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Development of a Long-term Monitoring Project to Estimate Abundance of Chinook Salmon in the Copper River, Alaska, 2001–2004

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ABSTRACT: We used fishwheels and 2-event mark–recapture methods to estimate the annual drainage-wide abundance of adult Chinook salmon *Oncorhynchus tshawytscha* returning to the Copper River in Southcentral Alaska. In the first event, fish were captured from May through July using 2 fishwheels operated in Baird Canyon (river km 66) in the lower Copper River. All marked fish received a back-sewn spaghetti tag during each year of study, and up to 500 fish in each of 2002, 2003 and 2004 were also fitted with radio tags. In the second event, marked fish were recaptured in one or 2 additional fishwheels operated on the Copper River near Canyon Creek (river km 157). The Baird Canyon fishwheels were operated from 2001 to 2004, and the Canyon Creek fishwheels were operated from 2002 to 2004. Unbiased system-wide abundance estimates were made in 2003 and 2004. An estimated 44,764 (SE=12,506) Chinook salmon measuring 810 to 1,070 mm fork length (FL) passed through Baird Canyon from 17 May to 1 July 2003. From 22 May to 22 June 2004, an estimated 40,564 (SE=4,650) Chinook salmon (≥ 600 mm FL) passed through Baird Canyon. Capture probabilities during both events varied over the season in 2003 and 2004 and appeared to be influenced by flow-related changes in fishwheel catchability. We developed vertical-slot “escape panels” to place in the fishwheel live tanks, which allowed the much more abundant sockeye salmon *O. nerka* to easily escape from the live tanks back into the river while retaining Chinook salmon. The project has evolved into a successful long-term monitoring program and has demonstrated that Federal, State and Tribal agencies can work cooperatively to collect valuable data on Copper River salmon stocks.

INTRODUCTION

The success of Alaska salmon management can be attributed in part to biologically sound escapement goal management, which strives to ensure that sufficient numbers of fish reach their spawning grounds (i.e., escapement) to sustain populations amid variable annual returns. Development of accurate escapement assessment programs is critical, but has proven problematic for populations such as Copper River Chinook salmon

Oncorhynchus tshawytscha. These fish are harvested from May to July in a gauntlet of commercial, sport, personal use and subsistence fisheries that extend over 300 km of river, and can be subject to high exploitation rates. Chinook salmon co-mingle with much more abundant sockeye salmon *O. nerka*, and fishery performance and state-of-the-art sonar counts are poor indicators of the abundance of returning Chinook salmon. Development of any assessment project on the Copper

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River is further complicated because the drainage is very large, glacially turbid and mostly remote.

Management of Copper River salmon fisheries is complex, in part because of the recent assertion of Federal authority to manage subsistence fisheries on Federal lands in Alaska under the authority of Title VIII of ANILCA (Buklis 2002). As part of this mandate, the Fisheries Resource Monitoring Program (Monitoring Program)¹ was created within the Federal subsistence program to enhance existing fisheries research and effectively communicate information

¹ The Monitoring Program is administered by U.S. Fish and Wildlife Service, Office of Subsistence Management, 3601 C St., Ste 1030, Anchorage, Alaska 99503.

needed for subsistence fisheries management on Federal lands. One desired outcome of the Monitoring Program is to enhance the capacity of Alaska Native and rural organizations to meaningfully participate in fisheries assessment and management—herein defined as capacity building. To this end, a high premium is put on projects where Alaska Native or rural organizations perform a meaningful role and collaborate with State or Federal resource management agencies.

In 2000, the Native Village of Eyak (NVE) proposed an assessment project designed to provide annual, system-wide abundance estimates of Chinook salmon to the Copper River in Southcentral Alaska (Figure 1). In this paper, we describe the development,

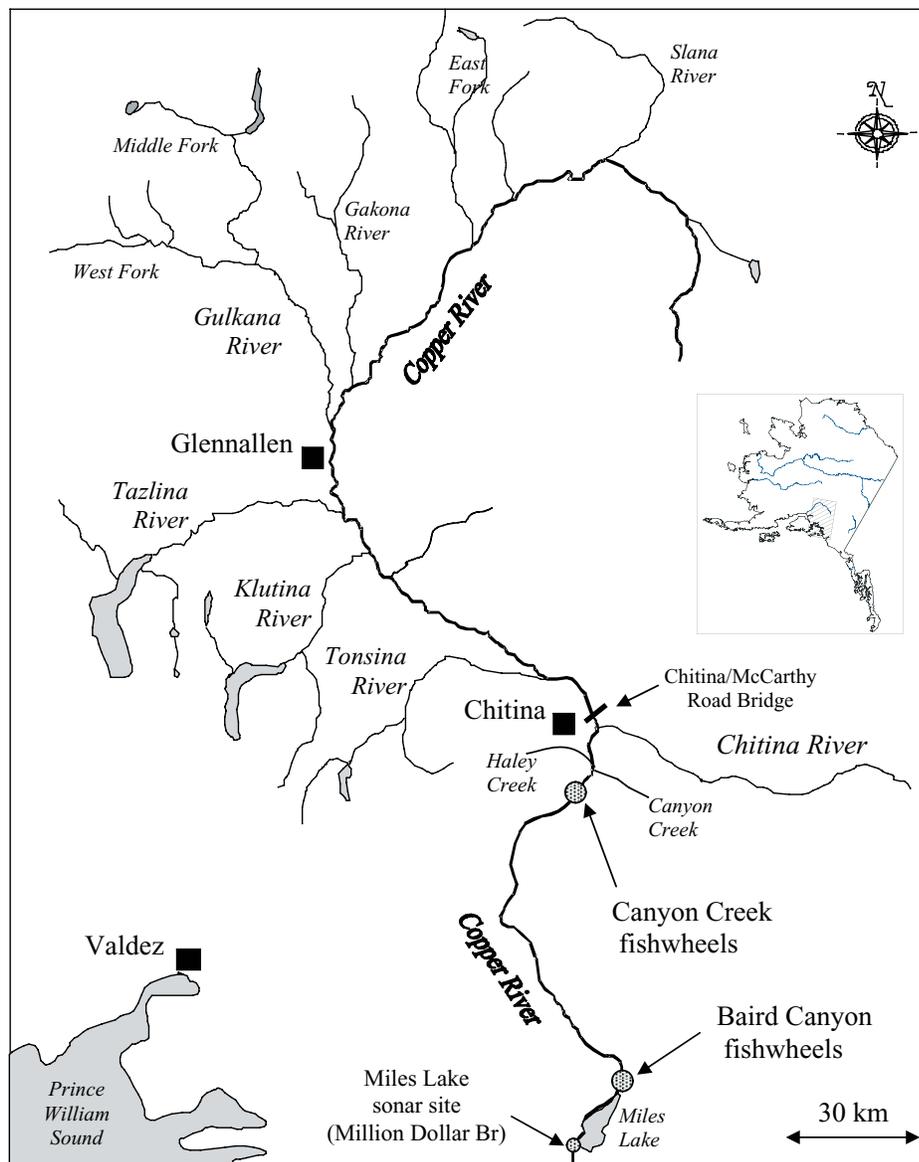


Figure 1. Map of the Copper River drainage showing the location of the Baird Canyon and Canyon Creek fishwheels.

evolution, results, and challenges of this project. Also discussed are capacity building and the details of the mark–recapture experiment.

Past escapement enumeration techniques for Chinook salmon in the Copper River have been largely unsuccessful due to the size of the watershed, the river's high discharge, and glacial turbidity. Since the late 1960s, the Alaska Department of Fish and Game (ADF&G) has relied on annual aerial surveys of 9 clear-water spawning tributaries to provide a relative index of the annual Chinook salmon escapement. To assess the validity of the aerial survey method and to begin to develop estimates of the absolute (as opposed to relative) estimates of the Chinook salmon abundance, ADF&G conducted radio telemetry studies beginning in 1999 and continuing in different forms through 2004. These studies were designed to estimate the spawning distribution, run timing and inriver abundance of Copper River Chinook salmon (Evenson and Wuttig 2000; Wuttig and Evenson 2001; Savereide and Evenson 2002; Savereide 2003, 2004). The radio telemetry studies have shown that the 9 streams surveyed on a regular basis represent a small and variable proportion (26%–46%) of the total drainage-wide escapement. A large and variable proportion of each year's escapement therefore spawns in turbid waters of major tributaries that can not be assessed by aerial surveys. In addition, the majority of surveyed streams support stocks with early run-timing patterns, and thus the late-run fish in these tributaries are not counted. This incomplete survey coverage further adds to the inaccuracy and imprecision of the method. For these reasons, the aerial surveys used to assess the spawning abundance of Chinook salmon are no longer considered a consistent or reliable measure of total escapement (Savereide 2004).

The ADF&G radio telemetry study also generated the first absolute estimates of Chinook salmon abundance in the Copper River. Estimated inriver abundance of Chinook salmon moving through the mid Copper River (i.e., entering the Chitina Subdistrict fishing area) was estimated at 32,090 in 1999, 38,047 in 2000, 39,778 in 2001, 32,873 in 2002 and 33,488 in 2003. Unfortunately, several potential sources of bias could not be explicitly tested with the study design, including unreported or illegal harvest, selection for tagged fish, and the inability to detect radio-tagged fish that were harvested and removal of tags (Savereide 2004).

In an effort to address shortcomings of the ADF&G study and develop a more robust and long-term solution to estimating the annual Chinook salmon escapement, NVE collaborated with several other

organizations (including ADF&G) to design and propose a multiple fishwheel-to-fishwheel mark–recapture project in late 2000. In contrast to the radio telemetry study, the NVE-led project was designed to produce a drainage-wide abundance estimate that did not depend on sampling fish from inriver fisheries, which do not allow for a consistent or comprehensive sample of the population. The project was funded under the Monitoring Program for 3 years (2001–2003) and funding has since been renewed through 2006.

Studies elsewhere have shown that using fishwheels (Meehan 1961; Donaldson and Cramer 1971; Link and English 1996) and mark–recapture methods can be effective for estimating salmon escapement on large rivers (McPherson et al. 1996; Cappiello and Bruden 1997; Gordon et al. 1998; Alexander et al. 2002; Johnson et al. 2002). Interestingly, from 1966 to 1968, Greenough (1971) used fishwheels and mark–recapture methods on the Copper River to estimate sockeye salmon abundance, but very few Chinook salmon were captured during the study.

We learned from those who had worked on fisheries research projects on the Copper River in the past (including projects with similar goals to the proposed NVE-led project) that our study goals were ambitious and the project faced little chance of success. The 3 biggest challenges believed to hinder our success were:

- 1) Capturing sufficient numbers of Chinook salmon at 2 sites over the entire migration to derive useful estimates of abundance. Those who had worked on the 1960s studies estimated that we might only capture a few dozen Chinook salmon (while we require annual catches in the range of 3,000 to 4,000 fish),
- 2) Effectively operating fishwheels over the entire migration throughout typically large intra-annual range in river discharge. Peak annual discharge in the lower river from 1991 to 1995 ranged from 1,020 m³/s (May 1992) to 10,392 m³/s (Sept 1995), a 10-fold difference (Brabets 1997), and
- 3) Efficiently handling several tens of thousands of sockeye salmon migrating at the same time without compromising sustained fishing effort for, and adding stress to, the targeted Chinook salmon.

In addition, there was the very real concern of whether a relatively small Alaska Native organization, even with the services of a professional consulting company, could generate and sustain sufficient expertise to conduct a project of this magnitude. NVE has a tribal enrollment of only 500 members and maintains a 3-person full-time natural resource staff that oversees other projects and functions. In comparison, similar tagging projects that utilize fishwheels to estimate

salmon abundance on large rivers are conducted by large State (Kerkvliet et al. 2003) or Federal (Underwood and Bromaghin 2003) natural resource agencies with substantially more human, financial and capital assets. Estimation of Chinook salmon abundance in the Copper River had been a chronic issue facing fisheries managers, and it was debatable whether the goal of capacity building could be accomplished while addressing such a large, complex, and problematic issue.

Lesser but significant challenges for the project were related to logistically servicing 2 remote camps (near Baird Canyon and Canyon Creek) in areas subject to early season heavy ice and enormous snow loads, high winds, sand storms, high river discharge and dangerous river conditions. This paper summarizes results from the NVE-led project for the 2001 to 2004 seasons and describes how the project evolved to overcome these challenges. Additional project details and results are available in the series of annual project reports (Link et al. 2001; Smith et al. 2003; Smith 2004; Smith and van den Broek *in press*).

STUDY AREA

The Copper River originates in the Wrangell Mountains and drains over 62,100 km² as it flows 467 km southward into the Gulf of Alaska near Cordova, Alaska (Figure 1). A high-flow period typically begins in May or June as a result of snowmelt runoff and continues through August due to rainfall and glacial melt. A relatively large proportion of the headwaters is glaciated and the melting of these glaciers during the summer results in high unit discharge (peak discharge of 3,650–4,235 m³/s in June between 1991 and 1995 [Brabets 1997]) and large sediment loads. Most Chinook salmon return to the Copper River from early May to mid-July and spawn from mid-July through August. Chinook salmon have been observed in approximately 40 different tributaries in the Copper River basin (Taube 2002) with major spawning areas consisting of the Chitina, Tonsina, Klutina, Tazlina, Gulkana and upper Copper rivers (Evenson and Wuttig 2000; Wuttig and Evenson 2001; Savereide and Evenson 2002; Savereide 2003, 2004).

The Copper River supports important fisheries for Chinook salmon. From 1999 to 2003, Copper River Chinook salmon harvests averaged approximately 55,318 fish annually (Brase and Sarafin 2004). The majority of Chinook salmon are caught in an ocean commercial gill net fishery that operates from mid-May to the end of July in the Copper River District near the mouth of the Copper River. Inriver personal use and subsistence fisheries occur from early June

through September between Haley Creek (12 km downstream of Chitina) and the confluence of the Slana River on the upper Copper River. Recreational rod-and-reel fisheries target Chinook salmon in tributaries of the upper Copper River (mainly the Gulkana, Klutina and Tonsina rivers).

STUDY OBJECTIVE

Our goal was to develop a means of estimating the annual, system-wide Chinook salmon abundance above Baird Canyon with error no greater than 25% of the true value 95% of the time. Using the methods of Robson and Regier (1964) and assuming an abundance of 40,000 fish above Baird Canyon, at least 1,600 fish (4% of the run) had to be captured in each of 2 locations to meet this goal. Given that not all fish captured would be tagged, that fish may have unequal vulnerability to capture (requiring stratification of the estimate), and that the actual run might exceed 40,000 fish, we developed a pre-project target of 2,000 fish (5% of the anticipated run) at each capture site.

METHODS

Tagging

In the first event, adult Chinook salmon were captured and marked at 2 fishwheels located in Baird Canyon (rkm 66) on the mainstem Copper River approximately 18 km upstream of the Miles Lake sonar site (Figure 1). Each fishwheel consisted of 2 welded aluminum pontoons (11.6 × 0.9 × 0.5 m), a 3.7-m long axle, 3 baskets (3.0 × 3.0 × 2.1 m) and a tower and boom assembly used to raise and lower the axle. Live tanks (4.3 × 0.6 × 1.5 m) for holding captured fish were fitted inside each pontoon. Apart from minor stoppages for moves and maintenance, the fishwheels were operated 24 hours per day 7 days a week to keep sampling effort relatively constant over the entire run. A minimum of 3 times per day, all Chinook salmon were removed from the live tanks with a dip net and placed into a foam-lined sampling trough that was partially filled with river water. All fish were counted, sexed from external characteristics, measured for fork length (FL) and inspected for injuries. Uninjured fish measuring 500 mm FL or greater received a primary and secondary mark before release. The majority of fish received a yellow spaghetti tag (Floy Tag and Manufacturing, Inc., Seattle, WA) and a 7-mm diameter hole in the right operculum applied with a paper punch. Up to 500 fish in each of 2002, 2003 and 2004 received both a radio tag (Advanced Telemetry Systems, Isanti, MN)

and gray spaghetti tag. Spaghetti tags were uniquely numbered and consisted of a 5-cm long section of 2-mm diameter PVC tubing shrunk onto a 38-cm piece of 36-kg monofilament fishing line (Pahlke and Etherton 1999). Spaghetti tags were sewn through the dorsal musculature immediately below the dorsal fin using a 16-gauge veterinary needle and were secured with a 1.3-mm metal crimp. Radio tags were identifiable by a specific frequency and pulse-encoded pattern and were orally inserted into the stomachs of fish with the antennae protruding from the mouth (Savereide 2004).

Tag Recovery

In the second event, Chinook salmon were captured and examined for marks at one (2002 and 2004) or 2 (2003) fishwheels operated near Canyon Creek, approximately 91 km upstream of the Baird Canyon fishwheels and 2 km downstream from the lower boundary of the Chitina Subdistrict (Figure 1). All Chinook salmon captured at Canyon Creek were counted, sexed, measured for length, and examined for both marks that were applied at Baird Canyon. The spaghetti-tag number and color of all marked fish were recorded. Travel times (days) were calculated for fish marked and released at Baird Canyon and later recaptured at Canyon Creek.

Data Analysis

In 2002, abundance of Chinook salmon was estimated using Chapman's modification of the Petersen estimator for a 2-event mark-recapture experiment on a closed population (Seber 1982). In 2003 and 2004, a temporally stratified estimator using Darroch's (1961) method was used to estimate abundance. Fish that received 2 marks at Baird Canyon comprised the first event and fish examined for both marks at Canyon Creek comprised the second event. The validity of this mark-recapture experiment depended on several assumptions, including: (a) every fish had an equal probability of being marked in the first event, or that every fish had an equal probability of being captured in the second event, or that marked fish mixed completely with unmarked fish between events; (b) recruitment (immigration) and death (emigration) did not occur between events; (c) marking did not affect catchability (or mortality) of the fish; (d) fish did not lose their marks between events; and (e) fish were not sampled twice (Ricker 1975; Seber 1982).

Among other things, assumption (a) implies that sampling was not selective with respect to fish body length. A Kolmogorov-Smirnov (KS) 2-sample test was used to compare the cumulative length-frequency distributions of marked (n_1) and recaptured (m_2) fish to test whether fish of different sizes were captured with equal probability. Failure to reject the null hypothesis indicates that stratification by size is not required to avoid bias in the estimate (Bernard and Hansen 1992). Contingency table analysis (chi-square statistic) was used to compare mark rates (m_2/n_2) over the study period to test whether all fish had an equal probability of being marked at Baird Canyon regardless of time (assumption a). Similarly, recapture rates (m_2/n_1) at Canyon Creek were compared to test whether fish had equal probabilities of being recaptured regardless of time. If the null hypotheses for both tests were rejected and a sufficient number of fish were recaptured, then a temporally stratified estimator was used to estimate abundance. In 2003 and 2004, sex-specific recapture rates were also compared to determine whether male and female fish had an equal probability of being captured. Differences in migratory timing of fish bound for different tributaries precluded complete temporal mixing of marked and unmarked fish across the entire run.

Assumption (b) was met because the life history of Chinook salmon isolates those fish returning to the Copper River as a 'closed' population; the second event also occurred downstream of any major spawning tributaries or inriver fisheries. The fishwheels at both sites were also operated over the same relative time periods. To ensure that handling and tagging fish did not make fish more or less vulnerable to capture (assumption c), sampling sessions were held frequently and visibly stressed or injured fish were not marked. Additionally, the time to travel the 91-km distance between events was thought to be sufficient to reduce the potential for handling-induced 'trap shyness' in marked fish. Nonetheless, radio-tagged fish that were never detected at or above the Canyon Creek fishwheels by fixed-station receivers or during aerial-tracking surveys were classified as 'failures' and censored from the analysis. The censored tags would include fish that either died or backed-out of the study area after being marked at Baird Canyon. Tag loss was assumed negligible because all fish received both a primary and secondary mark (assumption d). Unmarked fish captured in the second event received a 7-mm hole in the left operculum to avoid double sampling (assumption e).

RESULTS

Year One (2001)

The primary objective in 2001 was to establish the marking site in Baird Canyon and examine the feasibility of capturing sufficient numbers of Chinook salmon for the first event in the mark–recapture experiment.

In May 2001, 2 large aluminum fishwheels were assembled on the banks of the Copper River near Chi-

tina and floated 100 km downstream to Baird Canyon. From 24 May to 11 July, 7 potential fishwheel sites in Baird Canyon were monitored for sufficient depth (≥ 3 m), water velocity (0.5–1.5 m/s) and protection from floating debris over the course of the season. The 2 fishwheels operated for a total of 986 h and captured 914 Chinook salmon (Table 1), the majority (88%) of which were captured on the east (river's left) bank near the upper end of Baird Canyon (Figures 2 and 3).

Table 1. Summary of catch and effort at the Baird Canyon and Canyon Creek fishwheels on the Copper River, 2001–2004.

	Baird Canyon				Canyon Creek		
	2001	2002	2003	2004	2002	2003	2004
Number of fishwheels	1	2	2	2	1	2	1
Start date (d/m)	24 May	21 May	15 May	22 May	23 May	21 May	28 May
End date (d/m)	11 July	13 July	9 July	22 June	1 August	20 July	21 July
Fishwheel effort (h)	986	2,390	2,193	1,184	1,598	2,475	1,277
Sockeye catch (No. fish) ^a	23,230	12,496	1,849	1,468	3,689	243	67
Chinook catch (No. fish)	914	1,518	2,251	2,756	676	1,928	3,339
Chinook lengths (mm FL)							
Minimum	349	300	530	585	309	530	610
Maximum	1,193	1,258	1,280	1,265	1,222	1,240	1,270
Mean	884	897	928	900	913	944	914
Sample size (n)	320	1,393	2,074	2,550	632	1,863	3,121

^a Sockeye salmon catches in 2002, 2003 and 2004 do not reflect the actual number captured in the fishwheels. During these years, escape panels were installed in the fishwheel live tanks that allowed the majority of sockeye salmon captured to escape prior to enumeration.



Figure 2. One of the 3 large aluminum fishwheels operated on the Copper River from 2001 to 2004. This photo is of the east-bank fishwheel at Baird Canyon looking southwest and downstream at low water conditions in May 2003.



Figure 3. A small, 4-basket fishwheel that was operated on the Copper River near Canyon Creek during the 2003 and 2004 field seasons. The photo was taken from the river's west bank looking upstream.

The temporal distribution of Chinook salmon catches indicated that sampling was initiated (24 May) very near the start of the migration through Baird Canyon (Figure 4). Particularly noteworthy in 2001 was the season catch of 23,230 sockeye salmon from less than 1,000 h of fishing (peak daily CPUE of 105 fish per hour on 10 July). There was no directed recovery effort in 2001 and thus no Chinook salmon abundance estimate was generated.

Successes in 2001 included demonstrating the abilities to navigate and fish many parts of the river,

establish and service a camp and crew, and capture significant numbers of Chinook salmon with the fishwheel over a wide range of river conditions. However, 3 significant challenges still needed to be overcome. First, it was clear that more fish had to be captured at Baird Canyon to obtain adequate sample sizes for the mark–recapture experiment. Second, dealing with high sockeye catches was going to consume lots of energy and would make capturing and releasing healthy Chinook salmon difficult. The daily ratio of sockeye salmon to Chinook salmon over the course of 2001 ranged from 40:1 to as high as 190:1. Some way of efficiently sorting and preferably selectively removing sockeye salmon from the live tanks (while retaining Chinook salmon) was required so that the fishwheels could remain fully operational during periods of high sockeye salmon abundance. Finally, the Baird Canyon camp required some modifications to support a crew across the range of weather conditions and to provide a place to store gear so it was available early the following season when gear transportation options are severely limited and expensive. To meet these needs, a wood-framed cabin (9.3 m²) was built in the fall of 2001 on the west bank of the river approximately 2 km upstream from Baird Canyon.

Year 2 (2002)

The primary objectives in 2002 were to make the Baird Canyon marking site fully operational by capturing and tagging sufficient numbers of Chinook salmon throughout the migration; and to establish a recapture site at Canyon Creek that would catch a sufficient number of fish for the second event of the mark–recapture experiment.

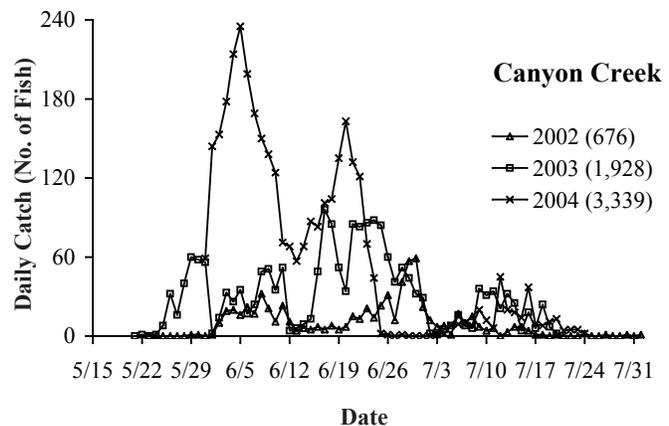
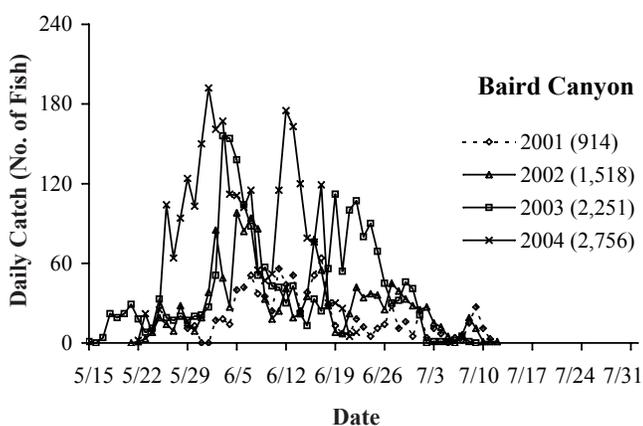


Figure 4. Daily number of Chinook salmon captured at the Baird Canyon and Canyon Creek fishwheels on the Copper River, 2001–2004.

From 9–21 May 2002, efforts to mobilize the Baird Canyon field camp and fishwheels were hindered by snow cover (>1 m deep) and extensive river ice. Boat access to Baird Canyon was blocked by a 1-km long, ice jam until 16 May. In 2002, both fishwheels were operated in tandem (back-to-front) at the same east-bank site that was used in 2001. The fishwheels operated for a total of 2,390 h from 21 May to 13 July and captured 1,518 Chinook (66% more than in 2001) and 12,496 sockeye salmon (Table 1). The majority (78%) of Chinook salmon were captured in the upstream fishwheel which operated closer to shore and in shallower water than the downstream fishwheel. The fishwheels operated continuously throughout the season despite encountering 3 periods where the stage height of the Copper River was in the upper end of the range observed over a recent 22-year period (Figure 5).

A third fishwheel, similar in design to the 2 fishwheels at Baird Canyon, was operated from 23 May to 1 August 2002 on the west bank of the Copper River approximately 2.3 km downstream from the mouth of Canyon Creek near the lower end of Wood Canyon. This fishwheel operated for a total of 1,598 h and captured 676 Chinook salmon and 3,689 sockeye salmon (Table 1). The first Chinook salmon was captured on 29 May despite continuous fishing effort from 23–28 May, and the last Chinook salmon was captured on 1 August (Figure 4). Although the Canyon Creek fishwheel operated 95% of the time it was in place, and was stopped only for minor repairs and repositioning, its catch of 676 Chinook salmon was well short of our goal of 2,000 fish. Deep-water sites where the large fishwheel could operate were rare in the Canyon Creek

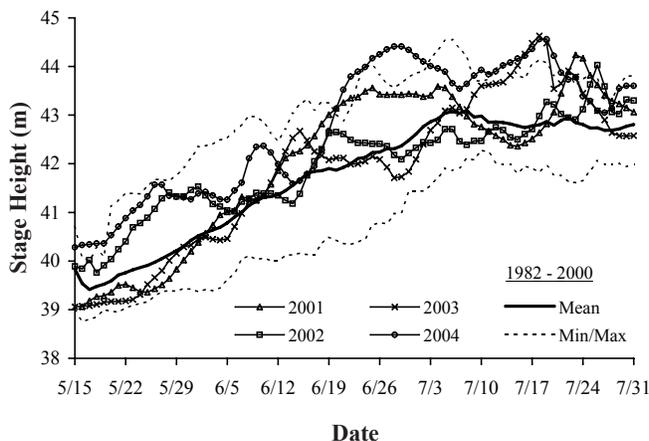


Figure 5. Stage height of the Copper River measured at the Million Dollar Bridge on the Copper River Highway, 1982–2004 (S. Moffitt, ADF&G, Cordova, personal communication).

area and it became apparent that a smaller fishwheel modeled after local subsistence fishwheels might be more effective.

In total, 1,345 Chinook salmon (885 spaghetti-tagged; 460 radio-tagged) were marked at Baird Canyon. Of the 632 Chinook salmon examined for marks at Canyon Creek, 16 were recaptures from Baird Canyon (Table 2). Length distributions of fish released with marks at Baird Canyon were not statistically different than length distributions of fish recaptured at Canyon Creek ($D_{\max} = 0.25$; $n_1 = 1,338$; $n_2 = 15$; $P = 0.31$), whereas lengths of marked and examined fish were significantly different ($D_{\max} = 0.13$; $n_1 = 1,338$; $n_2 = 631$; $P = 0.00$; Figure 6). The low number of recaptures precluded stratification by size, and it appeared most appropriate to conclude that size-selective sampling occurred in the first (tagging) event but not the second event, and therefore stratification by size was not needed to estimate abundance. No recaptured fish measured less than 750 mm FL and thus there was no information on the capture probability of these smaller fish, so subsequent tests for consistency were restricted to fish measuring 750 mm FL or greater. Sex-specific recapture rates were not compared in 2002 because gender was not recorded.

Although the sample size of recaptured fish was small, the probability of a Chinook salmon being marked at Baird Canyon appeared to be dependent on the time of capture. Mark rates varied significantly over the study period ($\chi^2 = 11.1$; $df = 3$; $P = 0.01$; Table 3). The probability of a marked fish being recaptured at Canyon Creek also varied over time ($\chi^2 = 17.4$; $df = 4$; $P = 0.00$). None of the 546 fish marked at Baird Canyon from 27 May to 11 June that were considered available for recovery (which represented 46% of all marked fish available) were recaptured. Based on the median travel time between sample events (11 d; range = 7–30 d; $n = 15$; Figure 7), this group of marked fish migrated past the Canyon Creek fishwheels from 7–22 June, which coincided with a period of increasing stage height and down time due to fishwheel damage. The lack of any recaptures from nearly half of the total marks in the first event precluded us from developing a robust or defensible abundance estimate in 2002.

Escape Panels for Sockeye Salmon

In 2002, we developed an innovative solution to reduce the potential for high fish densities in the fishwheel live tanks caused by abundant sockeye salmon. Slotted panels were installed in one end of each live tank and these allowed sockeye salmon to easily swim out of the fishwheel live tanks while retaining Chinook salmon.

Table 2. Capture history and abundance estimates for Copper River Chinook salmon, 2002–2004.

Capture history		2002	2003	2004
Marks applied during 1 st event	Spaghetti tag	885	1,577	2,017
	Radio tag	460	500	498
	Total	1,345	2,077	2,515
Marks censored ^a	Spaghetti tag	88	252	1
	Radio tag	77	102	37
	Total	165	354	38
Marks available for recovery	Spaghetti tag	797	1,325	2,016
	Radio tag	383	398	461
	Total (n _i)	1,180	1,723	2,477
Examined for marks during 2 nd event	Sampled	632	1,844	3,101
	Censored ^b	36	214	0
	Remaining (n _j)	596	1,630	3,101
Recaptured	Sampled	16	100	185
	Censored ^c	0	3	0
	Remaining (m _j)	16	97	185
Abundance estimate (N _{hat})		^d	44,764	40,564
Standard error (SE)		^d	12,385	4,650
Sample period (m/d)		21 May–13 July	17 May–1 July	22 May–22 June
Size classes incl. (mm FL)		≥ 750	810–1,070	≥ 600
Catch rate (% of run)	Baird Canyon	Fishwheel 1	1.8	3.4
		Fishwheel 2	2.1	2.9
	Canyon Creek	Fishwheel 3	0.8	
		Fishwheel 4	2.9	7.7

^a In 2002, 136 fish <750 mm FL, 23 radio-tag failures and 6 fish with no length measurement were censored. In 2003, 12 fish marked prior to 17 May or after 1 July, 316 fish <810 mm FL or >1,070 mm FL, and 26 radio-tag failures were censored. In 2004, 2 fish <600 mm FL and 36 radio-tag failures were censored.

^b In 2002, 36 fish <750 mm FL were censored. In 2003, 210 fish <810 mm FL or >1,070 mm FL and 4 fish with no length measurement were censored.

^c In 2003, 3 fish with no length measurement and no recorded tag number were censored.

^d In 2002, there was insufficient sampling to generate an unbiased estimate of abundance.

These “escape panels” consisted of 2 adjustable, vertical slots set in an aluminum frame that fit into the back of each live tank (Figure 8). After the first day of use at Baird Canyon (29 May), the field crew removed one of the escape panels and found that a sockeye salmon had been “gilled” in a slot while trying to escape the live tank. Subsequently, the openings in all of the escape panels were modified by tapering the exterior side of the slots, and this reconfigured design prevented any further mortalities.

To estimate the efficiency of the escape panels, we conducted a test on 8 July 2002 at the Baird Canyon fishwheels. The live tanks of both fishwheels were first emptied. The escape panels were then opened (65 mm on Fishwheel 1; 70 mm on Fishwheel 2) and catches were visually monitored for each live tank over a 2.5-h period. After this monitoring period, all fish were counted and released. At Fishwheel 1, 74% (23 of 31) and 76% (19 of 25) of sockeye salmon captured escaped from the port and starboard live tanks, respectively. At Fishwheel 2, 81% (91 of 113) and 92% (66 of

72) of sockeye salmon captured, respectively, escaped from the port and starboard live tanks. The length of sockeye salmon that did not escape from Fishwheel 2 during the test period averaged 670 mm FL and ranged from 580 to 720 mm FL (n=27). No Chinook salmon were captured during the test period.

The escape panels allowed the fishwheels to operate continuously throughout the Chinook salmon run and substantially reduced the risks associated with high sockeye salmon densities in the live tanks. The fishwheels were checked less frequently each day and the amount of effort required to handle fish was much reduced over the previous year.

Year 3 (2003)

The primary objective in 2003 was to increase sampling effort during the second event and make the Canyon Creek recapture site fully operational. In 2003, 2 fishwheels were operated at Baird Canyon and 2 at Canyon Creek.

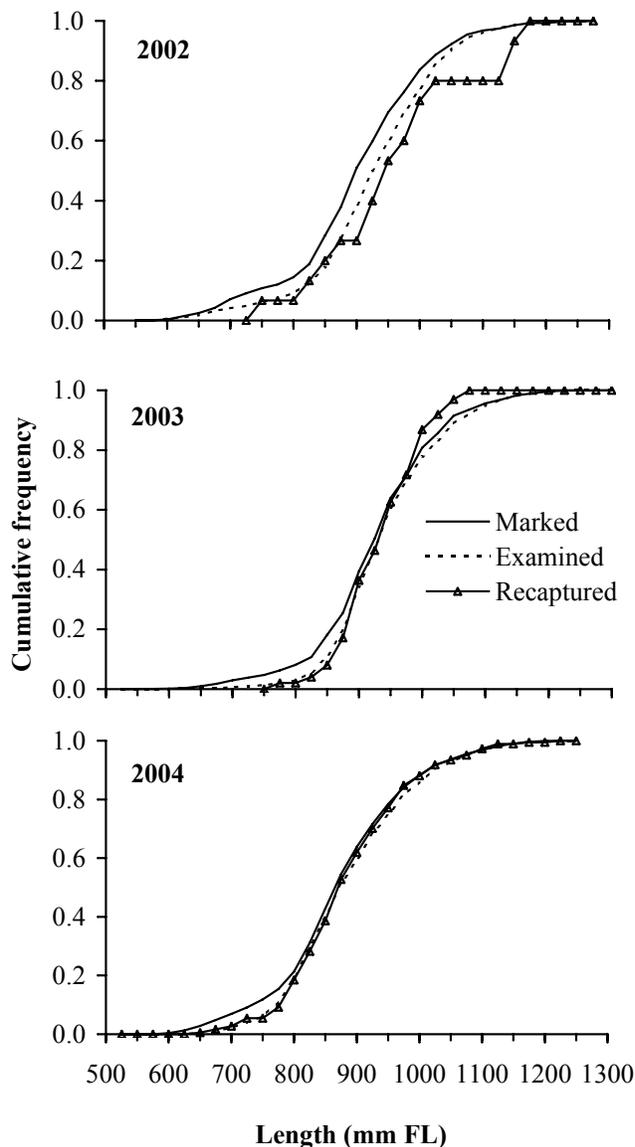


Figure 6. Cumulative length-frequency distributions for Chinook salmon marked, examined and recaptured at the Copper River fishwheels, 2002–2004.

One of the Baird Canyon fishwheels operated at the same east bank site used in 2001 and 2002, while the second fishwheel was operated at a new site on the west bank of the river near the upper end of Baird Canyon. The Baird Canyon fishwheels operated for 2,193 h from 15 May to 9 July and captured 2,251 Chinook salmon (Table 1). In contrast to previous seasons, there was little snow cover or river ice, and fish were captured the first day the fishwheel was operated. Chinook salmon catches increased in 2003 (48% more than 2002) as a result of the new and more productive west bank fishing site. Chinook salmon were captured from 15 May to 8 July and daily catch peaked at 156

fish on 3 June (Figure 4). Fishwheel operations were affected by anomalous water levels in 2003. During a low-water period from 15 May to 7 June, a spar log was required to hold the east bank fishwheel offshore in water with enough velocity to turn the baskets. In contrast, the Copper River exceeded the highest levels of a 22-year record in July which caused substantial damage to all project fishwheels and increased the amount of down time relative to previous years.

An escape panel test similar to the one performed in 2002 was conducted at Fishwheel one from 26–27 June 2003. We found that 91% (154 of 169) of sockeye salmon and no Chinook salmon ($n=4$) escaped from the port live tank (75-mm opening), while 75% (43 of 57) of sockeye salmon and no Chinook salmon ($n=4$) escaped from the starboard live tank (60-mm opening).

At Canyon Creek, one fishwheel operated at several sites on the west bank of the river (near the site used in 2002) and at one site on the east bank of the river approximately 300 m upstream of the camp. A second Canyon Creek fishwheel (and the fourth project fishwheel) was added in 2003 in an attempt to increase the number of fish sampled during the second event. The new fishwheel was smaller and could more easily fish shallow and high-velocity areas of the river, such as along gravel bars, than the other project fishwheels (Figure 3). This fishwheel was based on the design utilized by upper Copper River subsistence fishers and was constructed from 2 aluminum pontoons and 4 wooden baskets ($2.0 \times 1.8 \times 0.8$ m). The new fishwheel operated from 21 May to 7 July along a gravel bar on the west bank of the river and from 8–20 July on the east bank near the camp. Combined, the Canyon Creek fishwheels operated for 2,475 h from 21 May to 20 July and captured 1,928 Chinook salmon (Table 1; Figure 4). On 17 June, daily catch at the new fishwheel peaked at 96 fish and CPUE peaked at 3.4 fish per hour—the highest catch rates achieved to date over the multi-year project.

A total of 2,077 Chinook salmon (1,577 spaghetti-tagged; 500 radio-tagged) measuring 530 mm FL or greater were marked and released at Baird Canyon, and 1,844 fish were examined during the second event of which 100 were marked (73 spaghetti tagged; 27 radio tagged; Table 2). Length distributions of marked and recaptured fish were not significantly different ($D_{\max}=0.10$; $n_1=2,051$; $n_2=99$; $P=0.25$), whereas the size distributions of marked and examined fish were significantly different ($D_{\max}=0.07$; $n_1=2,051$; $n_2=1,840$; $P=0.00$; Figure 6). With a 6-fold increase in recaptures for this analysis, we could reach the same conclusion as in 2002, but with much more confidence, that these

Table 3. Contingency table tests comparing the mark and recapture rates for Chinook salmon (≥ 750 mm FL) sampled in 2002.

Test for equal probability of a fish being marked at Baird Canyon.

	Period of Recapture at Canyon Creek			
	21 May–10 June	11–24 June	24 June–1 July	2 July–1 August
Examined (n_2)	152	133	218	92
Recaptured (m_2)	1	0	9	5
Mark rate (m_2/n_2)	0.007	0.000	0.041	0.054

 $\chi^2=11.1$, $df=3$, $P=0.01$

Test for equal probability of a fish being recaptured at Canyon Creek.

	Period of Marking at Baird Canyon				
	21 May–3 June	4–10 June	11–17 June	18 June–1 July	12–15 July
Marked (n_1)	228	340	220	315	76
Recaptured (m_1)	1	0	8	6	0
Recapture rate (m_1/n_1)	0.004	0.000	0.036	0.019	0.000

 $\chi^2=17.4$, $df=4$, $P=0.00$

results indicated there was no size-selectivity at Canyon Creek. Interestingly, there was no difference in the size distributions of fish examined and recaptured at Canyon Creek ($D_{\max}=0.09$; $P=0.39$) which indicated there was no size selectivity at Baird Canyon either.

There were 354 fish in the first event and 214 fish in the second event censored from abundance calculations (Table 2). Twelve marked fish were censored because they were tagged prior to 17 May or after 1 July when the Baird Canyon fishwheels were not operating effectively (due to low or high water levels and logistical problems). Since only 2 recaptured fish measured less than 810 mm FL and none measured greater than 1,070 mm FL, subsequent tests of consistency and abundance calculations were restricted to fish with lengths ranging from 810–1,070 mm FL, which censored a total of 316 fish. Twenty six (6.1%) radio-tagged fish measuring 810–1,070 mm FL were censored because they were never detected at or above the Canyon Creek fishwheels.

Recapture rates for male (4.9%) and female (6.0%) fish were not significantly different ($\chi^2=0.88$; $P=0.35$) indicating that the probability of a fish being recaptured was not influenced by gender. The probability of a fish being captured at Canyon Creek appeared to be unaffected by the different handling and tagging procedures at Baird Canyon. Recapture rates of spaghetti- (5.4%) and radio-tagged (6.3%) fish were not significantly different ($\chi^2=0.41$; $P=0.52$). To test for equal capture probabilities over time, fish sampled during consecutive weeks with similar mark and recapture rates were pooled. The probability of a fish being marked at Baird Canyon was not independent of time of capture, as mark rates varied significantly over the study period

($\chi^2=25.5$; $df=1$; $P=0.00$; Table 4). Similarly, recapture rates were also significantly different over the study period ($\chi^2=6.6$; $df=1$; $P=0.01$) indicating that the probability of a fish being recaptured at Canyon Creek was not independent of time. The median travel time for fish marked and released at Baird Canyon and later recaptured at Canyon Creek was 13 d and ranged from 5–30 d (Figure 7).

To alleviate the bias from variable capture probabilities over time, we used Darroch's (1961) method to develop a temporally stratified abundance estimate. An estimated 44,764 (SE=12,385) Chinook salmon measuring 810–1,070 mm FL passed through Baird Canyon from 17 May to 1 July (Table 2). This estimate was based on 1,723 Chinook salmon (1,325 spaghetti- and 398 radio-tagged) marked at Baird Canyon from 17 May to 1 July and considered available for recovery upstream, 1,630 fish examined for marks at Canyon Creek and 97 recaptures (72 spaghetti- and 25 radio-tagged). This estimate appeared unbiased and met our objective for precision. This estimate did not address Chinook salmon measuring greater than 1,070 mm FL, which comprised 7.4% ($n=3,937$) of Chinook salmon sampled at the Copper River fishwheels and 7.3% ($n=794$) of fish sampled in the commercial gill-net fishery in 2003 (Steve Moffitt, ADF&G, Division of Commercial Fisheries, personal communication). Chinook salmon measuring less than 810 mm FL comprised 13.5% of fish sampled in the fishery.

Year 4 (2004)

Substantial improvements made in each of the first 3 years of study allowed the project to become fully

operational and achieve the study objective by 2003. The primary objective in 2004 was to sustain sufficient sampling effort across the entire Chinook salmon migration to estimate abundance with the desired levels of accuracy and precision.

In 2004, 2 fishwheels were operated at Baird Canyon and one at Canyon Creek. The Baird Canyon fishwheels were operated for 1,184 h from 22 May to 22 June and captured 2,756 Chinook salmon (Table 1). Both fishwheels operated at the same sites used in 2003. There was 2.5 m of snow cover at Baird Canyon when the crew arrived on 9 May, so our mobilization time increased and a fishwheel was not operational until 22 May.

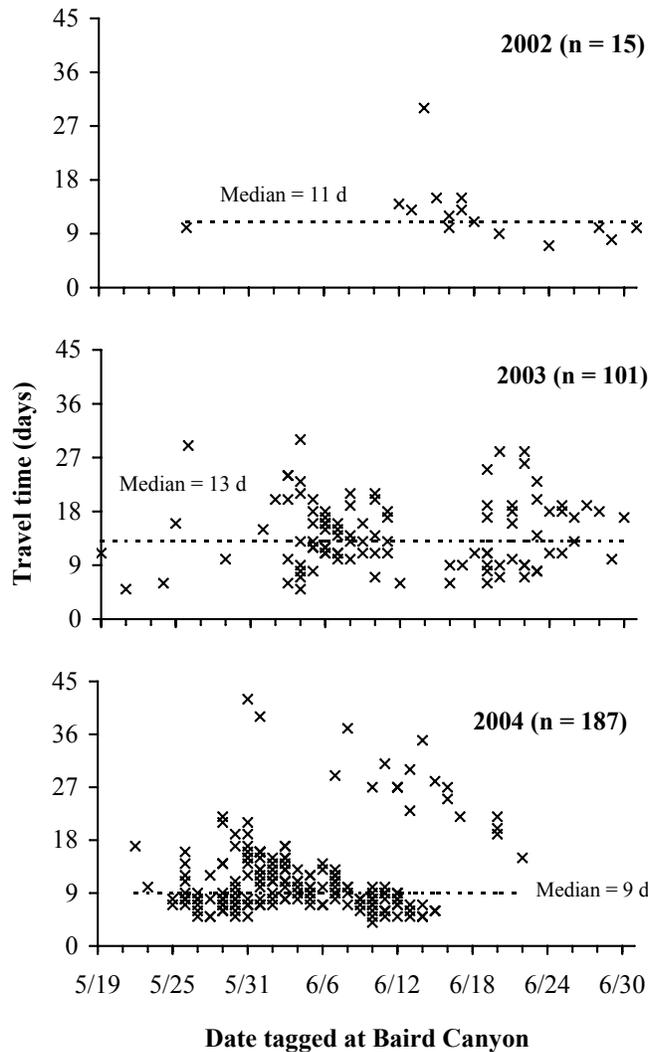


Figure 7. Travel time (in days) for Chinook salmon marked at Baird Canyon to migrate from Baird Canyon to Canyon Creek, 2002–2004.

The small fishwheel (first fished in 2003) operated at Canyon Creek from 28 May to 21 July and captured 3,339 Chinook salmon during 1,277 h of operation. Daily catch at Canyon Creek peaked at 235 Chinook salmon (CPUE=9.7 fish per hour) on 2 June. In 2004, all project fishwheels were shut down earlier than scheduled and prior to the end of the Chinook salmon run due to unusually high water levels. For the majority of the period from 20 June to 23 July, stage

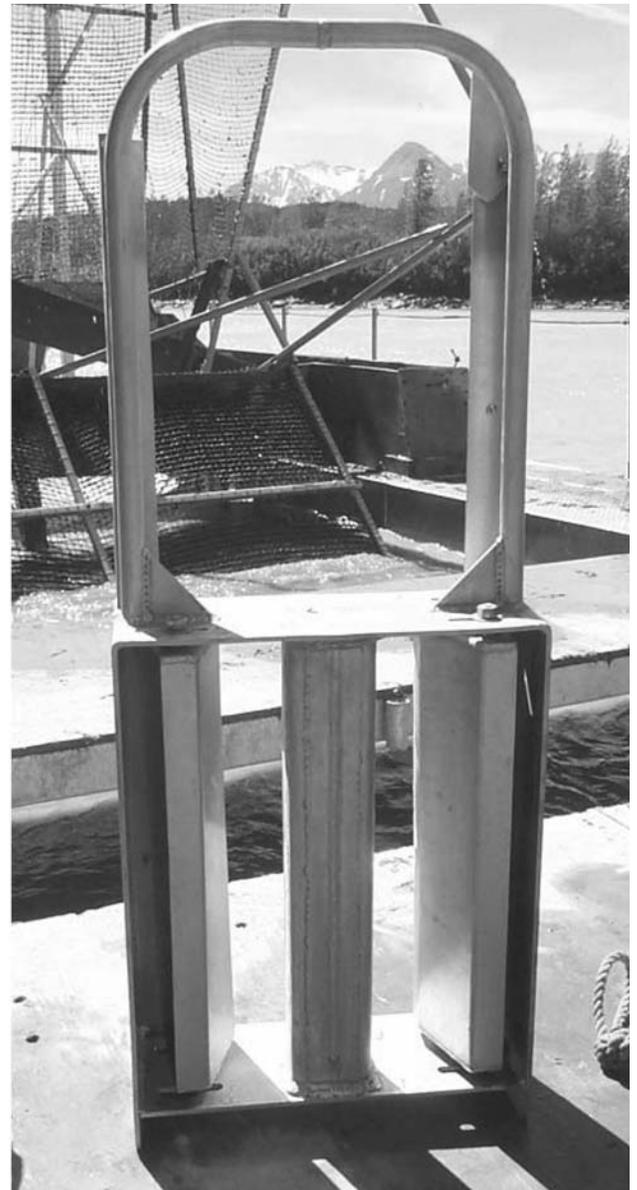


Figure 8. Photograph of an escape panel that was installed at one end of a fishwheel live tank to allow sockeye salmon to easily swim back to the river while retaining Chinook salmon in the live tank. Escape panels were used on all project fishwheels, 2002–2004.

Table 4. Contingency table tests comparing the mark and recapture rates for Chinook salmon (810–1,070 mm FL) sampled in 2003.

Period of marking	Period of Recapture		Recaps (m_2)	Marked (n_1)	Not recaptured ($n_1 - m_2$)	Recapture rate (m_2/n_1)
	21 May–10 June	11 June–20 July				
17 May–3 June	5	7	12	397	385	0.030
4 June–1 July	1	84	85	1,326	1,241	0.064
Recaps (m_2)	6	91				$\chi^2=6.6$, $df=1$, $P=0.01$
Unmarked ($n_2 - m_2$)	461	1,072				
Examined (n_2)	467	1,163				
Mark rate (m_2/n_2)	0.013	0.078				$\chi^2=25.5$, $df=1$, $P=0.00$

Data used for chi-square tests in bold.

height of the Copper River exceeded the highest levels recorded in the past 22 years (Figure 5).

A total of 2,515 Chinook salmon (2,017 spaghetti-tagged; 498 radio-tagged) measuring 585 mm FL or greater were marked at Baird Canyon from 22 May to 22 June 2004 (Table 2). Since there were only 2 Chinook salmon measuring less than 600 mm FL captured at Baird Canyon, and none captured at Canyon Creek, only fish measuring 600 mm FL or greater were included in abundance calculations. Two marked fish (one spaghetti-tagged; one radio-tagged) measuring less than 600 mm FL and 36 (7.2%) radio-tagged fish never detected at or above the Canyon Creek fishwheels were censored, leaving 2,477 marked fish available for recovery. At Canyon Creek, 3,101 Chinook salmon were examined for marks from 28 May to 21 July, of which 185 were tagged (152 spaghetti-tagged; 33 radio-tagged; Table 2).

As in 2002 and 2003, length distributions for marked and recaptured fish were not significantly different ($D_{\max}=0.07$; $n_1=2,474$; $n_2=184$; $P=0.32$) in 2004, whereas those for marked and examined fish were significantly different ($D_{\max}=0.057$; $n_1=2,474$; $n_2=3,100$; $P=0.00$; Figure 6). There was also no difference ($D_{\max}=0.04$; $P=0.89$) in the size distributions of fish examined and recaptured at Canyon Creek. Recapture rates for male (7.7%) and female (7.2%) fish were not significantly different ($\chi^2=0.31$; $P=0.58$). There was no significant difference in the recapture rates of spaghetti- (7.5%) and radio-tagged fish (7.2%; $\chi^2=0.08$; $P=0.78$). Similar to 2003, the probability of a fish being marked at Baird Canyon in 2004 was not independent of time of capture ($\chi^2=92.3$; $df=3$; $P=0.00$; Table 5). Recapture rates were also significantly different over the 2004 study period ($\chi^2=22.7$; $df=3$; $P=0.00$), indicating that the probability of a fish being recaptured at Canyon Creek was not independent of time. The travel time between sample events for recaptured fish ranged from 5–30 d and averaged 11.6 d (Figure 7).

Using a temporally stratified estimator, the estimated inriver abundance of Chinook salmon measuring 600 mm FL or greater that migrated above Baird Canyon from 22 May to 22 June was 40,564 (SE=4,650; Table 2). The estimate does not account for the portion of the run that migrated through Baird Canyon prior to 22 May or after 22 June. The number of fish that passed through Baird Canyon prior to the onset of tagging cannot be estimated; however it was thought to be quite small. Based on the previous 3 years, approximately 77% of all Chinook salmon captured annually at Baird Canyon were caught on or before 22 June (77% in 2001, 74% in 2002, 79% in 2003). This estimate appears unbiased and met our study objective for precision.

DISCUSSION

The biggest challenge facing this project was to capture enough Chinook salmon to generate mark–recapture estimates from an expected population of 40,000 fish that migrated over a period of 2 months through widely fluctuating water conditions. By the third year of the study (2003), catches of Chinook salmon at both the tagging (2,251 fish) and recapture sites (1,928 fish) met or exceeded our target levels. More importantly, the numbers of tagged fish recaptured at the recapture site (97 in 2003 and 185 in 2004) were sufficient to develop unbiased and reasonably precise abundance estimates (coefficient of variation measured at 28% of estimate in 2003 and 11% in 2004). Estimated annual catch rates (percent of run captured) for *individual* fishwheels ranged from 1.8% to 3.4% at Baird Canyon, and from 0.8% to 7.7% at Canyon Creek (Table 2). These rates were comparable to those reported for a similar fishwheel project on the Nass River—between 1994 to 2001, on average, 4.4% (range: 0.4% to 9.1%) of the Chinook salmon run was captured in each fishwheel (Alexander and Bocking 2002). The Copper River's high gradient and velocity (forcing fish to migrate

Table 5. Contingency table tests comparing the mark and recapture rates for Chinook salmon (≥ 600 mm FL) sampled in 2004.

Period of marking	Period of recapture				Recaps (m_2)	Marked (n_1)	Not recaptured ($n_1 - m_2$)	Recapture rate (m_2/n_1)
	28 May–6 June	7–15 June	16 June–6 July	7–21 July				
22–29 May	26	8	2	0	36	410	374	0.088
30 May–4 June	5	37	20	2	64	770	706	0.083
5–11 June	0	14	39	3	56	541	485	0.104
12–22 June	0	0	17	12	29	756	727	0.038
Recaps (m_2)	31	59	78	17		$\chi^2 = 22.8$, $df = 3$, $P = 0.00$		
Unmarked ($n_2 - m_2$)	1,510	646	590	170				
Examined (n_2)	1,541	705	668	187				
Mark rate (m_2/n_2)	0.020	0.084	0.117	0.091		$\chi^2 = 92.3$, $df = 3$, $P = 0.00$		

Data used for chi-square tests in bold.

close to the banks) combined with turbid water make it an excellent location to use fishwheel technology and mark–recapture methods. The large fishwheels we used were suitable for the deep-water areas at Baird Canyon, but not suitable in the wider, shallower and braided areas upriver near Canyon Creek. The small fishwheel we developed for Canyon Creek was far more effective than the larger version first deployed there. This smaller fishwheel substantially increased our catches at the upstream site—which really helped the project succeed.

An ongoing challenge for this project will be to achieve sufficient catch rates across the entire Chinook salmon migration (both across time and over all fish sizes). Flow-related changes in fishwheel catchability during both sample events contributed to variable capture probabilities over the run. Similar effects of river discharge on capture probabilities at fishwheels have been reported elsewhere (McPherson et al. 1996; Cappiello and Bruden 1997; Pahlke 1997; Hebert and Bruden 1998; McPherson et al. 1999; Hewitt and Hightower 2002). At low river levels, capture probabilities were usually low; this may be because water velocities were not fast enough to force migrating Chinook salmon nearshore (and into the path of the fishwheel) or to rotate the baskets at sufficient fishing speeds. Conversely, capture probabilities tended to be low at some good medium-flow sites during high water conditions because fish were more likely to swim beneath the reach of fishwheel baskets as depth increased. For example, from 19 May to 9 July 2003, river depth measured at the east bank fishwheel site in Baird Canyon increased by over 5.2 m, resulting in a dramatic reduction in the proportion of nearshore area covered by the fishwheel baskets.

Highly variable catch rates at both capture and recapture locations necessitates temporal stratification and, without an increase in catch, reduces the precision of estimates. This can be addressed by increasing

fishing power to increase the overall proportion of fish captured and tagged (which would ameliorate the effects of stratification) or by stabilizing the catch rates from the existing fishwheels and sites. We believe that continued evolution of the project toward developing low-, moderate-, and high-water sites at Baird Canyon and Canyon Creek to reduce intra-season variability in catch rates is preferable to simply increasing the overall proportion of the run captured. We intend to continue to refine how the fishwheels are operated at existing sites, as well as explore alternate fishwheel designs that may yield more consistent catch rates across a wide range of water conditions.

Incomplete coverage of all temporal components of the run and of all size classes prevented development of a robust estimate in 2002. The abundance estimates in 2003 and 2004 did not address moderate portions of the migratory timing (after 22 June in 2004, likely ~20% of the migration) or large fish ($>1,070$ mm FL in 2003, likely ~7% of the migration), and neither estimate addressed the smallest Chinook salmon (<810 mm in 2003 and <600 mm in 2004). The abundance estimate presented for 2003 represents the most statistically defensible estimate given the data that were collected. There was evidence (from the KS test), however, that sampling was not size-selective (which was supported by the results from 2004). Thus, if desired by managers, an estimate of total abundance could be calculated from the 2003 data with an unknown, but likely small bias. Censoring smaller Chinook salmon, which are typically 2-ocean fish, from mark–recapture experiments is common in Alaska (McPherson et al. 1999; Pahlke et al. 2000; Saveriede 2004). We anticipate that ongoing improvements to fishwheel sites and design will lead to better coverage of the run and help to address these issues.

A common concern when using mark–recapture methods with Chinook salmon, which return over a relatively wide size range compared with other salmon,

is that the probability of capture or recapture may vary with body size. Studies have shown that fishwheels can be size-selective for salmon (Meehan 1961; Cappiello and Bruden 1997; Link and Nass 1999); however, it requires tremendous differences in the relative vulnerability across sizes to create a meaningful bias in the abundance estimate (Ricker 1975). Despite relatively large sample sizes, we did not detect size selectivity in 2003 or 2004.

Another key to the success of the project was the development of escape panels (Figure 8), which to our knowledge have not been used by any other fishwheel program. This innovation allowed sockeye salmon—which were far more abundant in fishwheel catches prior to installation of the panels (2001)—to swim back to the river quickly and easily after being deposited into the live tanks. For example, in 2001, there were 25 times more sockeye salmon captured at Baird Canyon than Chinook salmon; whereas in 2004, there were nearly twice as many Chinook salmon handled at Baird Canyon than sockeye salmon (Table 1). Although the escape panels were designed to reduce the incidental catch of sockeye salmon, they likely contributed to low catches of small Chinook salmon. However, the benefits of less stress on the fish being marked and reduced effort by the sampling crews outweighed the costs of not estimating abundance for this small component of the population. Without this innovation, our capture and tagging goals for Chinook salmon would have required substantially more effort and cost and, combined with the stress on fish due to high densities in live tanks, may have compromised the entire project.

Substantial progress has been made in developing NVE's capacity to meaningfully participate in fisheries assessment and management. The success of a project of this magnitude can be attributed to 3 organizational factors. First, NVE has made the financial commitment to maintain a core full-time professional staff. Supervision and administration of such large projects require full-time commitment from the Tribe's supervisory, technical and administrative staff. Second, NVE's partnership with LGL Alaska

Research Associates, Inc., an environmental consulting firm, provided a level of technical expertise to the study team comparable to State or Federal natural resource agencies. Third, since the start of the project, there has been meaningful collaboration with ADF&G, an organization with substantial experience working in the Copper River watershed and expertise with similar mark–recapture projects.

The inclusion of non-governmental partners such as NVE in the management and assessment of Copper River fisheries has provided a significant benefit. Stock assessments and management decisions by State and Federal fisheries managers are usually more credible when data collected outside of normal governmental agencies are considered (Durrenberger and King 2000). Since the project's inception, NVE has hosted public workshops to first describe the proposed study and then each year since to report the study's results, which has allowed stakeholders to understand and provide timely feedback on the program. Over the last 4 years there has been a dramatic reduction in the tension and doubt among stakeholders over the Copper River Chinook salmon escapement estimates. The quality of escapement information for Copper River Chinook salmon has substantially improved and this information has been provided to State and Federal agencies without the need to increase their staff—an important feature in the face of declining agency budgets. Expansion of the expertise beyond that typically available to State and Federal agencies has resulted in significant innovations that were key to the project's success (e.g., development of the escape panels and smaller fishwheel).

With funding currently approved through 2006, this project has evolved into a successful and potentially long-term monitoring program that has made NVE an integral part of Copper River salmon research. The project has also demonstrated that Federal, State and Tribal agencies can work cooperatively to collect data on Copper River salmon stocks that are used to assess, and potentially improve, current management practices.

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