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Spawning and Seasonal Distribution of Adult Steelhead in the Kasilof River Watershed, Alaska, 2007 and 2008

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Kenneth S. Gates

Abstract

Radio telemetry was used to monitor the movements of 79 adult steelhead *Oncorhynchus mykiss* in the Kasilof River watershed from October 2007 to June 2008. Steelhead were radio-tagged between river kilometer 10 and 24 and tracked throughout the watershed using fixed receiver stations, boats, and fixed-wing aircraft. Sixty-eight percent (*N*=54) of the radio-tagged steelhead spawned in tributaries or the mainstem Kasilof River. Tributaries selected by radio-tagged steelhead included Coal, Crooked, Nikolai, and Indian creeks. The remaining 25 radio-tagged steelhead were classified as "Dead/Expelled" (*N*=14), "Back-out" (*N*=6), or "Non-spawner" (*N*=5). The seasonal distribution and movements of radio-tagged steelhead were described by dividing the watershed into five regions: the estuary, river, outlet, lake, and tributaries. Distribution varied as fish moved among regions throughout the study period. The majority (60%) of the radio-tagged steelhead remained in the river throughout the fall before dispersing to their overwintering areas. Seventy percent of all active radio-tagged steelhead utilized the lake and outlet regions during the winter months. Regions used as migration corridors increased in importance by April as fish began to move to their respective spawning locations. Movements of radio-tagged steelhead continued to increase throughout the spring as spawning commenced and steelhead kelts began to migrate back to saltwater. Movement among regions was highest during May and June but was observed during all months.

Introduction

Crooked and Nikolai creeks are the only two tributary streams in the Kasilof River watershed that support steelhead *Oncorhynchus mykiss* according to the Anadromous Waters Catalog (Johnson and Daigneault 2008). Crooked Creek historically supported a small wild run of steelhead estimated to consist of a maximum of several hundred fish (Gamblin et al. 2004). The Alaska Department of Fish and Game (Department) enhanced this run beginning in the 1980s to provide additional angling opportunity. Enhancement efforts created a fishery unique from other steelhead fisheries on the Kenai Peninsula because it provided anglers an opportunity to harvest fish. Sport catches of steelhead in the Kasilof River and Crooked Creek peaked during the mid-1990s and averaged 5,836 fish between 1993 and 1995 (Mills 1994; Howe et al. 1995, 1996). During the same period, harvest of steelhead averaged 1,397 fish annually and catch was a direct result of the enhancement program. The enhancement program was terminated in 1993 after concerns were raised about straying of hatchery steelhead into the Kenai River. Since termination of the enhancement program, catch has declined and has averaged 579 fish between 1997 and 2004 (Gamblin et al. 2004; Larry Marsh, Alaska Department of Fish and Game, personal communication). Anticipating a

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decline in the number of steelhead available to anglers, the Alaska Board of Fisheries restricted the fishery within Crooked Creek and the Kasilof River below the Sterling Highway Bridge to catch-and-release beginning in 1996.

Current fishery regulations limit fishing in Crooked Creek from August 1 through December 31, and only unbaited, single hook, artificial lures may be used between September 15 and December 31. In addition, no retention of rainbow or steelhead is allowed from Crooked Creek. Regulations pertaining to the Kasilof River from September 1 through May 15 allow fishing with one unbaited, single hook, artificial lure from the mouth to the Sterling Highway Bridge. In this same section of river from May 16 through June 30, only one single hook may be used. Like Crooked Creek, no retention of rainbow or steelhead is allowed in the Kasilof River below the Sterling Highway Bridge. Fishing above the Sterling Highway Bridge and in Nikolai Creek is open year-round for rainbow and steelhead, with a daily bag limit of 2 per day/2 in possession with only one fish exceeding 20 inches in length and not exceeding 2 fish per year over 20 inches. Harvest of steelhead above the Sterling Highway Bridge is typically fewer than 50 fish annually according to Statewide Harvest Surveys (Howe et al. 2001a-d; Jennings et al. 2004, 2006a, 2006b; Walker et al. 2003).

Steelhead returning to the Kasilof River watershed are considered fall-run fish, entering freshwater in the fall and overwintering before spawning in tributaries in May and June. Larson and Balland (1989) documented similar behavior in steelhead returning to the Anchor River on the lower Kenai Peninsula. Begich (1997) has also described the Karluk River steelhead population, the largest steelhead population on Kodiak Island, as a fall run. More recently, USGS operated a weir on the Ninilchik River to enumerate emigrating adult steelhead (kelts). The timing of kelts passing downstream through the weir varied considerably between years, starting as early as 19 May in 2000 and as late as 12 June in 2001 (USGS, unpublished data). Median cumulative downstream passage dates have ranged from 9 to 18 June in the Ninilchik River. Information pertaining to kelts in the Kasilof River and its tributaries was unavailable prior to 2008, but the timing of their downstream migration was considered to be similar to the Ninilchik River.

The overwintering distribution of steelhead in the Kasilof River watershed was also poorly understood prior to 2008. Steelhead were thought to overwinter in the mainstem river, as indicated by harvest and catch information collected by the Department (Gamblin et al. 2004). The importance of the mainstem Kasilof River as an overwintering area was also supported by the spring migration of spawning steelhead into Crooked Creek (Gates and Palmer 2006a, 2006b, 2008). Within the Kasilof River, the slack water near the outlet of Tustumena Lake was considered another important overwintering area, as evidenced by reports of anglers catching steelhead near the public boat launch between September and freeze-up. Twenty steelhead were also observed migrating upstream past the Crooked Creek weir during September 2005, suggesting that some overwintering may occur in tributaries (Jeff Breakfield, Alaska Department of Fish and Game, personal communication).

The U.S. Fish and Wildlife Service (Service) initiated a steelhead monitoring project in Crooked Creek during 2004 to address informational gaps related to steelhead in the Kasilof River watershed. Since then, the Service has installed and operated weirs equipped with underwater video systems in Crooked and Nikolai creeks. Objectives have been to estimate the abundance and run timing of steelhead and to collect biological information related to age, sex, length, and genetic composition. Combined weir counts have ranged from 463 to 1,465 steelhead between 2005 and 2008 (Gates and Palmer 2006a, 2006b, and 2008; Gates and Boersma 2009). Spawning populations other than Crooked and Nikolai creek steelhead were unknown prior to 2008.

The development of new federal subsistence fisheries in the Kasilof River watershed triggered the need for a more comprehensive understanding of steelhead life history. To address this need, the Service developed a project using radio telemetry to (1) describe the freshwater migratory patterns and overwintering distribution of radio-tagged adult steelhead which enter the Kasilof River during the fall; and (2) identify spawning areas selected by radio-tagged steelhead. Information collected during this project will improve our understanding of steelhead in the Kasilof River watershed and will assist managers in refining existing management strategies.

Study Area

The Kasilof River drains a watershed of 2,150 km^2, making it the second largest watershed on the Kenai National Wildlife Refuge (Refuge). The watershed consists of mountains, glaciers, forests, and the Kenai Peninsula's largest lake, Tustumena Lake. The Kasilof River is only 31 km long and drains Tustumena Lake, which has a surface area of 29,450 hectares, a maximum depth of 287 m, and a mean depth of 124 m. All tributary streams in the watershed which drain refuge lands enter Tustumena Lake except Crooked Creek (Figure 1). Several species of salmon, trout, char, and whitefish use this watershed for spawning and rearing habitat (Johnson and Daigneault 2008), including Chinook *O. tshawytscha*, coho *O. kisutch*, sockeye *O. nerka*, and pink salmon *O. gorbuscha*, rainbow/steelhead *O. mykiss*, Dolly Varden *Salvelinus malma*, lake trout *S. namaycush*, and round whitefish *Prosopium cylindraceum*.

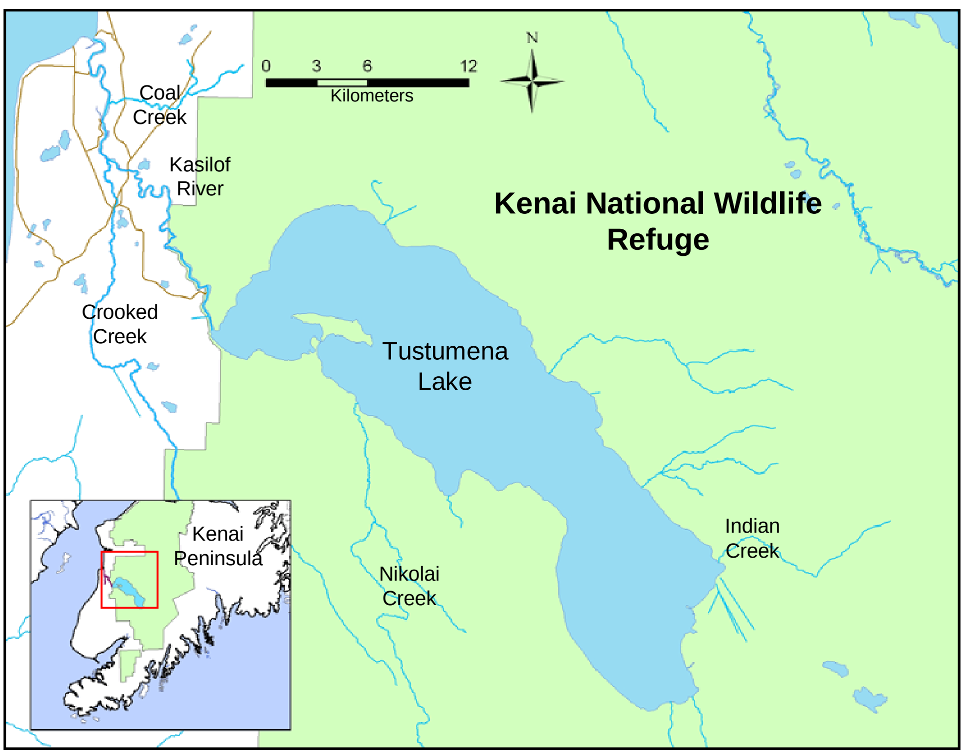

FIGURE 1.—Map of the Kasilof River watershed.

Methods

Radio Telemetry

Radio telemetry was used to uniquely identify and track movements of individual adult steelhead throughout the Kasilof River watershed. Movements of radio-tagged steelhead were documented using a combination of fixed data-logging receiver stations and mobile tracking using boats and fixed-wing aircraft.

Fish Capture.—Drift gillnets were actively fished between rkm 9 and 24 to capture steelhead for radio tagging. Methods for deploying gillnets were similar to those used to capture coho salmon for radio telemetry studies in the Holitna, Kenai, and Kasilof rivers (Chythlook and Evenson 2003; Carlon and Evans 2007; Palmer et al. 2008). A two to three person crew would deploy a single gillnet using a 5.5-m boat. One crew member piloted the boat while the other crewmember(s) positioned on or near the bow of the boat tended the net. Gillnets were constructed from Miracle® (MS-30) brand twisted nylon webbing. Each gillnet fished was 12.2-m long and was 11.4-cm stretched mesh and 29 meshes deep. Drift gillnets were fished until either the end of the fishing area was reached or a fish became entangled in the net. Once a fish became entangled in the net, the net was immediately pulled from the water until the fish was brought on board the boat. As the net was being pulled from the water, the portion of net containing the fish was placed in a large tote filled with river water at which time the fish was disentangled or cut from the net. Once freed from the net, steelhead were inspected for condition and either released or transported to a nearby onshore tagging station. These methods minimized stress associated with capture and handling.

Radio Tagging.—Steelhead were surgically implanted with radio transmitters between 4 and 16 October, 2007. Radio transmitters were manufactured by Lotek Wireless Incorporated® (Model SR-M11-25), measured 11 x 54 mm, were digitally encoded and equipped with a motion sensor, and outfitted with a 609 d battery. Radio transmitters weighed 9.7 g in air and did not exceed 2% of the fish's body weight (Winter 1983). Although we planned to deploy 80 transmitters, one failed before it was used. The remaining 79 transmitters were dispersed over four radio frequencies between 162.319 and 162.381 MHz. All radio-tagged steelhead received a Floy® T-Bar anchor (Model FD-94) as secondary identification.

Surgical procedures were similar to those described by Palmer (1998) and Summerfelt and Smith (1990). A stock solution of 100 g tricaine methanosulfate (MS-222) to one liter of water was diluted to 60 mg/L to anesthetize fish receiving a radio transmitter. The concentration of the anesthesia was sometimes altered depending on the reactions of each fish during anesthetizing but never exceeded 70 mg/L. Once fish were anesthetized, a measurement from the mid-eye to fork length was taken to the nearest 5 mm prior to being placed ventral side up in a cradle and irrigated with a combination of anesthesia water and plain river water throughout the surgical procedure. A 3 to 4 cm incision large enough to accommodate the transmitter was made anterior to the pelvic girdle approximately one centimeter from the midventral axis. The transmitter antenna was then routed under the pelvic girdle and through the body wall slightly off the midventral axis and anterior to the vent using a 25.4-cm hypodermic needle and grooved director. The incision was closed with three or four individual stitches of absorbable suture material and additionally secured with Vetbond™ tissue adhesive. After surgery, fish were immediately placed in a large tote with circulating river water to regain their equilibrium prior to being released near the capture site. The Floy® T-Bar anchor was applied near the base of the dorsal fin once the fish was placed in the recovery tote. Surgical instruments and transmitters were soaked in ChlorhexiDerm™ S disinfectant and rinsed in saline solution before each use.

Radio Tracking.—Radio telemetry receivers manufactured by Lotek Wireless Incorporated® were used for all mobile and fixed station tracking. Fixed receiver stations were used to automatically identify and record fish movements at the mouths of Nikolai, Glacier, Indian, Shantatalik and Crooked creeks, the lake outlet, and the Alaska Department of Fish and Game Crooked Creek facility (ADFG facility) (Figures 2 and 3). The station at the ADFG facility only was operated during May and June of 2008. The Nikolai Creek station was removed in November 2007 and reinstalled during April 2008. All other fixed receiver stations were operated from October through June.

Fixed receiver stations were similar to those used on the Kenai River to monitor rainbow trout movements (Palmer 1998) and on the Kasilof River to monitor coho salmon (Palmer et al. 2008). Each station was comprised of two Yagi antennas, antenna masts, solar panel(s), and a strongbox housing a single data logging receiver, an antenna switch box, 12-volt deep cycle batteries, and a voltage regulator. Mobile boat tracking was conducted on the Kasilof River each week during 2007 from the lake outlet to tidewater between 11 October and 29 November. Weekly tracking by boat commenced in the spring of 2008 between 5 May and 17 June. Aerial surveys were flown at approximately 300 to 400 m above the ground using either a Cessna 185 or PA-18 fixed-wing aircraft between 18 October, 2007 and 23 June, 2008. The frequency of flights was dependent on the observed movement of radio-tagged steelhead and pilot availability. Fall flights during October and November coincided with a study conducted by Palmer et al. (2008) which focused on tracking tributary streams and Tustumena Lake. Winter flights took place over the mainstem Kasilof River and Tustumena Lake shoreline. Aerial flights shifted to tributary streams and the mainstem Kasilof River during the spring spawning season. A portable global positioning system (GPS) was used during all mobile tracking surveys to accurately identify the latitude and longitude of each located fish.

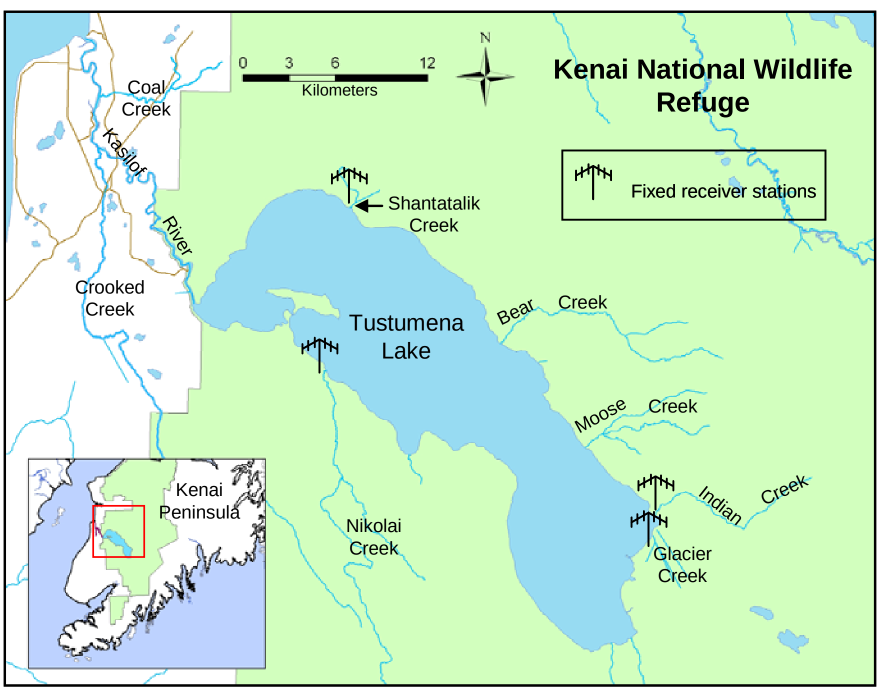

FIGURE 2.—Map of the Tustumena Lake illustrating the locations of fixed receiver stations during 2007 and 2008.

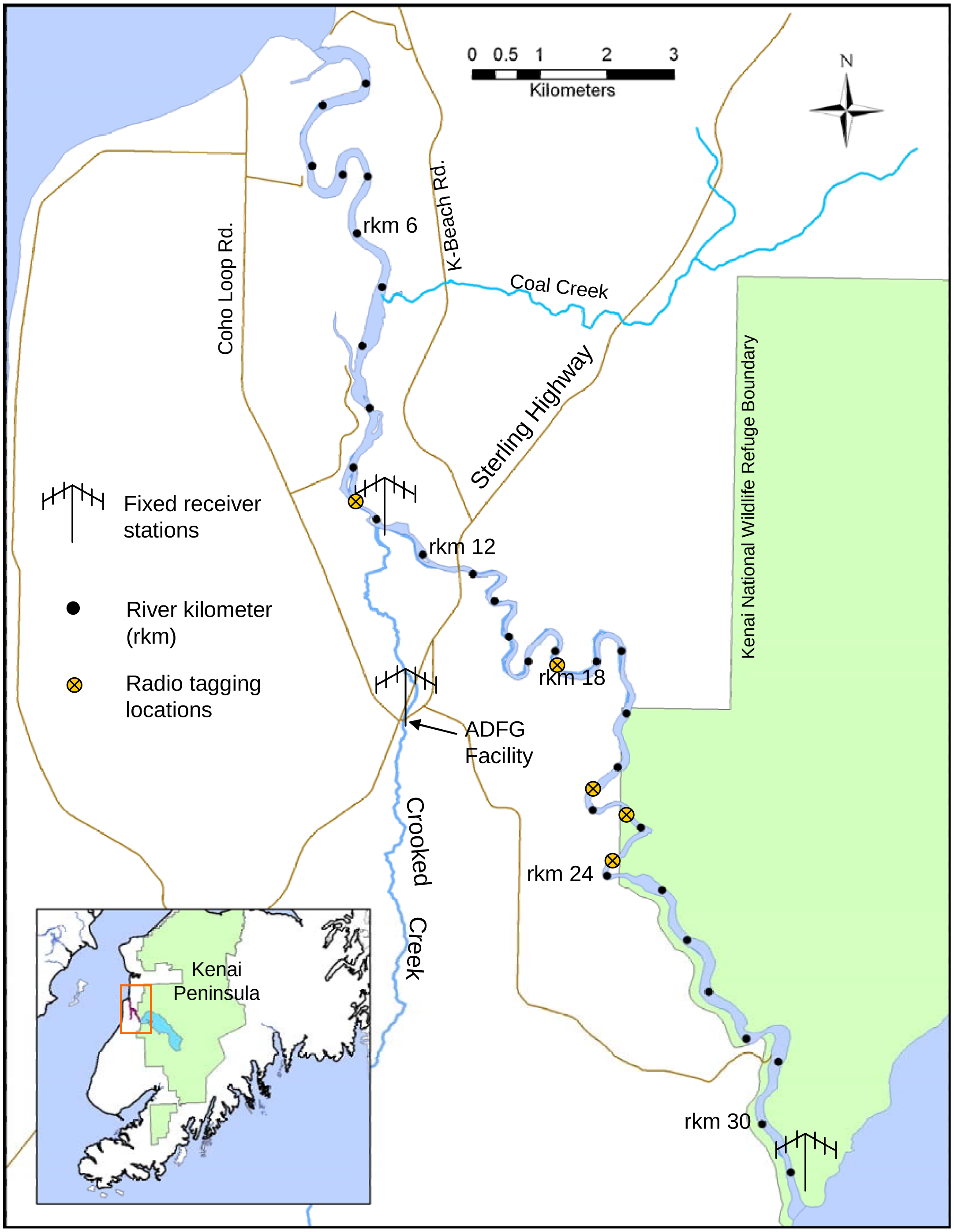

FIGURE 3.—Map of the Kasilof River and lower Crooked Creek illustrating the locations of fixed receiver stations during 2007 and 2008.

Data Analysis

Radio telemetry information collected with various tracking methods were integrated into one database that archived the dates, locations, and fates of radio-tagged steelhead. Locations identified during mobile tracking events were recorded as latitude and longitude coordinates (WGS84 datum). Each radio-tagged fish was assigned one of six possible final fates based on information collected throughout the study period (Table 1). The study period included nine months from October 2007 to June 2008 and was categorized into seasons consisting of fall (October and November), winter (December - March), and spring (April - June).

TABLE 1.—Possible fates of radio-tagged steelhead in the Kasilof River watershed during 2007 and 2008.

Fate	Description
Spawner	A fish that spawns in the Kasilof River watershed.
Dead/Expelled	A fish that did not complete its spawning migration because it has died or has expelled its radio transmitter.
Harvested	A fish that is harvested in either subsistence or sport fisheries.
Back-out	A fish that has dropped out of the Kasilof River watershed prior to the spawning period.
Non-spawner	A fish that has overwintered in the Kasilof River watershed, exhibited no signs of spawning based on abnormal movements, and returned to saltwater early in the spawning season.
Unknown	A fish that has a loss of contact with mobile or fixed radio receivers or cannot be assigned another fate with reasonable certainty.

Spawning locations and survival of radio-tagged steelhead were determined based on the tracking results. A radio-tagged fish that migrated to a particular location, and remained in the area for an extended period of time without activating the mortality sensor, was considered to have arrived at a potential spawning location. A radio-tagged fish that remained in one location for an extended period with an activated mortality sensor was considered to be dead. Radio-tagged steelhead emitting an active radio signal and remaining in freshwater beyond 23 June, 2008, the last day of mobile tracking, were considered to have survived the spawning event.

The duration of the spawning period and kelt emigration was determined for radio-tagged steelhead spawning in Crooked Creek and Tustumena Lake tributaries. Spawners in the mainstem Kasilof River and Coal Creek, and all radio-tagged steelhead that died in tributary streams were omitted from the analysis because exact entry and exit times could not be determined. Radio-tagged steelhead that died outside of spawning tributaries were omitted from the kelt emigration analysis. The fixed receiver station located at the mouth of Crooked Creek was operated through 30 June, marking the last day for potential detections of a radio-tagged steelhead in the lower Kasilof River. Mobile tracking was completed on 23 June. All fish that were detected below Crooked Creek during the last mobile tracking event or by the Crooked Creek fixed receiver prior to 30 June were included in the kelt emigration analysis. Radio-tagged steelhead that remained above Crooked Creek after 30 June were omitted from the kelt emigration analysis. The duration of spawning period was estimated as the number of days an individual radio-tagged fish resided in a tributary between its first and last detection by a fixed receiver station located near the mouth of each tributary stream. The timing of kelt emigration from Crooked Creek and Tustumena Lake tributaries was estimated using the dates of the first and last radio-tagged steelhead passing each respective fixed receiver station. After kelts passed fixed receiver stations at the mouths of respective spawning tributaries, the remainder of the kelt emigration period was estimated using fixed receiver stations and mobile tracking. This period was the number of days between the time a radio-tagged fish emigrated from a spawning tributary until it was last detected below Crooked Creek.

Seasonal movements and distributions of radio-tagged steelhead were described monthly by dividing the Kasilof River watershed into five regions consisting of the estuary, river, outlet, lake, and tributaries (Table 2). Each region represented different habitats available to steelhead. Radio-tagged fish were located and assigned to one or more regions during each month from October 2007 to June 2008. A radio-tagged fish detected within a region during a single month was included in the analysis and was assigned a unique detection regardless of the total number of observations recorded for that month. Since there were only five regions, a total of five unique detections were possible during a single month for an individual radio-tagged fish. The distribution by region was calculated as a percent of the total observed unique detections for each month (Table 3).

The number of radio-tagged steelhead traveling among regions during each month was used to describe seasonal movements. The amount of movement among regions was estimated as a percentage by dividing the difference of the total unique detections and active radio transmitters by the total active radio transmitters. This percentage would increase as more radio-tagged fish traveled among regions (Table 3). Additionally, the percent movement of radio-tagged fish could potentially exceed 100% if several fish utilized multiple regions within a single month. This would most likely occur during the spring period when steelhead migrate from overwintering areas to spawning locations.

TABLE 2.—Regions of the Kasilof River watershed used to describe seasonal movements and distributions of radio-tagged steelhead during 2007 and 2008.

Region	Description
Estuary	Area of the mainstem Kasilof River below Crooked Creek to Cook Inlet
River	Area of the mainstem Kasilof River above Crooked Creek to rkm 30.5
Outlet	Area at the outlet of Tustumena Lake within a one kilometer radius of the outlet fixed receiver station
Lake	Tustumena Lake
Tributary	Any tributary flowing into Tustumena Lake or the Kasilof River

TABLE 3.—An example of how movement and distribution were calculated for radio-tagged steelhead traveling among regions during each month in the Kasilof River watershed.

	Unique detections in October	Distribution by region (%)	Unique detections in November	Distribution by region (%)
Regions				
River	10	(10/20)*100 = 50	10	40
Lake	5	(5/20)*100 = 25	10	40
Outlet	5	(5/20)*100 = 25	5	20
Estuary	0	(0/20)*100 = 0	0	0
Tributary	0	(0/20)*100 = 0	0	0
Total unique detections	20		25	
Total active radio transmitters	15		10	
Difference between total unique detection and total active radio transmitters	5		15	
Percent movement among regions	(5/15)*100 = 33		150	

Results

Seventy-nine adult steelhead were radio-tagged in the Kasilof River between 4 and 16 October, 2007. All radio-tagged fish were captured between rkm 10 and 24 and transported to one of five locations for tagging (Figure 3). Tagging locations had no significance other than being easily accessible by boat and dry enough to set up surgical equipment. Females comprised 53% (*N*=42) of the radio-tagged fish, averaged 651 mm, and ranged from 540 mm to 780 mm. Males averaged 634 mm and ranged from 510 mm to 785 mm.

Radio-tagged steelhead were tracked throughout the fall, winter and spring. Fixed receiver stations were operated and maintained between 1 October, 2007 and 23 July, 2008. Station data were periodically downloaded throughout the fall, winter, and spring months. Boat tracking events occurred 18 times between 11 October, 2007 and 17 June, 2008. Nearly all boat tracking events took place between the lake outlet and tidewater, and those that occurred during late fall and early spring only occurred between the lake outlet and the boat launch immediately upstream of the Sterling Highway because of low water conditions. Aerial tracking consisted of 16 flights between 18 October, 2007 and 23 June, 2008.

Radio-tagged steelhead were assigned final "fates" based on information collected between October 2007 and June 2008 (Table 4). Fifty-four (68%) radio-tagged fish spawned either in a tributary (*N*=48) or the mainstem Kasilof River (*N*=6) and were assigned the fate of "Spawner". Spawning tributaries included Crooked (*N*=37), Nikolai (*N*=6), Coal (*N*=3), and Indian (*N*=2) creeks. Spawning destinations could not be determined for 32% of the radio-tagged steelhead; these fish were assigned fates of "Dead/Expelled", "Back-out", or "Non-spawner". Fourteen fish (18%) were assigned the fate "Dead/Expelled", and were either angler mortalities (*N*=6) or natural mortalities/expelled tags (*N*=8). Six fish (8%) moved out of the watershed immediately after being radio-tagged and were assigned the fate "Back-out". Five fish (6%) remained in freshwater and overwintered but did not show any indications of spawning in the spring, and were assigned a "Non-spawner" fate.

TABLE 4.—Final fates of adult steelhead radio-tagged in the Kasilof River during October 2007.

Fate		Male	Female	Total	Percent
Spawner					
	Mainstem Kasilof River	2	4	6	7.6
	Coal Creek	1	2	3	3.8
	Crooked Creek	21	16	37	46.8
	Nikolai Creek	5	1	6	7.6
	Indian Creek	0	2	2	2.5
		29	25	54	68.4
Dead/Expelled					
	Angler mortality	2	4	6	7.6
	Natural mortality/Expelled tag	1	7	8	10.1
		3	11	14	17.7
Back-out		2	4	6	7.6
Non-spawner		2	3	5	6.3
Total		36	43	79	100.0

The distribution of radio-tagged steelhead varied as fish moved among regions throughout the study period. The majority of the steelhead were located in the river during October (65%) and November (54%) (Figure 4). Overwintering occurred primarily in the outlet (36%), lake (34%), and river (29%) regions between December 2007 and March 2008. Radio-tagged steelhead began to move from their overwintering locations to spawning areas by the end of April as the May and June spawning season approached. The number of radio-tagged steelhead located in the outlet region decreased by 25% during April from the winter average (36%). During May, the distribution of fish had decreased in all regions from the winter averages except in the estuary and tributaries; distribution in these two regions had increased to 22% and 32%, respectively. The estuary (40%) and tributaries (33%) accounted for 73% of the radio-tagged steelhead during June (Figure 4).

Radio-tagged steelhead assigned "Spawner" fates overwintered in the river, outlet, and lake regions (Table 5). Steelhead that spawned in Crooked Creek (*N*=37) overwintered primarily in the lake (39%) and outlet (36%) regions. Nearly all (93%) of the Tustumena Lake tributary spawners (*N*=8) overwintered in the lake and outlet regions, whereas mainstem (*N*=6) and Coal Creek (*N*=3) spawners overwintered primarily in the river and outlet (85%).

The percent movement of radio-tagged steelhead traveling among regions ranged from 32 to 185% between October 2007 and June 2008 (Figure 5). The least movement among regions was observed during March while the most movement occurred during May. Movement during the fall, winter and spring periods averaged 52%, 45%, and 118%, respectively. Movement occurred throughout the entire study period and averaged 71%.

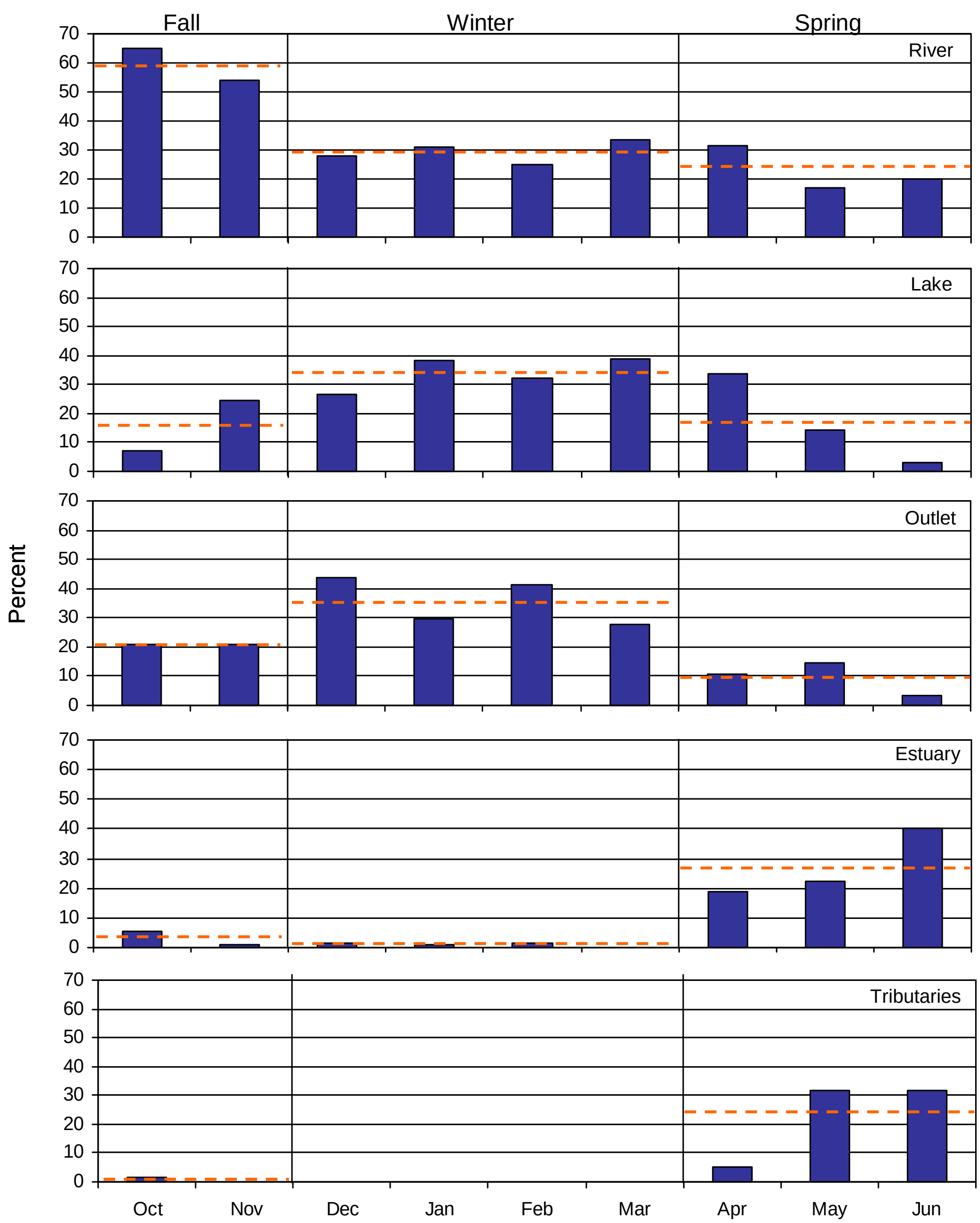

FIGURE 4.—Percent of radio-tagged steelhead distributed by month for each region in the Kasilof River watershed during 2007 and 2008. Dashed lines denote seasonal averages of distribution for each region.

TABLE 5.—Winter distribution by region of spawning radio-tagged steelhead in the Kasilof River watershed during 2007 and 2008.

		River		Outlet		Lake		
	Spawners (*N*)	Number of Fish Detected	Distribution (%)	Number of Fish Detected	Distribution (%)	Number of Fish Detected	Distribution (%)	Total Unique Detections
Mainstem	6	4	44.4	4	44.4	1	11.1	9
Coal Creek	3	1	25.0	2	50.0	1	25.0	4
Crooked Creek	37	16	25.8	22	35.5	24	38.7	62
Nikolai Creek	6	1	10.0	3	30.0	6	60.0	10
Indian Creek	2	0	0.0	2	50.0	2	50.0	4
Total	54	22		33		34		89

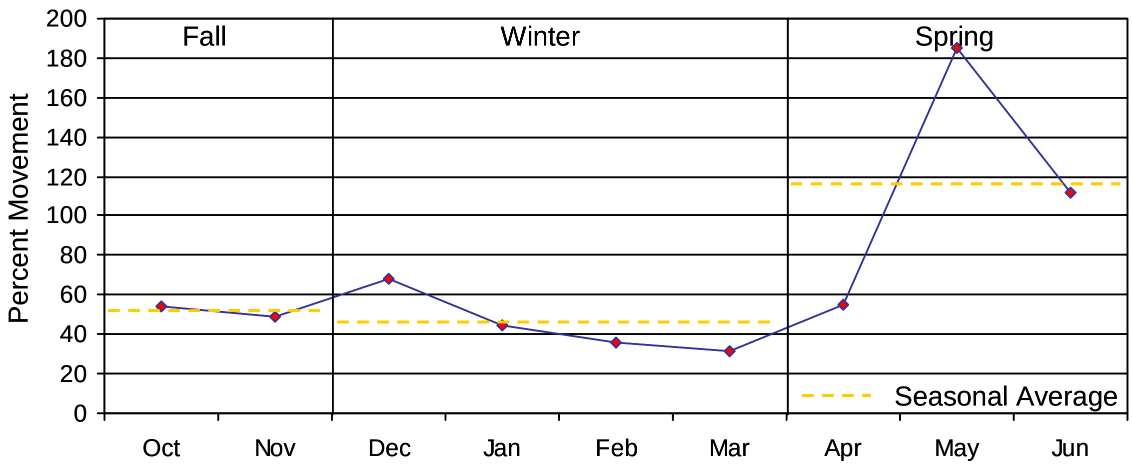

FIGURE 5.—Percent movement of radio-tagged steelhead traveling among regions during each month in the Kasilof River watershed, 2007 and 2008.

Pre-spawning and spawning survival was estimated for all radio-tagged steelhead except those with "Backout" fates (*N*=6). Steelhead with "Spawner", "Dead/Expelled", and "Non-spawner" fates exhibited 89% survivorship between tagging and the onset of the spawning season. Radio-tagged fish assigned "Dead/Expelled" fates were subcategorized into angler mortalities and natural mortality/expelled tag. All fish categorized as an angler mortality survived to the beginning of the spawning season whereas all fish categorized as a natural mortality/expelled tag died by 12 February. During this pre-spawning period, males (97%) exhibited higher survival than females (82%) (Table 4). Survival of spawning radio-tagged steelhead was 76% (Table 6). Female spawning survival was estimated to be 92% whereas male spawning survival was estimated to be only 62%.

The analysis of the spawning period and kelt emigration was limited to steelhead spawning in Crooked Creek and Tustumena Lake tributaries. On average, radio-tagged steelhead (*N*=30) remained in Crooked Creek for 26.8 d from 26 April to 21 June before returning to the Kasilof River (Table 7). Lake tributary spawners (*N*=6) remained at spawning locations an average of 23.8 d from 14 May to 23 June before entering Tustumena Lake. Time spent in the spawning tributaries ranged from 6 d to 42 d in Crooked Creek and 8 d to 33 d in Tustumena Lake tributaries. Kelts emigrated from Crooked Creek and Tustumena Lake tributaries from 16 May to 23 June (Figure 6; Table 7). Radio-tagged steelhead emigrating from Crooked Creek (*N*=28) traveled on average for 7.6 d in the Kasilof River before entering brackish water, with residence times in the Kasilof River ranging from 1 d to 16 d.

Kelts from Tustumena Lake tributaries (*N*=3) resided in the Kasilof River or Tustumena Lake from 9 d to 31 d and traveled an average of 16.7 d before reaching brackish water.

TABLE 6.—Number of radio-tagged steelhead surviving spawning in the Kasilof River during 2008.

	Mainstem Kasilof River		Coal Creek		Crooked Creek		Nikolai Creek		Indian Creek		Total				
	Survived	Died	Survived	Died	Survived	Died	Survived	Died	Survived	Died	Survived	Died	Total	% Survival [a]	% Mortality
Male	0	2	1	0	14	7	3	2	0	0	18	11	29	62.1	37.9
Female	4	0	2	0	14	2	1	0	2	0	23	2	25	92.0	8.0
Total	4	2	3	0	28	9	4	2	2	0	41	13	54	75.9	24.1

[a] Any radio-tagged steelhead that remained in freshwater through 23 June and whose transmitter was emitting an active signal was considered to have survived the spawning event.

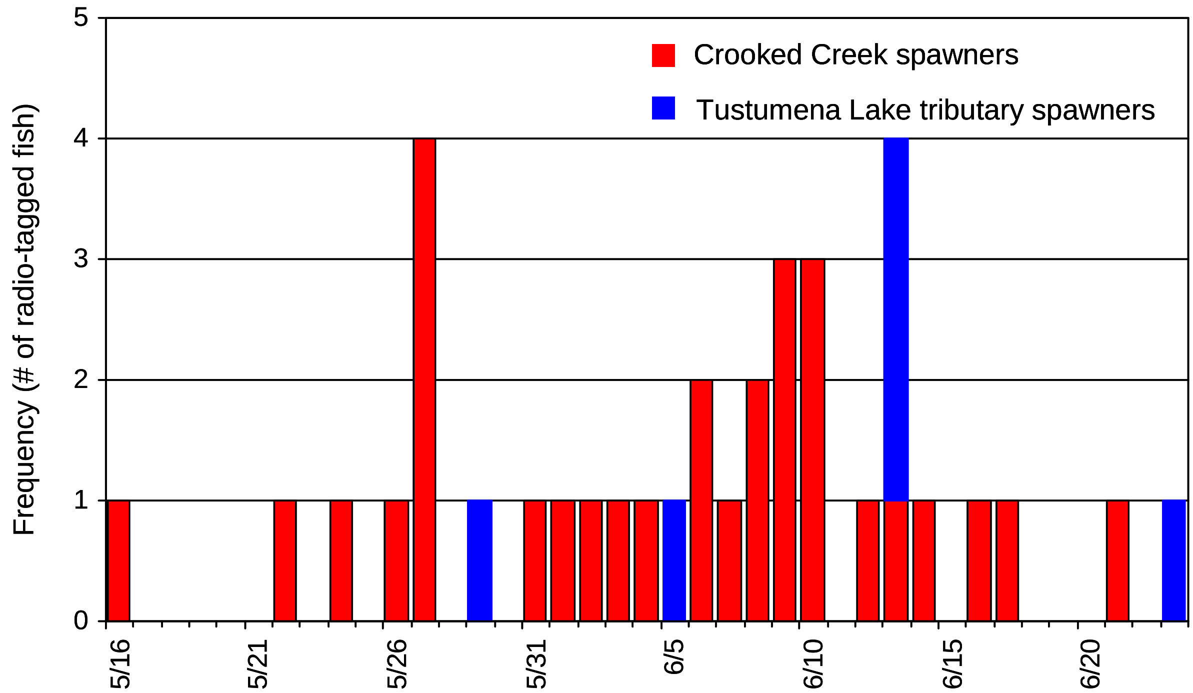

FIGURE 6.—Frequency of radio-tagged steelhead emigrating from spawning tributaries each day between 16 May and 23 June 2008.

TABLE 7.—Duration of the spawning period, tributary kelt timing, and kelt emigration for radio-tagged steelhead from Crooked Creek and Tustumena Lake tributaries during 2008.

Event		Crooked Creek	Tustumena Lake Tributaries
Spawning Period	*N* [a]	30	6
	Dates[b]	26 Apr - 21 Jun	14 May - 23 Jun
	Mean (d)	26.8	23.8
	Range (d)	6 - 42	8 - 33
Tributary Kelt Timing[c]	*N*	30	6
	Dates	16 May - 21 Jun	29 May - 23 Jun
Kelt Emigration[d]	*N* [e]	28	3
	Dates	23 May - 25 Jun	30 May - 29 Jun
	Mean (d)	7.6	16.7
	Range (d)	1 - 16	9 - 31

[a] Radio-tagged steelhead that spawned and died in Crooked (*N* =7) and Nikolai (*N* =2) creeks were omitted from the analysis.

[b] Dates of first and last radio-tagged steelhead to enter and exit spawning tributaries.

[c] Timing of the first and last kelt egressing spawning tributaries.

[d] Dates and duration of kelts from tributaries emigrating the Kasilof River and Tustumena Lake after spawning.

[e] Kelt emigration could not be determined for two radio-tagged steelhead from Crooked Creek and three from Tustumena Lake tributaries because they either died in the lower Kasilof River or remained in freshwater beyond the last tracking event.

Discussion

Waiting until October to begin radio tagging provided time for early and late arriving steelhead to thoroughly mix, and also allowed most steelhead to become acclimatized to freshwater, which reduced the number of radio-tagged fish backing out of the watershed. Tagging near rkm 11 occurred only once because few fish were caught and their overall condition was poor (e.g. open wounds and descaling). All three fish radio-tagged near rkm 11 backed out of the Kasilof River shortly thereafter.

Use of both fixed and mobile telemetry receivers to locate radio-tagged steelhead allowed collection of information throughout the freshwater residency period. Six fixed receivers were positioned throughout the watershed, and their data was downloaded approximately once each week during October and November. After November, the number of fixed receivers was reduced to five through the end of April. The information collected from these five receivers during the winter period was valuable despite the difficulties associated with accessing each site. Each of the five receivers provided information during a period when mobile tracking was limited to aircraft, and helped ensure that there were no data gaps during the change of seasons (April) when steelhead movements peaked. By early May, mobile tracking by boat had commenced and seven fixed receiver stations were operational.

Spawning areas selected by radio-tagged steelhead included four tributaries and the mainstem Kasilof River. Prior to 2008, Crooked and Nikolai creeks were the only two documented spawning areas for steelhead in the Kasilof River watershed (Gates and Palmer

2008). Radio-tagged steelhead selecting Crooked (69%) and Nikolai (11%) creeks comprised 80% of the "Spawners" during 2008. Based on escapement estimates from weirs operated by the Service in each creek (Gates and Boersma 2009), radio-tagged steelhead comprised 4% (*N*=37) of steelhead spawning in Crooked Creek and 1% (*N*=6) in Nikolai Creek. The difference in the percentage of "Spawners" detected between Crooked and Nikolai creeks may have been a result of our tagging strategy. Steelhead spawning in Nikolai Creek and possibly other lake tributaries could have passed through our tagging area by October or could have arrived after tagging was completed. If this occurred, steelhead returning to spawn in lake tributaries would not have been proportionately represented in our sample.

Timing of the spawning period and kelt emigration was determined only for radio-tagged steelhead spawning in Crooked Creek and Tustumena lake tributaries. Radio-tagged steelhead spawning in Coal Creek and the mainstem Kasilof River were omitted from the analysis because specific entry and/or exit times could not be determined for these fish; there was no fixed receiver station located near the mouth of Coal Creek and nearly all of the mainstem Kasilof River spawners overwintered in the Kasilof River making it difficult to determine the commencement of spawning. The spawning periods and kelt emigrations for these two spawning groups would have relied exclusively on mobile tracking events which occurred weekly but could have varied by as much as 10 days.

Steelhead assigned "Dead/Expelled" fates accounted for 18% of the radio-tagged fish. Of these, 43% were classified as angler mortalities from the spring steelhead catch and release sport fishery. All of the mortality associated with angling occurred during April and early May near the confluence of Crooked Creek and the Kasilof River. This was a period when several of the radio-tagged steelhead were staging to spawn and numerous anglers were observed fishing at the mouth of Crooked Creek (Figure 7 and 8). Several of the anglers reported catching radio-tagged steelhead on more than one occasion during this fishery. Radio-tagged fish classified as angler mortality were active throughout the fall, winter and early spring periods. Mortality sensors were triggered in each radio-tagged fish given a "Dead/Expelled" fate.

Steelhead are also likely experiencing further mortality during May and June from the in-river Chinook salmon sport fishery and Cook Inlet personal-use gillnet fishery. Radio telemetry findings indicate a significant overlap in the timing of the steelhead kelt emigration, the in-river sport fishery, and the personal-use gillnet fishery (Figure 8 and 9). Several of the radio-tagged steelhead were caught and reported to the Service by sport anglers during May and June. The Department also recorded a by-catch of 134 steelhead during the in-river Chinook salmon sport fishery between 16 May and 30 June below the Sterling Highway Bridge (ADFG, unpublished data). Similarly, radio-tagged steelhead were reported by fishers as being harvested in the June personal-use gill net fishery near the mouth of the Kasilof River. We were unable to determine which radio-tagged steelhead were harvested in the fishery because fishers either reported the fish but not leave a contact number or left garbled phone messages due to poor connections from their wireless phones. Mortality of steelhead associated with either fishery is unknown, but more detailed reporting requirements for the personal-use fishery could provide harvest information at minimal cost and effort.

Steelhead utilizing the river during the fall could also be caught during newly established federal subsistence fisheries. Several radio-tagged steelhead were located in the river above rkm 24 during October and November (Figure 10). We suspect that steelhead are utilizing this area for feeding during the fall and early winter as Palmer et al. (2008) identified several radio-tagged coho salmon spawning in this section of river. Steelhead were also observed traveling through this section of river during the fall to overwintering areas. The most recent proposal approved by the Federal Subsistence Board allows subsistence users to operate a fish wheel to capture salmon above rkm 24 from 16 June to 31 October. The fish wheel has yet to operate but if it is installed there could be some unknown level of steelhead mortality associated with this capture technique even though all steelhead must be released.

In conclusion, radio telemetry findings from 2007 and 2008 identified three additional spawning areas important to Kasilof River steelhead–Indian Creek, Coal Creek, and the mainstem Kasilof River. Findings also show that the estuary, river, outlet, lake and tributary regions were all important to steelhead during different times of the year for feeding, overwintering, spawning, and migration. This study was continued in the fall of 2008 when an additional 80 adult steelhead were radio-tagged. The objectives remained the same but tagging operations began in September rather than October to better represent all spawning populations of steelhead. All radio telemetry findings will be synthesized and documented in a 2010 final report. This information will be useful in evaluating and, if needed, modifying existing management strategies for steelhead returning to the Kasilof River.

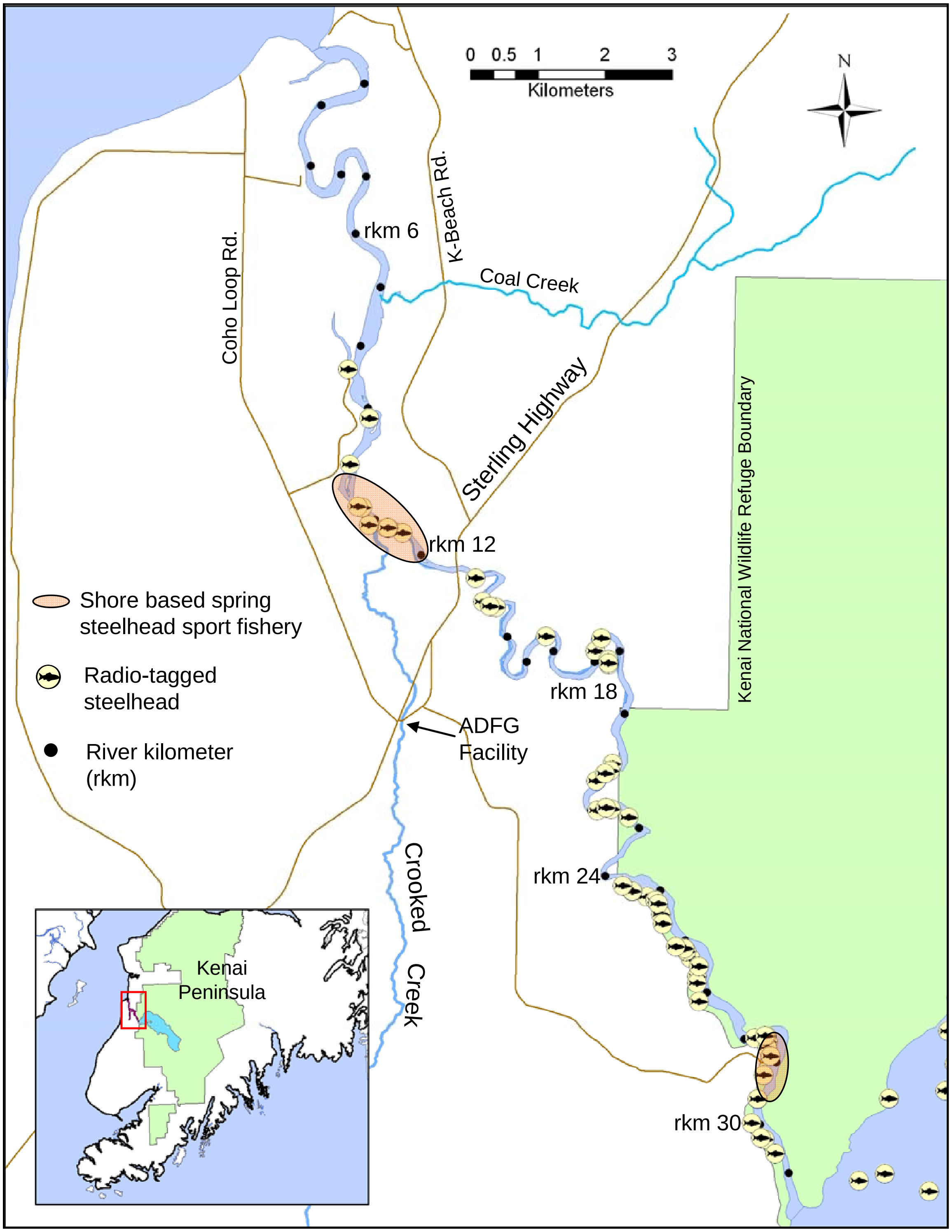

FIGURE 7.—Locations of radio-tagged steelhead during mobile tracking events conducted in the lower Kasilof River watershed during April, 2008. Shaded areas represent the general locations of fishing pressure from sport anglers in the Kasilof River during April.

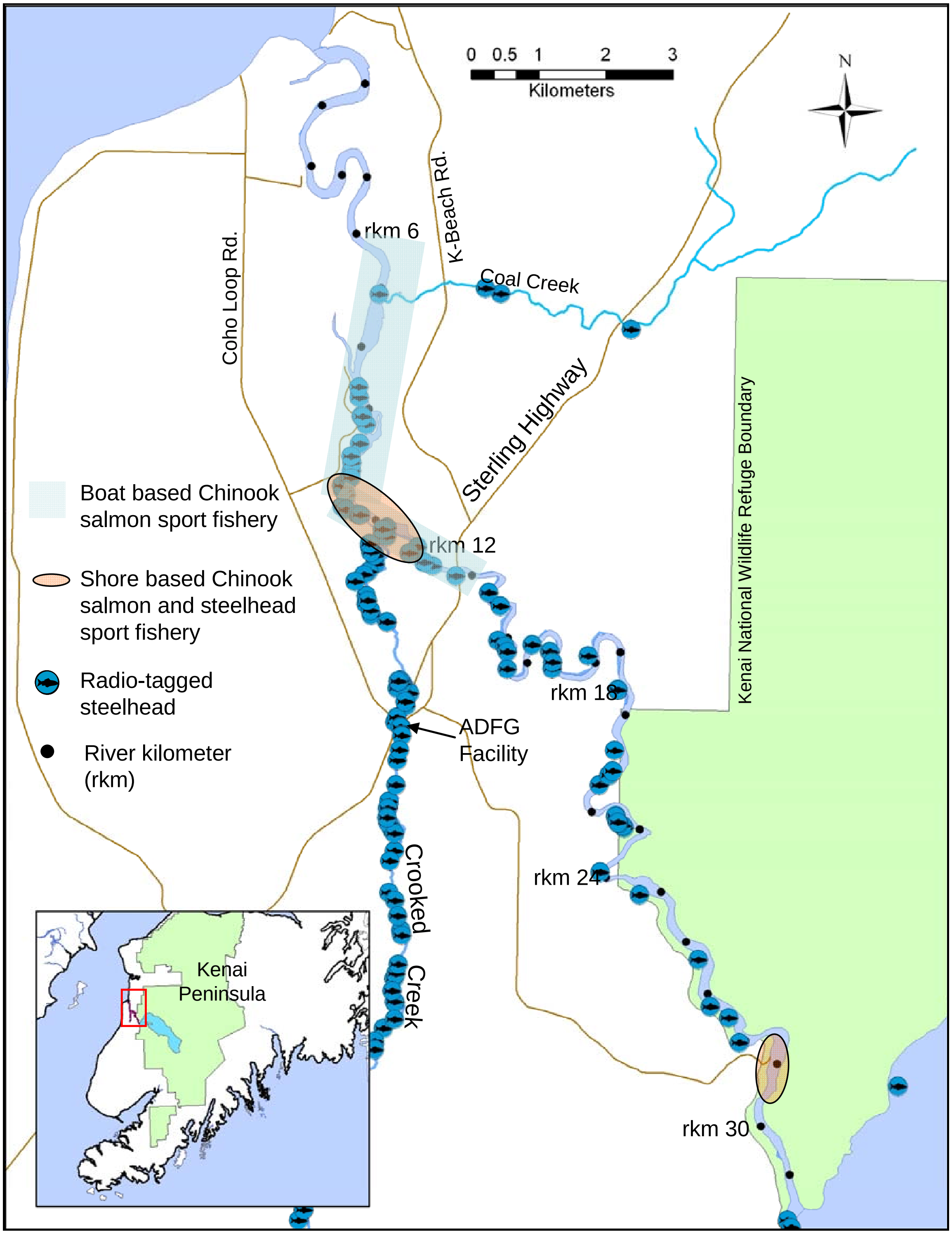

FIGURE 8.—Locations of radio-tagged steelhead during mobile tracking events conducted in the lower Kasilof River watershed during May, 2008. Shaded areas represent the general locations of fishing pressure from sport anglers in the Kasilof River during May.

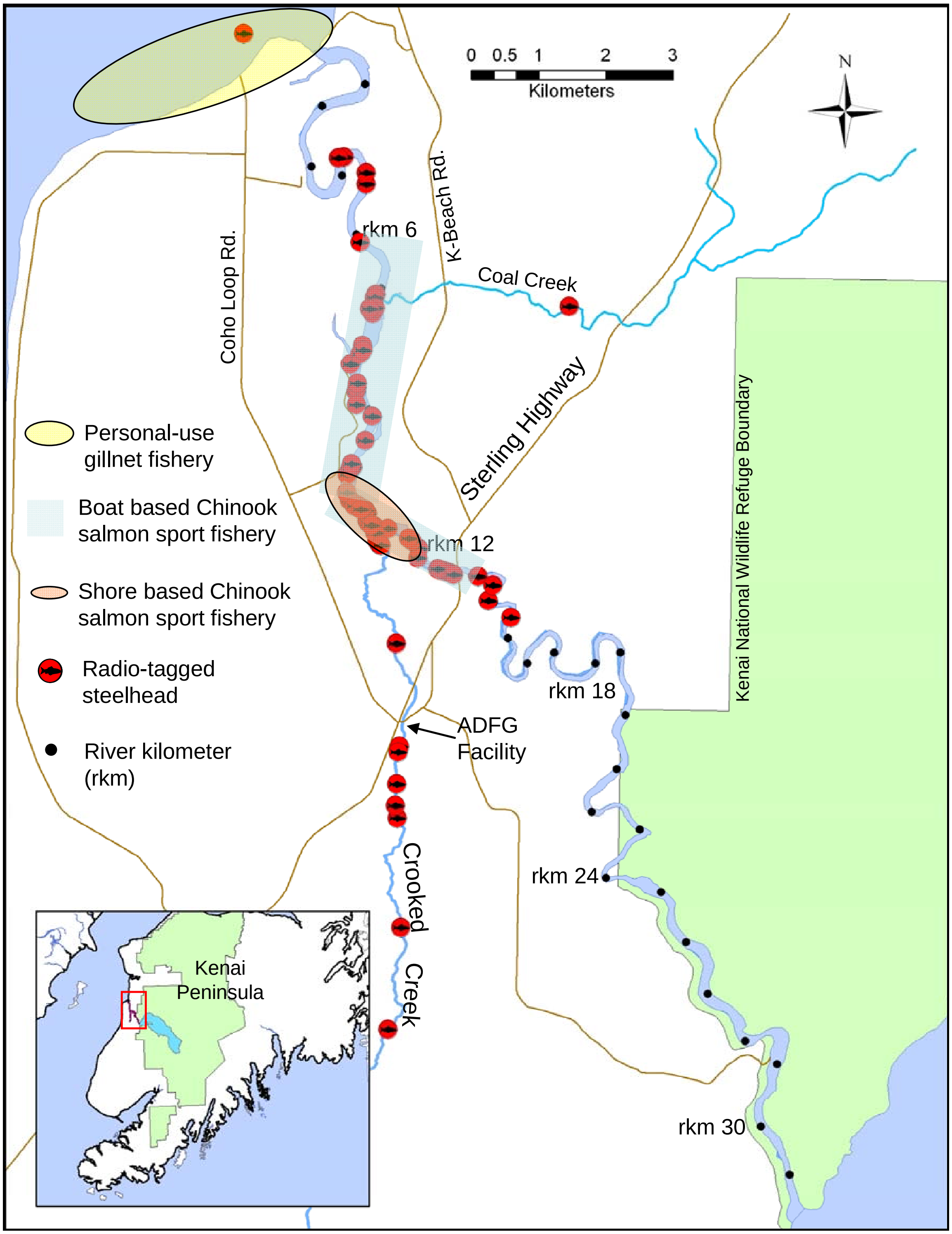

FIGURE 9.—Locations of radio-tagged steelhead during mobile tracking events in the lower Kasilof River watershed during June, 2008. Shaded areas represent the general locations of fishing pressure from sport anglers and personal-use fishers in the Kasilof River and Cook Inlet during June.

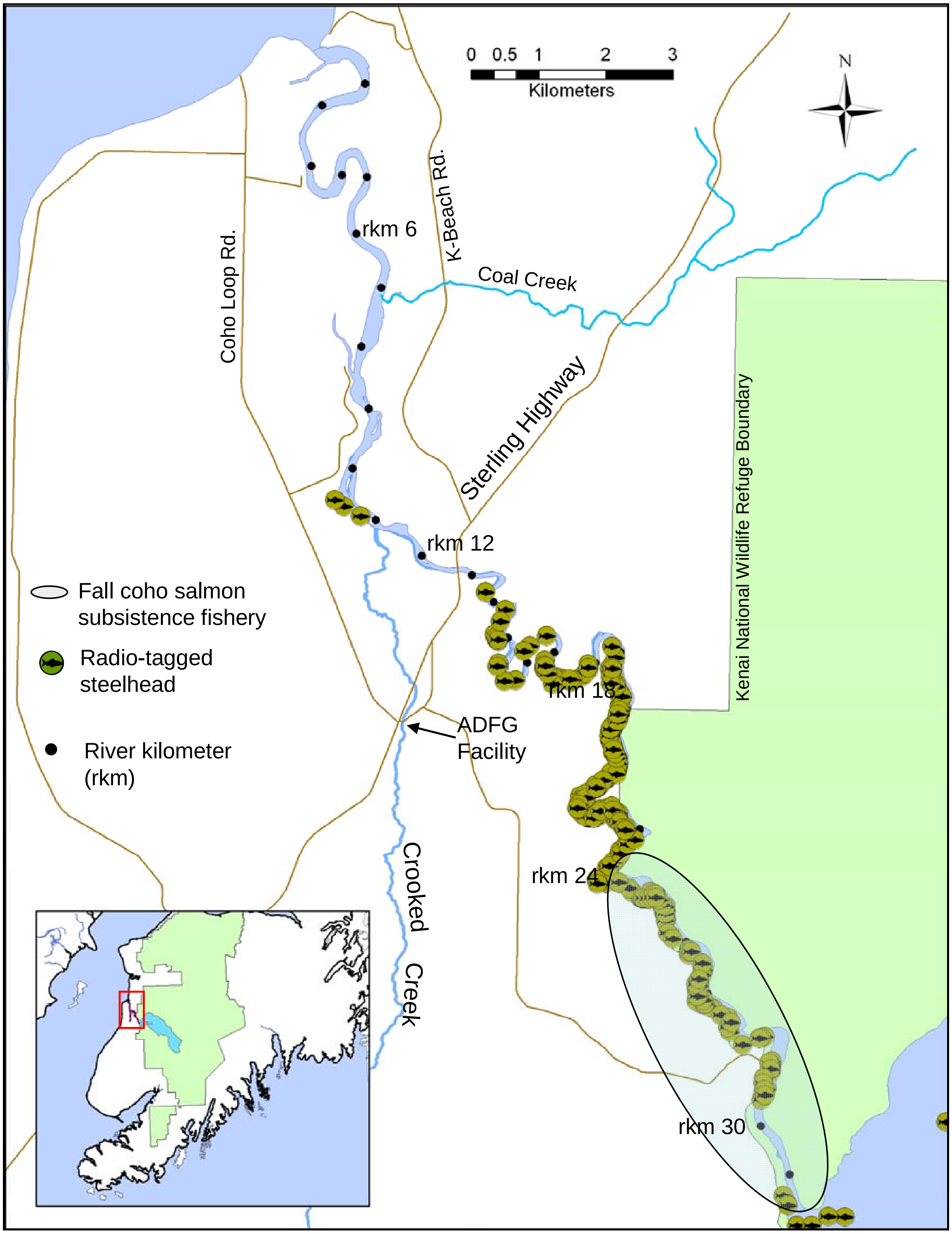

FIGURE 10.—Locations of radio-tagged steelhead during mobile tracking events in the lower Kasilof River watershed during October and November, 2007. Shaded areas represent the location of the federal subsistence fishery in the upper Kasilof River.

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APPENDIX 1. —Summary of steelhead radio-tagged in the Kasilof River during 2007.

Fish Number	Sex	Mid-eye to Fork Length (mm)	Tagging Date	Final Fate	Overwintering Regions
0323	M	730	4-Oct	Spawner (Mainstem)	Outlet
3423	M	725	4-Oct	Spawner (Crooked Creek)	River
3543	M	700	4-Oct	Dead (Angler Mortality)	River
3863	M	690	4-Oct	Dead (Natural/Expelled Tag)	–
0324	M	535	4-Oct	Dead (Angler Mortality)	Outlet, River
3424	F	655	4-Oct	Dead (Angler Mortality)	River
3544	F	610	4-Oct	Back Out	–
3864	F	780	4-Oct	Dead (Natural/Expelled Tag)	–
0325	F	655	4-Oct	Spawner (Crooked Creek)	Outlet, River, Lake
3425	M	670	4-Oct	Spawner (Crooked Creek)	Outlet, Lake
3545	F	645	5-Oct	Spawner (Mainstem)	Outlet, Lake
3865	F	640	5-Oct	Spawner (Crooked Creek)	Lake
0326	F	620	5-Oct	Spawner (Crooked Creek)	Outlet, Lake
3426	F	540	5-Oct	Spawner (Crooked Creek)	Outlet, Lake
3546	F	625	5-Oct	Non-Spawner	Outlet, River, Lake
3866	M	560	5-Oct	Back Out	–
0327	F	680	5-Oct	Dead (Natural/Expelled Tag)	–
3427	M	700	5-Oct	Spawner (Mainstem)	Outlet, River
3547	F	565	5-Oct	Back Out	–
3867	F	725	5-Oct	Spawner (Crooked Creek)	Outlet, River
0328	F	660	9-Oct	Spawner (Crooked Creek)	Lake
3428	F	640	9-Oct	Back Out	–
3548	M	600	9-Oct	Spawner (Nikolai Creek)	Outlet, Lake
3868	F	630	9-Oct	Spawner (Crooked Creek)	Outlet, River
0329	M	565	9-Oct	Spawner (Nikolai Creek)	Lake
3429	M	575	9-Oct	Spawner (Crooked Creek)	Outlet, Lake
3549	F	585	9-Oct	Non-Spawner	Lake
3869	M	660	9-Oct	Spawner (Crooked Creek)	Outlet, Lake
3210	M	700	9-Oct	Spawner (Crooked Creek)	Outlet, Lake
3430	F	685	9-Oct	Spawner (Crooked Creek)	Outlet
3550	F	695	10-Oct	Dead (Natural/Expelled Tag)	–
3870	M	565	10-Oct	Spawner (Crooked Creek)	Outlet, River, Lake
3211	M	645	10-Oct	Non-Spawner	Lake
3431	M	715	10-Oct	Spawner (Nikolai Creek)	Lake
3551	M	785	10-Oct	Spawner (Crooked Creek)	Outlet, River
3871	M	705	10-Oct	Spawner (Nikolai Creek)	Outlet, Lake
3212	M	625	10-Oct	Spawner (Crooked Creek)	Outlet, Lake
3432	F	605	10-Oct	Spawner (Crooked Creek)	River
3552	F	680	10-Oct	Spawner (Crooked Creek)	Lake
3213	F	705	11-Oct	Dead (Natural/Expelled Tag)	–
3433	F	560	11-Oct	Back Out	–
3553	M	690	11-Oct	Back Out	–
3873	F	610	12-Oct	Dead (Angler Mortality)	River
3214	M	630	12-Oct	Spawner (Crooked Creek)	Outlet, River, Lake
3434	M	580	12-Oct	Non-Spawner	Outlet
3554	M	520	12-Oct	Spawner (Coal Creek)	Outlet, River

-continued-

APPENDIX 1. —(Page 2 of 2)

Fish Number	Sex	MEF Length	Tagging Date	Final Fate	Overwintering Regions
3874	F	640	12-Oct	Spawner (Mainstem)	River
3215	F	665	12-Oct	Spawner (Mainstem)	River
3435	M	635	12-Oct	Spawner (Crooked Creek)	Outlet, Lake
3555	M	720	12-Oct	Spawner (Crooked Creek)	River
3875	F	645	12-Oct	Non-Spawner	Outlet, River
3216	F	650	12-Oct	Spawner (Indian Creek)	Outlet, Lake
3436	F	670	12-Oct	Spawner (Coal Creek)	Outlet, Lake
3556	F	700	12-Oct	Spawner (Crooked Creek)	Lake
3876	F	690	12-Oct	Dead (Natural/Expelled Tag)	–
3217	F	695	15-Oct	Dead (Natural/Expelled Tag)	–
3437	M	675	15-Oct	Spawner (Crooked Creek)	Lake
3557	F	645	15-Oct	Spawner (Nikolai Creek)	Outlet, River, Lake
3877	F	710	15-Oct	Spawner (Crooked Creek)	Lake
3218	F	675	15-Oct	Dead (Angler Mortality)	Outlet, River
3438	M	510	15-Oct	Spawner (Indian Creek)	Outlet, Lake
3558	M	570	15-Oct	Spawner (Crooked Creek)	Lake
3878	M	670	15-Oct	Spawner (Nikolai Creek)	Lake
3219	F	620	15-Oct	Spawner (Crooked Creek)	Outlet, River
3439	F	685	15-Oct	Spawner (Crooked Creek)	Outlet, River, Lake
3559	M	550	15-Oct	Spawner (Crooked Creek)	Outlet, River
3879	F	590	15-Oct	Spawner (Coal Creek)	Lake
3220	F	670	15-Oct	Dead (Angler Mortality)	Outlet, Lake
3440	F	640	15-Oct	Spawner (Mainstem)	Outlet, River
3560	M	575	15-Oct	Spawner (Crooked Creek)	Lake
3880	M	605	15-Oct	Spawner (Crooked Creek)	Outlet, River
3221	M	565	15-Oct	Spawner (Crooked Creek)	River
3441	F	650	15-Oct	Spawner (Crooked Creek)	River
3561	M	555	15-Oct	Spawner (Crooked Creek)	Outlet, Lake
3881	F	610	15-Oct	Dead (Natural/Expelled Tag)	–
3222	M	705	16-Oct	Spawner (Crooked Creek)	Outlet, Lake
3442	F	710	16-Oct	Spawner (Crooked Creek)	Outlet, River
3562	M	695	16-Oct	Spawner (Crooked Creek)	Lake
3882	M	540	16-Oct	Spawner (Crooked Creek)	Lake