NOAA Technical Memorandum NMFS-AFSC-165

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center

September 2006

NOAA Technical Memorandum NMFS

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This document should be cited as follows:

Eiler, J. H., T. R. Spencer, J. J. Pella, and M. M. Masuda. 2006. Stock composition, run timing, and movement patterns of Chinook salmon returning to the Yukon River Basin in 2004 U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-165, 107 p.

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by
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September 2006

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ABSTRACT

A radio telemetry study was conducted on Yukon River Chinook salmon (*Oncorhynchus tshawytscha*) during 2004 to provide information on stock composition and run timing, migration patterns, and locations of important spawning areas. A total of 995 fish were radio tagged in the lower Yukon River near the village of Russian Mission. After tagging, most (958, 96.3%) fish resumed upriver movements, with 329 fish harvested in fisheries and 629 fish tracked to upriver areas using remote tracking stations and aerial surveys. Stock composition estimates were developed for the 2004 return based on the distribution of daily releases of radio-tagged fish weighted by daily measures of abundance and adjusted for fish harvested in fisheries. The Chinook salmon run was composed primarily of Tanana River (24.4%) and upper basin (55.2%) stocks. Canadian-origin fish comprised a substantial proportion of the return (47.5%), with most traveling to reaches of the Yukon River (46.2%) and only small numbers to the Porcupine River (1.3%). Yukon River fish in Canada returned to large headwater tributaries including the Stewart, Pelly, Big Salmon, and Teslin rivers (27.3%), small tributaries associated with the main river (8.2%), and reaches of the Yukon River main stem (10.7%). Chandalar and Sheenjek River fish (2.9%) were the principle U.S. stocks in the upper basin. Tanana River fish were predominantly Chena, Salcha, and Goodpaster River stocks (17.9%), with small populations located in other tributaries. Middle basin fish traveling to the Koyukuk, Melozitna, Nowitna, and Tozitna rivers were a minor component of the run (5.5%). Stocks returning to lower basin tributaries (7.6%) were primarily Bonasila, Anvik, and Nulato River fish (7.1%). The two major stock groups, Canadian Yukon River and Tanana River fish, exhibited similar run timing with

most fish passing through the lower river in mid-June, although several distinct pulses were also observed in early June and late June-early July. In Canada, upper headwater stocks displayed a later and more protracted run timing. Lower basin stocks consisted primarily of late run fish, although other stocks, particularly Canadian Yukon River fish, were also present during this period. Movement rates for radio-tagged fish averaged 51.8 km/day. Middle and upper basin stocks averaged 46.4 km/day and 55.1 km/day, respectively. However, these stocks exhibited comparable movement rates in reaches of the Yukon River main stem, while slower swimming speeds were recorded as the fish approached their natal streams. Movement rates for lower basin stocks were substantially less, averaging from 34.6 km/day, possibly due to the shorter distances traveled to reach their spawning areas.

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INTRODUCTION

Large numbers of Chinook salmon (*Oncorhynchus tshawytscha*) return to the Yukon River basin to spawn. These returns support important fisheries in both the United States and Canada and have been the focus of numerous discussions between the two countries over management and harvest allocations. Ultimately these discussions contributed to the passage of the Yukon River Salmon Agreement, which provides for cooperative management of salmon returns in the basin (Yukon River Salmon Act 2000). However, Yukon River Chinook salmon declined dramatically in recent years (Joint Technical Committee of the Yukon River U.S./Canada Panel 2002), a phenomenon observed in other major river systems in western Alaska, and information is needed to better understand and manage these returns, and to facilitate conservation efforts.

The Yukon River basin drains a watershed of more than 855,000 km^2. The main river alone flows for more than 3,000 km from its headwaters in Canada to the Bering Sea (Fig. 1). Several major tributaries flow into the Yukon River main stem, including the Koyukuk and Tanana rivers in the United States; the Stewart, White, Pelly, and Teslin rivers in Canada; and the Porcupine River, which transects both countries. Most reaches of the drainage consist of a primary river channel with occasional side channels and sloughs, although the Yukon River main stem is extensively braided between the villages of Rampart and Circle--an area commonly referred to as the Yukon Flats. Sections of the Canadian main stem and the White River are also extensively braided. Water visibility in many areas is extremely poor, particularly in the Yukon River main stem, due to turbidity from the upper reaches of the drainage. The basin is remote with limited access to many areas.

Salmon are a major source of food in many remote communities within the basin, and often it provides the primary source of income for local residents. Subsistence, commercial, and personal use fisheries occur throughout the drainage with most fishing effort concentrated near villages along the Yukon River main stem. Fish are also harvested in reaches of the Koyukuk, Tanana, Chandalar, Porcupine, Stewart, Pelly, and Teslin rivers. Limited sport fishing takes place in a number of clearwater tributaries within the basin. The fisheries are managed to maintain essential spawning escapements, support adequate subsistence harvests for local residents, and provide commercial and sport fishing opportunities when appropriate. Chinook salmon harvests from 1961 to 2003 averaged 134,100 fish in the United States and 12,100 fish in Canada, with catches ranging from 45,300 fish (2000) to 198,400 fish (1983) in the United States, and 2,600 fish (1969) to 22,800 fish (1980) in Canada (Joint Technical Committee of the Yukon River U.S./Canada Panel 2004). From 1961 to 1999, commercial fishing accounted for more than 76% of the U.S. harvest and 42% of the Canadian harvest. These fisheries have been severely restricted in recent years due to declining returns, resulting in harvests composed primarily of fish caught for subsistence.

A basin-wide radio telemetry study was initiated in 2000 by the Alaska Department of Fish and Game (ADFG) and the National Marine Fisheries Service (NMFS). The primary objective of this study was to provide information on the run characteristics of Yukon River Chinook salmon returns, including stock composition and run timing, country of origin, migration patterns, and the location of important spawning areas. Information was also collected to evaluate other projects in the basin that assess run abundance. The study faced severe logistical challenges due to the large size and physical characteristics of the drainage. In addition, the sizeable runs of Chinook salmon returning to the basin to spawn required the tagging of large numbers of fish to obtain meaningful results. Chinook salmon reputedly travel in deep water during their spawning migration, further complicating efforts to monitor their movements. Work in 2000-2001 focused on the development of capture methods, improved telemetry equipment for tracking the fish, and the infrastructure necessary for a study of this size and scope. Distribution and movement data collected during this exploratory phase were used primarily to evaluate the response by Chinook salmon to the capture and handling procedures, and to provide preliminary information on migration patterns. Large-scale tagging and basin-wide monitoring programs were conducted in 2002 and 2003, which provided new information on the stock composition, run timing, and movement patterns of Yukon River Chinook salmon. A third year of the basin-wide study was conducted in 2004 to address questions related to study findings and annual variation, particularly in relation to run characteristics during years with greater run abundance.

MATERIALS AND METHODS

Fish Capture and Handling

Adult Chinook salmon returning to spawning areas in the Yukon River basin were captured with drift gill nets near the village of Russian Mission (Fig. 1). This site was selected because it 1) consisted of relatively narrow, unbraided sections of river, increasing the probability of capturing a representative sample, 2) was downriver of most known Chinook salmon spawning areas (i.e., only the Andreafsky River, located approximately 190 km downriver, was not included), and 3) was upriver of significant commercial and subsistence fisheries lower in the basin. Results from feasibility work in 2000-2001 (Spencer et al. 2003) and basin-wide programs in 2002 and 2003 (Eiler et al. 2004, 2006) indicated that sufficient numbers of Chinook salmon could be captured at this site. Local fishers were contracted to fish the site from early June to mid-July (Table 1), with project personnel handling the fish and collecting data. Two day shifts (0900-1700) and two night shifts (1800-0200) were fished throughout the tagging period. Fishing effort was divided between the lower and upper sections of the tagging area to minimize the recapture of tagged individuals by the other crew.

The site was fished with drift gill nets that were constructed with No. 21 seine twine, had 21.5 cm mesh size, and were 46 m long, 7.6 m deep, and hung at a 2:1 ratio. This configuration was effective in capturing Chinook salmon while minimizing chum salmon (*O. keta*) bycatch. Nets were monitored continually and fish were removed immediately after capture. The netting was cut to facilitate removal and minimize injuries. A dip net, constructed with soft, fine-mesh netting, was used to lift fish into the boat. A maximum of two fish were tagged per drift to minimize both handling time and potential sampling bias if stocks of fish were poorly mixed. Fish selected for tagging were placed in a neoprene-lined tagging cradle submerged in a trough of fresh water. A pump was used to circulate river water into the trough while fish were being processed. Anesthesia was not used during the tagging procedure.

Fish were tagged with pulse-coded radio transmitters (Fig. 2) manufactured by Advanced Telemetry Systems (Isanti, Minnesota)[1]. The transmitters (which were 5.4 cm long, 2.0 cm in

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

diameter, had a 30-cm transmitting antenna, and weighed 20 g) were gently inserted through the mouth and into the stomach using a plastic tube 0.7 cm in diameter. Each transmitter emitted a unique signal (i.e., transmitters were placed on 11 discrete frequencies in the 150-151 MHz frequency range spaced a minimum of 20 kHz apart, with up to 100 distinct pulse codes per frequency), making it possible to identify each individual fish. Transmitters were also equipped with a motion sensor and activity monitor. The motion sensor, an integrated tilt switch sensitive to movement, inserted additional signal pulses distinct from the basic signal pattern each time the transmitter moved. The activity monitor altered the signal pattern to an inactive mode (Eiler 1995) if the motion sensor was not triggered for 24 hours; the signal reverted to the original pattern if the motion sensor was activated. Transmitters had a minimum battery life of 90 days. Fish were marked externally with yellow spaghetti tags attached below the dorsal fin (Wydoski and Emery 1983). A subsample of fish was tagged with radio-archival tags, which recorded water depth and temperature every 3 minutes as well as transmit a signal. Fish with radio-archival tags were marked externally with pink spaghetti tags.

Information on length (mid-eye to fork of tail), skin color (bright iridescent silver, dull silver, and blush--silver with reddish tinges), and condition of the fish was also recorded. Data on gender were not collected because of difficulties in distinguishing the sexes in the lower river due to the lack of distinct external characteristics (Eiler et al. 2004). A tissue sample was taken from the axillary process for genetic stock identification studies being conducted by ADFG, and scales were collected to provide age data. Fish were released back into the main river immediately after the tagging procedure was completed. Handling, from removal of the net from the water to release, took from 6 to 8 minutes depending on the number of fish tagged per drift.

Tracking Procedures

Radio-tagged fish that moved upriver were tracked with remote tracking stations (Fig. 3) located at 40 sites throughout the basin (Table 2; Fig. 4). Sites selected were on important migration corridors and major tributaries of the drainage. When possible, the stations were placed on bluffs overlooking straight, narrow, single-channel sections of the river to maximize reception range and increase the probability of detecting fish moving past the site. Stations consisted of several integrated components, including a computer-controlled receiver developed by Advanced Telemetry Systems, and satellite uplink (Campbell Scientific, Logan, Utah). A self-contained power system--consisting of a bank of six 6-volt, sealed lead-acid batteries connected in series and parallel (12 V, 610 Ah) and charged by two 80-W solar panels--supplied power to the stations. Radio-tagged fish within reception range were identified and recorded by the stations. Information collected included the date and time tagged fish were present at the site, signal strength of the transmitter, and the orientation of the fish in relation to the station (i.e., upriver or downriver from the site). The information was summarized and recorded at 10-minute intervals. Because of the isolated nature of the sites, the telemetry data collected, including information on station operations (e.g., voltage levels for the station components, and whether the reference transmitter at the site was properly recorded) were transmitted every hour to a geostationary operational environmental satellite (GOES) and relayed to a receiving station near Washington D.C. (Fig. 3). Information was accessed daily via the Internet and uploaded into a computer database for analysis (Eiler and Masters 2000).

Radio-tagged Chinook salmon that passed the first set of tracking stations (hereafter referred to as Paimiut, Fig. 4), located approximately 62 km upriver from Russian Mission, were considered to have resumed upriver movements. Stations were operated at sites on the Yukon River main stem, including Paimiut, Yukon-Anvik River confluence, Yukon-Yuki River confluence, Rampart Rapids, Circle, U.S.-Canada Border (hereafter referred to as Yukon Border), downriver from the Yukon-White River confluence, upriver from the Yukon-White River confluence, Selkirk, Yukon-Tatchun Creek confluence, Yukon-Teslin River confluence, and Hootalinqua. United States tributaries monitored by tracking stations included the Bonasila, Anvik, Innoko, Nulato, Koyukuk (including sites near the mouth, Gisasa River, Hogatza River and upper section of the main stem), Melozitna, Nowitna, Tozitna, Tanana (including sites near Manley, Nenana, Chena River, Salcha River, and upper section of the main stem), Chandalar, and Porcupine (including sites on the Sheenjek River, Black River, Porcupine-Coleen River confluence, and U.S.-Canada Border, hereafter referred to as the Porcupine Border) rivers. Tracking stations were also operated on Canadian tributaries including the Stewart (including sites near the mouth and above Fraser Falls), Pelly, Big Salmon, and Kluane rivers (Yukon River drainage), and Fishing Branch River (Porcupine River drainage). Pairs of stations were operated at locations with special significance, including Paimiut, lower Koyukuk River, lower Tanana River, Rampart Rapids, Yukon Border, and Porcupine Border, to avoid potential loss of data from unforseen events (e.g., technical problems with equipment, damage from bears and other causes). Fish tracked to terminal reaches of the drainage were classified as distinct spawning stocks. The status of fish that remained in non-terminal areas, such as sections of the Yukon River main stem, was less certain because these fish could represent local spawners or fish destined for spawning areas farther upriver. Many non-terminal areas were turbid and hard to access, making verification of spawning activity difficult.

Aerial surveys were conducted in selected reaches of the drainage to locate radio-tagged fish that traveled to areas between station sites and upriver of stations on terminal tributaries. Fish were tracked from fixed-wing aircraft and helicopters equipped with 4-element Yagi receiving antennas mounted on both sides of the aircraft and oriented forward. Tracking receivers contained an integrated global positioning system (GPS) receiver to assist in identifying and recording locations. Areas surveyed in the United States included the Yukon River main stem from Russian Mission to the Yukon Border, and reaches of the Anvik, Innoko, Nulato, Koyukuk, Nowitna, Tanana, Chandalar, Sheenjek, Black, Charley, Kandik, Nation, and Tatonduk rivers. In Canada, surveys were flown along reaches of the Yukon River main stem, and in numerous mainstem tributaries including Chandindu River, Klondike River, White River, Stewart River, Pelly River, Tatchun Creek, Nordenskiold River, Little Salmon River, Big Salmon River, and Teslin River. Surveys were also flown in Canadian reaches of the Porcupine River, including Old Crow, Whitestone, Miner, and Fishing Branch rivers.

Stock Composition Estimation

Returning Chinook salmon passing through the lower Yukon River are composed of a number of distinct stocks. These stocks travel to spawning areas throughout the basin and differ in entry timing and magnitude. A portion of these fish are intercepted in Yukon River fisheries before reaching their spawning areas. Stock composition at the tagging site is assessed by capturing, radio tagging, and tracking individuals to their final destination. The upriver distribution of the fish tagged per day is weighted by daily measures of abundance at the tagging site and adjusted to account for tagged fish removed in upriver fisheries. This approach provides an estimate of the relative abundance of stocks passing through the lower river on both a daily and seasonal basis.

The number of radio-tagged fish released on day *t* at the capture sites in the lower Yukon River are denoted as $R = (R_1, \ldots, R_T)'$. Radio-tagged fish are assumed to represent a random sample from the mixture of Chinook salmon stocks passing the tagging site each day. A total of 46 separate stocks (Fig. 5) are considered in the analysis, and the unknown stock proportions of this mixture on day *t* are denoted by $\theta_t = (\theta_{t,1}, \ldots, \theta_{t,46})'$. Final destinations include 42 terminal spawning areas and 4 non-terminal areas (i.e., U.S. reaches of the Yukon River main stem potentially used for spawning or as a corridor for fish traveling farther upriver; these areas potentially include mainstem tributaries not surveyed during the study). The numbers of radio-tagged fish escaping to spawning areas from releases on day *t* are denoted as $\boldsymbol{r}_t = (r_{t,1}, \ldots, r_{t,46})'$. A total of 15 fisheries that harvest fish upriver from the tagging site were defined during the study (Table 3; Fig. 5); 14 of these fisheries (Fisheries B through O, numerically indexed in the estimation formulas as Fisheries 1 through 14, respectively) presumably alter the initial stock composition because together they disproportionally intercept stocks traveling to upriver spawning areas; that is, stocks traveling farther upriver are exposed to more fisheries than lower river stocks. The first of the 15 fisheries, Fishery A, is lowest in the study area, below all spawning areas, and therefore is assumed to exploit the stocks equally. Hereafter, radio-tagged fish caught in Fishery A are subtracted from the initial releases to provide a corrected set of daily releases, namely, $R = (R_1, \ldots, R_T)'$; fish caught in Fishery A are not considered further in this analysis. Tagged fish destined for any spawning stock, such as stock *s*, are exposed to a downriver subset of the 14 fisheries, and the collection of these fishery indices is denoted by F_s. Catches in the 14 fisheries from releases of day *t* are denoted by $C_t = (c_{t,1}, \ldots, c_{t,14})'$ and the corresponding exploitation rates, or fractions of tagged fish entering and removed by each fishery, are denoted by $\phi_t = (\phi_{t,1}, \ldots, \phi_{t,14})'$. The set of stock indices of upriver stocks passing through fishery *f* will be denoted by S_f, $f = 1, \ldots, 14$.

Observed counts of radio-tagged fish among spawning areas and catches were modeled so the effects of unequal harvests among the stocks would not bias estimates of the stock composition at the tagging site. The naive estimate of stock composition, equal to the observed distribution of radio-tagged fish escaping to spawning areas, was rejected out-of-hand because of its inherent bias. A probability model was developed using the schematic for the migration routes, fisheries, and spawning areas in the Yukon River basin (Fig. 5). Counts of fish in the escapements and catches from a daily release are assumed to have the multinomial distribution,

$$p(r_{t,1},\ldots,r_{t,46},c_{t,1},\ldots,c_{t,14}) = \left(\frac{R_t!}{\prod_{s=1}^{46} r_{t,s}!\prod_{f=1}^{14} c_{t,f}!}\right)\prod_{s=1}^{46}\left(\theta_{t,s}\cdot\psi_{t,s}\right)^{r_{t,s}}\prod_{f=1}^{14}\left(\mu_{t,f}\right)^{c_{t,f}}$$

$$\sum_{s=1}^{46}\theta_{t,s}\psi_{t,s} + \sum_{f=1}^{14}\mu_{t,f} = 1, \quad t = 1,\ldots,T, \tag{1}$$

where $\psi_{t,s} = \prod_{j\in F_s}(1-\phi_{t,j})$ is the probability that a fish destined for stock *s* escapes downriver fisheries, $\mu_{t,f} = \prod_{j\in H_f}(1-\phi_{t,j})\cdot\phi_{t,f}\cdot\sum_{s\in S_f}\theta_{t,s}$ is the probability that a tagged fish released on day *t* is caught in fishery *f*, and H_f is the set of indices for fisheries downstream from fishery *f*. The Lagrange function for the unknowns given the recoveries and catches from day *t*, which is the likelihood function with an added term to constrain the daily probabilities to equal 1, is

$$\log L(r,c;\theta_t,\phi_t) = \kappa + \sum_{s=1}^{46} r_{t,s}\log\left(\theta_{t,s}\cdot\psi_{t,s}\right) + \sum_{f=1}^{14} c_{t,f}\log\left(\mu_{t,f}\right) +$$

$$\gamma\left(\sum_{s=1}^{46}\theta_{t,s}\psi_{t,s} + \sum_{f=1}^{14}\mu_{t,f} - 1\right), \tag{2}$$

where κ is a constant and γ is a constant called the Lagrange multiplier. The Lagrange function is maximized by values of $\theta_{t,s}$ given in Table 4 with known values of $\phi_{t,f}$ given by

$$\phi_{t,f} = c_{t,f}\bigg/\left(R_t - \sum_{s\in G_f} r_{t,s} - \sum_{j\in H_f} c_{t,j}\right),\ f = 1,\ldots,14, \tag{3}$$

where G_f is the set of indices for stocks downstream from fishery *f*.

The numbers of radio-tagged fish released on any particular day, however, are quite limited for the estimation of the unknown daily fractions destined for the various stocks. Therefore, releases over longer periods than a single day are considered. The daily fractions destined for the various stocks are expected to be more similar on days nearby than they are on days distant. Therefore, this estimation for the days of release, $t = 1, 2, \ldots, T$, is accomplished by use of a moving window of width equal to $2d + 1$ days ($d = 0, 1, \ldots, d_{max}$) centered on the day t, namely, $[t - d, t + d]$. The moving-window estimate on day t, $\hat{\theta}_{t,s}^{(d)}$, is computed from the equations of Table 4, substituting $R_t^{(d)}$ for R_t, $r_{t,s}^{(d)}$ for $r_{t,s}$ and $c_{t,f}^{(d)}$ for $c_{t,f}$. Here $R_t^{(d)} = \sum_{j=t-d}^{t+d} R_j$ is the total number of radio-tagged fish released during days included in the window about t, $r_{t,s}^{(d)} = \sum_{i=t-d}^{t+d} r_{i,s}$ is the total number of radio-tagged fish migrating to stock s from releases of days included in the window about t, and $c_{t,f}^{(d)} = \sum_{j=t-d}^{t+d} c_{j,f}$.

The estimated fractions at day t destined for the stocks are the fractions of total releases during the window centered on day t that would have ultimately tracked to the various stocks had the fisheries not intercepted them. At the beginning and the end of the tagging interval, $[1, T]$, the window includes days for which no releases were made. These days represent periods of few migrants and have little effect on estimates. The recoveries from these days are set to zero in the moving-window estimator. For example, if window width is $2d + 1 = 3$, the moving-window estimator of migration composition at day 1 includes no recoveries of day 0, and $r_{0,s}$ is set to zero for $s = 1, 2, \ldots, S$. At day T, the window includes no recoveries of day $T + 1$, so $r_{T+1,s}$ is set to zero for s = 1, 2, …, S. In effect, the window width is reduced at the beginning and end of the tagging interval during which minimal numbers of migrants passed the tagging site. We chose d = 3, or a window width of 1 week, as reasonable.

Although the estimates of daily stock composition are of interest, they do not reflect the changes in magnitude of daily returns to the Yukon River. The unknown daily numbers of fish passing the capture site are denoted as E_1, E_2,..., E_T, and their season total is $E_. = \sum_{i=1}^{T} E_i$.

The daily fractions of the total return passing the capture site are denoted as

$$\pi_i = E_i \,/\, E_., \quad i = 1,\ldots,T \;. \tag{4}$$

Daily fractions of the total season return of Chinook salmon to the Yukon River that pass the capture site are estimated from the catch rates of gill nets used to capture fish for tagging. Gill nets are expected to capture fish in proportion to daily effort. Daily catches, $X_1,\ldots,X_T$, are assumed to be Poisson random variables with expected values,

$$\lambda_t = \lambda h_t E_t = \left(\lambda E_.\right) h_t \frac{E_t}{E_.} = \lambda_0 h_t \pi_t, \quad t = 1,\ldots,T \;, \tag{5}$$

where $\lambda_0 = \lambda E_.$ is a constant proportional to the total return, and h_t is the number of units of effort fished on day t. Maximum likelihood estimates of the daily migration fractions, $\pi = (\pi_1,\ldots,\pi_T)'$, can be shown to be the time series of normalized catch per effort,

$$\hat{\pi}_t = Y_t \Big/ \sum_{j=1}^{T} Y_j = \left(X_t / h_t \right) \Big/ \left(\sum_{t'=1}^{T} X_{t'} / h_{t'} \right), \quad t = 1, \ldots, T \quad . \tag{6}$$

The maximum likelihood estimate of λ_0 is $\hat{\lambda}_0 = \sum_{t=1}^{T} X_t / h_t$.

Daily fractions of the total season return to the Yukon River basin that are destined for any particular stock equal the products of the stock's daily proportions, $\theta_{t,s}$, and the corresponding daily fractions of the total season return passing the tagging site, namely, $\omega_{t,s} = \pi_t \theta_{t,s}$. These stock-specific daily fractions of the total return are estimated by the daily products of the estimates of stock composition (Table 4) and the daily migration fractions, $\hat{\pi}_t$, $t = 1, \ldots, T$, from Equation 6,

$$\hat{\omega}_{t,s} = \hat{\pi}_t \hat{\theta}_{t,s}, \quad s = 1, \ldots, 46; \; t = 1, \ldots, T \; . \tag{7}$$

Finally, the estimated fraction of the total season return to the Yukon River basin that belonged to any stock *s* equals the sum,

$$\hat{\alpha}_s = \sum_{t=1}^{T} \hat{\omega}_{t,s}, \quad s = 1,\ldots,46 \tag{8}$$

To evaluate the sampling variation in estimates, a parametric bootstrap was performed. First, random bootstrap samples of daily gillnet catches, $X_1^*, X_2^*, \ldots, X_T^*$, were drawn from Poisson distributions with expected values of the X_t^* determined from the maximum likelihood estimates and equal to $\hat{X}_t = \hat{\lambda}_0 h_t \hat{\pi}_t,\ t = 1,2,\ldots,T$. These random catches were used to compute corresponding bootstrap catch rates $Y_1^*, Y_2^*, \ldots, Y_T^*$, and daily migration fractions, $\pi_t^*,\ t = 1,\ldots,T$. Next, independent daily multinomial samples of radio-tagged fish, either migrating to the possible stocks, $r_{t,1}^*, r_{t,2}^*, \ldots, r_{t,S}^*$, or caught in the various fisheries, $c_{t,1}^*, \ldots, c_{t,14}^*$, from the daily known numbers released, R_t, were drawn with probabilities equal to the original maximum likelihood estimates,

$$p(r_{t,1}^*, \ldots, r_{t,S}^*, c_{t,1}^*, \ldots, c_{t,14}^*) = \left(\frac{R_t\,!}{\prod_{s=1}^{S} r_{t,s}^*\,! \prod_{f=1}^{14} c_{t,f}^*\,!} \right) \prod_{s=1}^{S} \left(\hat{\theta}_{t,s}^{(d)} \cdot \psi_{t.s}^{(d)} \right)^{r_{t,s}^*} \prod_{f=1}^{14} \left(\hat{\mu}_{t,f}^{(d)} \right)^{c_{t,f}^*} \quad . \tag{9}$$

Bootstrap samples of tagged fish in catches and escapements were used to compute the corresponding bootstrap estimates for stock proportions, such as $\hat{\theta}_t^{(d)*}$, just as with the original counts of tagged fish. Finally, bootstrap estimates for stock proportions were weighted by the bootstrap daily migration fractions. The next bootstrap sampling began with another draw of the daily gillnet catches and tagged numbers migrating to the possible stocks or caught in the fisheries, followed by computation of the bootstrap estimates of daily catch rates, daily migration fractions, daily stock compositions, and weighted stock compositions.

Migration Rates

Migration rates for radio-tagged Chinook salmon were calculated by comparing the date and time that the fish moved upriver past the Paimiut tracking stations with information (i.e., date and time of passage, and the distance traveled upriver from Paimiut) from the station farthest upriver that last recorded the fish. Movements by the fish between the tagging site and Paimiut were not included in these calculations to avoid incorporating tagging-induced behavior that would bias the results, although these data were used as a relative measure to evaluate how the fish responded to the capture and tagging procedures. Migration rates between tracking stations were also calculated to determine movement patterns within different reaches of the basin.

RESULTS

Fish Capture and Tagging

Drift gill nets were an effective method for capturing large numbers of adult Chinook salmon in suitable condition for tagging. Fishing commenced early in the run and continued until the end of the run when catch rates were low. A total of 583 hours were fished at Russian

Mission from 3 June to 19 July, and 2,107 Chinook salmon were captured (Table 1). Catch per unit effort (CPUE) data from the upper section of the tagging area was used as a daily measure of abundance during the study, and indicated that several distinct pulses of fish moved through the lower river, with the peak of the run passing Russian Mission during 13-20 June (Fig. 6).

Of the 2,107 Chinook salmon captured, 995 fish were radio tagged, ranging from 319 fish in Week 25 (13-19 June) to 5 fish in Week 30 (18-19 July) (Table 1). Six-year-old fish were the dominant age group in the tagged sample (68.4%). The remaining fish were primarily 5-year-olds (18.1%), with smaller percentages of 4-year-olds (8.3%), 7-year-olds (5.0%), 8-year-olds (0.1%), and 3-year-olds (0.1%). Radio-tagged fish averaged 825 mm in length, ranging from 395 mm to 1,060 mm. Fish were primarily bright, iridescent silver in color during the first 4 weeks of tagging, ranging from the entire sample in Week 23 to 59.7% of the sample in Week 26 (Table 5). This color phase was less prominent near the end of the run, ranging from 38.2% of the sample in Week 27 to 16.2% of the sample in Weeks 29-30. Increasing numbers of fish exhibited a dull silver coloration later in the run, with 70.3% of the sample displaying this color phase in Weeks 29-30. Fish with pre-spawning colors, ranging from blush (silver with reddish tinges) to a pronounced reddish coloration, were first observed in Week 26 (1.0% of the sample) and became more prevalent later in the run (13.5% of the sample in Weeks 29-30) (Table 5). Fish color in the lower river was also influenced by the final destination of the fish. Most Chinook salmon traveling to Canadian reaches of the basin were iridescent silver when passing the Russian Mission tagging site (85.6% of the Yukon River fish and 90.9% of the Porcupine River fish). Only a small percentage were dull silver, and no Canadian fish displayed pre-spawning coloration (Fig. 7). Iridescent silver color was also prominent for U.S. stocks traveling to upper reaches of the basin, ranging from 49.2% of the Tanana River fish to 72.7% of the Porcupine River fish. These stocks also exhibited the dull silver color (ranging from 27.3% of the Porcupine River fish to 50.8% of the Tanana River fish). Most fish traveling to lower and middle reaches of the basin were dull silver in color, including 53.6% of the Koyukuk River fish, 78.6% of the middle basin tributary fish, and 83.1% of the lower basin tributary fish. Fish destined for lower basin tributaries (8.5%) and the Koyukuk River (10.7%) also displayed pre-spawning coloration (Fig. 7).

Fish Response to Tagging

Chinook salmon responded well to the capture and tagging procedure, with most fish resuming upriver movements after release (Table 6; Fig. 8). A total of 958 (96.3%) radio-tagged fish passed Paimiut, and traveled to upriver reaches (626, 62.9%) or were caught in upriver fisheries (332, 33.4%). Thirty-seven (3.7%) fish did not resume upriver movements, and either regurgitated their tags or died due to handling, predation, or undocumented encounters with fisheries. Radio-tagged fish averaged 1.7 days after release to pass Paimiut, traveling an average of 31.0 km/day (Table 7). Comparable rates were observed throughout the tagging period (i.e., weekly averages), ranging from 27.8 km/day (Week 28) to 37.0 km/day (Week 24). Movement rates between the tagging area and Paimiut did not vary substantially by fish age or length, although average rates were faster for fish released in the lower section of the tagging area and that had farther to travel prior to reaching Paimiut (Table 8).

Fishery Recoveries

A total of 332 radio-tagged fish were harvested in fisheries throughout the Yukon River basin (Table 6). Most (276, 83.1%) of these fish were caught in U.S. fisheries (Table 9; Fig. 8). Harvest rates differed between regions, with 44 (13.4%) fish caught from Russian Mission to Holy Cross, 88 (26.5%) fish caught from Anvik to Ruby, and 108 (32.5%) fish caught in the upper Yukon River from the Yukon-Tanana River confluence to Eagle (Table 9; Appendix A). With the exception of the fishery near Eagle, these fish were likely from both U.S. and Canadian stocks. Fish caught near Eagle were assumed to be destined for spawning areas in Canada. Thirty-three (9.9%) fish were harvested in the Tanana River, with most (23, 6.9%) caught near Nenana and Fairbanks, including 8 fish caught in sport fisheries in the Chena and Salcha rivers (Appendix A). Three (0.9%) fish were caught near villages on the Koyukuk River. Aerial surveys, flown over villages along the Tanana River and Yukon River main stem, documented that 84 of the 332 (25.3%) fish harvested were not reported by fishers.

Fifty-six (16.9%) fish were harvested in Canadian reaches of the basin (Table 9). Fifty-three (16.0%) of these fish were destined for Yukon River spawning areas, with most of the recoveries from Dawson, Stewart River, Carmacks, Pelly River, and Teslin River (Appendix A). Three (0.9%) fish were caught in the Porcupine River fishery near the village of Old Crow.

Distribution of Radio-Tagged Fish

Radio-tagged Chinook salmon traveled to areas throughout the Yukon River basin (Fig. 9). A total of 719 fish were tracked to upriver reaches or recovered in terminal fisheries. Fish traveling to sections of the Yukon River upstream of the Yukon-Tanana River confluence (hereafter referred to as the upper basin) comprised the largest component of the sample, with 346 (48.1%) fish returning to the upper Yukon and Porcupine rivers (Table 10; Fig. 10). A substantial number of these fish traveled to Canadian reaches, including 284 (39.5%) Yukon River fish and 8 (1.1%) Porcupine River fish (Fig. 10). Most (195, 27.1%) Canadian fish were tracked to tributaries of the Yukon River main stem (Table 10), including the Stewart (26, 3.6%), Pelly (48, 6.7%), Big Salmon (25, 3.5%), and Teslin (49, 6.8%) rivers (Appendices B, C). Small numbers of fish were also located in the Chandindu (1, 0.1%), Klondike (12, 1.7%), Sixtymile (1, 0.1), White (12, 1.7%), Nordenskiold (2, 0.3%), and Little Salmon rivers (3, 0.4%), and in headwater areas upriver of the Yukon-Teslin River confluence (13, 1.8%) including 5 (0.7%) fish in the Takhini River (Appendix B). Fifty-seven (7.9%) fish remained in reaches of the Yukon River main stem or traveled to associated tributaries not monitored by tracking stations or surveyed by aircraft (Table 10); most (42, 5.8%) of these fish were located upriver of Selkirk (Appendix B). Canadian fish in the Porcupine River were tracked to headwater tributaries including the Old Crow (1, 0.1%) and Miner (3, 0.4%) rivers (Appendices B, D). One (0.1%) fish that passed the Porcupine Border, and was not harvested in the Old Crow fishery, was not located during aerial surveys flights, suggesting that Chinook salmon may utilize other spawning areas in the Porcupine River drainage.

Fifty-four (7.5%) fish were tracked to the U.S. portion of the upper basin, including 43 (6.0%) Yukon River fish and 11 (1.5%) Porcupine River fish (Table 10). Twenty (2.8%) fish in the upper Yukon River were tracked to tributaries (Fig. 10; Appendix E). Most of these fish returned to the Chandalar River (14, 2.0%), although small numbers were located in Beaver Creek (2, 0.3%), and the Hodzana (1, 0.1%), Charley (1, 0.1%), and Nation (2, 0.3%) rivers (Appendices B, E). Twenty-three (3.2%) fish remained in reaches of the Yukon River main stem or traveled to associated tributaries not monitored by tracking stations or surveyed by aircraft (Fig. 10), including 20 (2.8%) fish downriver from Circle and 3 (0.4%) fish upriver from Circle. Porcupine River fish returned to the Sheenjek River (6, 0.8%), Coleen River (4, 0.6%), and upper reaches of the Black River (1, 0.1%)(Appendices B, E).

Tanana River fish comprised a major component of the sample, with 195 (27.1%) fish returning to areas within the Tanana River drainage (Table 9; Fig. 8). Most (144, 20.0%) Tanana River fish traveled to tributaries in the upper reaches of the drainage, including the Chena (30, 4.2%), Salcha (68, 9.4%), and Goodpaster (28, 3.9%) rivers (Appendices B, F). Fish were also located in reaches of the Kantishna River (9, 1.3%), Tolovana River (5, 0.7%), Nenana River (1, 0.1%), and Clear Creek (3, 0.4%). Twenty-eight (3.9%) fish remained in reaches of the Tanana River main stem or traveled to associated tributaries not surveyed, including 8 (1.1%) fish upriver from Manley, 9 (1.3%) fish upriver from Nenana, and 11 (1.5%) fish upriver from the Tanana-Salcha River confluence (Appendix B).

Seventy-one (9.9%) fish traveled to tributaries in the lower basin (Table 10; Fig. 10). Anvik (40, 5.6%), Bonasila (14, 2.0%), and Nulato River (11, 1.5%) fish were most prevalent, with smaller numbers of fish traveling to the Innoko River (5, 0.7%) and Kako Creek (1, 0.1%)

(Appendices B, G). Fourteen (2.0%) fish returned to tributaries associated with the middle Yukon River (Table 10; Fig. 10), including the Melozitna (3, 0.4%), Nowitna (3, 0.4%), and Tozitna (8, 1.1%) rivers (Appendices B, H). Twenty-eight (3.9%) fish returned to the Koyukuk River (Table 10; Fig. 10), including 8 (1.1%) Gisasa River fish and 5 (0.7%) fish that traveled to middle drainage tributaries. Twelve (1.7%) Koyukuk River fish were tracked to upper reaches of the drainage, including the South Fork River (5, 0.7%) and Henshaw Creek (2, 0.3%). The 5 (0.7%) remaining fish were not located during aerial surveys of the upper headwaters, suggesting that Chinook salmon may utilize other spawning areas within the Koyukuk River drainage. Sixty-five (9.0%) fish were last recorded in non-terminal reaches of the Yukon River main stem, including 49 (6.8%) fish in the lower basin and 16 (2.2%) fish in the middle Yukon River (Table 10; Fig. 10). Some of these non-terminal fish may have traveled to mainstem tributaries not surveyed during the study.

Stock Composition and Timing

Stock composition estimates were derived for the Chinook salmon return based on the distribution of radio-tagged fish, adjusted to account for both the harvest of tagged individuals in upriver fisheries and changes in run abundance at the Russian Mission tagging site. The Chinook run was composed primarily of Tanana River (24.4%) and upper basin (55.2%) stocks (Fig. 11). Canadian fish comprised a substantial proportion of the return (47.5%), with the majority (46.2%) traveling to reaches of the Yukon River and only a small percentage (1.3%) traveling to the Porcupine River (Table 11; Fig. 11). Most Canadian fish (35.4%) returned to tributaries of the Yukon River main stem, primarily the Stewart (4.7%), Pelly (8.4%), Big Salmon (4.9%), and Teslin (9.2%) rivers (Fig. 12). Smaller stocks included the Klondike River (2.2%), White River (2.1%), Tatchun Creek (0.5%), Nordenskiold River (0.4%), Little Salmon River (0.5%), and reaches upriver of the Yukon-Teslin River confluence (2.5%)(Appendix I). Canadian fish also remained in reaches of the Yukon River main stem and small associated tributaries (10.8%), including 0.9% downriver from Dawson (i.e., the lower Canadian Yukon River, including fish in the Chandindu River), 4.9% between Dawson and the Yukon-Tatchun Creek confluence (i.e., the mid-Canadian Yukon River), and 5.0% upriver of the Yukon-Tatchun Creek confluence (i.e., the upper Canadian Yukon River). Most (0.7%) Porcupine River fish traveled to the Miner River, although small numbers also returned to the Old Crow River and other small tributaries within the drainage.

Chinook salmon stocks returning to U.S. reaches comprised a substantial proportion (52.5%) of the run, including 24.4% Tanana River fish and 7.7% upper basin fish (Table 11; Fig. 11). Fish returning to the Chena (4.1%), Salcha (10.1%), and Goodpaster (3.7%) rivers were the dominant Tanana River stocks (Table 11; Fig. 13). Tanana River fish also returned to the Kantishna River (1.3%), Tolovana River (0.6%), and other small tributaries (Appendix I). A proportion of the return (4.6%) also remained in reaches of the Tanana River main stem or traveled to small associated tributaries not surveyed during the study, including fish in the lower (1.1%), middle (1.3%), and upper (2.2) drainage. Upper basin fish traveled to U.S. reaches in both the Yukon (5.9%) and Porcupine (1.8%) rivers (Fig. 11). Spawning populations were documented in Yukon River tributaries including the Chandalar River (1.9%), Charley River (0.2%), Nation River (0.4%), and reaches of Beaver Creek and the Hodzana River (0.4%)

(Fig. 13; Appendix I). Fish also remained in reaches of the Yukon River main stem or traveled to small associated tributaries not surveyed during the study (3.0%), including 2.7% downriver from Circle and 0.3% between Circle and Eagle. Most Porcupine River fish returned to the Sheenjek (1.0%) and Coleen (0.7) rivers (Fig. 13; Appendix I), although small numbers also spawned in upper reaches of the Black River (0.1%).

Chinook salmon also spawned in reaches of the lower basin and middle Yukon River. A total of 7.6% of the run returned to tributaries in the lower basin (Table 11; Fig. 11), including the Innoko (0.5%), Bonasila (1.5%), Anvik (4.3%), and Nulato (1.3%) rivers (Fig. 13; Appendix I). Middle Yukon River tributaries comprised 1.9% of the return, with most fish traveling to the Tozitna River (1.1%), and smaller numbers spawning in the Melozitna (0.4%) and Nowitna (0.4%) rivers. Chinook salmon returned to the Koyukuk River (3.6%), with fish traveling to the Gisasa River (0.9%), and tributaries in the middle (0.8%) and upper (1.9%) reaches of the drainage (Table 11; Appendix I). Fish also remained in reaches of the Yukon River main stem downstream of the Yukon-Tanana River confluence or traveled to small associated tributaries not surveyed during the study (7.3%), with most (5.6%) of these in the lower basin (Table 11; Fig. 11).

Most Chinook salmon stocks passing through the lower Yukon River exhibited similar run timing patterns. Tanana River and Canadian Yukon River stocks were present throughout the return, but were most abundant from middle to late June (Fig. 14). Several distinct pulses were also observed during early June and late June-early July. A similar pattern was observed for Porcupine River fish and stocks returning to tributaries in U.S. reaches of the upper Yukon River. Koyukuk and middle Yukon River tributary fish were present in small numbers throughout the return; however, they too were most abundant in mid-June. Fish allocated to non-terminal areas in the Yukon River exhibited a similar pattern. Although present throughout the run, fish traveling to lower basin tributaries were more abundant during late June and July (Fig. 14).

Run timing differences were also observed within regions of the basin. Canadian stocks returning to tributaries in the upper Yukon River, including the Klondike, Stewart, White, and Big Salmon rivers, were primarily early and middle run fish, while the timing for Teslin River fish was more protracted (Fig. 15). Fish remaining in middle and upper reaches of the Canadian main stem also exhibited a protracted and somewhat later run timing, while headwater fish traveling to areas upriver of Hootalinqua were middle run fish. Porcupine River stocks were present during the early and middle run, although the timing of fish returning to U.S. reaches was more protracted than that observed for Canadian stocks (Figs. 15, 16). Black River fish were present in early June, while Sheenjek River and Coleen River fish were observed from mid-June to early July. Stocks returning to U.S. reaches of the upper Yukon River were primarily early run fish, with Hodzana River, Beaver Creek, Charley River, and Kandik River fish passing through the lower river during the first and second week of June. However, the Chandalar River return was more protracted, extending into mid-July (Fig. 16). In the Tanana River drainage, Kantishna, Chena, Salcha, and Goodpaster River fish were primarily early and middle run fish, although Chena River and Salcha River stocks were still present in mid-July. Koyukuk River fish were present throughout the return; however, upper headwater stocks were observed during the early and late run, compared to Gisasa River fish, which were present primarily during the middle run. The timing for Bonasila, Anvik, and Nulato River fish, the dominant stocks in the lower basin, was later than that exhibited by middle and upper basin fish (Fig. 16).

Differences were also observed in the daily composition of stocks moving through the lower river (Fig. 17; Appendix J). Canadian stocks were predominant throughout the run, comprising an average of 40.4% of the fish passing the Russian Mission tagging site per day. These stocks were somewhat more prevalent during early and mid-June, with daily composition averaging 51.7% and 29.0% during the first and last half of the run, respectively. Although less abundant than Canadian stocks, Tanana River fish (19.5% daily average) exhibited a similar pattern with daily averages of 27.9% and 11.2% during the first and last half of the run, respectively. Fish returning to tributaries in U.S. reaches of the upper basin also tended to enter the river during the early and middle run (Fig. 17). In contrast, fish returning to tributaries in the lower and middle basin were more prevalent later in the run. Although relatively minor in terms of overall abundance (Table 11; Fig. 14), these stocks comprised a substantial portion of the late run with daily composition averaging 35.2%, compared to 6.2% during the first half of the return. A similar pattern was observed for fish remaining in non-terminal areas, with low daily averages throughout most of the run, and higher levels in July.

Stock composition estimates were based on the assumption that fish allocated to designated stock groups, including those in non-terminal areas, represented spawning populations. Non-terminal stock groups that included fish in-transit to areas farther upriver (i.e., fish that were harvested in fisheries but not reported, or died due to disease, injuries, or predation prior to reaching their final destination) would bias composition estimates, and underestimate the contribution of upriver stocks. To address this concern, stock composition estimates were recalculated with fish remaining in non-terminal areas categorized as in-transit and treated as fishery recoveries. Composition estimates for most stocks were similar using the two approaches (Fig. 18). The greatest difference was observed for Yukon River fish in Canada, with estimates ranging from 46.2% of the return when non-terminal fish were categorized as spawning populations to 53.4% of the return when these fish were considered in-transit to spawning areas farther upriver. Similarly, stock composition estimates for Tanana River fish increased from 24.4% when non-terminal fish were categorized as spawning populations to 26.3% of the return when these fish were considered in-transit to spawning areas farther upriver.

Movement Patterns

Radio-tagged fish traveled an average of 51.8 km/day; however, regional and stock differences were observed. Upper basin fish traveled an average of 55.1 km/day. Fish returning to the Yukon River in Canada averaged 54.8 km/day, ranging from 50.5 km/day for fish traveling to reaches of the Yukon River main stem to 61.9 km/day for Klondike River fish (Table 12). Similar rates were observed for stocks traveling to U.S. reaches in the upper Yukon River, with averages of 54.6 km/day for tributary fish and 55.0 km/day for fish remaining in non-terminal areas (i.e., reaches of the main stem or associated tributaries not monitored during the study). Porcupine River fish generally traveled faster than upper Yukon River fish, averaging 58.5 km/day for U.S. stocks and 60.0 km/day for Canadian stocks (Table 12); fish traveling to the Coleen and Old Crow rivers displayed movement rates of more than 63 km/day (Appendix E). Tanana River fish exhibited slower migration rates (44.8 km/day), with rates for Chena, Salcha, and Goodpaster River fish ranging from 43.0 km/day to 45.6 km/day. Fish remaining in the Tanana River main stem and associated tributaries not surveyed averaged 43.8 km/day, while fish returning to middle drainage tributaries averaged 53.2 km/day (Table 12). Tributary fish returning to the middle Yukon River, including the Melozitna, Nowitna, and Tozitna rivers, averaged 49.3 km/day; a similar rate (46.3 km/day) was observed for non-terminal fish within this section of the basin. In the Koyukuk River drainage, Gisasa River fish averaged 34.0 km/day, compared to 68.6 km/day for fish traveling to the upper headwaters of the drainage (Table 12). Chinook salmon returning to reaches in the lower basin moved substantially slower than middle and upper basin stocks. Fish located in lower river tributaries averaged 34.6 km/day, ranging from 31.2 km/day for Anvik River fish to 43.1 km/day for Nulato River fish (Table 12; Appendix K).

Migration rates recorded for Chena, Salcha, and Goodpaster River fish were substantially slower than most middle and upper basin stocks. However, the tracking stations used to monitor these tributaries were located relatively close to spawning areas, and the lower rates likely reflect slower swimming speeds as the fish approached their natal streams. When comparing swimming rates based on movements from Paimiut to the lower Tanana River, these stocks averaged between 55.7 km/day and 56.8 km/day (Table 13), movement rates comparable to upper basin fish. A similar phenomenon was observed for other stocks, including fish traveling to the Gisasa and Nulato rivers. In contrast, tracking stations on tributaries associated directly with the Yukon River main stem, such as the Chandalar, Sheenjek, Stewart, Pelly, Big Salmon, and Teslin rivers, were typically placed near the confluence, and often located a substantial distance from spawning areas. The average movement rates for fish passing these stations were comparable to rates observed lower in the basin (Table 13; Fig. 19). For example, Stewart River fish averaged 57.7 km/day between Paimiut and the Stewart River station (located approximately 20 km from the Yukon-Stewart River confluence), compared to 58.7 km/day between Paimiut and the Yukon Border stations. Similarly, Chandalar River fish averaged 53.7 km/day between the Paimiut and Chandalar tracking station (located approximately 10 km from the Yukon-Chandalar River confluence), compared to 57.8 km/day between Paimiut and Rampart Rapids stations.

DISCUSSION

Management of Yukon River Chinook salmon is complicated by recent declines in run abundance and the international nature of their spawning distribution, which makes it necessary to address harvest allocation issues in both the United States and Canada. Radio telemetry has been used effectively to provide information on Pacific salmon (Burger et al. 1985, Eiler et al. 1992, Bendock and Alexandersdottir 1993); however, the logistical problems associated with capturing, tagging, and tracking large numbers of highly mobile fish in the Yukon River basin are unique and severe. Feasibility work in 2000-2001 and large-scale studies in 2002 (Eiler et al. 2004) and 2003 (Eiler et al. 2006), demonstrated that basin-wide radio telemetry programs on Yukon River Chinook salmon are feasible, and provide useful information on run characteristics and fish movements. The 2004 basin-wide study was conducted to collect additional data on Chinook salmon returns and address questions related to annual variation. Drift gill nets were effective in capturing adequate numbers of fish in the lower Yukon River in suitable condition for tagging, with approximately 1,000 fish tagged and released. The system of satellite-linked tracking stations, combined with aerial surveys in selected reaches of the basin, was able to collect and summarize telemetry data in-season, making it possible to monitor fish movements effectively and prioritize field activities.

A primary assumption in tagging studies is that the capture and tagging procedures do not adversely affect the fish (i.e., tagged fish behave the same as untagged fish), or that any effect is limited in severity and duration, and ultimately has negligible impact. Chinook salmon tagged during this study appeared to recover promptly from the procedures used, with most (96.3%) resuming upriver movements after release. Similar results were observed during basin-wide studies on Yukon River Chinook salmon in 2002 and 2003 when more than 97% of the tagged fish traveled to upriver areas or were recovered in upriver fisheries (Eiler et al. 2004, 2006). The percentage of Chinook salmon not moving upriver after release during the 2002-2004 studies (<4%) is lower than reported for many radio-tagging studies (Burger et al. 1985, Milligan et al. 1985, Johnson et al. 1992).

Fish adversely affected by tagging would likely show reduced vitality as they moved upriver, particularly those individuals traveling long distances. However, the movement rates observed during this study did not exhibit this pattern, with upper basin fish traveling an average of 55 km/day throughout their upriver migration. A similar pattern was observed during 2002 and 2003, with upper basin fish averaging 54 km/day (Eiler et al. 2004, 2006). Untagged Chinook salmon in the Yukon River are thought to travel between 48 km/day and 56 km/day based on estimated arrival times of distinct pulses of fish at village fisheries along the drainage (T. Vania, Fishery Management Biologist, ADFG, 333 Raspberry Road, Anchorage, AK 99518. Pers. commun). These estimates are comparable to migration rates observed for radio-tagged fish during this study. Information from previous tagging studies also suggests that handling had a negligible effect. Chinook salmon radio tagged at Rampart Rapids in 1998 traveled an average of 53 km/day (Joint Technical Committee of the Yukon River U.S./Canada Panel 1998), rates comparable to those for upper basin fish tagged during the 2004 study, even though these individuals traveled substantially greater distances after being tagged. By comparison, radio-tagged Chinook salmon in the Columbia River traveled between 43 km/day and 65 km/day through dam reservoirs in the lower basin (i.e., slow-moving water with minimal current), and about half that rate in free-flowing rivers in the upper basin (Bjornn et al. 2000).

A common response observed in tagging studies is for fish to hold in localized areas or drift with the current immediately after release prior to resuming normal patterns of movement. The initial response exhibited by fish tagged at Russian Mission (i.e., movement rates between the tagging site and the Paimiut tracking stations) indicates that the fish experienced a delay in upriver movements or slower swimming speeds initially after release. However, movement rates increased substantially after passing Paimiut (Table 12), suggesting that any adverse effect was limited. Differences in response rates observed for fish released in the lower and upper sections of the tagging area also support this interpretation, with faster movement rates recorded for fish released in the lower section. These fish traveled greater distances prior to passing Paimiut (Table 8), and the faster rates suggest that they had recovered from the initial handling affects and were swimming in a more typical manner as they moved farther upriver. Migration rates calculated for Chinook salmon (Table 12; Appendix K) were based on the movements of radio-tagged fish upriver from Paimiut to avoid including tagging-induced behavior that would bias the results and not reflect typical movements of untagged fish.

Regional differences were observed in migration rates of Chinook salmon stocks in 2004. Upper basin fish generally exhibited faster upriver movements, traveling an average of 55 km/day. These movements are noteworthy considering the distances traveled by the fish, with the uppermost Canadian headwater stocks traveling more than 2,300 km prior to reaching their spawning areas. Lower basin fish exhibited substantially slower rates (34.6 km/day) than middle and upper basin fish. The slower movements may be associated with the shorter distances these fish are traveling, and may reflect reduced swimming speeds as the fish approach their natal streams. This phenomenon was documented for fish leaving the Yukon River main stem and traveling up the Tanana River, with movement rates dropping substantially as the fish approached their spawning tributaries. Migration rates exhibited by stocks were remarkably similar while moving through reaches of the Yukon River main stem even for fish returning to reaches of the lower basin. Although Nulato River fish traveled an average of 43.1 km/day between Paimiut and the Nulato River, migration rates between Paimiut and the Yukon-Anvik River confluence averaged 57.6 km/day (Table 13), a rate comparable to the rate for upper basin fish. Milligan et al. (1985) reported migration rates of 36 km/day for Chinook salmon radio tagged above the Yukon Border in 1982-1983 compared to 54.8 km/day observed for Canadian stocks during this study. The slower speed reported in the 1985 report may relate to a variety of factors including differences in water levels, handling and tagging procedures, or tracking methods.

Chinook salmon returning to the Yukon River in 2004 were primarily Tanana River (24.4%) and upper basin stock (55.2%), comprising approximately 80% of the return. Similar patterns were observed during the 2002 and 2003 studies (Eiler et al. 2004, 2006). Canadian stocks were the dominant component in the upper basin during 2004, with most (29.3% of the return) traveling to large headwater tributaries, including the Stewart, White, Pelly, Big Salmon, and Teslin rivers. Smaller tributaries also supported spawning population (6.1% of the return). Substantial numbers of fish remained in Canadian reaches of the Yukon River main stem (10.7% of the return), although turbid conditions made it impossible to verify spawning activity. Chinook salmon spawning has been previously reported in these areas (Milligan et al. 1985), suggesting that these fish may represent spawning populations. However, local fishers in the Carmacks area have been reluctant to report harvests of radio-tagged fish, which could bias this estimate. Small numbers of fish also returned to Canadian reaches in the Porcupine River (1.3% of the return).

United States Chinook salmon stocks were also an important component of the 2004 return. Similar to the Canadian component, these fish included a combination of major and minor stocks. Chinook salmon returning to the Tanana River were predominantly Chena, Salcha, and Goodpaster River fish (17.9% of the return), although minor spawning populations were also documented in the Kantishna, Tolovana, and Nenana rivers, as well as in small tributaries associated with the Tanana River main stem. Salcha River fish were the most abundant individual stock within the basin (10.1% of the return). Although spawning has been reported for Chinook salmon in U.S. reaches of the upper basin, it was generally thought to be insignificant. However, these fish comprised 4.7% of the 2004 return, with Chandalar River and Sheenjek River fish as the primary stocks. Radio-tagged fish were also located in small mainstem tributaries, and remained in non-terminal areas or traveled to associated tributaries not surveyed during the study.

Relatively few radio-tagged fish returned to the middle Yukon River compared to other regions of the basin. The small middle river tributaries (i.e., Melozitna, Nowitna, and Tozitna rivers) comprised only 1.9% of the return combined. Although the Koyukuk River drains a large watershed, the percentage of fish returning to this tributary was also relatively low (3.6%). Chinook salmon traveled to lower basin tributaries, comprising 7.6% of the return. These stocks were composed primarily of Anvik, Bonasila, and Nulato River fish (7.1%), with small numbers of fish traveling to other areas.

Chinook salmon returns passing through the lower Yukon River are composed of a number of distinct stocks. These stocks travel to spawning areas throughout the basin, and differ in timing and magnitude. The two major stock groups, Canadian Yukon River and Tanana River fish, exhibited similar run timing patterns, with most fish passing through the lower river during the peak of the run in mid-June with several distinct pulses during the early and late run, while lower basin stocks were composed primarily of late-run fish (Fig. 14). Differences in run timing were also observed within regions. For example, fish returning to the Teslin River and middle-upper Yukon River main stem displayed a more protracted run timing that extended later into the run than other Canadian stocks (Fig. 15). Porcupine River fish traveling to U.S. reaches exhibited a more protracted run timing than Canadian stocks within this drainage (Figs. 15, 16). However, in general, most stocks were not temporally distinct, making it difficult to separate stocks based on run timing.

Daily stock composition estimates for Chinook salmon further illustrated the predominance of Canadian Yukon River and Tanana River stocks. Canadian fish were the most abundant stock group per day moving through the lower river during the early and middle run

(Fig. 17). Although less abundant, Tanana River fish displayed a similar pattern during this period. Fish destined for the Porcupine River and U.S. tributaries in the upper basin were present from early June to mid-July, although these stocks were a minor component throughout the run. Lower basin fish were prevalent later in the run, although the Canadian contribution was comparable during this period until mid-July when almost all fish were from lower basin tributaries.

Country of origin estimates for 2004 indicate that Canadian stocks comprised approximately 48% of the Yukon River Chinook salmon return, with most of these fish traveling to the Canadian portion of the Yukon River (46.2%) and a relatively minor component to the Porcupine River (1.3%). Comparable estimates were obtained from previous basin-wide telemetry studies on Yukon River Chinook salmon with Canadian contributions ranging from 53% in 2002 (Eiler et al. 2004) to 55% in 2003 (Eiler et al. 2006). The increased contribution of U.S. stocks in 2004 was due primarily to stronger returns of Tanana River fish.

Country of origin estimates based on telemetry information during 2002-2004 are also consistent with other estimates reported for the drainage. Scale pattern analysis from the early 1980s suggested that Canadian-origin fish comprised between 42% and 54% of the return (Anon 1985). Milligan et al. (1985) estimated that approximately 50% of the Chinook salmon return was made up of Canadian stocks, based on catch and escapement information, ranging from 44% to 51% in years with low returns and 48% to 57% during years of greater abundance. Genetic stock identification estimates of the Canadian contribution from 1987 to 1990 averaged 53% of the return, ranging from 42% to 61% (Wilmot et al. 1992). However, not all stocks were included in the genetic baseline used for this analysis, including U.S. stocks in the upper basin, notably fish returning to the Chandalar and Sheenjek rivers, which could bias the results. Similarities were also observed between the run timing of the significant stock groups reported by Wilmot et al. (1992) and those observed during the 2004 study. Although differences existed, particularly when comparing results from the different years of genetic sampling, the general agreement between the two methods suggests that the estimates derived from the 2004 telemetry study are credible.

Questions exist about the status of fish remaining in non-terminal areas (i.e., U.S. reaches of the Yukon River main stem). Non-terminal areas not only serve as migration corridors for fish traveling farther upriver, but potentially support spawning populations. However, many non-terminal areas are turbid and hard to access, making verification of spawning activity difficult. Ancillary observations in the lower and upper basin indicate that Chinook salmon spawners travel to tributary streams not surveyed during this study (Johnson and Weiss 2006), although these populations are thought to be minor. Radio-tagged fish were located during a partial survey of the upper Hodzana River, a small tributary of the Yukon River main stem located near the village of Beaver. It is not known if other fish last located in non-terminal reaches of the Yukon River main stem ultimately traveled to this river or other nearby tributaries. Mainstem spawning has been reported for Chinook salmon in the Canadian portion of the Yukon River (Milligan et al. 1985), although the extent has not been determined due to turbid conditions. It is not know if suitable salmon spawning habitat exists in U.S. reaches, although evidence of non-salmonid spawning has been reported (Brown 2000).

An alternative explanation is that non-terminal fish represent tagged individuals that have died while in-transit to upriver spawning areas due to handling, predation, disease, or injuries from encounters with fishing gear. These fish may also have been harvested in fisheries but not reported. Reluctance by fishers to provide information on tag recoveries is often a problem as demonstrated by the substantial number (25.3%) of unreported recoveries in 2004. Similar problems were encountered during the 2002 and 2003 telemetry studies. There is also ancillary information that tags were periodically thrown back into the river or left on the shore, further limiting our ability to determine fish status. Incidents of radio-tagged fish regurgitating their tags when captured and removed from fishing gear have also been reported by fishers within the basin. Although it is difficult to substantiate or to rule out these factors, tracking data collected during the study does provide some insights. The distribution pattern of non-terminal fish was clumped in the lower basin between Holy Cross and Nulato, and in the upper Yukon River between Tanana and Fort Yukon--both areas with intensive fishing--while relatively few non-terminal fish were observed in the middle Yukon River between Galena and Tanana, or in the upper Yukon River between Circle and the Yukon Border. Many non-terminal fish were last located in outlying areas near villages or in the general vicinity of fish camps (i.e., areas where their status could not be readily verified), suggesting some interaction with local fisheries (e.g., unreported harvests or mortalities associated with injuries from encounters with fishing gear) may have occurred.

Adverse impacts from handling are always a concern in tagging studies. Numerous studies have been conducted to assess tagging effects on fish, and anomalous behavior has periodically been reported (McCleave and Stred 1975, Mellas and Haynes 1985, Brown and Eiler 2000). However, the large percentage of fish that moved upriver (Table 6), the relatively rapid, sustained movement rates observed (Table 12), and the presence of non-terminal fish in the upper basin, suggests that adverse impacts from tagging were minimal.

Since the late 1990s, the fish parasite *Ichthyophonus* has been reported in Yukon River Chinook salmon (Kocan and Hershberger 1999). Recent sampling studies in the basin have suggested that infected fish destined for the Tanana River and the upper basin may succumb to the parasite while in-transit to upriver spawning areas. Although some of the non-terminal fish may be infected individuals that died prior to reaching spawning areas farther upriver, the distribution pattern observed during the study does not fully fit this explanation. Although *Ichthyophonus*-related mortality would potentially explain the presence of non-terminal fish between Rampart and Fort Yukon, it does not address the concentration of non-terminal fish in the lower basin or the general absence of non-terminal fish in the middle basin; however, it has been shown that the severity of the infection increases as the fish move farther upriver (Kocan and Hershberger 1999). Another explanation is that non-terminal fish represent a combination of factors, including fish that spawned in associated areas not monitored during the study, or that died while in-transit to spawning areas farther upriver because of undocumented encounters with fisheries, disease, or handling mortality.

Stock composition estimates for the 2004 Chinook salmon return were based on the assumption that fish in designated stock groups, including those in non-terminal areas, represent spawning populations. Stock groups that include fish that died while in-transit to spawning areas would bias these estimates and under-represent the contribution of fish traveling farther upriver, particularly for upper basin stocks, and to a lesser extent, Tanana River fish. However, estimates that assume all non-terminal fish were in-transit would potentially overestimate upper river stocks. Composition estimates derived for 2004 based on both assumptions were similar, suggesting minimal bias related to the treatment of non-terminal fish. In regard to country of origin, the estimates suggest that Canadian Yukon River stocks comprised from 46.2% to 53.4% of the Yukon River return; these proportions are consistent with other estimates reported for the basin.

The basin-wide telemetry study in 2004 was successful in obtaining additional information on the stock composition, run timing, spawning distribution, and movement patterns of Yukon River Chinook salmon. Adequate numbers of fish were captured, tagged, and tracked upriver, making it possible to identify and compare the principal components of the return. The system of satellite-linked tracking stations, in combination with the automated database and mapping program, was able to collect and summarize telemetry data in-season, making it possible to prioritize field activities and address management issues within the basin. Stock composition and run timing estimates derived from these data provide a detailed look at the temporal and spatial dynamics of the 2004 return, information needed to better address conservation and harvest allocation issues within the basin. The data collected will also be useful in addressing other research needs, such as expanding the genetic stock identification baseline by identifying spawning populations not currently included, evaluating abundance estimates from other assessment projects, and providing movement and behavioral data to address other concerns, such as the impacts of *Ichthyophonus* on Chinook salmon returns. Results from this study, combined with telemetry data from 2002 and 2003, will also be useful in addressing questions related to annual variation, particularly in relation to run characteristics during years with different levels of abundance.

ACKNOWLEDGMENTS

Primary funding for this study was provided by the U.S.-Canada Yukon River Treaty Implementation Fund, Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative Fund, ADFG, and NMFS. Support was also provided by the U.S. Fish and Wildlife Service (USFWS), U.S. Bureau of Land Management, Department of Fisheries and Oceans Canada (DFO), Bering Sea Fisherman's Association (BSFA), Yukon River Drainage Fisheries Association (YRDFA), National Park Service, U.S./Canada Yukon River Grant No. 03NMF4380185, and the Restoration and Enhancement Fund of the Yukon River Panel. We thank J. Baumer, J. Browning, K. DeYong, R. Driscoll, P. Duffy, M. Eisenman, Y. Kakizaki, K. Maledy, C. Mason, and B. Stephanoff (ADFG), P. Stephanoff (YRDFA), and T. Ferguson and B. Fost (University of Tennessee) for their assistance with field work. Local assistance provided by A. Alexie, P. Alexie, S. Askoak, J. Changsak, J. Duffy, L. Evan, R. Housler, R. James, P. Kozevnikoff, P. Larson, G. Nicholi, M. Nickoli, W. Pitka, V. Sergie, A. Stephanoff, and B. Stephanoff was invaluable to the success of the tagging effort in Russian Mission. Pilots S. Pfeifer and R. Swisher (Quicksilver Air), D. Lorring (Wrights Air Service), D. Miller (Caribou Air), K. Scholz (Fireweed Helicopters), D. Washington (Capitol Helicopters), and J. Webster (Webster Flying Service) provided aerial support for tracking surveys and logistical operations. We thank B. Mercer (B. Mercer and Associates), E. Kahler, T. Lingnau, and P. Salomone (ADFG), C. Osborne (Haldane Environmental Services), J. Duncan and G. Couture (Yukon Salmon Committee), I. Anderton (North Yukon Renewable Resources Council), and R. Brown (USFWS) for their assistance with aerial surveys. C. Osborne also assisted with the installation and maintenance of tracking stations in Canada. B. Busher, K. Boeck, P. Costello, A. Estes, E. Kahler, and K. Nyberg (ADFG), B. Berkbigler and G. Beyersdorf (USFWS), P. Milligan and M. Jarvis (DFO), and K. Gillis and C. Stark (BSFA) helped facilitate tag recoveries. Essential technical support for the telemetry equipment used during the study was provided by N. Christensen, L. Kuechle, A. Mayer, and R. Reichle (Advanced Telemetry Systems). We are particularly grateful to M. Masters (NMFS) for developing and maintaining the database and GIS mapping program used during the study, and providing critical support in processing the data. The report was critically reviewed by J. Hilsinger (ADFG), and J. Helle and R. Wilmot (NMFS). We thank G. Sandone (ADFG) and J. Helle (NMFS) for administrative support during the study.

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Table 1. -- Weekly and total numbers of Chinook salmon captured with drift gill nets and radio tagged in the lower Yukon River near the village of Russian Mission during 2004.

Capture Week	Dates	Fish Captured	Fish Tagged
23	3-5 June	19	8
24	6-12 June	290	160
25	13-19 June	784	319
26	20-26 June	414	196
27	27 June - 3 July	391	199
28	4-10 July	150	76
29	11-17 July	54	32
30	18-19 July	5	5
Total	3 June - 19 July	2,107	995

Table 2. -- Location of remote tracking stations used to monitor the movements of radio-tagged Chinook salmon in the Yukon River during 2004. Distances from Paimiut, located 62 km upriver from the village of Russian Mission, and the previous downriver station are indicated.

		Distance Traveled (km)	
Region	Tracking Station	From Paimiut	From Previous Station[1]
Lower Yukon River Basin[2]	Paimiut[3]	--	--
	Bonasila	112	112
	Anvik	142	142
	Innoko	261	261
	Yukon-Anvik[4]	134	134
	Nulato	396	262
Koyukuk River	Lower Koyukuk[3,4]	448	314
	Gisasa	522	74
	Hogatza	895	447
	Upper Koyukuk	934	486
Mid-Yukon River Basin[5]	Yukon-Yuki[4]	519	385
	Melozitna	566	47
	Nowitna	709	190
	Tozitna	732	213
Tanana River	Lower Tanana[3,4]	835	316
	Nenana[4]	1,012	177
	Lower Chena	1,086	76
	Chena	1,150	62
	Salcha	1,158	146

Table 2. -- Continued.

		Distance Traveled (km)	
Region	Tracking Station	From Paimiut	From Previous Station[1]
	Salcha	1,158	146
	Upper Tanana	1,204	192
Upper Yukon River (U.S.)[6]	Rampart Rapids[3,4]	811	292
	Chandalar	1,231	420
	Circle[4]	1,401	590
Upper Yukon River (Can)	Yukon Border[3,4]	1,704	303
	Stewart	1,901	197
	Fraser Falls	2,207	306
	Below Yukon-White[4]	1,898	197
	Above Yukon-White[4]	1,904	6
	Kluane	2,216	312
	Selkirk[4]	2,028	124
	Pelly	2,065	37
	Tatchun[4]	2,136	108
	Big Salmon	2,320	184
	Yukon-Teslin[4]	2,335	199
	Hootalinqua	2,354	19
Porcupine River (U.S.)	Black	1,405	594
	Sheenjek	1,313	502
	Lower Porcupine[4]	1,450	137

Table 2. -- Continued.

		Distance Traveled (km)	
Region	Tracking Station	From Paimiut	From Previous Station[1]
Porcupine River (Can)	Porcupine Border[3,4]	1,573	123
Porcupine River (Can)	Fishing Branch	2,062	489

[1] Station located immediately downriver on migration route traveled by fish.
[2] Section of the Yukon River from Russian Mission to the Yukon-Koyukuk River confluence.
[3] Two tracking stations located at site.
[4] Located on primary migration route, and used to calculate rates of fish traveling farther upriver.
[5] Section of the Yukon River from Galena to the Yukon-Tanana River confluence.
[6] Section of the Yukon River from Yukon-Tanana River confluence to Eagle.

Table 3. -- Fishery designations used to model stock composition estimates of Yukon River Chinook salmon. The corresponding fishing districts managed by the Alaska Department of Fish and Game (ADFG) and Department of Fisheries and Oceans Canada are noted.

Fishery	Area Covered by Fishery	Fishing District
A	Yukon River from Marshall to Holy Cross	ADFG District 3
B	Yukon River from Anvik to Nulato	ADFG District 4a
C	Yukon River from Nulato to Ruby	ADFG District 4b, 4c
D	Yukon River from Ruby to below Tanana	ADFG District 4b, 4c
E	Lower Tanana River	ADFG District 6a
F	Tanana River near Nenana	ADFG District 6b
G	Tanana River near Fairbanks	ADFG District 6c
H	Yukon River from Tanana to Beaver	ADFG District 5a, 5b, 5c, 5d
I	Yukon River near Fort Yukon	ADFG District 5d
J	Lower Porcupine River	ADFG District 5d
K	Porcupine River near Old Crow	Porcupine River Fishery, Canada
L	Yukon River near Circle	ADFG District 5d
M	Yukon River near Eagle	ADFG District 5d
M	Yukon River from the Border to Dawson	Yukon River Fishery, Canada
N	Yukon River from Dawson to Carmacks	Yukon River Fishery, Canada
O	Yukon River from Carmacks to Whitehorse	Yukon River Fishery, Canada

Table 4. -- Yukon River Chinook salmon stocks and the maximum likelihood estimates of their proportions among fish passing the Russian Mission tagging site.

Stock Name	Stock Index	Estimates of Stock Proportions
Innoko	1	$\hat{\theta}_{t,1} = r_{t,1} / R_t = r_{t,1} / D_{t,1}$
Bonasila	2	$\hat{\theta}_{t,2} = r_{t,2} / R_t = r_{t,2} / D_{t,1}$
Anvik	3	$\hat{\theta}_{t,3} = r_{t,3} / R_t = r_{t,3} / D_{t,1}$
Lower Yukon	4	$\hat{\theta}_{t,4} = r_{t,4} \Big/ \left[R_t - \dfrac{C_{t,1}}{1 - \sum_{s=1}^{3} \hat{\theta}_{t,s}} \right]$ $= r_{t,4} / D_{t,2}$
Nulato	5	$\hat{\theta}_{t,5} = r_{t,5} / D_{t,2}$
Lower Koyukuk	6	$\hat{\theta}_{t,6} = r_{t,6} / D_{t,2}$
Gisasa	7	$\hat{\theta}_{t,7} = r_{t,7} / D_{t,2}$
Middle Koyukuk	8	$\hat{\theta}_{t,8} = r_{t,8} / D_{t,2}$
Hogatza	9	$\hat{\theta}_{t,9} = r_{t,9} / D_{t,2}$

Table 4. -- Continued.

Stock Name	Stock Index	Estimates of Stock Proportions
Upper Koyukuk	10	$\hat{\theta}_{t,10} = r_{t,10} \big/ D_{t,2}$
Melozitna	11	$\hat{\theta}_{t,11} = \dfrac{r_{t,11}}{R_t - \dfrac{C_{t,1}}{1 - \sum_{s=1}^{3} \hat{\theta}_{t,s}} - \dfrac{C_{t,2}}{1 - \sum_{s=1}^{10} \hat{\theta}_{t,s}}}$ $= r_{t,11} \big/ D_{t,3}$
Nowitna	12	$\hat{\theta}_{t,12} = r_{t,12} \big/ D_{t,3}$
Tozitna	13	$\hat{\theta}_{t,13} = \dfrac{r_{t,13}}{R_t - \dfrac{C_{t,1}}{1 - \sum_{s=1}^{3} \hat{\theta}_{t,s}} - \dfrac{C_{t,2}}{1 - \sum_{s=1}^{10} \hat{\theta}_{t,s}} - \dfrac{C_{t,3}}{1 - \sum_{s=1}^{12} \hat{\theta}_{t,s}}}$ $= r_{t,13} \Bigg/ \left[D_{t,3} - \dfrac{C_{t,3}}{1 - \sum_{s=1}^{12} \hat{\theta}_{t,s}} \right] = r_{t,13} \big/ D_{t,4}$
Mid-Yukon	14	$\hat{\theta}_{t,14} = r_{t,14} \big/ D_{t,4}$
Entire Tanana	15-22	$\sum_{s=15}^{22} \hat{\theta}_{t,s} = \left[\sum_{f=4}^{6} C_{t,f} + \sum_{s=15}^{22} r_{t,s} \right] \Big/ D_{t,4}$

Table 4. -- Continued.

Stock Name	Stock Index	Estimates of Stock Proportions
Lower Tanana	15	$\hat{\theta}_{t,15} = r_{t,15} \Big/ \left[D_{t,4} - \frac{C_{t,4}}{\sum_{s=15}^{22} \hat{\theta}_{t,s}} \right] = r_{t,15} / D_{t,5}$
Kantishna	16	$\hat{\theta}_{t,16} = r_{t,16} / D_{t,5}$
Tolovana	17	$\hat{\theta}_{t,17} = r_{t,17} / D_{t,5}$
Mid-Tanana	18	$\hat{\theta}_{t,18} = r_{t,18} \Big/ \left[D_{t,5} - \frac{C_{t,5}}{\sum_{s=15}^{22} \hat{\theta}_{t,s} - \sum_{s=15}^{17} \hat{\theta}_{t,s}} \right] = r_{t,18} / D_{t,6}$
Chena	19	$\hat{\theta}_{t,19} = r_{t,19} \Big/ \left[D_{t,6} - \frac{C_{t,6}}{\sum_{s=15}^{22} \hat{\theta}_{t,s} - \sum_{s=15}^{18} \hat{\theta}_{t,s}} \right] = r_{t,19} / D_{t,7}$
Salcha	20	$\hat{\theta}_{t,20} = r_{t,20} / D_{t,7}$
Goodpaster	21	$\hat{\theta}_{t,21} = r_{t,21} / D_{t,7}$
Upper Tanana	22	$\hat{\theta}_{t,22} = r_{t,22} / D_{t,7}$
Entire Yukon above Tanana	23-46	$\sum_{s=23}^{46} \hat{\theta}_{t,s} = \left[\sum_{f=7}^{14} C_{t,f} + \sum_{s=23}^{46} r_{t,s} \right] \Big/ D_{t,4}$

Table 4. -- Continued.

Stock Name	Stock Index	Estimates of Stock Proportions
Upper Yukon (Rapids)	23	$\hat{\theta}_{t,23} = \dfrac{r_{t,23}}{D_{t,4} - \dfrac{C_{t,7}}{1 - \sum_{s=1}^{22} \hat{\theta}_{t,s}}}$ $= r_{t,23} / D_{t,8}$
Beaver/Hodzana	24	$\hat{\theta}_{t,24} = r_{t,24} / D_{t,8}$
Chandalar	25	$\hat{\theta}_{t,25} = r_{t,25} / D_{t,8}$
Entire Porcupine	26-30	$\sum_{s=26}^{30} \hat{\theta}_{t,s} = \dfrac{\sum_{s=26}^{30} r_{t,s} + \sum_{f=9}^{10} C_{t,f}}{D_{t,8} - \dfrac{C_{t,8}}{1 - \sum_{s=1}^{25} \hat{\theta}_{t,s}}}$ $= \left[\sum_{s=26}^{30} r_{t,s} + \sum_{f=9}^{10} C_{t,f} \right] \Big/ D_{t,9}$
Black	26	$\hat{\theta}_{t,26} = \dfrac{r_{t,26}}{D_{t,9} - \dfrac{C_{t,9}}{\sum_{s=26}^{30} \hat{\theta}_{t,s}}}$ $= r_{t,26} / D_{t,10}$
Sheenjek	27	$\hat{\theta}_{t,27} = r_{t,27} / D_{t,10}$
Coleen/U.S. Porcupine	28	$\hat{\theta}_{t,28} = r_{t,28} / D_{t,10}$

Table 4. -- Continued.

Stock Name	Stock Index	Estimates of Stock Proportions
Canadian Porcupine	29	$\hat{\theta}_{t,29} = \dfrac{r_{t,29}}{D_{t,10} - \dfrac{C_{t,10}}{\sum_{s=26}^{30}\hat{\theta}_{t,s} - \sum_{s=26}^{28}\hat{\theta}_{t,s}}}$ $= r_{t,29} \big/ D_{t,11}$
Miner	30	$\hat{\theta}_{t,30} = r_{t,30} \big/ D_{t,11}$
Upper Yukon above Porcupine	31-46	$\sum_{s=31}^{46}\hat{\theta}_{t,s} = \left[\sum_{f=11}^{14} C_{t,f} + \sum_{s=31}^{46} r_{t,s}\right] \Big/ D_{t,9}$
Upper Yukon (Circle)	31	$\hat{\theta}_{t,31} = \dfrac{r_{t,31}}{D_{t,9} - \dfrac{C_{t,11}}{\sum_{s=31}^{46}\hat{\theta}_{t,s}}}$ $= r_{t,31} \big/ D_{t,12}$
Charley	32	$\hat{\theta}_{t,32} = r_{t,32} \big/ D_{t,12}$
Kandik/Nation	33	$\hat{\theta}_{t,33} = r_{t,33} \big/ D_{t,12}$
Lower Canadian Yukon	34	$\hat{\theta}_{t,34} = \dfrac{r_{t,34}}{D_{t,12} - \dfrac{C_{t,12}}{\sum_{s=31}^{46}\hat{\theta}_{t,s} - \sum_{s=31}^{33}\hat{\theta}_{t,s}}}$ $= r_{t,34} \big/ D_{t,13}$
Klondike	35	$\hat{\theta}_{t,35} = r_{t,35} \big/ D_{t,13}$
Stewart	36	$\hat{\theta}_{t,36} = r_{t,36} \big/ D_{t,13}$

Table 4. -- Continued.

Stock Name	Stock Index	Estimates of Stock Proportions
White	37	$\hat{\theta}_{t,37} = r_{t,37} / D_{t,13}$
Pelly	38	$\hat{\theta}_{t,38} = r_{t,38} / D_{t,13}$
Mid-Canadian Yukon	39	$\hat{\theta}_{t,39} = r_{t,39} / D_{t,13}$
Tatchun	40	$\hat{\theta}_{t,40} = \dfrac{r_{t,40}}{D_{t,13} - \dfrac{C_{t,13}}{\sum_{s=31}^{46} \hat{\theta}_{t,s} - \sum_{s=31}^{39} \hat{\theta}_{t,s}}} = r_{t,40} / D_{t,14}$
Upper Canadian Yukon	41	$\hat{\theta}_{t,41} = \dfrac{r_{t,41}}{D_{t,14} - \dfrac{C_{t,14}}{\sum_{s=31}^{46} \hat{\theta}_{t,s} - \sum_{s=31}^{40} \hat{\theta}_{t,s}}} = r_{t,41} / D_{t,15}$
Nordenskiold	42	$\hat{\theta}_{t,42} = r_{t,42} / D_{t,15}$
Little Salmon	43	$\hat{\theta}_{t,43} = r_{t,43} / D_{t,15}$
Big Salmon	44	$\hat{\theta}_{t,44} = r_{t,44} / D_{t,15}$
Teslin	45	$\hat{\theta}_{t,45} = r_{t,45} / D_{t,15}$
Hootalinqua	46	$\hat{\theta}_{t,46} = r_{t,46} / D_{t,15}$

Table 5. -- Coloration of Chinook salmon captured with drift gill nets and radio tagged in the lower Yukon River near the village of Russian Mission during 2004. Percentages of the weekly totals are in parentheses.

Capture week	Fish tagged	Iridescent silver	Dull silver	Pre-spawning*
23	8	8 (100)	0 (0.0)	0 (0.0)
24	160	143 (89.4)	17 (10.6)	0 (0.0)
25	319	229 (71.8)	90 (28.2)	0 (0.0)
26	196	117 (59.7)	77 (39.3)	2 (1.0)
27	199	76 (38.2)	108 (54.3)	15 (7.5)
28	76	28 (36.8)	44 (57.9)	4 (5.3)
29-30	37	6 (16.2)	26 (70.3)	5 (13.5)
Total	995	607 (61.0)	362 (36.4)	26 (2.6)

* Ranging from blush (silver with reddish tinges) to pronounced reddish coloration.

Table 6. -- Tracking results for Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission during 2004. Percentages of the total are in parentheses.

Final Status	2004
Moved Upriver	958 (96.3)
Upriver Location[1]	626 (62.9)
Harvested in Fishery[2]	332 (33.4)
Not Located Upriver	37 (3.7)
Total	995

[1] Fish recorded upriver from the tagging site and not caught in fisheries.
[2] Including fish caught in terminal tributaries.

Table 7. -- Elapsed time and movement rates (km/day) by capture week for radio-tagged Chinook salmon traveling between the Russian Mission tagging area and the Paimiut tracking stations in 2004.

					95% Confidence Interval	
Capture Week	N[1]	Distance (km)[2]	Days ($\bar{x}$)	Rate	Lower	Upper
23	8	49.7	1.9	32.1	22.1	42.1
24	158	55.2	1.7	37.0	35.1	38.9
25	312	44.6	1.6	31.1	29.8	32.4
26	186	40.3	1.6	28.6	27.0	30.2
27	184	40.8	1.6	28.9	27.5	30.3
28	62	40.3	1.8	27.8	25.1	30.6
29-30	29	41.2	2.1	32.0	26.2	37.8
Combined	939	44.4	1.7	31.0	30.3	31.7

[1] Excluding radio-tagged fish not recorded passing the Paimiut tracking stations.
[2] Average distance from the tagging area to Paimiut; distances for individual fish varied based on the specific location within the area where the fish were captured, tagged, and released.

Table 8. -- Elapsed time and movement rates (km/day) by capture location and distance for radio-tagged Chinook salmon traveling between the Russian Mission tagging area and the Paimiut tracking stations in 2004.

			Average		95% Confidence Interval	
Capture Location	N[1]	Distance (km)[2]	Days	Rate	Lower	Upper
Lower Section[3]	5	70.0 - 79.7	1.7	44.4	35.7	53.0
Lower Section[3]	247	61.2 - 69.6	1.8	39.8	38.4	41.1
Combined[3]	252	61.2 - 79.7	1.8	39.9	38.5	41.2
Upper Section[4]	201	40.1 - 44.4	1.7	30.6	29.1	32.1
Upper Section[4]	486	28.5 - 39.9	1.5	26.6	25.7	27.4
Combined[4]	687	28.5 - 44.4	1.6	27.8	27.0	28.5
Entire Area	939	28.5 - 79.7	1.7	31.0	30.3	31.7

[1] Not including radio-tagged fish not recorded passing the Paimiut tracking stations.
[2] Distance from the tagging area to Paimiut based on the specific location within the area where the fish were captured, tagged, and released.
[3] Section of the Russian Mission tagging area located in the general vicinity of the village.
[4] Section of the Russian Mission tagging area located about 20 km upriver from the village near an abandoned fish camp.

Table 9. -- Harvests of radio-tagged Chinook salmon in the Yukon River basin during 2004.

Percentages of the total are in parentheses.

Fishing Area	Location	Tagged Fish
District 3	Russian Mission to Holy Cross	44 (13.3)
District 4	Anvik to Ruby	88 (26.5)
District 4	Koyukuk River	3 (0.9)
District 5	Yukon-Tanana confluence to Eagle	108 (32.5)
District 6	Tanana River[1]	33 (9.9)
Combined U.S.	Russian Mission to Eagle	276 (83.1)
Canada	Yukon River, Border to Dawson	25 (7.6)
Canada	Yukon River, upriver of Dawson	7 (2.1)
Canada	Yukon River tributaries[2]	21 (6.3)
Canada	Porcupine River, Old Crow	3 (0.9)
Combined Canada	Yukon and Porcupine rivers	56 (16.9)
Total		332

[1] Including sport fishery harvests in the Tolovana, Chena and Salcha rivers.
[2] Including harvests in the Stewart, Pelly and Teslin rivers.

Table 10. -- Regional distribution of Chinook salmon radio tagged in the Yukon River basin during 2004. Fish harvested in terminal reaches of the basin are included. Percentages of the total are in parentheses.

Region	Final Location	Number of Fish
Lower Basin[1]	Yukon River main stem[2]	49 (6.8)
	Tributaries	71 (9.9)
	Combined Areas	120 (16.7)
Koyukuk River	Middle-Upper Koyukuk River[2]	10 (1.4)
	Koyukuk River fishery	3 (0.4)
	Tributaries[3]	15 (2.1)
	Combined Areas	28 (3.9)
Middle Yukon River[4]	Yukon River main stem[2]	16 (2.2)
	Tributaries	14 (2.0)
	Combined Areas	30 (4.2)
Tanana River	Tanana River main stem[2]	28 (3.9)
	Tanana River fishery	23 (3.2)
	Tributaries[3]	144 (20.0)
	Combined Areas	195 (27.1)
Upper Basin[5]	Yukon River main stem (U.S.)[2]	23 (3.2)
	Yukon River tributaries (U.S.)	20 (2.8)
	Yukon River main stem (Canada)[2]	57 (7.9)
	Yukon River main stem fishery (Canada)	32 (4.5)
	Yukon River tributaries (Canada)[3]	195 (27.1)
	Porcupine River tributaries (U.S.)	11 (1.5)
	Porcupine River (Canada)[2]	1 (0.1)
	Porcupine River fishery (Canada)	3 (0.4)
	Porcupine River tributaries (Canada)	4 (0.6)

Table 10. -- Continued.

Region	Final Location	Number of Fish
Upper Basin[5]	Combined Areas	346 (48.1)
Total		719

[1] Section of the Yukon River from Russian Mission to the Yukon-Koyukuk River confluence.

[2] Includes associated tributaries not monitored with tracking stations or aerial surveys.

[3] Includes fish harvested in terminal tributaries.

[4] Section of the Yukon River from Galena to the Yukon-Tanana River confluence.

[5] Section of the Yukon River upriver from the Yukon-Tanana River confluence.

Table 11. -- Stock composition estimates of the Yukon River Chinook salmon return in 2004 based on the distribution of radio-tagged fish weighted by catch per unit effort information at the tagging site and adjusted for the harvest of tagged individuals in upriver fisheries. Bootstrap standard errors (SE) and 95% confidence intervals (CI) based on 10,000 bootstrappings are included.

Region	Stock Group	Estimate (%)	SE	95% CI
Lower Basin[1]	Lower Yukon[2]	5.6	0.8	(4.2, 7.2)
	Lower Basin Tributaries	7.6	0.9	(5.9, 9.4)
Koyukuk River	Gisasa	0.9	0.3	(0.4, 1.6)
	Middle Koyukuk	0.8	0.4	(0.1, 1.7)
	Upper Koyukuk	1.9	0.5	(1.0, 2.8)
	Combined Areas	3.6	0.7	(2.3, 5.0)
Middle Yukon River[3]	Mid-Yukon[2]	1.7	0.4	(0.9, 2.6)
	Mid-Yukon Tributaries[4]	1.9	0.5	(1.0, 3.0)
Tanana River	Tanana[5]	6.5	0.9	(4.8, 8.3)
	Chena	4.1	0.7	(2.8, 5.6)
	Salcha	10.1	1.1	(8.0, 12.4)
	Goodpaster	3.7	0.7	(2.4, 5.1)
	Combined Areas	24.4	1.5	(21.5, 27.5)
Upper Yukon River (U.S.)[6]	Upper Yukon[2]	3.0	0.6	(1.9, 4.2)
	Upper Yukon Tributaries	2.9	0.6	(1.8, 4.3)
Upper Yukon River (Canada)	Lower Canadian Yukon[7]	3.1	0.7	(1.8, 4.4)
	Mid-Upper Can. Yukon[8]	15.9	1.4	(13.1, 18.7)
	Stewart	4.7	0.8	(3.1, 6.4)
	Pelly	8.4	1.1	(6.4, 10.5)
	Big Salmon	4.9	0.9	(3.2, 6.7)

Table 11. -- Continued.

Region	Stock Group	Estimate (%)	SE	95% CI
Upper Yukon River (Canada)	Teslin	9.2	1.1	(7.0, 11.4)
	Combined Areas	46.2	1.8	(42.6, 49.5)
Porcupine River	U.S. Porcupine	1.8	0.5	(0.9, 2.8)
	Canadian Porcupine	1.3	0.4	(0.5, 2.2)

[1] Section of the Yukon River from Russian Mission to the Yukon-Koyukuk River confluence.

[2] Non-terminal areas and associated tributaries not surveyed during the study.

[3] Section of the Yukon River from Galena to the Yukon-Tanana River confluence.

[4] Including the Melozitna, Nowitna, and Tozitna rivers.

[5] Mainstem areas and associated tributaries including the Kantishna River, Tolovana River, Nenana River and Clear Creek.

[6] Section of the Yukon River from Yukon-Tanana River confluence to Eagle, Alaska.

[7] Mainstem areas and associated tributaries including the Chandindu, Klondike and Sixtymile rivers.

[8] Mainstem areas and associated tributaries including the White River, Tatchun Creek, Nordenskiold River, Little Salmon River, Takhini River and reaches of the Yukon River upstream of Hootalinqua.

Table 12. -- Movement rates (km/day) of Chinook salmon radio tagged in the lower Yukon River during 2004 based on fish passage by tracking stations located at Paimiut and the farthest upriver station site. The 95% confidence intervals (CI) and sample sizes are included.

Region	Stock Group	Average	95% CI	N
Lower Basin[1]	Lower Yukon[2]	45.3	38.4, 52.2	26
	Lower Basin Tributaries	34.6	31.9, 37.3	70
Koyukuk River	Gisasa	34.0	28.0, 40.0	8
	Middle Koyukuk	53.1	44.0, 62.2	5
	Upper Koyukuk	68.6	65.9, 71.3	12
Middle Yukon River[3]	Mid-Yukon[2]	46.3	38.7, 53.9	16
	Mid-Basin Tributaries	49.3	43.3, 55.3	14
Tanana River	Tanana[4]	43.8	39.0, 48.6	22
	Middle Tanana Tributaries[5]	53.2	49.5, 56.9	16
	Chena	45.6	43.0, 48.2	27
	Salcha	43.2	41.9, 44.5	61
	Goodpaster	43.0	41.3, 44.7	23
Upper Yukon River (U.S.)[6]	Upper Yukon[2]	55.0	49.9, 60.1	23
	Upper Yukon Tributaries	54.6	50.5, 58.7	19
Upper Yukon River (Canada)	Canadian Yukon[4]	50.5	48.7, 52.3	64
	Klondike	61.9	58.4, 65.4	12
	Stewart	57.7	53.9, 61.5	23
	White	59.5	56.6, 62.4	12
	Pelly	57.4	55.6, 59.2	40
	Little Salmon	56.3	41.8, 70.8	3

Table 12. -- Continued.

Region	Stock Group	Average	95% CI	N
Upper Yukon River (Canada)	Big Salmon	54.9	52.9, 56.9	25
	Teslin	54.3	52.1, 56.5	39
	Minor Canadian Stocks[7]	53.1	51.0, 55.2	22
Porcupine River	U.S. Porcupine	58.5	53.4, 63.6	11
	Canadian Porcupine	60.0	53.4, 66.6	8

[1] Section of the Yukon River from Russian Mission to the Yukon-Koyukuk River confluence.
[2] Non-terminal areas and associated tributaries not surveyed during the study.
[3] Section of the Yukon River from Galena to the Yukon-Tanana River confluence.
[4] Including stocks in mainstem areas and associated tributaries not surveyed during the study.
[5] Including the Kantishna River, Tolovana River, Nenana River, and Clear Creek.
[6] Section of the Yukon River from Yukon-Tanana River confluence to Eagle, Alaska.
[7] Including the Chandindu River, Sixtymile River, Tatchun Creek, Nordenskiold River, Little Salmon River, Takhini River, and headwater areas upriver of Hootalinqua.

Table 13. -- Comparison of movement rates (km/day) of Chinook salmon traveling to tributaries in the Yukon River basin during 2004 based on the passage of radio-tagged fish by tracking stations. Average rates and 95% confidence intervals (CI) between Paimiut and the first station within the region the fish were destined for (i.e., travel primarily through reaches of the Yukon River main stem), and between Paimiut and the farthest upriver station are presented.

	Paimiut to First Regional Station[1]			Paimiut to Terminal Station[2]		
Stock	Location	$\overline{X}$	CI	Location	$\overline{X}$	CI
Nulato	Yukon-Anvik	57.6	48.8, 66.4	Nulato[3]	43.1	37.4, 48.8
Gisasa	Lower Koyukuk	47.2	39.4, 55.0	Gisasa[3]	34.0	28.0, 40.0
Upper Koyukuk	Lower Koyukuk	61.5	58.5, 64.5	Mid-Koyukuk	68.5	65.8, 71.2
Mid-Basin trib.[4]	Yukon-Yuki	54.2	50.2, 58.2	Trib. mouth	49.3	43.3, 55.3
Chena	Lower Tanana	55.7	53.3, 58.1	Chena[3]	45.3	42.4, 48.2
Salcha	Lower Tanana	56.3	53.1, 59.5	Salcha[3]	43.2	41.9, 44.5
Goodpaster	Lower Tanana	56.8	54.9, 58.7	Upper Tanana	43.0	41.3, 44.7
Chandalar	Rampart Rapids	57.8	54.5, 61.1	Chandalar[3]	53.7	49.1, 58.3
Stewart	Yukon Border	58.7	54.9, 62.5	Stewart[3]	57.7	53.9, 61.5
Pelly	Yukon Border	58.2	56.4, 60.0	Pelly[3]	57.4	55.6, 59.2
Big Salmon	Yukon Border	58.1	55.9, 60.3	Big Salmon[3]	54.9	52.9, 56.9
Teslin	Yukon Border	57.4	55.2, 59.6	Teslin[3]	54.3	52.1, 56.5

[1] First station within the region containing the final destination of the fish (see Table 2).
[2] Last station passed by the fish prior to reaching its final destination.
[3] Station located near river mouth.
[4] Including the Melozitna, Nowitna and Tozitna rivers.

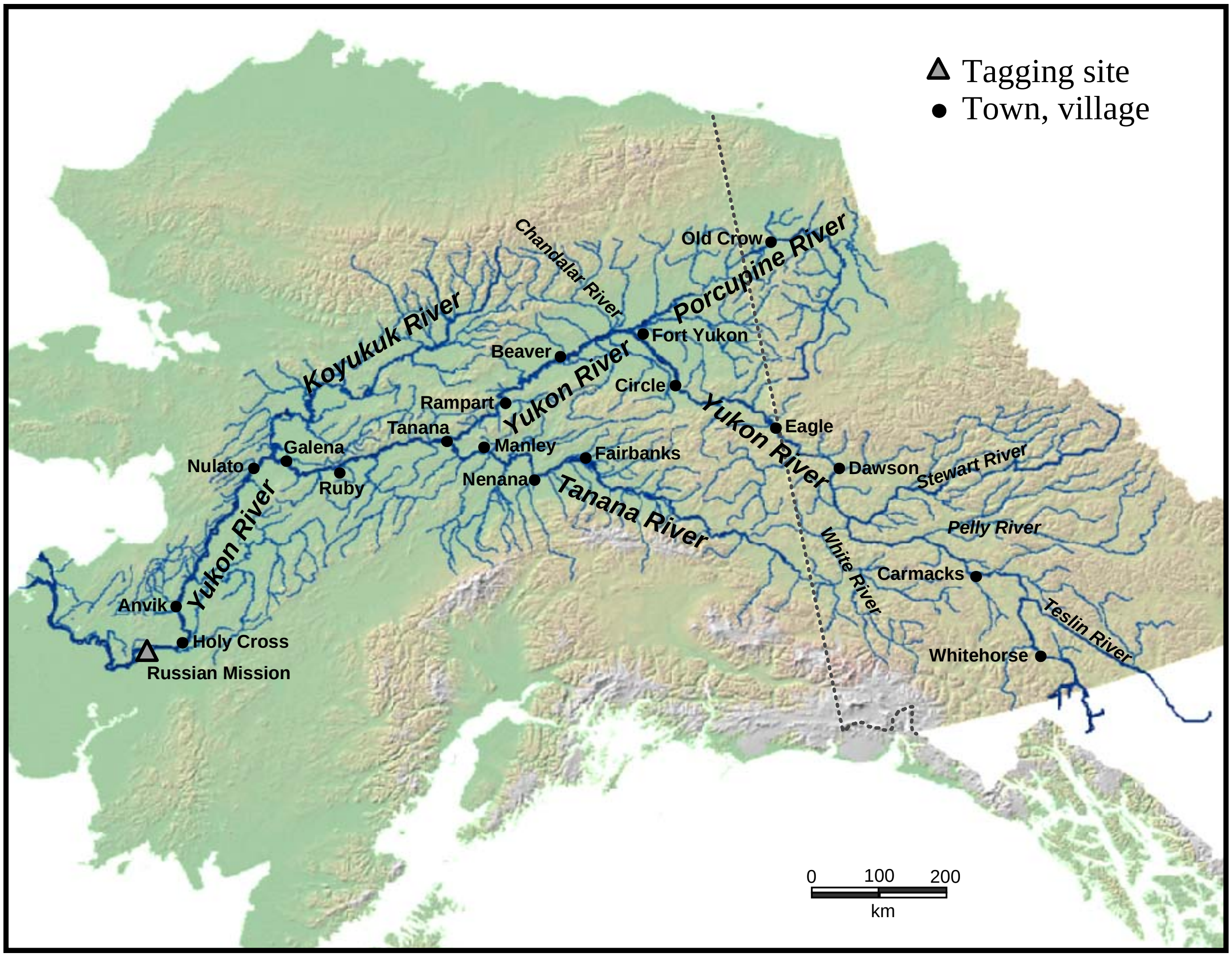


Figure 1. -- Map of the Yukon River basin showing the Yukon River main stem and major tributaries of the drainage, as well as the tagging site, and selected towns and villages.

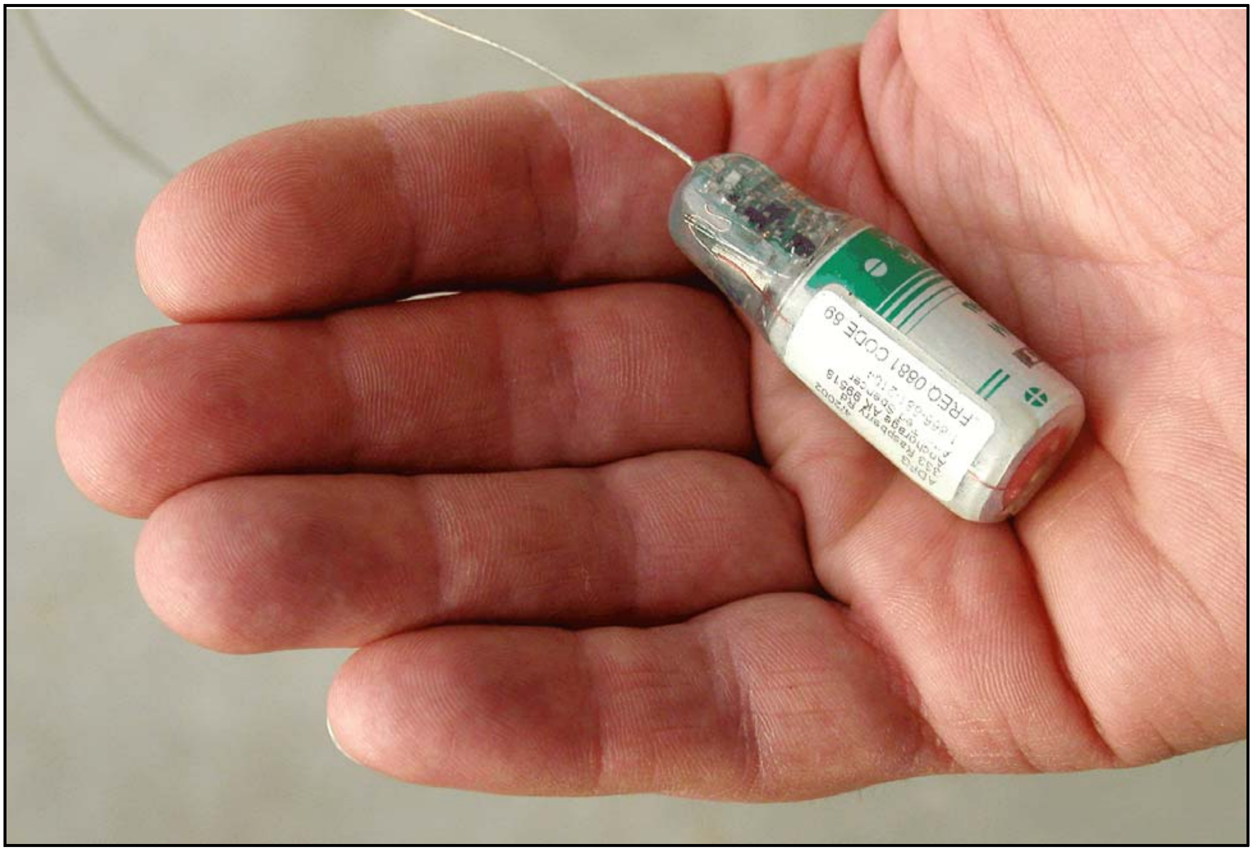


Figure 2. -- Radio transmitter used to tag Chinook salmon in the lower Yukon River near the village of Russian Mission during 2004. The transmitter is gently inserted through the mouth and placed in the stomach.

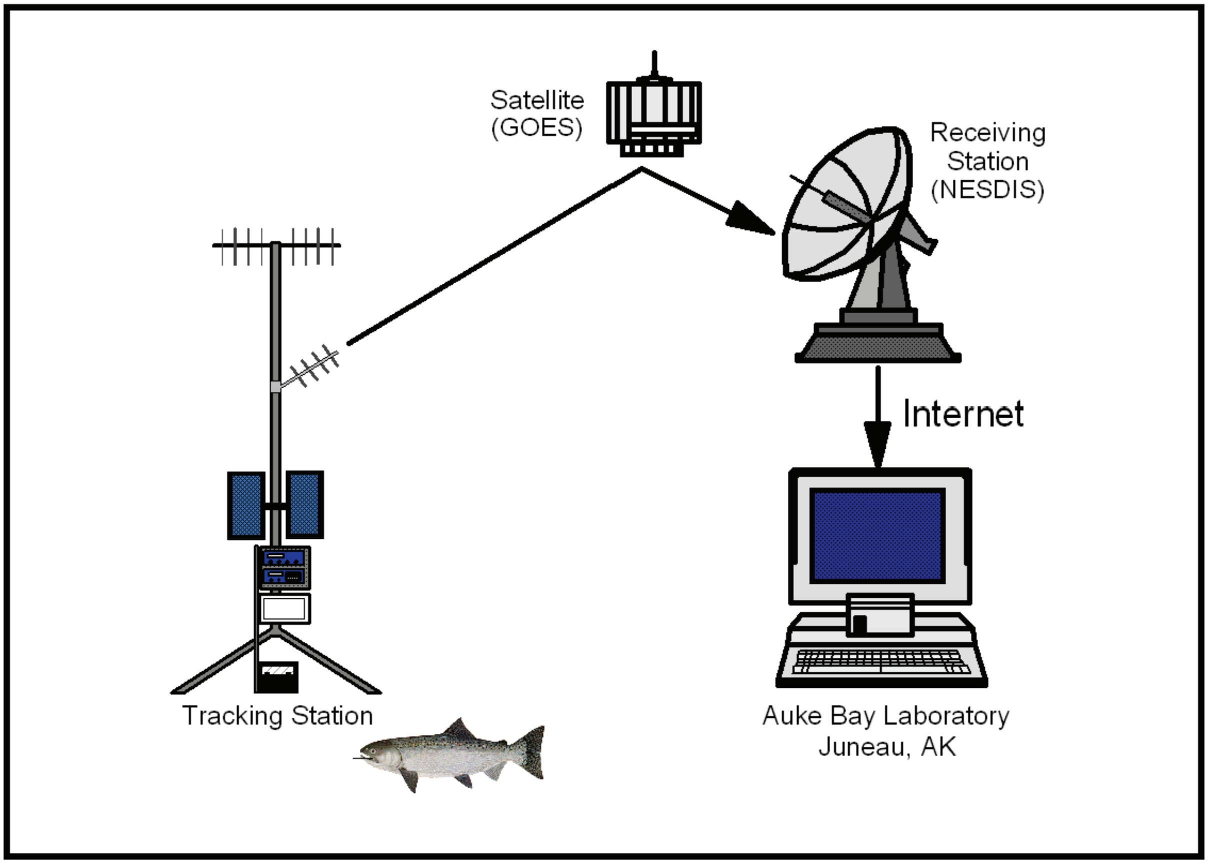


Figure 3. -- Remote tracking station and satellite uplink used to collect and access movement information of Chinook salmon in the Yukon River basin. Radio-tagged fish passing the station sites are recorded; the information is transferred to a receiving station via satellite and downloaded for in-season analysis.

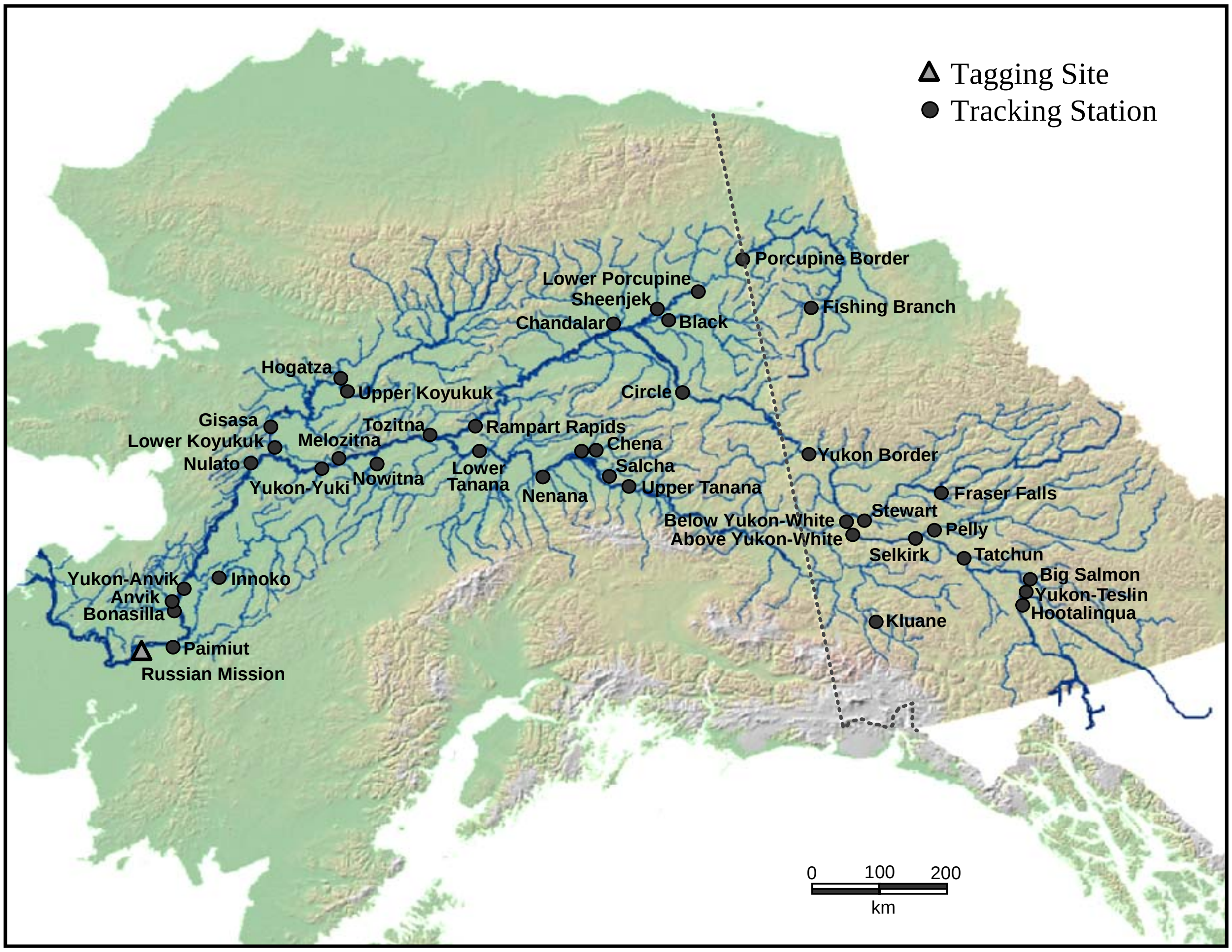


Figure 4. -- Map of the Yukon River basin showing the location of remote tracking stations used to track the upriver movements of radio-tagged Chinook salmon during 2004.

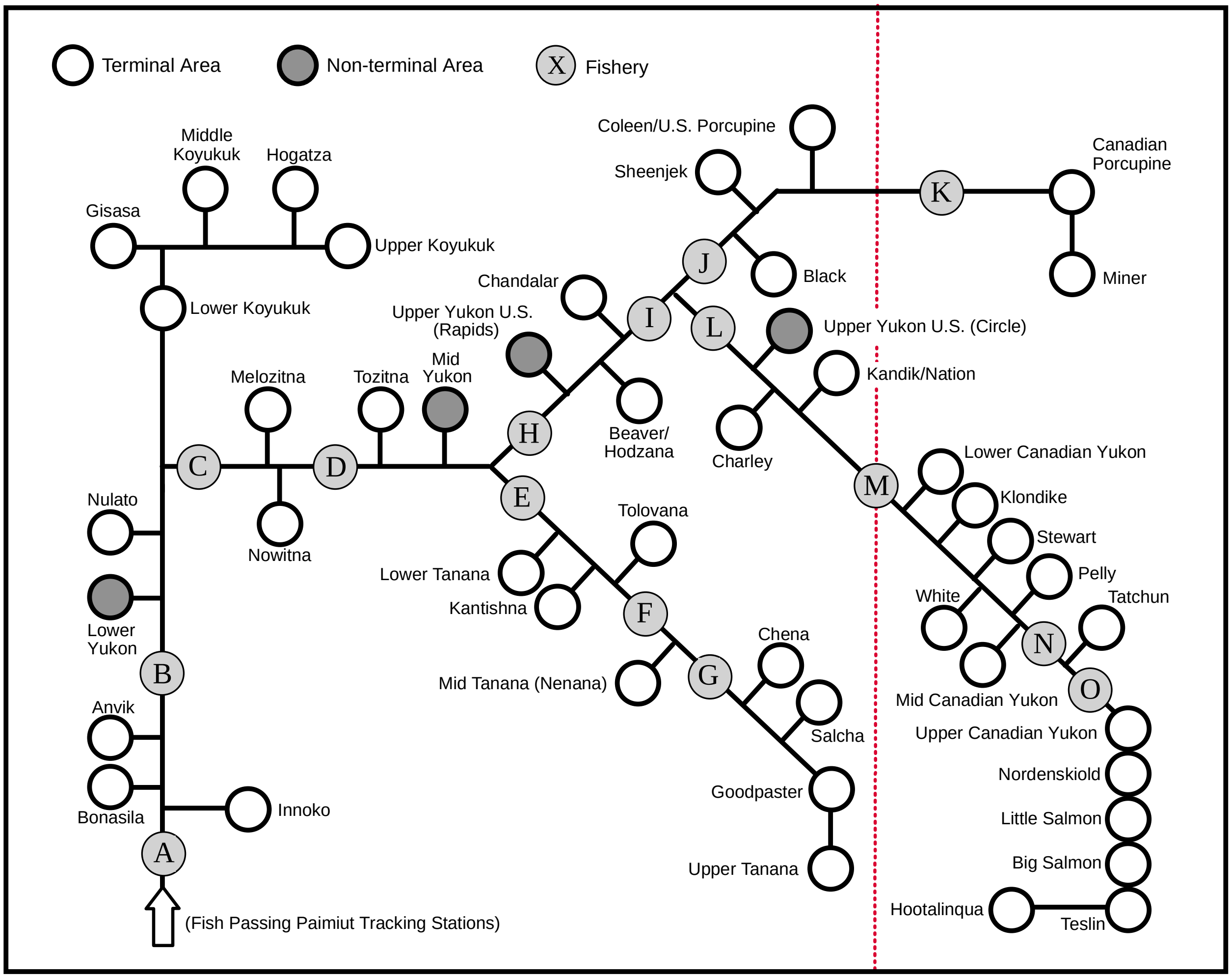


Figure 5. -- Migration model for calculating stock composition estimates of Chinook salmon returns in the Yukon River basin based on the distribution of radio-tagged fish. Spatial relationships of the fisheries and component stocks are indicated. Additional information on the fisheries, labeled as A through O, is contained in Table 3.

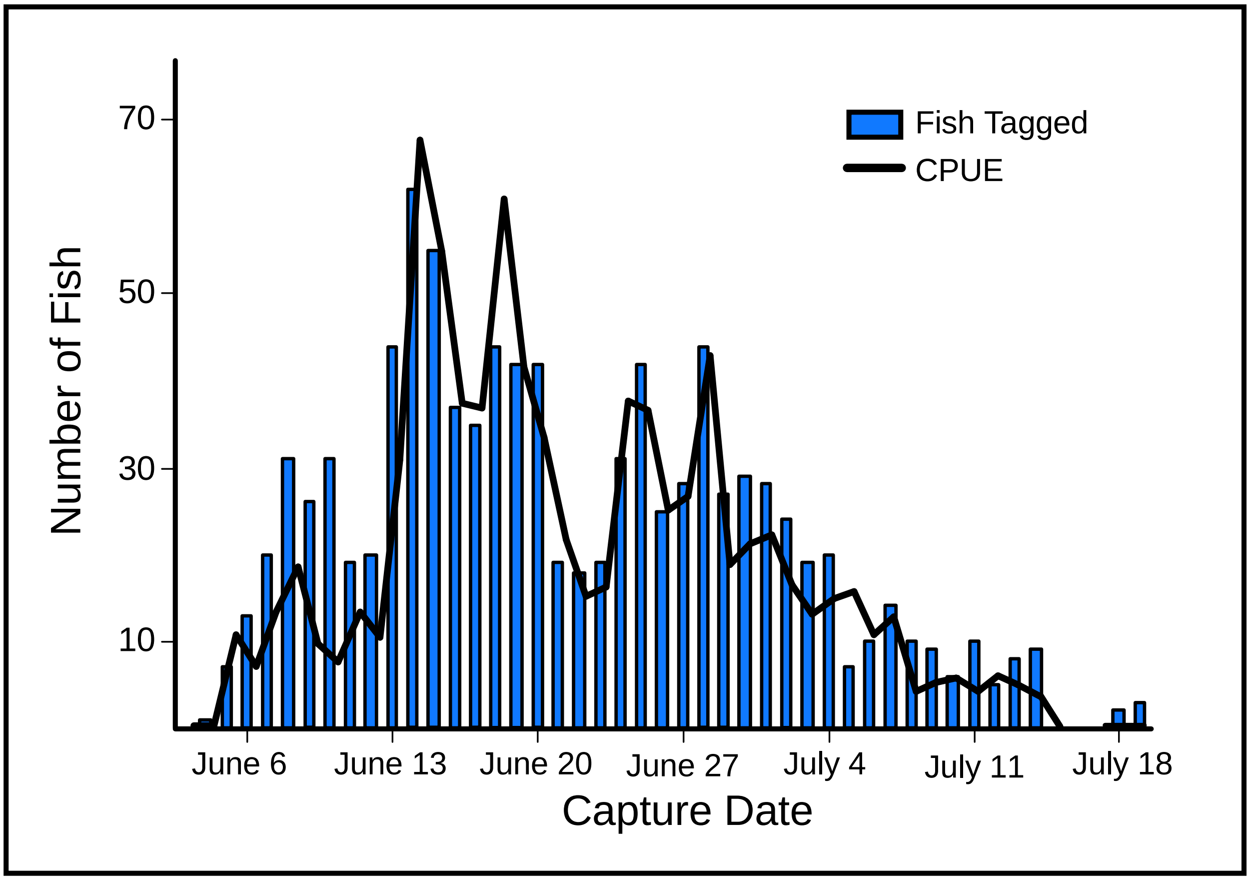


Figure 6. -- Number of Chinook salmon radio tagged per day in the lower Yukon River and daily catch per unit effort (CPUE) information for Chinook salmon captured at the Russian Mission tagging site during 2004.

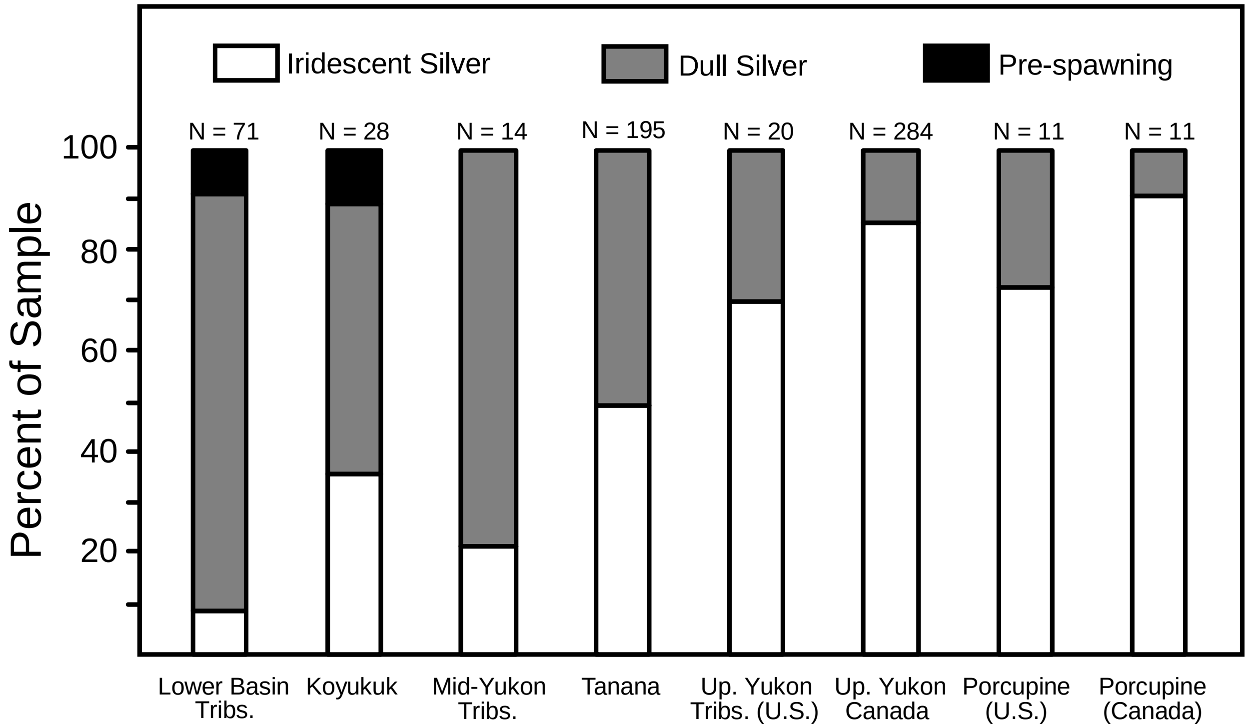


Figure 7. -- Lower River coloration of Chinook salmon captured with drift gill nets and radio tagged near the village of Russian Mission, and tracked to terminal reaches of the basin during 2004. Pre-spawning coloration ranged from blush (silver with reddish tinges) to a pronounced reddish coloration.

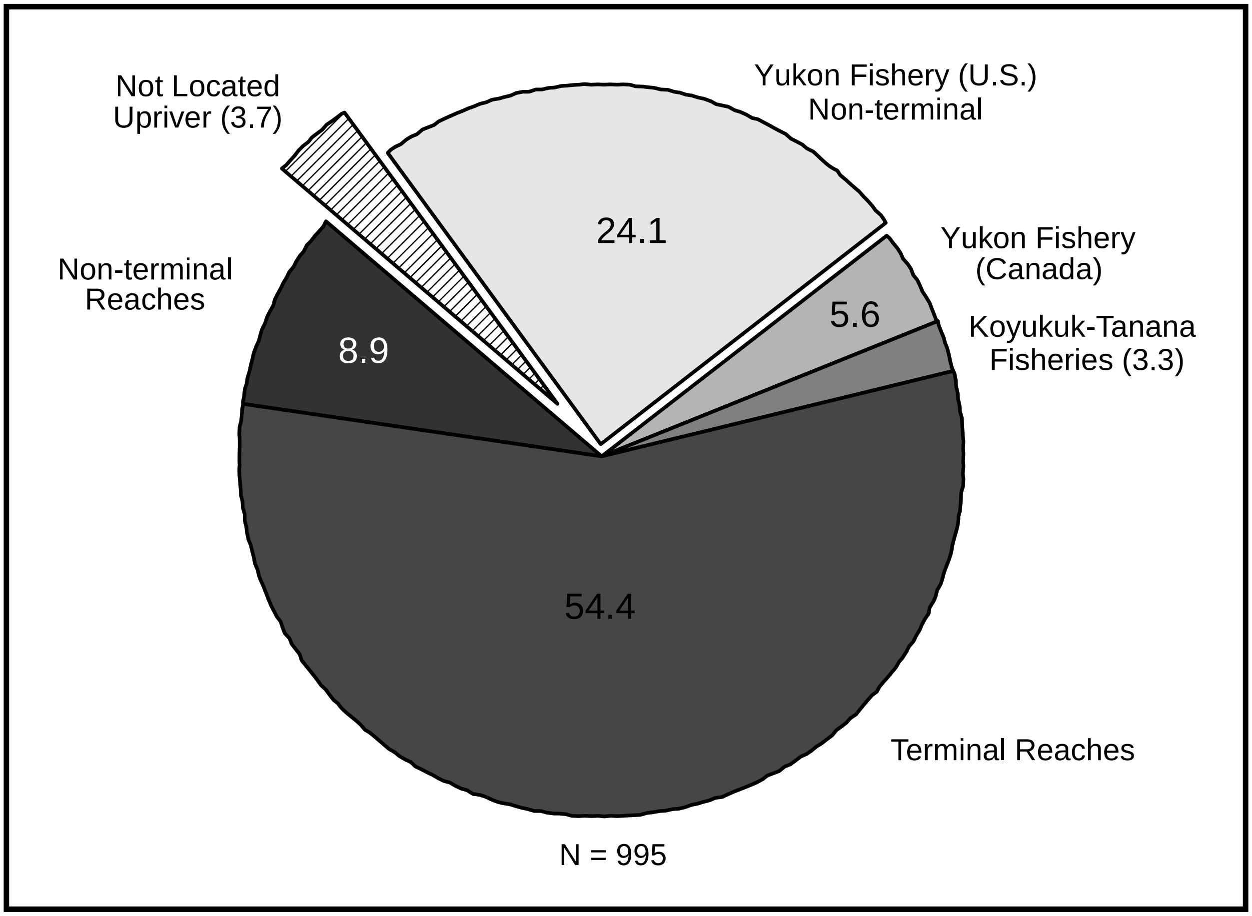


Figure 8. -- Final status of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission during 2004. Percentages of the total number of fish tagged are indicated.

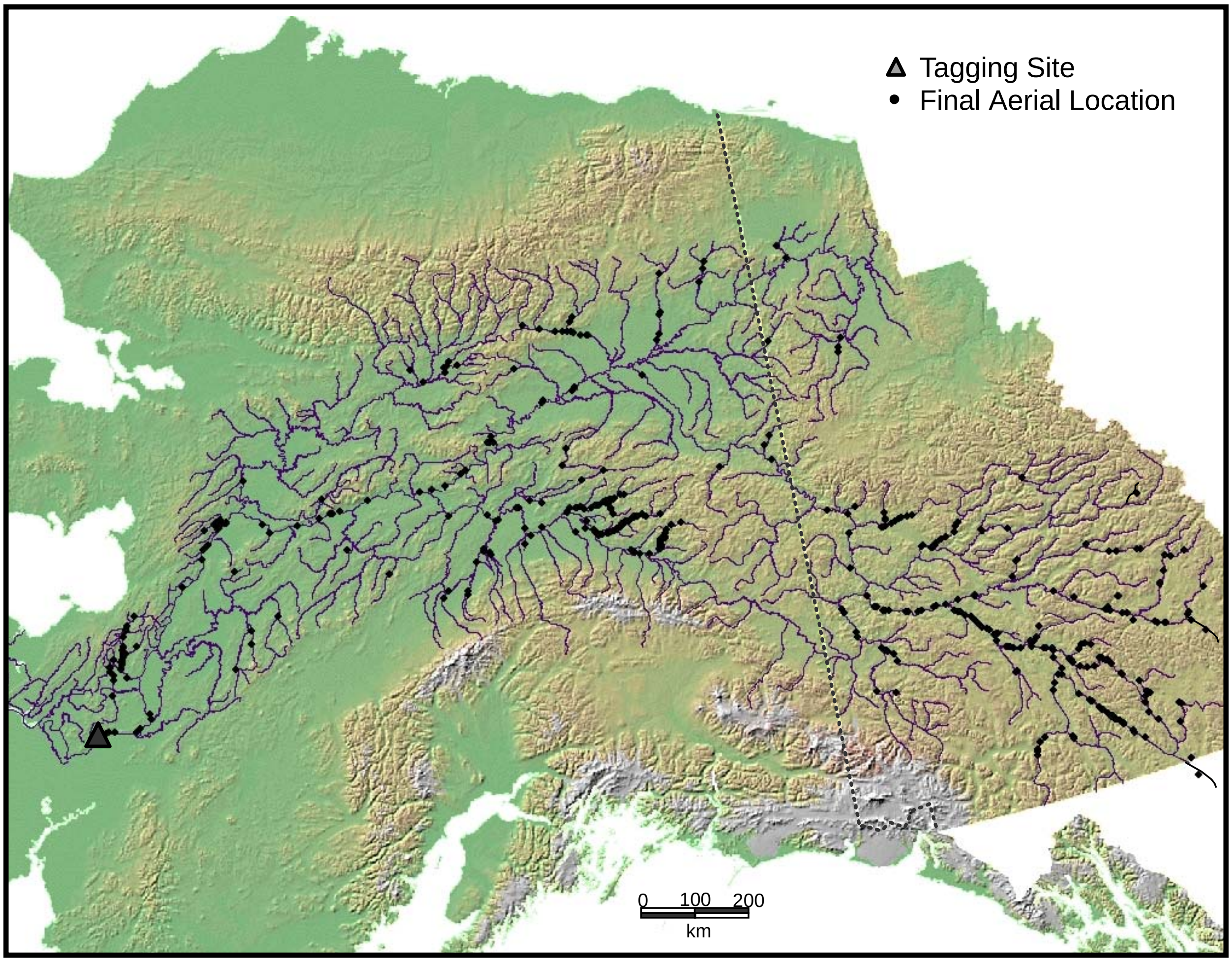


Figure 9. -- Final locations of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission and tracked upriver during their spawning migration based on aerial tracking surveys in 2004.

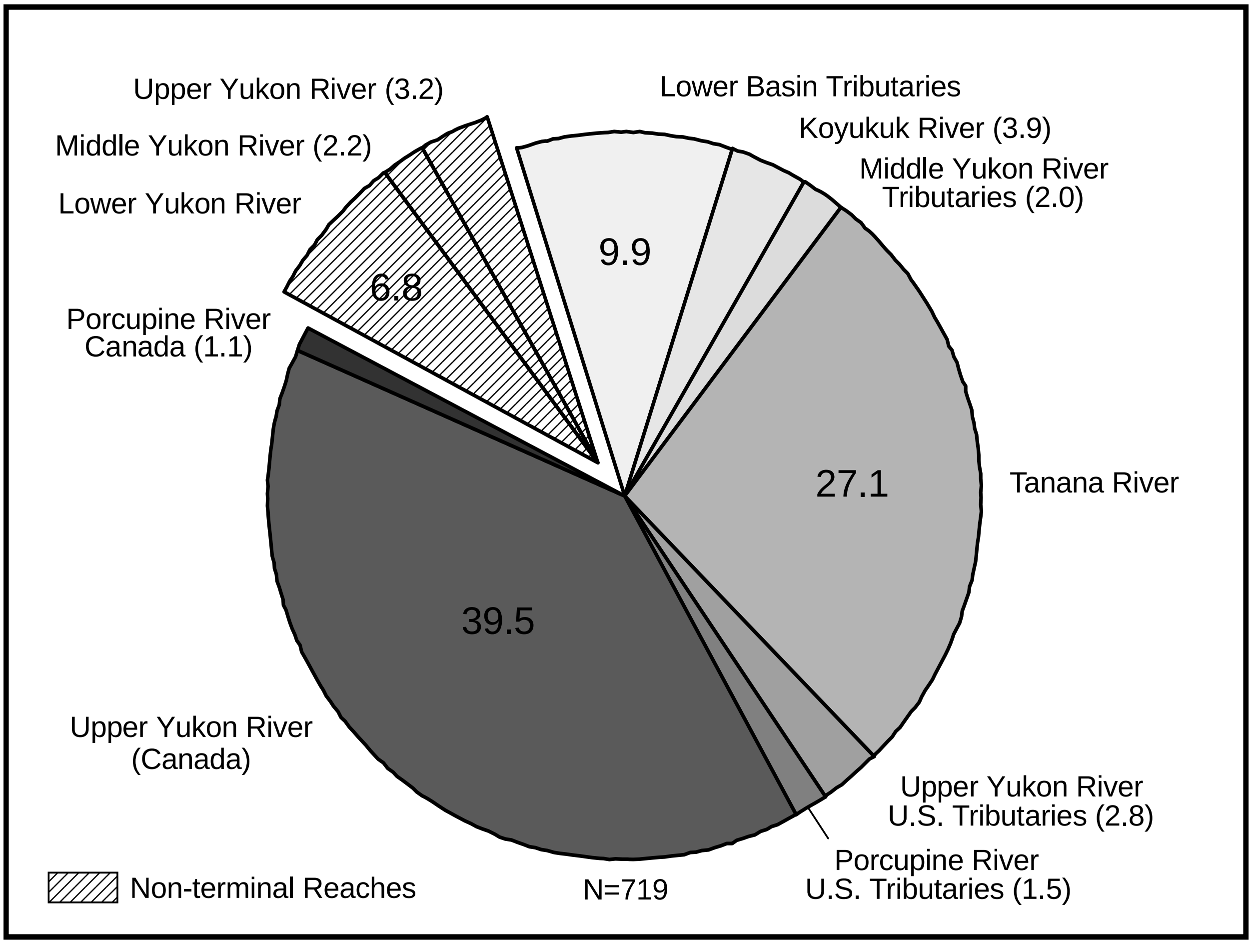


Figure 10. -- Distribution of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission during 2004. Percentage of the total number of fish that moved upriver and were not caught in non-terminal fisheries are indicated.

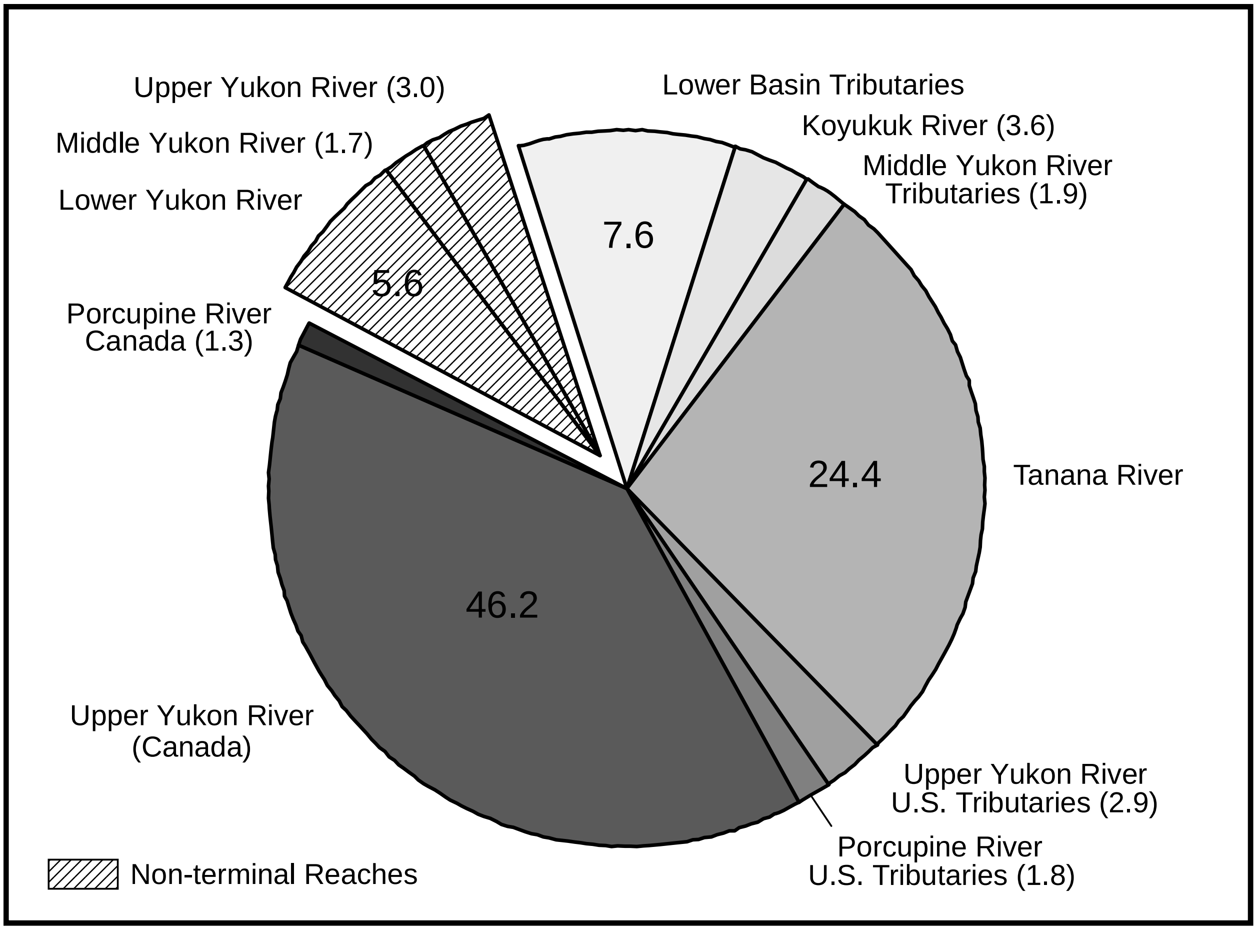


Figure 11. -- Stock composition estimates of the Yukon River Chinook salmon return in 2004 based on the distribution of radio-tagged fish (Fig. 10) weighted by catch per unit effort information at the tagging site and adjusted for the harvest of tagged individuals in upriver fisheries. Percentages of the return are indicated.

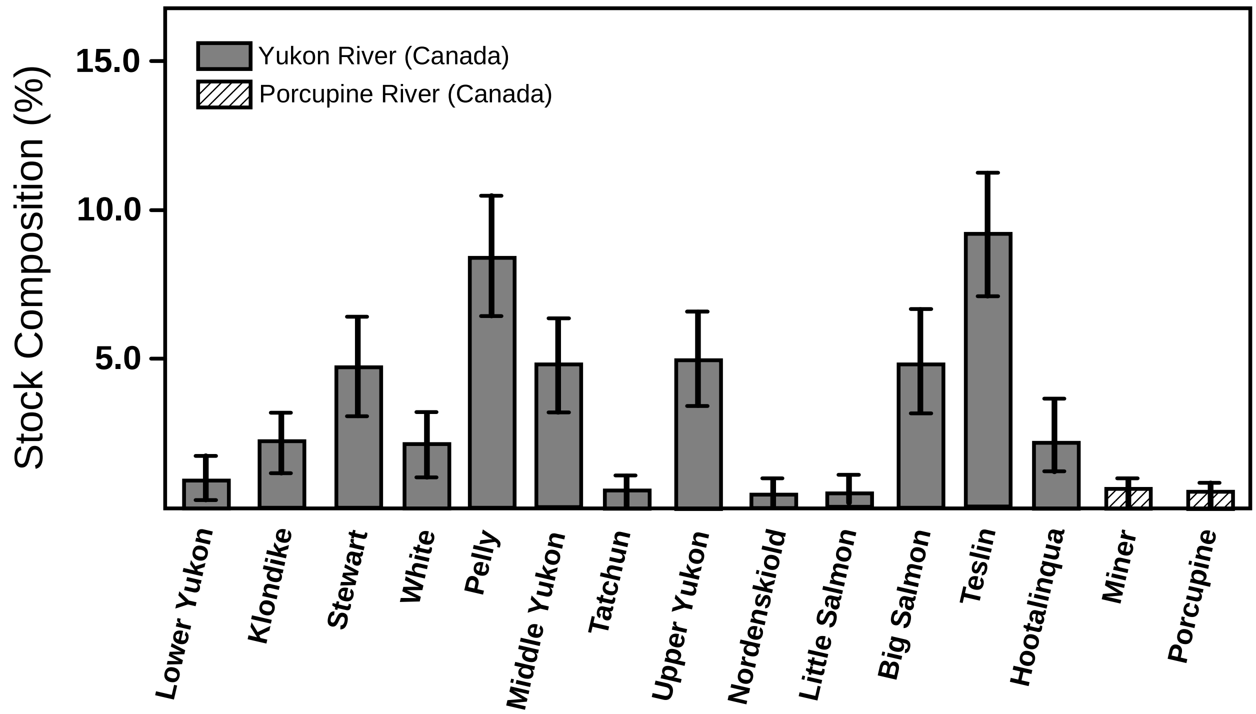


Figure 12. -- Composition of Chinook salmon stocks returning to Canadian reaches of the Yukon River basin in 2004, based on the distribution of radio-tagged fish weighted by catch per unit effort information at the tagging site and adjusted for the harvest of tagged individuals in upriver fisheries. Composition estimates and 95% confidence intervals are provided.

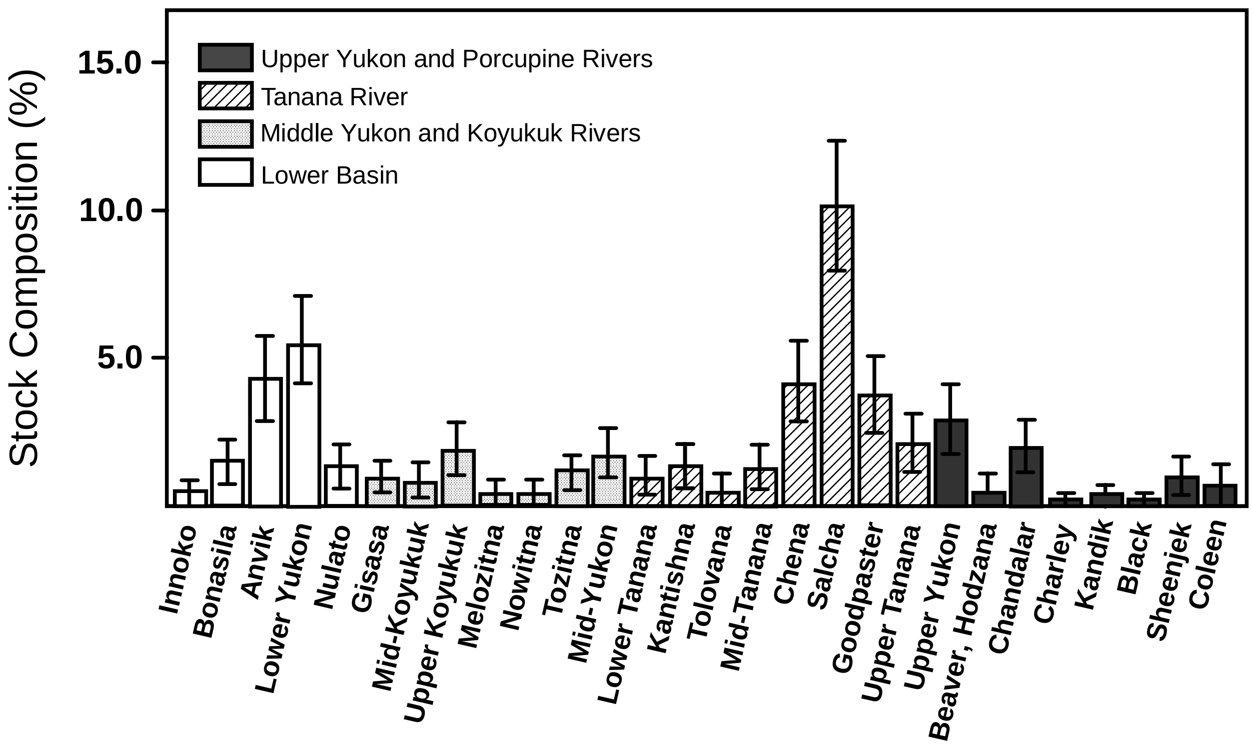


Figure 13. -- Composition of Chinook salmon stocks returning to U.S. reaches of the Yukon River basin in 2004, based on the distribution of radio-tagged fish weighted by catch per unit effort information at the tagging site and adjusted for the harvest of tagged individuals in upriver fisheries. Composition estimates and 95% confidence intervals are provided.

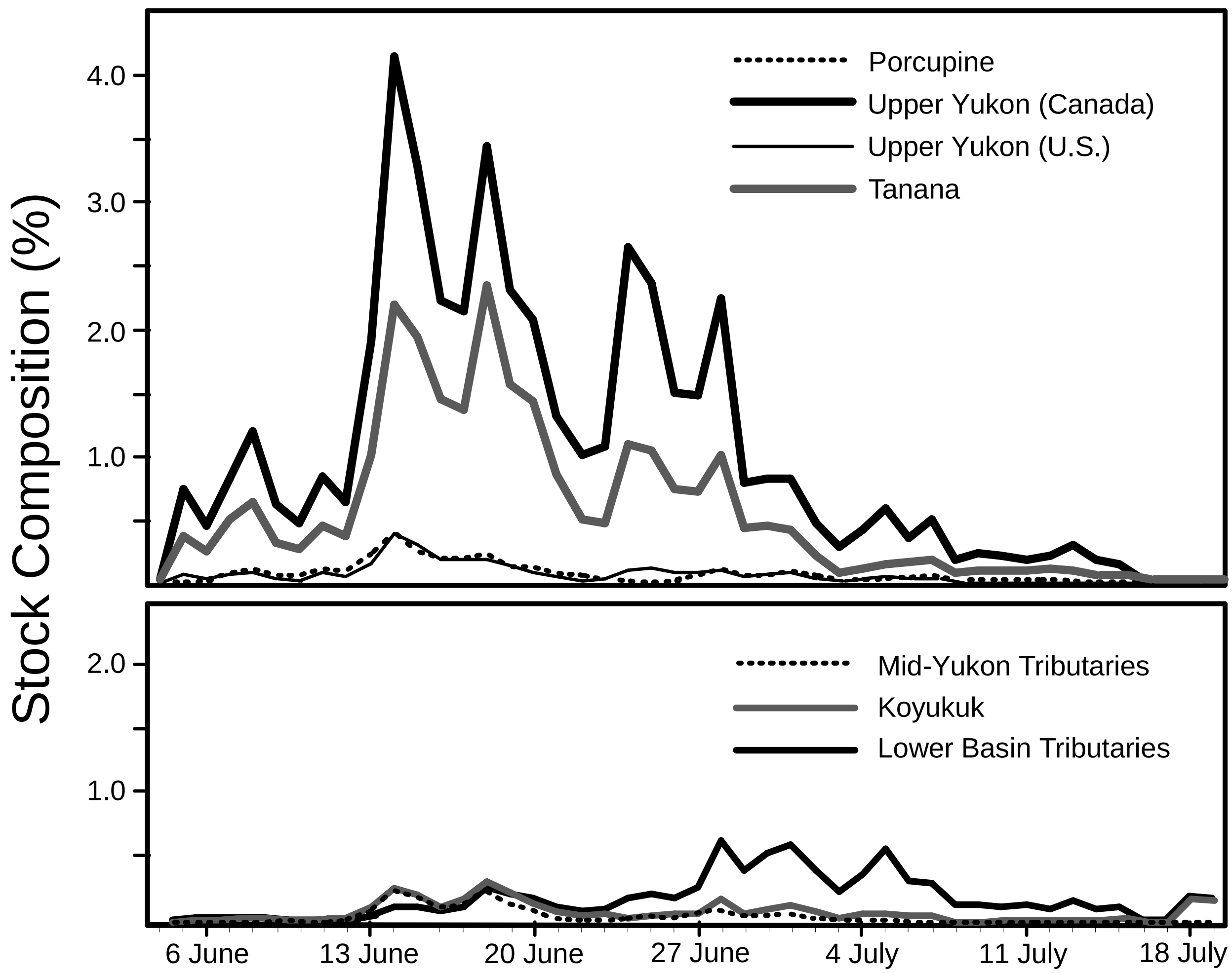


Figure 14. -- Run timing of Yukon River Chinook salmon stock groups returning to terminal reaches of the basin in 2004, based on composition estimates for the entire return derived from the distribution of radio-tagged fish weighted by catch per unit effort information at the tagging site and adjusted for the harvest of tagged individuals in upriver fisheries.

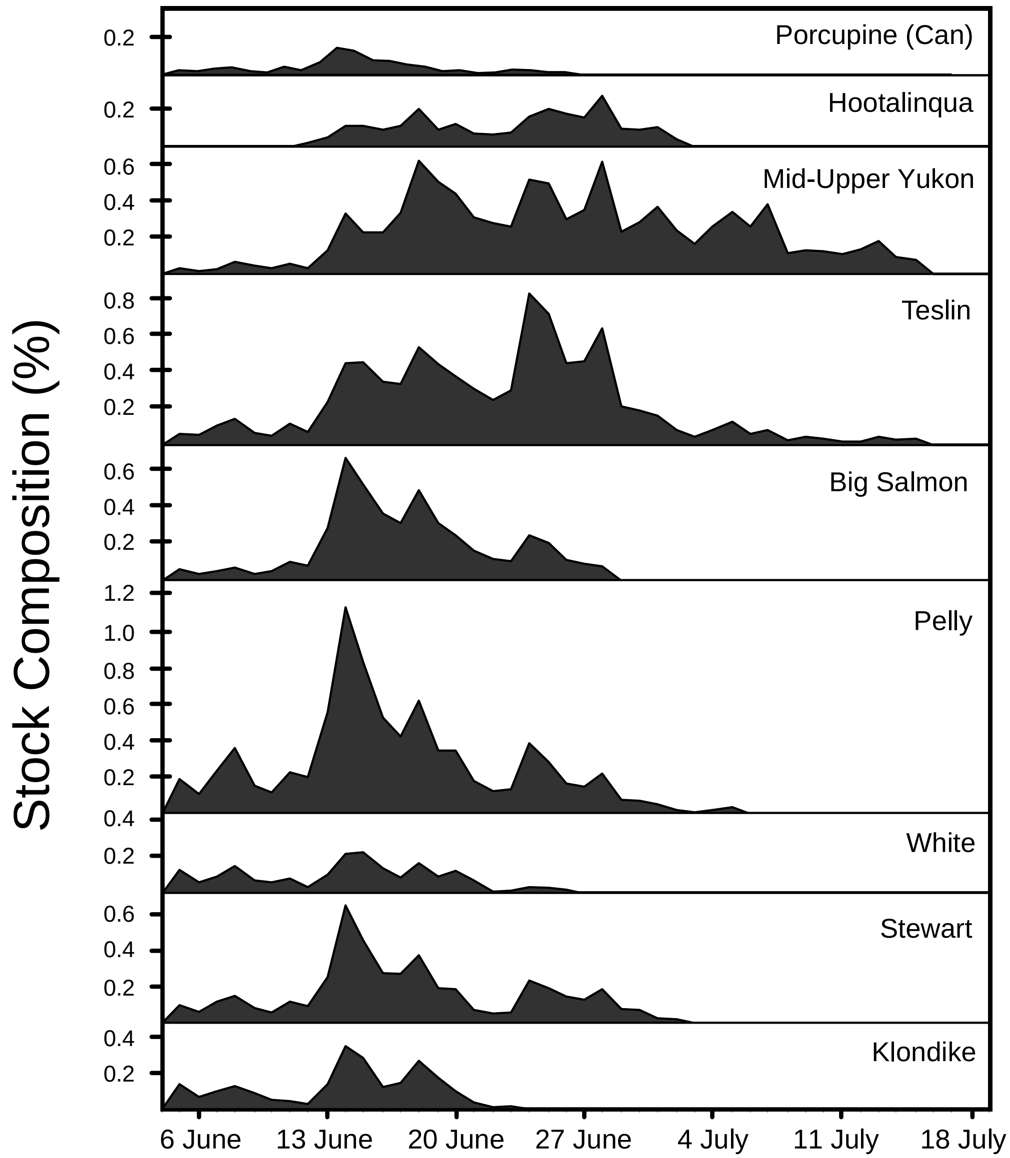


Figure 15. -- Run timing of major Chinook salmon stocks in Canadian reaches of the Yukon River basin in 2004, based on composition estimates for the entire return derived from the distribution of radio-tagged fish weighted by catch per unit effort information at the tagging site and adjusted for the harvest of tagged individuals in upriver fisheries. The mid-upper Yukon stock group represents fish remaining in mainstem areas and associated tributaries.

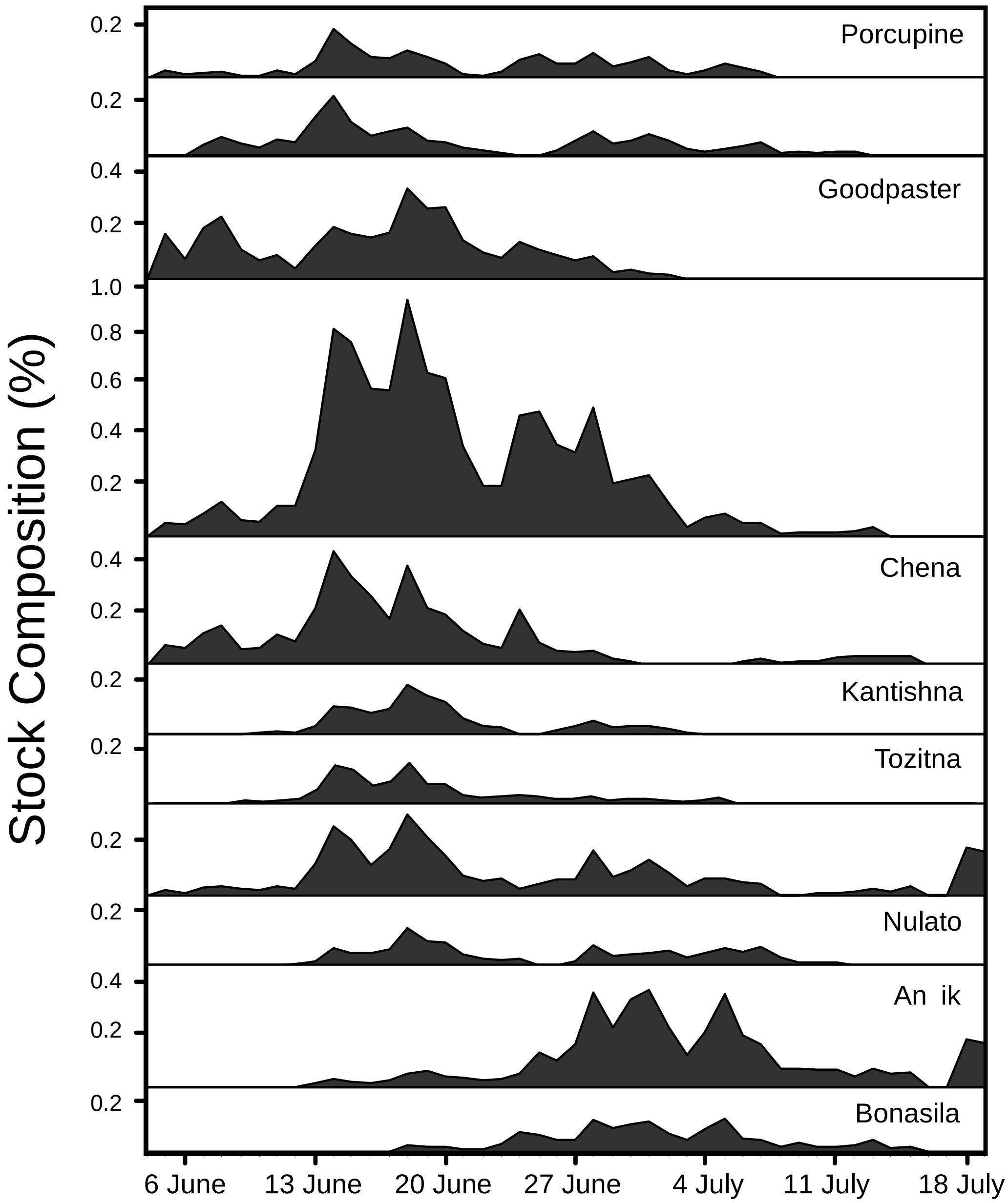


Figure 16. -- Run timing of major Chinook salmon stocks in U.S. reaches of the Yukon River basin in 2004, based on composition estimates for the entire return derived from the distribution of radio-tagged fish weighted by catch per unit effort information at the tagging site and adjusted for the harvest of tagged individuals in upriver fisheries.

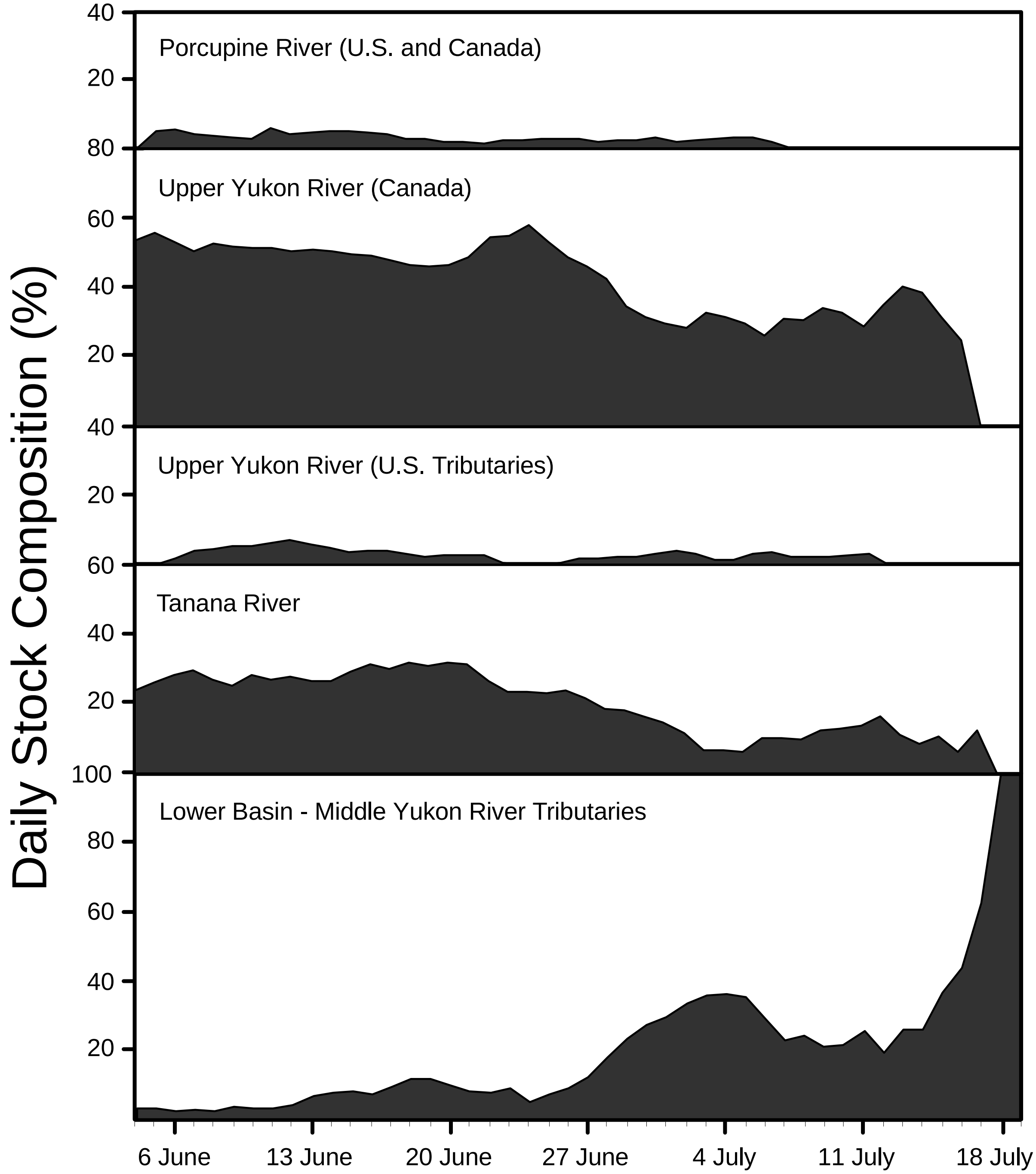


Figure 17. -- Daily stock composition of Chinook salmon passing through the lower Yukon River near the village of Russian Mission in 2004, based on the observed distribution of radio-tagged fish.

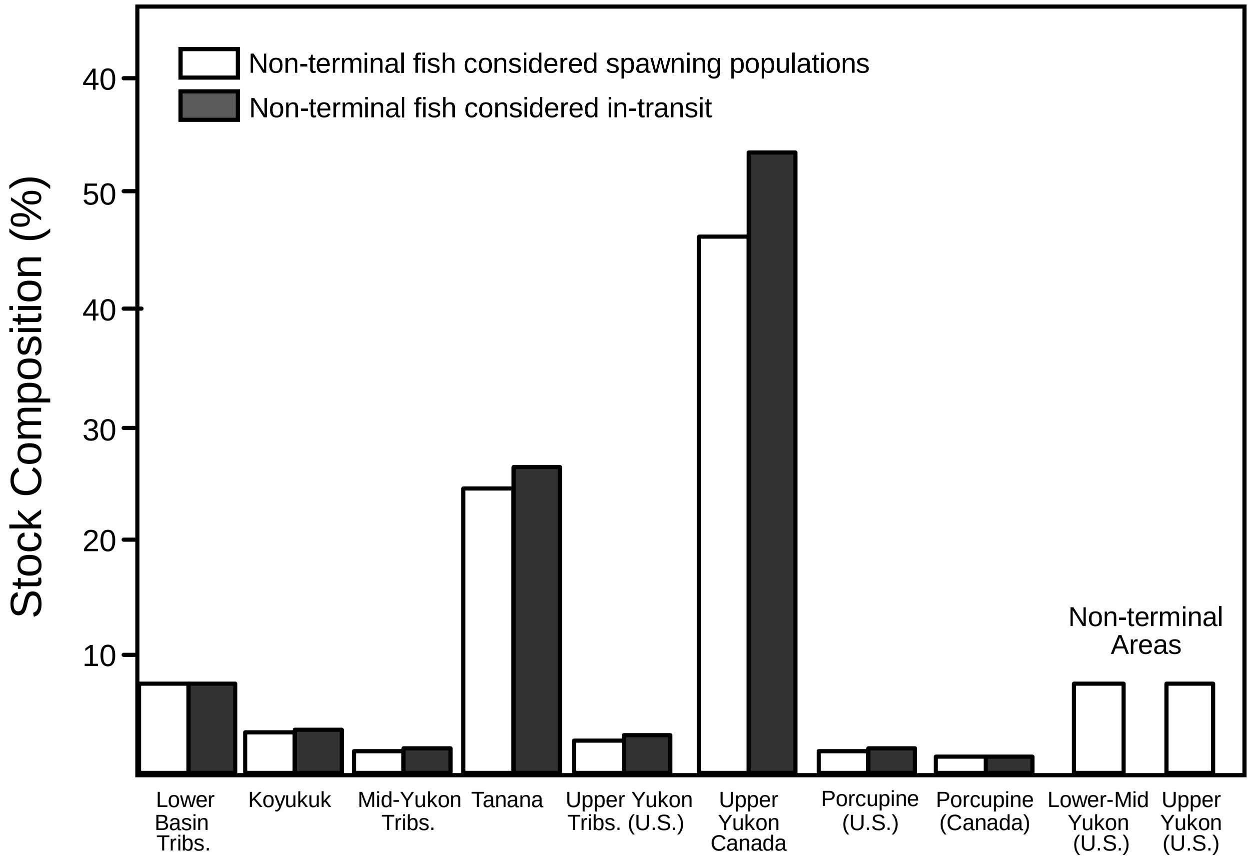


Figure 18. -- Comparison of stock composition estimates of the Yukon River Chinook salmon return in 2004 based on the distribution of radio-tagged fish weighted by catch per unit effort information at the capture site and adjusted for the harvest of tagged individuals in upriver fisheries, and the presumed status of fish remaining in non-terminal reaches of the Yukon River main stem. Non-terminal areas include associated tributaries not monitored during the study.

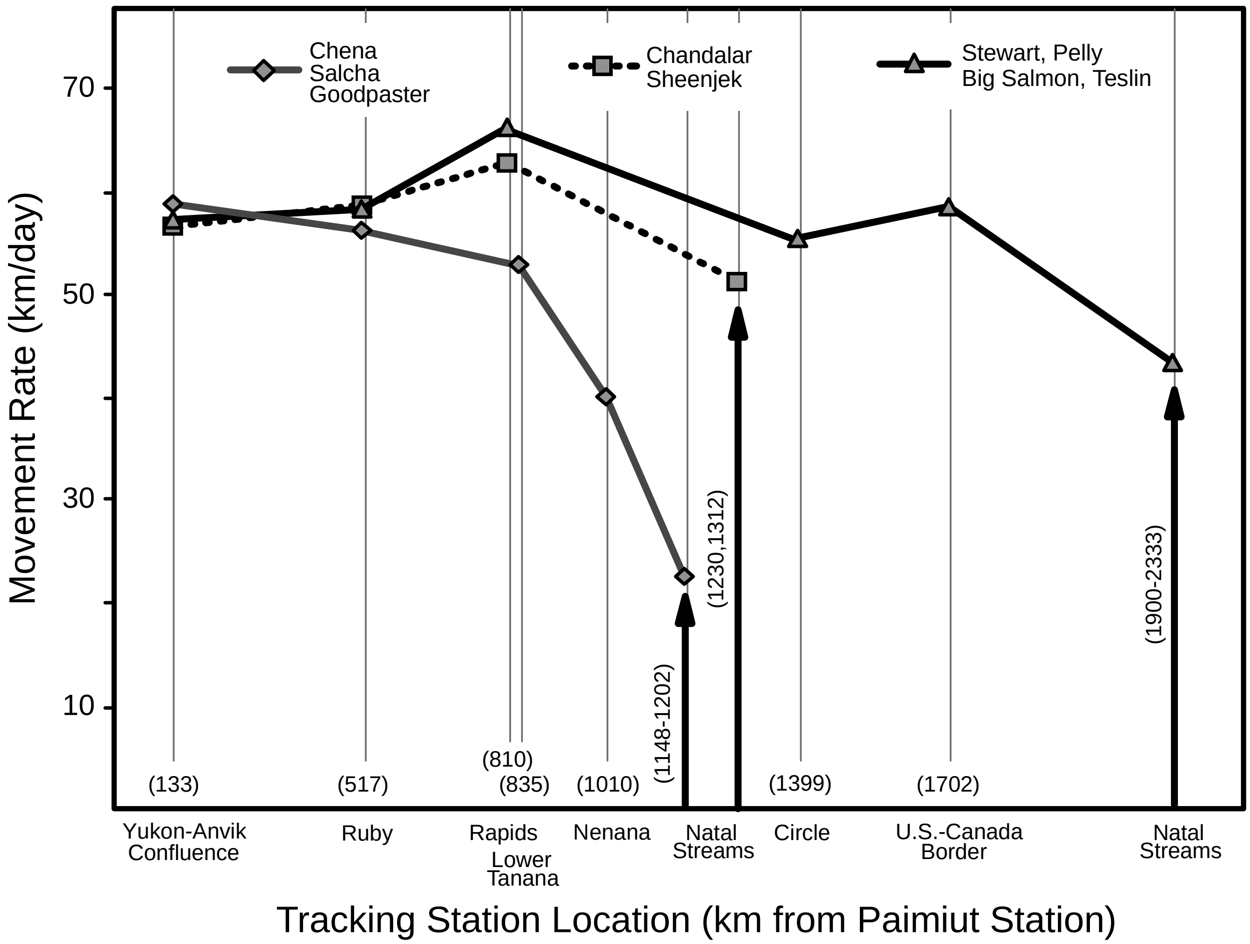


Figure 19. -- Movement rates (km/day) of radio-tagged Chinook salmon returning to tributaries in the upper Yukon River basin in 2004. Average rates by area and distances from the Paimiut tracking stations are provided.

APPENDICES

Appendix A. -- Fishery recoveries of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission during 2004. Percentages of the total are in parentheses.

Fishing Area	Fishery	Tagged Fish
District 3	Russian Mission	12 (3.6)
	Holy Cross	32 (9.7)
	Combined Fisheries	44 (13.3)
District 4	Anvik	5 (1.5)
	Grayling	15 (4.6)
	Kaltag	11 (3.3)
	Nulato	21 (6.3)
	Huslia, Hughes (Koyukuk River)[1]	3 (0.9)
	Galena	26 (7.8)
	Ruby	10 (3.0)
	Combined Fisheries	91 (27.4)
District 5	Tanana	7 (2.1)
	Yukon River (upriver of Tanana)	6 (1.8)
	Rampart Rapids	16 (4.8)
	Yukon River (upriver of Rampart Rapids)	5 (1.5)
	Rampart	15 (4.6)
	Yukon Bridge	4 (1.2)
	Stevens Village	14 (4.2)
	Beaver	12 (3.6)
	Chandalar River[1]	1 (0.3)
	Ft. Yukon	15 (4.5)
	Circle	4 (1.2)
	Eagle	9 (2.7)
	Combined Fisheries	108 (32.5)
District 6	Lower Tanana River[1]	8 (2.4)
	Tolovana River[1,2]	2 (0.6)
	Nenana[1]	5 (1.5)

Appendix A. -- Continued.

Fishing Area	Fishery	Tagged Fish
District 6	Fairbanks[1]	10 (3.0)
	Chena River[1,2]	2 (0.6)
	Salcha River[1,2]	6 (1.8)
	Combined Fisheries	33 (9.9)
Canada	Border-Dawson	25 (7.6)
	Stewart River[1]	3 (0.9)
	Pelly River[1]	8 (2.4)
	Minto Landing	1 (0.3)
	Carmacks	5 (1.5)
	Upper Yukon River	1 (0.3)
	Teslin River[1]	10 (3.0)
	Old Crow (Porcupine)[1]	3 (0.9)
	Combined Fisheries	56 (16.9)
Total		332

[1] Fish harvested in tributary of the Yukon River main stem.
[2] Includes fish harvested in sport fishery.

Appendix B. -- Distribution of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission during 2004, including fish caught in terminal fisheries in the U.S. and Canada. Percentages of total are in parentheses.

Region	Final Location	Tagged Fish
Lower Basin	Yukon River main stem (upriver of Holy Cross)[1]	49 (6.8)
	Kako River	1 (0.1)
	Innoko River	5 (0.7)
	Bonasila River	14 (2.0)
	Anvik River	40 (5.6)
	Nulato River	11 (1.5)
	Combined Areas	120 (16.7)
Koyukuk	Middle Koyukuk River[1]	5 (0.7)
	Gisasa River	8 (1.1)
	Koyukuk Fishery	3 (0.4)
	Upper Koyukuk River[1]	5 (0.7)
	Henshaw Creek	2 (0.3)
	Koyukuk River South Fork	5 (0.7)
	Combined Areas	28 (3.9)
Middle Yukon	Yukon River main stem (upriver of Galena)[1]	16 (2.2)
	Melozitna River	3 (0.4)
	Nowitna River	3 (0.4)
	Tozitna River	8 (1.1)
	Combined Areas	30 (4.2)
Tanana	Tanana River fishery	23 (3.2)
	Lower Tanana River (upriver of Manley)[1]	8 (1.1)
	Kantishna River	9 (1.3)
	Tolovana-Chatanika River[2]	5 (0.7)
	Nenana River	1 (0.1)
	Middle Tanana River (upriver of Nenana)[1]	9 (1.3)
	Clear Creek	3 (0.4)

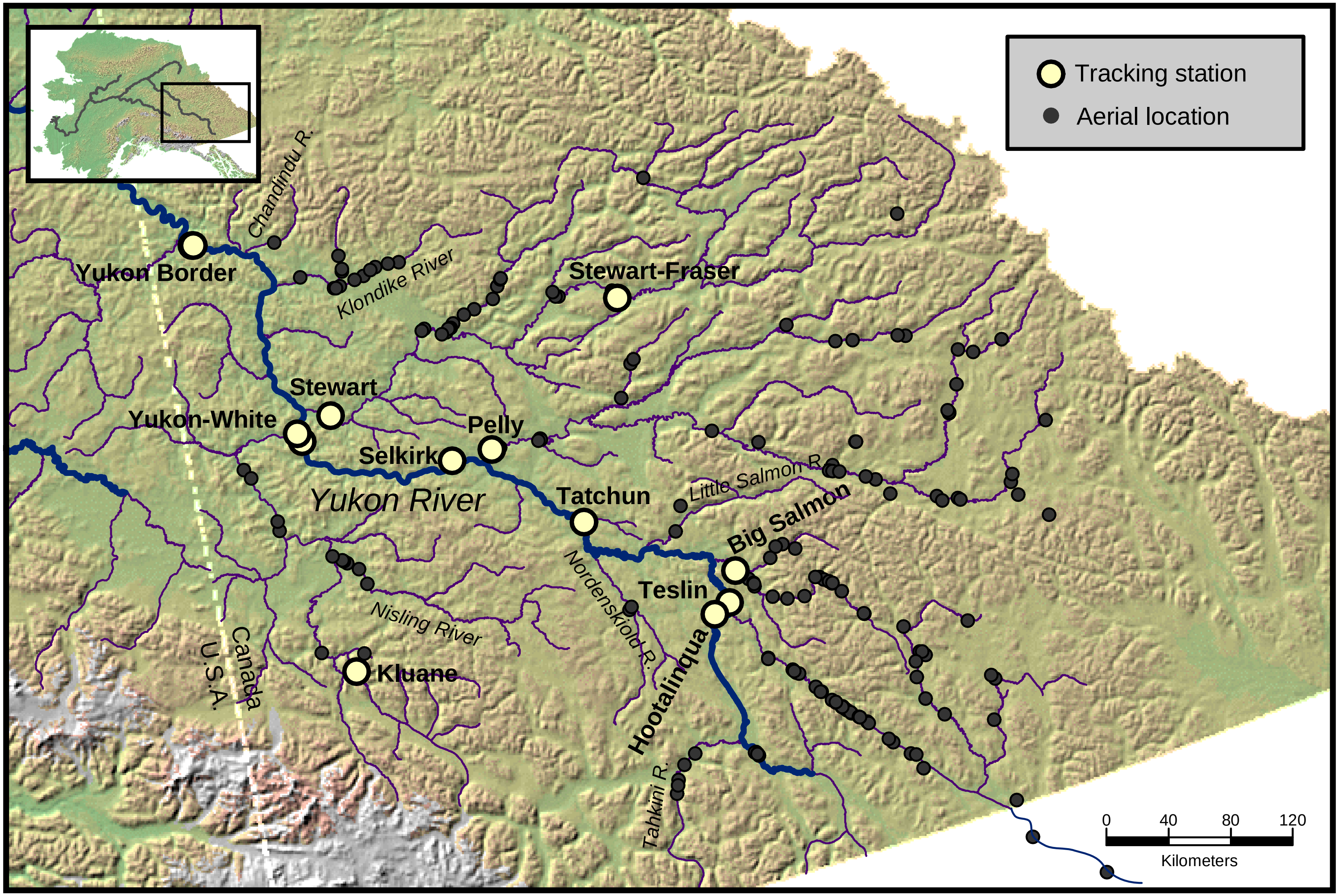
Appendix B. -- Continued.

Region	Final Location	Tagged Fish
Tanana	Chena River[2]	30 (4.2)
	Salcha River[2]	68 (9.4)
	Upper Tanana River (upriver of Salcha River)[1]	11 (1.5)
	Goodpaster River	28 (3.9)
	Combined Areas	195 (27.1)
Upper Yukon (U.S.)	Yukon River main stem (upriver of Tanana)[1]	20 (2.8)
	Hodzana River[3]	1 (0.1)
	Beaver Creek	2 (0.3)
	Chandalar River	14 (2.0)
	Yukon River main stem (upriver of Circle)[1]	3 (0.4)
	Charley River	1 (0.1)
	Nation River	2 (0.3)
	Combined Areas	43 (6.0)
Upper Yukon (Canada)	Yukon River main stem (upriver of Border)[1]	3 (0.4)
	Yukon River fishery	32 (4.5)
	Chandindu River	1 (0.1)
	Klondike River	12 (1.7)
	Sixtymile River	1 (0.1)
	Stewart River[2]	23 (3.2)
	Stewart River (upriver of Fraser Falls)	3 (0.4)
	White River	12 (1.7)
	Yukon River main stem (upriver of White River)[1]	12 (1.7)
	Pelly River[2]	48 (6.7)
	Yukon River main stem (upriver of Selkirk)[1]	16 (2.2)
	Tatchun Creek	3 (0.4)
	Yukon River main stem (upriver of Tatchun Cr)[1]	26 (3.6)
	Nordenskiold River	2 (0.3)
	Little Salmon River	3 (0.4)
	Big Salmon River	25 (3.5)
	Teslin River[2]	49 (6.8)

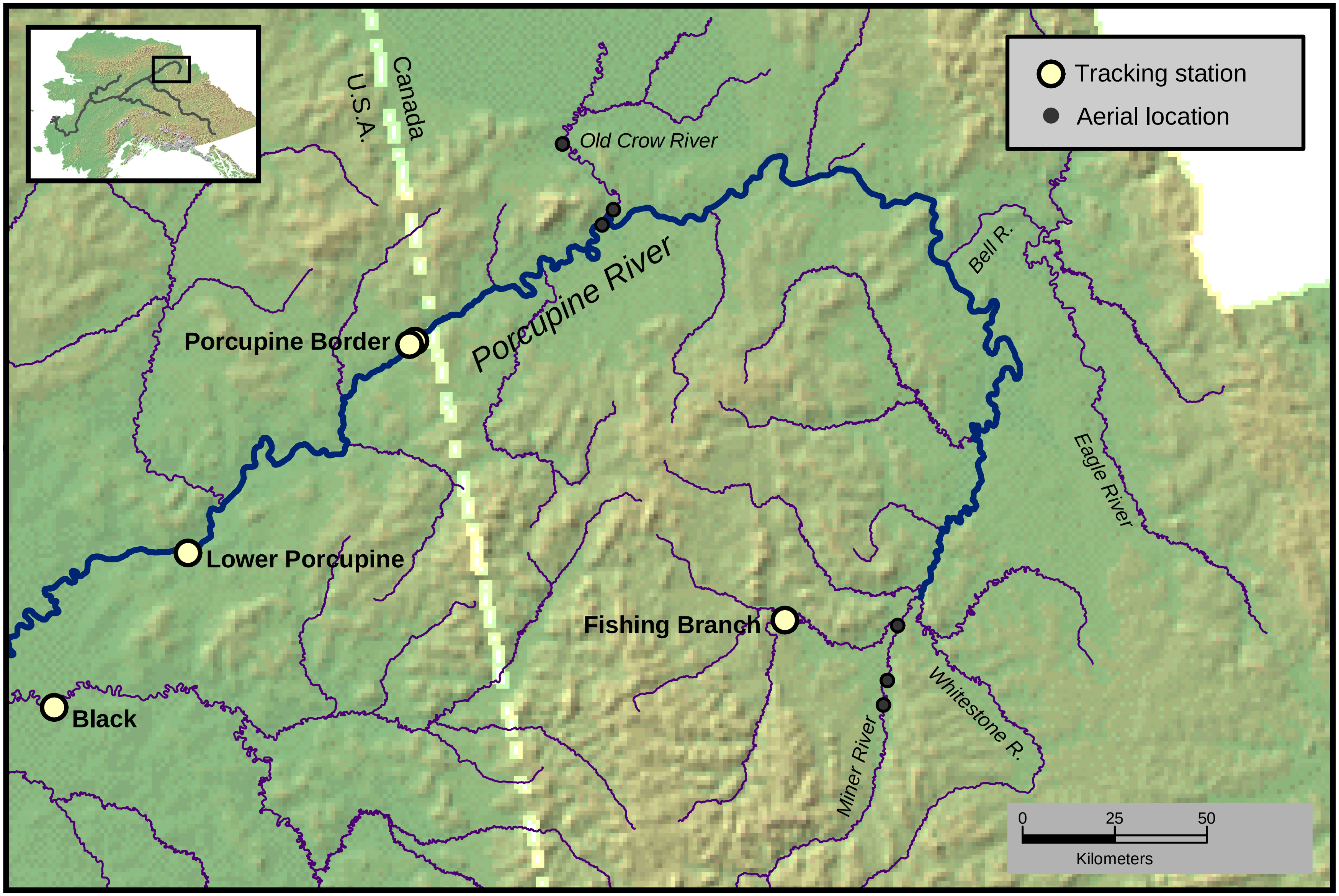
Appendix B. -- Continued.

Region	Final Location	Tagged Fish
Upper Yukon (Canada)	Yukon River main stem (upriver of Hootalinqua)[1]	8 (1.1)
	Takhini River	5 (0.7)
	Combined Areas	284 (39.5)
Porcupine (U.S.)	Black River	1 (0.1)
	Sheenjek River	6 (0.8)
	Coleen River	4 (0.6)
	Combined Areas	11 (1.5)
Porcupine (Canada)	Porcupine River (upriver of Border)[1]	1 (0.1)
	Old Crow Fishery	3 (0.4)
	Old Crow River	1 (0.1)
	Miner River	3 (0.4)
	Combined Areas	8 (1.1)
Total		719

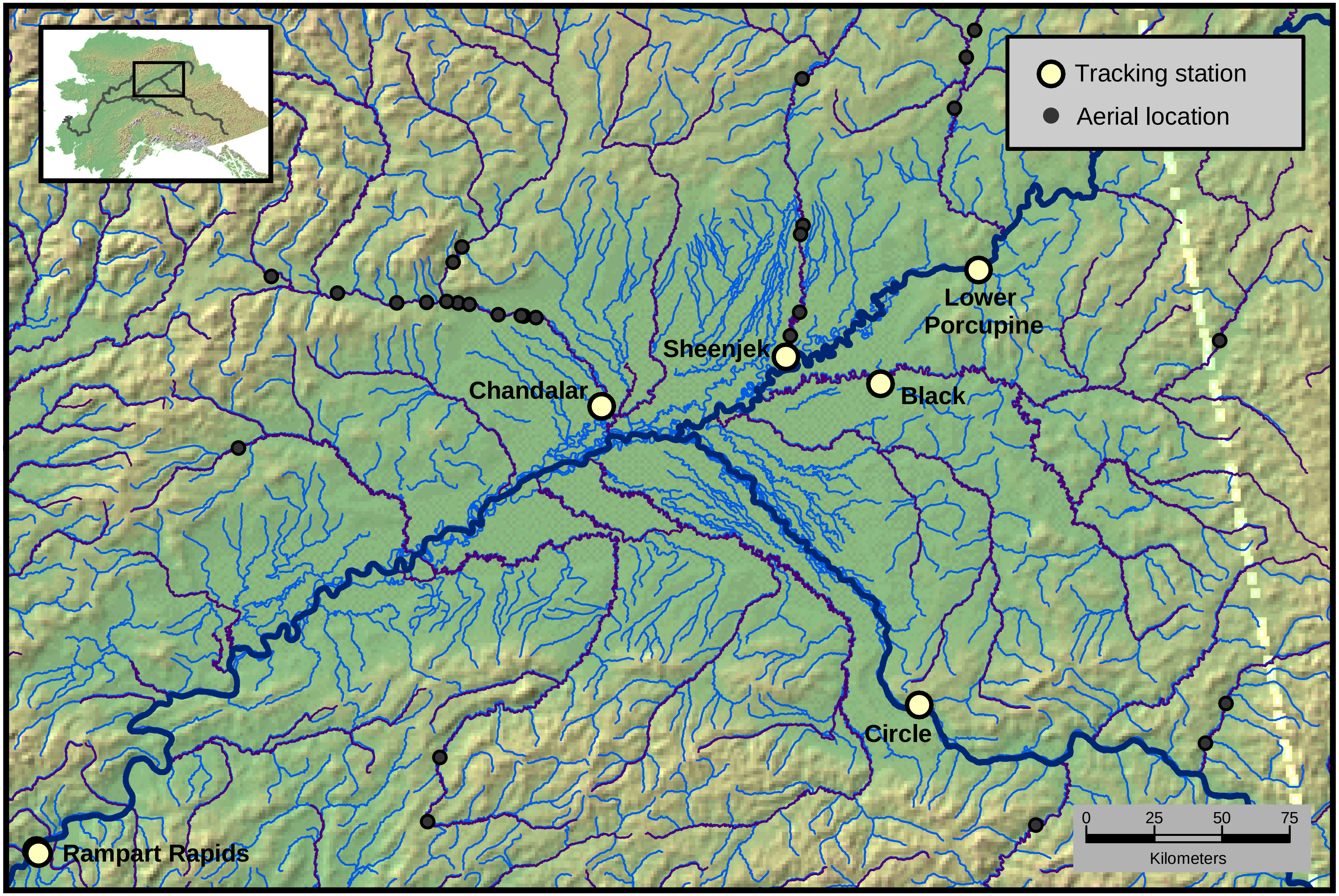
[1] Including associated tributaries not monitored with tracking stations or aerial surveys.
[2] Includes fish caught in terminal fisheries.
[3] Minimum count based on partial aerial survey.



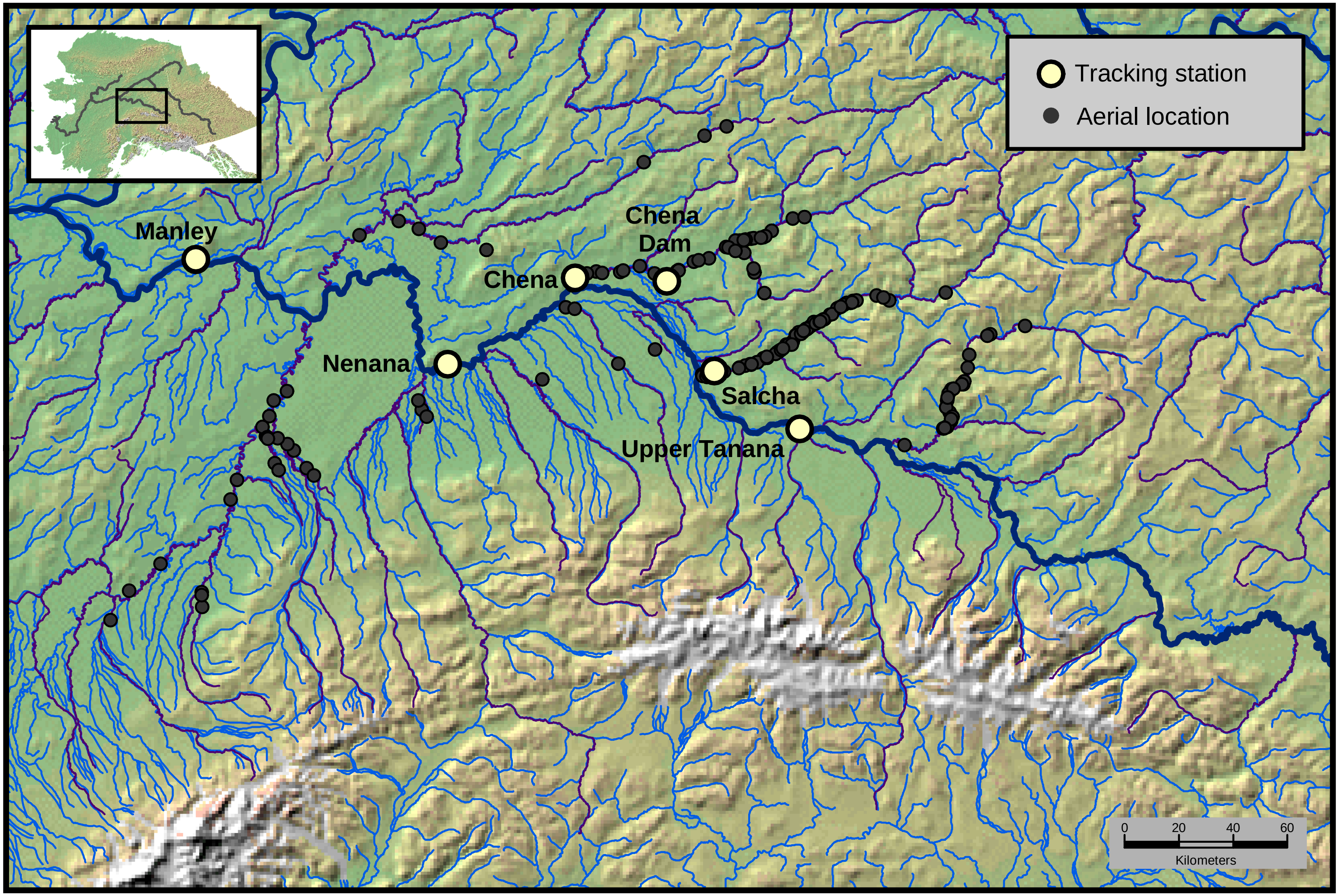
Appendix C. -- Final location of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission and tracked to tributaries in Canadian reaches of the Yukon River during aerial tracking surveys in 2004.



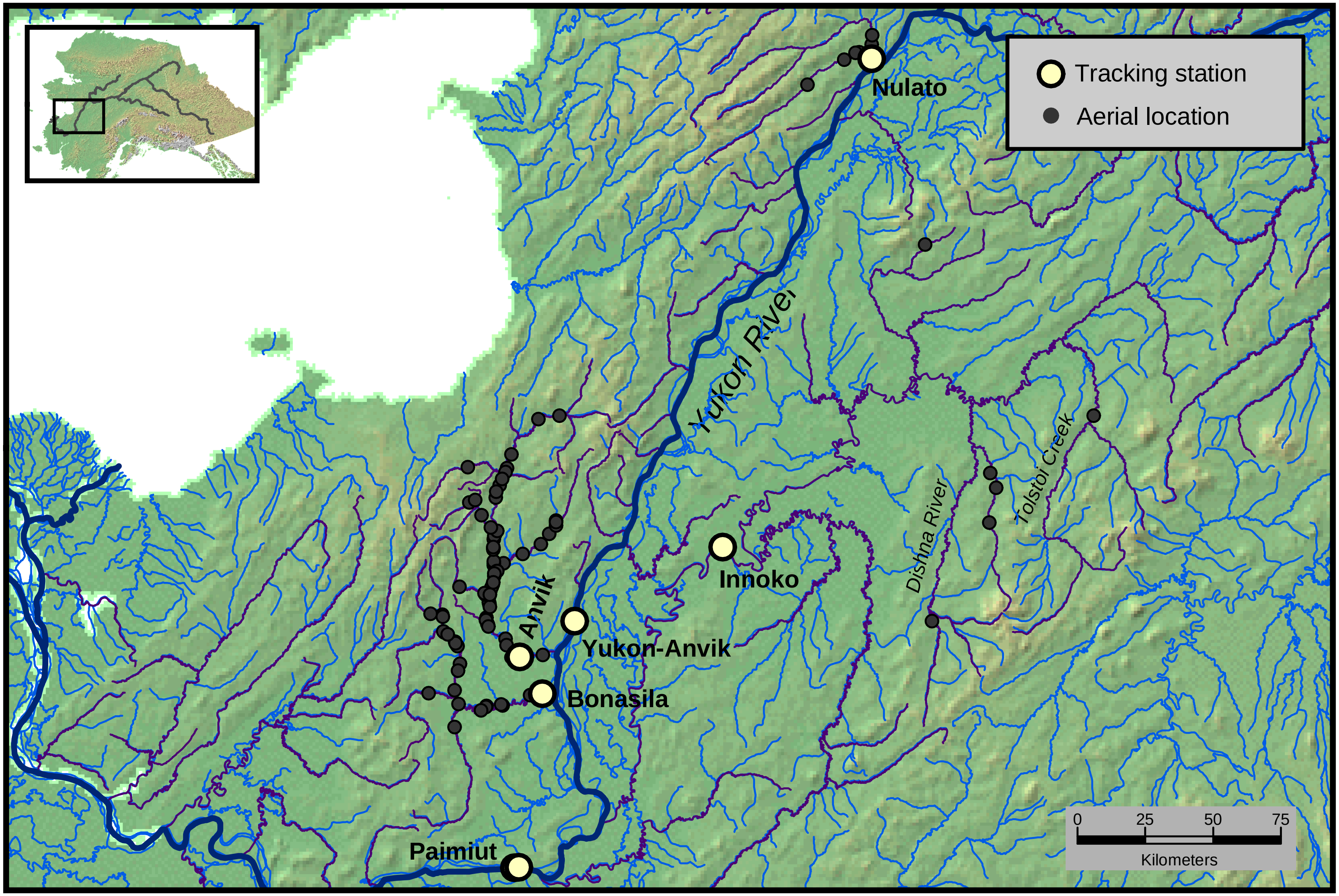
Appendix D. -- Final location of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission and tracked to tributaries in Canadian reaches of the Porcupine River during aerial tracking surveys in 2004.



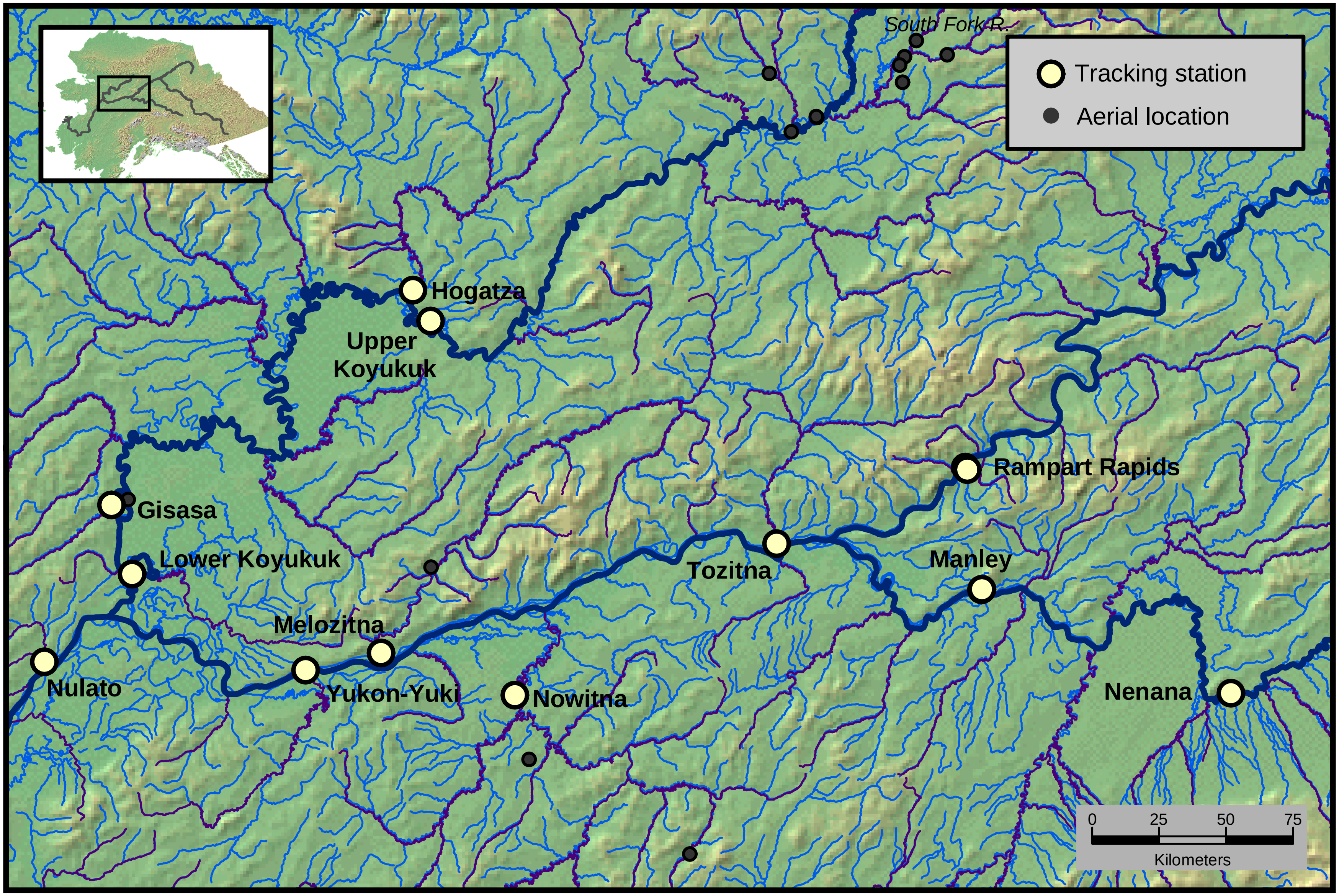
Appendix E. -- Final location of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission and tracked to tributaries in U.S. reaches of the upper Yukon and Porcupine rivers during aerial tracking surveys in 2004.



Appendix F. -- Final location of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission and tracked to Tanana River tributaries during aerial tracking surveys in 2004.



Appendix G. -- Final location of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission and tracked to lower basin tributaries during aerial tracking surveys in 2004.



Appendix H. -- Final location of Chinook salmon radio tagged in the lower Yukon River near the village of Russian Mission and tracked to middle basin tributaries during aerial tracking surveys in 2004.

Appendix I. -- Stock composition estimates of the Yukon River Chinook salmon return in 2004 based on the distribution of radio-tagged fish weighted by catch per unit effort information at the Russian Mission tagging site and adjusted for the harvest of tagged individuals in upriver fisheries. Bootstrap standard errors (SE) and 95% confidence intervals (CI) based on 10,000 bootstrappings are included.

Region	Stock Group	Estimate (%)	SE	95% CI
Lower Basin[1]	Lower Yukon[2]	5.6	0.8	(4.2, 7.2)
	Innoko	0.5	0.2	(0.1, 1.0)
	Bonasila	1.5	0.4	(0.7, 2.3)
	Anvik	4.3	0.7	(3.0, 5.8)
	Nulato	1.3	0.4	(0.6, 2.1)
Koyukuk River	Gisasa	0.9	0.3	(0.4, 1.6)
	Middle Koyukuk	0.8	0.4	(0.1, 1.6)
	Upper Koyukuk	1.9	0.5	(1.0, 2.9)
Middle Yukon River[3]	Melozitna	0.4	0.2	(0.0, 0.9)
	Nowitna	0.4	0.3	(0.0, 1.0)
	Tozitna	1.1	0.4	(0.4, 1.9)
	Mid-Yukon[2]	1.7	0.4	(0.9, 2.6)
Tanana River	Lower Tanana[4]	1.1	0.4	(0.4, 1.9)
	Kantishna	1.3	0.4	(0.5, 2.2)
	Tolovana	0.6	0.3	(0.1, 1.3)
	Mid-Tanana[4]	1.3	0.4	(0.6, 2.2)
	Chena	4.1	0.7	(2.8, 5.6)
	Salcha	10.1	1.1	(8.0, 12.4)
	Goodpaster	3.7	0.7	(2.4, 5.1)
	Upper Tanana[4]	2.2	0.5	(1.2, 3.3)
Upper Yukon River (U.S.)[5]	Upper Yukon (Rapids)[2]	2.7	0.6	(1.6, 3.8)
	Beaver Creek, Hodzana	0.4	0.2	(0.0, 1.0)
	Chandalar	1.9	0.5	(1.1, 3.1)
	Upper Yukon (Circle)[2]	0.3	0.2	(0.0, 0.8)
	Charley	0.2	0.2	(0.0, 0.6)
	Nation	0.4	0.2	(0.0, 0.9)
Upper Yukon River (Canada)	Lower Canadian Yukon [4]	0.9	0.4	(0.3, 1.7)
	Klondike	2.2	0.6	(1.1, 3.3)
	Stewart	4.7	0.8	(3.1, 6.4)
	White	2.1	0.6	(1.1, 3.2)

Appendix I. -- Continued.

Region	Stock Group	Estimate (%)	SE	95% CI
Upper Yukon River (Canada)	Pelly	8.4	1.1	(6.4, 10.6)
	Mid-Canadian Yukon[4]	4.9	0.8	(3.2, 6.4)
	Tatchun	0.5	0.3	(0.0, 1.2)
	Upper Canadian Yukon[4]	5.0	0.9	(3.4, 6.7)
	Nordenskiold	0.4	0.2	(0.0, 1.0)
	Little Salmon	0.5	0.3	(0.1, 1.2)
	Big Salmon	4.9	0.9	(3.2, 6.7)
	Teslin	9.2	1.1	(7.0, 11.4)
	Hootalinqua	2.5	0.6	(1.4, 3.9)
Porcupine River, U.S.	Black	0.1	0.1	(0.0, 0.4)
	Sheenjek	1.0	0.4	(0.3, 1.8)
	Coleen	0.7	0.3	(0.1, 1.4)
Porcupine River, Canada	Canadian Porcupine[4]	0.6	0.3	(0.0, 1.2)
	Miner	0.7	0.3	(0.1, 1.4)

[1] Section of the Yukon River from Russian Mission to the Yukon-Koyukuk River confluence.
[2] Non-terminal areas.
[3] Section of the Yukon River from Galena to the Yukon-Tanana River confluence.
[4] Including stocks in mainstem areas and associated tributaries.
[5] Section of the Yukon River upriver from the Yukon-Tanana River confluence.

Appendix J. -- Daily stock composition estimates of Chinook salmon passing through the lower Yukon River based on the distribution of radio-tagged fish in 2004.

	Non-Terminal Reaches[1]		Terminal Reaches			
Date	Lower-Mid Yukon	Upper Yukon (U.S.)[2]	Lower Basin-Middle Yukon Tributaries	Tanana River	Upper Basin Tributaries (U.S.)	Canada[2]
4 June	0.0000	0.1858	0.0294	0.2426	0.0000	0.5422
5 June	0.0000	0.0917	0.0318	0.2641	0.0236	0.5889
6 June	0.0000	0.0851	0.0232	0.2865	0.0341	0.5710
7 June	0.0194	0.0645	0.0274	0.3010	0.0514	0.5362
8 June	0.0171	0.0700	0.0242	0.2752	0.0582	0.5554
9 June	0.0157	0.0853	0.0376	0.2530	0.0635	0.5450
10 June	0.0309	0.0543	0.0309	0.2847	0.0623	0.5370
11 June	0.0254	0.0288	0.0305	0.2720	0.0854	0.5578
12 June	0.0279	0.0262	0.0418	0.2840	0.0839	0.5361
13 June	0.0304	0.0181	0.0650	0.2682	0.0782	0.5402
14 June	0.0297	0.0180	0.0771	0.2680	0.0718	0.5355
15 June	0.0309	0.0105	0.0810	0.2934	0.0570	0.5273
16 June	0.0283	0.0000	0.0706	0.3200	0.0609	0.5203
17 June	0.0289	0.0044	0.0961	0.3055	0.0590	0.5061
18 June	0.0332	0.0050	0.1142	0.3203	0.0465	0.4809
19 June	0.0427	0.0112	0.1171	0.3132	0.0407	0.4751
20 June	0.0475	0.0123	0.0985	0.3238	0.0392	0.4788
21 June	0.0528	0.0118	0.0817	0.3162	0.0313	0.5061
22 June	0.0533	0.0120	0.0778	0.2691	0.0317	0.5561
23 June	0.0769	0.0134	0.0913	0.2359	0.0211	0.5614
24 June	0.0717	0.0302	0.0495	0.2366	0.0161	0.5959
25 June	0.0905	0.0395	0.0708	0.2330	0.0212	0.5450
26 June	0.1072	0.0372	0.0881	0.2408	0.0262	0.5004
27 June	0.1101	0.0418	0.1222	0.2186	0.0367	0.4705
28 June	0.1208	0.0437	0.1775	0.1895	0.0386	0.4299
29 June	0.1423	0.0509	0.2309	0.1831	0.0445	0.3483
30 June	0.1367	0.0547	0.2743	0.1675	0.0480	0.3190
1 July	0.1470	0.0463	0.2964	0.1480	0.0632	0.2992
2 July	0.1522	0.0482	0.3357	0.1170	0.0584	0.2884
3 July	0.1406	0.0446	0.3577	0.0669	0.0572	0.3330
4 July	0.1653	0.0476	0.3614	0.0690	0.0374	0.3193
5 July	0.1692	0.0720	0.3518	0.0614	0.0445	0.3011
6 July	0.1862	0.0937	0.2906	0.1017	0.0642	0.2636
7 July	0.1990	0.1050	0.2274	0.1012	0.0535	0.3140

Appendix J. -- Continued.

	Non-Terminal Reaches[1]		Terminal Reaches			
Date	Lower-Mid Yukon	Upper Yukon (U.S.)[2]	Lower Basin-Middle Yukon Tributaries	Tanana River	Upper Basin Tributaries (U.S.)[2]	Canada[2]
8 July	0.2400	0.0884	0.2400	0.1000	0.0221	0.3095
9 July	0.2292	0.0691	0.2083	0.1250	0.0230	0.3454
10 July	0.2340	0.0709	0.2128	0.1277	0.0236	0.3310
11 July	0.2326	0.0532	0.2558	0.1395	0.0266	0.2924
12 July	0.2222	0.0321	0.1944	0.1667	0.0321	0.3526
13 July	0.2222	0.0000	0.2593	0.1111	0.0000	0.4074
14 July	0.2609	0.0000	0.2609	0.0870	0.0000	0.3913
15 July	0.2105	0.0000	0.3684	0.1053	0.0000	0.3158
16 July	0.2500	0.0000	0.4375	0.0625	0.0000	0.2500
17 July	0.2500	0.0000	0.6250	0.1250	0.0000	0.0000
18 July	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
19 July	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000

[1] Reaches of the Yukon River main stem and associated tributaries not monitored by tracking stations.
[2] Including reaches of the upper Yukon and Porcupine rivers.

Appendix K. -- Movement rates (km/day) of Chinook salmon radio tagged in the Yukon River basin during 2004 based on fish passage by tracking stations located at Paimiut and the furthest upriver station site.

Region	Stock	Average (km/d)	CI (95%)	N
Lower Basin	Lower Yukon[1,2]	45.3	38.4, 52.2	26
	Innoko	35.6	14.5, 56.7	5
	Bonasila	37.6	30.6, 44.6	14
	Anvik	31.2	28.2, 34.2	40
	Nulato	43.1	37.4, 48.8	11
Koyukuk River	Gisasa	34.0	28.0, 40.0	8
	Middle Koyukuk	53.1	44.0, 62.2	5
	Upper Koyukuk	69.8	65.9, 73.7	5
	Henshaw	67.0		2
	South Fork	68.0	60.7, 75.3	5
Middle Yukon River	Mid-Yukon[1,3]	46.3	38.7, 53.9	16
	Melozitna	40.2	21.4, 59.0	3
	Nowitna	55.2	31.0, 79.4	3
	Tozitna	50.5	41.8, 59.2	8
Tanana River	Lower Tanana[4,5]	47.9	36.9, 58.9	6
	Kantishna	55.2	51.1, 59.3	9
	Tolovana	49.3		3
	Middle Tanana[4,6]	44.4	31.7, 57.1	8
	Nenana	47.8		1
	Clear	52.9		3
	Chena	45.6	43.0, 48.2	27
	Salcha	43.2	41.9, 44.5	61
	Goodpaster	43.0	41.3, 44.7	23
	Upper Tanana[4,7]	40.2	36.7, 43.7	8
Upper Yukon River (U.S.)	Upper Yukon, Tanana-Circle[1,8]	54.6	48.7, 60.5	20
	Upper Yukon, Circle-Eagle[1,8]	57.7	41.3, 74.1	3
	Beaver	62.6		2
	Hodzana	52.3		1
	Chandalar	54.3	49.3, 59.3	13
	Charley	38.2		1
	Nation	57.5		2
Upper Yukon River (Canada)	Lower Canadian Yukon[4]	47.8		3
	Chandindu	59.2		1
	Klondike	61.9	58.4, 65.4	12

Appendix K. -- Continued.

Region	Stock	Average (km/d)	CI (95%)	N
Upper Yukon River (Canada)	Sixtymile	49.9		1
	Stewart	57.7	53.9, 61.5	23
	White	59.5	56.6, 62.4	12
	Mid Canadian Yukon, White-Tatchun[4]	48.7	45.8, 51.6	28
	Pelly	57.4	55.6, 59.2	40
	Tatchun	50.1		3
	Upper Canadian Yukon, Tatchun-Teslin[4]	52.0	49.7, 54.3	26
	Nordenskiold	57.5		2
	Little Salmon	56.3		3
	Big Salmon	54.9	52.9, 56.9	25
	Teslin	54.3	52.1, 56.5	39
	Upper Canadian Yukon, upriver of Teslin[4]	52.8	48.1, 57.5	7
	Takhini	51.1	48.4, 53.8	5
Porcupine River	Black	43.5		1
	Sheenjek	57.2	51.7, 62.7	6
	Coleen[4]	63.9	55.9, 71.9	4
	Canadian reaches	56.8		1
	Old Crow River	64.0		1
	Miner	54.9		3

[1] Non-terminal areas and associated tributaries not surveyed.
[2] Section of the Yukon River from Russian Mission to the Yukon-Koyukuk River confluence.
[3] Section of the Yukon River from Galena to the Yukon-Tanana River confluence.
[4] Including fish in mainstem areas and associated tributaries.
[5] Section of the Tanana River from the Yukon-Tanana River confluence to Nenana.
[6] Section of the Tanana River from Nenana to the Tanana-Salcha River confluence.
[7] Section of the Tanana River upriver from the Tanana-Salcha River confluence.
[8] Section of the Yukon River upriver from the Yukon-Tanana River confluence.

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