Radiotelemetry Monitoring of Adult Chinook and Sockeye Salmon in the Nushagak River, Alaska, 2006

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EXECUTIVE SUMMARY

The purpose of the 2006 Nushagak River radiotelemetry study was to increase our understanding of Nushagak River Chinook and sockeye salmon and potentially improve the management of these important commercial, subsistence, and sport fishery resources. For Chinook salmon, the sonar-estimated inriver abundance is considered an index and a more accurate abundance estimate was desired. Also, spawning distribution and associated stock-specific run timing data were needed to investigate harvest effects on specific stocks. For sockeye salmon, recent Nushagak River escapements have been relatively consistent while there seems to be considerable fluctuation in the Nuyakuk and Mulchatna river components. Thus, there is interest in verifying the proportion of sockeye salmon passing Portage Creek that escape to the Nuyakuk and Mulchatna rivers.

The study was designed to identify major spawning tributaries and the associated proportion of Chinook and sockeye salmon in each, describe the stock-specific run timing of Chinook and sockeye in the lower Nushagak River, and estimate the abundance of sockeye in the Nushagak River and determine the precision of the estimate. A secondary objective of the study was to estimate the abundance of Chinook salmon in the Nushagak River and determine the precision of the estimate.

In June and July, 2006, 474 Chinook salmon (*Oncorhynchus tshawytscha*) and 222 sockeye salmon (*O. nerka*) were radio tagged in the lower Nushagak River near Ekwok, Alaska. Eight fixed stations and eight mobile surveys were used to track adult salmon through August, during their spawning migration.

The King Salmon, Koktuli, mainstem Mulchatna, and mainstem upper Nushagak rivers were important Chinook salmon spawning areas in 2006. Most Nushagak River Chinook salmon stocks exhibited similar run timing in the lower Nushagak River; Chinook salmon passed Ekwok from mid-June to mid-July and the date of 50% passage was July 1. The system-wide abundance of Nushagak River Chinook salmon was not estimated because mark-recapture sample size requirements were not met.

The Nuyakuk, King Salmon, and Koktuli rivers were important sockeye salmon spawning areas in 2006. Nuyakuk River sockeye salmon run timing in the lower Nushagak River appears to be 5-7 days later than other sockeye salmon stocks. The temporally-stratified mark-recapture abundance estimate of Nushagak River sockeye salmon was 558,852 (SE = 82,423), which is similar to the Portage Creek sonar estimate of 548,410 sockeye salmon. The Portage Creek (548,410) and Nuyakuk Tower (170,760) sockeye salmon estimates result in an allocation of 31% Nuyakuk River sockeye salmon and 69% Mulchatna sockeye salmon under current management, which differs considerably from the sockeye salmon spawning distribution based on radiotelemetry data (i.e., 46% Nuyakuk, 32% upper Nushagak, and 22% Mulchatna). Although the Mulchatna River appears to be an important sockeye salmon spawning area (i.e., 22% of spawners in 2006 based in radiotelemetry), the contribution of Mulchatna sockeye salmon to the total Nushagak River run may not be as high as recent ADF&G estimates (i.e., 68 to 84% since 1998).

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INTRODUCTION

The Bristol Bay region of Alaska has ten river systems that support major salmon runs (Figure 1). The Nushagak River produces the largest run of Chinook salmon (*Oncorhynchus tshawytscha*) in Bristol Bay and is a major producer of sockeye salmon (*O. nerka*; Dunaway and Sonnichsen 2001, Clark 2005, Westing et al. 2005). Nushagak Chinook and sockeye salmon support a commercial fishery in Nushagak Bay (Westing et al. 2005) and subsistence harvest throughout the Nushagak drainage (Figure 2 and Figure 3). Nushagak Chinook salmon also support a thriving sport fishery in the lower Nushagak River (Figure 2; Dye 2005).

The Alaska Department of Fish and Game (ADF&G) estimates Nushagak Chinook and sockeye salmon escapement using the Portage Creek sonar counts (McKinley 2003). The Portage Creek sonar system is designed and operated to target sockeye salmon and serves as an index count of Chinook salmon (Miller 1999, 2000). ADF&G also operates a counting tower on the Nuyakuk River, a tributary of the Nushagak River, to estimate sockeye salmon escapement to Tikchik Lakes. Aerial surveys are used to estimate peak spawning counts in primary spawning areas (Dunaway and Sonnichsen 2001).

Nushagak Chinook salmon escapement estimates have ranged from 40,000 to 173,000 (Figure 4). Nushagak sockeye escapement estimates have ranged from 281,000 to 3.3 million (Figure 5). Nuyakuk River sockeye escapement estimates have ranged from 20,000 to 3 million (Figure 6).

Chinook salmon run timing at Portage Creek extends from early June to mid August and generally peaks around late June (Figure 7). The run timing data for the beginning and end of the run are influenced by the operational period of the Portage Creek sonar. Sockeye salmon run timing at Portage Creek occurs from early June to late August and generally peaks around the beginning of July; sockeye salmon run timing passed the Nuyakuk tower appears to be about 1 week after Portage Creek passage (Figure 8).

Chinook salmon spawning areas are distributed throughout the drainage. Historical and recent information suggests that the mainstem Mulchatna, Stuyahok, Koktuli, mainstem Upper Nushagak, and King Salmon rivers are important spawning areas (Table 1; Nelson 1987, Dye 2005). Sockeye salmon spawning distribution throughout the Nushagak drainage is segregated into broader geographic regions: the Mulchatna and Nuyakuk rivers are thought to be the primary spawning areas for Nushagak sockeye salmon (Figure 9).

Despite the data available to fishery managers, there is considerable uncertainty regarding the management of Nushagak River Chinook and sockeye salmon. For Chinook salmon, the primary issues are: 1) lack of an annual system-wide inriver abundance estimate, 2) difficulties trying to limit the sport fishery to the 5,000 fish guideline harvest level, and 3) potential commercial fishery management effects on sport-fishing opportunity and escapement quality (Dunaway and Sonnichsen 2001). For sockeye salmon, escapements to the Nushagak and Nuyakuk rivers are estimated annually, but escapement to the

Mulchatna River system is not enumerated. The proportion of Nuyakuk River sockeye salmon in the total Nushagak River sockeye salmon escapement has declined in recent years (Figure 9), triggering interest in verifying the proportion of sockeye salmon passing Portage Creek that escape to the Nuyakuk and Mulchatna rivers. It is unclear how Nushagak River sockeye salmon escapements have maintained levels between 300,000 and 800,000 in recent years while Nuyakuk River escapements have steadily declined (Figure 9).

OBJECTIVES

This study used radiotelemetry methods to estimate the distribution and run timing of the Nushagak River Chinook and sockeye salmon escapements. We also used a combination of radiotelemetry and mark-recapture methods to estimate salmon abundance. Specific objectives of the 2006 Nushagak radiotelemetry study were to:

1) Identify the major spawning tributaries and estimate the proportion of spawning Chinook and sockeye salmon in each;
2) Describe the stock-specific run-timing patterns for Chinook and sockeye salmon at the point of capture in the lower Nushagak River; and
3) Estimate the system-wide abundance of sockeye salmon returning to the Nushagak River and determine the precision of the estimate.

A secondary objective of the study was to estimate the system-wide abundance of Chinook salmon returning to the Nushagak River using mark-recapture methods.

STUDY AREA

The Nushagak River watershed encompasses 134,000 mi^2 with a length of 285 miles from the source to the mouth (Kammerer 1990). The average discharge at the mouth is 36,000 ft^3/s, which ranks 20th among the largest rivers in the United States (Kammerer 1990). The largest tributaries include the Nuyakuk and Mulchatna rivers. The Nuyakuk River drains numerous lakes in the Wood-Tikchik State Park region and the headwaters of the Mulchatna River extend into the Lake Clark National Park and Preserve. Other sizable tributaries include the King Salmon, Chilikadrotna, Koktuli, Stuyahok, Kokwok, and Iowithla rivers and Klutuspak Creek. The watershed is bordered on the east by the Kvichak River, the west by the Wood River, and the north by the Kuskokwim River. Communities along the Nushagak River include Koliganek, New Stuyahok, Ekwok, and Portage Creek; Dillingham is located near the river mouth.

Vegetation throughout the watershed is diverse. White spruce, birch, and cottonwood forests are generally concentrated along streams. The lower Nushagak, Nuyakuk, and upper Mulchatna rivers have large spruce stands. Much of the low rolling mountainous terrain in the northern portion of the watershed is covered with lichen shrub tundra interspersed with open low shrub tundra. The coastal lowlands adjacent to Bristol Bay have hundreds of small lakes and ponds, and large areas of open shrub tundra.

METHODS

General Operations

The 2006 migration of adult Chinook and sockeye salmon in the Nushagak River was monitored and tracked using radiotelemetry techniques. The project was accomplished through the cooperative efforts of the Bristol Bay Science and Research Institute (BBSRI), ADF&G, and LGL Alaska Research Associates, Inc. The study period extended from late May through August, and included telemetry array setup, capture and tagging, post-release monitoring, and in-season analysis (Table 2). Radiotagging goals were 450 Chinook salmon and 250 sockeye salmon. Esophageal radio tags were gastrically implanted into salmon at numerous capture locations near Ekwok (Figure 10). The omission of two minor lower Nushagak River Chinook salmon producing systems (the Iowithla and Kokwok rivers) from the study design was not expected to significantly affect the project objectives. The tags were monitored at eight fixed stations upstream of the release site (Figure 11) and with boat and aerial surveys.

Capture and Tagging

Capture and tagging of adult Chinook and sockeye salmon was conducted in the lower Nushagak River near the village of Ekwok with two 2- to 3-person crews. Ekwok was a convenient, accessible location upstream of most of the sport fishing activity and the heavily braided reach of the lower Nushagak River.

Tagging sites, on both banks of the river and representing a variety of habitats, were tested and established to distribute fishing effort over as many areas as possible, to find the most productive capture locations near Ekwok, and to minimize conflicts with the sport fishery.

Gillnets (set and drift), beach seines, and hook and line gear were tested for capturing Chinook and sockeye salmon for radiotagging.

Gillnets were 18.3-m long and 3.7-m deep and three mesh sizes were used to target different size fish: 10.2 cm, 14.0 cm, and 19.1 cm stretched mesh. Gillnets were deployed from the bow of a skiff and drifted with the current through areas expected to contain migrating or holding salmon (Plate 1) or were anchored and continuously monitored. All fish captured in gillnets were removed from the net as soon as observed. Captured fish were kept in the river, enclosed in a dipnet, and carefully removed from the gillnet mesh. When necessary, gillnet material was cut to speed the removal of the fish and/or to avoid injuring it.

The beach seine was approximately 50 m long, 3 m deep, with 2.5 cm square mesh. A 30 m lead and bridle assembly was attached to each end of the beach seine. The seine was deployed from shore with a skiff.

Hook and line gear was not tested for use with sockeye salmon. Multiple types of terminal gear were tested for effectiveness at capturing Chinook salmon. Strong line (i.e.,

~40 lb. test) was used with all hook and line gear so that Chinook salmon could be retrieved quickly to minimize capture stress.

Captured fish were removed from the gear as quickly as possible and placed in a water-filled sampling trough (Plate 2). If more than one fish was captured, the largest fish was placed in the water-filled trough and the remaining fish were placed in a temporary holding tank. If the abundance of captured fish created crowding in the holding tank (i.e., 2 to 5 fish, depending on size), excess fish were released back to the river without tagging or sampling. Chinook or sockeye salmon injured or otherwise in visibly poor condition upon capture were not tagged. Minimum size thresholds were used to avoid tagging early maturing fish (Chinook salmon) and to minimize potential fish injury from tagging extremely small fish (sockeye salmon). The Chinook salmon size threshold was 600 mm from mid eye to the fork of the tail (MEF) and the sockeye salmon size threshold was 400 mm MEF.

Chinook and sockeye salmon were radiotagged with cylindrical Grant Systems Engineering (GSE) *Pisces* coded tags (www.grantsystems.com). The tags were programmed to emit a signal on average every 2.5 s (using a randomization feature that reduces tag collisions among deployed tags). Tags were programmed to operate until December 31, 2006. The Chinook salmon tags were 19 mm wide by 41 mm long; the sockeye salmon tags were 17 mm wide by 41 mm long, Both tags had a 220 mm long whip antenna; this antenna length was determined to emit the highest signal strength at a frequency of 150 MHz (Beeman et al. *in press*). An 8-mm diameter hollow plastic tube was used to implant the tags through the esophagus and into the anterior part of the stomach (Plate 3). To achieve proper placement, the distance from a point 1 cm posterior of the base of the pelvic fin to the tip of the snout was used as a guide to determine how far to insert the radio tag. All radio-tagged fish were marked with a 5-mm diameter right operculum hole using a paper hole punch to quickly identify recaptured radio-tagged fish.

Chinook and sockeye salmon tags were separated into unique continuous channel sequences to separate tag detections by species. Sockeye salmon tags were programmed on 6 channels (from 150.36 to 150.46 MHz) with 20 MHz separation and about 40 codes per channel. Chinook salmon tags were programmed on 10 frequencies (150.48 and 150.62 to 150.78 MHz) with a minimum of 20 MHz separation and about 45 codes per channel. Because of the broadband detection capabilities of the GSE *Orion* receiver, the short separation between frequencies created less noise in tag detection while preventing collisions between frequencies.

A predetermined schedule was established to apply tags evenly over the run. The Chinook salmon tagging schedule was based on the most recent 6-year average run timing and the sockeye salmon tagging schedule was based on the most recent decade of run timing (Table 3). Because the run timing of Nushagak River Chinook salmon (Figure 12) and sockeye salmon (Figure 13) is variable, the tagging schedule was adjusted in-season based on the observed 2006 run timing at the Portage Creek sonar.

Beyond the daily radio tag goals, captured Chinook salmon were tagged with uniquely numbered spaghetti tags (Floy Tag and Manufacturing Inc., Seattle, WA) and marked with a 5-mm diameter hole punch in the right operculum. Spaghetti tags consisted of a 5 cm long section of 2 mm diameter PVC tubing shrunk onto a 38 cm long piece of 36 kg monofilament fishing line. Spaghetti tags were sewn through the dorsal musculature about 1 cm below the dorsal fin using a 16-gauge veterinary needle and were secured using a 1.3 mm metal crimp. All tagged fish were immediately released in available slackwater near the tagging site.

Telemetry Array

Fixed Stations

Eight fixed stations were installed to track adult Chinook and sockeye salmon migration (Table 4). Fixed stations were strategically located at the mouths of known Chinook and sockeye salmon tributaries, as well as at interim locations along the mainstem Nushagak River (Figure 11). Each station included a series of 4-element yagi antennas mounted on a 6-m tower or available tree, signal amplifiers, an antenna switching box, a GSE *Orion* receiver, a satellite transceiver, and a solar charged power system. Antennas were oriented to determine the direction of passage (i.e., mainstem vs. tributary, upstream vs. downstream). Electric fencing was installed around each fixed station to protect them from damage by wildlife.

At each fixed station, tag testing was conducted to determine the detection efficiency throughout the cross-section of the river. An active radio tag was drifted from upstream to downstream past the station in three general areas of the river: river-right, river-left, and river-center. At stations that covered two river channels, the process was repeated for each channel. The tag was attached to a line 2 m below a float with the antenna mounted in the horizontal plane; the line was weighted so the tag remained at depth. The free-floating test tag assembly was deployed from a boat approximately 200 m upstream of the station; the telemetry receiver was monitored as the radio tag drifted past the telemetry station. If necessary, test tag drifts were repeated to verify adequate detection and allow for adjustment of the input signal strength. Target signal strength at the receiver was -70 to -90 db; this range was preferred to ensure that input signals do not exceed -50 db (which may cause noise and signal identification issues), but also allowed for detection of weaker signals (e.g., -100 db) that may be the result of tags at depths greater than 2 m.

“Beacon” radio tags were deployed at each fixed station to monitor the operational performance and functionality of the station. The beacon tag, with a known code and burst rate, was anchored to the river bottom approximately 6 m offshore from the fixed station at a depth of about 2 m. The only exception to this was the beacon tag at the Koktuli River station where a deep, swift channel along the bank required that it be anchored on the opposite side of the river about 50 m from the station. Beacon tags were programmed to emit a signal every 10 minutes, resulting in a total of 6 possible tag detections each hour and 144 possible beacon tag detections each day.

The detection rates of radio-tagged fish that were subsequently detected at upstream locations (fixed stations and mobile surveys) were used to evaluate the season-long station detection efficiency of each fixed station. Radio-tagged fish were assigned a specific fate (Table 5) based on the detection history of each tag.

MOBILE SURVEYS

Mobile-tracking surveys by boat were conducted in the mainstem Nushagak River in the vicinity of Ekwok (Table 6). These surveys provided an immediate assessment of tag movement and some indication of any negative effects of the handling and tagging procedures. Mobile tracking surveys by boat were also conducted in various parts of the watershed during station data downloads and maintenance checks. A handheld Garmin Etrex global positioning system (GPS) was used to record position data and the internal clock on the telemetry receiver was synchronized with the GPS time. The location of each tag was determined by comparing the time fields in the receiver and GPS files. When tags were detected more than once, tag locations were based on the location with the highest detected signal strength.

In early August, mobile tracking surveys by fixed-wing aircraft were conducted throughout the drainage (Table 6). The timing of these aerial surveys was intended to coincide with peak Chinook salmon spawning activity. The purpose of the aerial surveys was to search for tags in areas not monitored with fixed stations and to document tag distribution of Chinook salmon in primary spawning areas. Aerial surveys were conducted from a Cessna 185 on floats, in accordance with procedures detailed in Gilmer et al. (1981) and Roberts and Rahel (2005). The target altitude was 700 ft; target speed was 70 knots. A single 4-element yagi antenna was attached to each wing strut; the intended antenna angle was about 30° to the ground surface to maximize detection capability, however, limitations of the wing strut clamp resulted in the antennas oriented toward the ground (Plate 4). A handheld GPS was used to record position data of the aircraft. The location of each tag was determined by comparing the synchronized time in the telemetry receiver and GPS files, based on the highest signal strength.

Spawning Ground Surveys

Carcass surveys were conducted in the Koktuli and King Salmon rivers to inspect Chinook salmon for marks as part of the mark-recapture study. These surveys were completed by floating each river in a non-motorized inflatable raft, which also provided an opportunity to collect mobile telemetry data. Peak spawning for Nushagak River Chinook salmon generally occurs around the first week of August, so carcass surveys began in the third week of August to allow for adequate mortality after spawning. All inspected fish were marked with a left operculum hole punch to prevent resampling. The number of marked and unmarked carcasses was recorded, and whenever possible, the length and sex of carcasses was also recorded.

Age, Sex, and Length Data

Age, sex, and length data were collected from Chinook and sockeye salmon implanted with radio tags, as well as Chinook salmon tagged with spaghetti tags. Three scales per adult Chinook salmon and one scale per adult sockeye salmon were collected on standard ADF&G scale gum cards following accepted protocols for scale collection location, scale handling, and scale orientation (INPFC 1963; Morstad et al. 2005). MEF length was measured to the nearest mm. Sex was determined using external physical characteristics (Groot and Margolis 1991). Fish age was determined by examining scale growth patterns (Mosher 1968) and European notation (Koo 1962) was used to record ages.

Testing for age- and size-selectivity was conducted to assess whether radio-tagged fish were representative of the population at large. Contingency table analyses were used to identify if there were differences in the age composition of different fish groups. The age composition of upriver migrant radio-tagged Chinook salmon (i.e., spawners and upstream migrants, see Table 5) was compared to Chinook salmon ≥ 600 mm length captured at the Portage Creek sonar site. Four comparisons were made with sockeye salmon age composition: upriver migrant radio-tagged sockeye salmon and Portage Creek sockeye salmon ≥ 400 mm length, radio-tagged sockeye salmon at Nuyakuk Tower and Nuyakuk Tower escapement ≥ 400 mm, Portage Creek sockeye salmon ≥ 400 mm and Nuyakuk Tower escapement ≥ 400 mm, and a three-way comparison of upriver migrant radio-tagged sockeye salmon, Portage Creek sockeye salmon ≥ 400 mm, and Nuyakuk Tower escapement ≥ 400 mm.

Using the same groups of fish as described above, Kolmogorov-Smirnov (KS) two- and three-sample tests were used to compare the length frequency distributions of radio-tagged and non-tagged fish.

Genetic Data

Tissue samples were collected from Chinook and sockeye salmon implanted with radio tags to supplement genetic baseline data for the Nushagak River. The axillary process adjacent to the pelvic fin was clipped and stored in individual vials according to ADF&G genetics lab protocols. The genetic samples were sent to the ADF&G genetics lab in Anchorage for analysis.

Spawning Distribution

The distribution of Chinook and sockeye salmon in spawning areas was estimated as the ratio of radio-tagged fish migrating into a specific spawning area to the total number of radio-tagged fish migrating to all spawning areas, according to the formula (Savereide 2005):

$$P_j = \frac{\sum_{i}^{days} R_{ij}}{\sum_{j}^{fates} \sum_{i}^{days} R_{ij}} \qquad (1)$$

where P_j was the proportion of fish that had fate j and R_{ij} was the number of tagged fish on day i having fate j. The variance was estimated using bootstrap resampling techniques

(Efron and Tibshirani 1993).

To derive unbiased estimates of spawning distribution from radio tag data, two assumptions must be met: radio tagging does not affect the migratory behavior (i.e., spawning destination) of the fish and fish are tagged in proportion to the magnitude and timing of the run. The migratory behavior assumption cannot be directly tested.

Radio tags were not applied in proportion to 2006 salmon passage (as estimated at Portage Creek). To account for non-proportional tagging, radio-tagged fish were given a numeric weight based on weekly fish passage at Portage Creek and the weekly number of tags applied according to Savereide (2005):

$$w_k = \frac{A_k}{x_k} \tag{2}$$

where w_k was the weighted value during period k, A_k was the estimated abundance during period k, and x_k was the number of radio tags deployed during period k. Because of the estimated travel time between Portage Creek and Ekwok, the Portage Creek abundance estimates were offset 2 days to correspond with passage at Ekwok. For each day that radio tags were deployed, the weighted radio-tag value was substituted into the spawning distribution equation above. The weighted estimate of spawning distribution was compared to the unweighted estimate with contingency table analysis.

Run Timing

Escapement timing patterns were described as time-density functions of the number of fish bound for a given tributary on a given day according to the equation (Savereide 2005):

$$f_j(t) = \frac{R_{tj}}{\sum_{i}^{days} R_{ij}} \tag{3}$$

where $f_j(t)$ was the empirical temporal probability distribution over the entire run for fish spawning in tributary j, R_{tj} was the subset of radio-tagged fish bound for tributary j that are caught and tagged during day t, and the denominator was the total number of radio-tagged fish bound for tributary j (Savereide 2005). The mean date of passage (t_j) at the tagging site for fish spawning in tributary j was estimated as:

$$\bar{t}_j = \sum_t t f_j(t) \tag{4}$$

and the variance of the run timing was estimated as:

$$Var(t_j) = \sum_t (t - \bar{t}_j)^2 f_j(t) \tag{5}$$

The same assumptions described for estimating the spawning distribution also apply to deriving unbiased estimates of stock-specific run timing. Thus, to account for possible bias associated with non-proportional tagging, radio-tagged fish were weighted as described above to estimate stock-specific cumulative run timing at Ekwok.

Abundance Estimate

ASSUMPTIONS FOR UNBIASED ESTIMATE

A number of conditions must be met for mark-recapture methods to produce an unbiased estimate of abundance (Seber 1982), including:

1) Every fish has an equal probability of being captured and marked, or every fish has an equal probability of being recaptured, or marked fish mix completely with unmarked fish between capture and recapture events;
2) Recruitment (immigration) and death (emigration) does not occur between capture events;
3) Marking does not affect the catchability of fish;
4) Fish do not lose their marks between capture events; and
5) Individual tagged fish are recognized and not counted twice.

Assumption 1 was tested using a contingency table analysis and the chi-square statistic to determine whether all fish had an equal probability of being captured and an equal probability of being recaptured over time. KS tests were used to determine whether fish of different sizes were marked, examined, and recaptured with equal probability.

Assumption 2 could not be tested directly. Given how far upriver the tagging site was, it seemed valid that the sockeye salmon in the Nushagak River were a ‘closed’ population. The capture and tagging locations were upstream of the commercial fishery and sport fishery harvest of sockeye salmon is uncommon. Subsistence fishery harvest occurs between the tagging and recapture locations, near the villages of Ekwok, New Stuyahok, and Koliganek. The actual subsistence harvest of Chinook and sockeye salmon is not known but is small relative to the total run. To account for harvest between the marking and recapture events, we assumed that radio-tagged sockeye were harvested at the same rate as untagged sockeye salmon but did not have a good estimate of the sockeye subsistence harvest. The 2005 subsistence salmon harvest for Ekwok, New Stuyahok, and Koliganek was 13,021 fish (Westing et al. 2006). The proportion of this harvest composed of sockeye salmon cannot be reliably determined, although a reasonable estimate would be about 12,000 fish (assuming subsistence harvest was 90% sockeye salmon).

Assumption 3 could not be directly tested, but was expected to be satisfied. Only radio-tagged sockeye passing the Ekwok station were considered to be available for recapture. In the recapture event, marked fish were not captured but instead were detected as they passed by the Nuyakuk Tower fixed station. Because the Nuyakuk Tower fixed station operated well for most of the season (particularly during Nuyakuk River escapement timing), we expected the probability of a radio-tagged fish being detected to be consistent throughout the season.

Assumption 4 could not be directly tested, but was expected to be met. If a sockeye salmon did not regurgitate the radio tag shortly after tag insertion, we expected the tag to be retained.

Assumption 5 was met for tagged fish because they are uniquely marked. In the case of the Nuyakuk tower escapement, ADF&G counts both upstream and downstream migrating fish. To the extent the crew can accurately count downstream migrants, the tower count represents an unbiased count of marked and unmarked fish.

CHINOOK SALMON

We intended to use two-sample mark-recapture techniques to estimate the inriver abundance of Chinook salmon passing the Ekwok tagging site. Marked fish for the first event comprised radio-tagged Chinook salmon migrating upstream of the Ekwok Station and an adjusted number of spaghetti-tagged Chinook salmon based on the proportion of radio-tagged Chinook salmon that migrated upstream. The methods of Robson and Regier (1964) were used to determine sample sizes assuming a pre-season population estimate of 100,000 and a target abundance estimate with error less than 25% of the true value 95% of the time. The target sampling goal was 2,000 marked fish released into the population. Fish examined for marks during carcass surveys constituted the second event. The target sampling goal was 3,309 Chinook salmon examined for marks. Radio- and spaghetti-tagged Chinook salmon constituted the marked portion of the second sample.

SOCKEYE SALMON

A system-wide sockeye salmon abundance estimate was calculated using the number of upriver migrant radio-tagged sockeye salmon released in the lower Nushagak River, the number of radio-tagged sockeye salmon detected at the Nuyakuk Station, and the abundance estimate at the Nuyakuk counting tower. A temporally stratified estimator using Darroch's (1961) method was used to estimate abundance.

The methods of Robson and Regier (1964) were used to determine the appropriate sample sizes necessary to achieve 25% accuracy and 95% precision, assuming a pre-season population estimate of 550,000. If the target sampling goal of 200 marked fish released into the population was met, then 142,304 sockeye salmon must be examined for marks.

RESULTS

Capture and Tagging

In total, 578 Chinook salmon and 261 sockeye salmon were captured from June 12 to July 16 at 12 different sites in the lower Nushagak River (Figure 10). Of those captured, 474 (82%) Chinook salmon and 222 (85%) sockeye salmon were radiotagged. Sites 4, 9, and 10 were the primary capture locations and accounted for 86.7% of radio-tagged Chinook salmon and 93.2% of radio-tagged sockeye salmon (Table 7). Drift gillnets were used to capture 98% of Chinook salmon and 90% of sockeye salmon (Table 8).

We adjusted our Chinook and sockeye salmon tagging schedules (Table 3) inseason based on the observed 2006 run timing at the Portage Creek sonar site. However, we did not observe a relationship between the Portage Creek estimates and the catch efficiency of our gear at Ekwok (Figure 14).

Consistent tag rates for Chinook salmon (Figure 15) and sockeye salmon (Figure 16) over the season were not attained. In 2006, daily tag rates for Chinook salmon ranged from 0.001 to 0.06 of fish counted at the sonar site, and 0.0001 to 0.007 of fish counted at the sonar site for sockeye salmon. Based on escapement estimates and the number of radio tags deployed, stable tag rates would have been one tag deployed for every 236 Chinook salmon in the escapement and one tag for every 2,470 sockeye salmon in the escapement.

Telemetry Array

Fixed Stations

Fixed stations were operated from early June through August (Table 4). The satellite transceivers were removed from each station by June 20, 2006, because they created considerable radio-frequency noise and used more power than anticipated.

During station testing, the test tag was typically detected at signal strengths from -91 dB to -100 dB, slightly above the target signal strength range of -70 dB to -90 dB. The test tag was first detected at distances near 150 m upstream of the station; the tag signal drifted out of range of the station at similar distances downstream. At those stations with detection distances approaching 200 m (i.e., Ekwok, Mulchatna, Nuyakuk Mouth), the test tag was intermittently detected at target strengths near -100 dB in areas farthest from the station. The default signal strength noise floor (-100 dB) was adjusted at these stations so weaker tag signals could be detected. The adjusted noise floor levels resulted in more frequent test tag detections in areas farthest from the station. The noise floor setting of -110 dB for the Ekwok station and -105 dB for the Mulchatna and Nuyakuk Mouth stations was a compromise between increasing the ability to detect weak tag signals while minimizing the amount of radio frequency noise detections.

The number of hourly beacon signals detected at each station identified the number of hours each day the station was operating (Table 9). Periods when the fixed stations were not operating properly were caused by a lack of power from a combination of factors: higher than anticipated power draw from satellite modems (prior to June 27 when they were removed), lack of consistent sunlight to solar panels, incorrectly wired solar panels, damaged wiring, and insufficient time to restore batteries to a fully-charged condition. During periods of station operation, beacon tag detections less than 24 hours indicated that detection conditions were not always optimal.

The detection efficiency of the mainstem fixed stations (i.e., Ekwok, Mulchatna, and Nuyakuk Mouth) was relatively low while the detection efficiency of most tributary stations was relatively high (Table 10). The detection efficiency of the Koktuli and

Klutuspak stations were biased low because these stations were installed adjacent to side channels and were not expected to detected fish migrating upstream in the mainstem of the Mulchatna or Nushagak rivers.

MOBILE SURVEYS

The mobile survey zones are described in Table 6. Successive mobile surveys provided repetitive zone coverage; repeat detections confirmed the location of some radio tags (Table 11). A total of 36 radio tags were detected during mobile surveys that were not detected by fixed stations (Table 12). Most of these mobile survey detections were located in zones in the lower part of the watershed (Table 12).

Boat surveys were conducted from Ekwok on July 1, July 9, July 17, and July 18. Tag distribution data are not available for the July 1 or July 17 surveys because of problems with the GPS files; the July 1 survey was conducted near Ekwok and the July 17 survey was conducted between Ekwok and the Nuyakuk Tower station. The July 9 survey covered all capture locations near Ekwok (Figure 17). Most fish detected during this survey represent fish that never moved upstream, although a few were recent tag releases that were later detected at upstream stations. The July 18 survey was conducted between Ekwok and the Koktuli station, while traveling to service the Stuyahok and Koktuli stations (Figure 18). Tags detected in the mainstem Nushagak were not generally detected at upstream fixed stations, while many of the tags detected in the Mulchatna River were later detected at either the Stuyahok or Koktuli stations.

Aerial surveys were conducted on August 2 and August 6. The August 2 survey covered the mainstem Nushagak, Nuyakuk, and King Salmon rivers and Klutuspak Creek (Figure 19). The August 6 survey covered the mainstem Nushagak, Mulchatna, Stuyahok, and Koktuli rivers (Figure 20). Both surveys reveal tag distribution at the time of suspected peak Chinook salmon spawning. Most tags detected in spawning tributaries were previously detected at the fixed station that monitored that tributary.

Spawning Ground Surveys

Carcass surveys were conducted on the Koktuli River from August 14 to August 16 and the King Salmon River from August 18 to August 20. Water levels and turbidity were very high; only 12 Chinook salmon carcasses were examined during the surveys (Table 13). During these surveys, 19 radio-tagged Chinook salmon were tracked in the Koktuli River (Figure 21) and 31 Chinook salmon were tracked in the King Salmon River (Figure 22). Tags detected during these surveys correspond well with the previous aerial surveys and tag detections at the fixed stations.

Age, Sex, and Length Data

Dominant age groups for radio-tagged Chinook and sockeye salmon were age 1.3 and age 1.4 (Table 14). Radio-tagged Chinook salmon were composed of 53% males, whereas sockeye salmon consisted of 76% males. On average, female Chinook salmon (804 mm) were larger than males (756 mm), while male sockeye salmon (561 mm) were larger than females (542 mm).

The age composition of upriver migrant radio-tagged Chinook salmon was significantly different than the age composition of Chinook salmon escapement $\geq$ 600 mm length at Portage Creek (Table 15).

The age composition of different groups of radio-tagged sockeye salmon was compared to sockeye salmon escapement at Portage Creek and the Nuyakuk Tower (Table 16). There was a significant difference in age composition for each comparison of these fish groups (Table 16).

The cumulative length-frequency distribution of upriver migrant radio-tagged Chinook salmon was not significantly different than the cumulative length-frequency distribution of Chinook salmon captured at Portage Creek (D = 0.07, p = 0.3, Figure 23). There was a significant difference in the length frequency distribution of upriver migrating sockeye salmon and sockeye salmon $\geq$ 400 mm at the Portage Creek sonar site (D = 0.26, p = 0.00, Figure 24). The length frequency distribution of radio-tagged sockeye salmon detected at the Nuyakuk Tower fixed station was significantly different than the length frequency of sockeye salmon escapement $\geq$ 400 mm past the Nuyakuk Tower (D = 0.41, p = 0.00, Figure 25). There was also a significant difference in the size distribution of Portage Creek and Nuyakuk River sockeye salmon (D = 0.17, p = 0.00, Figure 24).

Genetic Data

At the time of report publication, genetic samples of radio-tagged Chinook and sockeye salmon had been added to the ADF&G archive; there were no plans to analyze the samples.

Spawning Distribution

Of the 474 radio-tagged Chinook salmon, 261 (55%) were confirmed to enter spawning areas in the upper river (Table 17). The Mulchatna River accounted for 37% of the Chinook salmon spawners, with most fish located in the Koktuli River and the lower reaches of the mainstem (Table 18, Figure 26). The upper Nushagak River accounted for 53% of the Chinook salmon spawners, with most fish located in the King Salmon River and the lower mainstem (Table 18, Figure 26). The Nuyakuk River accounted for about 10% of the Chinook salmon spawners (Table 18, Figure 26). The weighted estimate of Chinook salmon spawning distribution was not significantly different from the unweighted estimate (χ^2 = 0.005, p = 1.00).

Of the 222 radio-tagged sockeye salmon, 154 (69%) were confirmed to enter upriver spawning areas (Table 17). The Mulchatna River accounted for 22% of the sockeye salmon spawners, with most located in the Koktuli River (Table 19, Figure 26). The upper Nushagak River accounted for 32% of the sockeye salmon spawners, with most located in the King Salmon River and the lower mainstem (Table 19, Figure 26). The Nuyakuk River accounted for about 46% of the sockeye salmon spawners; most of these were above the Nuyakuk counting tower (Table 19, Figure 26). Similar to Chinook salmon, the weighted spawning distribution estimates for sockeye salmon were not significantly different from the unweighted estimates ($\chi^2 = 0.02$, $p = 1.00$).

Run Timing

The mean date of passage at Ekwok for most Chinook salmon stocks was late June; fish from these Chinook salmon stocks passed Ekwok over a period of 26 to 30 days (Table 20). The only exception was Chinook salmon destined for the Stuyahok River that migrated a little later and were present for a shorter period of time (Table 20). However, the run-timing statistics of Stuyahok River Chinook salmon may be affected by the small sample size relative to the other tributaries. Cumulative run-timing curves demonstrate that the Koktuli and King Salmon River Chinook salmon stocks have comparable run timing, while Klutuspak Creek and Stuyahok River Chinook salmon run timing differs (Figure 27). For each Chinook salmon stock, the weighted run timing estimate was not significantly different than the unweighted estimate.

The mean date of passage at Ekwok for Nuyakuk River sockeye salmon was July 5; Ekwok passage occurred from June 25 to July 16 (Table 20). However, Nuyakuk River sockeye salmon were likely present at Ekwok after tagging operations ceased on July 16. Other sockeye salmon stocks passed Ekwok earlier and were present for a shorter period of time (Table 20), although these data are likely affected by small sample size. Cumulative run-timing curves for the major Nushagak River sockeye salmon stocks were quite different (Figure 28). For each sockeye salmon stock, the weighted run timing estimate was not significantly different than the unweighted estimate.

Migration rates of Chinook salmon were fairly consistent and ranged from 11 to 15 km/d (Table 21). Migration rates of sockeye salmon were more variable and ranged from 10 to 20 km/d (Table 21). The travel time and migration rate of radio-tagged sockeye salmon were consistent with the estimated travel time between Portage Creek and the Nuyakuk Tower (Figure 8). Travel time was used as an indirect measure of whether marking affected fish behavior (i.e., ultimate spawning destination); the spawning distribution and run timing estimates do not appear to be biased by altered migratory behavior.

Abundance Estimate

ASSUMPTIONS FOR UNBIASED ESTIMATE

Contingency table analysis indicated that, over time, sockeye salmon had an unequal probability of being marked at Ekwok and an unequal probability of being recaptured at the Nuyakuk Tower fixed station (assumption 1; Table 22). Thus, a temporally stratified estimator was needed to provide an unbiased estimate of sockeye salmon abundance. The cumulative length-frequency distribution of fish marked (M) in the first sampling event was not statistically different than the cumulative length-frequency distribution of marked fish recaptured (R) in the second sampling event ($D = 0.09$, $p = 0.72$; Figure 29). However, we found a significant difference between the cumulative length-frequency distributions of fish inspected (C) and recaptured (R) during the second sampling event ($D = 0.41$, $p = 0.00$; Figure 29). These tests indicate that there was no size selectivity in the second event, but there was during the first event. In this case, stratification by size was not required to estimate abundance (Bernard and Hansen 1992, Smith et al. 2006).

CHINOOK SALMON

Not enough Chinook salmon were marked and examined for a reliable abundance estimate in 2006. The number of Chinook salmon captured and marked in the lower Nushagak River (i.e., 565) was limited by the type of gear used and the amount of fishing effort. The number of Chinook salmon examined for marks was limited by the water level and water visibility conditions during the carcass surveys.

SOCKEYE SALMON

For the marked sample, an estimated 182 radio-tagged sockeye salmon were detected at or above the Ekwok Station. For the second event, an estimated 170,760 sockeye salmon were counted at the Nuyakuk Tower and 66 radio-tagged sockeye salmon were detected at or above the Nuyakuk Tower fixed station during the tower's operational period. Using these data and a temporally-stratified Darroch (1961) estimator with 2 marking strata and 3 recapture strata (Table 22), an estimated 558,852 (SE = 82,423) sockeye salmon passed Ekwok from June 16 to July 16, 2006.

DISCUSSION

In 2006, we accomplished the study's primary objectives. We identified major spawning areas and estimated the proportion of spawning Chinook and sockeye salmon in each, described the stock-specific run timing for Chinook and sockeye salmon passing Ekwok, and estimated the system-wide abundance of sockeye salmon returning to the Nushagak River. However, the secondary objective of estimating the system-wide abundance of Chinook salmon was not possible because we were unable to mark and recapture adequate numbers of fish.

We experienced two problems with our radiotelemetry equipment in 2006 that decreased the detection efficiency of radio tags at fixed stations and during mobile surveys. First, early-season, fixed-station configuration and testing indicated that the signal strength of the radio tags was weaker than anticipated, and weaker than the same model of radio tags that were used during the 2005 study. Post-season testing by the radio-tag manufacturer confirmed this finding (Cam Grant, Grant Systems Engineering, personal communication). Second, the batteries at some fixed stations were unable to maintain adequate power storage which resulted in periods when the stations were not operational (Table 9). This problem was caused by a number of factors, including: high power consumption of satellite modems and minimal power input from solar panels because of shading, overcast weather, wiring, and inadequate time to restore batteries to a fully-charged condition. These operational issues explain the relatively high proportion of radio tags that went undetected (Table 17) and the relatively low detection efficiency of mainstem fixed stations (Table 10).

The poor performance of fixed stations prior to June 20 did not substantially affect the results of the study because few radio tags had been deployed by this time. The poor performance of the Mulchatna, Stuyahok, and Koktuli stations in late June to early July and the Ekwok and King Salmon stations in late July to early August resulted in undetected radio-tagged fish. The mobile surveys accounted for a portion of these previously undetected radio tags (Table 12).

Radio-tagged Chinook and sockeye salmon were useful for making inferences about the population. We expected the age composition of radio-tagged fish to differ from other fish groups because of differences in capture gear and capture methods (Table 15 and Table 16). Similarly, we expected the length frequency of Nuyakuk sockeye to differ from other sockeye groups (Figure 24). The difference in radio-tagged sockeye length frequency and other sockeye groups is likely related to the sensitivity of the KS test to small differences in length when samples sizes are large; it is unlikely that the measured statistical differences are biologically meaningful. The length frequency of radio-tagged Chinook salmon were not significantly different than Chinook salmon $\geq$ 600 mm length passing Portage Creek (Figure 23).

Chinook salmon spawning distribution in the Nushagak River has been previously described by Nelson (1987) and Dye (2005; Table 1). The 2006 Nushagak River Chinook salmon spawning distribution (Table 18 and Figure 26) was relatively consistent with these former accounts. The King Salmon, Koktuli, mainstem Mulchatna, and upper mainstem Nushagak rivers and Klutuspak Creek were important spawning areas in 2006. However, the importance of mainstem spawning areas in 2006 may be overstated because radio-tagged Chinook salmon detected at mainstem fixed stations but not confirmed in other spawning areas were considered mainstem spawners. Chinook salmon spawning in the upper Mulchatna River (i.e., above the Koktuli River) was likely underrepresented because of the configuration of fixed stations and the lack of aerial coverage during mobile surveys. The 2006 radiotelemetry data suggest that Chinook salmon spawning in the Stuyahok River was lower than expected while spawning in the Nuyakuk River was higher than expected.

The 2006 radiotelemetry data suggest that the Nuyakuk, upper Nushagak, and Mulchatna rivers are important spawning areas for Nushagak River sockeye salmon (Table 19 and Figure 26). Historically, the upper Nushagak River has not been considered an important spawning area. The proportion of sockeye salmon spawners in the Mulchatna River (Table 19) was considerably lower than recent estimates (Figure 9). Similar to Chinook salmon, sockeye salmon spawning in the upper Mulchatna River may be underestimated because of the configuration of fixed stations and the lack of coverage during mobile surveys.

The 2006 Chinook salmon escapement at Portage Creek was characterized by a large spike early in the season, followed by peak movement that was similar to historical run timing (Figure 30). We found no evidence in Ekwok of the early season pulse of fish recorded at Portage Creek. Nushagak River Chinook salmon stocks passed Ekwok from mid-June to mid-July (Table 20). The date of 50% passage at Ekwok for Chinook salmon stocks was about July 1 (Figure 27).

The 2006 sockeye salmon escapement at Portage Creek was characterized by a large spike early in the season, followed by steady movement throughout the rest of the season (Figure 31). Sockeye salmon passage at Ekwok occurred from late June until July 16 (Table 20); sockeye salmon were abundant in the Ekwok area when tagging ended. The date of 50% passage at Ekwok for sockeye salmon destined for the Koktuli and King Salmon rivers was 5 to 7 days early than Nuyakuk River sockeye salmon (Figure 28). Other researchers have observed a similar pattern of salmon stocks spawning further from the river mouth exhibiting earlier run timing (Merritt and Roberson 1986, Saveriede 2005, Eiler et al. 2006).

An estimated 558,852 sockeye salmon returned to the lower Nushagak River in 2006. This estimate was only 1.9% more than the Portage Creek sonar estimate of 548,410 sockeye salmon. Although the system-wide estimates from both methods were similar, estimates of each component of the sockeye salmon run differed considerably. The spawning distribution estimated from radio-tagged sockeye salmon suggests that the 2006 sockeye salmon run consisted of 46% Nuyakuk, 22% Mulchatna, and 32% upper Nushagak. However, the estimates of 548,410 Portage Creek sockeye salmon and 170,760 Nuyakuk Tower sockeye salmon result in an allocation of 31% Nuyakuk River sockeye salmon (compared to the 46% based on telemetry results).

Multiple sources of bias can affect the sockeye salmon abundance estimate, particularly disproportionate harvest of untagged and radio-tagged sockeye salmon in the subsistence fishery between Ekwok and the Nuyakuk Tower and periods at the beginning and end of sockeye salmon passage at the Nuyakuk Tower when no recaptures were reported.

Subsistence harvest occurs near the villages of Ekwok, New Stuyahok, and Koliganek. Most subsistence harvest near Ekwok occurs downstream of the Ekwok fixed station and does not need to be taken into account for the abundance estimate. The 2005 subsistence salmon harvest for New Stuyahok and Koliganek was 10,405 fish (Westing et al. 2006). The proportion of this harvest composed of sockeye salmon cannot be reliably determined, although we assumed that 90% (about 9,000 fish) were sockeye salmon. Considering the overall 2006 tag rate of 1 radio tag for every 2,470 sockeye salmon, we would expect about 4 radio-tagged sockeye to be included in this harvest. Two radio-tagged sockeye salmon were reported as harvested in the subsistence fishery in 2006. Thus, we have no evidence that untagged and radio-tagged sockeye salmon were unequally harvested in the subsistence fishery and assumed that the potential bias was minor.

Generating a reliable abundance estimate for Chinook salmon was not possible because of an inability to meet sample-size requirements. Considering the 2006 escapement estimate of 124,683 Chinook salmon and 565 tags released into the population, an abundance estimate with 25% accuracy and a 95% relative precision would require about 13,660 Chinook salmon to be examined in the second event (Robson and Regier 1964). Although attaining these sample sizes may be possible, it is not practical with realistic funding limitations.

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TABLES

Table 1. Aerial escapement index counts of Chinook salmon in the Nushagak and Mulchatna rivers, 1967 to 1999.

Year	Nushagak River					Mulchatna River			
	Iowithla River	Kokwok River	Klutuspak Creek	King Salmon River	Nushagak River[a]	Stuyahok River	Koktuli River	Mulchatna River[b]	Nushagak Drainage Total
1967	200	-	-	-	-	2,500	3,300	-	6,000
1968	850	-	310	1,000	970	2,470	4,220	510	10,330
1969	580	90	90	670	910	1,220	1,600	680	5,840
1970	700	110	320	1,060	1,180	1,900	1,500	880	7,650
1971	390	80	-	-	-	-	-	-	470
1972	170	-	280	900	690	610	1,450	510	4,610
1973	-	-	380	1,470	-	1,220	950	-	4,020
1974	860	60	440	2,000	2,340	2,300	3,920	2,160	14,080
1975	1,040	270	670	2,900	2,320	2,530	4,080	1,710	15,520
1976	1,110	560	1,180	3,510	1,760	3,750	6,710	2,580	21,160
1977	840	310	650	1,420	820	2,700	4,630	1,980	13,350
1978	1,700	520	1,940	4,450	5,850	4,400	6,730	2,280	27,870
1979	1,350	170	1,040	2,150	2,880	3,570	6,260	1,730	19,150
1980	2,310	70	970	4,500	5,300	7,200	10,620	3,920	34,890
1981	2,630	70	1,650	2,950	4,960	5,980	9,960	3,670	31,870
1982	2,520	90	350	8,390	4,380	3,640	6,780	3,240	29,390
1983	2,430	350	2,090	5,990	6,330	2,910	8,060	4,260	32,420
1984	1,080	110	770	1,780	2,800	2,010	2,860	1,060	12,470
1985	1,610	60	1,950	4,460	3,420	2,690	4,940	2,390	21,520
1986	270	-	170	380	380	520	290	260	2,270
1987	140	-	340	570	390	280	440	270	2,430
1988	550	-	780	1,380	1,800	2,040	2,580	710	9,840
1989	-	-	-	-	-	190	240	-	430
1990	120	-	340	900	630	830	3,390	800	7,010
1991	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-
1995	170	75	630	3,150	-	660	2,230	-	6,915
1996	-	-	-	-	-	-	-	-	-
1997[c]	640	-	1,190	8,900	21,818	1,460	6,220	1,496	41,724
1998	-	150	2,620	5,510	8,390	550	720	180	18,120
1999	450	145	1,545	6,825	6,467	645	2,075	-	18,152
Min	120	60	90	380	380	190	240	180	430
Max	2,630	560	2,620	8,900	21,818	7,200	10,620	4,260	41,724
Avg	988	183	908	3,089	3,773	2,251	3,954	1,694	16,840
Percent	6%	1%	5%	18%	22%	13%	23%	10%	

[a]Includes upper Nushagak River, from Nuyakuk River to King Salmon River (up to Big Bend in 1997).

[b]Includes Mulchatna River, from Koktuli River to Mosquito Creek (down to Stuyahok in 1997).

[c]The excellent survey conditions (water clear and low) in 1997 produced the highest aerial survey count.

Table 2. Schedule of Activities - Nushagak Radiotelemetry Study, 2006.

Activity	Timing	Description
Setup	29 May - 6 June	Install and test eight fixed telemetry stations
Field Camp Mobilization	7 June - 11 June	Mobilize personnel and gear to Ekwok
Tagging	12 June - 16 July	Tag and release in lower Nushagak River
Monitoring	12 June - 1 September	Collect data from stations; boat surveys in lower river
In-season Analysis	12 June - 16 July	Review data to determine adjustments
Aerial Survey	1 - 6 August	Establish tag distribution during peak spawning
Spawning Ground Survey	13 - 23 August	Carcass/tag recovery in primary spawning areas

Table 3. Proposed radio tag distribution based on recent Nushagak River Chinook salmon (2000-2005) and sockeye salmon (1996-2005) run timing at Portage Creek.

Species	Time Period	Historical Run Passage	Days in Time Period	Total Tags for Time Period	Daily Tag Distribution
Chinook	6/8 – 6/18	First 20%	11	90	8-9
	6/19 – 7/3	Peak Passage	15	270	18
	7/4 – 7/20	Last 20%	17	90	5-6
Total Tags				**450**	
Sockeye	6/18 – 6/26	First 20%	9	50	5-6
	6/27 – 7/8	Peak Passage	12	150	12-13
	7/9 – 7/16	Last 20%	8	50	6-7
Total Tags				**250**	

Table 4. Description of fixed stations used to detect radio-tagged fish, 2006.

Station	Dates of Operation	General Location	GPS Location (WGS 84 datum)	# of Antennas	Height (m) above Water	Channel Width (m)	Purpose
Ekwok	June 10 - August 31	Mid-channel island in mainstem Nushagak River near Ekwok	N 59°22.248 W 157°25.066	3	10	West Ch-186 East Ch-197	Identify upstream movement; Starting point for migration rate estimates
Mulchatna	June 4 - August 16	Island at confluence of Nushagak and Mulchatna rivers	N 59°37.781 W 157°06.339	3	7	Nush-236 Mulch-185	Detect tags entering the Mulchatna River or continuing upstream in the Nushagak River
Stuyahok	June 6 - August 22	Upstream side of Stuyahok and Mulchatna River confluence	N 59°50.007 W 156°41.716	3	10	Stuy-55 Mulch-139	Detect tags entering the Stuyahok River or continuing upstream in the Mulchatna River
Koktuli	June 5 - August 11	75 m upstream of mouth of Koktuli River	N 59°55.947 W 156°25.590	2	10	Kok-55	Detect tags entering the Koktuli River
Nuyukuk Mouth	June 4 - August 27	Island at confluence of Nushagak and Nuyakuk rivers	N 59°48.141 W 157°26.245	3	10	Nush-177 Nuy-183	Detect tags entering the Nuyakuk River or continuing upstream in the Nushagak River
Nuyakuk Tower	June 3 - August 30	Nuyakuk escapement counting tower site	N 59°52.933 W 157°33.620	2	10	Nuy-103	Detect tags migrating passed Nuyakuk tower; Provide proportion of Nuyakuk escapement that was radiotagged
Klutuspak	June 2 - August 31	50 m upstream of mouth of Klutuspak Creek	N 60°02.863 W 157°21.892	2	8	Klut-46	Detect tags entering Klutuspak Creek
King Salmon	June 1 - August 28	Island at confluence of Nushagak and King Salmon rivers	N 60°15.484 W 157°17.200	3	10	Nush-137 KingSal-65	Detect tags entering the King Salmon River or continuing upstream in the Nushagak River

Table 5. List of possible fates of radio-tagged salmon in the Nushagak River, 2006.

Fate	Description
Fishery Mortality	A fish harvested in subsistence or sport fisheries upstream of Ekwok.
Spawner	A fish that migrates into a spawning area (mainstem Mulchatna, upper Nushagak, or tributary). There are a number of sub-fates under this fate, depending on the specific spawning area.
Upstream Migrant	A fish that migrates upstream of the Ekwok Station, is never reported harvested, and is never located in a spawning area.
Not Detected	A fish that is never detected after release.
Failure	A fish that is consistently detected downstream of the tagging area.

Table 6. Description of fixed station and mobile survey zones used to track radio-tagged Chinook and sockeye salmon in the Nushagak River, 2006.

Zone #	River	Description
5	Nushagak	Mobile - Nushagak River, below Ekwok Station
-1	Nushagak	Release sites in mainstem Nushagak River near Ekwok
11	Nushagak	Ekwok Station, antenna 1, west channel
12	Nushagak	Ekwok Station, antenna 2, east channel
13	Nushagak	Ekwok Station, antenna 3, downstream main channel
15	Nushagak	Nushagak River, Ekwok Station to Mulchatna Station
21	Nushagak	Mulchatna Station, antenna 1, downstream mainstem Nushagak
22	Nushagak	Mulchatna Station, antenna 2, upstream Nushagak
23	Mulchatna	Mulchatna Station, antenna 3, upstream Mulchatna
25	Mulchatna	Mobile - Mulchatna River, mouth to Stuyahok River
26	Nushagak	Mobile - Nushagak River, Mulchatna Station to Nuyakuk Mouth Station
31	Mulchatna	Stuyahok Station; antenna 1, downstream Mulchatna
32	Stuyahok	Stuyahok Station; antenna 2, upstream Stuyahok
33	Mulchatna	Stuyahok Station; antenna 3, upstream Mulchatna
35	Mulchatna	Mobile - Mulchatna River, Stuyahok Station to Koktuli Station
35	Stuyahok	Mobile - Stuyahok River, above Stuyahok Station
41	Koktuli	Koktuli Station, antenna 1, downstream Koktuli, Mulchatna side channel
42	Koktuli	Koktuli Station, antenna 2, upstream Koktuli
45	Koktuli	Mobile - Koktuli River, above Koktuli Station
46	Mulchatna	Mobile - Mulchatna River, above Koktuli Station
51	Nushagak	Nuyakuk Mouth Station, antenna 1, downstream Nushagak
52	Nushagak	Nuyakuk Mouth Station, antenna 2, upstream Nushagak
53	Nuyakuk	Nuyakuk Mouth Station, antenna 3, upstream Nuyakuk
55	Nuyakuk	Mobile - Nuyakuk River, Nuyakuk Mouth Station to Nuyakuk Tower Station
56	Nushagak	Mobile - Nushagak River, Nuyakuk Mouth Station to Klutuspak Station
61	Nuyakuk	Nuyakuk Tower Station, antenna 1, downstream Nuyakuk
62	Nuyakuk	Nuyakuk Tower Station, antenna 2, upstream Nuyakuk
65	Nuyakuk	Mobile - Nuyakuk River, above Nuyakuk Tower Station
71	Klutuspak	Klutuspak Station, antenna 1, downstream Klutuspak, Nushagak side channel
72	Klutuspak	Klutuspak Station, antenna 2, upstream Klutuspak
75	Nushagak	Mobile - Nushagak River, Klutuspak Station to King Salmon Station
75	Klutuspak	Mobile - Klutuspak Creek, above Klutuspak Station
81	Nushagak	King Salmon Station, antenna 1, downstream Nushagak
82	Nushagak	King Salmon Station, antenna 2, upstream Nushagak
83	King Salmon	King Salmon Station, antenna 3, upstream King Salmon
85	King Salmon	Mobile - King Salmon River, above King Salmon Station
86	Nushagak	Mobile - Nushagak River, above King Salmon Station

Table 7. Number and percent of radio-tagged Chinook and sockeye salmon, by capture site, 2006.

Species		Capture Site[a]												Total
		1	2	3	4	5	6	7	8	9	10	11	12	
Chinook	n	15	26	3	196	5	2	2	3	174	41	2	5	474
	%	3.2	5.5	0.6	41.4	1.1	0.4	0.4	0.6	36.7	8.6	0.4	1.1	
Sockeye	n	5	6	1	13	1	2	0	0	92	102	0	0	222
	%	2.3	2.7	0.5	5.9	0.5	0.9	-	-	41.4	45.9	-	-	

[a] Capture site locations are depicted in Figure 10.

Table 8. Number and percent of radio-tagged Chinook and sockeye salmon, by capture gear, 2006.

Species		Capture Gear: Drift Gillnet	Set Gillnet	Beach Seine	Hook and Line	Total
Chinook	n	464	2	3	5	474
	%	97.9	0.4	0.6	1.1	
Sockeye	n	200	1	21	0	222
	%	90.1	0.5	9.5	0.0	

Table 9. Number of hours per day that each fixed station was operating properly, based on beacon tag detections.

	Station							
Date	Ekwok	Mulchatna	Stuyahok	Koktuli	Nuyakuk Mouth	Nuyakuk Tower	Klutuspak	King Salmon
6/1	-	-	-	-	-	-	-	5*
6/2	-	-	-	-	-	-	9*	**24**
6/3	-	-	-	-	-	10*	**24**	**24**
6/4	-	*	-	-	*	**24**	**24**	**24**
6/5	-	-	-	10*	-	**24**	**24**	16
6/6	-	-	9*	**24**	-	**24**	**24**	0
6/7	-	-	**24**	**24**	-	**24**	**24**	0
6/8	-	-	**24**	**24**	-	**24**	**24**	0
6/9	-	-	**24**	**24**	-	**24**	5	0
6/10	8*	-	**24**	**24**	-	23	0	0
6/11	**24**	10	**24**	**24**	7	**24**	0	0
6/12	**24**	9	**24**	**24**	**24**	22	0	0
6/13	**24**	0	**24**	1	**24**	17	0	0
6/14	**24**	0	**24**	0	1	**24**	0	0
6/15	**24**	0	**24**	0	0	23	0	0
6/16	**24**	0	**24**	0	0	11	0	0
6/17	**24**	14	**24**	0	0	0	0	0
6/18	**24**	**24**	**24**	0	0	0	0	0
6/19	**24**	**24**	**24**	6	0	0	0	9
6/20	**24**	23	**24**	**24**	10	3	0	**24**
6/21	**24**	**24**	23	4	**24**	8	0	**24**
6/22	**24**	**24**	**24**	0	**24**	11	12	**24**
6/23	**24**	5	**24**	0	**24**	9	23	**24**
6/24	**24**	0	**24**	0	**24**	11	23	**24**
6/25	**24**	0	**24**	0	**24**	6	22	**24**
6/26	**24**	0	**24**	0	**24**	8	**24**	23
6/27	**24**	0	**24**	0	**24**	7	20	**24**
6/28	**24**	7	22	0	**24**	8	**24**	**24**
6/29	**24**	**24**	0	0	**24**	4	20	22
6/30	**24**	**24**	0	0	**24**	6	22	**24**
7/1	**24**	**24**	0	0	**24**	7	23	23
7/2	**24**	**24**	0	0	**24**	9	23	23
7/3	**24**	**24**	0	0	**24**	12	**24**	**24**
7/4	**24**	**24**	0	0	**24**	23	**24**	**24**
7/5	**24**	**24**	0	8	**24**	23	**24**	**24**
7/6	**24**	**24**	11	**24**	**24**	**24**	**24**	**24**
7/7	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**
7/8	**24**	**24**	**24**	**24**	**24**	23	**24**	**24**
7/9	**24**	**24**	**24**	**24**	**24**	23	**24**	**24**
7/10	**24**	**24**	**24**	**24**	**24**	23	**24**	**24**
7/11	**24**	**24**	**24**	23	**24**	**24**	**24**	**24**
7/12	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**
7/13	**24**	**24**	23	**24**	**24**	**24**	**24**	**24**
7/14	**24**	21	**24**	**24**	**24**	23	**24**	**24**
7/15	**24**	20	**24**	**24**	**24**	**24**	**24**	**24**
7/16	**24**	**24**	23	**24**	**24**	**24**	**24**	**24**
7/17	**24**	23	**24**	**24**	**24**	**24**	23	**24**
7/18	12	**24**	23	**24**	**24**	23	23	**24**
7/19	0	**24**	**24**	23	**24**	**24**	**24**	**24**
7/20	0	**24**	**24**	**24**	**24**	**24**	**24**	23

Table 9 (cont.). Number of hours per day that each fixed station was operating properly, based on beacon tag detections.

	Station							
Date	Ekwok	Mulchatna	Stuyahok	Koktuli	Nuyakuk Mouth	Nuyakuk Tower	Klutuspak	King Salmon
7/21	0	**24**	23	**24**	**24**	**24**	**24**	**24**
7/22	0	**24**	**24**	**24**	**24**	**24**	**24**	**24**
7/23	0	**24**	**24**	**24**	**24**	**24**	**24**	**24**
7/24	4	**24**	**24**	23	**24**	**24**	**24**	**24**
7/25	14	**24**	**24**	**24**	**24**	23	23	**24**
7/26	4	**24**	**24**	**24**	**24**	**24**	**24**	1
7/27	0	23	**24**	**24**	**24**	**24**	**24**	0
7/28	0	**24**	**24**	23	**24**	**24**	**24**	0
7/29	0	**24**	**24**	**24**	**24**	**24**	**24**	0
7/30	0	**24**	23	**24**	**24**	23	**24**	0
7/31	0	**24**	**24**	**24**	**24**	23	**24**	0
8/1	0	**24**	23	23	**24**	**24**	**24**	0
8/2	12	**24**	**24**	23	**24**	**24**	**24**	9
8/3	**24**	**24**	**24**	23	**24**	**24**	**24**	**24**
8/4	**24**	**24**	23	**24**	**24**	**24**	**24**	**24**
8/5	**24**	**24**	**24**	23	**24**	**24**	**24**	**24**
8/6	**24**	23	**24**	**24**	**24**	**24**	**24**	**24**
8/7	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**
8/8	**24**	**24**	**24**	**24**	**24**	23	**24**	**24**
8/9	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**
8/10	**24**	**24**	**24**	**24**	**24**	**24**	23	**24**
8/11	**24**	**24**	**24**	8	**24**	**24**	19	**24**
8/12	**24**	**24**	**24**	0	**24**	23	21	**24**
8/13	**24**	**24**	**24**	0	**24**	23	**24**	**24**
8/14	23	**24**	**24**	0	**24**	**24**	23	**24**
8/15	0	23	**24**	0	**24**	**24**	22	**24**
8/16	0	18	**24**	*	**24**	**24**	19	23
8/17	0	0	**24**	-	**24**	23	17	**24**
8/18	0	0	**24**	-	**24**	**24**	22	**24**
8/19	0	0	**24**	-	**24**	**24**	16	**24**
8/20	0	0	**24**	-	**24**	**24**	10	**24**
8/21	0	0	**24**	-	**24**	**24**	16	**24**
8/22	0	0	13	-	**24**	**24**	13	**24**
8/23	0	0	0	-	**24**	**24**	22	23
8/24	0	0	0	-	**24**	**24**	12	**24**
8/25	0	0	0	-	**24**	**24**	23	**24**
8/26	0	0	0	-	**24**	**24**	21	23
8/27	0	0	0	-	13	**24**	23	**24**
8/28	0	0	0	-	0	**24**	14	7
8/29	0	0	0	-	0	23	23	0
8/30	0	0	0	-	0	11*	**24**	0
8/31	*	0	0	-	*	-	12*	*
9/1	-	*	*	-	-	-	-	-

* denotes dates of station installation and removal.
The Mulchatna and Nuyakuk Mouth stations were installed on 6/4, but beacon tags were not set until 6/11.
The low number of beacon tag detections at the Nuyakuk Tower station from 6/20 to 7/3 was because of a displaced beacon tag and not station performance.

Table 10. Detection efficiency for each fixed station in the Nushagak River, 2006.

	Detected At or Above		Total Detected		Detection Efficiency	
Fixed Stations	Chinook	Sockeye	Chinook	Sockeye	Chinook	Sockeye
Ekwok	329	187	168	103	51%	55%
Mulchatna	196	91	68	20	35%	22%
Stuyahok	72	20	58	16	81%	80%
Koktuli	30	11	26	9	87%	82%
Nuyakuk Mouth	141	99	91	59	65%	60%
Nuyakuk Tower	20	70	20	70	100%	100%
Klutuspak	59	15	28	6	47%	40%
King Salmon	71	17	70	17	99%	100%

Table 11. Detection statistics for mobile tracking surveys, Nushagak River, 2006.

Survey Date	Detections by Zone[a]													Detections[b]		
	5	15	25	26	35	45	46	55	56	65	75	85	86	Total	Repeat	% New
9-Jul	16	-	-	-	-	-	-	-	-	-	-	-	-	16	0	100%
18-Jul	3	6	4	6	-	-	-	-	-	-	-	-	-	19	1	95%
2-Aug	21	0	-	0	-	-	-	1	2	0	14	10	0	48	7	85%
6-Aug	21	8	13	-	11	25	8	-	-	-	-	-	-	86	23	73%
14-16 Aug	-	-	-	-	1	23	-	-	-	-	-	-	-	24	16	33%
18-20 Aug	-	-	-	-	-	-	-	-	-	-	5	36	-	41	9	78%

[a]Zones are described in Table 6.
[b]Includes mobile survey detections only; statistics do not consider fixed station detections.

Table 12. Distribution of radio tags detected only during mobile surveys, 2006.

Survey Date	New[a] Detections by Zone[b]													Totals		
	5	15	25	26	35	45	46	55	56	65	75	85	86	New[a] Detections	Unique[c] Detections	Mobile Survey Only
9-Jul	12	-	-	-	-	-	-	-	-	-	-	-	-	12	16	75%
18-Jul	1	1	1	0	-	-	-	-	-	-	-	-	-	3	18	17%
2-Aug	4	0	-	0	-	-	-	0	0	0	1	0	0	5	41	12%
6-Aug	1	3	3	-	2	4	1	-	-	-	-	-	-	14	63	22%
14-16 Aug	-	-	-	-	0	0	-	-	-	-	-	-	-	0	8	0%
18-20 Aug	-	-	-	-	-	-	-	-	-	-	1	1	-	2	32	6%
Totals	18	4	4	0	2	4	1	0	0	0	2	1	0	36	178	20%

[a]Includes tags detected during mobile surveys that were never detected at any fixed station.
[b]Zones are described in Table 6.
[c]Includes tags detected during mobile surveys that were not detected during previous mobile surveys.

Table 13. Statistics for Chinook salmon examined during the carcass surveys.

River	Capture Date	Capture Time	Sex	Length	Tag Recap
Koktuli	8/15/06	1250	F	865	No
	8/16/06	1125	M	735	No
	8/16/06	1240	M	520	No
King Salmon	8/18/06	1420	F	850	No
	8/18/06	1545	M	740	No
	8/18/06	1615	M	845	No
	8/18/06	1735	M	770	No
	8/18/06	1805	F	925	No
	8/19/06	1625	M	800	No
	8/19/06	1625	F	770	No
	8/19/06	1735	M	780	No
	8/20/06	1340	F	935	No

Table 14. Age, sex, and length statistics for specified groups of radio-tagged Chinook and sockeye salmon, Nushagak River, 2006.

					Length (mm)			
Species	Parameter	Group	n	% of Total	Min	Max	Avg	St Dev
Chinook	All Fish	-	474	-	477	1165	779	108
	Sex	Female	223	47	530	1000	804	95
		Male	251	53	477	1165	756	114
	Age	1.2	76	16	575	750	632	34
		1.3	147	31	610	897	757	58
		1.4	159	34	625	1113	869	64
		1.5	6	1	693	1165	936	165
		2.4	1	0	891	891	891	-
		Unknown	85	18	477	1000	765	108
Sockeye	All Fish	-	222	-	405	804	557	67
	Sex	Female	54	24	443	620	542	34
		Male	168	76	405	804	561	74
	Age	0.2	1	0	430	430	430	-
		0.3	5	2	525	589	564	33
		1.2	27	12	405	530	447	33
		1.3	100	45	461	695	573	41
		2.2	1	0	489	489	489	-
		1.4	29	13	533	804	625	43
		2.3	5	2	592	648	607	24
		Unknown	54	24	405	645	543	62

Table 15. Age composition of Chinook salmon ≥600mm captured at the Portage Creek sonar site and upriver migrant radio-tagged Chinook salmon captured near Ekwok, 2006.

		Age						
Location		1.1	1.2	1.3	1.4	1.5	Total	χ^2 test
Portage Creek Sonar	n	**1**	**55**	**153**	**197**	**4**	410	χ^2=13.92
(≥600mm)	%	0.2%	13.4%	37.3%	48.0%	1.0%		df=4
								p=0.01
Ekwok Tagging Sites	n	**0**	**56**	**107**	**92**	**4**	259	
(upriver migrants)	%	-	21.6%	41.3%	35.5%	1.5%		

Bold text indicates data used for chi-square tests.

Table 16. Age composition of sockeye salmon ≥400mm captured at the Portage Creek sonar site, upriver migrant radio-tagged sockeye salmon captured near Ekwok, radio-tagged sockeye salmon at the Nuyakuk Tower, and sockeye salmon escapement ≥400mm at the Nuyakuk Tower, 2006.

		Age									$\chi 2$ test	
Location		0.2	0.3	1.2	0.4	1.3	2.2	1.4	2.3	Total	Test	Results
Portage Creek	n	**9**	**11**	**191**	**1**	**699**	**6**	**102**	**7**	1,026	PC/Ek	χ^2=20.48
(≥400mm)	%	0.9%	1.1%	18.6%	0.1%	68.1%	0.6%	9.9%	0.7%			df=7
												p=0.01
Ekwok	n	**1**	**4**	**21**	**0**	**78**	**1**	**21**	**5**	131	PC/Ek/	χ^2=150.15
(upriver migrants)	%	0.8%	3.1%	16.0%	-	59.5%	0.8%	16.0%	3.8%		Nuy Esc.	df=14
												p=0.00
Nuyakuk	n	**0**	**1**	**9**	**0**	**32**	**1**	**1**	**3**	47	Nuy tags/	χ^2=22.46
Radiotags	%	-	2.1%	19.1%	-	68.1%	2.1%	2.1%	6.4%		Nuy esc.	df=6
												p=0.00
Nuyakuk	n	**5**	**6**	**278**	**0**	**585**	**19**	**8**	**5**	906	PC/Nuy	χ^2=110.27
Tower (≥400mm)	%	0.6%	0.7%	30.7%	-	64.6%	2.1%	0.9%	0.6%		Esc.	df=7
												p=0.00

Bold text indicates data used for chi-square tests.

Table 17. Fates of Chinook and sockeye salmon radiotagged near Ekwok in 2006.

	Species	
Fate	Chinook	Sockeye
Not Detected	131	33
Detected Below Ekwok	29	7
Fishery Mortality[a]	0	2
Upstream Migrant[b]	53	26
Spawner[c]	261	154
Total	474	222

[a] Sockeye salmon were captured in the subsistence fishery; one at Ekwok, the other at Koliganek.
[b] Tags that passed the Ekwok station but were never located in a spawning area.
[c] Spawning areas included the Mulchatna, Stuyahok, Koktuli, King Salmon, and Nuyakuk rivers, Klutuspak Creek, and the mainstem Nushagak above the Nuyakuk River. The mainstem Nushagak from Ekwok to the Nuyakuk River was not considered a spawning area.

Table 18. Weighted estimate of radio-tagged Chinook salmon spawning distribution ("spawners" only) in 2006.

Watershed	Spawning Area	Number of Tags[a]	Proportion[b]	95% Confidence Limits Lower	95% Confidence Limits Upper
Mulchatna	Mainstem; mouth to Stuyahok[c]	25	0.104	0.072	0.133
	Mainstem; Stuyahok to Koktuli	24	0.098	0.072	0.129
	Mainstem; above Koktuli	5	0.026	0.011	0.046
	Stuyahok	8	0.030	0.015	0.049
	Koktuli	31	0.113	0.084	0.148
	Subtotal	*93*	*0.371*		
Upper Nushagak	Mainstem; Nuyakuk to Klutuspak[d]	37	0.163	0.122	0.202
	Mainstem; Klutuspak to King Salmon	0	0.000	0.000	0.000
	Mainstem; above King Salmon	27	0.102	0.072	0.133
	Klutuspak	29	0.101	0.072	0.129
	King Salmon	46	0.168	0.129	0.205
	Subtotal	*139*	*0.534*		
Nuyakuk	Mouth to Nuyakuk Tower	9	0.031	0.015	0.049
	above Nuyakuk Tower	20	0.064	0.042	0.091
	Subtotal	*29*	*0.095*		
TOTAL		***261***			

[a] Actual unweighted number of tags detected.
[b] Proportions are based on the weighted tag values.
[c] Includes tags detected at the Mulchatna station but not seen in other specific upstream spawning areas.
[d] Includes tags detected at the Nushagak Mouth station but not seen in other specific upstream spawning areas.

Table 19. Weighted estimate of radio-tagged sockeye salmon spawning distribution ("spawners" only) in 2006.

Watershed	Spawning Area	Number of Tags[a]	Proportion[b]	95% Confidence Limits Lower	95% Confidence Limits Upper
Mulchatna	Mainstem; mouth to Stuyahok[a]	8	0.040	0.013	0.065
	Mainstem; Stuyahok to Koktuli	7	0.024	0.006	0.052
	Mainstem; above Koktuli	3	0.021	0.006	0.039
	Stuyahok	4	0.035	0.006	0.052
	Koktuli	13	0.102	0.065	0.148
	Subtotal	*35*	*0.224*		
Upper Nushagak	Mainstem; Nuyakuk to Klutuspak[b]	23	0.127	0.084	0.174
	Mainstem; Klutuspak to King Salmon	5	0.036	0.013	0.065
	Mainstem; above King Salmon	4	0.032	0.013	0.058
	Klutuspak	1	0.003	0.000	0.019
	King Salmon	14	0.121	0.077	0.168
	Subtotal	*47*	*0.320*		
Nuyakuk	Mouth to Nuyakuk Tower	4	0.022	0.000	0.039
	above Nuyakuk Tower	68	0.435	0.368	0.497
	Subtotal	*72*	*0.457*		
TOTAL		***154***			

[a] Actual unweighted number of tags detected.
[b] Proportions are based on the weighted tag values.
[c] Includes tags detected at the Mulchatna station but not seen in other specific upstream spawning areas.
[d] Includes tags detected at the Nushagak Mouth station but not seen in other specific upstream spawning areas.

Table 20. Run timing statistics passed the capture sites near Ekwok of the primary spawning stocks of Chinook and sockeye salmon in the Nushagak River, 2006.

			Duration			Date of Passage	
Species	Tributary	n	Start	End	Total (d)	Mean	SE
Chinook	Stuyahok	8	25-Jun	6-Jul	12	2-Jul	1.3
	Koktuli	31	18-Jun	13-Jul	26	28-Jun	1.0
	Klutuspak	29	15-Jun	10-Jul	26	27-Jun	1.1
	King Salmon	46	16-Jun	15-Jul	30	29-Jun	0.9
Sockeye	Koktuli	13	25-Jun	3-Jul	9	29-Jun	0.8
	King Salmon	14	22-Jun	9-Jul	18	29-Jun	1.1
	Nuyakuk Tower	68	25-Jun	16-Jul	22	5-Jul	0.7

Table 21. Travel time and migration rate summary from release to the Ekwok Station and from the Ekwok Station to the respective fixed stations throughout the Nushagak River, 2006.

Species/	Distance		Travel Time (d)			Migration Rate (km/d)		
Location	(km)	n	Median	Min	Max	Median	Min	Max
Sockeye								
Release to Ekwok	-	103	0.82	0.17	9.19	-	-	-
Ekwok to:								
Mulchatna	46	8	3.19	1.58	10.77	14.43	4.27	29.03
Stuyahok	90.6	7	5.63	2.84	20.33	16.08	4.46	31.94
Koktuli	113.4	6	6.67	4.29	9.99	17.00	11.35	26.42
Nuyakuk Mouth	81.8	31	4.27	2.48	39.85	19.17	2.05	32.93
Nuyakuk Tower	97.9	33	4.94	3.24	39.60	19.80	2.47	30.24
Klutuspak	121.3	1	12.99	12.99	12.99	9.34	9.34	9.34
King Salmon	153.6	6	14.81	6.93	20.88	10.37	7.36	22.16
Chinook								
Release to Ekwok	-	168	1.80	0.25	25.47	-	-	-
Ekwok to:								
Mulchatna	46	32	3.38	1.75	26.45	13.61	1.74	26.32
Stuyahok	90.6	22	6.84	2.61	20.97	13.25	4.32	34.69
Koktuli	113.4	9	9.45	6.79	34.20	12.01	3.32	16.70
Nuyakuk Mouth	81.8	44	5.88	2.54	44.97	13.91	1.82	32.19
Nuyakuk Tower	97.9	6	7.54	3.49	16.94	12.98	5.78	28.08
Klutuspak	121.3	12	10.64	7.19	25.35	11.40	4.79	16.88
King Salmon	153.6	28	10.16	4.90	40.74	15.11	3.77	31.36

Table 22. Contingency table analysis comparing the mark and recapture rates for sockeye salmon sampled in 2006.

Period of marking	Period of recapture 6/26-7/4	7/5-7/12	7/13-7/24	Recaptured	Not recaptured	Marks	Recapture Rate
6/16-7/1	8	11	0	**19**	**55**	74	0.257
7/2-7/16	0	12	35	**47**	**61**	108	0.435
Recaps	**8**	**23**	**35**	66	116	182	0.363
Unmarked	**64,696**	**54,475**	**51,523**	170,694		χ^2 = 6.05, df = 1, p = 0.01	
Examined	64,704	54,498	51,558	170,760			
Mark Rate	0.0001	0.0004	0.0007	0.0004	χ^2 = 23.15, df = 2, p = 0.00		

Bold text indicates data used for chi-square tests.

FIGURES

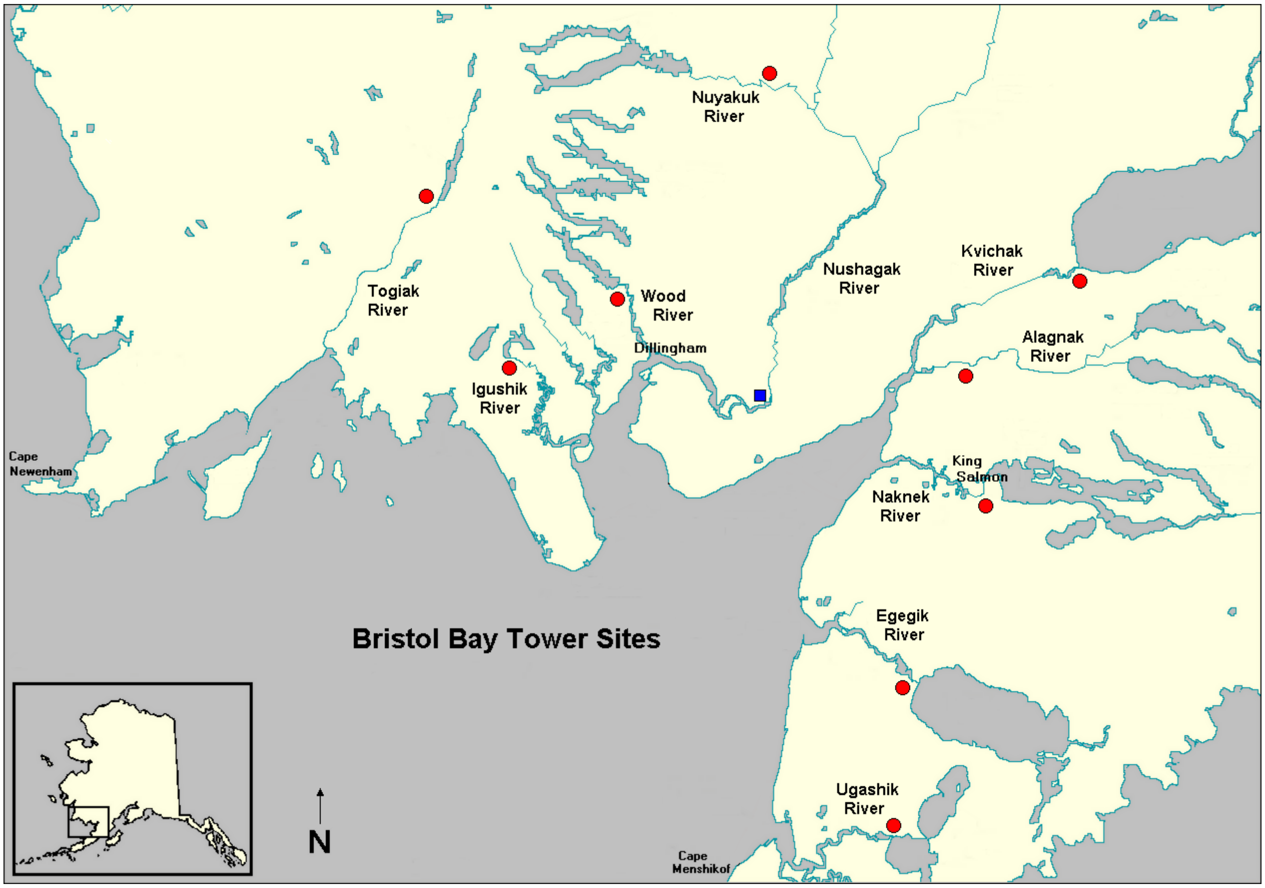

Figure 1. Major river systems and escapement projects in Bristol Bay. Red circles identify tower counting sites and the blue square identifies the Portage Creek sonar counting site (Morstad et al. 2005).

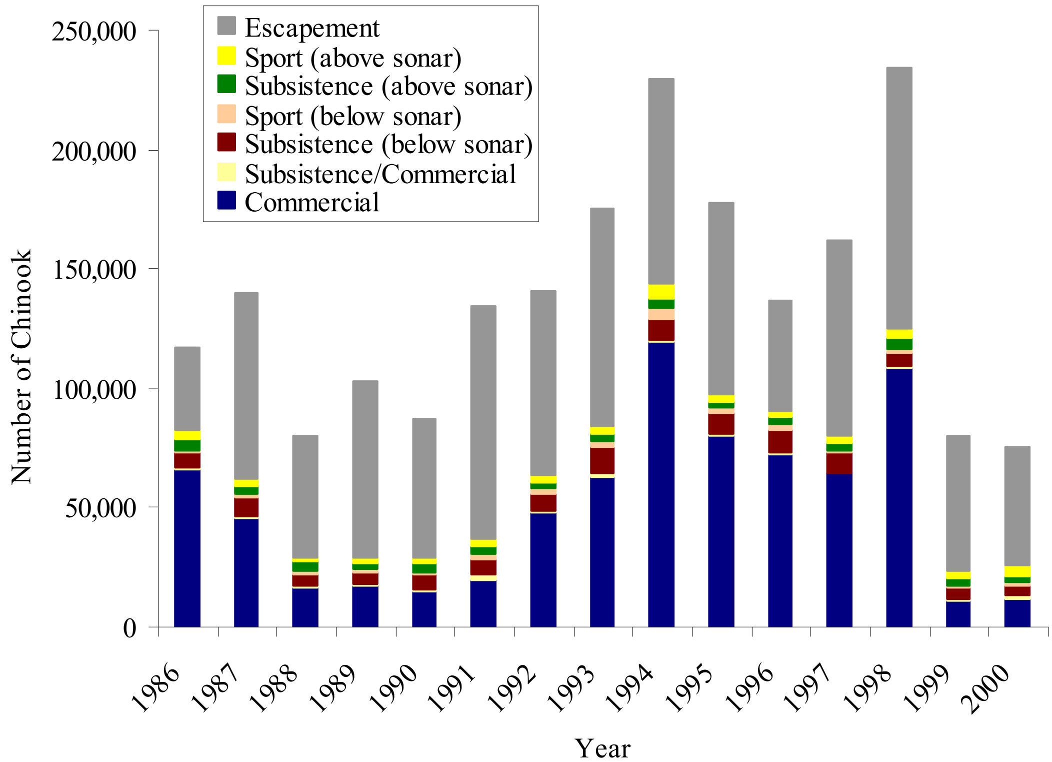

Figure 2. Specific harvest and escapement components of the total Nushagak River Chinook salmon run, 1986-2000.

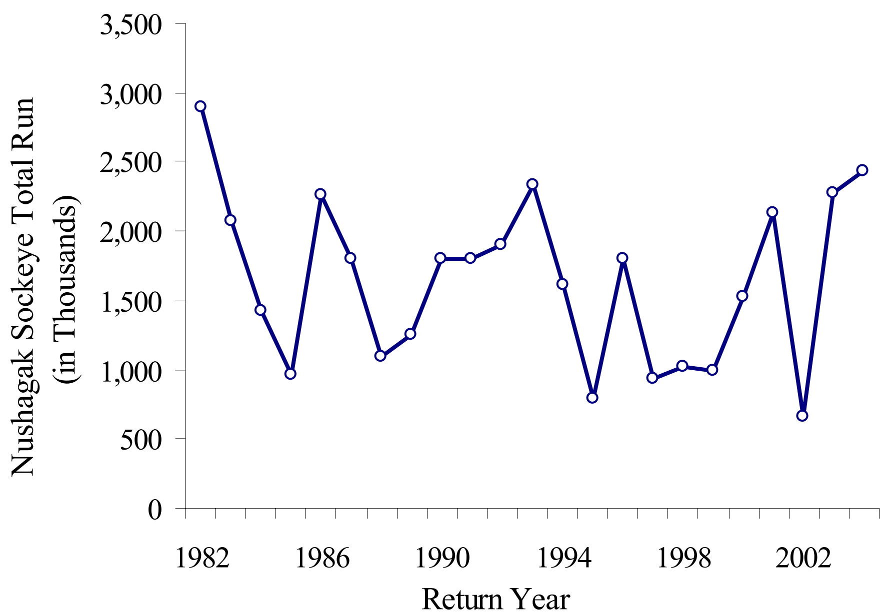

Figure 3. Total run of sockeye salmon in the Nushagak River, 1982-2004 (includes catch and escapement of Nuyakuk and Mulchatna components).

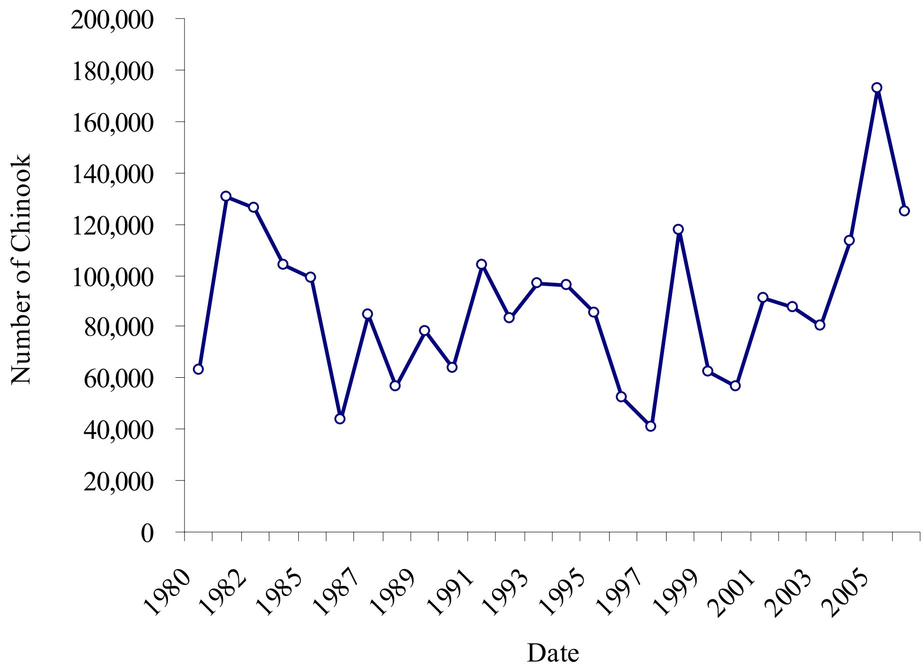

Figure 4. Estimated Nushagak River Chinook salmon escapement at the Portage Creek sonar site, 1980-2006.

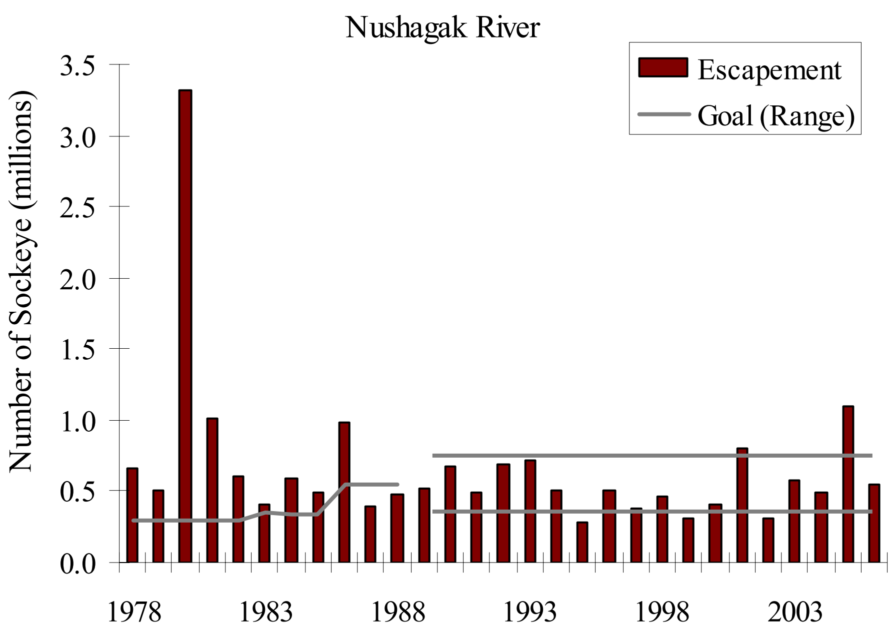

Figure 5. Total Nushagak River sockeye salmon escapement compared to the annual escapement goal, 1978-2005. In 1989, management shifted to an escapement goal range of 340-760 thousand. Before 1980, escapement was based on Nuyakuk Tower counts and Nushagak and Mulchatna river aerial surveys. Since 1980, escapement was estimated using Portage Creek sonar counts, Nuyakuk Tower counts, and aerial surveys.

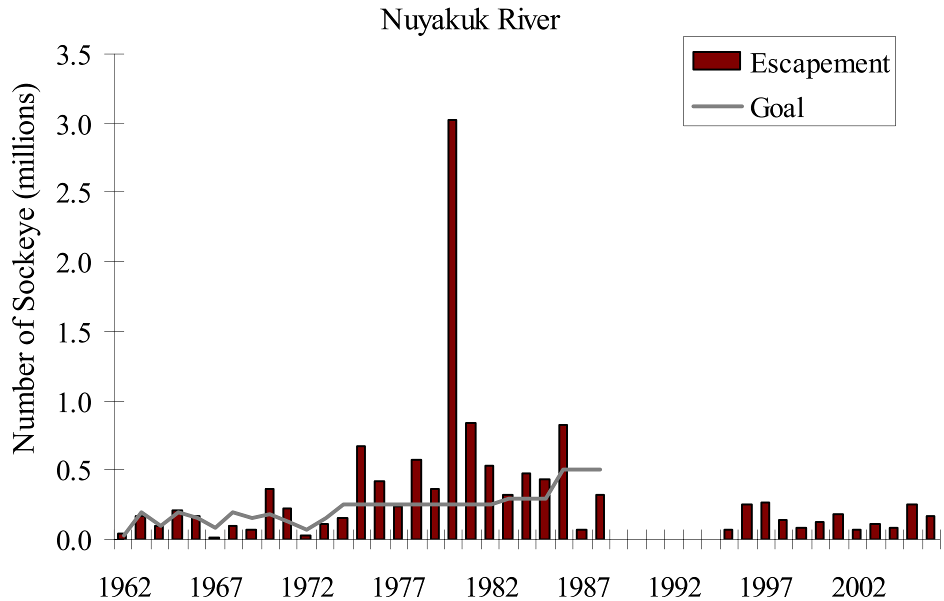

Figure 6. Nuyakuk River escapement (millions) based on tower counts compared to the annual escapement goal, 1962-2006. In 1989, the escapement goal was combined with the Nushagak-Mulchatna goal for an overall drainage goal (Figure 5). Nuyakuk Tower counts were not conducted from 1989-1994.

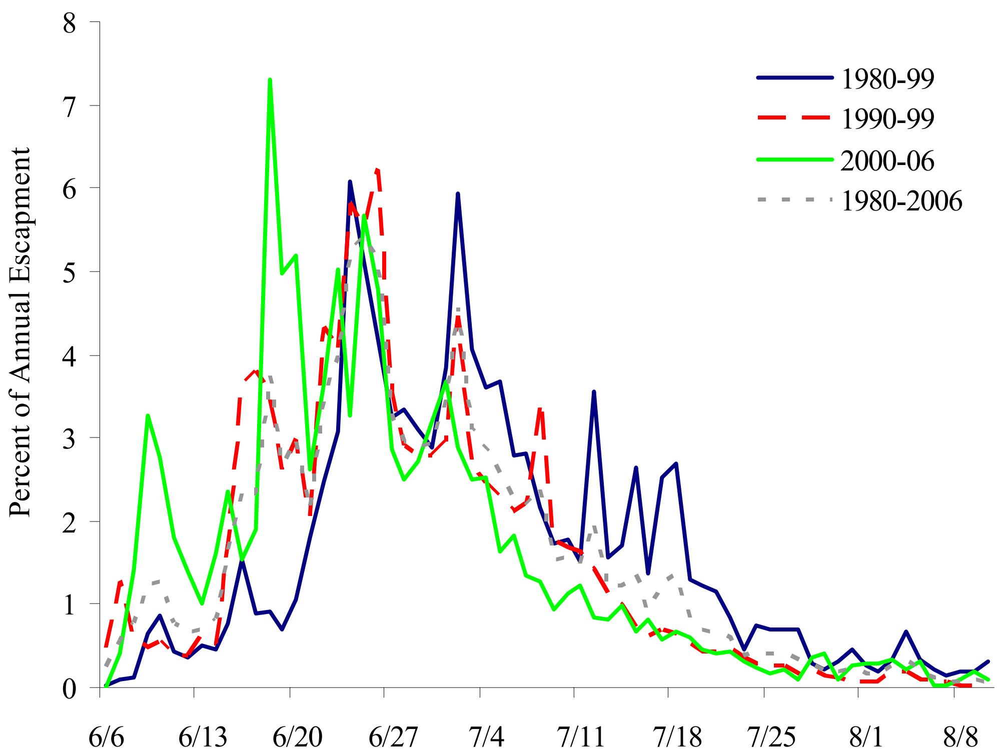

Figure 7. Chinook salmon run timing at the Portage Creek sonar site, by time period.

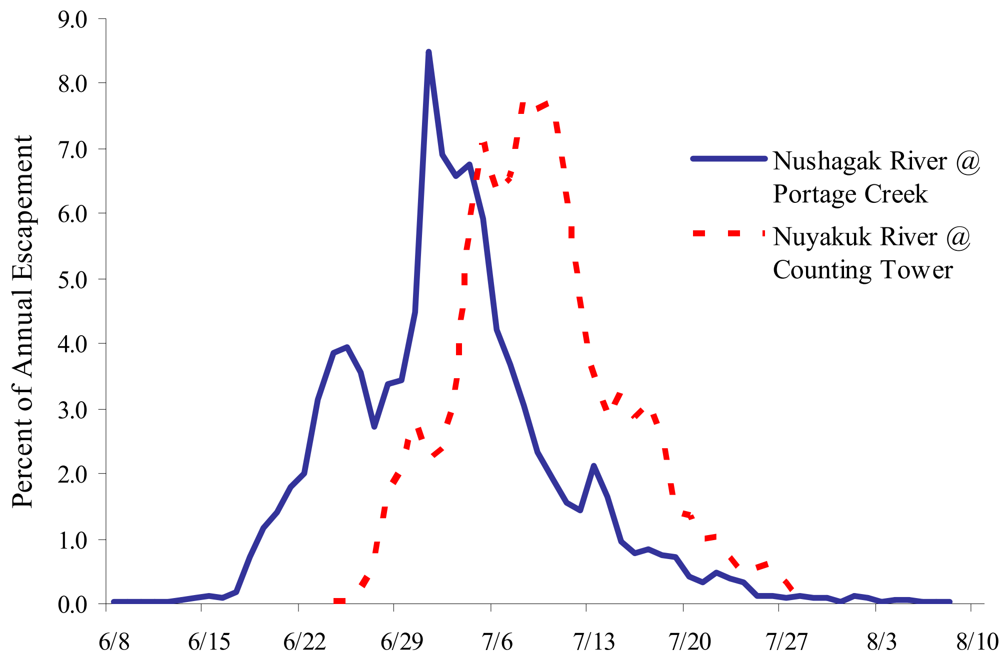

Figure 8. Average daily sockeye salmon run timing comparison at the Portage Creek sonar site and the Nuyakuk River counting tower, 1996-2005.

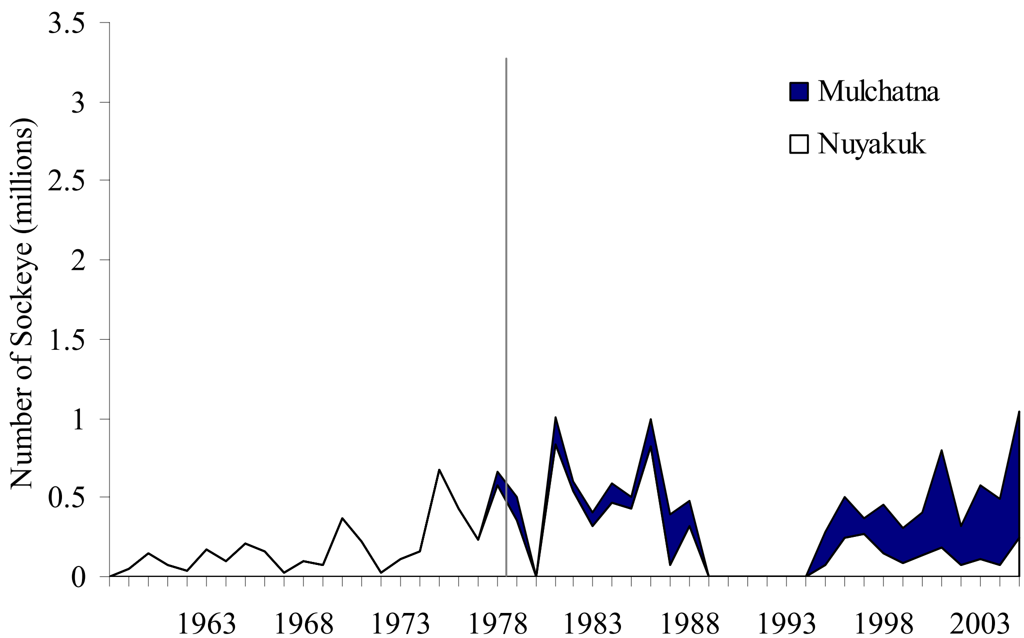

Figure 9. Apportionment of Nushagak River sockeye salmon escapement to Mulchatna and Nuyakuk rivers, 1959-2005. Systemwide estimates for the entire Nushagak drainage have been made since 1978 at the Portage Creek sonar site. Nuyakuk River escapement is estimated at the Nuyakuk Tower. Mulchatna River escapement is calculated as the difference between the Portage Creek and Nuyakuk Tower estimates.

Figure 10. Capture, tagging, and release sites on the Nushagak River near Ekwok. All sites were downstream of the Ekwok telemetry station. Note that the river channel has changed since the base topographic map was completed; thus, Sites 4 and 5 are located in the main channel. Also note that capture site 12 was beyond the range of the map, but coordinates are provided.

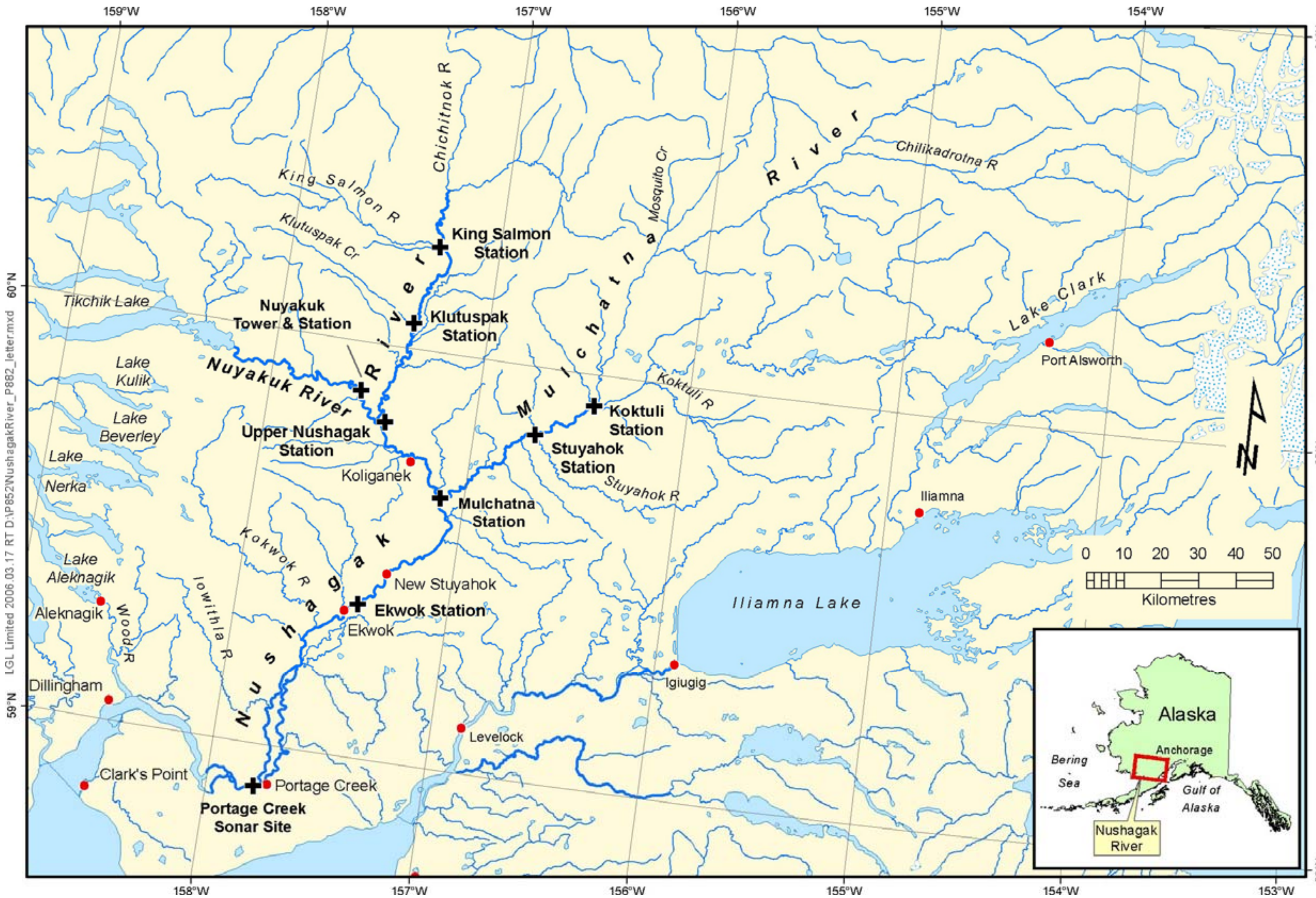

Figure 11. Map of study area depicting major villages and fixed station sites in the Nushagak drainage.

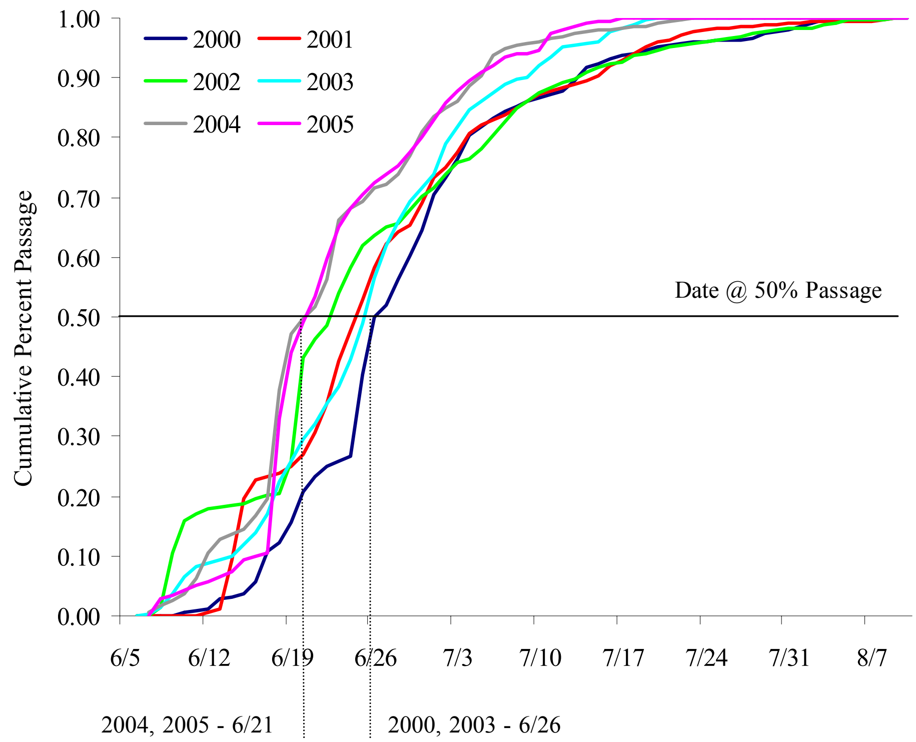

Figure 12. Cumulative percent passage of Nushagak River Chinook salmon at Portage Creek sonar site by year, 2000-2005.

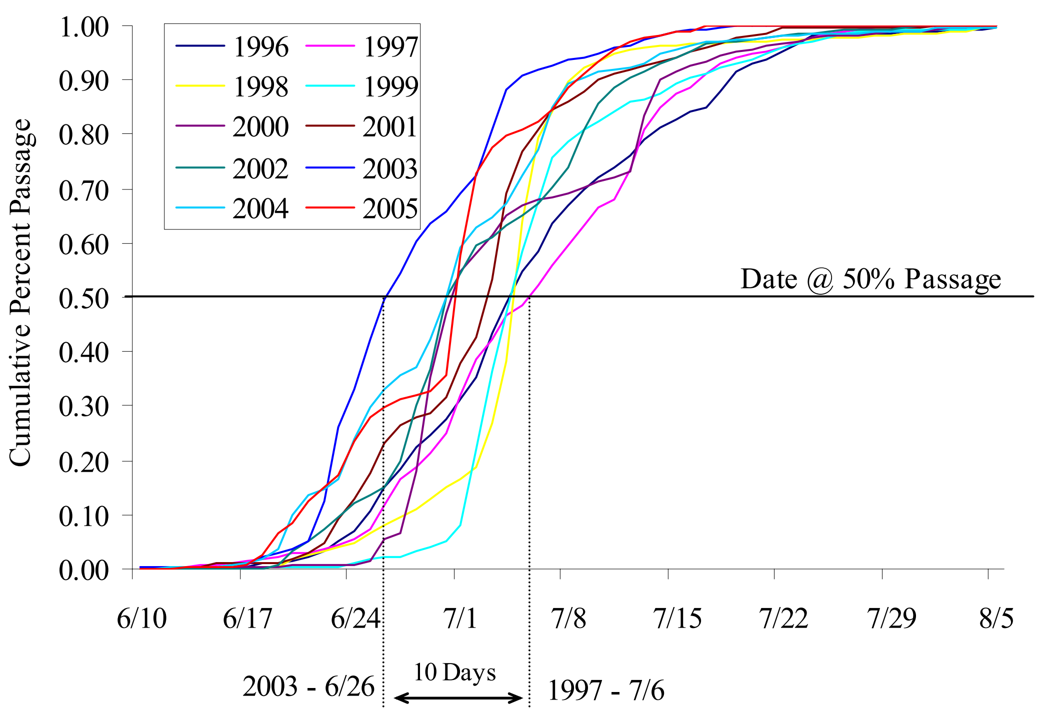

Figure 13. Cumulative percent passage of Nushagak River sockeye salmon at Portage Creek sonar site, 1996-2005.

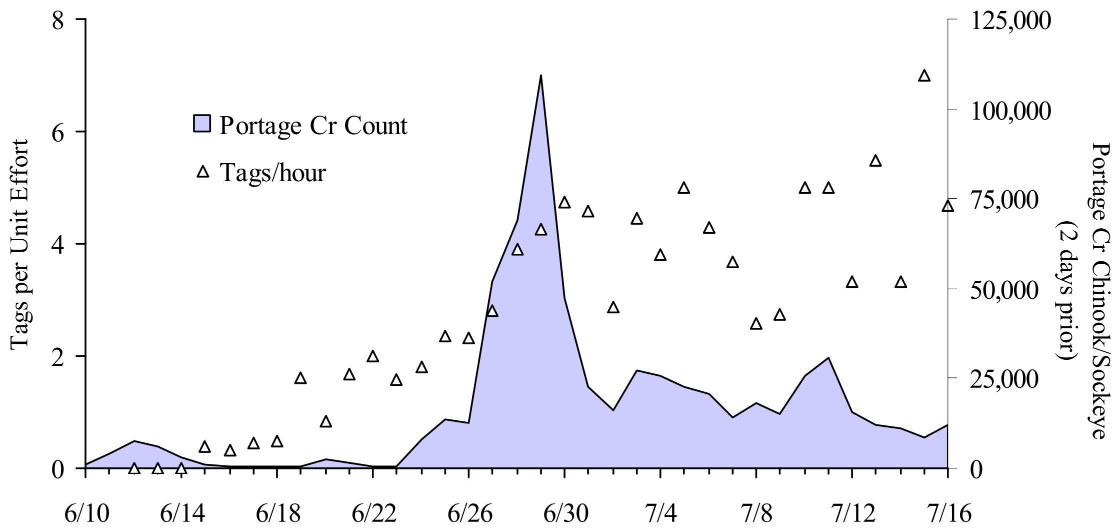

Figure 14. Number of tags deployed per hour of fishing effort compared to the Portage Creek sonar combined Chinook and sockeye salmon count 2 days prior.

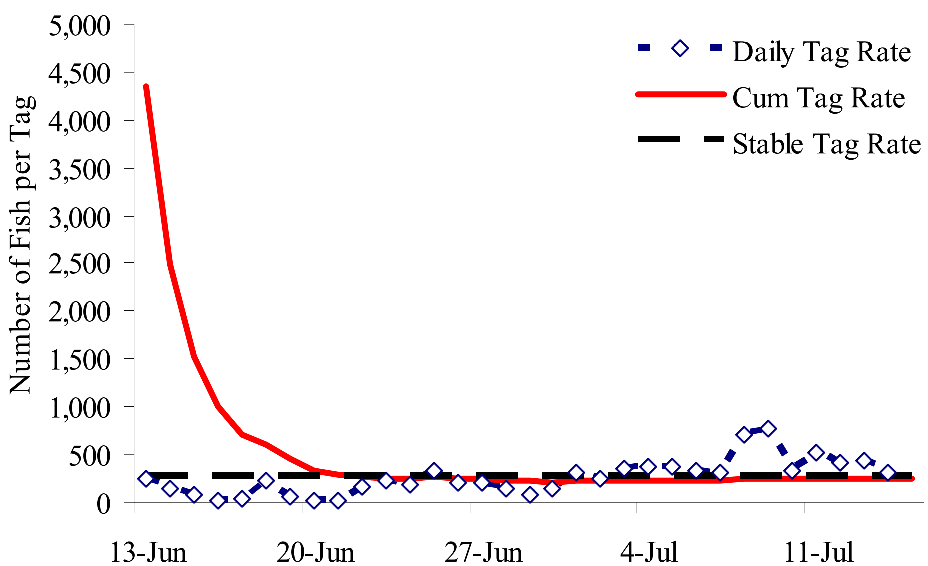

Figure 15. Daily and cumulative Chinook salmon tagging rates compared to a stable tagging rate (derived from total tags applied and 2006 Chinook salmon escapement). Because of the travel time between Portage Creek and Ekwok, tag releases were compared to the Portage Creek escapement 2 days prior.

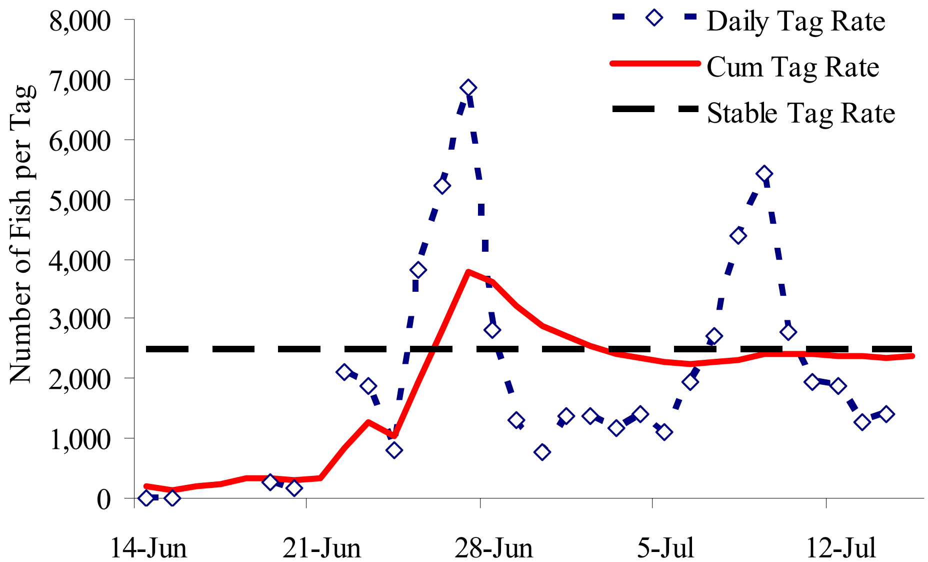

Figure 16. Daily and cumulative sockeye salmon tagging rates compared to a stable tagging rate (derived from total tags applied and 2006 sockeye salmon escapement). Because of the travel time between Portage Creek and Ekwok, tag releases were compared to the Portage Creek escapement 2 days prior.

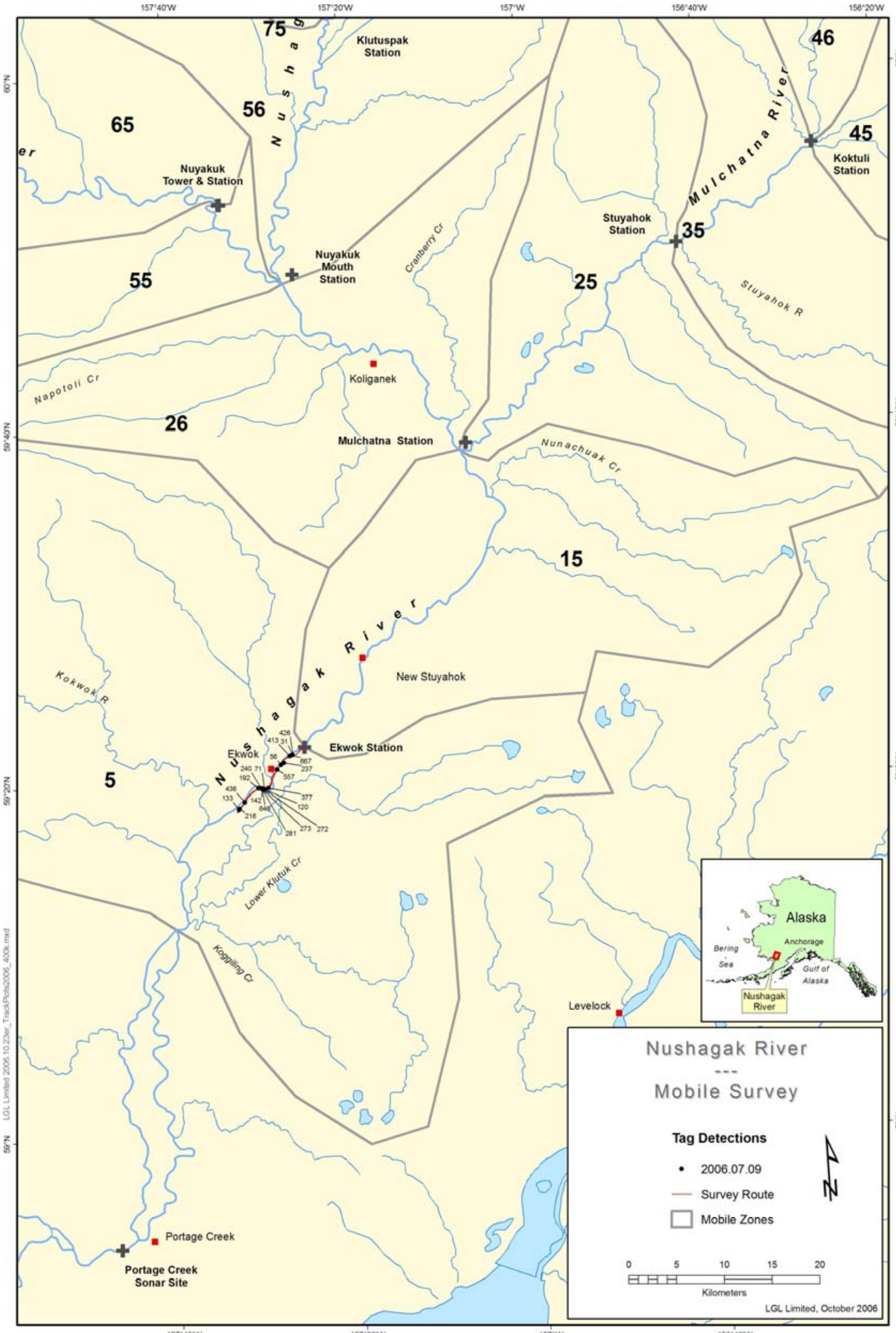

Figure 17. Individual tag locations during the boat survey on July 9, 2006. The red line represents the survey track.

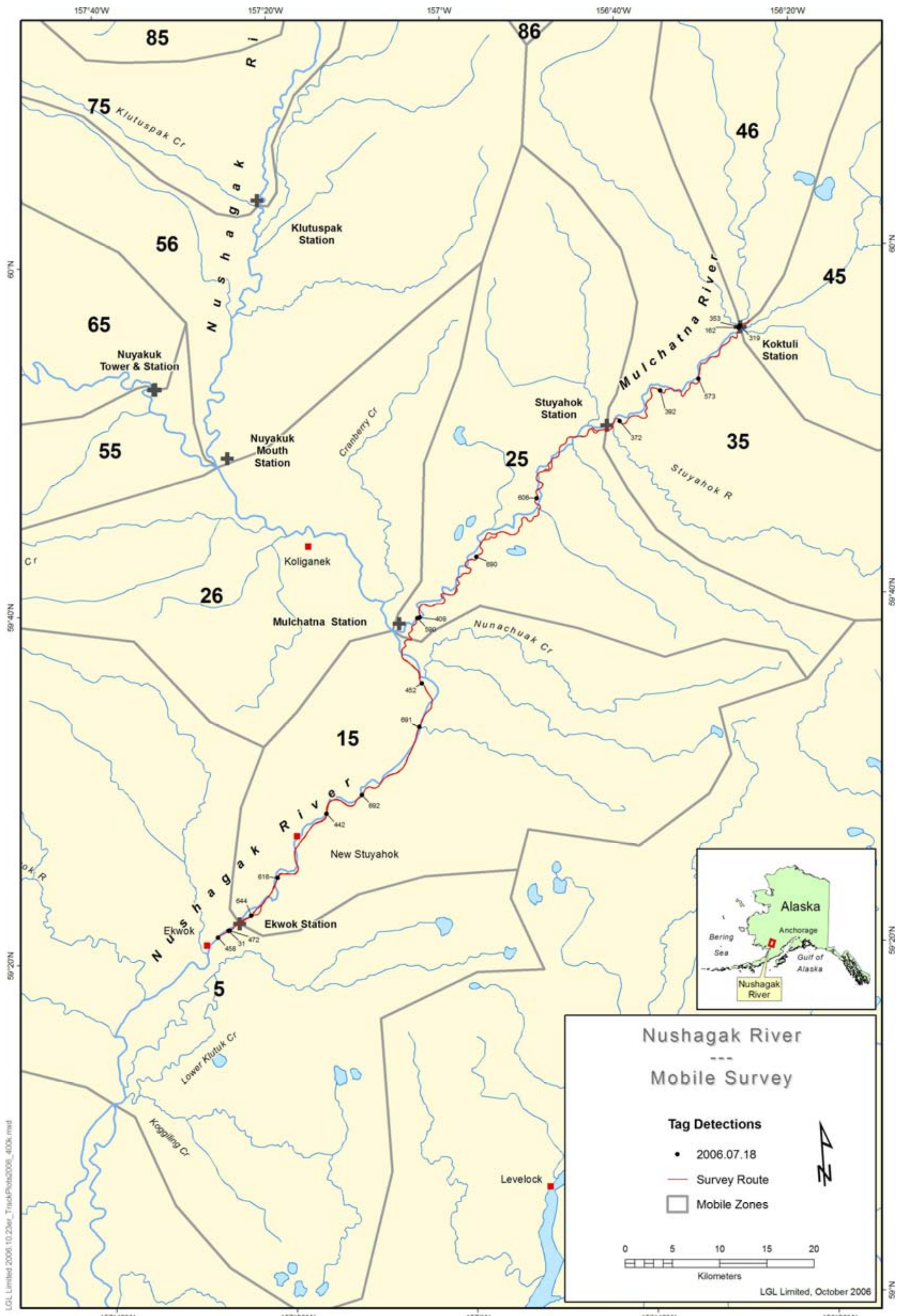

Figure 18. Individual tag locations during the boat survey on July 18, 2006. The red line represents the survey track.

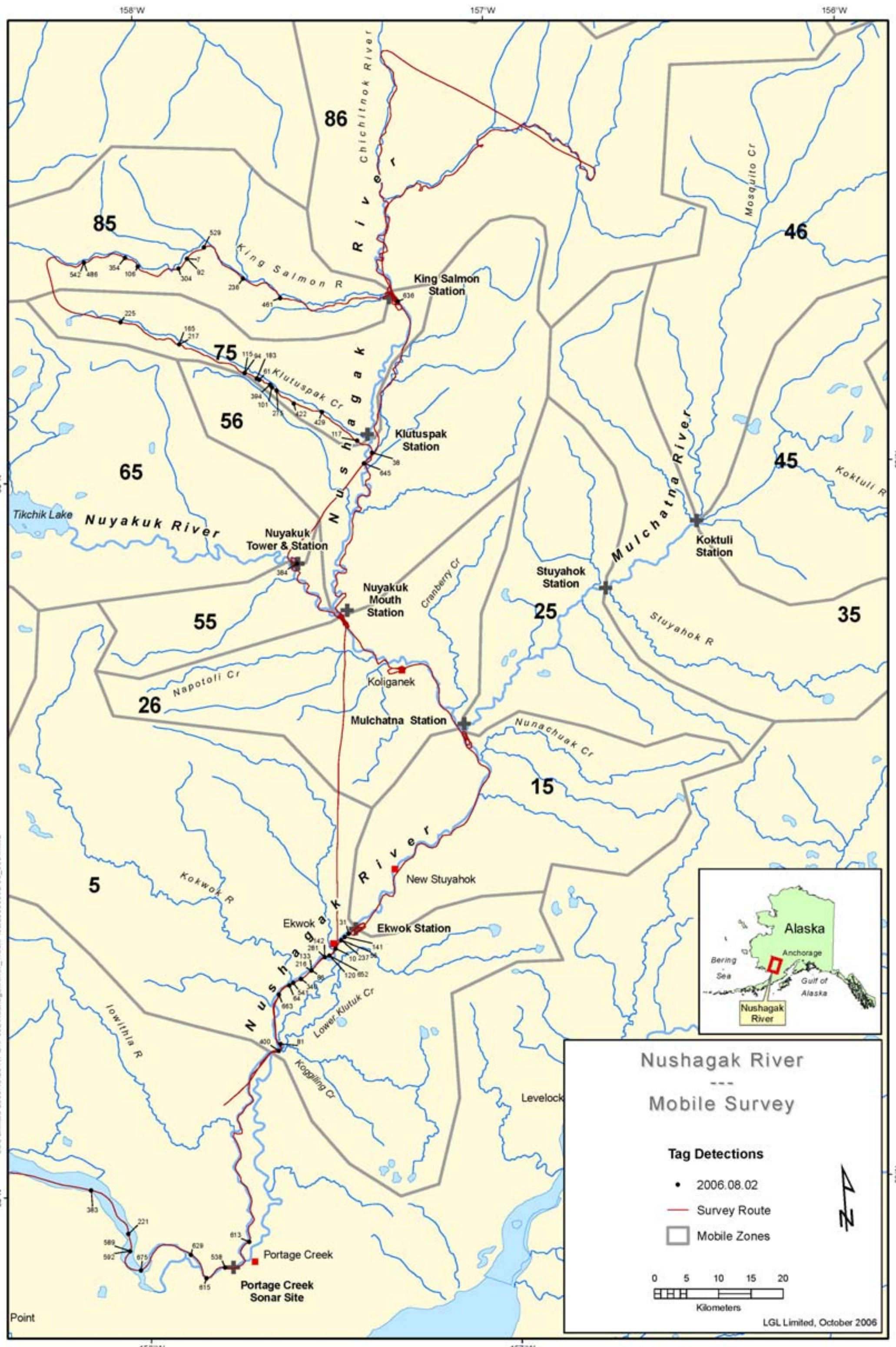

Figure 19. Individual tag locations during the aerial survey on August 2, 2006. The red line represents the survey track.

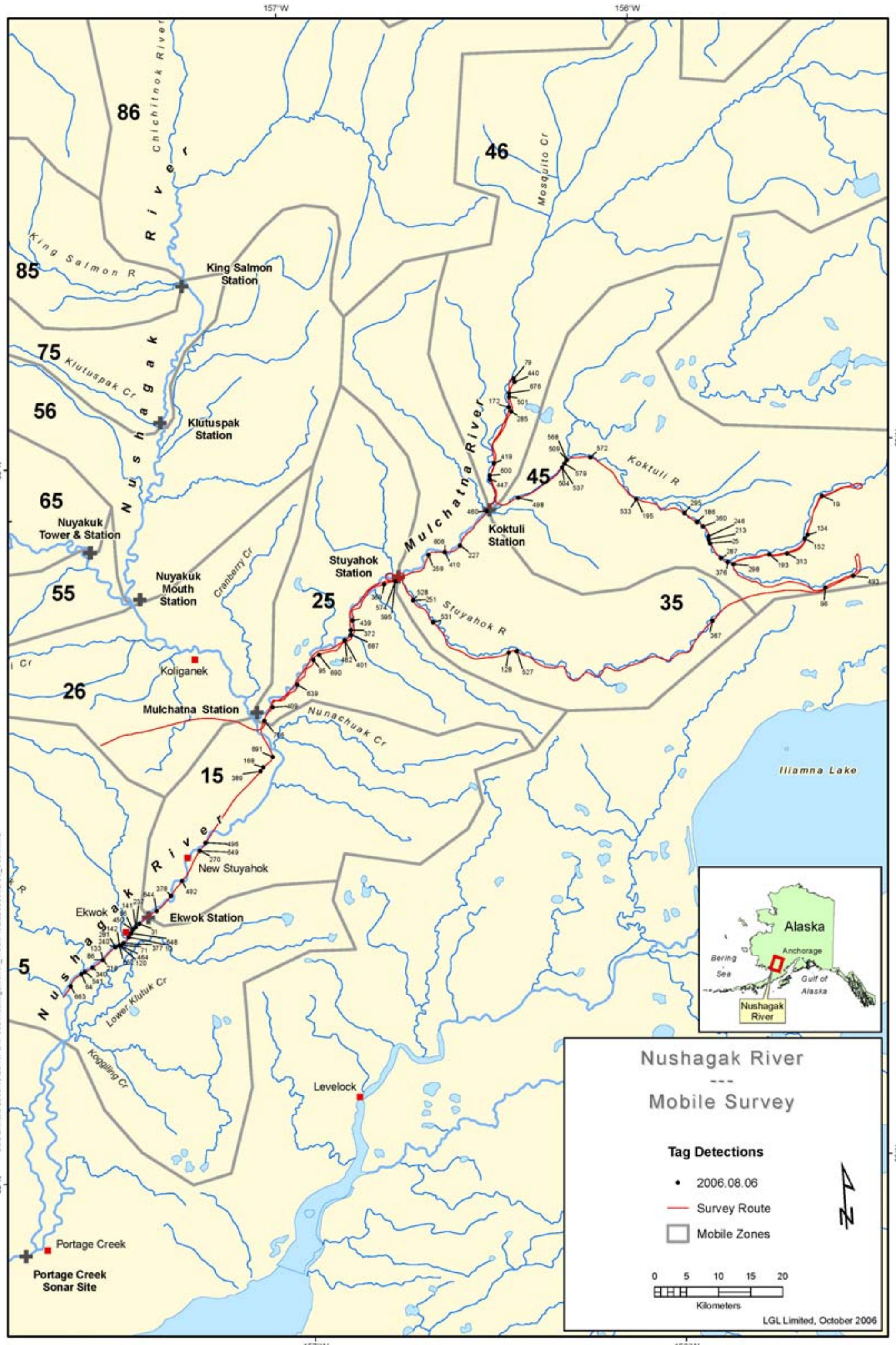

Figure 20. Individual tag locations during the aerial survey on August 6, 2006. The red line represents the survey track.

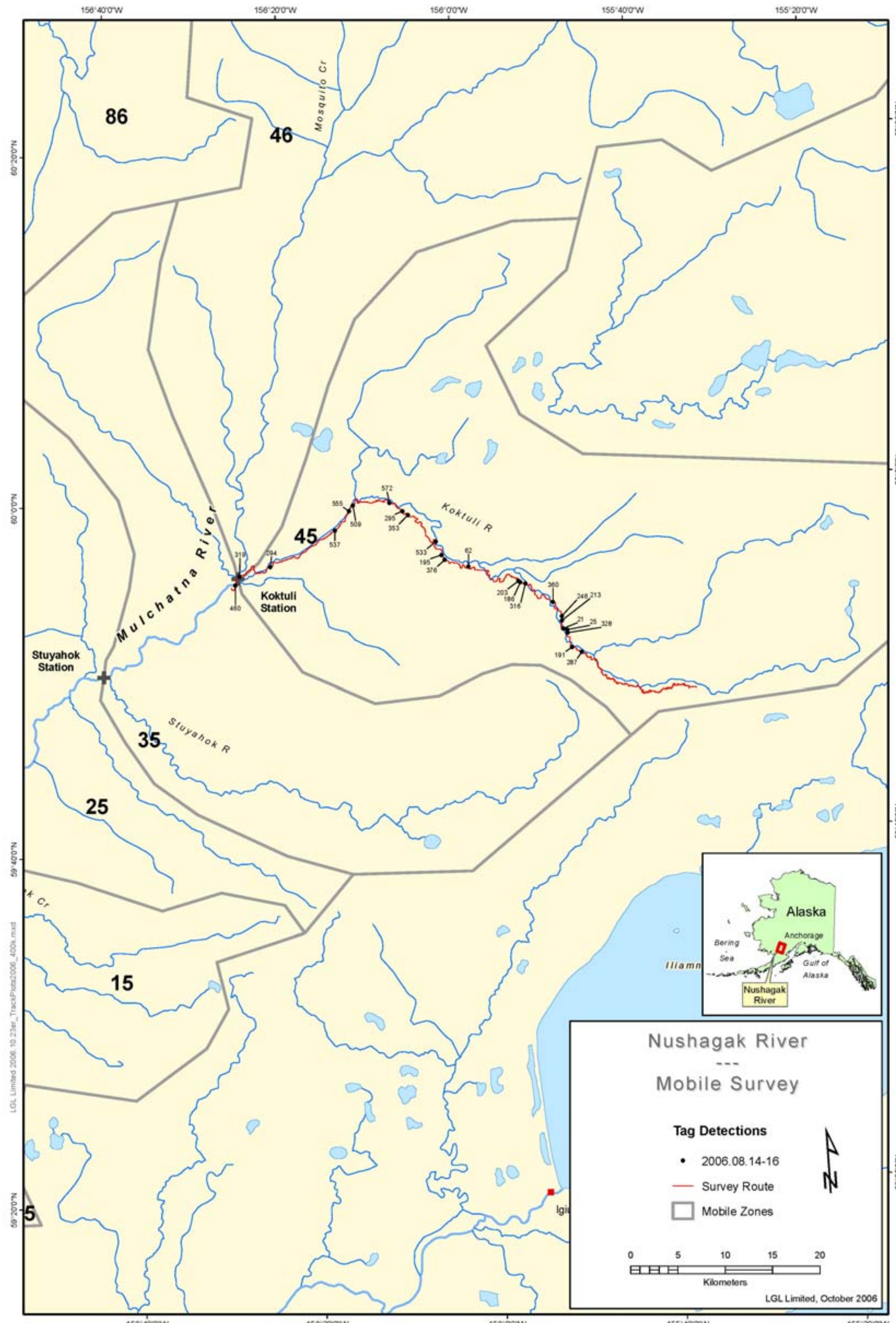

Figure 21. Individual tag locations during the carcass survey on August 14-16, 2006. The red line represents the survey track.

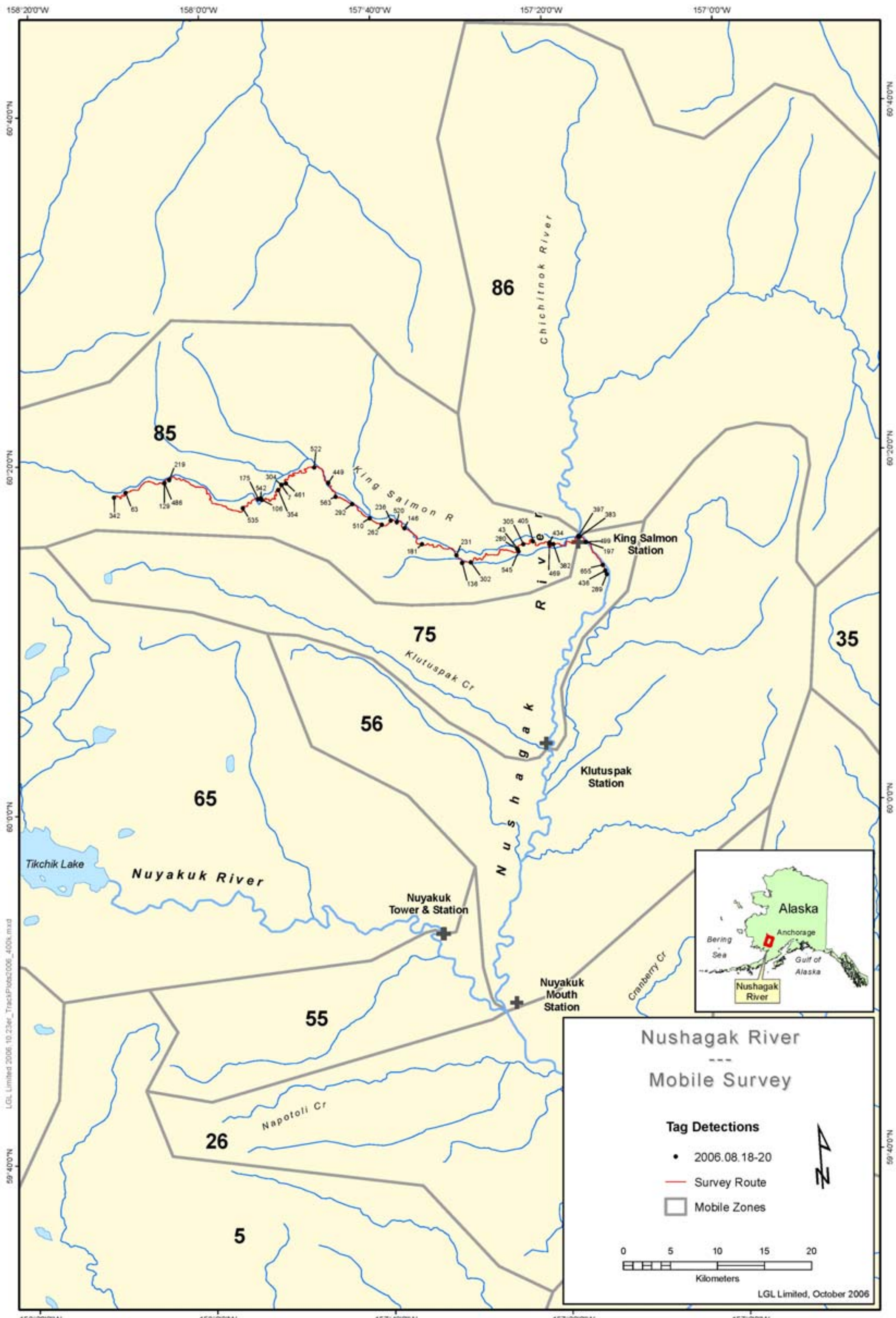

Figure 22. Individual tag locations during the carcass survey on August 18-20, 2006. The red line represents the survey track.

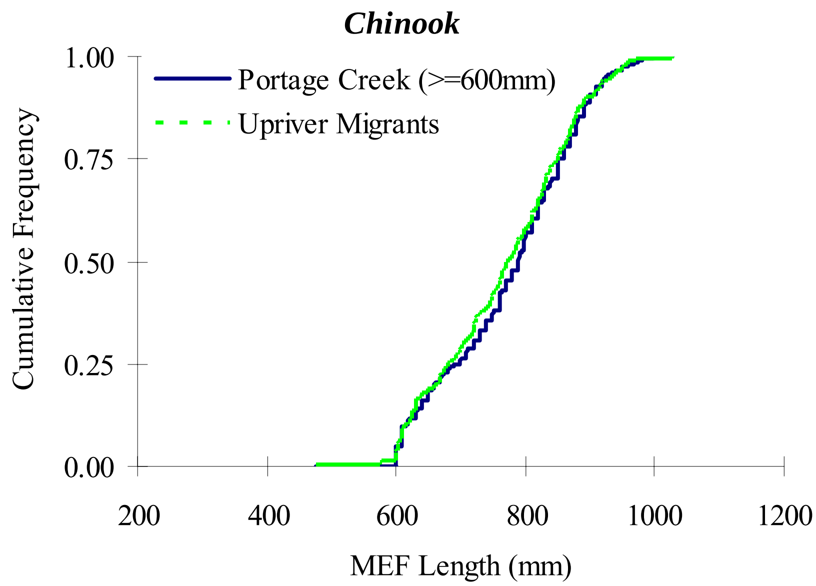

Figure 23. Cumulative length frequency distributions for upriver migrant radio-tagged Chinook salmon and Chinook salmon ≥600mm sampled at the Portage Creek sonar site.

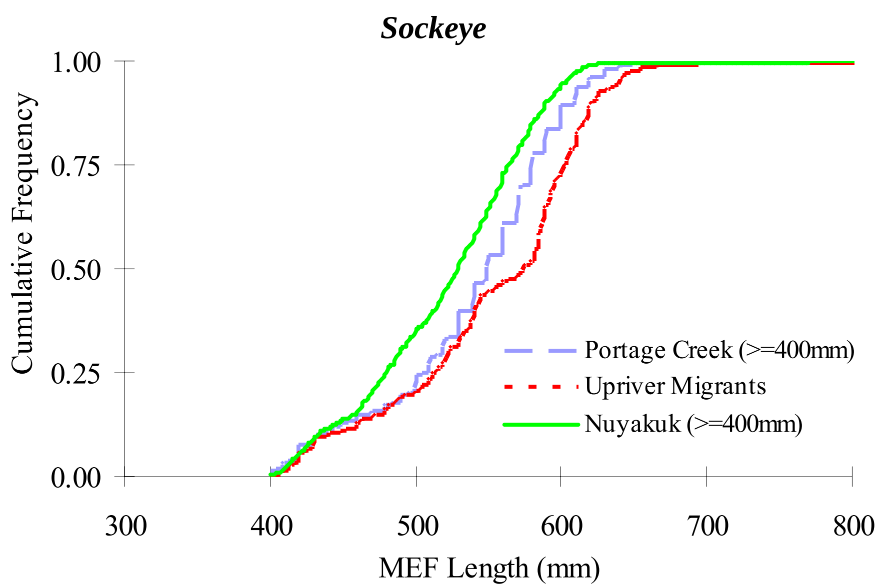

Figure 24. Cumulative length frequency distributions for sockeye salmon escapement ≥400mm at Portage Creek sonar, upriver migrant radio-tagged sockeye salmon, and sockeye salmon escapement ≥400mm at the Nuyakuk Tower.

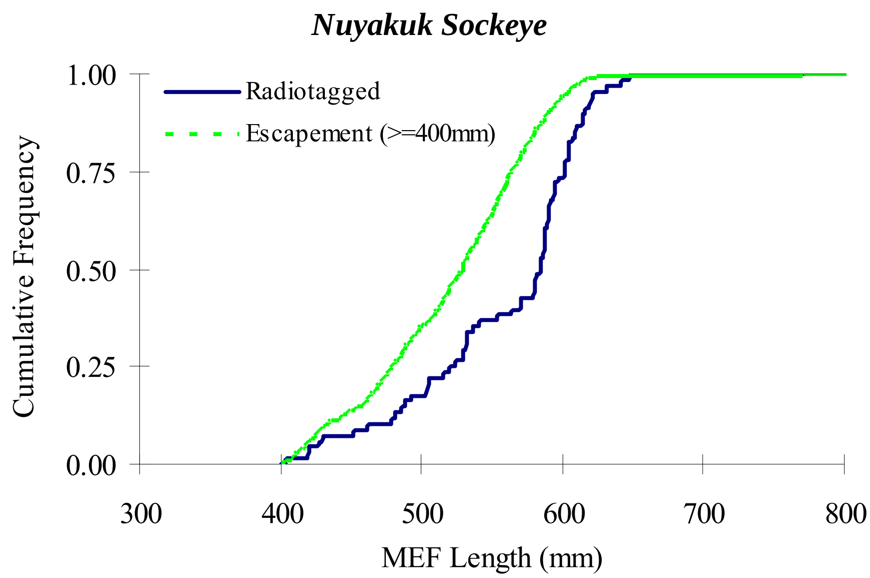

Figure 25. Cumulative length frequency distributions for radio-tagged sockeye salmon detected at the Nuyakuk Tower fixed station and sockeye salmon escapement ≥400mm sampled at the Nuyakuk Tower.

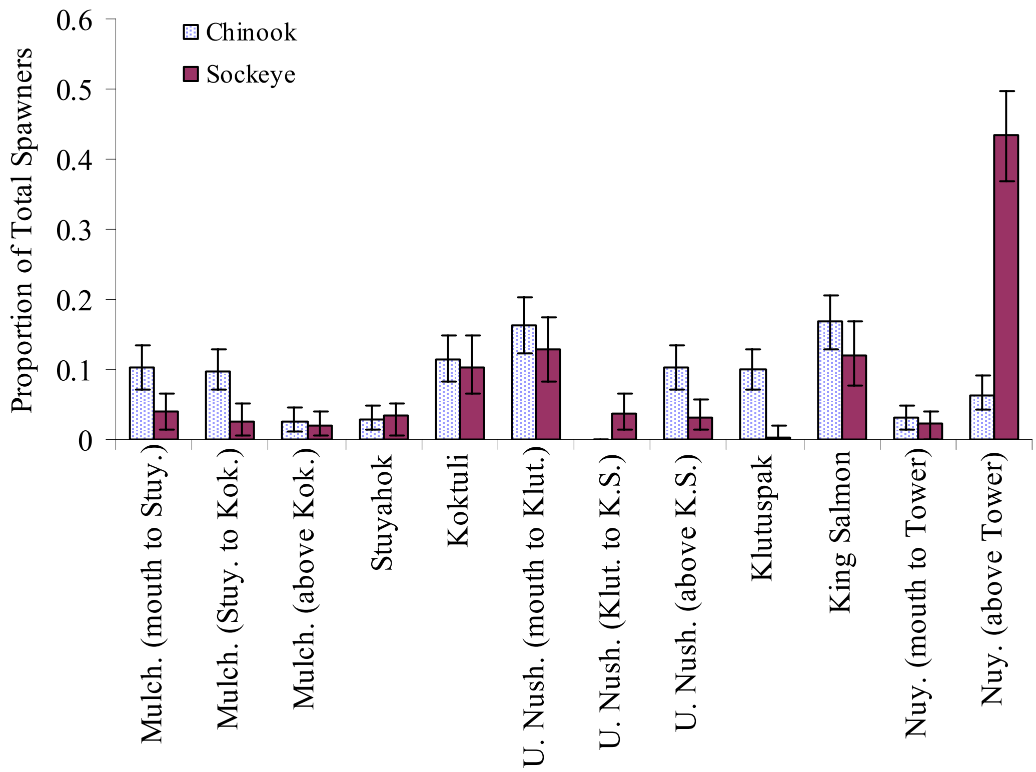

Figure 26. Weighted estimate of Chinook and sockeye salmon spawning distribution in 2006. Error bars show 95% confidence intervals.

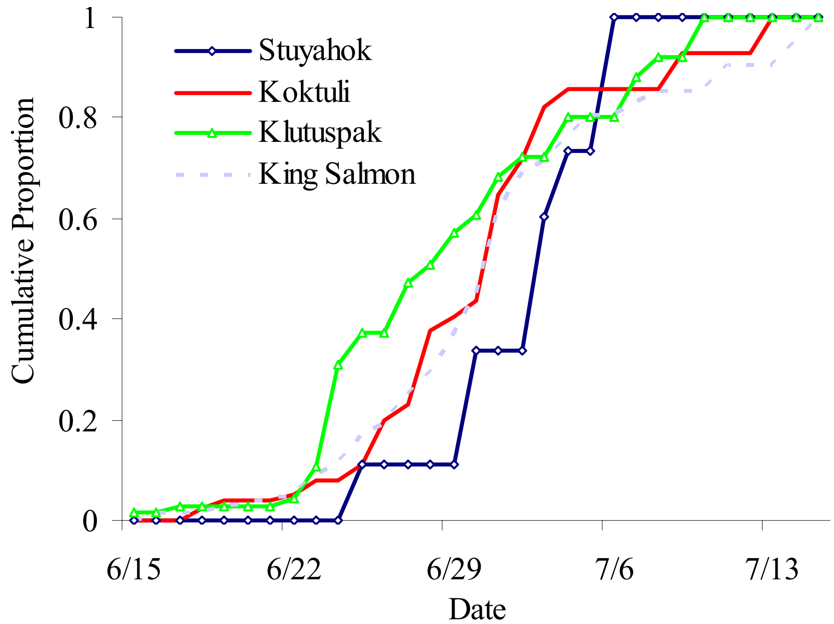

Figure 27. Weighted estimate of the run timing of Nushagak River Chinook salmon stocks at the capture sites near Ekwok, 2006.

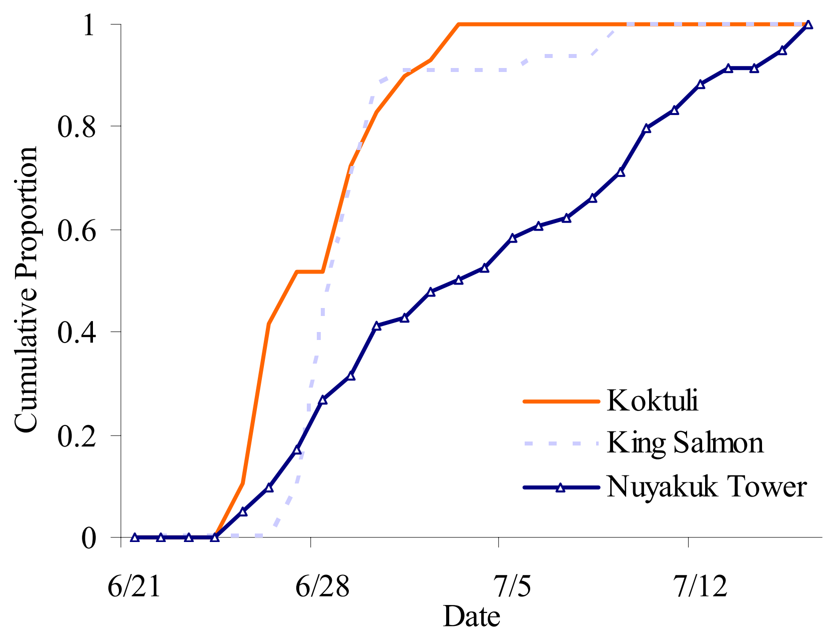

Figure 28. Weighted estimate of the run timing of Nushagak River sockeye salmon stocks at the capture sites near Ekwok, 2006.

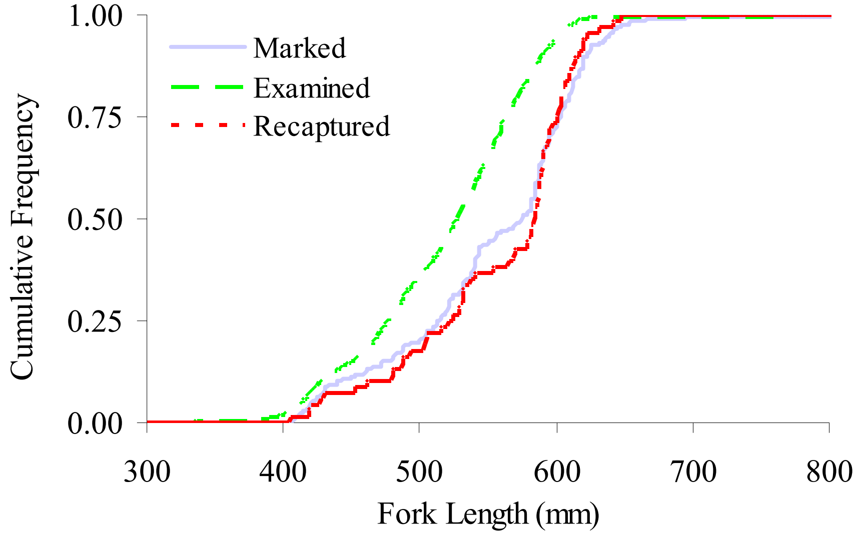

Figure 29. Cumulative length frequency distributions for sockeye salmon marked, examined, and recaptured in the Nushagak River, 2006.

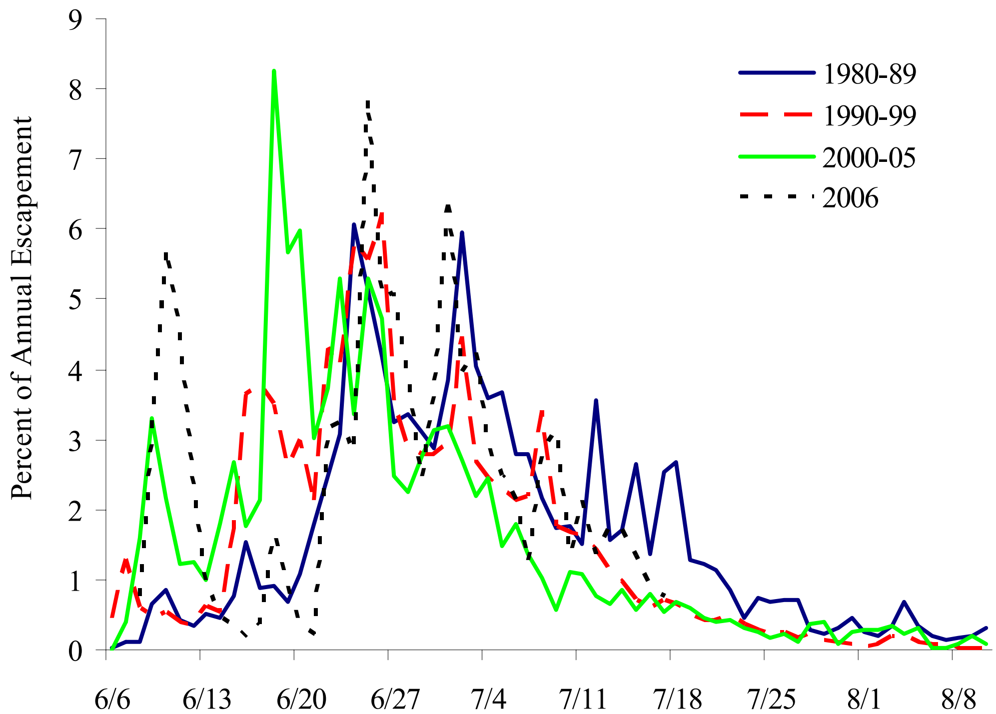

Figure 30. Daily Nushagak River Chinook salmon run timing at the Portage Creek sonar site in 2006 compared to the average run timing, by decade.

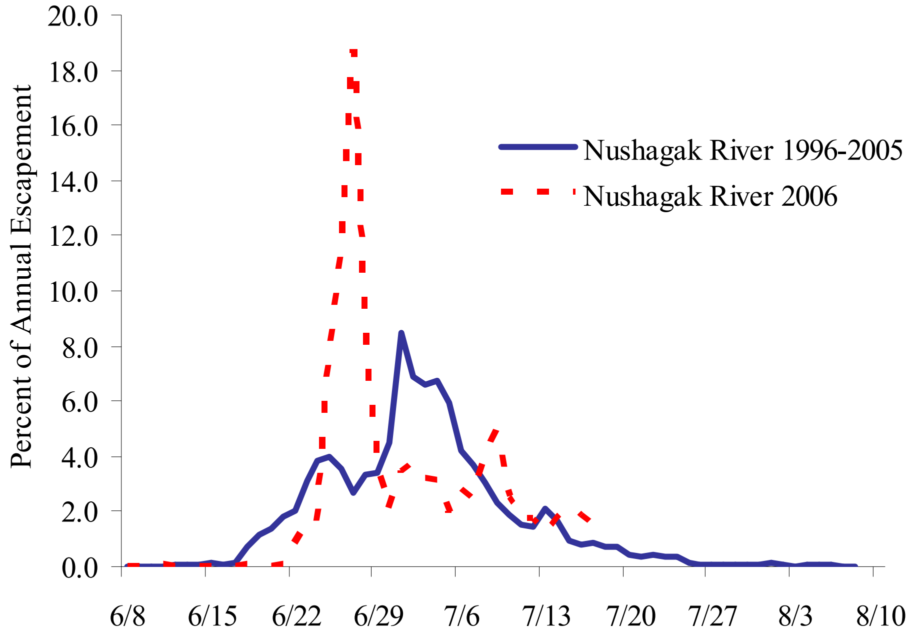

Figure 31. Daily Nushagak River sockeye salmon run timing at the Portage Creek sonar site in 2006 compared to the average run timing for the most recent decade, 1996-2005.

PLATES

Plate 1. Gillnet attached to the bow of a boat and drifted through salmon holding areas or migration paths.

Plate 2. Water-filled trough used to tag Chinook and sockeye salmon.

Plate 3. Water-filled trough used to tag Chinook and sockeye salmon, with plunger used to insert radio tags.

Plate 4. Mounting configuration of 4-element yagi antennas for detecting radio-tagged fish from a Cessna 185.