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Estimating the Inriver Abundance of Copper River Sockeye Salmon, 2006 Annual Report

Annual Report for Study 06-502

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ANNUAL REPORT SUMMARY PAGE

Title: Estimating the inriver abundance of Copper River sockeye salmon

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Management Region: Cook Inlet/Gulf of Alaska (Southcentral)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF PHOTOS

EXECUTIVE SUMMARY

The objective of this project was to estimate the inriver abundance of Copper River sockeye salmon *Oncorhynchus nerka* at Baird Canyon (rkm 66) using fishwheels and two-sample mark-recapture methods. For the first sampling event, 11,309 adult sockeye salmon received passive integrated transponder (PIT) tags from 25 May to 24 July at three fishwheels located in Baird Canyon. For the second sampling event, 73,888 sockeye salmon were counted using digital video recording (DVR) systems from 4 June to 14 August at two fishwheels located near Canyon Creek (rkm 157). A total of 713 PIT-tagged sockeye salmon were detected at the Canyon Creek recovery fishwheels using automated PIT-tag readers and rectangular pass-through antennas mounted on the fishwheel slides. The median travel time of fish tagged at Baird Canyon and recaptured at Canyon Creek was 9 d (range = 3-31 d).

No size selectivity was detected during either sampling event. The proportion of PIT-tagged sockeye salmon recaptured at the Canyon Creek fishwheels averaged 5.8% and varied significantly over the study period (χ^2 = 129.2, df = 4, P = 0.000). The marked fraction of fish examined at Canyon Creek averaged 0.9% and also varied significantly over time (χ^2 = 275.7, df = 4, P = 0.000). Unfortunately, due largely to unquantifiable errors associated with the automated DVR and PIT-tagging equipment used at Canyon Creek, recovery data were not considered reliable enough to generate an unbiased or defensible abundance estimate. This report was submitted as the annual report to U.S. Fish and Wildlife Service, Office of Subsistence Management, Subsistence Fisheries Resource Monitoring Program for project number 06-502.

Citation: van den Broek, K. M., J. J. Smith, and G. Wade. 2007. Estimating the inriver abundance of Copper River sockeye salmon, 2006 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 06-502), Anchorage, Alaska.

INTRODUCTION

Three major stock components of sockeye salmon *Oncorhynchus nerka* return to the Copper River each year (Ashe and Taube 2002). The Upper Copper River wild stock complex is the most abundant component and it consists of both early and late returns, all of which spawn in tributaries above Miles Lake. The second component comprises enhanced sockeye salmon, which are produced from the Gulkana Hatchery, and their run timing overlaps the late-run (upper river) wild stock complex. Lower delta stocks, which make up the third component, spawn in systems below the Chugach Mountains between Eyak Lake and the Katalla River.

Copper River sockeye salmon sustain large and important subsistence fisheries under both State and Federal jurisdiction; and subsistence, commercial, personal use and sport harvests are significant in comparison to abundance. The majority of Copper River sockeye salmon are harvested in an ocean commercial gill net fishery from mid May through August in the Copper River District (in and around the mouth of the Copper River). In 2006, an estimated 1,462,451 sockeye salmon were harvested in the Copper River District, the 5th largest harvest on record (ADF&G 2007). From 1996 to 2005, annual harvests in the Copper River District averaged 1,416,518 fish (Ashe et al. 2005; ADF&G 2007). Personal use and subsistence fisheries occur from mid May through September, and a rod-and-reel sport fishery harvests sockeye salmon in tributaries of the upper Copper River (mainly the Gulkana, Klutina, and Tonsina rivers).

The 2005-2006 Federal Subsistence Fisheries Regulations (OSM 2005) identified two main areas in the Copper River drainage where subsistence fisheries for sockeye salmon take place: 1) Upper Copper River District (Chitina and Glennallen subdistricts), or all waters of the mainstem Copper River from the mouth of the Slana River downstream to an east-west line crossing the Copper River approximately 200 yards upstream of Haley Creek; and 2) Batzulnetas area, or waters of the Copper River and Tanada Creek between National Park Service regulatory markers. Salmon within these areas also have a Customary and Traditional Use determination for certain Alaskan residents (OSM 2005). In the Upper Copper River District, salmon may only be harvested using fishwheels, dip nets and rod and reel. In the Batzulnetas area, salmon may be harvested using fishwheels, dip nets, rod and reel and fyke nets and spears (in Tanada Creek only). The fishing season for both areas typically runs from mid May to the end of September. Since 2003, the Alaska Department of Fish and Game (ADF&G) has managed the commercial fishery to achieve a sustainable escapement goal of 300,000 to 500,000 sockeye salmon into the Copper River, which includes allowances of 160,000 to 240,000 salmon for inriver harvest goals.

Management of Copper River sockeye salmon is complex due to inter-annual variation in the size and timing of stocks, fisheries that target a mixture of stocks and difficulties in estimating abundance due to the physical characteristics of the drainage. This is further confounded by the interplay of numerous Federal and State government agencies in the management of this gauntlet of fisheries. Recently, counted returns of sockeye salmon to several tributaries of the upper Copper River basin (e.g., Gulkana Hatchery, Tanada Creek weir) have been lower than expected given the acoustic-based estimates of abundance obtained from the Miles Lake sonar site. Personal testimony by many upriver residents at 2005 Board of Fisheries hearings also indicated an overall failure of adequate viable spawners to reach headwaters. In 2001, the Native Village of Eyak (NVE) and various other groups expressed concerns over an apparent decline in sockeye salmon returns to tributaries of the upper Copper River (Bruce Cain, NVE, Cordova, pers. comm.). For example, the Gulkana Hatchery was not able to meet brood requirements from Paxson Lake in 2000 and 2001, and hatchery staff observed low returns for seven Gulkana River stocks that they had worked with for over 20 years. Sockeye salmon counts at the Tanada Creek weir from 2001 to 2003 (range: 1,649-5,856) were also well below the counts in 1997 (27,521) and 1998 (28,992). In contrast, these apparent declines in sockeye salmon returns were not detected at the Miles Lake sonar site. Based on this information, the factors contributing to this apparent decline are occurring at or above the Miles Lake sonar site.

ADF&G uses a combination of fishery performance statistics and estimates of sockeye entering the river to make decisions on whether and for how long to open the weekly fishery. Past attempts to assess and enumerate Copper River sockeye salmon have been met with limited success. From 1960-1964, 9,143 salmon (mostly sockeye) were tagged in the Copper River District and recovered in commercial and subsistence fisheries and on the spawning grounds; however, no results from these studies could be found (ADF&G 1962; Willette 2000). From 1966-1968, fishwheels were used to capture and tag sockeye salmon downstream of Wood Canyon as part of a mark-recapture study (Larson 1967; Larson and Fridgen 1968; Greenough 1971); and abundance estimates were generated for each of these three years. Other tagging studies were conducted in the early 1970s but did not generate abundance estimates (Fridgen and Roberson 1971; Roberson and Fridgen 1972; Roberson 1974; Roberson and Fridgen 1974). From 1969-1972, prior to establishing the Miles Lake sonar site, acoustic systems were operated at three different sites (Wood Canyon, Klutina River, Gulkana River) in the Copper River drainage in an attempt to assess sockeye salmon abundance (Roberson and Fridgen 1974). After 1974, sockeye enumeration efforts shifted from mark-recapture studies to weirs and aerial surveys (Willette 2000). Estimates of fish escaping the commercial fishery have been made using sonar counts at a site near the outlet of Miles Lake. In addition, a test fishing project at Flag Point Channel in the lower Copper River has been used to index salmon abundance from 2001-2006 (Link et al. 2001a; Lambert et al. 2003; Degan et al. 2004; Mueller and Degan 2005; Degan et al. 2006; van den Broek and Degan *In prep*). The information provided from this project is taken into consideration by fishery managers who make decisions regarding commercial openings.

There are several issues associated with the acoustic counts generated at Miles Lake that need to be addressed. First, only the near-shore areas are ensonified with the acoustic system, so any fish migrating offshore and outside of the ensonified area are not counted. Second, the sonar system is not species-specific, and thus can not distinguish between co-mingled sockeye, Chinook and coho salmon. As a result, the sonar counts provide an index of overall salmon abundance. To further confound certainty in the abundance estimates provided by the Miles Lake sonar, ADF&G is currently upgrading their Bendix acoustic system (used since 1978) with a newer and much different acoustic system (dual frequency identification sonar – DIDSON). The management system and management plans for Copper River sockeye salmon have been built around the old Bendix sonar counts. The degree of comparability of the old and new acoustic systems is uncertain, although when tested side-by-side in 2005, there was no significant difference in counts obtained by the two systems (Steve Moffitt pers. comm.). However, the efficacy of neither the new DIDSON system nor of the original Bendix acoustic counter has never been independently validated with an alternative and statistically reliable technique, nor can a coefficient of variation in the Miles Lake estimate be known.

The purpose of this project is to use mark-recapture methods to estimate the inriver abundance of Copper River sockeye salmon at Baird Canyon. These abundance estimates will then be used to compare to salmon counts provided by the Miles Lake sonar gear. It is important to note that this project is not intended to replace or become redundant with the existing Miles Lake sonar site. Instead, the project will provide fishery managers with additional information that can be used to better manage the fishery and ensure that an adequate number of fish make it upriver for subsistence harvests and spawning requirements. In addition, abundance estimates from this study may be used to generate more reliable run timing and distribution information for a concurrent radiotelemetry study (FIS05-501).

This project addresses one of the priority information needs for Federal subsistence fisheries that were identified by the Fisheries Resource Monitoring Program (FRMP) in their 2006 request for proposals. Specifically, this project will conduct "research to improve and verify estimates of inriver returns for Copper River sockeye salmon." This project is also integrated with two ongoing FRMP projects: 1) FIS04-503 – Estimating the annual escapement and run timing of Chinook *O. tshawytscha* salmon in the Copper River using fishwheels and a mark-recapture experiment; and 2) FIS05-501 – Spawning distribution and run timing of Copper River sockeye salmon. This report was submitted as the annual report to U.S. Fish and Wildlife Service (USFWS), Office of Subsistence Management (OSM), Subsistence Fisheries Resource Monitoring Program for project number 06-502.

Objectives

The main objective of the 2006 study was to estimate the inriver abundance of sockeye salmon returning to the Copper River at Baird Canyon such that the estimate was within 25% of the actual abundance 95% of the time. For the first sampling event of the mark-recapture experiment, sockeye salmon were captured and tagged at three fishwheels located at Baird Canyon approximately 66 km upstream of where the Copper River enters the Gulf of Alaska. For the second sampling event, fish were captured and examined for tags at two recovery fishwheels located near Canyon Creek (rkm 157) approximately 12 km downstream from Chitina, Alaska. This report documents the methods, results, and conclusions from the 2006 field season.

Study Area

The Copper River, which drains an area of more than 62,100 km^2, flows southward through Southcentral Alaska and enters the Gulf of Alaska near the town of Cordova (Figure 1). Between the ocean and Miles Lake (rkm 48), the river channel traverses the Copper River Delta which is a large, highly braided, alluvial flood plain. A relatively high proportion of the Copper River's headwaters are glaciated (18% in 1995), resulting in very high unit discharge (volume per square kilometer of drainage area) and sediment loads (Brabets 1997). From 1988 to 1995, the annual mean discharge on the lower Copper River was 1,625 m^3/s, with the majority of flow occurring during the summer months from snowmelt, rainfall and glacier melt (Brabets 1997).

Over the same historical period, peak discharge in June ranged from 3,650 to 4,235 m^3/s while annual peak discharge ranged from 6,681 to 11,750 m^3/s. Water levels in Baird Canyon typically rise sharply from late May through June, level off in July, and then peak in August. Sediment loads cause the water to be unusually turbid and fill the river with numerous ephemeral sandbars and channel braids for most of its length.

Two major channel constrictions in the lower Copper River between Miles Lake and the mouth of the Chitina River (rkm 172) offer the potential to capture substantial proportions of migrating Chinook salmon using fishwheels. Baird Canyon is the first major channel constriction on the Copper River upstream of Miles Lake that is suitable for operating the capture-tag fishwheels. The east bank of Baird Canyon is a steep, often sheer, rock wall that rises over 600 m above the river. The west bank slopes more moderately to a maximum height of 20 m above the river, is densely wooded, and has a substrate ranging from sand to boulders. The land beyond the west bank is primarily a wetland area that drains the Allen Glacier to the west. The north branch of the Allen River enters on the west bank and is the only major tributary entering Baird Canyon.

Wood Canyon is the second major channel constriction on the Copper River upstream of Miles Lake and is located approximately 91 km upstream of Baird Canyon. The lower end of Wood Canyon, below the mouth of Canyon Creek and the lower boundary of the Chitina Subdistrict dip net fishery, was considered a suitable location for operating the recapture fishwheels. The west bank in this area consists mostly of steep rock walls, whereas the east bank is a mix of sand bars, rock outcroppings, and rock walls.

METHODS

Copper River Stage Height

Copper River stage height was measured daily near the Baird Canyon and Canyon Creek fishwheels using aluminum staff gauges that were bolted to the canyon walls. Stage height of the Copper River was also recorded daily at the Million Dollar Bridge near the Miles Lake sonar site and available through the U.S. Geological Survey (USGS) web site (USGS 2007).

Fishwheel Operation

Three tagging fishwheels (fishwheels 1, 2, and 5) operated at Baird Canyon, and two recovery fishwheels (fishwheels 3 and 4) at Canyon Creek in 2006. Two of the fishwheels at Baird Canyon (fishwheels 1 and 2) and 1 fishwheel at Canyon Creek (fishwheel 3) were large aluminum models intended for fishing against deep canyon walls. These were made of two, welded aluminum pontoons (11.6 m long x 0.9 m wide x 0.5 m deep), a 3.7 m long axle, three baskets (3.0 x 3.0 m x 2.1 m), and a tower (6.1 m high) and boom (4.9 m long) assembly that was used to raise and lower the axle. The baskets were designed to fish up to about 3 m below the water surface and were lined with knotless nylon mesh (6.4 cm stretch). The baskets on fishwheel 3 were shorter than those on fishwheels 1 and 2 which allowed it to fish at shallower depths. An aluminum tank (4.3 m long x 1.5 m deep x 0.6 m wide) for holding captured fish was fitted inside each pontoon. The bottom of each live tank was fitted with windows of extruded aluminum mesh to allow for ample water circulation.

The third fishwheel at Baird Canyon (fishwheel 5) was similar in design to fishwheel 4 that operated at Canyon Creek. These smaller fishwheels were composed of two aluminum pontoons (11.6 m long x 0.6 m wide x 0.5 m deep), four lumber and spruce pole baskets (2 m long x 1.8 m wide x 0.8 m deep), and a tower assembly designed to raise and lower the axle. The baskets were lined with knotless nylon mesh (6.4 cm stretch). As with the other fishwheels, each live tank was fitted with windows of extruded aluminum mesh and an escape panel.

In order to reduce the potential for high densities and crowding of fish in the live tanks, escape panels were installed in the live tanks of all project fishwheels (see Photo 6 on p. 84 in Smith et al. 2003). The escape panels consisted of two, adjustable vertical slots in a removable aluminum frame. When installed and opened to the appropriate width (6 to 7.5 cm), the escape panels allow smaller fish (e.g., sockeye and by-catch species) to easily swim out of the live tanks while retaining Chinook salmon. As a result, the escape panels reduce crowding and the potential for mortalities during high-catch periods as well as the amount of crew labor for handling fish. Tests in 2004 indicated that the escape panels allowed 69-100% of sockeye salmon to escape from the live tanks, while retaining 100% of the adult Chinook salmon captured (Smith 2004). The escape panels on the Baird Canyon fishwheels were closed intermittently on pre-arranged intervals to allow retention of sockeye salmon for this study and the concurrent radiotelemetry study (FIS05-501).

The fishwheels used in 2006 were installed and operated similar to the methods used in previous years (Link et al. 2001b; Smith et al. 2003; Smith 2004; Smith et al. 2005; Smith and van den Broek 2005, 2006). However, fishwheels 3 and 4 were modified in 2006 so that all captured fish were directed down a single slide and into one live tank. The fishwheels were operated 24 hours per day, except for stoppages when they were being re-positioned or repaired. Daily fishing effort was computed as the number of hours that a fishwheel operated on a given calendar day from midnight to midnight. Fishwheel speed (revolutions per minute, rpm) was determined one or more times each day by measuring the time required for the fishwheel baskets to complete three revolutions, thus mitigating for the effects of temporary surges in water velocity. If fishwheel speed was recorded more than once in a day, the arithmetic mean of the measurements was calculated.

Tag Application

A systematic approach was used to deploy passive integrated transponder (PIT) tags at Baird Canyon in proportion to the magnitude and timing of the sockeye salmon run (so that all fish had an equal probability of being tagged). A schedule for deploying approximately 12,000 PIT tags was drafted prior to the field season using a forecast for Copper River sockeye salmon that was provided by ADF&G fishery managers in Cordova (S. Moffitt, ADF&G, Cordova, personal communication). The tagging schedule was then adjusted inseason based on daily salmon counts at the Miles Lake sonar site and the number of PIT tags remaining. Only a portion of the sockeye salmon captured in the fishwheels each day were PIT-tagged. Tags were deployed in a manner that would reduce the potential of bias from factors such as day of the week, time of day, and bank of deployment. To obtain fish for PIT-tagging each day, the live tanks in one or more fishwheels were emptied following either the morning (~0830 hours) or afternoon (~1500 hours) sampling periods. The fishwheels were then operated for a specified period, typically until the crew returned to the fishwheels for the next scheduled visit, and all fish captured in the live tanks were retained for sampling. Once the daily tag quota was met, the remaining sockeye salmon were counted and released. The escape panels in the live tanks were then re-opened.

Using a dip net, healthy sockeye salmon were transferred from the live tanks to a water-filled, foam-lined trough for sampling. Fish were held with their ventral-side facing upwards. The PIT tags (Model TX1411L) were manufactured by Biomark, Inc. (Boise, ID; Photo 1). Prior to insertion, each PIT tag was scanned using a hand-held, Pocket Reader scanner (Destron Fearing, St. Paul) and the unique identification number was automatically recorded on a personal digital assistant (PDA). The tags were inserted into the stomach cavity using a 12-gauge hypodermic needle and syringe (Photo 2) . Needles were inserted into fish posterior to the tips of the pectoral fins, and on the left side of the mid-ventral line in order to avoid damaging the spleen. Needles were directed in a posterior direction that was away from the vital organs. A subset of PIT-tagged fish were measured for fork length (mm FL) from the tip of the snout to the fork of the tail.

Tag Recovery

Digital Video Recorder

Rather than physically handle and count each fish captured at the Canyon Creek fishwheels, the number of sockeye salmon captured and examined for PIT tags was obtained using digital video recorders (DVR; Everfocus Model EDSR400H). Mounted above the slide on each fishwheel were color, digital-video cameras (ProVideo CVC-7706 DNV) housed in waterproof cases (Photo 3). The cameras were operated through DVR systems that were housed separately in large waterproof cases on the decks of the fishwheels. The DVR systems were configured to record upon detection of motion from the video camera, and video footage was recorded to removable and hot-swappable hard drives (Maxtor QuickView ATA/133, 250 GB) capable of recording up to 12 h of video. When a fish was captured, it traveled down a plywood slide and into the frame of the camera. Once triggered, the DVR system recorded the fish on video before it continued down the slide and dropped into the live tank. The video systems were assembled by SeeMore Wildlife Systems, Inc. (Homer, AK). Each complete DVR and PIT-tag system was powered by two deep-cycle batteries (12 V) and a 500-W inverter. The batteries were charged using four 40-W solar panels regulated by a solar controller (ProStar Model PS-15M). A 2-KW generator (Honda EU2000) provided backup power when necessary (Photo 3).

PIT-tag Reader and Antenna

The number of PIT-tagged fish recaptured at the Canyon Creek fishwheels was obtained using automatic PIT-tag readers (Destron Technologies Model 2001F-ISO). Mounted on the fishwheel slides were rectangular pass-through antennas (81 cm x 31 cm) that were each connected to a PIT-tag reader (Photo 3). The pass-through antennas were shielded from the aluminum fishwheel pontoons using plywood and rubber mats in order to minimize interference. The antennas continuously transmitted a signal and thus immediately detected any PIT tags that passed through them. Upon detection, the identification number of PIT tags was automatically recorded on the PIT-tag reader.

Sampling Protocol

At least twice daily, technicians visited the fishwheels to swap-out the hard drives containing video footage with blank hard drives, and download PIT-tag data from the readers. At camp, the hard drives were connected to a laptop computer and video footage was observed. All fish captured on video were identified by species and the daily number of sockeye salmon was recorded in an MS Excel spreadsheet. Similarly PIT-tag data was recorded in an MS Excel spreadsheet. During periods of high sockeye salmon catches, or when motion sensing software was deemed unreliable due to environmental conditions, video data were typically recorded 24 hours a day. Then, technicians used a subsampling strategy whereby, for example, counts were obtained for a 15 minute block every other 15 minutes and then expanded by a factor of two; the exact subsampling strategy varied daily based on overall counts, system downtime and other factors, however, the aim was to obtain a minimum of 12-h and up to 24-h counts each day of the season, and to spread the count evenly throughout the day. A subset of sockeye salmon captured daily at the Canyon Creek fishwheels were measured for length (mm FL).

Abundance Estimate

Two-sample mark-recapture methods were used to estimate the inriver abundance of adult sockeye salmon above the Baird Canyon fishwheels. The computer program SPAS (Arnason et al. 1996) was used to calculate the estimate and associated standard error. If the assumptions of the mark-recapture model were met (e.g., temporal stratification by marking and/or recapture period were not required), then we used Chapman's modification of the pooled Petersen estimator (Ricker 1975; Seber 1982):

$$\hat{N} = \frac{(M+1)(C+1)}{R+1} - 1, \qquad (1)$$

where $\hat{N}$ = estimated abundance of sockeye salmon above Baird Canyon; M = number of fish marked during Event 1 that were available for sampling during Event 2; C = number of fish inspected for marks during Event 2; and R = number of marked fish sampled during Event 2.

The conditions for accurate use of this methodology were:

1) All fish had an equal probability of being marked in Event 1; or
2) All fish had an equal probability of being inspected for marks in Event 2; or
3) Marked fish mixed completely with unmarked fish between sampling events; and
4) There was no recruitment or emigration between sampling events; and
5) There was no tag-induced mortality; and
6) Fish did not lose their marks and all marks were recognizable and reported.

Meeting the first condition was difficult for a variety of reasons. First, despite relatively constant fishing effort at Baird Canyon over the run, only a portion of the fish captured each day were tagged. Second, due to potential changes in fishwheel catch efficiency over time, catch per unit effort (CPUE) data for sockeye salmon was not considered a reliable indicator of the timing and magnitude of the run. And third, the total daily catch of sockeye salmon was unknown on most days because the escape panels in the live tanks allowed the majority of fish to escape prior to sampling. Despite these conditions, the Baird Canyon crew monitored salmon counts at the Miles Lake sonar site and adjusted the number of fish PIT-tagged each day if deemed necessary. Meeting the second condition depended primarily upon fishing effort at the Canyon Creek fishwheels, but also on maintaining effective operation of the DVR equipment and PIT-tag reader.

Stock-specific differences in the migratory timing of sockeye salmon precluded complete mixing of marked and unmarked fish (condition 3). However, efforts were made to capture and sample fish on both banks of the river during both sampling events. In addition, since the Copper River is heavily braided in many sections between Baird Canyon and Canyon Creek it probably limits the ability of salmon to migrate along the same bank or even in the same channel.

Three consistency tests described by Seber (1982) were used to test for temporal and/or spatial violations of conditions 1-3. Contingency table analyses (Appendix A.1) were used to test three null hypotheses:

1) The probability that a marked fish was recovered during Event 2 was independent of when it was marked;
2) The probability that a fish that was inspected during Event 2 was marked was independent of when/where it was caught during the second event; and
3) For all marked fish, time of marking was independent of if and when/where recovery occurred during Event 2. Failure to reject at least one of these three hypotheses was sufficient to conclude that at least one of conditions 1-3 was satisfied.

Conditions 1-3 could also be violated if size-selective sampling occurred. Determination of whether all size categories of the sockeye salmon population were subject to similar probabilities of capture during sampling in both sampling events was based upon the Kolmogorov-Smirnov (KS) test (Conover 1980). Procedures are described in Appendix A.2, as well as corrective measures (e.g., stratification) based on diagnostic test results to minimize bias in estimates of abundance and size composition.

The life-history of sockeye salmon isolates those fish returning to the Copper River as a closed population (condition 4). Fishwheels at both camps began fishing as soon as the river was free of ice in order to reduce the chances of fish immigrating into the study area prior to the onset of sampling. However, due to budgetary reasons, both camps were demobilized prior to end of the sockeye salmon migration and thus an unknown but likely small component of the run was not represented. Also, radiotelemetry studies have shown that 6-7% of Copper River sockeye salmon return to spawning areas that are located between Baird Canyon and Canyon Creek (Smith et al. 2006; Wade et al. 2007). For this study, we assumed the same proportion of tagged and untagged fish returned to these lower-river spawning areas.

Mortality rates from natural causes for tagged and untagged fish were assumed to be the same (condition 5). The PIT tags were injected directly into the body cavity so there was very little risk of tag loss (condition 6). Due to the nature of the recovery system, it was not possible to use a secondary mark.

Spawning Ground Sampling

Staff from the Gulkana Hatchery scanned sockeye salmon for PIT tags at the hatchery and during broodstock collection in Fish Creek and Crosswind Lake. Although these data were not used to estimate abundance in 2006, the marked fraction of fish sampled by the hatchery staff was compared to the marked fraction of fish sampled at the Canyon Creek fishwheels.

Migration Rates

Migration rates (km/d) for sockeye salmon that were tagged at the Baird Canyon fishwheels and subsequently recaptured at the Canyon Creek fishwheels (91 km upstream) were calculated.

RESULTS

Copper River Stage Height

Copper River stage height at Baird Canyon varied by 6.9 m from 21 May to 31 July (Figure 2). At Canyon Creek, water levels varied by 3.3 m from 23 May to 14 August (Figure 2). Water levels increased dramatically over three periods (21-28 May, 9-18 June, and 28 June to 8 July) and peaked on 15 July at Baird Canyon. In 2006, the stage height of the Copper River at the Million Dollar Bridge exceeded the 1982 to 2005 average from 24 May to 8 June, 11-23 June, and 7-17 July (Figure 3).

Fishwheel Operation

Fishwheel 1 operated on the east bank of Baird Canyon for 1,448 h (96.3% of the time) from 22 May to 23 July (Figure 4, Appendix A.3). Fishwheel 2 operated on the west bank of Baird Canyon for 1,107 h (94.0% of the time) from 23 May to 11 July. Fishwheel 5 operated on the west bank of the Copper River approximately 1.5 km upstream from Baird Canyon for 1,665 h (98.4% of the time). Fishwheel speeds averaged 1.8, 2.7, and 2.3 rpm for fishwheels 1, 2, and 5, respectively (Figure 4, Appendix A.3).

At Canyon Creek, fishwheel 3 operated along the east bank of the Copper River approximately 2.5 km downstream from the mouth of Canyon Creek. From 29 May to 14 August, it operated for 1,803 h (98.1% of the time; Figure 4, Appendix A.3). Fishwheel 4 operated on the west bank and fished for 1,894 h (95.5% of the time) from 23 May to 14 August. Fishwheel speeds averaged 2.1 and 5.2 rpm for fishwheels 3 and 4, respectively (Figure 4, Appendix A.3).

Tag Application

From 25 May to 24 July, 11,309 sockeye salmon were PIT-tagged at the Baird Canyon fishwheels (Figure 5, Appendix A.4). The number of fish PIT-tagged each day varied from 65 (25 May) to 486 (17 June). The majority of fish were tagged at fishwheel 5 (6,404), followed by fishwheel 1 (4,341), and fishwheel 2 (564). Sockeye salmon measured for length at Baird Canyon averaged 566 mm FL and ranged from 320 mm FL to 720 mm FL.

During post-season data analysis, we found 221 records in the database where the same PIT-tag number was recorded on two or more occasions. The most likely explanation for this problem was that some PIT-tag numbers were retained in the memory of the Pocket Reader scanner (instead of being cleared) after the tags had been inserted into fish. When the crew went to sample another fish, the PIT-tag number from the previous fish may have been accidentally recorded a second time in the PDA. In this scenario, the duplicate PIT-tag numbers would represent valid marked fish that were available for recovery at Canyon Creek, but we would have no record of the actual PIT-tag numbers applied. For the purposes of this study, we assumed that duplicate PIT-tag numbers represented valid marked fish and included them in calculations of abundance.

Tag Recovery

From 4 June to 14 August, 73,888 sockeye salmon were counted from video files at the Canyon Creek fishwheels (Figure 5, Appendix A.4). The majority (56%) of fish were counted at fishwheel 4. The daily number of sockeye salmon counted at Canyon Creek varied from 0 to 4,045 (9 June) fish. Fish were not counted during periods when the PIT tag recovery system was known to be inoperative, and subsampled video counts were expanded to reflect the total sampling hours rather than a complete 24 hour count in instances where the fishwheel was not fishing or other components of the recovery system were inoperative. A total of 713 PIT-tagged sockeye salmon (248 in fw3, 465 in fw4) were detected at the Canyon Creek fishwheels (Figure 5, Appendix A.4), and the daily number of recaptures varied from 0 to 37 fish. The first PIT-tagged fish was recaptured on 2 June and the last was recaptured on 14 August, and the majority (65%) were recovered in fishwheel 4. Sockeye salmon measured for length at Canyon Creek averaged 569 mm FL and ranged from 380 mm FL to 700 mm FL.

Digital Video Recorder

The quality of fish-count data collected at Canyon Creek using the DVR systems was compromised for a variety of reasons, including:

1. Due to the design of the fishwheel slides (particularly those on fishwheel 4), captured fish traveled down the slides so quickly that some fish were not detected by DVR motion sensing software, or in instances when motion sensing was not used, were often missed by technicians reviewing the video feed.

2. Motion sensors on the video system were difficult to fine-tune. If set too sensitive, shadows cast by the rotating fishwheel baskets, water trickling down the fishwheel slides, or rain

would trigger the video system and record "bogus" video files. If set too insensitive, some fish would pass through the camera's field of view without being recorded.

3. Identifying fish to species was typically straightforward; however, on occasion it was difficult to distinguish between large sockeye salmon and small Chinook salmon, particularly when lighting conditions were poor or fish were moving fast through the field of view.

4. Reviewing video files each day was time consuming for the crew, particularly during periods of high fish abundance or when large numbers of "bogus" video files were recorded on the DVR. Individual video files had to be opened, viewed, and closed separately. The playback speed of the video files could be increased during viewing, but this increased the probability of sampling errors. This process could be improved if software were available to stitch the video files together into one large file that could be viewed continuously. This process could also be improved with higher quality and larger video files, which would in turn require larger digital storage capacity and processor capability.

5. Because of limitations with computing and storage capacity in camp, it was impossible to backup video files for later review by project managers. Therefore the daily count recorded by field technicians was the final and only record of sampling, and any questionable data had to be censored from the experiment due to lack of ability to validate uncertainties.

6. On several occasions, video and/or PIT-tag data collected over a 12-24 h period were deemed unreliable. Unfortunately, even if only the video or PIT-tag data were considered unreliable, all of the second event data collected during this time period had to be censored from the experiment. In future years, we recommend that data be collected and recorded at a minimum of 2-4 h intervals.

PIT-tag Reader

The quality of recapture data collected at Canyon Creek using PIT-tag readers and pass-through antennas was also compromised for various reasons:

1. Due to the design of the fishwheel slides (particularly those on fishwheel 4), fish traveled down the slides so quickly that a portion of PIT-tagged fish were not detected and recorded as they passed down the slides and through the pass-through antennas. In addition to the speed of the fish, the orientation of the PIT tag in the fish appeared to influence whether it was detected.

2. The aluminum pontoons and live tanks created electrical interference that decreased the detection efficiency of the pass-through antennas. Plywood and rubber mats were used to shield the pass-through antennas from the aluminum, but they did not stop the interference altogether. It was discovered inseason that some of the electrical interference was originating from an inverter that was used to charge the built-in battery of the PIT-tag reader. The PIT-tag reader was immediately re-wired so that it connected directly to the 12-V power supply being used to run the DVR system. Despite the many changes to prevent interference, some interference remained, and was too variable to be able to find the source. In order to entirely

eliminate electrical, it seems that it would be necessary to re-build key components of the fishwheel out of fiberglass or plastic, and somehow isolate the antennas from any source of movement or vibration. It is unknown how this would be possible on the Copper River.

3. On 4 June, the cable of the PIT-tag reader on fishwheel 3 was accidentally damaged when it was caught in a turning fishwheel basket and torn from its connection on the antenna. To prevent the loss of data and potential down time in future studies, these cables should be adequately shielded from moving fishwheel parts.

4. Apart from time stamps when PIT tags were detected passing through an antenna, there was no record of whether the PIT-tag reader and antenna were operational on an hourly or daily time frame. To help assess the operational status of the PIT-tag reader, it would help if the reader could be modified to log a “battery OK” record every hour. Or, perhaps a “beacon” tag could be placed inside the pass-through antenna (or passed through the antenna by the crew on occasion) that would log a record on the reader every hour.

5. On 23 July, the crew noticed that the pass-through antenna on fishwheel 4 was not working because the seal had broken and it was partially filled with water. It was replaced the following day.

6. There were 37 PIT-tagged fish detected at the Canyon Creek fishwheels for which we had no record of their release at Baird Canyon. As a result, we could not determine their species (sockeye or Chinook) and had to censor them from the experiment.

Abundance Estimate

Due to the problems associated with the DVR and PIT-tag equipment, recovery data were not considered reliable enough to generate an unbiased abundance estimate. However, we tried to extract as much information as possible from the data set in order to evaluate whether the various assumptions of the mark-recapture model may have been violated, and to help identify shortcomings in the project design and execution that should be corrected in future studies.

Testing for size-selective sampling during both sampling events was conducted. To evaluate the null hypothesis of equal probability sampling during the second sampling event, the cumulative length-frequency distribution of fish marked during Event 1 (M) was compared to that of all marked fish recaptured during Event 2 (R). We rejected the null hypothesis (d_{max} = 0.076, P = 0.117; Figure 6). To evaluate the null hypothesis of equal probability sampling during Event 1, the cumulative length-frequency distribution of fish inspected during Event 2 (C) was compared to that of marked fish recaptured during Event 2 (R). Again, the null hypothesis was rejected (d_{max} = 0.066, P = 0.266; Figure 6). Based on these results, there was no size selectivity detected during either sampling event (Case I experiment as described in Appendix A.2).

Data collected at the Canyon Creek fishwheels that were considered unreliable for the reasons described earlier were censored from subsequent analyses (see shaded cells in Appendix A.4). Recapture data were summarized across corresponding marking and recovery periods (daily) and used to conduct diagnostic tests for temporal violations of conditions 1-3 (as described in Methods section).

The null hypothesis that the probability that a marked fish was inspected for marks during Event 2 was independent of the time during the run that it was marked in Event 1 was rejected (χ^2 = 129.2, df = 4, P = 0.000; Table 1). The daily proportion of PIT-tagged fish that were recaptured at Canyon Creek varied from 0.0% to 13.3% and averaged 5.8% over the study period (Table 1, Figure 7). Similarly, the null hypothesis that the probability that an Event 2 fish was marked was independent of the time during Event 2 when the fish was sampled was also rejected (χ^2 = 275.7, df = 4, P = 0.000; Table 2). Marked fractions of fish sampled at Canyon Creek varied from 0.0% to 3.1% and averaged 0.9% over the study (Table 2, Figure 8). In addition, the marked fraction of fish sampled at fishwheel 3 (0.8%) was significantly lower than the marked fraction of fish sampled at fishwheel 4 (1.0%; χ^2 = 9.3, df = 1, P = 0.002; Table 3). Based on these results, a partially stratified model would have been required to estimate abundance.

We also identified 53 PIT-tagged sockeye salmon that were recaptured two or more times at the Canyon Creek fishwheels, which represents 7.0% (53/753) of all PIT-tagged fish recaptured. In these cases, only the first recapture event would be used to generate an abundance estimate.

Spawning Ground Sampling

From 27 June to 22 October, Gulkana Hatchery staff sampled 22,827 sockeye salmon of which 16 (0.1%) were PIT-tagged (Table 4). The marked fractions of fish sampled at the Gulkana Hatchery (0.09%), Fish Creek (0.14%), and Crosswind Lake (0.00%) were significantly different (χ^2 = 6.3, df = 2, P = 0.043). The marked fractions of fish sampled at these sites were substantially less than the marked fractions of fish sampled at the Canyon Creek fishwheels.

Migration Rates

The median travel time of sockeye salmon that were PIT-tagged at Baird Canyon and subsequently recaptured at Canyon Creek was 9.0 d (range: 3-31 d; n = 753; Figure 9). Assuming a distance of 91 km between sampling events, the median migration rate was 10.1 km/d (range 2.9-30.3 km/d). Travel times between samplings were plotted relative to the date of tagging and relative to the Copper River stage height at the Million Dollar Bridge on the date of tagging (Figure 10; Figure 11), although no significant trend was evident in either case.

DISCUSSION

Due largely to problems associated with the DVR and PIT-tag equipment that was used in 2006, recovery data collected at Canyon Creek were not considered reliable enough to generate an unbiased abundance estimate for Copper River sockeye salmon. This outcome was extremely disappointing considering the high cost of the project and considerable effort put forth to conduct the field component of the study. Despite this outcome, many lessons were learned with respect to the study design and equipment operation that can be carried forward to future years.

Based on the sample sizes observed in 2006, a sufficient number of sockeye salmon can be captured and sampled using fishwheels to generate a reasonably precise abundance estimate. According to the methods of Robson and Regier (1964), if we assume an inriver abundance of 1,000,000 sockeye salmon and that 10,000 PIT tags are applied at Baird Canyon, then about 7,000 fish must be examined for marks at Canyon Creek in order to derive an estimate that is within 25% of the true abundance 95% of the time. All else being equal, just over 37,000 fish would have to be examined for marks at Canyon Creek to achieve 10% relative precision. These second event sample sizes are considerably smaller than the nearly 78,000 fish sampled at Canyon Creek in 2006. In contrast, a difficult challenge facing this project will be trying to determine what level of sampling effort is required to balance the trade-offs between meeting precision targets and other factors such as budgetary constraints (cost of PIT tags, personnel time) and concerns regarding fish health (sampling more fish typically increases the risk of overcrowding in the live tanks and stress on captured fish).

Using PIT tags to mark sockeye salmon at Baird Canyon was relatively straightforward. The entire process of scanning a PIT tag with the Pocket Reader scanner, logging the tag number on the PDA, loading a syringe, and inserting the tag into a fish took less than a minute per fish. Using a Pocket Reader scanner and PDA to record PIT-tag numbers was faster and probably contributed to fewer data-entry errors compared to using datasheets (and typing data into an electronic spreadsheet). Some problems were identified that must be addressed in future studies. During post-season analysis, we noticed that approximately 100 PIT-tag numbers had been logged into the database more than once. We assumed that these duplicate tag numbers were the result of data not being cleared from the Pocket Reader scanner memory prior to sampling another fish. To fix this problem, we will modify the PDA software to ensure that the crew is prompted whenever a duplicate tag number is logged. It is also possible for inriver harvesters to consume PIT tags that were accidentally implanted into the belly tissue of a fish. This could be avoided by encapsulating the PIT tags in an externally applied anchor/spaghetti tag that could be easily identified if harvested. One other disadvantage of using PIT tags is their high cost ($4.00/tag) relative to conventional spaghetti tags (< $1.00/tag).

Potential sources of bias that may affect inriver abundance estimates generated in subsequent studies were identified. As mentioned earlier, radiotelemetry studies on sockeye salmon have shown that a small proportion (6-7%) of fish tagged at Baird Canyon spawn in areas downstream of the Canyon Creek fishwheels. For this mark-recapture study, we assume that tagged and untagged fish return to these lower-river spawning areas in similar proportions. However, if a larger (smaller) proportion of tagged fish spawn downstream of Canyon Creek compared to untagged fish, then the abundance estimate may be biased high (low). Thus, it is important to ensure that sockeye salmon are PIT-tagged at Baird Canyon in relative proportion to the magnitude and timing of the run.

Bias may also be introduced if the assumption that handling and tagging fish at Baird Canyon does not affect survival is violated. Despite being relatively straightforward, the process of inserting a PIT tag into the belly cavity of a fish using a syringe is fairly invasive. Even for an experienced crew, there is a risk that vital organs could be punctured by the needle. However, unlike many radiotelemetry studies (where the final fate of most tagged fish is known), the mortality rate of PIT-tagged fish can not be estimated. If the mortality rate of PIT-tagged fish migrating between sampling events is higher (lower) than the mortality rate of untagged fish, then the abundance estimate may be biased high (low). This is another reason why less-invasive, external tags should be used in future studies.

The fact that 7% of PIT-tagged sockeye salmon detected at Canyon Creek were recaptured more than once points to yet another potential source of bias. If a similar proportion of untagged fish were captured more than once, and we did not adjust the number of fish examined for tags in our mark-recapture calculations, then the abundance estimate would be biased high. This potential source of bias may be present regardless of whether an automated system is used or whether fish are physically counted and manually scanned for tags. It is therefore important that the number of PIT-tagged fish captured more than once be recorded by the Canyon Creek crew so that these data can be used to adjust the number of unmarked fish used in calculations of abundance.

CONCLUSIONS

This year (2006) marked the first complete field season for this study. Although it was disappointing to put forth so much effort and cost without producing an inriver abundance estimate of Copper River sockeye salmon, many lessons were learned that will help to ensure future years are successful in meeting the stated project objectives. It was also proven possible to effectively use fishwheels and technician labor to capture and sample at both events the large number of fish required to derive an unbiased estimate on a population of approximately 1,000,000 fish. The FRMP and ADF&G have approved funding for this project for 2007, and the Native Village of Eyak has submitted a pre-proposal to the FRMP for continued funding in 2008 and 2009. As requested by the TRC, a full investigation plan for this continued work will be submitted in May. This project will continue to strengthen NVE's position as an integral part of Copper River salmon research. In addition, this project has demonstrated that several agencies (e.g., USFWS, NVE, and ADF&G) can work cooperatively to collect valuable data on Copper River salmon stocks that will be used to assess current management practices.

RECOMMENDATIONS

In light of the preceding discussion and the fact this project will be funded for at least another year, the following are recommended for the 2007 field season:

(1) Stop using the DVR system and PIT-tag readers to collect second event samples at the Canyon Creek fishwheels. The Canyon Creek fishwheel crew will physically count captured fish and use hand-held Pocket Reader scanners to manually scan sockeye salmon for PIT tags.
(2) Tag at least 10,000 sockeye salmon at Baird Canyon to ensure that sample sizes are sufficient for generating a reasonably precise abundance estimate.

(3) Apply PIT tags externally, rather than internally, which will make it easier for the Canyon Creek crew to identify marked fish and eliminate the chances of PIT tags being consumed by inriver harvesters.
(4) Modify PDA software to prevent duplicate tag numbers from being logged in the database at Baird Canyon.
(5) Increase the amount of pre-season and inseason training that the crews receive to ensure that all project data is collected in a standardized manner.
(6) Continue to develop and test the DVR and PIT-tag equipment as resources permit.

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TABLES

Table 1. Proportion of sockeye salmon PIT-tagged at Baird Canyon that were subsequently recaptured at Canyon Creek, 2006.

Period of marking	Recaptured	Not Recaptured	Marked	Recapture rate (%)
5/25 - 6/5	**36**	**2,380**	2,416	1.5
6/6 - 6/21	**248**	**3,352**	3,600	6.9
6/22 - 6/30	**132**	**1,887**	2,019	6.5
6/31 - 7/16	**143**	**2,261**	2,404	5.9
7/17 - 7/24	**92**	**778**	870	10.6
Total	651	10,658	11,309	5.8

Numbers in bold were used in Chi-square tests.

Table 2. Proportion of sockeye salmon examined at Canyon Creek that had been PIT-tagged at Baird Canyon, 2006.

	Period of recapture					
	6/5 - 6/20	6/21 - 7/5	7/6 - 7/11	7/12 - 8/3	8/4 - 8/14	Total
Marked	**83**	**306**	**8**	**235**	**19**	651
Unmarked	**24,134**	**18,877**	**1,667**	**17,921**	**7,414**	70,013
Examined	24,217	19,183	1,675	18,156	7,433	70,664
Mark rate (%)	0.3	1.6	0.5	1.3	0.3	0.9

Numbers in bold were used in Chi-square tests.

Table 3. Marked fractions of sockeye salmon sampled at fishwheels 3 and 4, 2006.

	Fishwheel 3	Fishwheel 4	Total
Marked	**241**	**410**	651
Not marked	**30,072**	**39,941**	70,013
Examined	30,313	40,351	70,664
Mark rate (%)	0.8	1.0	0.9

Numbers in bold were used in Chi-square tests.

Table 4. Marked fractions of sockeye salmon sampled by the Gulkana Hatchery staff at three different locations in the Gulkana River drainage, 2006.

	Gulkana Hatchery	Fish Creek	Crosswind Lake	Total
Marked	**14**	**2**	**0**	16
Not marked	**15,219**	**1,453**	**6,139**	22,811
Examined	15,233	1,455	6,139	22,827
Mark rate (%)	0.09	0.14	0.00	0.07

Numbers in bold were used in Chi-square tests.

FIGURES

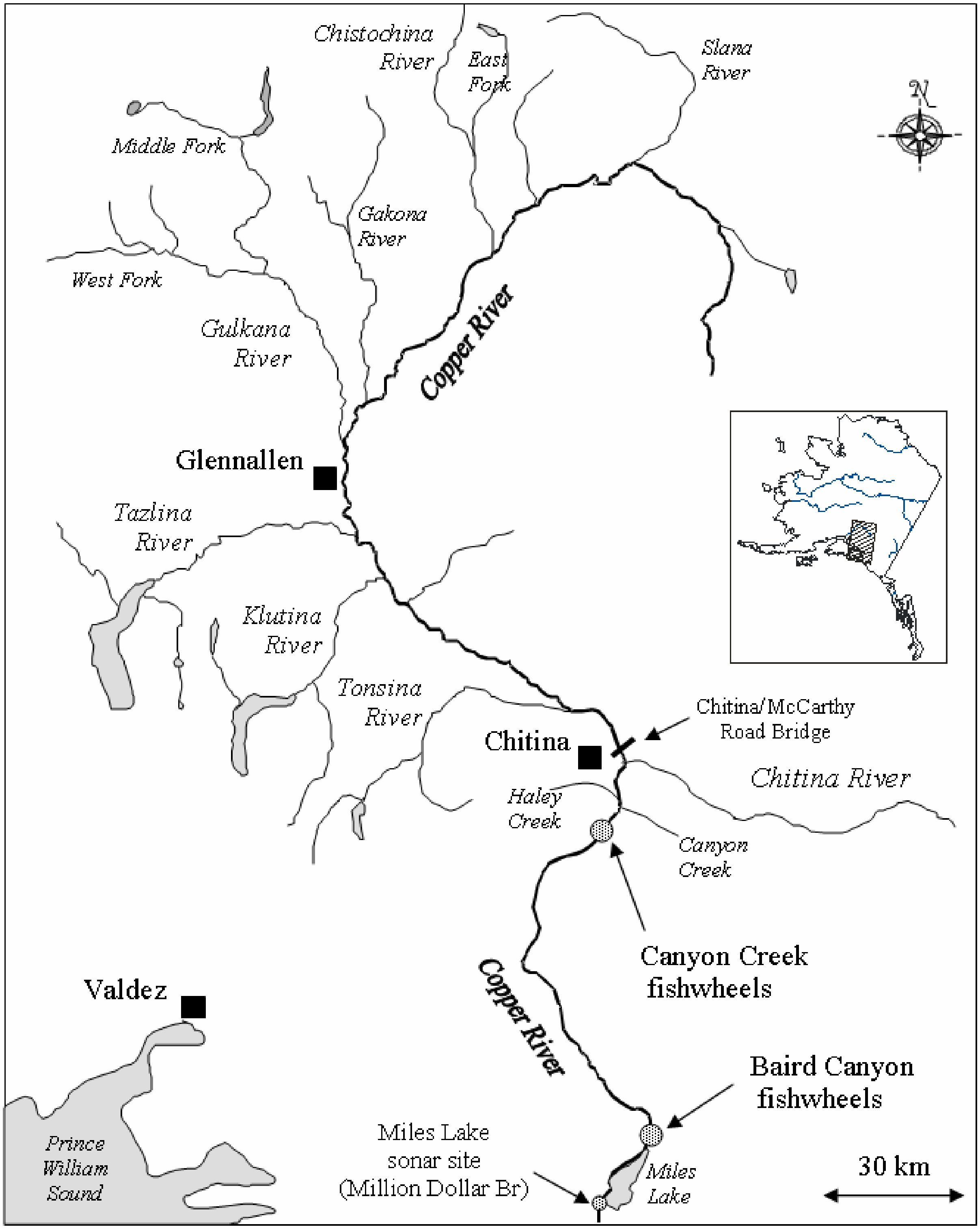

Figure 1. Map of the study area showing the location of the Baird Canyon and Canyon Creek fishwheels on the Copper River in Alaska, 2006.

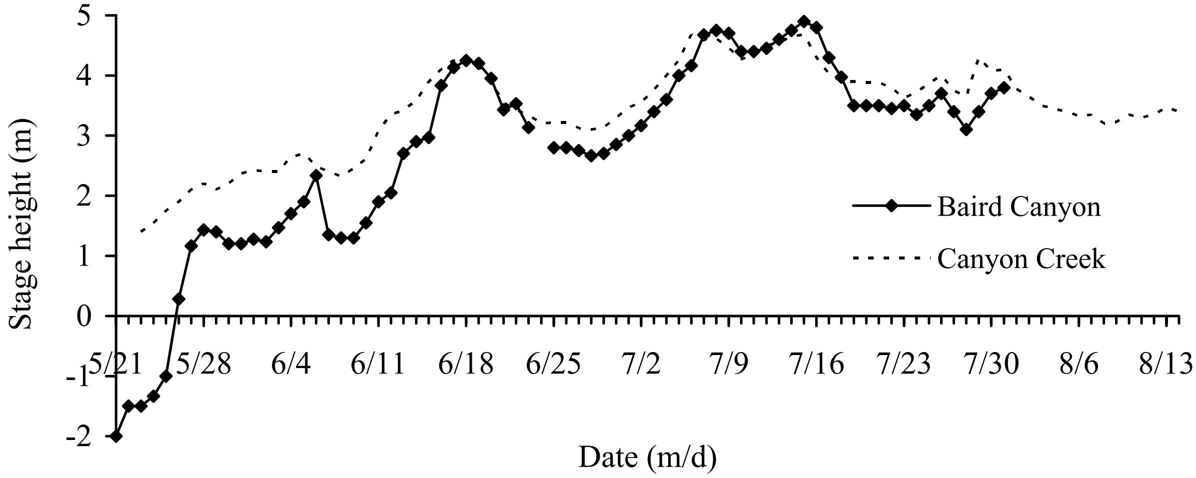

Figure 2. Average daily water level of the Copper River near the Baird Canyon and Canyon Creek fishwheels, 2006.

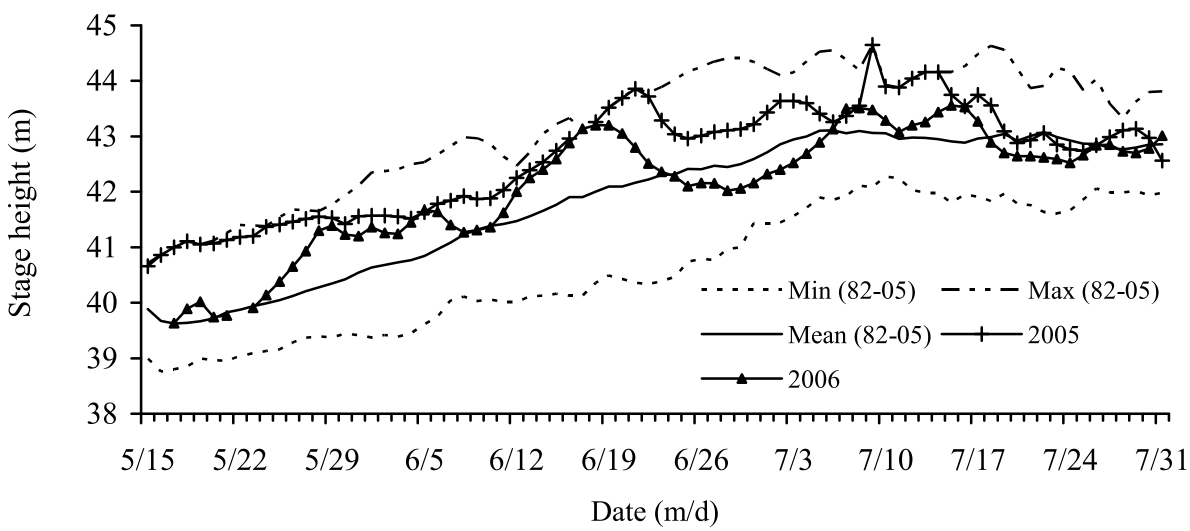

Figure 3. Stage height of the Copper River at the Million Dollar Bridge, 1982 to 2006.

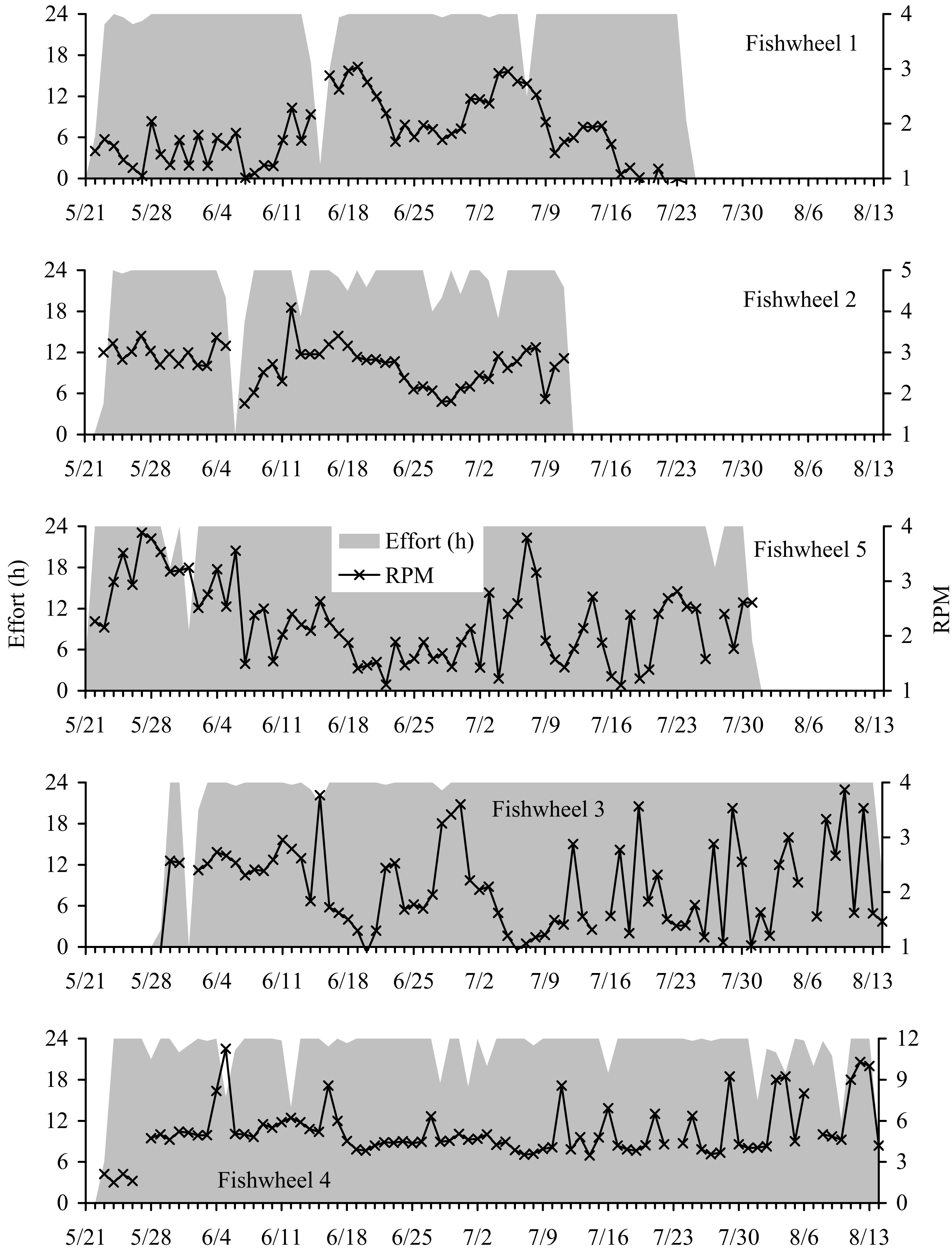

Figure 4. Fishwheel effort (h) and speed (rpm) at the Baird Canyon (fw 1, 2, and 5) and Canyon Creek (fw 3 and 4) fishwheels on the Copper River, 2006.

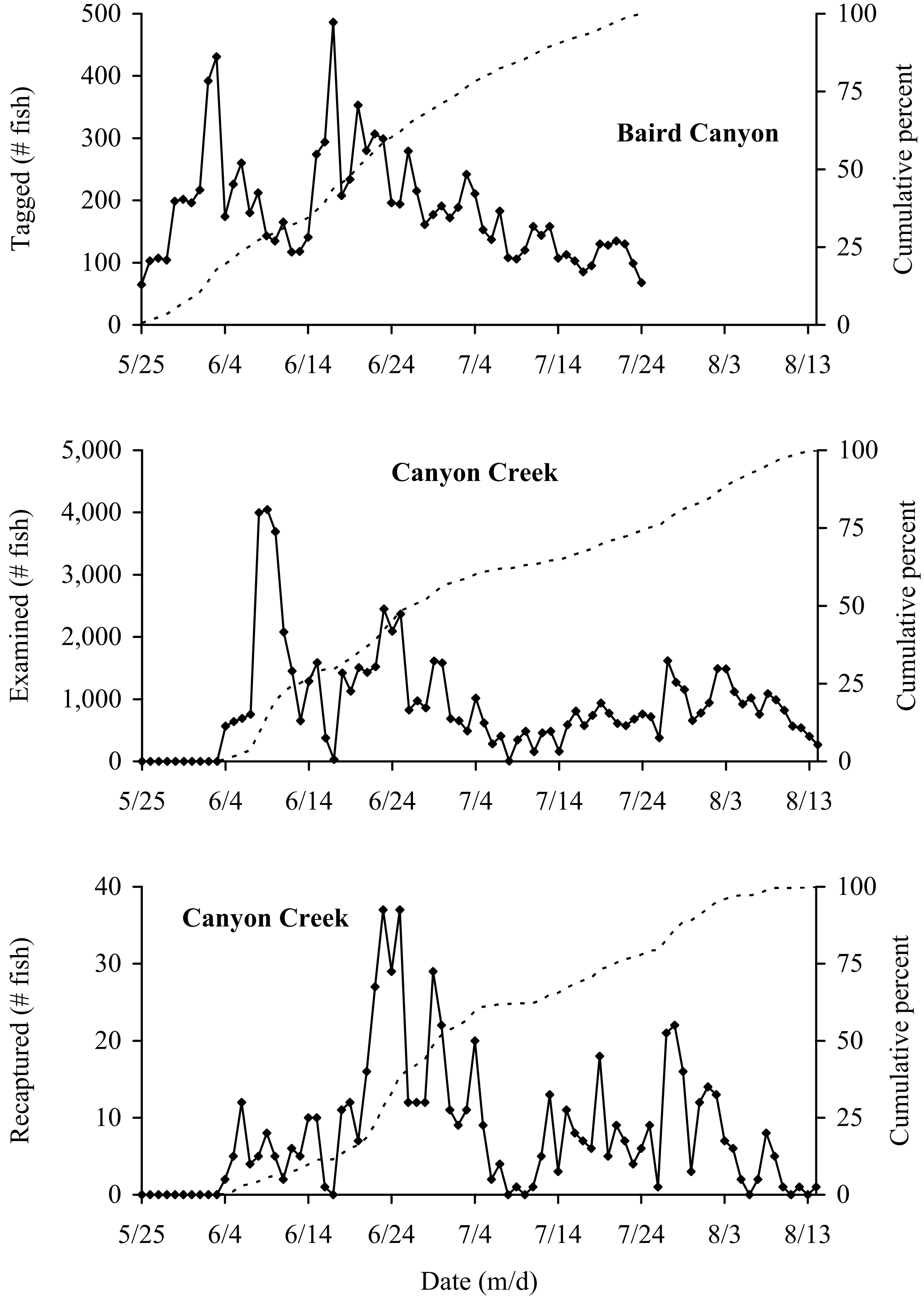

Figure 5. Daily number of sockeye salmon tagged, examined for tags, and recaptured at the Copper fishwheels, 2006.

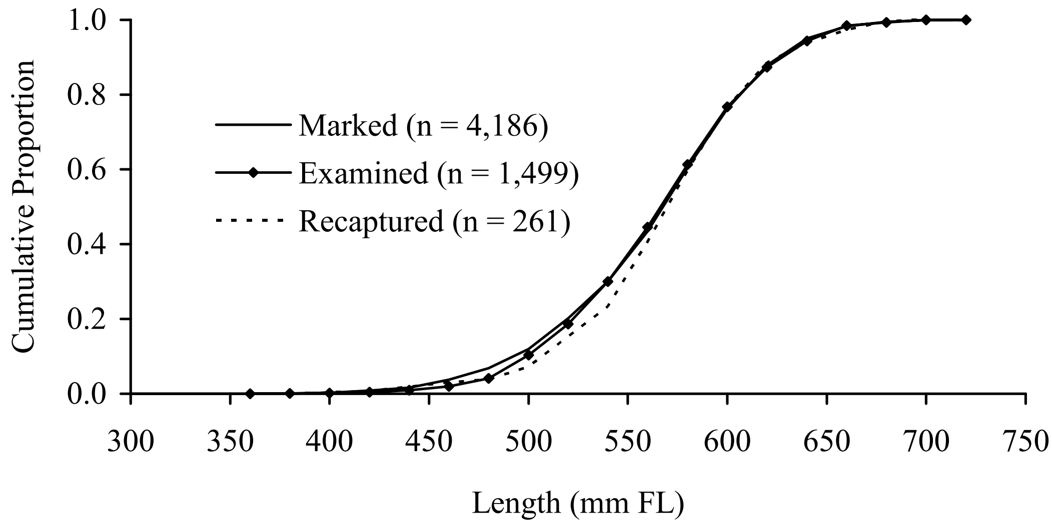

Figure 6. Cumulative length-frequency distributions for sockeye salmon tagged at the Baird Canyon fishwheels, and examined and recaptured at the Canyon Creek fishwheels, 2006.

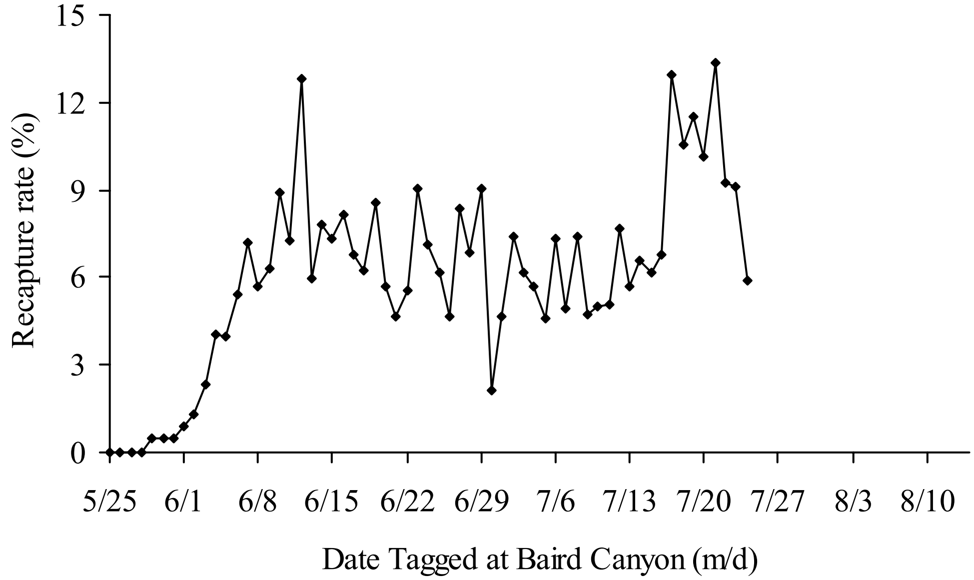

Figure 7. Recapture rate of PIT-tagged sockeye salmon at the Canyon Creek fishwheels, 2006.

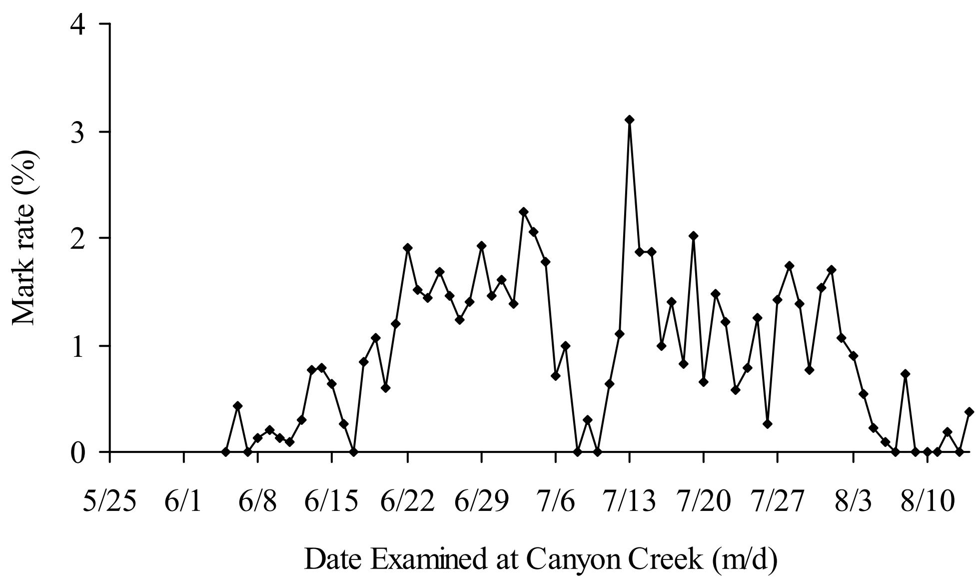

Figure 8. Mark rate of sockeye salmon examined at the Canyon Creek fishwheels, 2006.

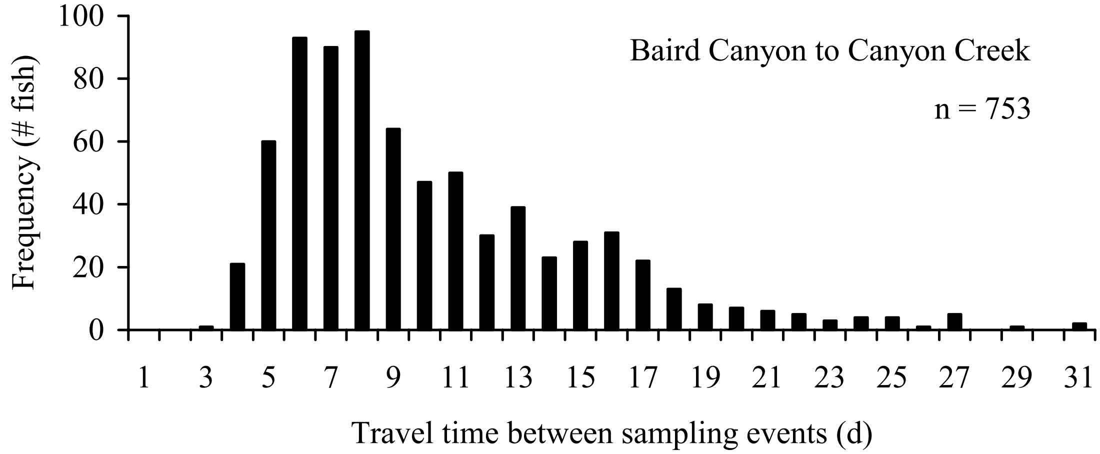

Figure 9. Travel time (d) of sockeye salmon that were tagged at the Baird Canyon fishwheels and recaptured at the Canyon Creek fishwheels, 2006.

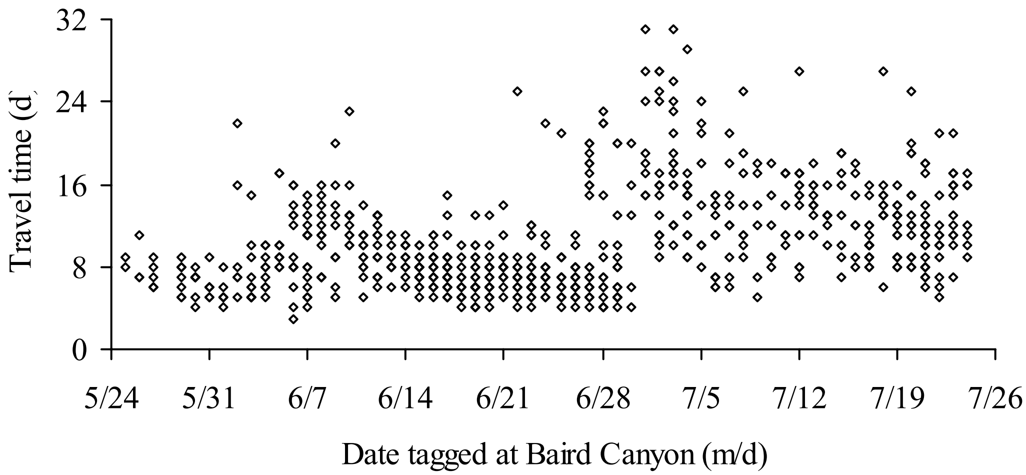

Figure 10. Travel time (d) of PIT-tagged sockeye salmon between Baird Canyon and Canyon Creek relative to the date of tagging at Baird Canyon, 2006.

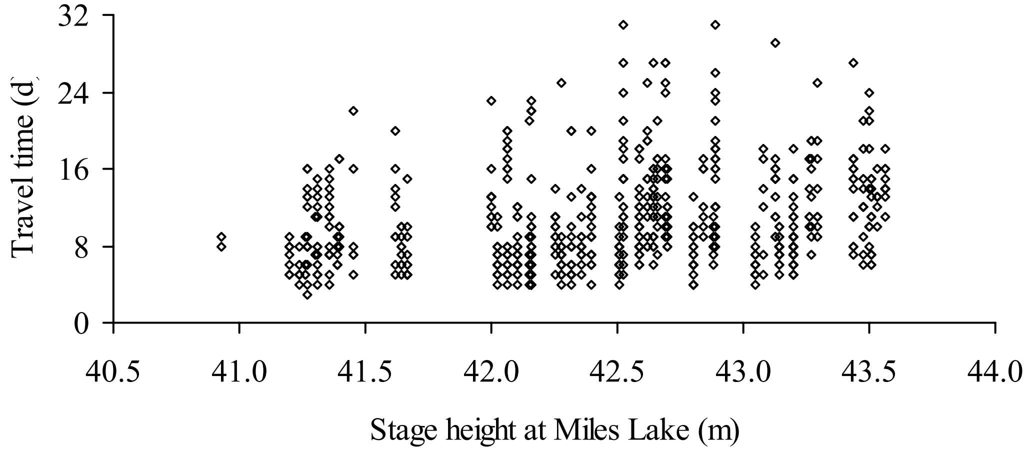

Figure 11. Travel time (d) of PIT-tagged sockeye salmon between Baird Canyon and Canyon Creek relative to the Copper River stage height at Miles Lake on the date of tagging at Baird Canyon, 2006.

APPENDICES

Appendix A.1. Tests of consistency for the Petersen estimator.

Tests of Consistency for the Petersen Estimator (from Seber 1982, p. 438)

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during Event 1; or,
3. Every fish has an equal probability of being captured and examined during Event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Seber 1982) to be valid. If all three tests are rejected, a temporally or geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test for complete mixing[a]

Area/Time Where Marked	Time/Area Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	(n_1-m_2)
1					
2					
…					
S					

II.-Test for equal probability of capture during Event 1[b]

	Area/Time Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked (n_2-m_2)				

III.-Test for equal probability of capture during Event 2[c]

	Area/Time Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from time or area i (i = 1, 2, ...s) to section j (j = 1, 2, t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among time or area designations: H_0: $\Sigma_i a_i\theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among time or area designations: H_0: $\Sigma_j\theta_{ij}p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix A.2. Detection of size or sex selective sampling during a 2-sample mark recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first or second sampling Events. The second sampling Event is evaluated by comparing the length frequency distribution of all fish marked during the first Event (M) with that of marked fish recaptured during the second Event (R), using the null test hypothesis of no difference. The first sampling Event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second Event (C) with that of R. A third test, comparing M and C, is conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (chi-square test) is generally used to detect significant evidence that sex selective sampling occurred during the first of second sampling Events. The counts of observed males to females are compared between M&R, C&R, and M&C as described above, using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. When the proportions by gender are estimated for a sample (usually C), rather an observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are compared between samples using a two sample test (e.g. Student's t-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no size/sex selectivity detected during either sampling Event.		
Case II:		
Reject H_o	Fail to reject H_o	Reject H_o
There is no size/sex selectivity detected during the first Event but there is during the second Event sampling.		
Case III:		
Fail to reject H_o	Reject H_o	Reject H_o
There is no size/sex selectivity detected during the second Event but there is during the first Event sampling.		
Case IV:		
Reject H_o	Reject H_o	Reject H_o
There is size/sex selectivity detected during both the first and second sampling Events.		
Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R *P*-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R *P*-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second Event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

C. If a) sample sizes for C vs. R are small, b) the C vs. R *P*-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R *P*-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first Event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R *P*-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both Events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling Events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling Event without stratification. If composition is estimated from second Event data or after pooling both sampling Events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling Event without stratification. If composition is estimated from first Event data or after pooling both sampling Events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling Events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling Events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling Events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both Events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, an overall composition parameters (p_k) is estimating by combining within stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ , and} \tag{1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k \right)^2 \hat{V}[\hat{N}_i] \right) \tag{2}$$

where:
- j = the number of sex/size strata;
- $\hat{p}_{ik}$ = the estimated proportion of fish that were age or size k among fish in stratum i;
- $\hat{N}_i$ = the estimated abundance in stratum i;
- $\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A.3. Summary of daily fishwheel effort (h), effort used to calculate catch per unit effort (CPUE), and fishwheel speed (RPM) for the Copper River fishwheels, 2006.

	Baird Canyon						Canyon Creek			
	Fishwheel 1		Fishwheel 2		Fishwheel 5		Fishwheel 3		Fishwheel 4	
Date	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM
21-May					4.5					
22-May	6.3	1.5			24.0	2.3				
23-May	22.5	1.7	4.5	3.0	24.0	2.2			6.1	2.1
24-May	24.0	1.6	24.0	3.2	24.0	3.0			24.0	1.5
25-May	23.5	1.3	23.5	2.8	24.0	3.5			24.0	2.1
26-May	22.5	1.2	24.0	3.0	24.0	2.9			24.0	1.6
27-May	23.0	1.0	24.0	3.4	24.0	3.9			24.0	
28-May	24.0	2.0	24.0	3.0	24.0	3.8			21.0	4.7
29-May	24.0	1.4	24.0	2.7	24.0	3.5	2.5	0.9	24.0	5.0
30-May	24.0	1.2	24.0	3.0	18.0	3.2	24.0	2.6	24.0	4.6
31-May	24.0	1.7	24.0	2.7	24.0	3.2	24.0	2.5	22.0	5.2
1-Jun	24.0	1.2	24.0	3.0	8.8	3.2	0.0		23.0	5.1
2-Jun	24.0	1.8	24.0	2.7	24.0	2.5	20.0	2.4	24.0	4.9
3-Jun	24.0	1.2	24.0	2.7	24.0	2.8	24.0	2.5	23.7	5.0
4-Jun	24.0	1.7	24.0	3.4	24.0	3.2	24.0	2.7	24.0	8.2
5-Jun	24.0	1.6	20.0	3.2	24.0	2.5	24.0	2.7	15.5	11.3
6-Jun	24.0	1.8	0.0		24.0	3.6	23.5	2.5	22.3	5.0
7-Jun	24.0	1.0	16.5	1.8	24.0	1.5	24.0	2.3	24.0	5.0
8-Jun	24.0	1.1	24.0	2.0	24.0	2.4	24.0	2.4	24.0	4.8
9-Jun	24.0	1.2	24.0	2.5	24.0	2.5	24.0	2.4	24.0	5.7
10-Jun	24.0	1.2	24.0	2.7	24.0	1.5	24.0	2.6	24.0	5.5
11-Jun	24.0	1.7	24.0	2.3	24.0	2.0	24.0	3.0	23.8	5.9
12-Jun	24.0	2.3	24.0	4.1	24.0	2.4	23.7	2.8	14.0	6.2
13-Jun	24.0	1.7	17.3	3.0	24.0	2.2	24.0	2.6	24.0	5.9
14-Jun	17.0	2.2	24.0	3.0	24.0	2.1	23.0	1.8	24.0	5.4
15-Jun	2.0		24.0	3.0	24.0	2.6	21.0	3.8	24.0	5.2
16-Jun	16.0	2.9	24.0	3.2	24.0	2.2	24.0	1.7	22.8	8.6
17-Jun	23.5	2.6	23.0	3.4	24.0	2.0	24.0	1.6	24.0	6.0
18-Jun	24.0	3.0	21.0	3.2	24.0	1.9	24.0	1.5	23.3	4.5
19-Jun	24.0	3.0	24.0	2.9	24.0	1.4	24.0	1.3	24.0	3.9
20-Jun	24.0	2.8	21.5	2.8	24.0	1.5	24.0	0.9	24.0	3.8
21-Jun	24.0	2.5	24.0	2.8	24.0	1.5	24.0	1.3	24.0	4.2
22-Jun	24.0	2.2	24.0	2.7	24.0	1.1	23.7	2.4	24.0	4.4
23-Jun	24.0	1.7	24.0	2.8	24.0	1.9	24.0	2.5	24.0	4.4
24-Jun	24.0	2.0	24.0	2.4	24.0	1.5	24.0	1.7	24.0	4.5
25-Jun	24.0	1.8	24.0	2.1	24.0	1.6	24.0	1.8	24.0	4.4
26-Jun	24.0	2.0	24.0	2.2	24.0	1.9	24.0	1.7	24.0	4.5

Appendix A.3. Summary of daily fishwheel effort (h), effort used to calculate catch per unit effort (CPUE), and fishwheel speed (RPM) for the Copper River fishwheels, 2006.

	Baird Canyon						Canyon Creek			
	Fishwheel 1		Fishwheel 2		Fishwheel 5		Fishwheel 3		Fishwheel 4	
Date	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM
27-Jun	24.0	1.9	18.0	2.1	24.0	1.6	24.0	2.0	24.0	6.3
28-Jun	23.5	1.7	20.0	1.8	24.0	1.7	22.8	3.3	17.5	4.5
29-Jun	24.0	1.8	24.0	1.8	24.0	1.4	24.0	3.4	24.0	4.5
30-Jun	24.0	1.9	20.5	2.1	24.0	1.9	24.0	3.6	24.0	5.0
1-Jul	24.0	2.5	24.0	2.2	24.0	2.1	24.0	2.2	17.0	4.6
2-Jul	24.0	2.4	24.0	2.4	24.0	1.4	24.0	2.0	24.0	4.7
3-Jul	23.5	2.4	22.5	2.4	24.0	2.8	24.0	2.1	20.0	5.0
4-Jul	24.0	2.9	17.0	2.9	24.0	1.2	24.0	1.6	24.0	4.3
5-Jul	24.0	3.0	24.0	2.6	24.0	2.4	24.0	1.2	24.0	4.5
6-Jul	24.0	2.8	24.0	2.8	24.0	2.6	24.0	0.9	24.0	3.9
7-Jul	12.0	2.7	24.0	3.1	24.0	3.8	24.0	1.1	24.0	3.5
8-Jul	24.0	2.5	24.0	3.1	24.0	3.2	24.0	1.2	23.0	3.6
9-Jul	24.0	2.0	24.0	1.9	24.0	1.9	24.0	1.2	24.0	4.0
10-Jul	24.0	1.5	24.0	2.6	24.0	1.6	24.0	1.5	24.0	4.1
11-Jul	24.0	1.7	21.5	2.9	24.0	1.4	24.0	1.4	24.0	8.6
12-Jul	24.0	1.7			24.0	1.8	24.0	2.9	24.0	3.9
13-Jul	24.0	1.9			24.0	2.1	24.0	1.6	24.0	4.8
14-Jul	24.0	1.9			24.0	2.7	24.0	1.3	24.0	3.5
15-Jul	24.0	2.0			24.0	1.9	24.0		24.0	4.8
16-Jul	24.0	1.6			24.0	1.3	24.0	1.6	19.0	6.9
17-Jul	24.0	1.1			24.0	1.1	24.0	2.8	24.0	4.2
18-Jul	24.0	1.2			24.0	2.4	24.0	1.3	24.0	3.9
19-Jul	24.0	1.0			24.0	1.2	24.0	3.6	24.0	3.8
20-Jul	24.0	0.7			24.0	1.4	24.0	1.8	24.0	4.2
21-Jul	24.0	1.2			24.0	2.4	24.0	2.3	24.0	6.5
22-Jul	24.0	0.9			24.0	2.7	24.0	1.5	24.0	4.3
23-Jul	24.0	1.0			24.0	2.8	24.0	1.4	24.0	
24-Jul	8.5	0.9			24.0	2.5	24.0	1.4	24.0	4.4
25-Jul					24.0	2.5	24.0	1.8	23.7	6.4
26-Jul					24.0	1.6	24.0	1.2	24.0	3.9
27-Jul					18.0		24.0	2.9	23.7	3.6
28-Jul					24.0	2.4	24.0	1.1	24.0	3.7
29-Jul					24.0	1.8	24.0	3.5	24.0	9.2
30-Jul					24.0	2.6	24.0	2.6	24.0	4.3
31-Jul					7.3	2.6	24.0	1.0	24.0	4.0
1-Aug							24.0	1.6	15.0	4.0
2-Aug							24.0	1.2	22.5	4.1

Appendix A.3. Summary of daily fishwheel effort (h), effort used to calculate catch per unit effort (CPUE), and fishwheel speed (RPM) for the Copper River fishwheels, 2006.

	Baird Canyon						Canyon Creek			
	Fishwheel 1		Fishwheel 2		Fishwheel 5		Fishwheel 3		Fishwheel 4	
Date	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM	Total effort (h)	RPM
3-Aug							24.0	2.5	22.0	9.0
4-Aug							24.0	3.0	19.0	9.2
5-Aug							24.0	2.2	24.0	4.5
6-Aug							24.0		23.8	8.0
7-Aug							24.0	1.6	20.0	
8-Aug							24.0	3.3	23.7	5.0
9-Aug							24.0	2.7	21.5	4.9
10-Aug							24.0	3.9	12.0	4.6
11-Aug							24.0	1.6	24.0	9.0
12-Aug							24.0	3.5	24.0	10.3
13-Aug							24.0	1.6	24.0	10.0
14-Aug							10.5	1.5	9.0	4.2
Effort (h)	1,448	1.8	1,107	2.7	1,665	2.3	1,803	2.1	1,894	5.2
Effort (d)	60.3		46.1		69.4		75.1		78.9	
Percent operational:										
	96.3%		94.0%		98.4%		98.1%		95.5%	

Appendix A.4. Number of sockeye salmon PIT-tagged, examined for tags, and recaptured at the Baird Canyon and Canyon Creek fishwheels, 2006. Shaded cells in the table show recovery data that were considered unreliable.

	Baird Canyon						Canyon Creek							
	Fishwheel 1		Fishwheel 2		Fishwheel 5		Fishwheel 3				Fishwheel 4			
Date	Tags	Cum	Tags	Cum	Tags	Cum	Exam	Cum	Recap	Cum	Exam	Cum	Recap	Cum
25-May	5	5	30	30	30	30								
26-May	7	12	67	97	29	59								
27-May	6	18	39	136	62	121								
28-May	35	53	20	156	49	170					3	3	0	0
29-May	110	163	0	156	89	259	0	0	0	0	2	5	0	0
30-May	129	292	0	156	73	332	0	0	0	0	0	5	0	0
31-May	95	387	0	156	101	433	0	0	0	0	5	10	0	0
1-Jun	10	397	0	156	207	640	0	0	0	0	58	68	0	0
2-Jun	1	398	0	156	391	1,031	0	0	0	0	180	248	6	6
3-Jun	0	398	0	156	431	1,462	0	0	0	0	0	248	5	11
4-Jun	46	444	0	156	128	1,590	567	567	1	1	0	248	2	13
5-Jun	0	444	0	156	226	1,816	641	1,208	0	1	0	248	5	18
6-Jun	0	444	0	156	260	2,076	691	1,899	3	4	0	248	9	27
7-Jun	45	489	0	156	135	2,211	758	2,657	0	4	0	248	4	31
8-Jun	67	556	0	156	145	2,356	777	3,434	2	6	3,221	3,469	3	34
9-Jun	71	627	0	156	72	2,428	873	4,307	4	10	3,172	6,641	4	38
10-Jun	96	723	0	156	39	2,467	877	5,184	2	12	2,813	9,454	3	41
11-Jun	79	802	0	156	86	2,553	765	5,949	1	13	1,312	10,766	1	42
12-Jun	0	802	0	156	117	2,670	1,125	7,074	5	18	327	11,093	1	43
13-Jun	0	802	0	156	118	2,788	557	7,631	5	23	95	11,188	0	43
14-Jun	61	863	0	156	80	2,868	450	8,081	6	29	839	12,027	4	47
15-Jun	0	863	0	156	274	3,142	531	8,612	5	34	1,055	13,082	5	52
16-Jun	51	914	0	156	243	3,385	284	8,896	1	35	90	13,172	0	52
17-Jun	64	978	176	332	246	3,631	18	8,914	0	35	13	13,185	0	52

Appendix A.4. Number of sockeye salmon PIT-tagged, examined for tags, and recaptured at the Baird Canyon and Canyon Creek fishwheels, 2006. Shaded cells in the table show recovery data that were considered unreliable.

	Baird Canyon						Canyon Creek							
	Fishwheel 1		Fishwheel 2		Fishwheel 5		Fishwheel 3				Fishwheel 4			
Date	Tags	Cum	Tags	Cum	Tags	Cum	Exam	Cum	Recap	Cum	Exam	Cum	Recap	Cum
18-Jun	0	978	13	345	195	3,826	26	8,940	1	36	1,395	14,580	11	63
19-Jun	155	1,133	0	345	79	3,905	89	9,029	0	36	1,038	15,618	12	75
20-Jun	201	1,334	0	345	152	4,057	371	9,400	0	36	1,139	16,757	9	84
21-Jun	198	1,532	0	345	82	4,139	391	9,791	7	43	1,041	17,798	10	94
22-Jun	196	1,728	0	345	111	4,250	437	10,228	4	47	1,085	18,883	25	119
23-Jun	189	1,917	39	384	71	4,321	851	11,079	12	59	1,601	20,484	25	144
24-Jun	99	2,016	0	384	97	4,418	767	11,846	6	65	1,324	21,808	24	168
25-Jun	137	2,153	0	384	57	4,475	1,135	12,981	14	79	1,233	23,041	26	194
26-Jun	190	2,343	0	384	89	4,564	824	13,805	12	91	903	23,944	7	201
27-Jun	97	2,440	0	384	118	4,682	974	14,779	12	103	0	23,944	0	201
28-Jun	61	2,501	0	384	100	4,782	860	15,639	12	115	433	24,377	7	208
29-Jun	65	2,566	0	384	112	4,894	825	16,464	13	128	789	25,166	18	226
30-Jun	86	2,652	0	384	105	4,999	871	17,335	8	136	710	25,876	15	241
1-Jul	99	2,751	0	384	73	5,072	685	18,020	11	147	273	26,149	6	247
2-Jul	128	2,879	0	384	61	5,133	653	18,673	9	156	0	26,149	15	262
3-Jul	175	3,054	0	384	67	5,200	490	19,163	11	167	10	26,159	0	262
4-Jul	163	3,217	0	384	48	5,248	465	19,628	6	173	552	26,711	15	277
5-Jul	28	3,245	62	446	63	5,311	148	19,776	1	174	472	27,183	10	287
6-Jul	39	3,284	16	462	82	5,393	2	19,778	0	174	279	27,462	2	289
7-Jul	8	3,292	102	564	73	5,466	1	19,779	0	174	405	27,867	4	293
8-Jul	54	3,346	0	564	54	5,520	5	19,784	0	174	277	28,144	2	295
9-Jul	64	3,410	0	564	42	5,562	2	19,786	0	174	342	28,486	1	296
10-Jul	45	3,455	0	564	75	5,637	4	19,790	0	174	479	28,965	0	296
11-Jul	114	3,569	0	564	44	5,681	3	19,793	0	174	153	29,118	1	297

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	Baird Canyon						Canyon Creek							
	Fishwheel 1		Fishwheel 2		Fishwheel 5		Fishwheel 3				Fishwheel 4			
Date	Tags	Cum	Tags	Cum	Tags	Cum	Exam	Cum	Recap	Cum	Exam	Cum	Recap	Cum
12-Jul	78	3,647	0	564	66	5,747	9	19,802	0	174	447	29,565	5	302
13-Jul	103	3,750	0	564	55	5,802	5	19,807	2	176	478	30,043	13	315
14-Jul	30	3,780	0	564	77	5,879	1	19,808	0	176	160	30,203	3	318
15-Jul	80	3,860	0	564	33	5,912	1	19,809	0	176	587	30,790	11	329
16-Jul	46	3,906	0	564	57	5,969	3	19,812	0	176	806	31,596	8	337
17-Jul	39	3,945	0	564	46	6,015	186	19,998	3	179	388	31,984	5	342
18-Jul	57	4,002	0	564	38	6,053	377	20,375	3	182	360	32,344	3	345
19-Jul	34	4,036	0	564	96	6,149	488	20,863	5	187	450	32,794	14	359
20-Jul	87	4,123	0	564	41	6,190	772	21,635	5	192	668	33,462	8	367
21-Jul	84	4,207	0	564	51	6,241	608	22,243	9	201	420	33,882	0	367
22-Jul	60	4,267	0	564	70	6,311	576	22,819	7	208	807	34,689	0	367
23-Jul	49	4,316	0	564	50	6,361	680	23,499	4	212	0	34,689	0	367
24-Jul	25	4,341	0	564	43	6,404	585	24,084	5	217	175	34,864	1	368
25-Jul							630	24,714	6	223	86	34,950	3	371
26-Jul							382	25,096	1	224	0	34,950	9	380
27-Jul							393	25,489	4	228	1,223	36,173	19	399
28-Jul							453	25,942	4	232	818	36,991	18	417
29-Jul							634	26,576	7	239	519	37,510	9	426
30-Jul							173	26,749	1	240	485	37,995	4	430
31-Jul							53	26,802	0	240	726	38,721	12	442
1-Aug							222	27,024	4	244	722	39,443	12	454
2-Aug							376	27,400	1	245	1,114	40,557	15	469
3-Aug							483	27,883	1	246	1,005	41,562	9	478
4-Aug							440	28,323	0	246	678	42,240	6	484

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	Baird Canyon						Canyon Creek							
	Fishwheel 1		Fishwheel 2		Fishwheel 5		Fishwheel 3				Fishwheel 4			
Date	Tags	Cum	Tags	Cum	Tags	Cum	Exam	Cum	Recap	Cum	Exam	Cum	Recap	Cum
5-Aug							412	28,735	0	246	507	42,747	2	486
6-Aug							435	29,170	0	246	585	43,332	1	487
7-Aug							464	29,634	0	246	292	43,624	2	489
8-Aug							431	30,065	0	246	656	44,280	8	497
9-Aug							517	30,582	0	246	474	44,754	5	502
10-Aug							536	31,118	0	246	283	45,037	1	503
11-Aug							342	31,460	0	246	222	45,259	0	503
12-Aug							362	31,822	1	247	180	45,439	0	503
13-Aug							400	32,222	0	247	13	45,452	1	504
14-Aug							266	32,488	1	248	0	45,452	1	505
Total	4,341		564		6,404		32,488		248		45,452		505	

These data represent the actual number of unique fish examined and recaptured at the fishwheels. However, the numbers of fish examined and recaptured each day were not necessarily collected during similar time periods and as such should not be used to evaluate mark and recapture rates over time.

PHOTO PLATES

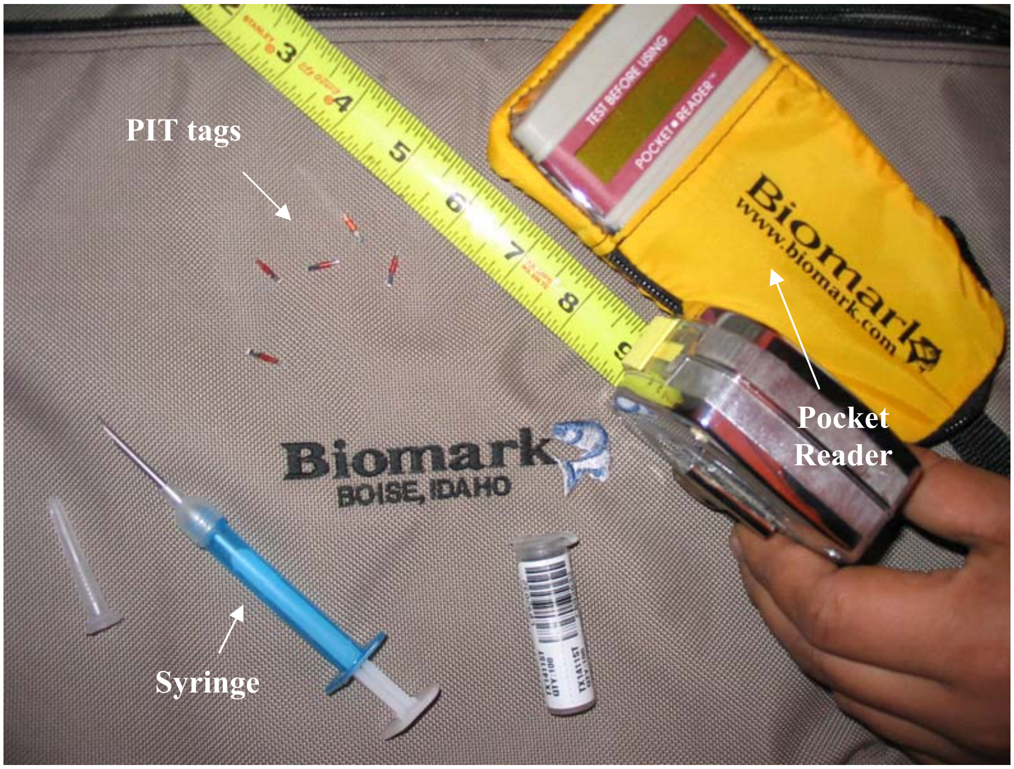

Photo 1. Passive integrated transponder (PIT) tags, Pocket Reader scanner, and syringe used during the 2006 sockeye salmon mark-recapture study on the Copper River.

Photo 2. PIT tags were inserted into the body cavity of sockeye salmon using a syringe.

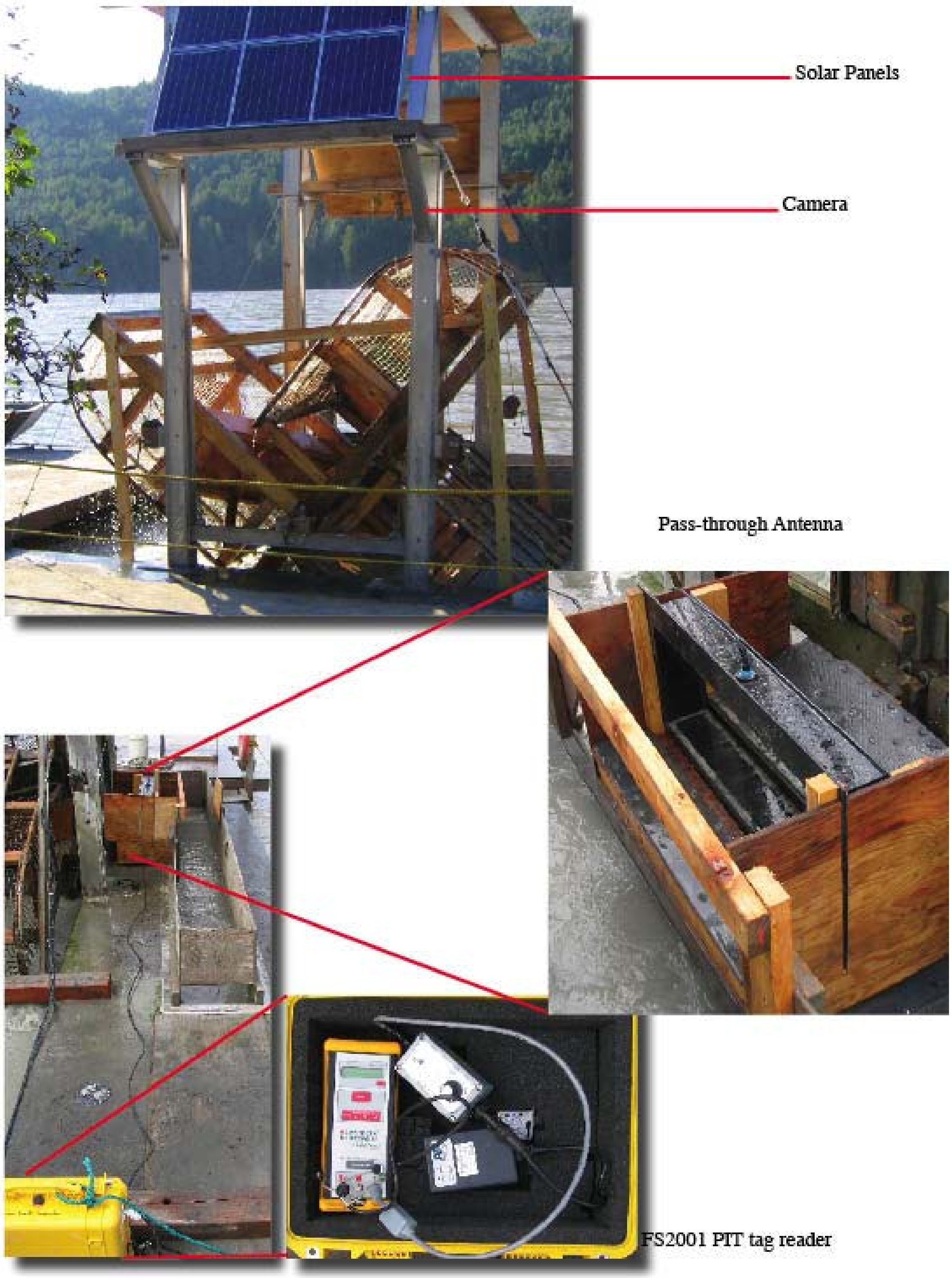

Photo 3. Fishwheel 4 with modifications relevant to this project, showing placement of PIT tag reading equipment, digital video equipment and power supply.