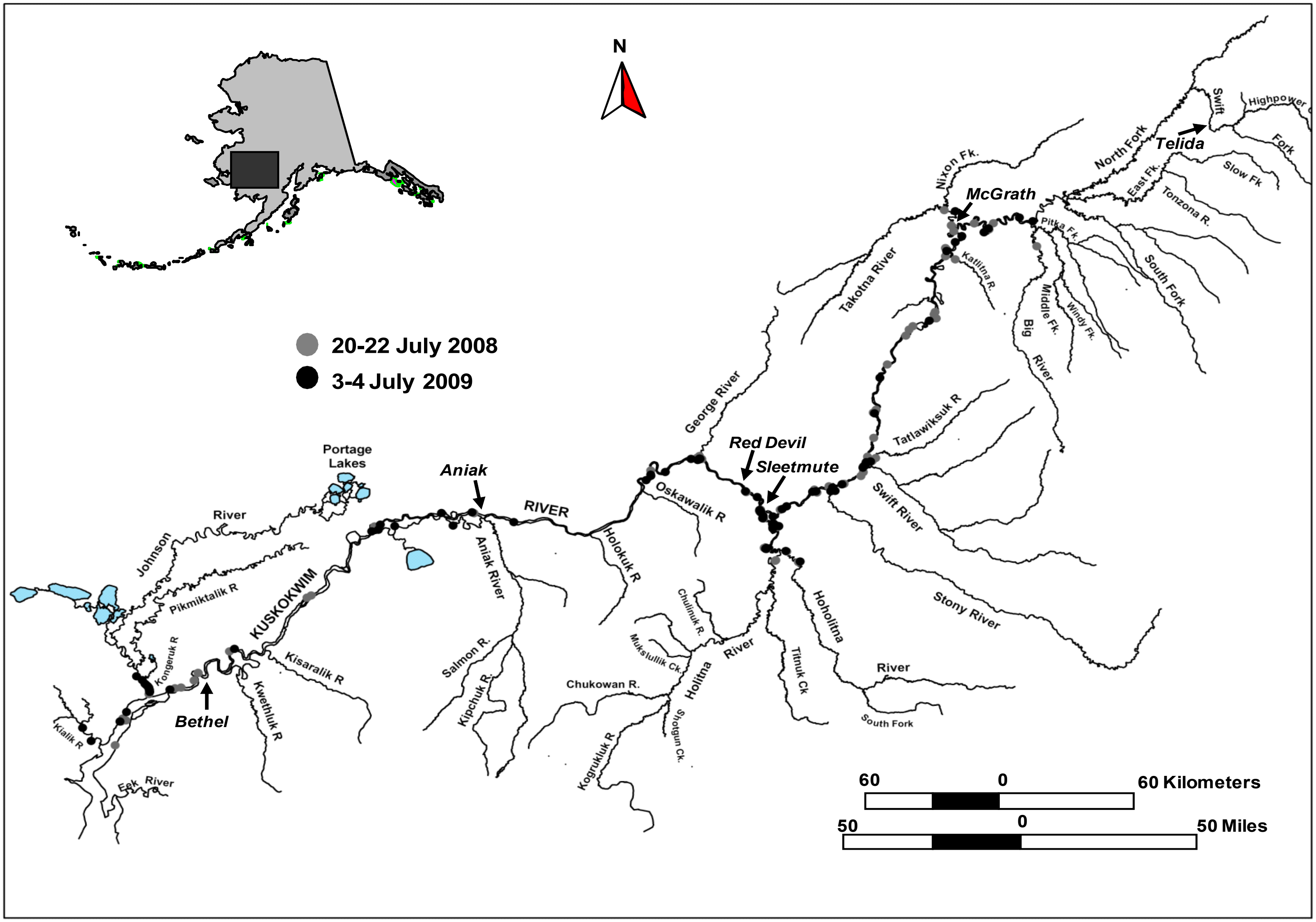
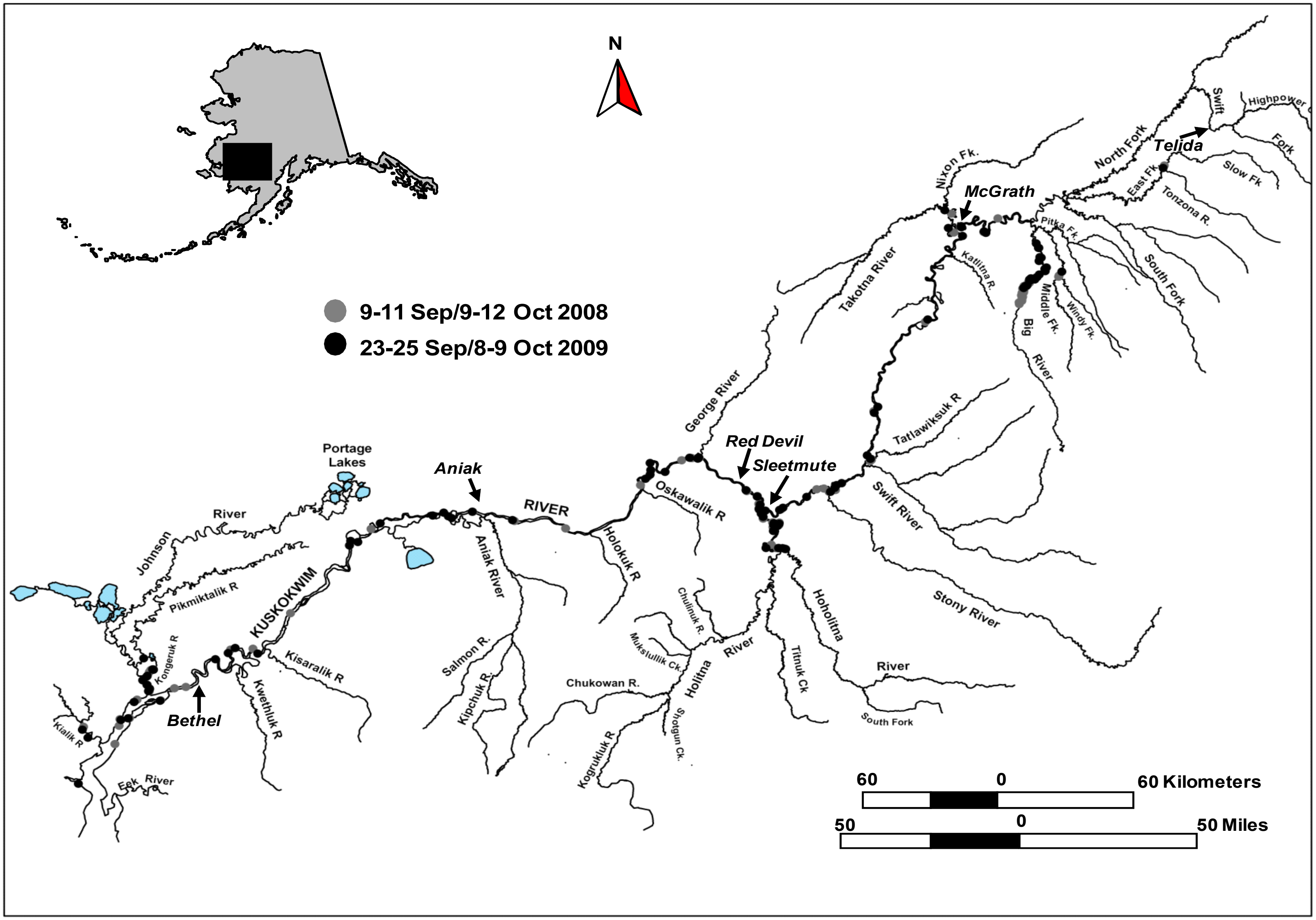
APPENDIX A. MAPS SHOWING LOCATIONS OF RADIO-TAGGED SHEEFISH DURING THE AERIAL TRACKING FLIGHTS IN 2008 AND 2009



Appendix A1.–Map showing the locations of sheefish that were captured and radio-tagged in the Kuskokwim River during 2007 and 2008 and located during the July 2008 and 2009 aerial tracking flights.



Appendix A2.–Map showing the uppermost locations of sheefish that were captured and radio-tagged in the Kuskokwim River during 2007 and 2008 and located during the September and October 2008 and 2009 aerial tracking flights.