U.S. Fish & Wildlife Service

Migration Timing and Seasonal Distribution of Broad Whitefish, Humpback Whitefish, and Least Cisco from Whitefish Lake and the Kuskokwim River, Alaska, 2004 and 2005

Alaska Fisheries Technical Report Number 105

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Migration Timing and Seasonal Distribution of Broad Whitefish, Humpback Whitefish, and Least Cisco from Whitefish Lake and the Kuskokwim River, Alaska, 2004 and 2005

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Abstract

During 2004 and 2005, radio transmitters were surgically implanted and used to track the migration of 54 broad whitefish *Coregonus nasus*, 60 humpback whitefish *C. pidschain*, and 53 least cisco *C. sardinella* in the Kuskokwim River watershed. All fish implanted with transmitters were captured at Whitefish Lake, except 33 broad whitefish that were tagged during 2005 at fish wheels operated in the mainstem Kuskokwim River near Kalskag. Movements of radio-tagged whitefish were monitored using fixed receiver stations, boats, and fixed-wing aircraft. Migration of radio-tagged whitefish from Whitefish Lake occurred from May to October. Many of the whitefish migrated up the Kuskokwim River from early June through late September. Broad whitefish were tracked in the fall to possible main channel spawning areas near the Swift and Kuskokwim river confluence and over 500 river kilometers (rkm) to an area between the villages of McGrath and Medfra. Humpback whitefish radio-tagged at Whitefish Lake migrated to suspected spawning habitats in the Holitna, Swift, and Big rivers, indicating multiple spawning aggregates use this lake. These suspected spawning locations were characterized by swift current and gravel substrate. Humpback whitefish traveled over 600 rkm to reach the Big River location. Success at tracking the movements of radio-tagged least cisco was minimal and only one least cisco was tracked to a suspected spawning location in the Holitna River in September 2004. Both broad and humpback whitefish showed inter-year fidelity to Whitefish Lake as a feeding area. Technical difficulties with transmitters and fixed receiver stations, and difficulties conducting flights during peak spawning times from late September to November because of poor weather and aircraft/pilot availability limited the effectiveness of tracking fish to spawning areas in both years.

Introduction

Whitefish *Coregonus* spp. have long been recognized as important subsistence fish for local inhabitants of the Yukon-Kuskokwim Delta in western Alaska. Harvest of whitefish was largely unregulated until concerns over declines in the size and number led to regulations during the 1970s (5 AAC 39.780) that eliminated commercial harvests in Whitefish Lake and the Johnson River. Regulations governing subsistence users were first enacted during 1992 after residents from Kalskag and Aniak voiced concerns over reduced size and abundance of large whitefish in Whitefish Lake. These large whitefish were suspected to be broad whitefish *C. nasus.* Whitefish are harvested with a variety of methods, including gill nets set under the ice during the winter or in open water during the spring, summer, and fall; speared during fall and winter; and with hook and line (Simon et al. 2007). During 1998, broad and humpback whitefish comprised 24% of the non-salmon harvest in the village of Akiachak (M. Coffing, Alaska Department of Fish and Game, personal communications). Coffing (1991) conducted a similar study in the village of Kwethluk between 1985 and 1986 and estimated that residents harvested 101,903 kg of salmon

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and 62,598 kg of other fish with whitefish comprising 22% (13,535 kg) of the non-salmon harvest. Fish other than salmon were actively pursued by 87% of households, while only 70% actively harvested salmon. The loss of the whitefish subsistence fishery or even more restrictive regulations could be detrimental to the subsistence lifestyle along the Kuskokwim River.

The life history of whitefish in the Kuskokwim drainage is poorly understood. This is partly due to anadromy, confused taxonomy, distribution, migration patterns, and breeding habits of the different species. Only a few spawning areas have been documented in the drainage for whitefish. While conducting spawning ground surveys of inconnu *Stenodus leucichthys*, Alt (1972) observed broad and humpback whitefish *C. pidschain* in spawning condition in Highpower Creek, a headwater tributary of the North Fork Kuskokwim River. Humpback whitefish in spawning condition were also captured during a spawning ground survey of inconnu in Big River, a tributary of the Kuskokwim River near McGrath (Alt 1982). Some life history traits can be inferred from studies conducted on McKenzie River whitefish populations in Canada. For example, Reist and Bond (1988) noted that during the fall spawning period, mature broad and humpback whitefish are generally found upstream of both mature non-spawners and immature fish. Broad and humpback whitefish in the McKenzie River are also suspected of skipping one or more years between spawning events (Bond and Erikson 1985, 1993).

Broad whitefish, humpback whitefish, and least cisco *C. sardinella* exhibit similar life history traits. These species overwinter in large rivers and typically enter freshwater tundra ponds and lakes during April or May after oxygen levels increase (Alt 1979; Reist 1997; Harper et al. 2007). Fish remain in these summer feeding areas until they migrate to fall spawning locations or until oxygen levels drop in fall or winter, forcing them back into the Kuskokwim River. Whitefish typically mature at 4–8 years of age (Morrow 1980). In the Kuskokwim River, Harper et al. (2007) found the approximate minimum length and age at maturity for humpback whitefish was 350 mm and age four, and 300 mm and age three for least cisco. The minimum length at maturity for broad whitefish sampled from the Yukon River was 380 mm (R. Brown, USFWS, unpublished data). Spawning humpback whitefish are located in areas with relatively swift currents and gravel substrate during late September and early October (Alt 1979; Chang-Kue and Jessop 1997; Fleming 1996; Brown 2006) but less is currently known of broad whitefish and least cisco. Whitefish are broadcast spawners. Eggs and milt are deposited in the water column for fertilization, after which the eggs settle to the bottom and lodge in crevices in the gravel. The eggs winter in the gravel, hatch during early spring, and the small fry are carried downstream by river currents to the lower river sections or estuaries. Young of the year whitefish in the McKenzie River are found in brackish waters and immigrate into freshwater lakes on the Tuktoyaktuk Peninsula during their first summer (Bond and Erickson 1985). Otolith microchemistry of whitefish from Whitefish Lake revealed a high strontium signature during early life for some adults, indicating time was spent in brackish or salt waters (Harper et al. 2007).

Preliminary efforts to gain a better understanding of whitefish life history in the Kuskokwim River were undertaken at Whitefish Lake from 2001 to 2003 (Harper et al. 2007). The primary objectives for this initial study were to assess abundance, age at length composition, and migratory patterns of broad whitefish, humpback whitefish, and least cisco. Multi-year tag returns indicated that many whitefish displayed fidelity to Whitefish Lake as a summer feeding area. Analysis of otolith microchemistry revealed that these whitefish species were primarily amphidromous, and that most had spent a portion of their lives in salt or brackish waters prior to being sampled in Whitefish Lake. Tag returns from subsistence users indicated that whitefish

tagged at Whitefish Lake were being harvested along the Kuskokwim River between Tuluksak and Medfra, a distance of about 700 kilometers.

To gain a better understanding of whitefish movements from Whitefish Lake to other areas in the Kuskokwim River watershed, a radio telemetry study was initiated during 2004. The objectives of this study were to: 1) determine migrational timing and seasonal distribution of broad and humpback whitefish and least cisco using Whitefish Lake; 2) locate spawning areas; 3) identify potential areas of harvest for whitefish from Whitefish Lake; and 4) monitor for previously tagged fish during the spring migration into Whitefish Lake.

Study Area

The Kuskokwim River is the second largest watershed in Alaska (Moody et al. 1986, Brown 1983) (Figure 1). This glacially turbid river originates in the Alaska Range, on the northwest side of Mt. McKinley. Numerous tributaries join the river as it courses approximately 1,498 rkm in a southwest direction before draining into the Bering Sea.

Whitefish Lake (N 61° 24' W 160° 01', NAD 83), located 30 km southwest of Aniak, Alaska on a tributary of the Kuskokwim River, covers approximately 8,064 hectares, and averages less than 1.5 m in depth. Whitefish Lake Creek drains Whitefish Lake and connects to the Kuskokwim River at rkm 276 via a sinuous 15-rkm channel. Ophir Creek, the largest inlet stream and several smaller inlet streams drain approximately 44,340 hectares and enter Whitefish Lake at an elevation of about 20 m above sea level. Pondweed *Potamogetan* spp. is the primary rooted aquatic vegetation that occurs throughout the lake and is very dense around the lake's perimeter. Lake turbidity is affected by suspension of bottom sediments through wave actions caused by high winds.

Methods

Fish Capture

Several gear types were used to capture fish for radio-tagging including a fish trap, fish wheels, gill nets, and hoop nets. The fish trap and weir were operated at the outlet of Whitefish Lake (Harper et al. 2007). Each wing of the weir angled downstream at 45-degrees from the trap apex, ending about 2–3 m short of each riverbank (Figure 2). This configuration funneled the majority of upstream migrant fish that used the deep mid-channel waters into the trap while allowing downstream migrants to pass. Fish captured in the trap were sampled four times daily. A 10-m gill net, 14 cm stretch × 15 meshes deep, was drifted in the outlet to capture fish when ice flows forced the removal of the weir (9–12 May 2004). Hoop nets were set in Whitefish Lake during May after ice-out through the middle of June and checked three times daily. Capture operations continued until catch rates declined or water temperatures exceeded 15°C, the maximum recommended temperature for surgeries (R. Brown, U.S. Fish and Wildlife Service, personal communication). Whitefish selected to receive radio transmitters were held in a 3 × 2 m rectangular holding pen. Whitefish previously tagged during 2002–2003 with a T-bar anchor tag as they entered or left the lake, and recaptured during 2004, received priority for surgical implantation of radio transmitters to extend the movement history for these fish. Few broad whitefish (N = 3) were available at Whitefish Lake for radio-tagging during 2005; therefore, migrant broad whitefish were captured during September using fish wheels operated by the Alaska Department of Fish and Game (ADFG) at rkm 270 of the Kuskokwim River, near the village of Upper Kalskag (Pawluk et al. 2006).

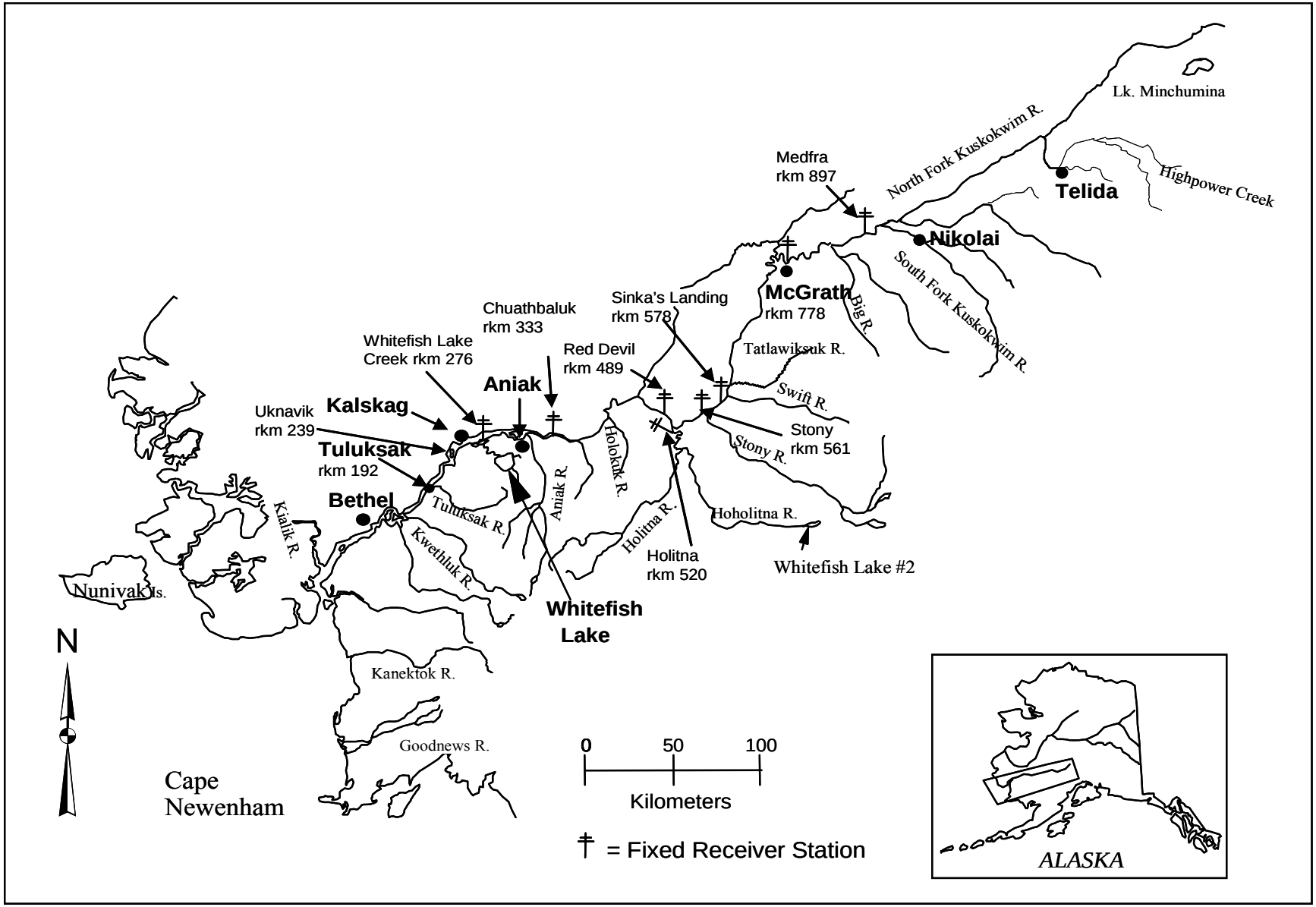

FIGURE 1.—Whitefish Lake and locations of fixed receiver stations in the Kuskokwim River drainage, Alaska.

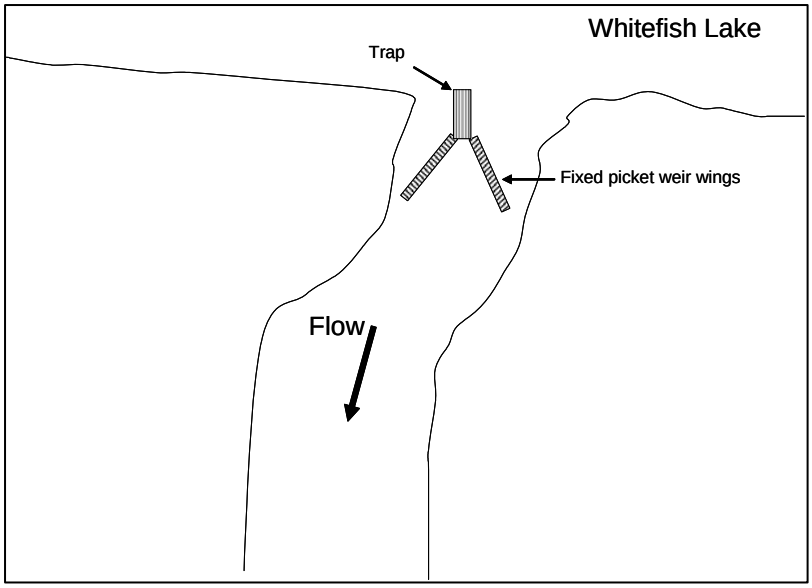

FIGURE 2.—Diagram of the weir and fish trap used to capture whitefish at the outlet of Whitefish Lake.

Implanting Transmitters

Radio transmitters were surgically implanted in whitefish during 2004 and 2005. Radio transmitters used during 2004 were manufactured by Lotek Engineering Incorporated™. Radio transmitter size varied by species. Broad whitefish transmitters (Model MCFT-3FM) measured 11 × 59 mm; humpback whitefish transmitters (Model MCFT-3EM) were 11 × 49 mm; and, those used for least cisco (Model MCFT-3BM) measured 11 × 43 mm. These radio transmitters weighed 10, 8.9, and 7.7 g in air, respectively, which is well under the 2% ratio of transmitter weight to body weight recommended by Winter (1983). Radio transmitters implanted in broad and humpback whitefish had a 30 week on / 15 week off duty cycle. Therefore, if the radio transmitters were turned on beginning 1 May they would transmit until mid November, then restart in mid March. Later start dates would delay the on/off duty cycle. This duty cycle extended the estimated transmitter life to 331 days for humpback whitefish and 418 days for broad whitefish. Radio transmitters used in least cisco were smaller, had a transmitter life of 177 days, and were not programmed to turn off during the winter. These transmitters were only expected to operate through the fall spawning period.

Radio transmitters manufactured by Grant Engineering™ were selected for all three species during 2005 because they provided extended transmitter life. These transmitters measured approximately 11 × 47 mm, weighed 8 g in air and were programmed for two duty cycles during each 24 hr period. The duty cycle included a 3.5–s burst cycle from 08:00 to 20:00 hours and a 16–s burst cycle from 20:00 to 08:00. On/off duty cycles were also included in the programming to activate the transmitters from the start date until to 19 November 2005, 16 March to 1 July 2006, and 18 September to 20 November 2006. This programming provided an estimated transmitter life of 551 days, at least 130 days longer than the Lotek Engineering Incorporated™ transmitters used in 2004. In addition to the Grant Engineering™ transmitters, ten of the Lotek Engineering Incorporated™ transmitters originally planned for broad whitefish during 2004 were implanted in this species during 2005. All transmitters were equipped with a 30-cm external antenna.

Radio transmitters were surgically implanted in mature broad whitefish (≥425 mm fork length

[FL]), humpback whitefish (≥365 mm), and least cisco (≥315 mm). Fish selected to receive transmitters were anesthetized, tagged with a numbered T-bar anchor tag, placed ventral side up in a neoprene-lined cradle, and their gills irrigated using a combination of anesthesia and water. A 2–3 cm incision large enough to accommodate the transmitter was made anterior to the pelvic girdle, approximately 1 cm from the mid-ventral axis. The transmitter antenna was routed under the pelvic girdle and through the body wall, slightly off the mid-ventral axis and anterior to the vent using a hypodermic needle and grooved director. The incision was closed with 3 to 4 individual stitches of absorbable suture and Vetbond™ adhesive. Surgery times typically ranged between 4 and 10 min. After surgery, fish were immediately placed in a large tote with fresh water to regain their equilibrium prior to being released near the capture site. Surgical instruments and transmitters were soaked in ChlorhexiDerm™ disinfectant and rinsed in saline solution before each use.

Radio Tracking

Radio telemetry receivers manufactured by Lotek Engineering Incorporated™ were used for all mobile and fixed station tracking. Fixed receiver stations were used to automatically identify and record fish movements at key locations throughout the Kuskokwim watershed. These fixed receiver stations (FRS) were installed in 2004 at the confluence of Whitefish Lake Creek and the Kuskokwim River on 22 June (rkm 276), Chuathbaluk on 18 June (rkm 333), Red Devil on 30 June (rkm 489), Stony River on 29 June (rkm 561), McGrath on 8 August (rkm 778), Medfra on 27 August (rkm 897), and Sinka's Landing on 30 August (rkm 578) (Figure 1). River ice and logistics delayed installation of the fixed receiver stations until after the radio transmitters were implanted in the whitefish during 2004. All stations were operated for the remainder of the study period except the Stony River FRS. This station was removed after two months of operation because channel morphology at this location interfered with receiving signals from radio-tagged fish. Two additional stations were installed during 2005. One station was installed on the Kuskokwim River at Uknavik (rkm 239) on 19 March, and the other was installed on 8 August approximately 1 rkm up the Holitna River from the confluence with the Kuskokwim River (Figure 1). Flooding associated with break up during late May in 2005 destroyed the stations at Uknavik and Whitefish Lake Creek. The Whitefish Lake Creek FRS was replaced on 3 June 2005; however, the Uknavik FRS was not replaced because of financial constraints.

Fixed receiver stations were similar to those used on the Kenai River to monitor rainbow trout movements (Palmer 1998). Each station was comprised of a single data-logging receiver, two Yagi antennas, antenna switch box, antenna mast, two 12-volt deep cycle batteries, solar panel(s), voltage regulator, and a strongbox.

Mobile tracking was conducted from fixed-wing aircraft and boats. Aerial tracking was conducted 3–4 times between September and mid November during 2004 and 2005 using a Cessna 185 fixed-wing aircraft equipped with two Yagi antennas. The aircraft was flown approximately 200–400 m above ground at speeds of 80–115 knots along the mainstem Kuskowim River and tributary streams between Tuluksak and Telida. Major tributaries searched included the North and South Forks of the Kuskokwim, Big, Tatlawiksuk, Swift, Stony, Holitna, Hoholitna, and Aniak rivers. In addition to aerial searches in the fall to locate spawning areas, one survey was conducted to locate potential overwintering areas during April 2005. Boat tracking was conducted opportunistically between June and September of 2004 and 2005 when field crews traveled between fixed receiver stations. Boat tracking was conducted using various watercraft with antennas mounted on each side of the boat facing at a 45 degree angle forward of

the centerline of the bow. A portable global positioning system (GPS) was used during all mobile tracking surveys to identify the latitude and longitude of each located fish.

Age, Sex and Length Determination

The first fin ray was removed from the right pectoral fin of each whitefish radio-tagged during 2005 for age determination. Fin rays were stored dry in scale envelopes, then mounted using a Spurr Low Viscosity™ embedding mixture. Individual fin rays were sectioned using an Isomet® thin-sectioning machine with a diamond saw. Thin sections were mounted on glass slides using Crystal Bond®. Sections were magnified 100X using a compound microscope and images captured with a digital camera. We followed age determination procedures outlined by Chilton and Beamish (1982). Because Miles and Chalanchuk (2004) found no significant difference between fin-ray and otolith ages of lake whitefish *C. clupeaformis*, we assumed similar results would have been found for these fish. Each annulus consisted of a wide, light, opaque (summer growth) zone and an adjacent narrow dark translucent zone (winter growth) that formed a ring around the center of the ray. Each fin ray was aged by a single reader at least two times. If these two readings agreed, then no additional readings were necessary. If the first two readings did not agree, a third or fourth reading was conducted. Samples that did not agree after four readings were discarded.

Basic data summaries and statistical analyses were used to compare lengths and age data between sampling events and locations.

Sex could not be determined for radio-tagged fish based upon external characteristics of whitefish during transmitter implantation. Similarly, sex identification by examination of gonads was not possible through the small incision made to implant radio transmitters.

Data Analysis

Radio telemetry information collected with various tracking methods was integrated into one database that archived the dates and locations of radio-tagged whitefish. Individual fish locations were assigned a latitude and longitude for display on a background map using Arc-Map® software. River kilometers traveled by fish were derived from a base map with the river line divided into equal 1 km segments using a geographic coordinate system (NAD 1983). These river kilometers differ from those published by ADFG (Ward et al. 2003).

Results

Radio transmitters were implanted in 18 broad whitefish, 30 humpback whitefish, and 30 least cisco during 2004 (Table 1). After 30 days, 17 broad and 30 humpback whitefish and 11 least cisco were relocated. After 120 days, 10 broad whitefish (56%), 28 humpback whitefish (93%), and 10 least cisco (33%) were relocated. Nine broad whitefish and 24 humpback whitefish radio-tagged during 2004 were relocated at least once during 2005.

During 2005, radio transmitters were implanted in 36 broad whitefish, 30 humpback whitefish, and 23 least cisco (Table 1). Fish located 30 days after radio implants included 21 broad whitefish, 17 humpback whitefish, and 12 least cisco. After 60 days, numbers of fish with active transmitters dropped to 20 broad whitefish, 16 humpback whitefish, and 10 least cisco. Only seven broad whitefish (19%), 14 humpback whitefish (47%), and 10 least cisco (43%) provided movement information 90 days after transmitters were implanted.

Some radio transmitters received in 2005 were returned to the manufacturer because of technical defects. This delayed radio-tagging efforts until 23 May. Limited tracking success with some of these transmitters suggests that technical problems may have persisted after fish were implanted.

TABLE 1.—Mean length and weights of broad whitefish (BW) humpback whitefish (HW) and least cisco (LC) implanted with radio transmitters. No weights were taken during 2004.

		Sample	Length (mm)		Weight (kg)	
Tagging location and year	Species	(n)	Mean	Range	Mean	Range
Whitefish Lake 2004	BW	18	542	430-610		
Whitefish Lake 2005	BW	3	460	425-500	1.33	0.91-1.60
ADF&G Fish Wheels 2005	BW	33	464	425-590	1.51	1.04-2.37
Whitefish Lake 2004	HW	30	449	370-490		
Whitefish Lake 2005	HW	30	436	385-490	1.05	0.67-1.44
Whitefish Lake 2004	LC	30	336	270-390		
Whitefish Lake 2005	LC	23	347	315-385	0.44	0.30-0.74

Broad Whitefish

A total of 54 broad whitefish were captured and radio-tagged during 2004 and 2005 (Table 1). Eighteen broad whitefish were captured and implanted with radio transmitters at Whitefish Lake in 2004 and three were radio-tagged in Whitefish Lake during 2005. The remaining 33 broad whitefish were captured between 3 and 7 September 2005 at fish wheels operated by ADFG near Kalskag in the mainstem Kuskokwim River (Figure 3). The capture and radio-tagging of broad whitefish at the fish wheels in 2005 was necessary because of low catch rates at the Whitefish Lake weir after 23 May and from trap nets set in the lake during late May and early June. Water temperature in Whitefish Lake exceeded the upper limit recommended for whitefish surgeries (15°C) after mid June 2005.

Radio-tagged broad whitefish migrated out of Whitefish Lake during two distinct periods in 2004 and 2005 (Appendices 1 and 2). The early group left in June and included five of the 18 broad whitefish tagged in Whitefish Lake during 2004 and one of the three broad whitefish tagged in the lake during 2005. The second emigration period was from mid-September through early October when seven of the fish tagged in 2004 and two from 2005 migrated out of Whitefish Lake.

Of the 55 radio-tagged broad whitefish, 27 were successfully tracked to other areas in the watershed (12 to suspected spawning areas), 17 provided limited movement information, six were never relocated after tagging, and five were presumed tagging mortalities. Suspected spawning areas for broad whitefish include the Kuskokwim River between McGrath and Medfra and an area near the Swift River (Figure 4). Fourteen fish provided movement information over more than one year. Eight of the 18 broad whitefish radio-tagged in Whitefish Lake during 2004 and one of the three tagged in Whitefish Lake in 2005 were tracked to at least one other location within the Kuskokwim River watershed, three were only located by the Whitefish Lake Creek FRS, two were only relocated in Whitefish Lake but over two consecutive years, two were never relocated after tagging, and five were mortalities (Appendix 1 and 2). Eighteen of the 33 broad whitefish radio-tagged at the fish wheels during 2005 continued their upstream migration, 12 were only located by the Whitefish Lake Creek FRS, and four were never relocated (Appendix 2). Narrative tracking details for individual broad whitefish are presented in Appendix 3.

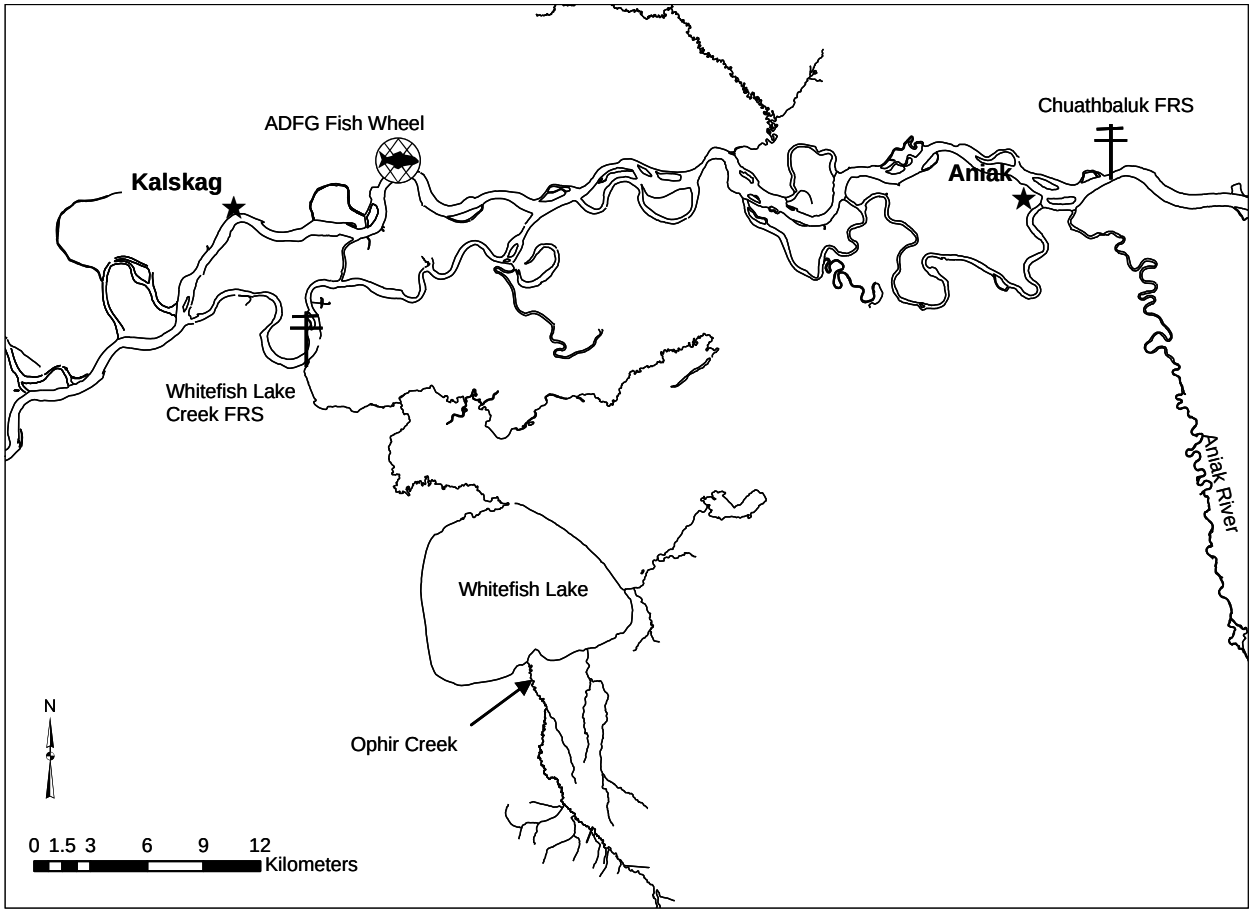

FIGURE 3.—Radio-tagging locations of whitefish during 2004 and 2005. All broad and humpback whitefish and least cisco were radio-tagged in Whitefish Lake during 2004. During 2005, all fish were radio-tagged at Whitefish Lake except for 33 broad whitefish that were tagged at the ADFG fish wheels.

Several radio-tagged broad whitefish demonstrated fidelity to Whitefish Lake. Seven of the 18 broad whitefish radio-tagged in the lake during 2004 returned in 2005 (Appendix 1). Of these, five fish had been previously captured and tagged with T-bar anchor tags as they migrated out of Whitefish Lake during 2002-2003.

The 18 broad whitefish implanted with radio transmitters at Whitefish Lake from 5 to 15 May 2004 (mean FL = 542 mm, SE 10.681 mm, range = 430–610 mm,) were significantly larger ($t = 6.628$, $df = 49$, $P<0.001$) than the 33 fish (mean FL = 464 mm, SE = 6.439 mm, range = 425–590 mm) implanted with radio transmitters at the fish wheels from 3 to 7 September 2005 (Table 1). The mean FL of the three fish radio-tagged in Whitefish Lake from 10 May to 6 June 2005 was 460 mm (Table 1). Ages were estimated for 25 of the 36 broad whitefish radio-tagged tagged during 2005 (Figure 5). Ages ranged from 2 to 9 years and the majority of fish (N= 15) were age 4 and 5. No age structures were collected from fish in 2004.

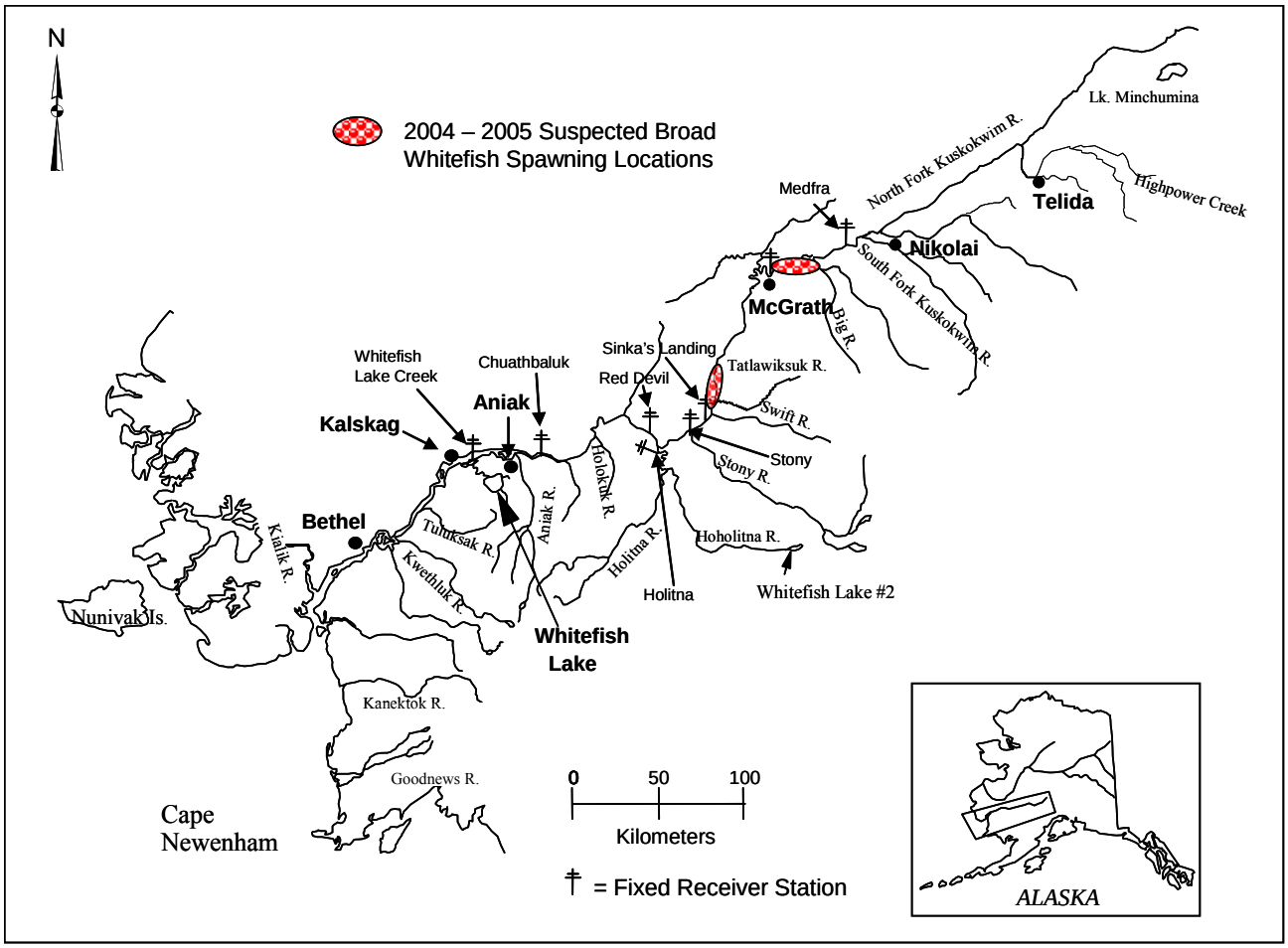

FIGURE 4.—Suspected spawning areas of radio-tagged broad whitefish. These areas were identified by the maximum upriver distribution of radio-tagged fish October–November 2004.

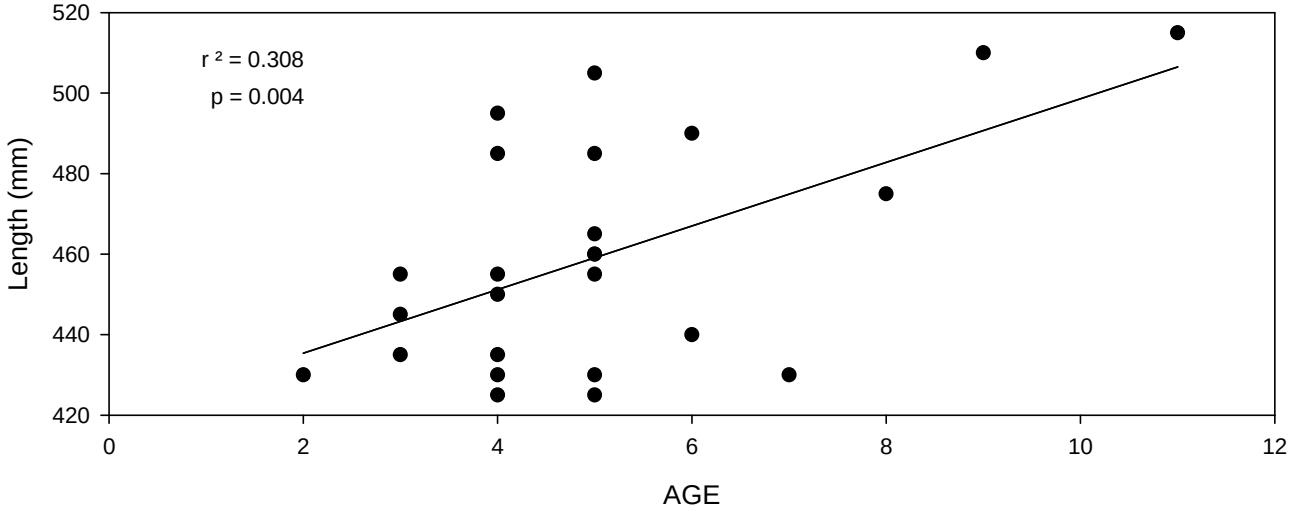

FIGURE 5.—Length at age relationship for broad whitefish radio-tagged during 2005.

Humpback Whitefish

A total of 60 humpback whitefish were implanted with radio transmitters during 2004 and 2005 (Table 1). Thirty humpback whitefish were captured and radio-tagged as they entered Whitefish Lake during May 2004 and 24 humpback whitefish were radio-tagged as they entered the lake between 26 May and 9 June 2005. Six additional fish were radio-tagged after being captured with hoop nets in Whitefish Lake between 11 and 15 June 2005. All radio-tagged fish appeared to be mature adults.

Radio-tagged humpback whitefish migrated out of Whitefish Lake during two distinct periods in 2004 and 2005 (Appendices 4 and 5). During 2004, fifteen fish migrated out of the lake by early July. The remaining fish spent the entire summer in Whitefish Lake. Of these, seven fish migrated from the lake during September and four fish migrated during October. One fish stayed in Whitefish Lake and over wintered in Ophir Creek, the primary inlet creek to Whitefish Lake (Figure 3). Movement patterns of humpback whitefish out of Whitefish Lake during 2005 were similar to those observed during 2004. Twelve fish migrated out of the lake by early July and the others remained in the lake until September or October.

Twenty-eight of the 60 humpback whitefish implanted with radio transmitters were successfully tracked to other areas of the watershed, 16 to suspected spawning areas. Suspected spawning areas for humpback whitefish include the Holitna, Swift, and Big rivers, and Ophir Creek (Figure 6). Twenty-one fish provided limited movement information, eight were never relocated after tagging, and two were mortalities. One fish only tracked in Whitefish Lake was suspected to have spawned in Ophir Creek. Twenty-six fish provided movement information over more than one year. Twenty-five of the 30 humpback whitefish radio-tagged during 2004 were tracked to at least one other location within the Kuskokwim River watershed, two were only located by the Whitefish Lake Creek FRS, two were never relocated after tagging, and one was only relocated in Whitefish Lake and probably spawned in Ophir Creek. Only three of the 30 humpback whitefish radio-tagged in 2005 were tracked to other areas in the Kuskokwim River watershed. Nineteen were only located by the Whitefish Lake Creek FRS, six were never relocated after tagging, and two were mortalities. Narrative tracking details for individual humpback whitefish are presented in Appendix 6.

Fourteen radio-tagged humpback whitefish tagged in 2004 demonstrated fidelity to Whitefish Lake and returned during 2005. Of these, 11 fish demonstrated multiple year fidelity because they had been previously captured and tagged with T-bar anchor tags as they migrated out of Whitefish Lake during 2002–2003.

Fish captured in 2004 had a mean FL of 449 mm (range = 370–490 mm) and fish captured in 2005 had a mean FL of 436 (range = 385–490). The mean weight of fish during 2005 was 1.05 kg. Ages were estimated for all 30 humpback whitefish radio-tagged during 2005 (Figure 7). Ages ranged from 5 to 18 years and the majority of fish (N=21) were age 8 through 11. No age structures were collected from fish radio-tagged in 2004.

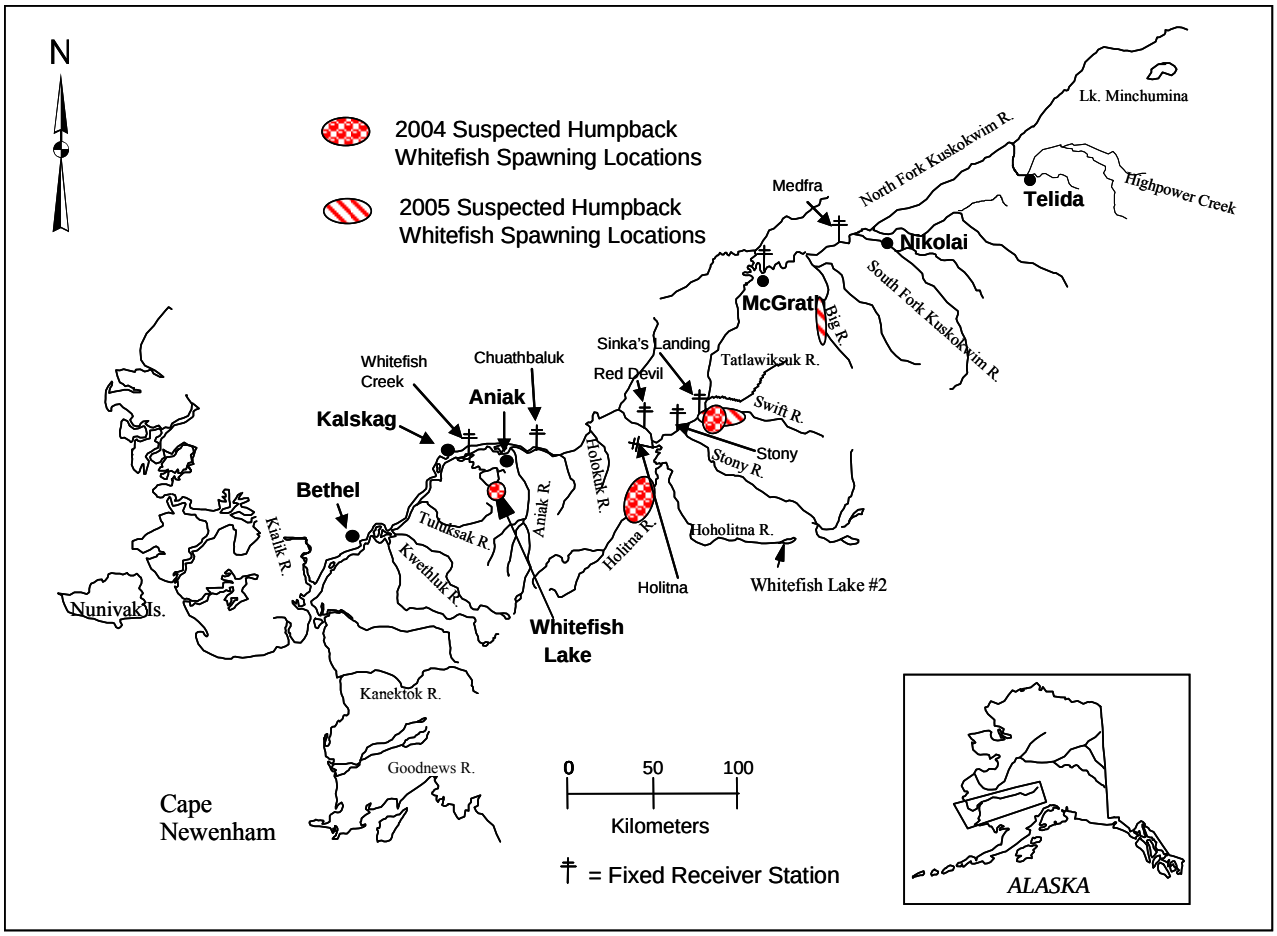

FIGURE 6.—Suspected spawning areas of radio-tagged humpback whitefish. These areas were identified by the maximum upriver distribution of radio-tagged fish during October and November 2004–2005. Ophir Creek, the primary inlet creek of Whitefish Lake, was also identified as a possible spawning site during 2003 (Harper et al. 2007).

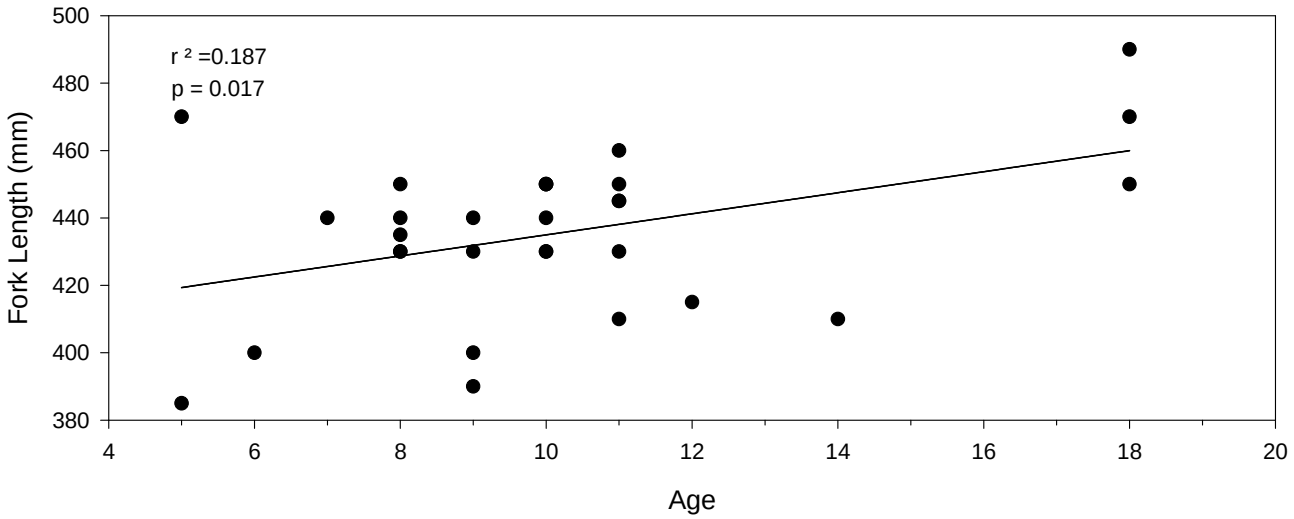

FIGURE 7.—Length at age relationship for humpback whitefish radio-tagged during 2005.

Least Cisco

Radio transmitters were implanted in 30 least cisco as they entered Whitefish Lake during May 2004 (Table 1). An additional 23 least cisco were radio-tagged during 2005 as they entered Whitefish Lake between 22 May and 16 June (Table 1).

Only five of the 53 least cisco radio-tagged in 2004 and 2005 were successfully tracked to other areas of the watershed, and one of these to a suspected spawning area in the Holitna River (Figure 8). Thirteen fish provided limited movement information, 30 fish were never relocated or only relocated in Whitefish Lake 1 to 6 weeks after tagging, and 3 were mortalities. Two fish were only tracked in Whitefish Lake and were suspected to have spawned in Ophir Creek, the

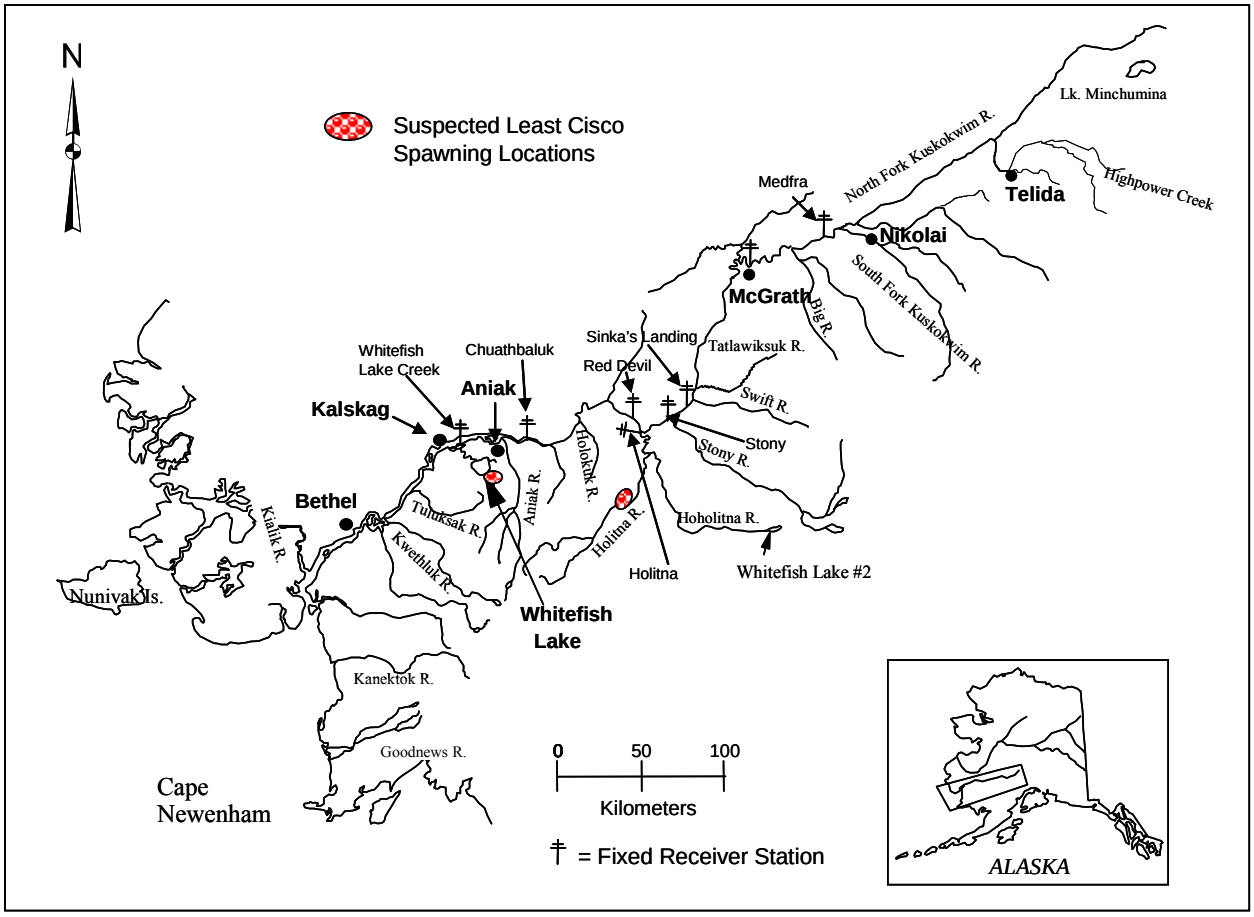

FIGURE 8.—Suspected spawning areas of radio-tagged least cisco. These areas were identified by the maximum upriver distribution of radio-tagged fish October–November 2004. Ophir Creek, the primary inlet creek of Whitefish Lake, was also identified as a possible spawning site during 2003 (Harper et al. 2007).

primary inlet creek to Whitefish Lake. Four of the 30 fish tagged in 2004 were tracked to at least one other location within the Kuskokwim River watershed, three were only located by the Whitefish Lake Creek FRS, three were only located within Whitefish Lake, 17 were never relocated after tagging, and three were mortalities (Appendix 7). Only one of the 23 fish tagged in 2005 was tracked to another location in the watershed, four were only located by the Whitefish Lake Creek FRS, five were only located within Whitefish Lake, and 13 were never relocated after tagging (Appendix 8). Narrative tracking details for individual least cicso are presented in Appendix 9.

Least cisco radio-tagged in 2004 had a mean FL of 336 mm (range 270–390 mm) and fish tagged in 2005 were slightly larger with a mean FL of 347 mm (range 315–385 mm). Ages estimated for 20 of the least cisco radio-tagged during 2005 ranged from 4 to 10 years (Figure 9) and the majority (N=14) were age 6 through 8. No age structures were collected from fish radio-tagged in 2004.

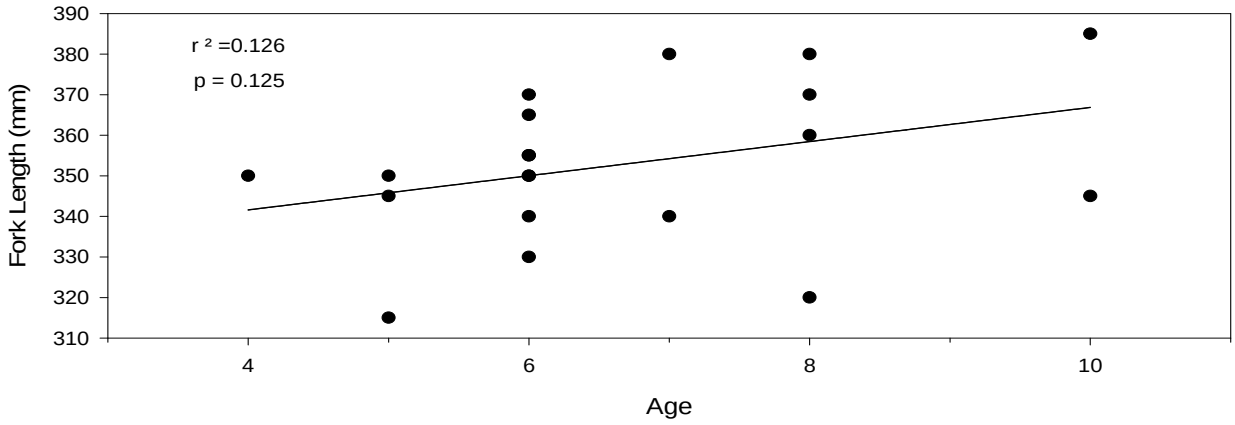

FIGURE 9.—Length at age relationship for least cisco radio-tagged during 2005.

Discussion

Broad Whitefish

Radio-tagged broad whitefish migrated from Whitefish Lake during two distinct periods. Some fish migrated out of Whitefish Lake during June after only a short lake residency and spent the entire summer slowly moving up the Kuskokwim River to suspected spawning areas. Other fish spent the entire summer in Whitefish Lake and quickly migrated to suspected spawning areas in October. These two outmigration patterns were also observed by Harper et al. (2007) at Whitefish Lake weir operations between 2001 and 2003. One possible explanation for this behavior is that some broad whitefish may require additional time between spawning events to build gametes and energy reserves (Lambert and Dodson 1990). The amount of time it takes to develop gametes and energy reserves requires some whitefish to skip years between spawning events (Bond and Erikson 1985, 1993; and Reist and Bond 1988).

The timing, concentration, and location of radio-tagged broad whitefish during October and early November suggest two possible spawning areas in the Kuskokwim River. One spawning area is located between McGrath and Medfra, where seven fish were located during October, one fish in 2004, and six fish in 2005 (Figure 4). The second possible spawning area is the mainstem Kuskokwim River near the Swift River confluence. Three fish were relocated at this location in 2004 and two in 2005 during late September and October. Further investigation of this area may be warranted to confirm spawning activity.

Post-spawning downstream migration to possible wintering areas was observed and had generally started by early November. Movement information is not available from late November through mid-March when transmitters were programmed to turn off; however, fish movements both before and after this period provided some information about possible wintering areas. Some radio-tagged fish remained above the Sinka's FRS (rkm 578) over winter because they were recorded during April and May passing this location and other fixed receiver stations located downstream. Other radio-tagged fish were relocated during April aerial surveys as far down the Kuskokwim River as the Kwethluk River (rkm 138). The largest proportion of over

wintering radio-tagged fish was located in the Kuskokwim River between Aniak and Kalskag during April and May.

Several radio-tagged broad whitefish demonstrated fidelity to Whitefish Lake during this study by migrating from the lake to spawning areas, and then back to the lake during late April or early May the following year. Fidelity to Whitefish Lake was also supported by the recapture of ten broad whitefish in 2004 that had previously been captured and tagged with T-bar anchor tags as they migrated out of Whitefish Lake between 25 September and 16 October 2003 (Harper et al. 2007). Broad whitefish that were initially tagged with T-bar anchor tags during the earlier study and then subsequently implanted with radio transmitters during this study provided an extra year of outmigration timing from Whitefish Lake (Table 2; Appendices 1 and 2). Two of these radio-tagged fish left the lake during late May or early June prior to the installation of the Whitefish Lake Creek FRS. This outmigration timing was approximately 12 weeks earlier than what was observed for these fish during 2003. Six fish left the lake after mid-September in 2004, the same time as their departure during 2003. One of the remaining two fish died in the lake and the fate of the other was unknown.

There was a large disparity between lengths of broad whitefish radio-tagged during 2004 in Whitefish Lake and those tagged at the fish wheels in 2005 (Table 1; Figure 10). Fish radio-tagged at the fish wheels were smaller than those radio-tagged at Whitefish Lake during 2004 or previously sampled in Whitefish Lake (Harper et al. 2007). Fish radio-tagged at the fish wheels that continued upstream to the suspected spawning area above McGrath (Figure 8) ranged between 430 and 485 mm. These fish were considered mature and lengths were similar to those of small mature broad whitefish (380–450 mm) sampled in the Yukon River (Randy Brown USFWS, unpublished data). This suggests that fish radio-tagged at the fish wheels were possibly younger adults and might be first year spawners. By contrast, broad whitefish using Whitefish Lake may be older, larger fish that have spawned at least once. After their first spawning migration to distant up-river locations, they may disperse back down the Kuskokwim River and find suitable wintering areas. The following spring they recruit to a feeding area, such as

TABLE 2.—Migration timing and fall mainstem locations of broad whitefish from Whitefish Lake that were tagged with T-bar anchor tags during 2003 and subsequently implanted with radio transmitters during 2004.

Radio-tag number	Migration date from Whitefish Lake		Difference in inter-year migration timing from Whitefish Lake	Fall location (October 2004)
	2003	2004		
58-2	9/27/2003	9/18/2004	Same	Kuskokwim R. above Red Devil
58-3	9/26/2003	6/26/2004	12 weeks earlier	Kuskokwim R. above Holitna R.
58-4	9/25/2003	9/20/2004	Same	Kuskokwim R. above Sinka's Landing
58-5	9/23/2003	10/30/2004	4 weeks later	Unknown.
58-7	10/16/2003	9/20/2004	3 weeks later	Kuskokwim R. above McGrath
60-12	9/28/2003	Dead	---	---
60-14	9/27/2003	9/20/2004	Same	Kuskokwim R. above Chuathbaluk
60-18	9/27/2003	5/29/2004	12 weeks earlier	Kuskokwim R. above Sinka's Landing
60-19	9/28/2003	Unknown	---	Unknown
60-21	9/29/2003	9/25/2004	Same	Kuskokwim R. above Chuathbaluk

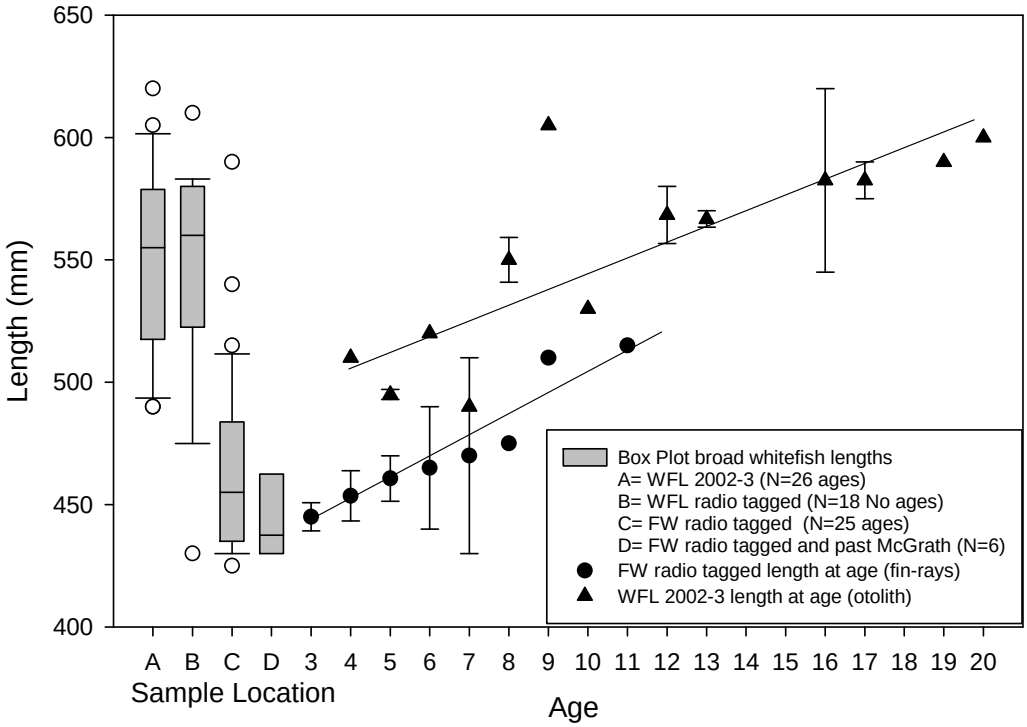

FIGURE 10.—Box plot comparisons of length distributions of broad whitefish sampled in (A) Whitefish Lake (WFL; 2002-2003), (B) radio-tagged fish from Whitefish Lake (2004), (C) radio-tagged fish at the fish wheels (FW; 2005), (D) fish tagged at the fish wheels during 2005 that migrated past McGrath (Shaded bar 25–75 percentiles and median, open circles represent outliers). Comparison of length at age relationships (otolith age) from samples taken in Whitefish Lake 2002-2003 (Harper et al. 2007) and fin-ray ages from radio-tagged fish during 2005.

Whitefish Lake where many appear to exhibit annual fidelity. The majority may never return to the lower river rearing-feeding areas where they spent their first several years as immature fish. The strontium signature present on broad whitefish otoliths collected from in Whitefish Lake supports the fact that many of these fish frequent brackish water areas associated with the lower river prior to their use of the lake (Harper et al. 2007).

No radio-tagged broad whitefish were reported as harvested during this study, although one fish (number 58-3) was likely harvested near the village of Napaimiut. Whitefish are targeted for harvest throughout the migratory corridors that fish utilize to reach spawning, feeding, and over-winter areas. Broad whitefish leaving Whitefish Lake are particularly vulnerable because much of the subsistence fishing effort in the lake occurs during the fall spawning emigration.

Humpback whitefish

Radio-tagged humpback whitefish resided in Whitefish Lake between one and six months during 2004 and 2005 before migrating out of the lake. Approximately half of the fish left the lake before the middle of July and the remainder left between September and November. Some fish that migrated early spent the entire summer moving to their spawning areas, while those that left in September migrated quickly to their spawning areas. Maximum upstream locations in both cases were observed during mid October of 2004 and 2005. Periods of time that humpback whitefish resided in Whitefish Lake during this study were similar to those observed by Harper et al. (2007) between 2001 and 2003, except the earlier study noted fish leaving the lake during all months between May and October.

The timing, concentration, and locations of radio-tagged humpback whitefish during late September and early October suggests three possible spawning areas in the Kuskokwim River drainage (Figure 6). One is located approximately 135 rkm up the Holitna River. The second area is the lower 30 rkm of the Swift River, and the third area is approximately 90 rkm up the Big River, a large tributary located above McGrath. Each of these sites is characterized by swift currents over gravel substrates. Humpback whitefish may spawn in additional areas of the Kuskokwim River, including tributaries above McGrath. This is supported by the harvest of a humpback whitefish at Medfra in September 2004 that was T-bar anchor tagged in Whitefish Lake during 2003 (Harper et al. 2007). Humpback whitefish in spawning condition have also been observed by Alt (1972) in Highpower Creek, a headwater tributary of the North Fork of the Kuskokwim and in Ophir Creek the main tributary to Whitefish Lake. Areas containing smaller numbers of spawning humpback whitefish may also occur. Based upon the known spawning destinations of humpback whitefish radio-tagged during 2004 and 2005, fish using Whitefish Lake appear to be a mixed stock comprised of Swift River (70%), Holitna River (20%), and Kuskokwim River tributaries upstream of McGrath (5%). Further investigation of these areas is warranted to confirm as spawning areas and to determine the abundance of spawners.

Radio transmitters were programmed to shut off during the winter months; however, locations of radio-tagged fish before late November and after mid-March provided some information about post-spawning movement to potential wintering areas. Post-spawning downstream movement of humpback whitefish was observed and generally started by mid-October with most fish passing the Red Devil FRS (rkm 489) between late October and November. One exception to this pattern was two fish that migrated into and overwintered in the lower section of the Holitna River. Other humpback whitefish likely overwintered in the Kuskokwim River between the Holitna (rkm 520) and Kwethluk (rkm 138) rivers. The largest spring concentration of radio-tagged fish was found near Kalskag.

Several radio-tagged humpback whitefish demonstrated fidelity to Whitefish Lake during this study by migrating from the lake to spawning areas, and then back to the lake during late April or early May the following year. Fidelity to Whitefish Lake was also supported by the recapture of 21 humpback whitefish in 2004 that had previously been captured and tagged with T-bar anchor tags as they migrated out of Whitefish Lake during 2002 and 2003 (Harper et al. 2007).

Humpback whitefish that were initially tagged with T-bar anchor tags by Harper et al. (2007) and then subsequently implanted with radio transmitters during this study provided an extra year of outmigration timing from Whitefish Lake (Table 3; Appendices 3 and 4). Six of these radio-tagged fish left the lake three to four months earlier and four left the lake between eight and 12 weeks later than when they were originally tagged with T-bar anchor tags during 2002 and 2003. Twelve fish left the lake within six weeks of their departure in previous years. Although not fully understood, this behavior is similar to that observed for broad whitefish and may suggest that some humpback whitefish require additional time to develop gametes and build energy reserves for the spawning migration.

The potential for harvest of humpback whitefish occurs throughout the migratory corridors that these fish utilize to reach spawning, feeding, and over-winter areas. One radio-tagged humpback whitefish was harvested during this study near the village of Akiachak. Another transmitter from a fish was found on the riverbank near the village of Napaimiut suggesting this fish may have also been harvested. Humpback whitefish that were previously tagged with T-bar anchor tags in

TABLE 3.—Migration timing and fall mainstem locations of humpback whitefish from Whitefish Lake that were tagged with T-bar anchor tags during 2002 and 2003 and subsequently implanted with radio transmitters during 2004.

Radio-tag number	Migration date from Whitefish Lake		Difference in inter-year migration timing from Whitefish Lake	Fall location (October 2004)
58-40	7/12/2002	6/24/2004	Same	Holitna River
60-41	7/21/2002	10/28/2004	12 weeks later	Unknown
60-42	6/25/2002	7/01/2004	Same	Holitna River
60-43	7/23/2002	5/31/2004	6 weeks earlier	Kuskokwim R. above McGrath
62-52	7/16/2002	9/12/2004	8 weeks later	Swift River
62-60	8/02/2002	6/24/2004	4 weeks earlier	Swift River
62-59	8/14/2003	9/02/2004	Same	Swift River
62-58	10/12/2003	6/24/2004	16 weeks earlier	Swift River
62-57	8/30/2003	9/05/2004	Same	Kuskokwim R. tributary near Sinka's Landing
62-56	7/07/2003	10/05/2004	12 weeks later	Unknown
62-55	10/10/2003	5/27/2004	16 weeks earlier	Unknown
62-54	7/07/2003	6/24/2004	Same	Dead
62-53	6/15/2003	6/24/2004	Same	Kuskokwim R. tributary above Chuathbaluk
62-51	9/29/2003	6/24/2004	12 weeks earlier	Holitna River
60-46	8/22/2003	9/07/2004	2 weeks later	Kuskokwim R. tributary above Red Devil
60-45	7/13/2003	9/30/2004	8 weeks later	Swift River
60-44	9/27/2003	6/24/2004	12 weeks earlier	Holitna River
60-42	6/25/2002	6/15/2004	Same	Holitna River
58-39	8/28/2003	9/05/2004	Same	Kuskokwim R. tributary above Red Devil
58-35	9/30/2003	6/24/2004	12 weeks earlier	Kuskokwim R. tributary near Sinka's Landing
58-34	7/12/2003	7/10/2004	Same	Swift River
58-32	9/25/2003	7/01/2004	12 weeks earlier	Swift River

Whitefish Lake have been harvested from several locations in the Kuskokwim River and included one harvested as far away as Medfra (Harper et al. 2007). Therefore, fish using Whitefish Lake are vulnerable to harvest over a wide geographic range in the Kuskokwim River. Humpback whitefish leaving Whitefish Lake are probably less vulnerable to harvest than broad whitefish because they leave the lake over a protracted period of time throughout the summer and fall.

Least cisco

Success in tracking the movements of radio-tagged least cisco was well below that of broad and humpback whitefish. During both 2004 and 2005, contact with over half of the radio-tagged fish was lost within two weeks of tagging (Appendices 7 and 8). Three factors could account for the reduced contacts. First, several least cisco died immediately after surgeries and others are suspected of dying within a few days. Least cisco appeared to be a relatively frail fish when handled in a similar manner as broad whitefish and humpback whitefish during this study. The body cavity wall in least cisco was also much thinner in the ventral area where the radio transmitters were surgically inserted than either broad whitefish or humpback whitefish. Handling and surgical techniques may therefore need to be changed to achieve a higher survival rate in this species. Second, failure of radio transmitters could account for some reduction in tracking success. Some of the same difficulties that were experienced with transmitters used in

broad and humpback whitefish were observed with transmitters used in least cisco. Third, some least cisco may have moved into locations within the Kuskokwim River that were not routinely tracked such as the area between Whitefish Lake and Bethel. Despite the limited success tracking radio-tagged least cisco, some information was obtained on the seasonal usage of Whitefish Lake and migration within the Kuskokwim River.

Radio-tagged least cisco resided in Whitefish Lake between two and six months during 2004 and 2005 before migrating out of the lake. Two least cisco left the lake in June, several left between August and the first week of October, and others remained in the lake until November. Periods of time that least cisco resided in Whitefish Lake during this study were similar to those observed by Harper et al. (2007) between 2001 and 2003, except the earlier study noted fish leaving the lake during all months between May and October. Only five fish were relocated in the Kuskokwim River beyond the Whitefish Lake Creek FRS. These fish migrated up the Kuskokwim River and one entered the Holitna River where it was located at a possible spawning location during October (Figure 8). The other four fish were never tracked beyond Sinka's Landing FRS but may have entered one of the tributaries in the area including the Holitna, Stony, or Swift rivers. Additional work will be required to locate and sample least cisco spawning aggregates.

Fidelity to Whitefish Lake was demonstrated in only one least cisco, which was previously marked with a T-bar anchor tag as it emigrated from Whitefish Lake on 13 September 2002 (Harper et al. 2007). This fish was recaptured entering the lake and radio-tagged on 2 May 2004 (Appendix 7). Movements of this fish were recorded only within the lake during 2005. However, the transmitters used with least cisco only provided one season of movement data, so we were not able to document fish using Whitefish Lake in consecutive years as we were for broad and humpback whitefish.

The potential for harvest of least cisco occurs throughout the migratory corridors that these fish utilize to reach spawning, feeding, and over-winter areas. No harvest of radio-tagged least cisco was reported during this study, although Harper et al. (2007) noted that least cisco tagged with T-bar anchor tags in Whitefish Lake during 2002 and 2003 were harvested from several locations in the Kuskokwim River and from Whitefish Lake.

Summary

Information needs for fishery management are complex, and include an understanding of the species life history, population size, growth, age at sexual maturity, fecundity, mortality rates, and migration and timing patterns. Determining the extent to which the populations are exploited can be straightforward for closed lake populations but are more complex for Kuskokwim River whitefish, which are amphidromous and harvested year round throughout the entire Kuskokwim River drainage. Some information on population size, growth, age, and sexual maturity exists for broad and humpback whitefish and least cisco using Whitefish Lake (Harper et al. 2007). This radio tracking study has provided additional information, concluding that whitefish using Whitefish Lake follow complex migration patterns and are comprised of mixed stocks that migrate at different times to distinct spawning and overwintering locations. Migration patterns indicate that whitefish travel long distances and stocks are vulnerable to subsistence harvests, not only in Whitefish Lake but also along the majority of the Kuskokwim River. Management still lacks information on harvest numbers, natural mortality, population size, and age and size structure of the various spawning and feeding aggregates.

Genetic techniques for separating mixed stocks of whitefish in the Kuskokwim River appear promising. For example, humpback whitefish sampled from different Alaskan river systems, including Whitefish Lake, were determined to be genetically distinct (Olsen et al. 2007). Although baseline genetic work on individual spawning aggregates within the Kuskokwim River has not been conducted, known spawning groups could be sampled to determine if they are genetically distinct. If genetic techniques prove useful, then total abundance of one stock with the use of mixed stock analysis could estimate the total relative abundance available to the fishery and approximate sustainable yield.

Various issues with radio tracking affected our ability to collect complete movement information for whitefish. First, technical difficulties with radio transmitters used during 2005 required their return to the manufacturer. Problems with the transmitters may not have been fully resolved, and may have resulted in early failure for some transmitters. Second, some radio-tagged fish may have been harvested but not reported to the investigators. Third, fixed receiver stations were not operational for the entire period and some failed to operate properly. Several fish were known to have migrated out of Whitefish Lake prior to the June installation of the Whitefish Lake Creek FRS. Several fish were also known to have migrated past other fixed receiver sites in the basin without being detected. Fourth, data were lost from the Whitefish Lake Creek FRS and Uknavik FRS (rkm 243) during flooding that occurred on the Kuskokwim River during ice breakup in 2005. The Uknavik FRS was not replaced due to budget constraints that limited our ability to track fish moving down the Kuskokwim River. Finally, the critical period to track the migration of whitefish is from October through November when fish have moved to their highest locations in tributaries or the main stem to suspected spawning locations. During this period, the number of data points collected for radio-tagged fish was reduced due to poor weather conditions, and limited plane and pilot availability.

Recommendations

After collecting baseline habitat use, migration, and distribution information for whitefish utilizing Whitefish Lake from 2001 to 2005, we make the following recommendations to improve subsistence management of whitefish stocks in the Kuskokwim River basin.

- All suspected spawning grounds should be sampled to confirm and delineate spawning areas. Because of potential resource development within the Kuskokwim River watershed, these identified areas should then be classified as critical habitat.
- Collect and analyze genetic samples from all identified spawning aggregates to provide information on population structure.
- Estimate population size and annual variation in spawning numbers in selected spawning areas (e.g., Swift River) using multiple year open population mark-recapture models. With multiple year analysis, survival and annual fidelity to the spawning locations may be determined, as well as recruitment, and age and sex composition of the spawning aggregates.
- As the broad whitefish population that utilizes Whitefish Lake appears to be small in comparison to humpback whitefish and least cisco, extra emphasis should be placed on determining spawning locations and obtaining spawning numbers for this species.
- Determine harvest rates for of each species so that managers can make informed decisions when determining allowable exploitation rates.

- Initiate climate-change related studies on Whitefish Lake because of it's importance as a feeding lake for numerous spawning stocks of whitefish.

- Tag fish on the spawning grounds to indentify other important feeding and overwintering areas.

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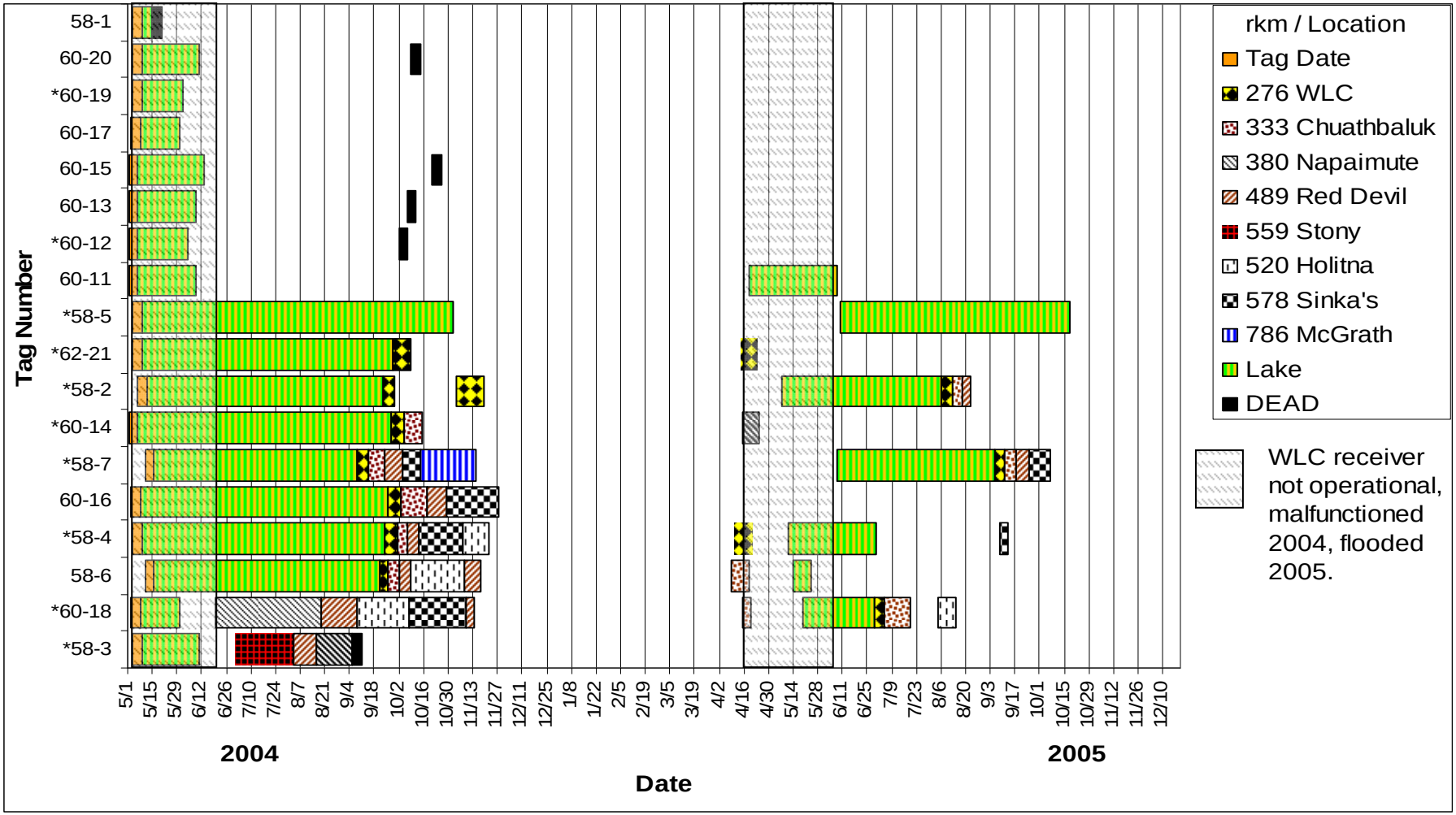
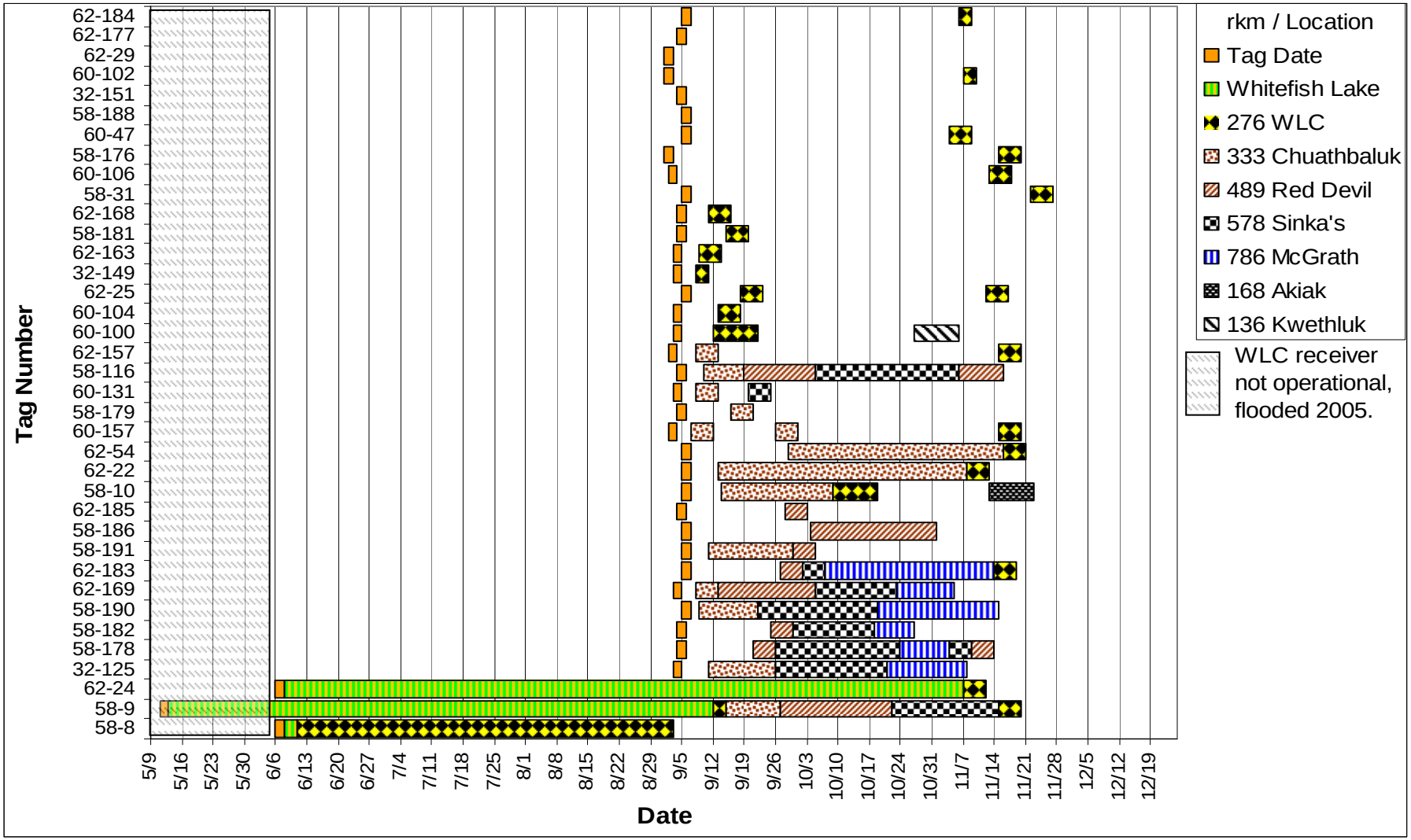


APPENDIX 1.—Seasonal distribution of broad whitefish radio-tagged in Whitefish Lake during 2004 and relocated 2004–2005 by boat, aerial surveys or FRS. Colored bars represent date of radio-tagging and residence in Whitefish Lake, followed by the approximate time fish was at FRS. The length of unique bar colors does not necessarily represent time spent at individual FRS, only lapsed time until recorded at subsequent FRS or relocated by boat or aerial survey. Ten broad whitefish (*) were previously marked with a T-bar anchor tags as they left Whitefish Lake 21 September–16 October 2003. Transmitters were programmed to turn off between the end of November 2004 and March 2005. Fish leaving Whitefish Lake after 22 June 2004 had to pass by the Whitefish Lake Creek FRS. All dead fish were recovered in Whitefish Lake except 60-15 which died halfway down the outlet creek, and 58-3 which was found in the Kuskokwim River.



APPENDIX 2.—Seasonal distribution of broad whitefish radio-tagged in Whitefish Lake during 2005, and relocated by boat, aerial surveys or FRS. Colored bars represent date of radio-tagging and residence in Whitefish Lake, followed by the approximate time fish was at FRS. The length of unique bar colors does not necessarily represent time spent at individual FRS, only lapsed time until recorded at subsequent FRS or relocated by boat or aerial survey. Three broad whitefish were captured and radio-tagged in Whitefish Lake during May and June. Thirty-three fish were captured during September at the Alaska Department of Fish and Game fish wheels located near Kalskag, Alaska.

APPENDIX 3.—Narrative tracking details for broad whitefish radio-tagged in Whitefish Lake, 2004 and 2005, and using fish wheels near Kalskag, 2005.

Nine of the 18 broad whitefish radio-tagged in Whitefish Lake during 2004 were tracked to at least one other location within the Kuskokwim River watershed (Figure 1; Appendix 1). Two fish were only recorded entering the Kuskokwim River at the Whitefish Lake Creek FRS during September and one reappeared at this location again during November. The other seven fish migrated up the Kuskokwim River and past the Chuathbaluk FRS. Six fish continued past the Red Devil FRS. On 1 August, one fish (number 58-3) was recorded migrating back down the Kuskokwim River past the Red Devil FRS. Boat surveys conducted on 14, 18, and 31 August located this fish further down the Kuskokwim River near the village of Napaimiut (rkm 380). The transmitter from this fish was retrieved from the riverbank near the village on 11 September. Of the remaining five fish, two entered the Holitna River (rkm 520). Fish number 60-18 entered the Holitna River and passed the fixed receiver station located 1 km upstream from the confluence with the Kuskokwim River on 11 September. This fish remained in the Holitna River for about a month before reentering the Kuskokwim River on 6 October and continuing its migration upstream past the Sinka's Landing FRS on 12 October. After spending about two weeks above the Sinka's Landing FRS, this fish began moving downstream and past the Red Devil FRS on 10 November. The other fish (number 58-6) entered the Holitna River on 8 October and remained through approximately 7 November when it moved down past the Red Devil FRS. The other three fish (numbers 60-16, 58-4, and 58-7) continued upriver past the Sinka's Landing FRS. Two of these fish were located approximately 60 rkm above the Sinka's Landing FRS during October. Fish number 58-4 moved back down the Kuskokwim River and was relocated near the mouth of the Holitna River on 7 November and fish number 60-16 was not relocated. The remaining fish (number 58-7) continued upstream past McGrath and was located at a suspected spawning area near rkm 829 on 27 October. This location was approximately 553 rkm above the Whitefish Lake Creek FRS and represented the furthest upstream migration observed for broad whitefish in the Kuskokwim River during 2004.

During 2005, nine of the 18 broad whitefish radio-tagged during 2004 were relocated. Five fish were located in the Kuskokwim River between Whitefish Lake Creek (rkm 276) and Napaimiut (rkm 380) during aerial surveys conducted 11–15 April 2005. The remaining four fish were not relocated during the April aerial survey but were found in Whitefish Lake during May and June. Four of the nine broad whitefish left Whitefish Lake again during 2005 and migrated up the Kuskokwim River.

The three broad whitefish radio-tagged in Whitefish Lake during 2005 exhibited similar movement patterns to those tagged in the lake during 2004. One broad whitefish (number 58-9) moved out of the lake during September and migrated up the Kuskokwim River. This fish passed the Sinka's Landing FRS on 22 October and was relocated on 11 November near the mouth of the Swift River. Three days after this fish was observed at the Swift River, it was recorded moving downstream past the Whitefish Lake Creek FRS. The other two broad whitefish provided limited movement information. One fish exited Whitefish Lake during June and the other left the lake in November. The Whitefish Lake Creek FRS was the last known location for these two fish.

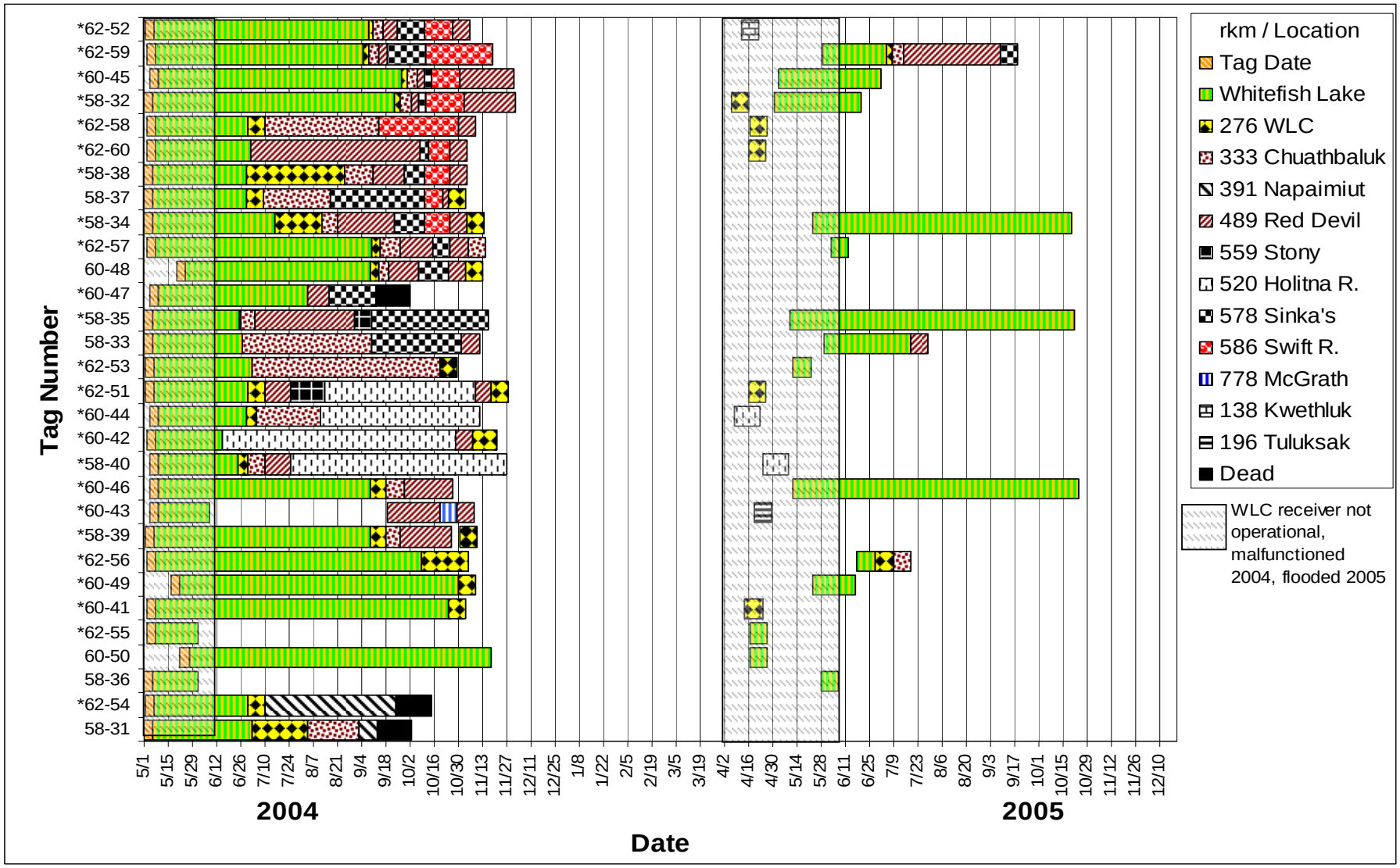
Sixteen of the 34 broad whitefish radio-tagged at the fish wheels during 2005 continued their upstream migration (Appendix 2). All of these fish passed the Chuathbaluk FRS located approximately 50 rkm above the fish wheels; nine of them passing within one week of being radio-tagged. Eleven broad whitefish continued upstream past the Red Devil FRS. Eight of

these fish continued past Sinka's Landing FRS between the end of September and the first week of October. Six fish continued their upstream migration past the McGrath FRS during October to a suspected spawning area located between rkm 786 and 851. Spawning likely occurred during late October and by early November radio-tagged fish began migrating down the Kuskokwim River.

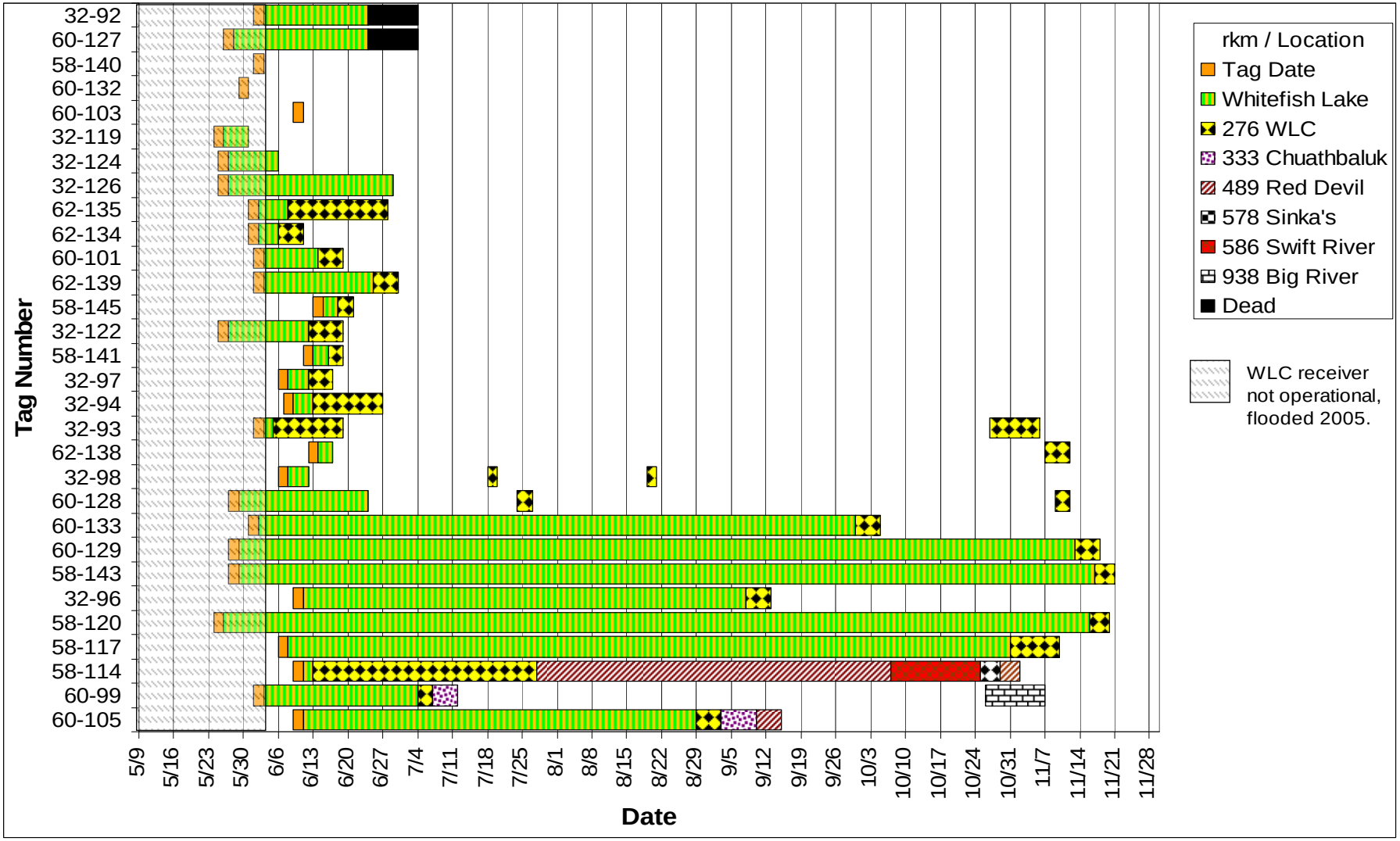
One broad whitefish radio-tagged at the fish wheels during 2005 provided some evidence that downstream migrations occurs to possible overwintering locations (Appendix 2). This fish (number 58-10) first migrated above the Chuathbaluk FRS on 14 September. After spending 11 days above the Chuathbaluk FRS, this fish began moving downriver and was located twice at the Whitefish Lake Creek FRS between 9 October and 15 November. The final location for this fish was recorded on 22 December near the village of Akiak (rkm 168) over 100 rkm below the fish wheel tagging location.

The remaining broad whitefish (N=17) radio-tagged at the fish wheels during 2005 provided limited movement information. Most of these fish (N=13) were only observed, some multiple times, at the Whitefish Lake Creek FRS. This fixed receiver station was located in a separate channel approximately 12 rkm south of the fish wheels (Figure 3). One of the fish observed at the Whitefish Lake Creek FRS was also observed downriver on 27 October near the confluence of the Kuskokwim and Kwethluk Rivers (rkm 136). Contact with four fish was lost immediately after radio transmitters were implanted.

Five broad whitefish radio-tagged during 2005 were relocated during 2006. One fish migrated up the Kuskokwim River, passed the Sinka's Landing FRS on 20 September 2006, and was located 64 rkm below McGrath during October. This fish (number 58-116) migrated down the Kuskokwim River past Sinka's Landing FRS on 19 November. Two other fish (numbers 58-190 and 62-169) moved downriver past the Sinka's Landing FRS on 16 and 17 May. One of these fish was recorded on the Whitefish Lake Creek FRS on 19 May. Another fish (number 58-182) was only located below Bethel at rkm 92 on 17 October. The last fish (number 58-10) was located near the village of Akiak, but was a suspected mortality because it was located at this site during December of 2005 and remained at the same location from September through November of 2006.



APPENDIX 4.—Seasonal distribution of humpback whitefish radio-tagged in Whitefish Lake during 2004 and relocated 2004–2005 by boat, aerial surveys or FRS. Colored bars represent date of radio-tagging and residence in Whitefish Lake, followed by the approximate time fish was at FRS. The length of unique bar colors does not necessarily represent time spent at individual FRS, only lapsed time until recorded at subsequent FRS or relocated by boat or aerial survey. Twenty-four humpback whitefish (*) were previously marked with T-bar anchor tag as they left or entered Whitefish Lake between 2002 and 2003.



APPENDIX 5.—Seasonal distribution of humpback whitefish radio-tagged in Whitefish Lake during 2005, and relocated by boat or aerial surveys or FRS. Colored bars represent date of radio-tagging and residence in Whitefish Lake, followed by the approximate time fish was at FRS. The length of unique bar colors does not necessarily represent time spent at individual FRS, only lapsed time until recorded at subsequent FRS or relocated by boat or aerial survey. Humpback whitefish number 60-99 was relocated in Big River above McGrath, and number 58-114 in the lower 10 km of the Swift River during aerial surveys during October 2005, both suspected spawning areas. .

APPENDIX 6.—Narrative tracking details for humpback whitefish radio-tagged in Whitefish Lake, 2004 and 2005.

Twenty-seven of the 30 humpback whitefish radio-tagged in Whitefish Lake during 2004 were tracked to other locations within the Kuskokwim River watershed (Figure 1; Appendix 4). Three fish were only recorded once as they entered the Kuskokwim River at the Whitefish Lake Creek FRS during October while twenty-four fish migrated up the Kuskokwim River past the Chuathbaluk FRS. Twenty-one fish continued past the Red Devil FRS, after which four fish entered the Holitna River, one fish in early June followed by another fish in July and two fish in August. All four of these fish were relocated approximately 85 rkm up the Holitna River during October aerial surveys. Fourteen fish continued up the Kuskokwim River past the Sinka's Landing FRS. Of these, nine fish were located within the lower 30 rkm of the Swift River during October aerial surveys. Only one humpback whitefish continued up the Kuskokwim River and passed the McGrath FRS in October.

Twenty-two of the 30 humpback whitefish radio-tagged in Whitefish Lake during 2005 left the lake and passed the Whitefish Lake Creek FRS (Figure 1; Appendix 5). Only three of these fish migrated beyond the Whitefish Lake Creek FRS and up the Kuskokwim River past the Chuathbaluk FRS. Two fish continued moving upriver past fixed receiver stations at Red Devil and Sinka's Landing. One of these fish (number 58-114) migrated into the Swift River during October to the same area used by nine radio-tagged humpback whitefish the previous year. The other humpback whitefish (number 60-99) continued past the McGrath FRS and was located on 26 October at a suspected spawning area approximately 90 rkm up the Big River. This fish migrated out of Whitefish Lake in early July and traveled over 600 rkm to this suspected spawning area.

Radio-tagged humpback whitefish that were located on suspected spawning grounds during 2004 and 2005 began their migration from Whitefish Lake during both early and late periods. Five of the nine humpback whitefish that migrated to the Swift River during 2004 left Whitefish Lake in June or July while the other four left in September. The first fish arrived at the Swift River in early September followed by the others in October (Appendix 4). These fish were relocated during October aerial surveys, spread out over approximately 32 rkm of the lower Swift River, which is characterized by swift currents and a gravel-cobble substrate. The one fish that migrated to the Swift River during 2005 left Whitefish Lake by early July and was relocated in the Swift River during October. All radio-tagged fish using the Swift River began moving downriver past the Red Devil FRS by the end of October and several passed the Whitefish Lake Creek FRS in November.

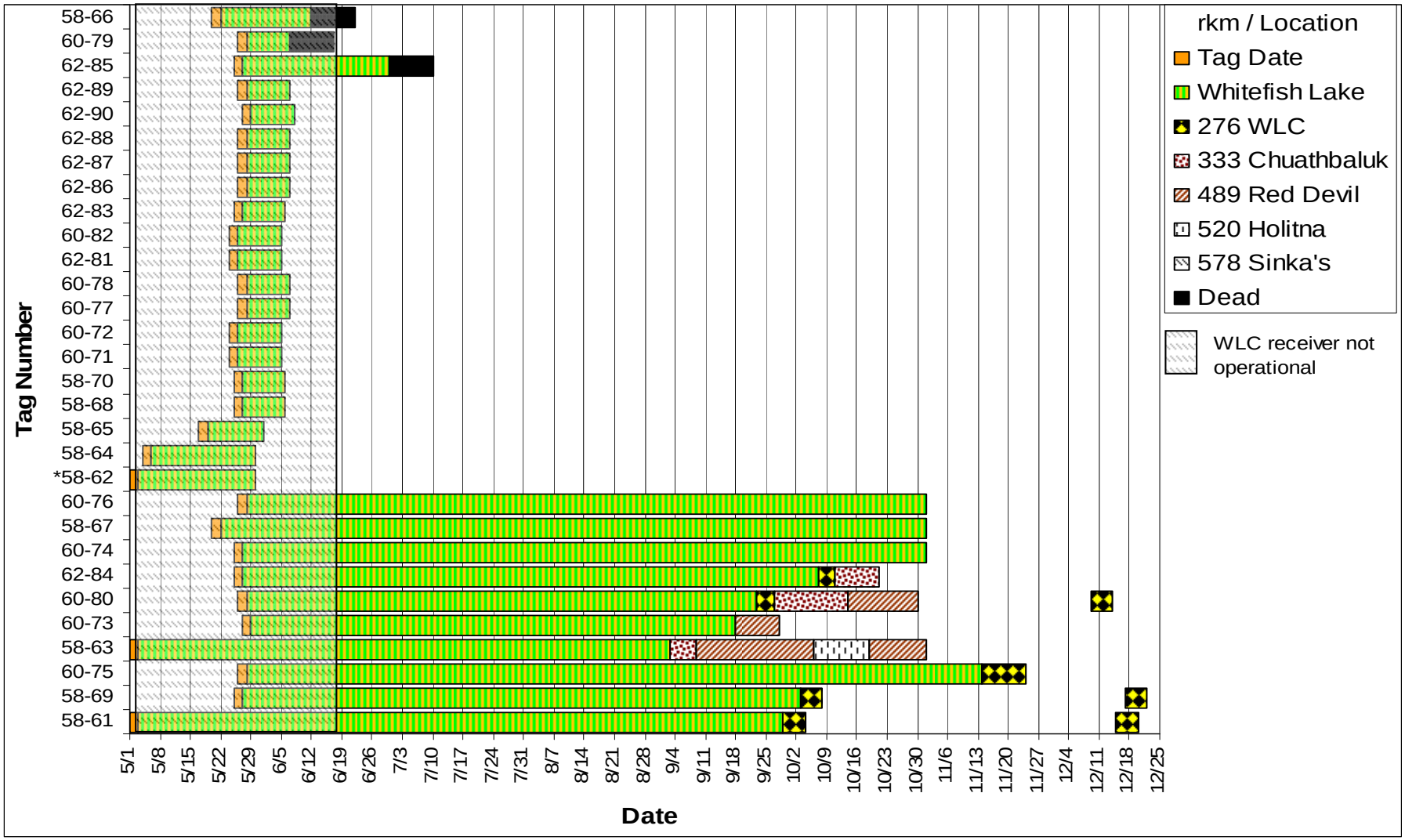
The four humpback whitefish from 2004 that migrated to the Holitna River left Whitefish Lake during June. One fish migrated quickly and entered the Holitna River in June, followed by two in August and one in October. All four fish were located approximately 85 rkm up the Holitna River during October at suspected spawning locations. Two of these humpback whitefish dropped down into the lower 10 rkm of the Holitna River during late October and early November. These two fish were relocated in the lower 10 rkm of the Holitna River the following spring suggesting that this area maybe an overwintering location.

Twenty-three of the 30 humpback whitefish radio-tagged during 2004 were relocated at least once during 2005. Twelve fish were located in the Kuskokwim River scattered between the Kwethluk River (rkm 138) and the Holitna River (rkm 520) during April aerial surveys. Fourteen radio-tagged humpback whitefish demonstrated fidelity to Whitefish Lake and returned

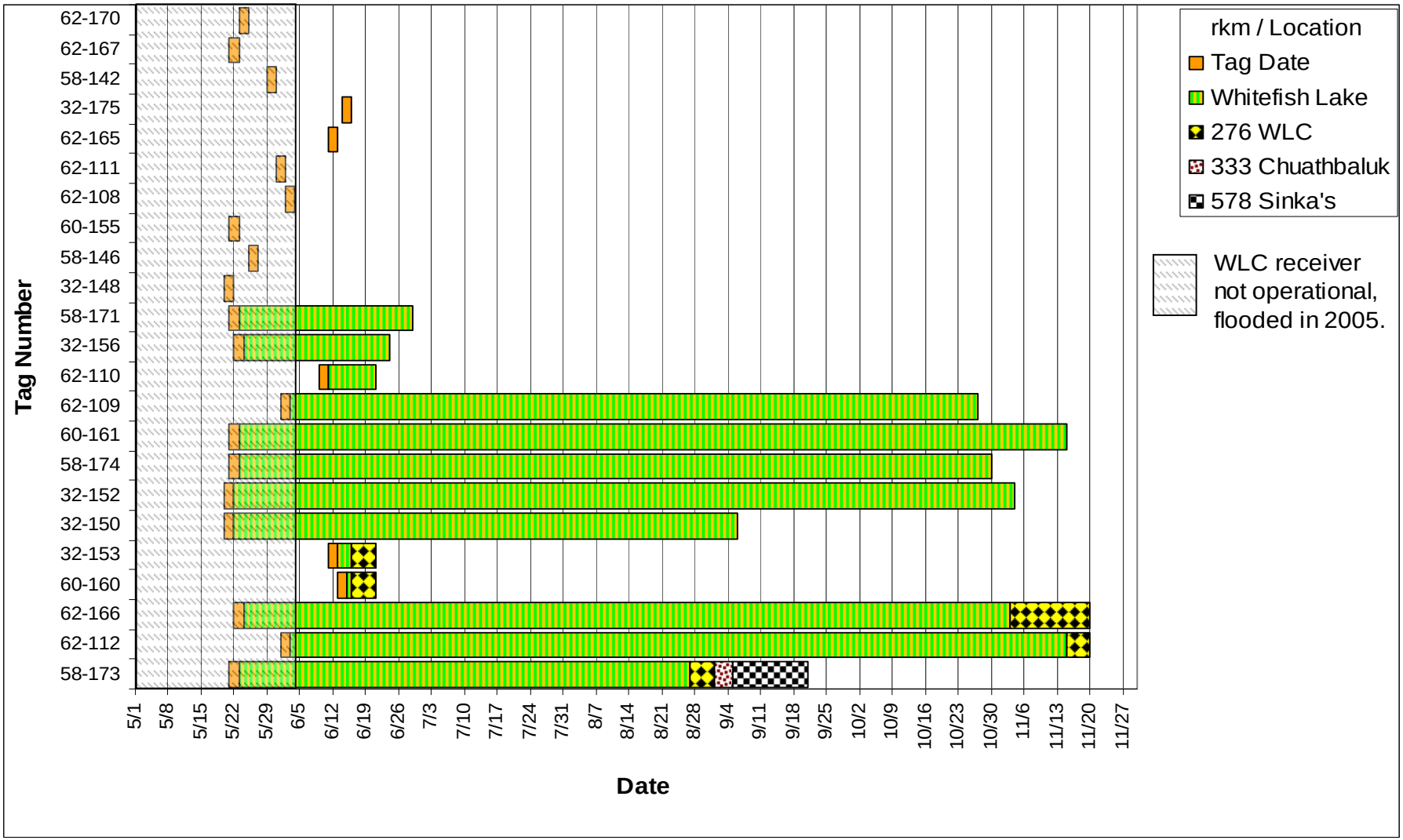
during 2005. Of these, eleven fish demonstrated multiple year fidelity because they had been previously captured and tagged with T-bar anchor tags as they migrated out of Whitefish Lake during 2002–2003.

Four of the humpback whitefish radio-tagged during 2005 were relocated during 2006. One fish was located in the Swift River on 18 October within the suspected spawning area that was identified during 2004. This fish (number 58-114) exited the Swift River and began moving downstream passing Sinka's Landing FRS on 27 October and Chuathbaluk FRS on 14 November. A second fish (number 60-127) was only located in Whitefish Lake during November. The third fish (number 32-92) was relocated in Whitefish Lake Creek and at the Whitefish Lake Creek FRS. The fourth fish (number 32-97) was relocated between Tuluksak and Whitefish Lake Creek during October and again in November (Figure 1).

The migration timing for some humpback whitefish using Whitefish Lake changed between 2004 and 2005 (Appendices 4 and 5). Two fish (numbers 62-56 and 62-59) that migrated out of the lake in September of 2004 left the lake before the middle of July during 2005. Two other fish (numbers 58-34 and 58-35) displayed the opposite pattern; migrating from the lake by the end of June 2004. The following year these fish remained in Whitefish Lake through November.



APPENDIX 7.—Seasonal distribution of least cisco radio-tagged in Whitefish Lake during 2004 and relocated by boat, aerial surveys or FRS. Colored bars represent date of radio-tagging and residence in Whitefish Lake, followed by the approximate time fish was at FRS. The length of unique bar colors does not necessarily represent time spent at individual FRS, only lapsed time until recorded at subsequent FRS or relocated by boat or aerial survey. One least cisco (*) was previously marked with a T-bar anchor tag leaving whitefish Lake during 2002. Fish number 58-63 was relocated in the Holitna River during October 2004 in a suspected spawning area.



APPENDIX 8.—Seasonal distribution of least cisco radio-tagged in Whitefish Lake during 2005, and relocated with boat, aerial surveys or FRS. Colored bars represent date of radio-tagging and residence in Whitefish Lake, followed by the approximate time fish was at FRS. The length of unique bar colors does not necessarily represent time spent at individual FRS, only lapsed time until recorded at subsequent FRS or relocated by boat or aerial survey. Fish number 62-109 and 62-166 were located in or near Ophir Creek, the main inlet creek to Whitefish Lake, on 27 October 2005 by aerial survey.

APPENDIX 9.—Narrative tracking details for least cicso radio-tagged in Whitefish Lake, 2004 and 2005.

Seven of the 30 least cisco radio-tagged in Whitefish Lake during 2004 migrated out of the lake and passed the Whitefish Lake Creek FRS (Figures 1 and 3; Appendix 7). These fish began leaving the lake the first week of September and the last fish entered the Kuskokwim River during mid-November. Four of these fish migrated up the Kuskokwim River past the Chuathbaluk FRS. Three fish continued up past the Red Devil FRS and one fish (number 58-63) was relocated approximately 147 rkm up the Holitna River during an aerial survey on 8 October. Three of the seven least cisco that entered the Kuskokwim River at the Whitefish Lake Creek FRS were recorded back at that site during mid-December. The short life of these transmitters (177 days) precluded any observations beyond December 2004.

Five of the 23 least cisco radio-tagged during 2005 entered the Kuskokwim River. Two fish left the lake the third week of June, followed by one fish in late August, and two additional fish during November. Least cisco number 58-173 was the only fish tracked beyond the Whitefish Lake Creek FRS during 2005. This fish emigrated from Whitefish Lake during August and passed the fixed receiver stations at Whitefish Lake Creek, Chuathbaluk, and Sinka's Landing (Appendix 8). After passing the Sinka's Landing FRS in mid-September, this fish was never located again. Eight least cisco were tracked only within Whitefish Lake and 10 were not relocated after tagging. Two of the least cisco that were tracked only within the lake during 2005 were relocated near the mouth of Ophir Creek on 27 October suggesting this creek may be a possible spawning location.