Seasonal Migration and Habitat Use of Humpback Whitefish in the Copper River Delta, Alaska

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Abstract

Research conducted on humpback whitefish (*Coregonus pidschian*) on the Copper River Delta, Alaska has revealed a complex life history involving seasonal migrations and the occupation of a variety of freshwater and marine habitats including lacustrine, riverine, estuarine, and marine. Seventy-six whitefish were tagged with biotelemetry transmitters from 2006 to 2009 at McKinley Lake and sixteen whitefish were tagged with biotelemetry transmitters at Martin Lake in 2007 and 2009. Movements and migration of tagged fish were tracked using biotelemetry techniques from boats, airplanes, and fixed receiver stations throughout the spring, summer, and fall. Biotelemetry results revealed that tagged fish migrated into McKinley Lake in mid to late spring and left the lake by late summer and early fall. Fish migrated to the Copper River in the fall by traveling down Alaganik Slough through freshwater and estuarine waters and then to the Copper River by traveling through Pete Dahl Cutoff Slough or the Gulf of Alaska. Individuals tagged at Martin Lake also migrated out of the lake in the fall and traveled to the Copper River. Fish from both lakes traveled up the Copper River presumably to their spawning grounds. Nine tagged fish returned to McKinley Lake in 2007 and four tagged fish in 2008, indicating fidelity to the summer feeding site.

Introduction

Humpback whitefish are known to migrate extensively throughout lacustrine, riverine, estuarine, and marine environments in Alaska and Canada (Chang-Kue and Jessop 1992; Brown 2004; Brown 2006). Studies throughout Alaska and Canada have shown a high variation of habitat use and migratory behavior among and within populations, but many aspects of their life history are still largely unknown. Some individuals may use a number of habitats in a single year, while other individuals or year classes may only occupy a single habitat (Brown 2004; Brown 2006).

Generally, migration to lakes and ponds occurs in early spring, where whitefish spend the summer feeding (Bond and Erickson 1985; Brown 2006; Harper et al. 2007). Lakes are thought to be the main feeding areas for humpback whitefish during summer months (Bond and Erickson 1985; Brown 2006). Fidelity to summer feeding lakes is common (Brown 2006; Harper et al. 2007). Emigration from the lake occurs in midsummer to early fall, in order to reach spawning grounds by late fall (Alt 1979; Bond and Erickson 1985; Brown 2006). Overwintering habitats occur in estuaries, lakes, and lower rivers (Chang-Kue and Jessop 1992; Brown 2004; Brown et al. 2006). Rearing is thought to occur in rivers, lakes and ocean (Bond and Erickson 1985; Brown 2004; Brown et al. 2006).

Little information has been documented concerning the humpback whitefish population of the Copper River Delta (CRD). Alt (1979) sampled whitefish in the upper Copper River basin at

Slana River and Crosswind Lake, in an effort to describe the morphology, distribution, and habitat use of humpback whitefish throughout Alaska. He described their distribution to include Eyak Lake, which lies approximately 12 km west of McKinley Lake, in the town of Cordova, Alaska. In addition, local knowledge of humpback whitefish through subsistence harvest and sport fishing is limited.

To better manage and understand humpback whitefish, additional knowledge of their life history and migration is needed. A lack of basic life history information in addition to local requests for subsistence harvest permits for humpback whitefish at McKinley Lake initiated a U.S. Forest Service investigation. The objectives of this study were to (1) identify habitats used by humpback whitefish on the CRD and (2) determine the seasonal timing of migrations to habitats throughout the CRD.

Methods

Study Area

This study was conducted primarily at McKinley Lake with additional work conducted at Martin Lake. McKinley Lake is located on the West CRD, Alaska, 33 km east of the town of Cordova (Fig. 1). McKinley Lake has a surface area of approximately 87 ha. Maximum depth is 11 m, averaging 5.1 m. Lake substrate is predominantly silt, covered by a dense algal mat. Cobble and gravel occur along the shoreline and the outlet is primarily silt and sand. Aquatic vegetation consists primarily of *Potamogetan* sp., *Ranunculus* sp., and *Myriophyllum* sp., which densely colonize areas of depth < 3 m throughout the summer and fall.

Alaganik Slough drains McKinley Lake and changes considerably within the 21-km distance to the Gulf of Alaska (Fig. 1). Upper reaches of Alaganik Slough are more constrained, with channel widths of 10-20 m, and substrates composed mainly of sand and gravel. In lower reaches (4.5 to 21 km from the lake), the channel becomes wider (100 to1000 m), more braided, and substrates are composed primarily of silt, and sand. The lower 12 to14 km is tidally influenced. Water turbidity appears to be high due to glacial sediment inputs from Sheridan River, Salmon Creek, and the Copper River. Alaganik Slough is connected to a complex network of tributaries, tidal sloughs, lakes, and ponds throughout the west CRD.

Martin Lake is located on the East CRD, Alaska, 65 km from the town of Cordova (Fig. 1). It is one of the largest lakes on the Copper River Delta with a surface area of approximately 760 ha. The lake is situated in a long glacial valley and is relatively shallow with average depth of approximately 2 m. Dense blooms of aquatic vegetation grows throughout the lake and consists primarily of *Potamogetan sp., Ranunculus sp*., and *Myrophyllum sp.* The Martin River drains the lake and enters the Copper River roughly 18 km downstream. The mouth of Martin River is located 13 km to the Gulf of Alaska.

The roughly 500-km long Copper River drains more than 62,000 square km of the heavily glaciated Copper River basin. Because of the numerous glaciers in the basin, the river carries high suspended sediment loads. The lower 44 km of the river, below Miles Lake, is a large (3 to 14 km wide) braided alluvial floodplain, while the upper river (0.2- 7 km) has a higher gradient and is more constrained.

Sampling

At McKinley Lake, fish were captured using fyke nets, gill nets, and beach seines. Two, 15-m fyke nets were set at the McKinley Lake outlet in an upstream V-pattern, fishing from 1 June- 3 July 2007, 14 May - 18 July 2008, 18 May – 26 June 2009. Nets spanned roughly 50% of the width of the lake outlet and covered the primary channels. In addition, a 6.35-cm stretched mesh monofilament gill net (31 x 3.3 m) was deployed from a jet boat and soaked for 5 to 60 minutes on each of 21 days from 15 May- 14 July 2006 and 12 days from 17 June – 27 August 2008. The net was monitored constantly and whitefish were removed immediately after capture. Gill nets were deployed at depths varying from 3-8 m. Sampling occurred throughout the entire lake, but areas of high catch rates and shallow depths (3-5 m) were fished more often. Later in the summer (mid July) areas with high numbers of sockeye and coho salmon were avoided to minimize bycatch. Gill nets were set during the day, except for two night surveys on 14 July and 16 July 2008. Fish were also captured using a beach seine net (30 m x 4.8 m), which was deployed from a jet boat and pulled to shore by hand, on 5 days between 29 July and 6 August 2008. A variety of locations in the lake were targeted during each sample period. However, the northeast end of the lake was fished predominantly because of high catch rates of whitefish and ideal depths and shore for beach seining.

At Martin Lake fish were captured with a gill net using similar methods as described above. The net was fished on 1 June, 13 June, 14 June 2007 and 26 June, 1 July 2009. The narrow channel section of the lake, near the cabin was fished predominantly with additional sets in the main (eastern) side of the lake.

Tagging

At McKinley Lake, 76 humpback whitefish were tagged in 2006, 2007, 2008 and 2009 with six types of radio and acoustic transmitters (Table 1). At Martin Lake, 10 fish were tagged in 2007 and six fish were tagged in 2009 with radio and acoustic tags (Table 1). Fish were measured, weighed, and internally tagged with transmitters using a ≤ 3% tag to-body-weight rule and released back into the lake. Methods similar to Brown et al.'s (2002) whitefish surgical technique were used to implant transmitters. Surgical tools and transmitters were sterilized in a 70% ethanol solution before each surgery. Fish were anesthetized with a 20 mg/l buffered MS-222 (methane tricane sulfonate) or clove oil (isoeugenol) solution until the fish lost equilibrium and became docile. The fish was placed belly up in a V- shaped padded cradle and the gills bathed with water constantly during the procedure. Scales were removed from the incision area, and a small ventral incision (1.5-3 cm) was made parallel to the long axis, left of center, exposing the peritoneal cavity. For radio tags, a V-shaped groove director was inserted 14 cm into the body cavity parallel to the flesh. The sharp end of a 20-cm cannula was used to puncture the flesh 4-6 cm posterior of the pelvic fin. The cannula was inserted into the body cavity dull end first, using the groove director as a guide to protect organs and exit the body cavity through the initial incision. The radio antenna was threaded into the cannula and pulled through the anterior end. The cannula and groove director were removed and a tag was inserted into the peritoneal cavity. Additionally all fish were tagged with a passive integrated transponder (PIT tag) in order to identify individuals after the radio receiver batteries expired. Surgical staples (1-4 depending on the size of the incision) were used to close the incision and one drop of Vetbond was used to seal the incision and antenna wounds. Whip antennas were trimmed to approximately 20 cm. Surgery times took an average of 45 seconds. After surgery, fish were allowed to recover in a net pen set in 4-8°C flowing water until they regained equilibrium. Recovered fish were transported from the outlet approximately 100 m into the lake to avoid recapture. For acoustic tags, a similar yet simplified procedure was used, since transmitters had no external antenna. A small incision was made to expose the peritoneal cavity and the tag was inserted in the cavity and incision was closed with surgical staples and sealed with Vetbond.

A total of 92 fish were tagged over the course of four field seasons. Twenty nine fish were tagged in 2006 with MBFT-3A radio tags (Lotek, Newmarket, Ontario, Canada), which had a projected tag battery life of 553 days (Table 1 and Appendix A). All of these fish were captured with gill nets between 6 June and 30 June, 2006. In 2007, 20 whitefish (16 at McKinley Lake and 4 at Martin Lake) were surgically implanted with MCFT-3FM coded radio tags (Lotek, Newmarket, Ontario, Canada), which had a projected tag battery life of 472 days (Table 1 and Appendix A). In addition, one fish at McKinley Lake and six fish at Martin Lake were tagged with a MBFT-3A radio tag that were purchased in 2006; battery life was projected at 553 days in 2006, but probably decreased due to degradation. All tagged fish in 2007 at McKinley Lake were captured with fyke nets and all tagged fish at Martin Lake were captured with gill nets.

In 2008, 15 coded acoustic transmitters (V13-1L,Vemco, Halifax, Nova Scotia, Canada) were surgically implanted into fish at McKinley Lake. Five of the tags were equipped with pressure sensors (V13P-1L, Vemco, Halifax, Nova Scotia, Canada) to estimate fish depth (Table 1). In addition, eight fish were implanted with V7-2L coded transmitters (Vemco, Halifax, Nova Scotia, Canada) and six fish were implanted with V7-1L transmitters (Vemco, Halifax, Nova Scotia, Canada) (Table 1 and Appendix A). The projected battery life was 110 days and 240 days for the V7-1L and V7-2L tags respectively. However, these tags were 1 year old in 2008 and battery life was projected to be 55-75 days, owing to degradation.

In 2009, two acoustic transmitters (V9-2L, Vemco, Halifax, Nova Scotia, Canada) were implanted into fish at McKinley Lake and six acoustic transmitters of the same type were implanted into whitefish at Martin Lake (Table 1 and Appendix A). V9 acoustic transmitters had a projected battery life of approximately 224 days.

Biotelemetry

Tagged fish were located using fixed receiver stations and manual biotelemetry techniques from a boat and a fixed-wing aircraft. When tracking from a boat, fish were located within 10-20 m depending on the fish's depth. Manual radio tracking from a boat was carried out one to four times per month in McKinley Lake, Martin Lake and Alaganik Slough from May-October in all years. Aerial biotelemetry surveys were conducted in 2006 (23 September and 24 October, 2006), 2007 (21 September, 16 October, and 5 November, 2007), and 2008 (22 September, 25 September, 26 September, and 6 November). Survey dates were determined by weather conditions and aircraft availability. Surveys covered Alaganik Slough and the Copper River below Miles Lake (Fig. 1). Flight surveys were approximately two hours long. Fish were tracked within 1 km of their location. Flight time was used so as to cover more area and locate more tagged fish rather than increase the precision and accuracy of tag locations. In 2007, the 21 September and 16 October flights only scanned the high frequency tags (168.000 and 169.000) because antennas were not available for the low frequency (148.540) tags. Both frequencies were scanned on the 5 November 2006 survey. Tag signal range was approximately 5 km for high frequency tags and 3 km for low frequency coded radio tags estimated from stationary tags at known locations.

In 2007 and 2008, fixed receiver stations were used in addition to manual tracking to locate tagged fish. Fixed radio biotelemetry receiver stations were set-up in four locations on Alaganik Slough and the Copper River (Fig. 2 and Fig. 3). Fixed receiver stations had a four-element yagi antenna connected with a coaxial cable to a Lotek SRX 400 biotelemetry receiver (Newmarket, Ontario). A 12-volt battery attached to a solar panel powered the receiver. Receivers logged the date, time, and unique identification code of tagged fish as they passed the receiver station. In 2007, upper Alaganik receiver was deployed from 29 June to 20 November, 2007. Lower Alaganik-Pete Dahl Cuttoff Slough receiver was deployed from 19 July to 16 October 2007. The upper Alaganik receiver was deployed from 27 March to 17 October 2008. Receivers did not scan continuously for several one to seven day periods due to battery power issues. The lower Alaganik Slough receiver scanned from 26 May to 3 June and 29 July to 27 September 2008.

Acoustic tagged fish were detected in McKinley Lake, Alaganik Slough, Martin Lake, and Martin River with omnidirectional VR2 receiver-hydrophones (Vemco, Halifax, Nova Scotia, Canada) attached to anchors. Hydrophone-receivers logged the date, time and unique identification code of tagged fish leaving McKinley Lake from 29 July 2008 to 11 November, 2008 and 5 May to 5 August 2009. At Martin Lake hydrophone-receivers were deployed from 10 July to 7 October 2009.

Statistical Analysis

SAS statistical software, analysis of variation (ANOVA) approach was used to evaluate the differences in mean weight and lengths of sampled fish among seasons (2006, 2007, and 2008). A Tukey's test was used to statistically adjust P-values for multiple comparisons. Martin Lake data was excluded from this part of the analysis as a result of a small sample size (10 fish in 2007 and 6 fish in 2009). The 2009 McKinley Lake data was also excluded from this analysis due to a small sample size (2 fish).

Results

2006 Sampling

In 2006, 41 whitefish were sampled in McKinley Lake and 29 fish were tagged from 1 June to 30 June, 2006. The overall mean length of sampled fish was 369.7 mm (SE ± 3.6, range 302-407 mm) and mean weight was 728.3 g (SE ± 22.3, range 560 to 1100 g) (Fig. 4). Tagged fish mean length was 371.1 mm (SE ± 3.3, range 333 to 407) and mean weight was 761.6 g (SE ± 22.2, range 340 to 1100 g) (Appendix A). The ratio of tag weight to body weight was less than 3% (Appendix A). Fourteen tagged fish expelled their tags or perished.

No tags were detected in the lake after fall 2006. Fourteen fish migrated out of the lake by 29 August 2006 and one remaining fish migrated out of the lake by 23 October 2006. Exact dates of entering and exiting the lake are unknown, however, estimated residency times in McKinley Lake ranged from 29 days to 125 days (Table 2).

Aerial biotelemetry flights detected six fish outside of the lake throughout the fall. These fish were found in Alaganik Slough, Pete Dahl Cutoff Slough, and the Copper River (Fig.5). Two fish were detected multiple days in late October and the fish had moved approximately 9 km up the Copper River (Fig. 5). The remaining nine fish that had left the lake were not located in the fall surveys. No other tags were detected on the flights that covered Alaganik Slough and Copper River from Miles Lake to the mouth.

2007 Sampling

In 2007, 136 whitefish were sampled in McKinley Lake and 16 fish were radio tagged between 2 June and 15 June 2007. In June, 127 fish were sampled migrating into the lake including four that were tagged in 2006 (Fig. 6). The overall mean length of sampled fish was 309.6 mm (SE ± 5.6, range 141 to 414 mm) and mean weight was 383.7 g (SE ± 17.3, range 20 to 953 g) (Fig. 4). Mean tagged fish length was 374.3 mm (SE ± 4.3, range 346 to 414 mm) and mean weight was 611.3 g (SE ± 18.8, range 515 to 800 g). Tag ratio of body to tag weight did not exceed 3%. Two fish mortalities or expelled tags occurred.

Sampling with fyke nets in 2007 captured a wider range of size classes than sampling with gill nets in 2006 (Fig. 4). Mean lengths (Fig. 4A) were 60 mm greater and mean weights (Fig. 4B) were 344.6 g greater in 2007 compared to 2006 and these differences were significant (Tukey's test, $P < 0.001$).

Whitefish migrated into the lake steadily throughout June (Fig. 6). Counts peaked during the first two weeks of June and ended 29 June 2007 (Fig. 6). Since whitefish run timing was unknown, fyke nets were deployed late into the migration (1 June 2007), during peak counts (Fig. 6). Therefore our sampling effort may not have captured the beginning of the run.

All fish tagged in 2007 left the lake by early October. Tagged fish remained in the lake an average of 89.4 days (SE ± 8.46, range 36 to 133). Exact exit dates were not recorded for three 2007 tagged fish because fixed receivers could not detect high frequency tags, and two fish exited the lake prior to deployment of the fixed receiver station. Thus, the residency times for fish 35 and 36 were less than 23 days and were between 67 and 98 days for fish 30 (Table 2). Ten fish left the lake between the hours of 21:00 and 6:00, while two fish left during the day at approximately 12:00 and 16:30.

Not all fish made single directed movements out of the lake. Two fish returned to the lake after reaching lower Alaganik Slough roughly 20 km away. After returning to the lake, one fish returned to Alaganik Slough two days later and the other fish perished or expelled its tag at the lake.

Of the 15 fish tagged in 2006, nine fish returned to McKinley Lake in early June 2007. All of these fish left the lake by early October. The fixed radio receiver station was only compatible with low frequency, 2007 tags. Therefore, exact dates of entering and exiting the lake were unknown. Six fish left the lake between 21 August and 21 September 2007. Two fish left the lake before 25 June 2007 and another fish left the lake before 16 October 2007.

A number of tagged fish were tracked into upper and lower Alaganik Slough, Pete Dahl Cutoff Slough, and the Copper River throughout the summer and fall (Fig. 2). Ten fish were detected in upper Alaganik Slough from July to August 2007. Twenty fish were detected in lower Alaganik Slough and connecting Pete Dahl Cutoff Slough from July to October 2007.

Mean migration time from McKinley Lake to lower Alaganik Slough was 5.9 days (SE ± 3.3, n = 12) and ranged from 0.4 to 40.0 days. This estimate is based on 12 fish tagged with coded low frequency radio tags. The two fish that returned to McKinley Lake from lower Alaganik Slough took 0.4 and 2.3 days traveling upstream.

Mean residency time in Alaganik Slough was at least 12.7 days (SE ± 4.35, n = 12) and ranged from 0.61 to 43.9 days. These are minimum estimates since fish may have spent time in Alaganik Slough outside of the receiver detection range. Residency time in Alaganik Slough was at least 29.9 days for fish 35 and at least 38.4 days for fish 36. Detection times in lower Alaganik occurred throughout day and night (Fig. 7).

Only one fish was detected at the fixed receiver located on the Copper River (Fig. 2). Fish can use multiple channels within the 15-km wide lower Copper River but a receiver was only placed on one channel. One individual traveled from lower Alaganik Slough to the Copper River (over 18 km upstream from the mouth) in 6 days. The fish was detected in the Copper River throughout the night and day in early and late September. Manual tracking surveys were too infrequent to estimate other fish travel times between Alaganik Slough and the Copper River.

Twelve fish were detected in various locations in the Copper River from September through October (Fig. 2). Short range movements between surveys were difficult to detect unless it was beyond the estimated 1 km detection error. A fixed receiver set up on the Copper River below

Miles Lake, roughly 48 km from the mouth, did not detect any tagged whitefish moving past the receiver. The receiver was removed 11 October 2007, while it was still accessible. Aerial surveys indicated that fish were 30 km below this crossing in early November; therefore the fixed receiver may have been removed too early. No other tags were detected on the flights which covered Alaganik Slough and Copper River from Miles Lake to the mouth.

At Martin Lake 10 fish were tagged with radio tags. Fish length ranged from 366 to 488 mm and averaged 428.9 (SE ± 14.47). Fish weight ranged from 700 to 1650 g and averaged 1114 g (SE ± 110.89). Five of the ten fish tagged were detected outside of the lake in the fall (Fig.2). Three fish were detected in Martin River in October and two fish were detected in the Copper River in September and October (Fig. 2). Five fish remained in Martin Lake during the October surveys.

2008 Sampling

In 2008, 53 whitefish were sampled and 29 fish were tagged with acoustic transmitters between 1 June and 8 August 2008. Mean overall length of sampled fish was 344.8 mm (SE ± 6.6, range 250 to 433 mm) and mean weight was 579.3 g (SE ± 32.0, range 222.4 to 1096.4 g) (Fig. 4). Sampled fish size in 2008, significantly differed from fish sampled from 2006 and 2007 (Fig. 4A and 4B). Mean lengths (Fig. 4A) and weights (Fig. 4B) of 2008 samples were 24.8 mm and 149.0 g lower than 2006 samples (Tukey's test, $P < 0.001$). Mean lengths of 2008 samples not significantly different than 2007 samples (adjusted $P = 0.105$) (Fig. 4A). Mean weights were 195.7 g larger than 2007 samples and this difference was significant (Tukey's test, $P = 0.001$) (Fig. 4B). Mean length of tagged fish was 334.5 mm (250 to 430 mm) and mean weight was 561.5 g (range 222.4 to 1027 g) (Appendix A). Tag weight to body weight did not exceed 3%. Three tags showed little movement within a month after tagging, indicating mortality or expelled tags. One fish disappeared from detection range shortly after tagging, suggesting mortality or exit from the lake.

Fourteen whitefish were captured in the fyke net moving into the lake from 14 May to 18 July 2008. The capture success and/or run size was considerably lower than what was observed in 2007, despite fishing the nets two weeks earlier and nearly three weeks later (Fig. 6). Gill netting and biotelemetry surveys confirmed that fish were entering the lake, but were not captured by the fyke nets at the outlet. A series of high water events in early June may have enabled whitefish to swim around the nets.

In 2008, four of the 16 fish tagged in 2007 returned to the lake. Another 2007 tagged fish (tag 13) traveled within 0.5 km of the lake, but perished as a result of predation. Fish tagged in 2007 returned to the lake an average of 35.8 days later (SE ± 8.1, range 23 to 57 days, n = 4) than their capture date at the lake outlet in 2007. No fish tagged in 2006 returned to the lake.

The lower Alaganik Slough fixed radio receiver detected four 2007 tags all within a nine-day period in late May to early June 2008 (Fig. 3). Fish 32 and fish 43 moved upstream to McKinley Lake in 16 days and 48 days, respectively. Fish 42 moved within 0.5 km of the lake within 30 days. Fish 32 returned back to the lower receiver within one day of leaving the lake. Precise dates of entering and exiting the lake were not recorded for all 2007 tags as a result of receiver incompatibility with high frequency tags and battery issues. Residency time in the lake was between 11 and 44 days for 2007 tagged fish (Table 2).

Of the 29 fish tagged in 2008, 11 fish left the lake between 29 July and 25 August 2008. This was a few weeks earlier than the date fish exited in 2007. Five of the 11 fish, left the lake within a 24-h period between 19 August and 20 August 2008. Eight of the 12 fish left the lake during night time hours 2200 to 0300. The other two fish left the lake at 0600, 1745 and 1930. Fish 32 left the lake at approximately 0100. Mean residency of the 2008 tagged fish was at least 14 days (SE ± 1.83, n = 11) and ranged from 3 to 21 days (Table 2). This is a minimum estimate since date of entrance into the lake was unknown. The remaining 14 fish were tagged with smaller V7 tags with shorter battery lives and were not detected leaving the lake. Nine of these tags were not detected after July. The remaining five tags were last detected into August (1 tag) and September (4 tags). No V7 tags were detected in Alaganik Slough. Due to the short tag battery life it was not possible to conclude that the fish remained in the lake.

Residency time in Alaganik Slough was unknown since only one receiver was deployed in upper Alaganik. One fish (54), was detected moving back and forth between the lake and Alaganik Slough seven times between 18 August and 5 September, 2008. Two other fish (55 and 52) spent two and three days respectively, around upper Alaganik Slough receiver (Fig. 3).

Fall aerial biotelemetry surveys detected four fish tagged in 2006 and 2007 in the Copper River in late September (Fig. 3). Fish 30 was manually tracked from a boat on the Copper River and where it was found holding in a pool on the west fork of the Copper River. No other tags were detected on the flights which covered Alaganik Slough and Copper River from Miles Lake to the mouth. An additional flight in November covering the Copper River from Miles Lake to Chitina (171 km upstream) detected no tagged fish in the upper river. Fish holding or traveling through the Gulf of Alaska may not be detected by aerial surveys since radio waves are highly absorbed by salt water.

2009 Sampling

Two fish were sampled at McKinley Lake at the lake outlet in early June (5 June and 9 June 2009). The fish were 447 mm and 382 mm in length and 800 g and 700 g in weight respectively. Both fish left the lake and were detected in the Alaganik Slough in August (5 August and 10 August 2009). At Martin Lake six fish were tagged and length ranged from 387 to 416 mm, and averaged 390.2 mm (SE ± 7.32). Fish weight ranged from 727 to 982.6 g and averaged 808.3 g (SE ± 53.70). One fish was detected outside of the lake in the Martin River below the lake outlet on 5 September and again in the lower Martin River near the Copper River on 6 September, 2009. All other fish remained in the lake when the receivers were removed on 7 October, 2009.

A seasonal migration was observed of tagged humpback whitefish between McKinley Lake and the Copper River in 2006, 2007, 2008, and 2009. Most whitefish moved into McKinley Lake in the spring and early summer and remained in the lake throughout the summer. In late summer and early fall, fish moved out of the lake and down Alaganik Slough towards the Gulf of Alaska. Some fish remained in Alaganik Slough for up to six weeks. Several fish moved back and forth between Alaganik Slough and McKinley Lake. During midsummer, fish may access the Copper River by traveling through Pete Dahl Cutoff Slough near the mouth of Alaganik Slough. Tagged fish were detected in Pete Dahl Cutoff Slough near Alaganik Slough in 2006 and 2007 during September and October surveys. However, aerial surveys from 2006-2008 found that Pete Dahl Cutoff Slough dried up in several places by late August; making this route to the Copper River inaccessible in the fall. The Gulf of Alaska was the only other accessible route between Alaganik Slough and the Copper River during fall. No fish were detected in the Gulf of Alaska, which was expected given the high absorption of radio waves in salt water, however fish were detected near the Gulf of Alaska in lower Copper River in 2007 (Fig. 2) and lower Alaganik in 2006 (Fig. 5). Whitefish were detected on both the east and west forks of the lower Copper River, indicating that multiple channels were used to access the upper river. Tagged fish traveled up the Copper River toward unknown spawning site locations. The furthest upstream point that tagged fish were detected was approximately 29 km upstream of the mouth in the west channel.

A fall migration was also observed in some individuals tagged at Martin Lake. Whitefish migrated out of the lake in the fall and moved down the Martin River. Some fish moved into the Copper River. Seasonal operating hours of airplane contractors and poor weather conditions prevented any surveys beyond early November to assess the extent of the fall migration for McKinley Lake or Martin Lake humpback whitefish.

Discussion

The migratory behavior exhibited by the McKinley Lake humpback whitefish population was consistent with observations of other populations in Alaska and Canada, where lakes are occupied during summer months followed by a fall migration to spawning grounds (Chang-Kue and Jessop 1992; Brown 2006; Harper et al. 2007). Although the upstream extent of the migration was not located, it is possible that they travel a great distance up the Copper River and connecting tributaries. Brown et al. (2007) found evidence of whitefish migrations to marine environments of up to 1700 km away from the sample site in the Yukon drainage, and Harper et al. (2007) reported spawning migrations of up to 670 km on the Kuskokwim River. Studies in Alaska have documented humpback whitefish spawning to occur in September and October (Alt 1979; Brown 2006; Harper et al. 2007). Aerial tracking surveys indicated that tagged fish were still moving up the Copper River in early November suggesting that spawning occurs in November or later.

Aerial biotelemetry surveys indicated that fish tagged at McKinley Lake travel through the Gulf of Alaska in order to enter the Copper River in the fall. Due to the high absorption of radio waves in salt water, this could not be verified with biotelemetry. Aerial surveys in 2007 detected fish in the lower Copper River channel, indicating entrance from the Gulf of Alaska (Fig. 2). Migration routes may change over time as a result of the dynamic nature of the Copper River and Alaganik Slough. Predominant flows shift between channels regularly in the heavily-braided lower Copper River. Over time, Copper River flows may shift westward and increase water volume in tributaries between Alaganik Slough and the Copper River. If this were to occur, a fall migration corridor may be available between McKinley Lake and the Copper River.

Fidelity to lakes during summer months, as found in the McKinley Lake population, has been documented in other humpback whitefish populations in Alaska (Brown 2006; Harper et al. 2007). Site fidelity can be exhibited when high quality habitat is available (Switzer 1995). Therefore, humpback whitefish may return to McKinley Lake annually to use optimal foraging habitats for benthic invertebrate resources, which may be more abundant at the lake compared to other areas in the CRD. In addition, humpback whitefish seek out McKinley Lake from a separate basin (Copper River) also suggesting that the lake provides abundant resources or other selective advantages. It is unclear how young whitefish initially find McKinley Lake assuming larvae hatch in the Copper River basin. The spring run of humpback whitefish observed in 2007, suggests that fish migrate in groups and young fish (age 2 and 3) may find summer feeding lakes by following older individuals that are returning to lake habitats occupied in previous years.

Whitefish tended to migrate out of McKinley Lake during the night time. This was also observed in McKenzie River, Canada whitefish populations where fish moved between the hours of 1700 and 0600 (Bond and Erickson 1985). Night-time may be the best hours to enter the shallower, less-protected habitats of upper Alaganik Slough in order to decrease predation risks. However, the same pattern was not observed in lower Alaganik Slough, where fish were detected throughout the day and night time. High turbidity levels of lower Alaganik Slough may provide more cover than the clearer upper reaches.

Overwintering

There was no evidence based on biotelemetry results that overwintering occurs in McKinley Lake. Local residents have reported catching whitefish with gillnets in McKinley Lake under the ice during winter months, however, the lake was not sampled during winter. Spring sampling and biotelemetry results indicate that whitefish leave the lake in the fall and return in the spring. All tagged fish with extended battery lives, left the lake by late fall. In the spring, tagged fish were detected in lower Alaganik Slough before entering McKinley Lake, indicating an upstream migration to the lake. In addition, a large run of whitefish was sampled while entering the lake in June of 2007, suggesting that winter and early spring months were spent elsewhere. Since tagged fish were generally larger size classes, It was unconfirmed whether younger size classes overwinter in the lake. Surveys at Martin Lake also could not confirm overwintering in the lake.

Overwintering in other Alaska and Canada humpback whitefish populations occur in freshwater and marine habitats. In Canada, McKenzie River stocks were reported to overwinter in the lower river and the estuary (Bond and Erickson 1985; Chang-Kue and Jessop 1992). In Alaska, Alt (1979) reported Kobuk River stocks overwinter in the estuary and lower river habitats. Similarly, Brown (2006) reported upper Tanana River stocks overwintered primarily in lower river reaches and to a lesser extent in lakes. It is possible that individuals from the McKinley Lake population occupy both marine and freshwater overwintering habitats, and this may also change from year to year. An aerial biotelemetry survey was conducted in late January 2007 that covered the majority of the Copper River and tributaries; however no tagged fish were detected. This survey indicates that whitefish overwinter in lower Alaganik Slough, Gulf of Alaska or another connecting tributary not covered by the survey.

Larval Rearing

Larval rearing areas on the Copper River remain mostly unknown. Smaller size classes captured with fyke nets at the lake outlet in 2007 were possibly immature fish (Fig. 4). Other studies have estimated the minimum length of maturity to be between 328 to 350 mm (Fleming 1996; Chang-Kue and Jessup 1992; Bond and Erickson 1985). Using a conservative estimate of minimum length of maturity of 300 mm for 2007 samples, 43 possibly immature fish entered the lake in the spring. Therefore, rearing of young whitefish may occur in McKinley Lake during summer months. These fish were too small to tag to determine whether fish remained in the lake throughout the winter.

Summary of Findings

The results of this study provide the first documentation of the migratory behavior and seasonal habitat use of humpback whitefish on the CRD. Humpback whitefish demonstrated the use of a wide range of diverse habitats available on the CRD including lakes, rivers, sloughs, estuary, and possibly the Gulf of Alaska. Migrations between these habitats occur seasonally and are repeated by some individuals annually. Lakes are occupied during the summer months, and fidelity to these sites was demonstrated by some individuals. This study also suggests that rearing and spawning occurs in separate basins. Overwintering, rearing of immature fish, and spawning areas still remain unknown and warrant further investigation.

Figures

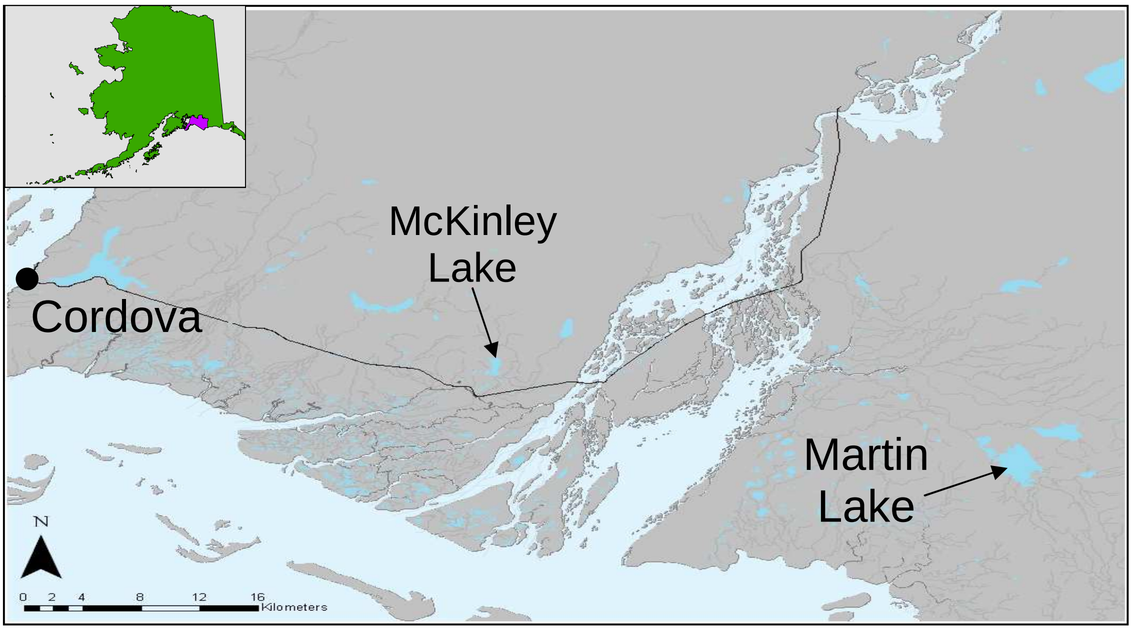

Fig. 1. Location of Martin lake and McKinley Lake on the Copper River Delta, Alaska (USA).

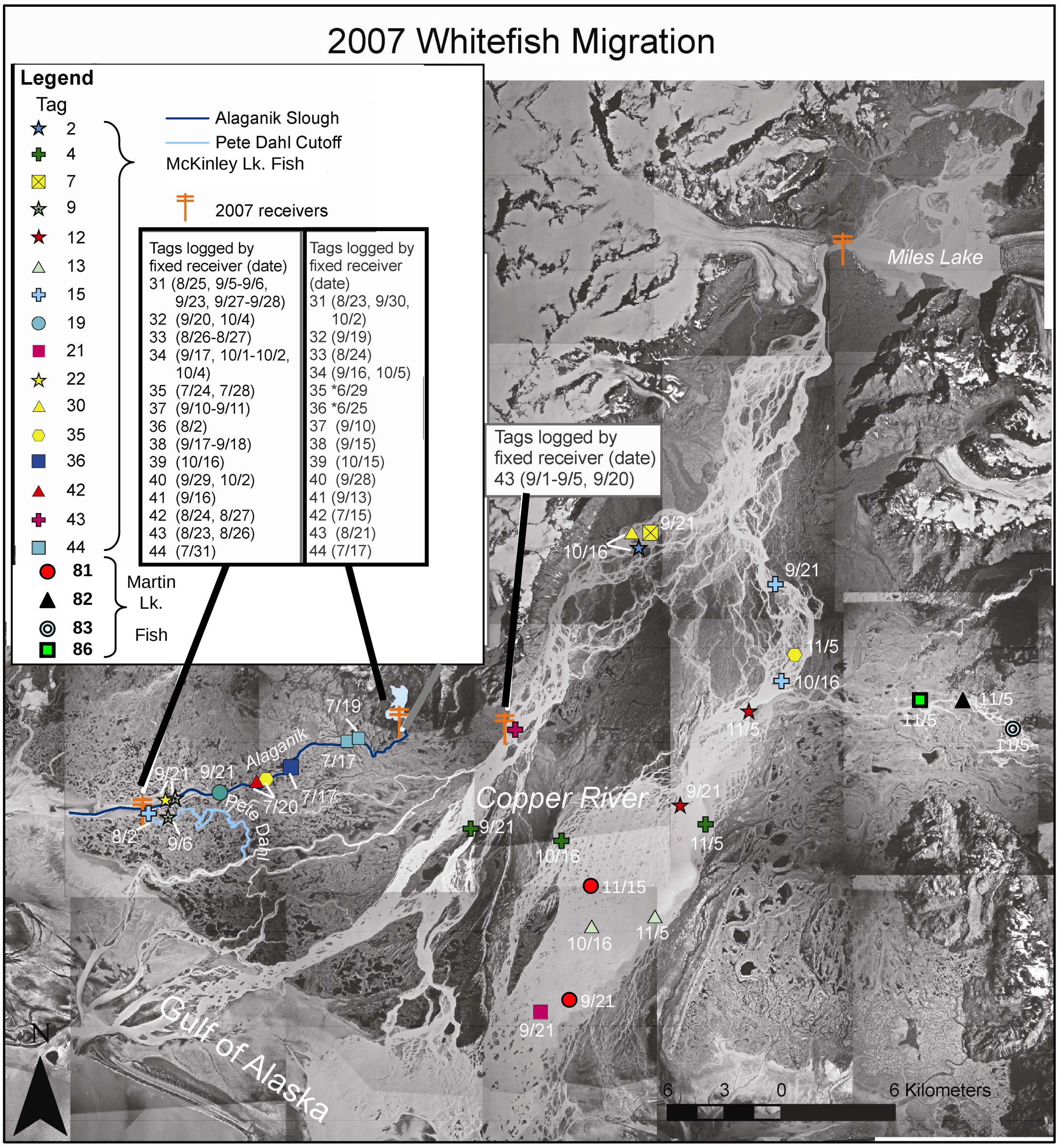

Fig. 2. Locations and date of detection of tagged humpback whitefish of McKinley Lake and Martin Lake on the Copper River Delta, Alaska in 2007. Radio tagged whitefish were detected by fixed receivers, aerial, and boat telemetry surveys. Each tag is represented by a unique symbol on the map and the date of detection is included in parenthesis next to the tag symbol. Detection error was approximately 1 km for aerial telemetry surveys. Boxes associated with fixed receiver stations include the fish tag number and date the fish was logged by the receiver in 2007.

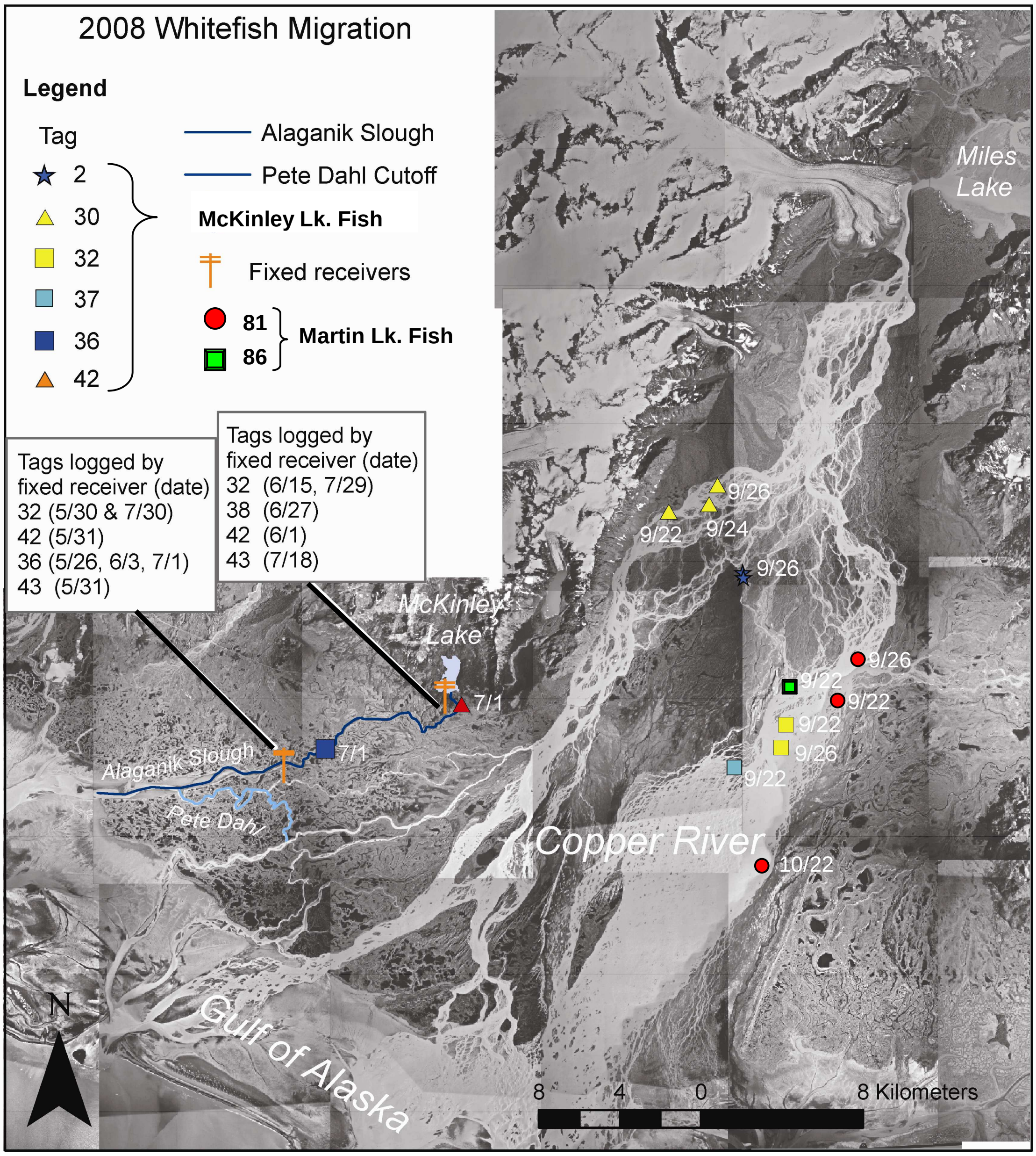

Fig. 3. Locations and date of detection of tagged humpback whitefish of McKinley Lake on the Copper River Delta, Alaska in 2008. Radio tagged whitefish were detected by fixed receivers, aerial, and boat telemetry surveys. Each tag is represented by a unique symbol on the map and the date of detection is included in parenthesis next to the tag symbol. Detection error was approximately 1 km for aerial telemetry surveys. Boxes associated with fixed receiver stations include the fish tag number and date the fish was logged by the receiver in 2008.

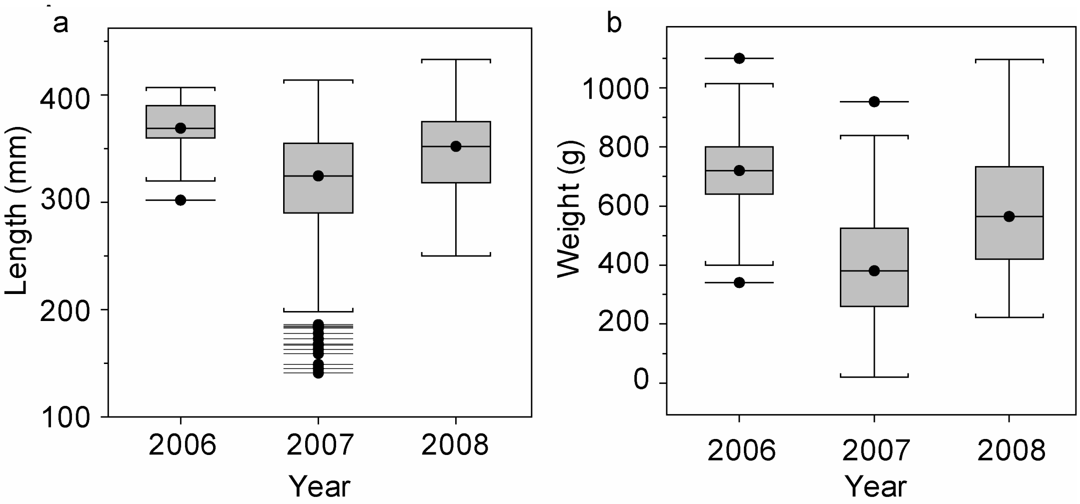

Fig. 4. Box plots of (a) length (mm) and (b) weight (g) of humpback whitefish captured at McKinley Lake, Alaska in 2006-2008. The horizontal lines forming the box represent the 25th (lower line), 50th (median, middle line and dot) and 75th (upper line) percentile of the distribution of weight and length data. The lower vertical lines represent the smallest observations and the upper vertical lines. The dots represent extreme observations. The overall plot dimensions represent the spread of the data.

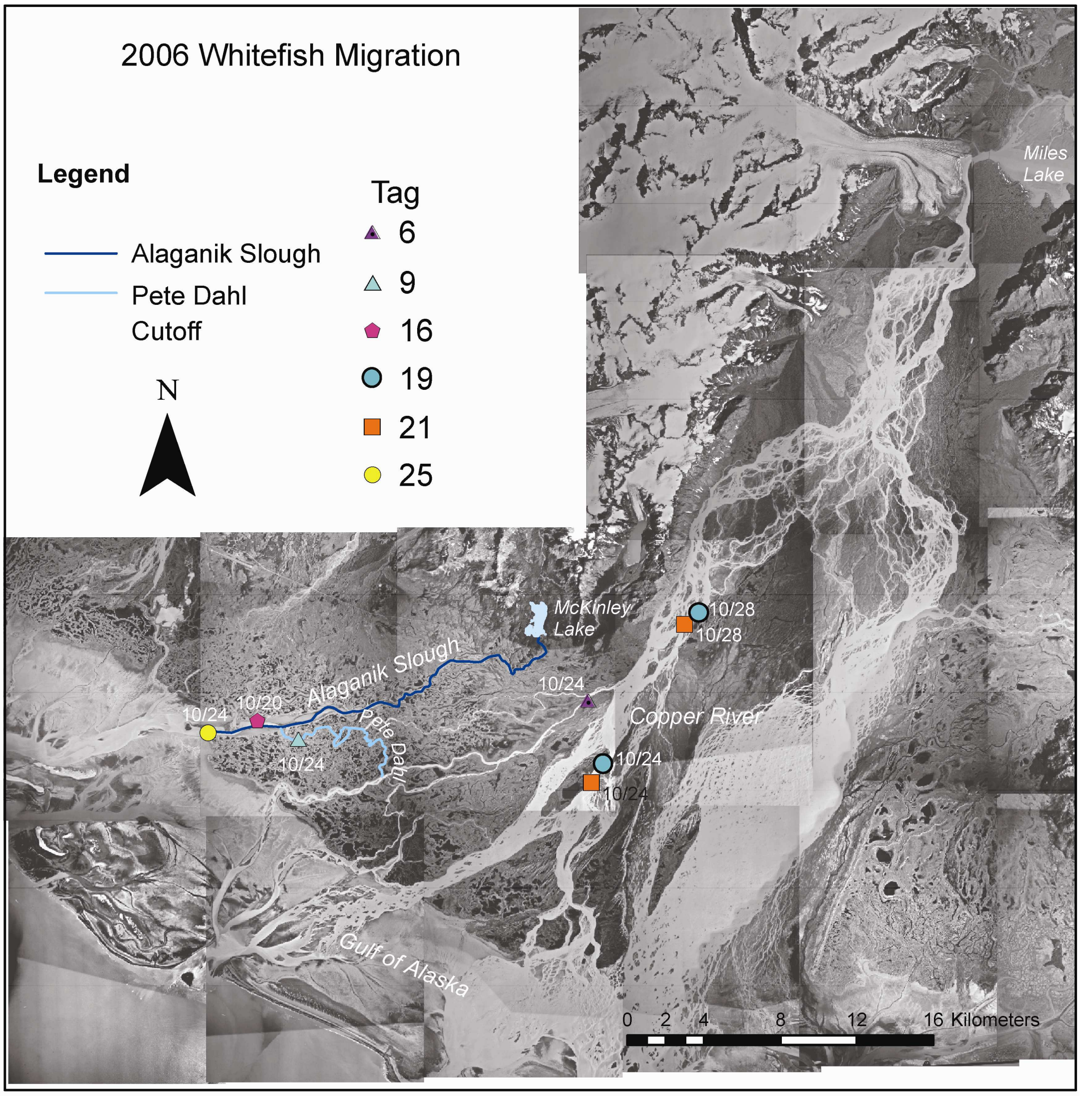

Fig. 5. Locations and date of detection of tagged humpback whitefish of McKinley Lake on the Copper River Delta, Alaska in 2006. Radio tagged whitefish were detected by fixed receivers, aerial, and boat telemetry surveys. Each tag is represented by a unique symbol on the map and the date of detection is included in parenthesis next to the tag symbol. Detection error was approximately 1 km for aerial telemetry surveys. Boxes associated with fixed receiver stations include the fish tag number and date the fish was logged by the receiver in 2006.

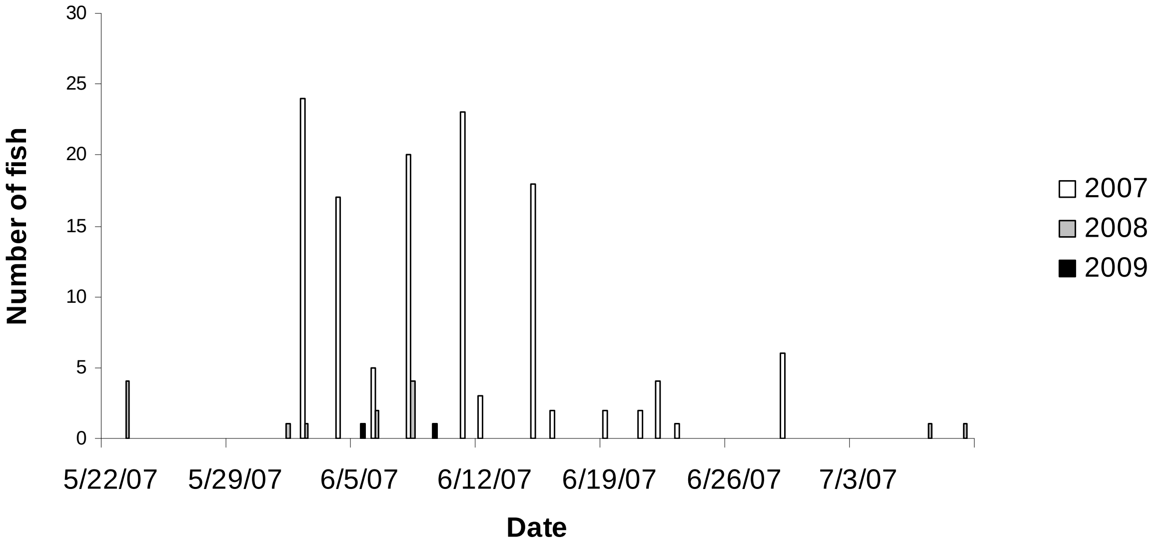

Fig. 6. Number of humpback whitefish captured with fyke nets at the outlet of McKinley Lake, Alaska in the spring of 2007 and 2008.

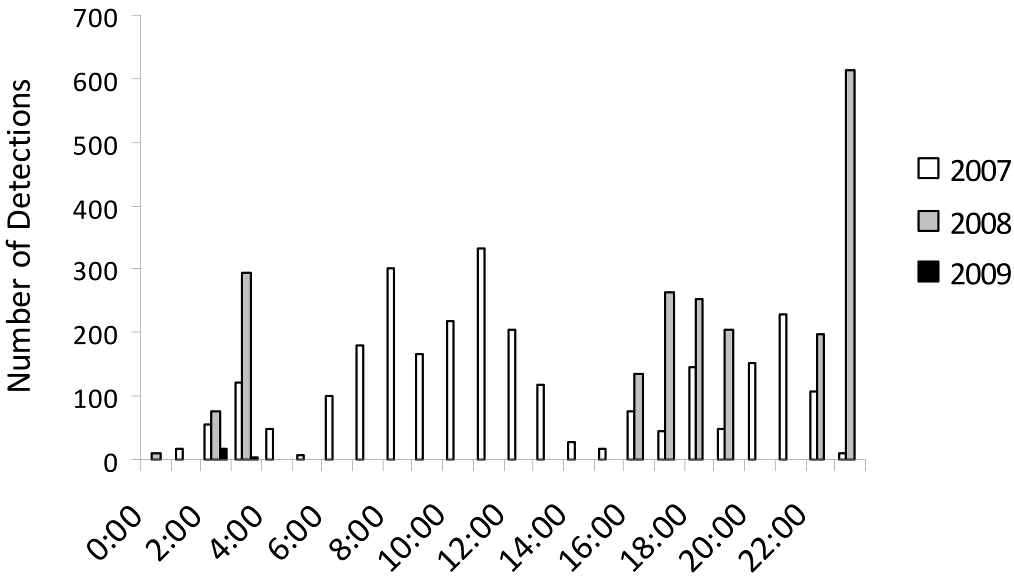

Fig. 7. Detection times of tagged humpback whitefish in lower Alaganik Slough, Alaska in 2007 and 2008.

Tables

Table 1. Specifications of acoustic and radio tags surgically implanted into humpback whitefish in McKinley Lake, Alaska. Dimensions represent the length and width of cylindrical shaped tags. Battery life estimates were based on the manufacturer's warranty battery life with exception of estimates with asterisk.

Tag type (frequency)	# tags	Water weight (g)	Dimensions (mm)	Acoustic power (dB at 1 m)	Burst rate (sec.)	Battery life (days)
Lotek: MCFT-3FM (Radio: 148.540)	19	4.6	11 x 59	N/A	5.0	472
Lotek: MBFT-3A (Radio: 168.xxx, 169.xxx)	36	6.7	16 x 46	N/A	5.0	553
Vemco: V7-2L (Acoustic: R64KHz)	8	0.75	7 x 20	136	150-300 (avg = 225)	*55-75
Vemco: V7-1L (Acoustic: R64KHz)	6	0.7	7 x 18	136	150-300 (avg = 25)	*55-75
Vemco: V13-1L (Acoustic: 64KHz)	10	6.0	36 x 13	147	30-90 (avg = 60)	625
Vemco: V13P-1L (Acoustic: 64KHz)	5	6.0	44 x13	150	30-90 (avg = 60)	525
Vemco: V9-2L (Acoustic: 69 KHz)	2	2.9	30 x 9	142	30-90 (avg = 60)	224

*Tags were a year old and batteries had degraded over that period. Number represents estimated battery life.

Table 2. Residency times of humpback whitefish in McKinley Lake, Alaska, from 2006-2008. Exact dates of entering and exiting the lake were not recorded for all fish. For 2006 tags, a maximum estimate is given. For 2007 and 2008, a range is given for fish when exact times were not recorded.

	Residency time (days)				Residency time (days)			
Tag	2006	2007	2008	Tag	2006	2007	2008	2009
2	77	-	-	36	-	< 23	-	-
3	77	-	-	37	-	98	-	-
4	77	76-107	-	38	-	104	32-40	-
6	75	-	-	39	-	133	-	-
7	75	1-4	-	43	-	74	11-19	-
8	75	70-101	-	40	-	114	-	-
9	75	-	-	41	-	97	-	-
12	125	-	-	42	-	37		-
13	70	102-127	-	44	-	36		-
14	29	-	-	47	-	-	15	-
15	63	80-111	-	49	-	-	21	-
19	63	76-107	-	50	-	-	15	-
20	29	-	-	51	-	-	16	-
21	63	71-102	-	52	-	-	20	-
22	27	76-115	-	53	-	-	4	-
25	27	1-19	-	54	-	-	3	-
30	-	67-98	12-38	55	-	-	17	-
31	-	82	-	57	-	-	20	-
32	-	109	44	59	-	-	11	-
33	-	83	-	60	-	-	12	-
34	-	106	-	75	-	-	-	61
35	-	< 23	-	76	-	-	-	62

Appendix. A. Date of capture, tagged fish length (mm), weight (g), tag type, and lake caught at.

Date	Tag I.D.	Length	Weight	Tag Type	Lake
6/6/2006	1	380	700	MBFT-3A (Radio)	McKinley
6/13/2006	2	364	740	MBFT-3A (Radio)	McKinley
6/13/2006	3	369	780	MBFT-3A (Radio)	McKinley
6/13/2006	4	381	780	MBFT-3A (Radio)	McKinley
6/15/2006	5	364	740	MBFT-3A (Radio)	McKinley
6/15/2006	6	375	800	MBFT-3A (Radio)	McKinley
6/15/2006	7	390	720	MBFT-3A (Radio)	McKinley
6/15/2006	8	365	600	MBFT-3A (Radio)	McKinley
6/15/2006	9	400	1015	MBFT-3A (Radio)	McKinley
6/15/2006	10	375	800	MBFT-3A (Radio)	McKinley
6/15/2006	11	355	680	MBFT-3A (Radio)	McKinley
6/20/2006	12	333	560	MBFT-3A (Radio)	McKinley
6/20/2006	13	374	790	MBFT-3A (Radio)	McKinley
6/27/2006	14	347	640	MBFT-3A (Radio)	McKinley
6/27/2006	15	407	900	MBFT-3A (Radio)	McKinley
6/27/2006	16	360	720	MBFT-3A (Radio)	McKinley
6/27/2006	17	364	710	MBFT-3A (Radio)	McKinley
6/27/2006	18	390	900	MBFT-3A (Radio)	McKinley
6/27/2006	19	390	920	MBFT-3A (Radio)	McKinley
6/27/2006	20	365	680	MBFT-3A (Radio)	McKinley
6/27/2006	21	367	740	MBFT-3A (Radio)	McKinley
6/29/2006	22	394	840	MBFT-3A (Radio)	McKinley
6/29/2006	23	385	820	MBFT-3A (Radio)	McKinley
6/29/2006	24	342	640	MBFT-3A (Radio)	McKinley
6/29/2006	25	366	700	MBFT-3A (Radio)	McKinley
6/30/2006	26	346	640	MBFT-3A (Radio)	McKinley
6/30/2006	27	355	740	MBFT-3A (Radio)	McKinley
6/30/2006	28	368	690	MBFT-3A (Radio)	McKinley
6/30/2006	29	392	1100	MBFT-3A (Radio)	McKinley
6/15/2007	30	414	740	MBFT-3A (Radio)	McKinley
6/2/2007	31	378	600	MCFT-3FM (Radio)	McKinley
6/2/2007	32	346	580	MCFT-3FM (Radio)	McKinley
6/2/2007	33	364	600	MCFT-3FM (Radio)	McKinley
6/2/2007	34	362	560	MCFT-3FM (Radio)	McKinley
6/2/2007	35	362	590	MCFT-3FM (Radio)	McKinley
6/2/2007	36	365	515	MCFT-3FM (Radio)	McKinley
6/4/2007	37	365	525	MCFT-3FM (Radio)	McKinley
6/4/2007	38	365	580	MCFT-3FM (Radio)	McKinley
6/4/2007	39	366	540	MCFT-3FM (Radio)	McKinley
6/6/2007	40	375	660	MCFT-3FM (Radio)	McKinley
6/8/2007	41	381	580	MCFT-3FM (Radio)	McKinley
6/8/2007	42	393	640	MCFT-3FM (Radio)	McKinley
6/8/2007	43	378	620	MCFT-3FM (Radio)	McKinley
6/11/2007	44	405	800	MCFT-3FM (Radio)	McKinley
6/11/2007	45	370	650	MCFT-3FM (Radio)	McKinley
7/7/2008	46	430	1027	V13 (Acoustic)	McKinley
7/14/2008	47	389	1005.9	V13 (Acoustic)	McKinley
7/14/2008	48	366	785.9	V13 (Acoustic)	McKinley
7/29/2008	49	350	566	V13 (Acoustic)	McKinley

Appendix A (Cont'd). Date of capture, tagged fish length (mm), weight (g), tag type, and lake caught at

Date	Tag I.D.	Length	Weight	Tag Type	Lake
7/29/2008	50	375	695.2	V13 (Acoustic)	McKinley
7/29/2008	51	372	806.6	V13 (Acoustic)	McKinley
7/30/2008	52	354	656.6	V13 (Acoustic)	McKinley
8/5/2008	53	325	434.2	V13 (Acoustic)	McKinley
8/5/2008	54	327	475.2	V13 (Acoustic)	McKinley
8/8/2008	55	388	853.2	V13 (Acoustic)	McKinley
6/8/2008	56	405	820	V13P (Acoustic)	McKinley
7/30/2008	57	375	856	V13P (Acoustic)	McKinley
8/5/2008	58	353	663.7	V13P (Acoustic)	McKinley
8/8/2008	59	392	892.8	V13P (Acoustic)	McKinley
8/8/2008	60	376	779.9	V13P (Acoustic)	McKinley
6/1/2008	61	360	564	V7-1L (Acoustic)	McKinley
6/6/2008	62	283	232	V7-1L (Acoustic)	McKinley
6/6/2008	63	333	419.9	V7-1L (Acoustic)	McKinley
6/8/2008	64	351	454	V7-1L (Acoustic)	McKinley
7/17/2008	65	255	225	V7-1L (Acoustic)	McKinley
7/29/2008	66	301	375.2	V7-1L (Acoustic)	McKinley
7/14/2008	67	345	613	V7-2L (Acoustic)	McKinley
7/14/2008	68	312	500.3	V7-2L (Acoustic)	McKinley
7/17/2008	69	264	276.2	V7-2L (Acoustic)	McKinley
7/17/2008	70	252	246.2	V7-2L (Acoustic)	McKinley
7/17/2008	71	250	222.4	V7-2L (Acoustic)	McKinley
7/17/2008	72	278	318.4	V7-2L (Acoustic)	McKinley
7/17/2008	73	264	251.4	V7-2L (Acoustic)	McKinley
7/17/2008	74	275	267.3	V7-2L (Acoustic)	McKinley
6/5/2009	75	447	800	V9-2L (Acoustic)	McKinley
6/9/2009	76	382	700	V9-2L (Acoustic)	McKinley
6/1/07	77	366	700	MCFT-3FM (Radio)	Martin
6/1/07	78	470	1650	MCFT-3FM (Radio)	Martin
6/1/07	79	460	1250	MCFT-3FM (Radio)	Martin
6/13/07	80	456	1150	MCFT-3FM (Radio)	Martin
6/14/07	81	417	1100	MBFT-3A (Radio)	Martin
6/13/07	82	369	710	MBFT-3A (Radio)	Martin
6/13/07	83	398	910	MBFT-3A (Radio)	Martin
6/13/07	84	488	1300	MBFT-3A (Radio)	Martin
6/13/07	85	473	1620	MBFT-3A (Radio)	Martin
6/13/07	86	392	750	MBFT-3A (Radio)	Martin
6/26/2009	87	387	727	V9-2L (Acoustic)	Martin
6/26/2009	88	392	804	V9-2L (Acoustic)	Martin
7/1/2009	89	416	953.4	V9-2L (Acoustic)	Martin
7/1/2009	90	372	668.1	V9-2L (Acoustic)	Martin
7/1/2009	91	370	714.5	V9-2L (Acoustic)	Martin
7/10/2009	92	404	982.6	V9-2L (Acoustic)	Martin

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