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Abundance, Timing of Migration, and Egg-to-Smolt Survival of Juvenile Chum Salmon, Kwethluk River, Alaska

By Sean E. Burril, Cristian E. Zimmerman, James E. Finn and Daniel Gillikin[1]

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[1]US Fish and Wildlife Service, Yukon Delta National Wildlife Refuge, P.O. Box 346, Bethel AK 99559

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Contents

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List of Acronyms

AYK .... Arctic Yukon Kuskokwim
CI .... Confidence Interval
NRC .... National Research Council
OVK .... Organized Village of Kwethluk
PED .... Potential Egg Deposition
SD .... Standard Deviation
SE .... Standard Error
USFWS .... U.S. Fish and Wildlife Service
USGS .... U.S. Geological Survey

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square kilometer (km^2)	247.1	acre
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

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Abstract

To better understand and partition mortality among life stages of chum salmon (*Oncorhynchus keta*) we used inclined-plane traps to monitor the migration of juveniles in the Kwethluk River, Alaska in 2007 and 2008. The migration of juvenile chum salmon peaked in mid-May and catch rates were greatest when water levels were rising. Movement of chum salmon was diurnal with highest catch rates occurring during the hours of low light (i.e., 22:00 to 10:00). Trap efficiency was determined using mark-recapture and ranged from 0.37% to 4.04% (overall efficiency = 1.94%). Total abundance of juvenile chum salmon was estimated to be 2,004,691 fish (95% CI = 1,714,381 – 2,140,580) in 2007 and 2,925,384 fish (95% CI = 2,803,109 – 3,210,697) in 2008. Using the estimate of chum salmon females passing the Kwethluk River weir and age-specific fecundity, we estimated the potential egg deposition (PED) upstream of the weir and trapping site. Egg-to-smolt survival was calculated by dividing the estimate of juvenile chum salmon emigrating past the Kwethluk weir site by the estimate of PED. Egg-to-smolt survival (± SD) was 4.6 ± 0.71% in 2007 and 5.2 ± 0.90% in 2007. In addition to chum salmon, we captured Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), sockeye

salmon (*O. nerka*), and pink salmon (*O. gorbuscha*), as well as ten other fish species. As with chum salmon, catch of these species increased during periods of increasing discharge and peaked during hours of low light. This study successfully determined the characteristics of juvenile salmon migrations and estimated egg-to-smolt survival for chum salmon. This is the first estimate of survival for any juvenile salmon in the Arctic-Yukon-Kuskokwim region of Alaska and demonstrates an approach that can help to partition mortality between freshwater and marine life stages, a critical information need if we are to understand the dynamics of salmon in this region.

Introduction

Declines in salmon returns to western Alaska rivers within the Arctic-Yukon-Kuskokwim (AYK) Region in the late 1990's and early 2000's resulted in restrictions to commercial and subsistence fisheries (NRC 2005; AYK SSI 2006). The reasons for these declines are unknown and difficult to identify because of a general lack of knowledge concerning salmon populations and their habitats within this region. This severely hampers efforts by fishery managers and scientists to identify appropriate management actions (NRC 2005). Determining the relative importance of mortality in freshwater, estuarine, or marine habitats as drivers of recruitment variation would aid in assessing how management can respond to declining salmon returns. Traditionally, fishery managers have relied on escapement estimates to monitor anadromous salmonid population status and management effectiveness (Hilborn and others 1999). Within the Kuskokwim River watershed, adult salmon returns are monitored at nine locations and counts of adult salmon are used to construct stock-recruit relationships that are used to establish escapement goals (Clark and others 2009; Linderman and Bergstrom 2009). When based on adult returns only, these stock-recruit relationships integrate mortality across all life stages and habitats. Estimates of population abundances at earlier life stages would enable partitioning of survival among life-stages and aid in developing hypotheses for restoration and management actions (Moussalli and Hilborn 1986, Mobrand and others 1997; Beamish and Sweeting 2009).

Within the Kuskokwim River, little has been done to understand the ecology of juvenile salmon. Quantification of juvenile salmon production at sites where adult salmon escapement is monitored would allow partitioning of mortality between the freshwater life stages (egg-to-smolt) and marine life stages (smolt-to-adult) (Volkhardt and others 2007). Juvenile fish traps are frequently used to estimate the abundance (Tsumura and Hume 1986, Orciari and others 1994, Thedinga and others 1994, Letcher and others 2002), timing of migration (Wagner and others 1963, Hartman and others 1982), size at migration (Orciari and others 1994), survival (Tsumura and Hume 1986, Letcher and others 2002), and behavior (Brown and Hartman 1988, Roper and Scarnecchia 1996) of downstream migrating anadromous salmonids. Coupled with estimates of adult salmon escapement, estimates of smolt abundance can be used to assess the capacities of freshwater habitats and effects of fishery and land-use management (Moussalli and Hilborn 1986; Solazzi and others 2000).

In this study, we estimated the population size, and calculated egg-to-smolt survival of migrating juvenile chum salmon (*Oncorhynchus keta*) on the Kwethluk River, Alaska. While we focused our efforts on chum salmon, we also determined the timing of migration and relative abundance of Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*) and pink salmon (*O. gorbuscha*).

Methods

Study Area

Located in southwest Alaska, the Kwethluk River originates in the Kilbuk Mountains and flows northeast approximately 230 km before joining the Kuskokwim River 31 km upstream of Bethel (Figure 1). The Kwethluk watershed drains approximately 3,400 km^2 and is characterized as a clearwater/tannin-stained run-off system. The Kwethluk River supports runs of chum, Chinook, coho, sockeye, and pink salmon. Other fish species occurring within the watershed include: rainbow trout (*O. mykiss*), Dolly Varden (*Salvelinus malma*), Alaska blackfish (*Dallia pectoralis*), Arctic grayling (*Thymallus arcticus*), Northern pike (*Esox lucius*), whitefish (Coregonidae), burbot (*Lota lota*), ninespine stickleback (*Pungitius pungitius*), sculpin (Cottidae), and lamprey (Petromyzontidae). To monitor adult salmon returns to the Kwethluk River, the U.S. Fish and Wildlife Service, in cooperation with the Organized Village of Kwethluk, operates a resistance board weir at approximately river km 88 (60° 29.38' N, 161° 05.54' W). Counts of salmon at the Kwethluk weir began in 2000, although a similar weir was also operated at this site in 1992 (Miller and others 2009). Seven-year averages of salmon passing the Kwethluk weir are: 37,000 chum salmon, 14,000 Chinook salmon, 2,100 sockeye salmon, 1,900 even-year pink salmon, and 45,000 coho salmon (Miller and others 2009).

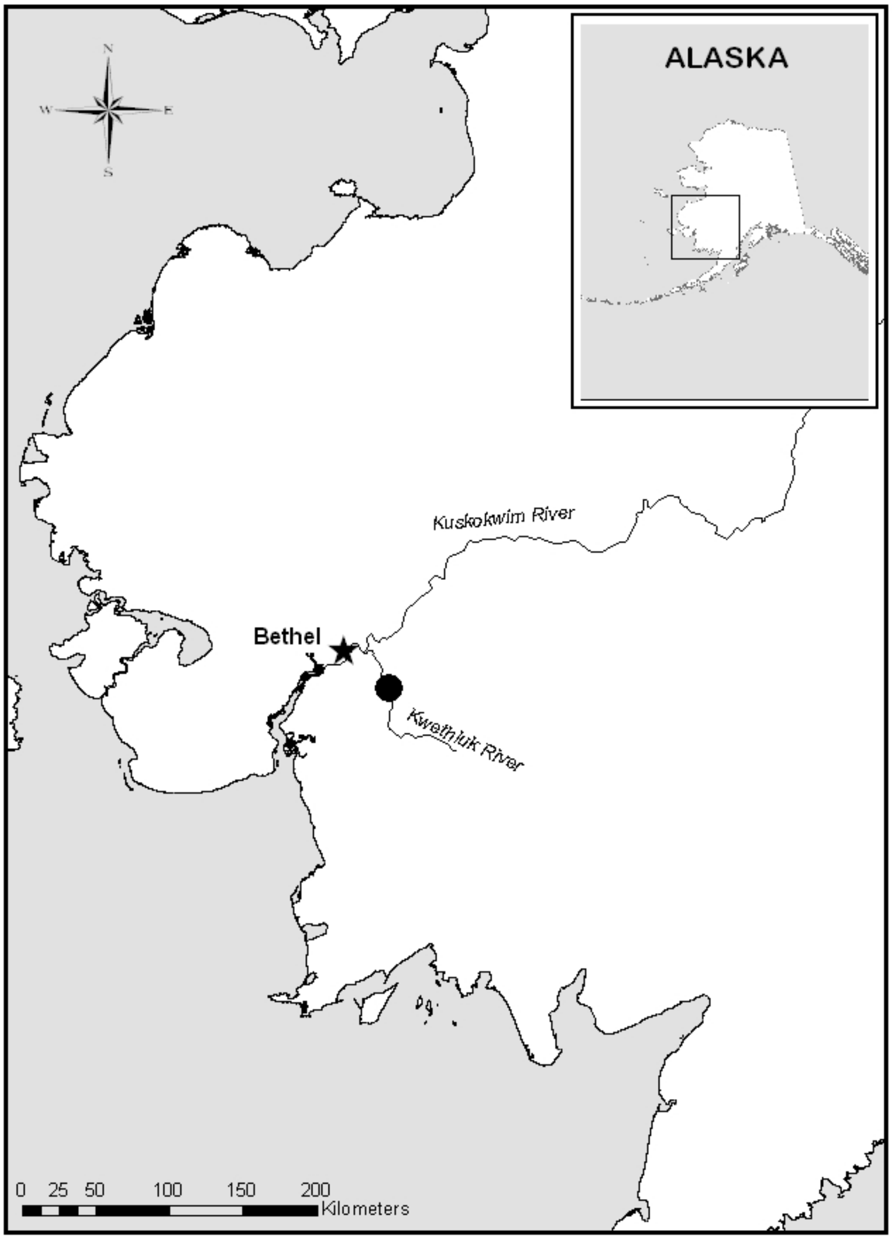

Figure 1. Location of study site (circle), Kwethluk River, Alaska.

Fish Capture

Two floating inclined-plane traps, similar to those described by Todd (1994), were used to capture migrating salmon at the Kwethluk River weir site (Figure 1). The original design (Todd 1994) was optimized for collecting sockeye salmon smolts. Our traps were modified for sampling smaller rivers and fish species. Specifically, the trap was scaled down for transportation in small cargo aircraft, an additional winch was installed at the funnel/live-box junction so the entire trap could be lifted from the water, and perforations in the live-box and funnel were reduced to 9.5 mm and 3.5 mm, to retain the smaller (compared to sockeye salmon smolts) juvenile chum salmon. These traps have a 1.2 m x 1.2 m opening that narrows to a 0.9 m x 0.2 m end that deposits fish into a live box (Figure 2).

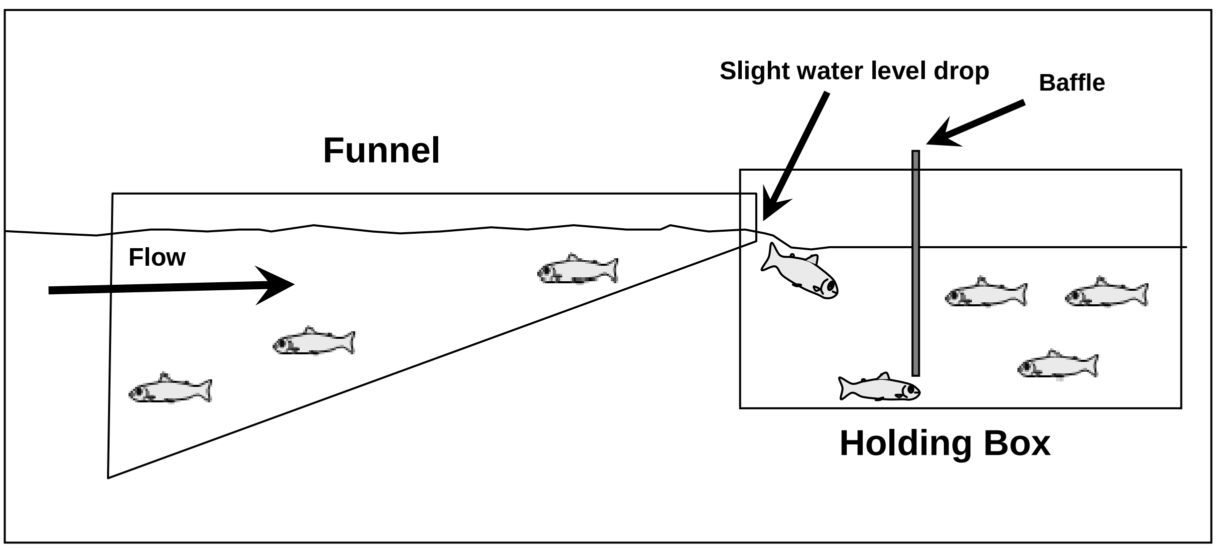

Figure 2. Schematic side view of an inclined plane trap.

The plane and live-box are mounted atop two pontoon floats (Figure 3). Further, all anchors and lines were above water to avoid entanglement with floating debris and ice and we installed a floating deflector to minimize floating ice and debris from entering the traps (Figure 4). The debris deflector was only used during periods when floating ice was present.

Figure 3. Photo of floating inclined plane trap as used on the Kwethluk River, Alaska.

Traps were deployed as soon as the river was free of ice cover at the trap site and continued fishing until the seaward migration of juvenile chum salmon subsided. Traps were tethered to a suspended cable that spanned the river width (Figure 5). Traps were checked every four hours in a 24 hour period except during periods of high flow or debris loads, when it was necessary to check the traps every 2 hours to avoid clogging of the plane and live box by debris. When traps were checked, all fish were counted and immediately released, except when fish were held for marking or measurement. Every third day, a sub-sample of up to 100 fish was measured and released.

Figure 4. Inclined plane trap with ice-breaker bow attached, Kwethluk River, Alaska.

Figure 5. Inclined plane traps attached to cable spanning the Kwethluk River, Alaska.

Numbers of chum salmon migrants passing the trap site were estimated using the mark-recapture methods and estimators of Carlson and others (1998), using a “One Trap” scenario consisting of two traps positioned on opposite banks. Trap efficiency was determined by releasing marked fish upstream of the trap site and trap efficiency was measured anytime traps were moved, when stream stage height changed by 10 cm or more, or once per week.

During mark-recapture events, fish were marked using a solution of Bismarck Brown Y dye (0.5 g dye/15 liters of water). Fish were immersed in the marking solution for up to 2 hours and then held in flow through tubs for a minimum of 2 hours prior to release. Following marking, 10-100 marked fish were held to monitor mortality and mark visibility during each marking event. The target number of marked smolts for any marking period was selected based on estimated trap efficiency and the desired level of precision (Carlson and others 1998). Marked fish were transported approximately 1 km upstream and released. For all marking events, fish were released as close to midnight as possible.

Egg-to-Smolt Survival

Percent survival of juvenile chum salmon was determined using estimates of potential egg deposition (PED, i.e., the maximum number of eggs brought into the system by spawning females) and the estimated abundance of juvenile chum salmon passing the trap site. We estimated PED using the number of female chum salmon and their age distributions as determined at the weir (Miller and others 2007, 2009) and literature values of age-specific fecundity (Gilk and others 2005). After each field season, we used the estimated smolt number in conjunction with the previous (parental year) female escapement-fecundity estimate to calculate the survival. The survival estimate was calculated as:

$$\%\text{Survival} = \frac{\text{estimated smolt abundance}}{\text{PED}} \cdot 100$$

Variance was calculated using the delta method (Seber 1982).

Environmental Data

Depth and temperature were monitored at the trap site. Upon arrival at the Kwethluk River field location, we installed a staff gage. Each day, stage height was recorded in the morning (08:00 hours) and again in the evening (20:00 hours). Daily recordings of air temperature were taken using a min/max thermometer. Water temperature was recorded using three temperature data loggers (set at 15 minute intervals) suspended from each trap, and one to a solid bank structure.

Results

Inclined-plane traps were fished from 26 April - 31 May 2007 and from 29 April - 18 June 2008. All five species of Pacific salmon and ten other species of fish were caught as they moved downstream past the trapping site (Table 1). Juvenile chum salmon were the most abundant species in both years (Table 1).

Table 1. Total catch for salmon species by age and total catch for all other fish species caught in inclined plane traps on the Kwethluk River, Alaska, 2007 -2008.

Species	**2007**	**2008**
Chum salmon (*Oncorhynchus keta*)	99415	43979
Pink salmon (*O. gorbuscha*)	3005	963
Total Chinook salmon (*O. tshawytscha*)	14221	2135
-- Age-0 Chinook salmon	7812	422
--Age 1 Chinook salmon	6409	1713
Total Coho salmon (*O. kisutch*)	3872	2274
-- Age-0 Coho salmon	478	226
--Age 1 Coho salmon	3394	2048
Sockeye salmon (*O. nerka*)	3533	3326
-- Age-0 Sockeye salmon	2878	2688
--Age 1 Sockeye salmon	655	638
Sculpin (unidentified species)	347	54
Dolly Varden (*Salvelinus malma*)	13	4
Rainbow trout (*O. mykiss*)	0	5
Arctic grayling (*Thymallus arcticus*)	1	0
Northern pike (*Esox lucius*)	1	1
Whitefish (unidentified species)	0	1
Alaska blackfish (*Dallia pectorallis*)	34	17
Lamprey (unidentified species)	1187	243
Ninespine stickleback (*Pungitius pungitius*)	23	3
Burbot (*Lota lota*)	2	2

Chum Salmon

A total of 99,415 and 43,979 juvenile chum salmon were captured in 2007 and 2008, respectively (Table 1). In 2007, daily catches of chum salmon ranged from 29 on 26 April to 10,074 on 19 May. In 2008, catches of chum salmon ranged from 1 on 1 May to 2,640 on 2 June (Figure 6). The highest catches occurred at night, between 02:00 and 0:600 (Figure 7), and during increases in water depth (Figure 6). Juvenile chum salmon ranged in length from 30 mm to 46 mm fork length (FL) in 2007 (mean = 36 mm; SD = ± 2.2 mm), and from 28 mm to 55 mm FL in 2008 (mean = 38 mm; SD = ± 3.3 mm).

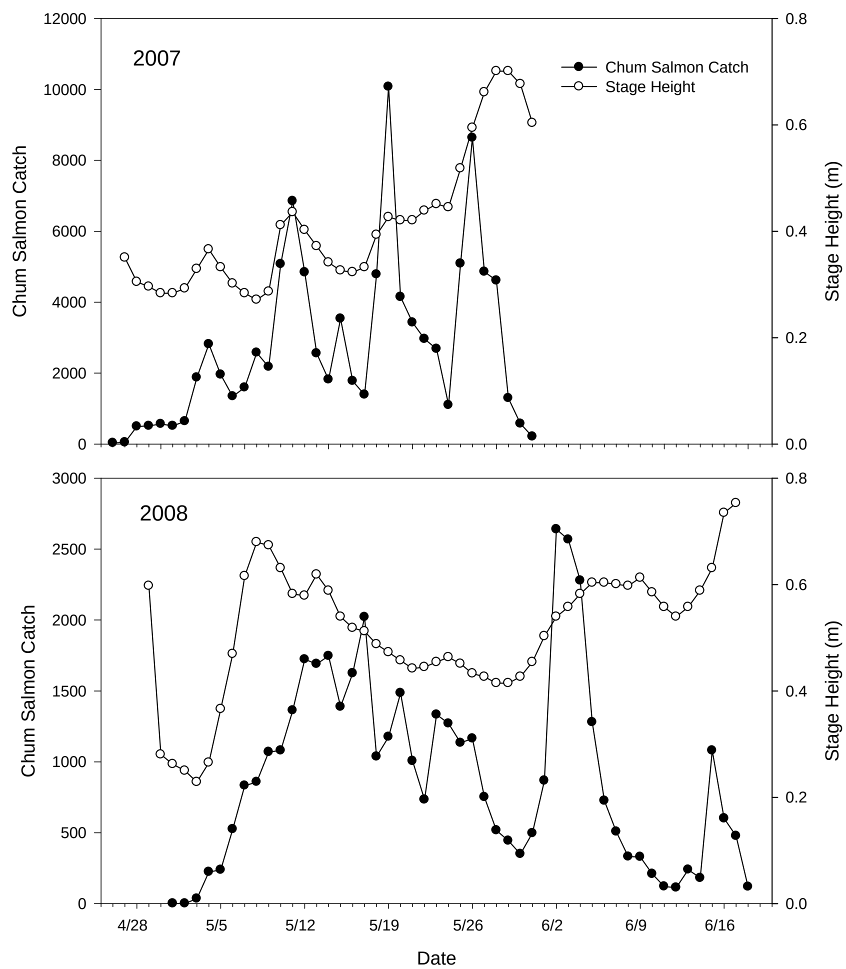

Figure 6. Daily catch of juvenile chum salmon and maximum daily stage height for the Kwethluk River, Alaska.

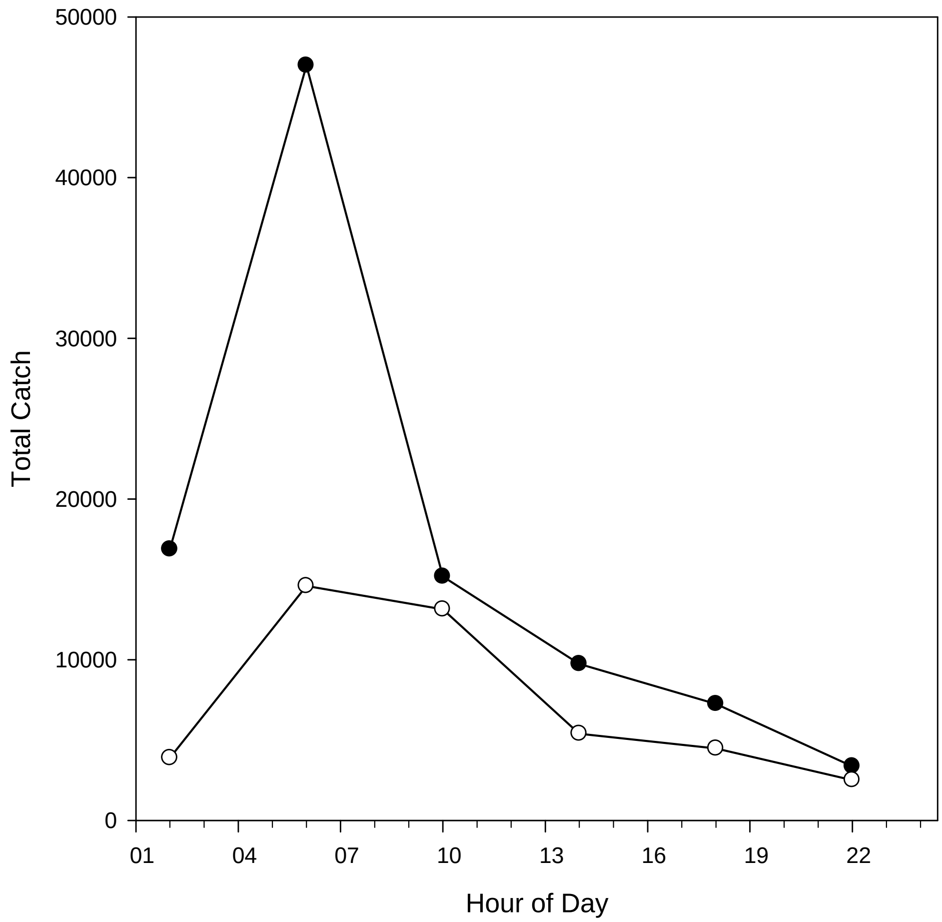

Figure 7. Total catch of juvenile chum salmon by hour of day in 2007 (solid circles) and 2008 (open circles), Kwethluk River, Alaska.

Other Salmonids

In 2007, peak catches of age-0 Chinook and sockeye salmon occurred between 7 May and 29 May (Figure 8). In 2008, peak age-0 Chinook salmon catches were much lower than 2007, and occurred between 20 May and 6 June (Figure 8). Daily catches of age-0 coho salmon were always less than 65 (Figure 8). Similar to juvenile chum salmon, other salmon catches increased during periods of increased river depth, and were highest between 02:00 and 06:00 (Figures 9 and 10).

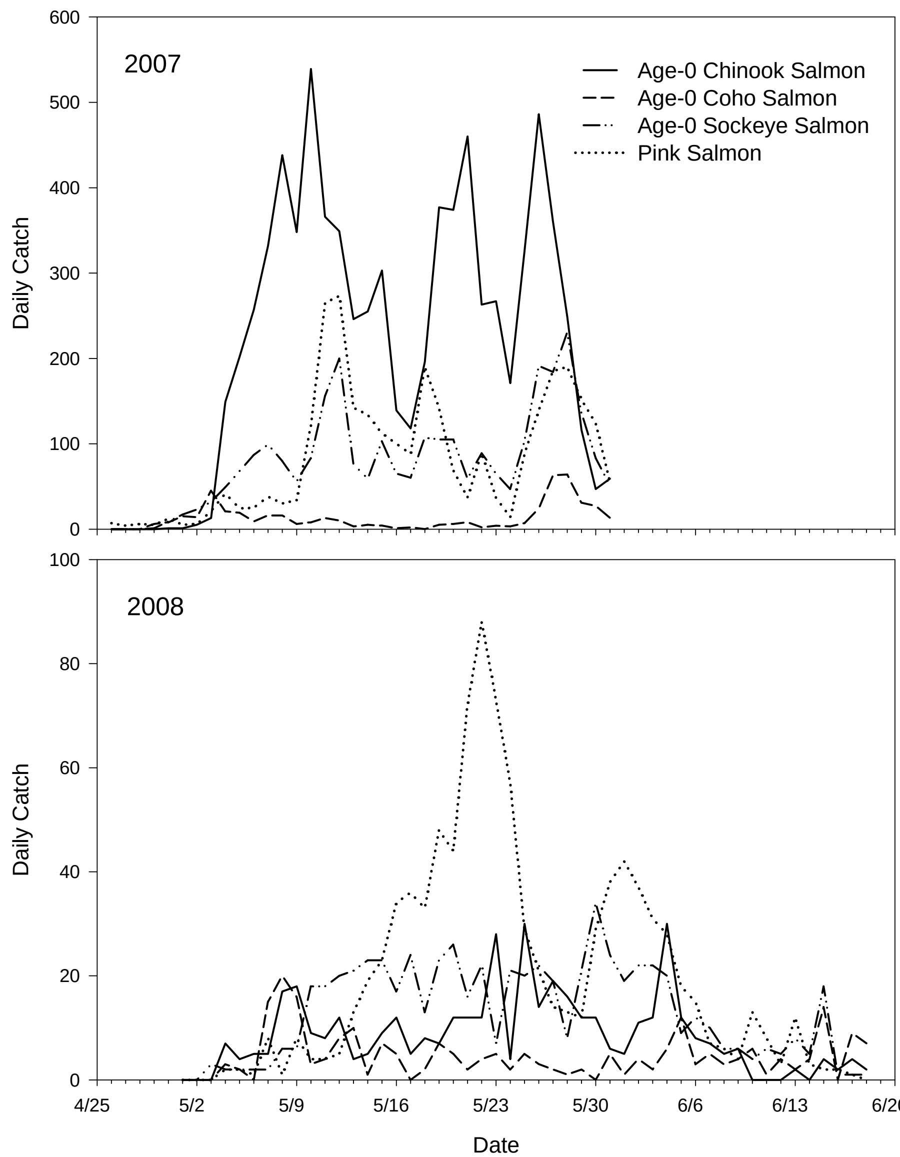

Figure 8. Daily catch of age-0 juvenile salmon on the Kwethluk River, Alaska.

Age-1+ Chinook, sockeye, and coho salmon catches were highest from 8 May – 30 May in 2007 and from 28 May - 6 June in 2008 (Figure 11). Peak catches of Chinook and coho salmon were on 26 May in 2007 (catches > 800), and on 3 June in 2008 (coho salmon > 250, Chinook salmon > 150; Figure 11). Daily catch of age-1+ sockeye salmon was usually < 100 per day in both years and peak catches (> 100 fish) occurred on 18 May in 2007 and 6 June in 2008 (Figure 11). Capture of all age-1+ salmon was closely associated with peaks in river height (Figure 11) and during early morning (02:00 - 06:00) hours (Figures 9 and 10). Catch of pink salmon peaked on 13 May in 2007 and 23 May in 2008. As with other salmon species, pink salmon catches were highest during hours of low light (Figures 9 and 10) and high water events.

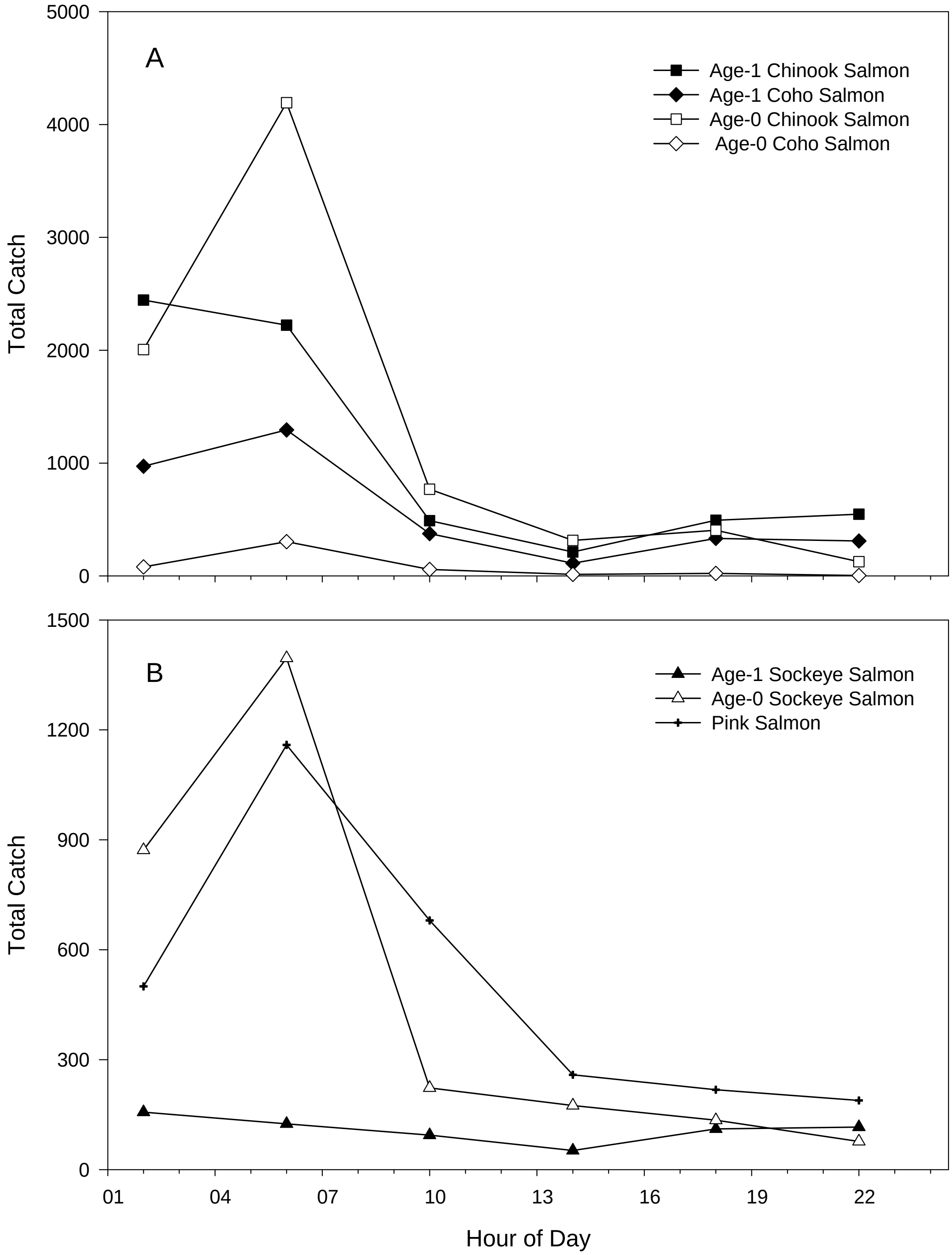

Figure 9. Total catch of Chinook and coho salmon (A) and sockeye and pink salmon (B) in the Kwethluk River, Alaska, 2007.

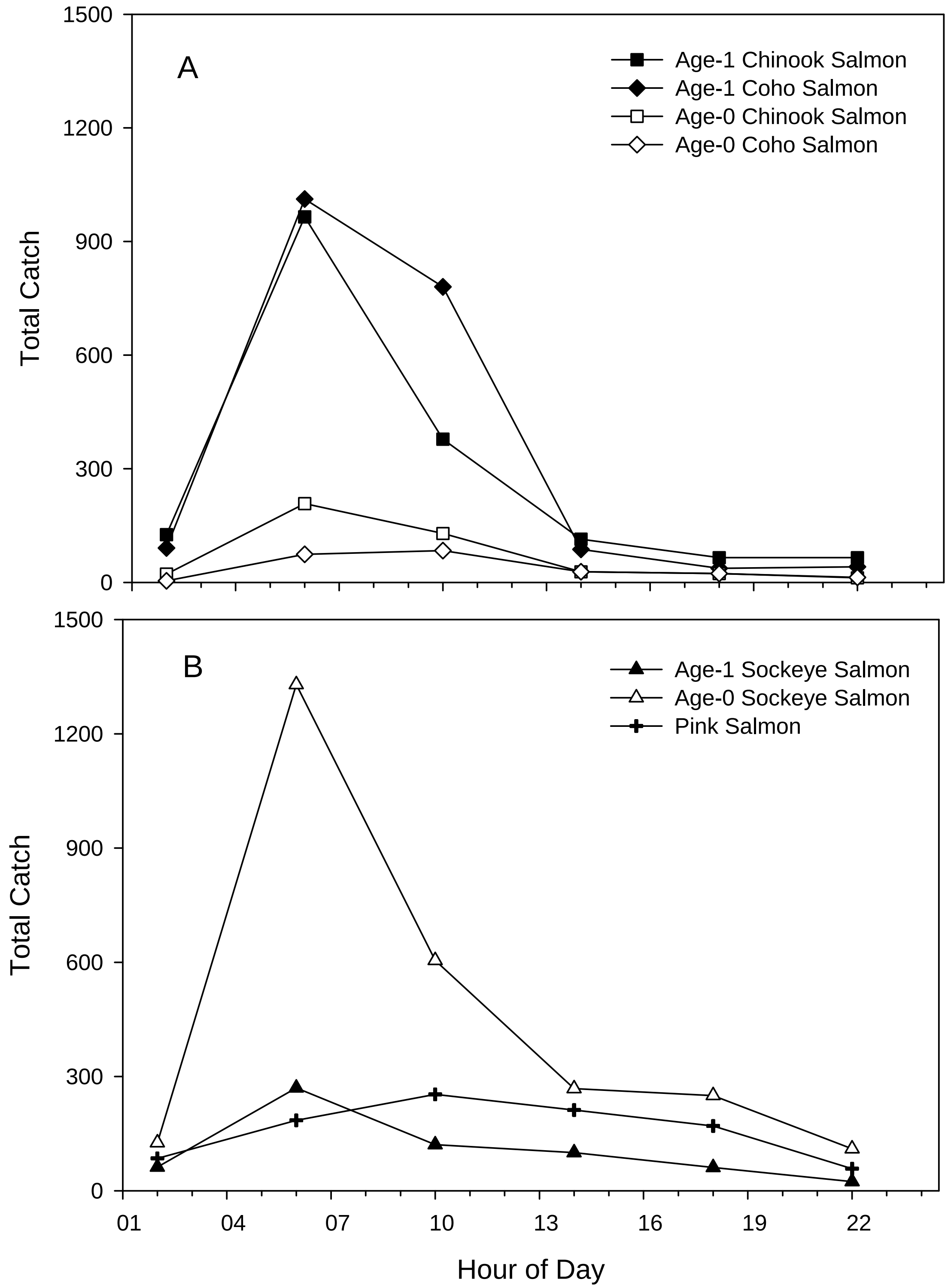

Figure 10. Total catch of juvenile Chinook and coho salmon (A) and sockeye and pink salmon (B) in the Kwethluk River, Alaska, 2008.

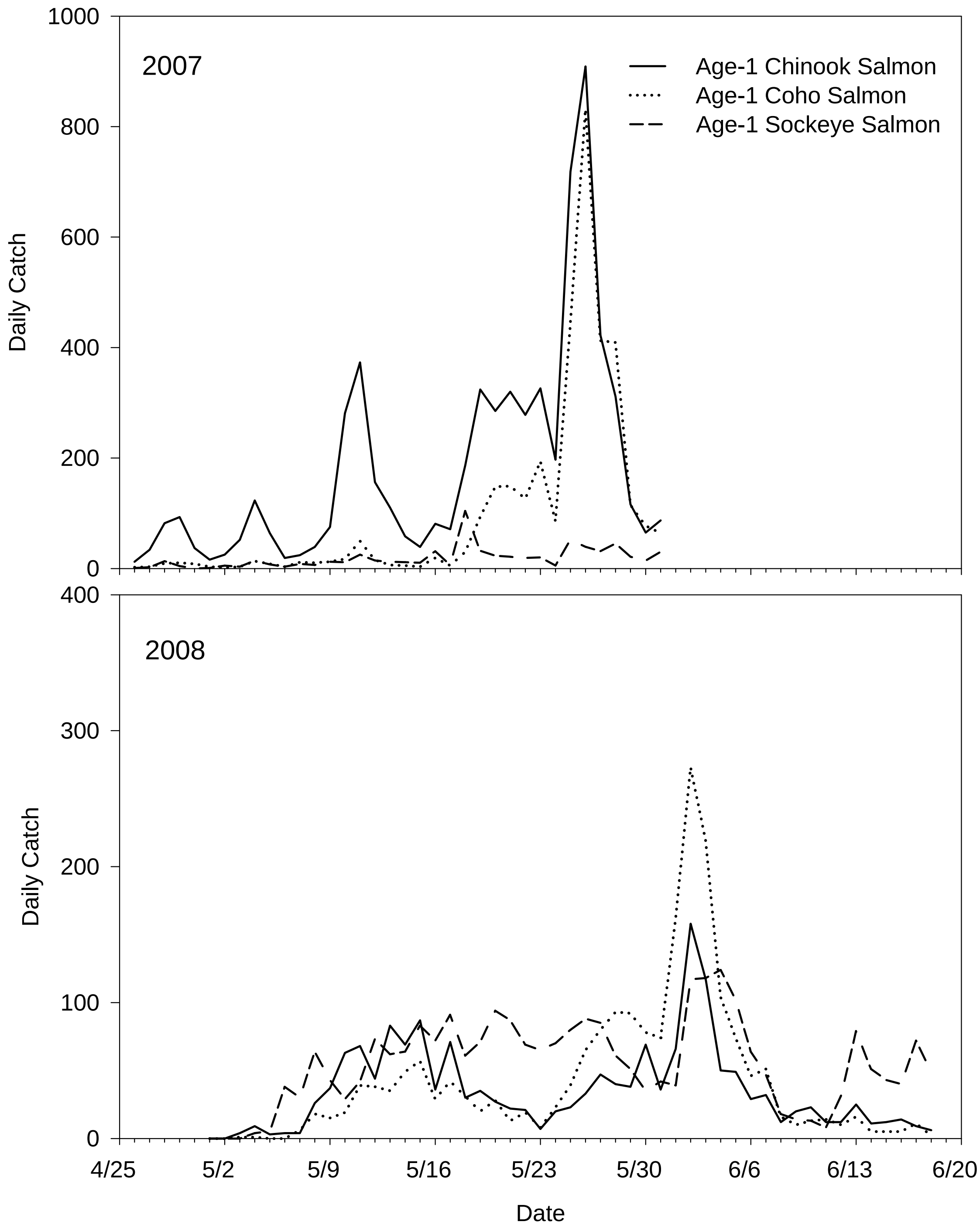

Figure 11. Daily catch of age 1+ juvenile salmon in the Kwethluk River, Alaska, 2007 - 2008.

Chum Salmon Abundance and Survival Estimates

We conducted 12 marking events, in 2007, and 24 marking events, in 2008, to determine trap efficiency (Table 2). In 2007, 20,950 juvenile chum salmon were marked and released and 415 were recaptured, resulting in an overall trap efficiency of 1.98% (Table 2). Individual Trap (Trap 1 and Trap 2) catches varied, and as a general trend the trap with the highest daily catch had the fewest number of recaptures (Appendix A). Trap 1 and Trap 2 had efficiencies of 1.1 % and 0.8 %, respectively.

In 2008, 35,301 juvenile chum salmon were marked and released and 685 were recaptured, resulting in an overall trapping efficiency of 1.94% (Table 2). Individual trap catches varied, but unlike in 2007, the trap with the highest catch in 2008 also had the highest number of recaptures (Appendix A).

In 2007, the estimated abundance of downstream migrant juvenile chum salmon was 2,004,691 fish (95% CI = 1,714,381 – 2,140,580). In 2008, the estimated abundance of downstream migrant juvenile chum salmon was 2,925,384 fish (95% CI = 2,803,109 – 3,210,697).

In 2006, PED for chum salmon (ages 0.2, 0.3, and 0.4) was 43,691,193 eggs (SD = ± 5,966,514). In 2007, PED was 56,094,447 eggs (SD = ± 892,062). Estimated egg-to-smolt survival for salmon migrating down stream in 2007 was 4.6% (SD = ± 0.71%). Estimated egg-to-smolt survival for salmon migrating down stream in 2008 was 5.2% (SD = ± 0.90%).

Table 2. Mark-recapture events, numbers of juvenile chum salmon marked and recaptured, and overall efficiency of incline plane traps on the Kwethluk River, Alaska.

Year	Event	Marks	Recaptures	Efficiency (%)
2007	1	782	12	1.53
	2	1463	18	1.23
	3	1102	17	1.54
	4	2229	37	1.66
	5	1869	27	1.44
	6	3102	102	3.29
	7	1592	22	1.38
	8	911	20	2.20
	9	3123	72	2.31
	10	1864	29	1.56
	11	2192	41	1.87
	12	721	18	2.50
Total		**20950**	**415**	**1.98**

Year	Event	Marks	Recaptures	Efficiency (%)
2008	1	1276	10	0.78
	2	793	6	0.76
	3	1011	8	0.79
	4	1088	8	0.74
	5	1421	10	0.70
	6	1576	10	0.63
	7	1484	18	1.21
	8	1696	27	1.59
	9	1221	22	1.80
	10	1524	17	1.12
	11	2816	50	1.78
	12	1871	53	2.83
	13	1705	25	1.47
	14	2138	47	2.20
	15	2244	75	3.34
	16	1295	25	1.93
	17	813	17	2.09
	18	942	20	2.12
	19	2351	55	2.34
	20	2871	88	3.07
	21	1249	30	2.40
	22	644	34	5.28
	23	564	18	3.19
	24	708	12	1.69
Total		**35301**	**685**	**1.94**

Environmental Data

Minimum and maximum air temperature fluctuated from -5 °C to 20 °C in 2007 and from -12 º C to 21 º C in 2008 (Appendix B). Water temperature ranged from a low of 1 °C to a high of 10 °C in 2007 and from 0 ºC to 13 ºC in 2008 (Figure 12, Appendix B). Stage height ranged from a low of 0.27 m on 9 May to a high of 0.70 m on 30 May in 2007 and from 0.23 m on 3 May to 0.75 m on 17 June in 2008 (Figure 12).

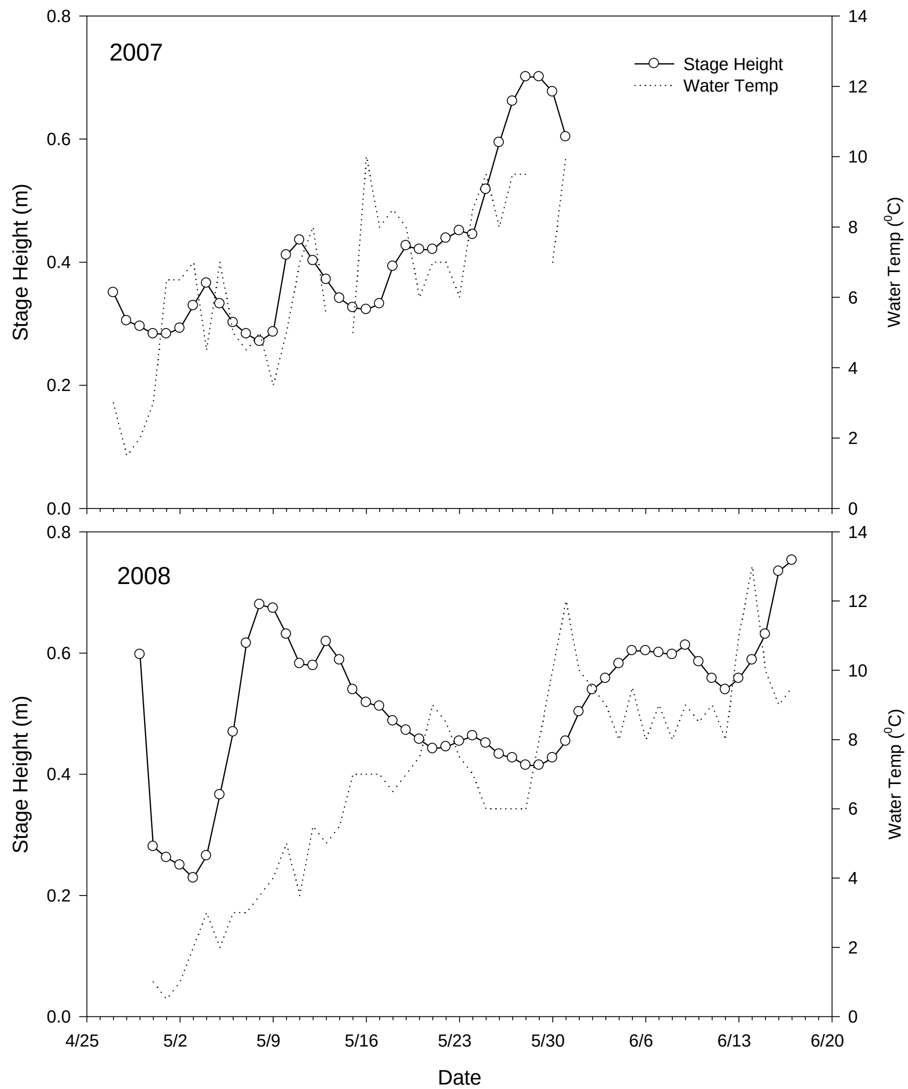

Figure 12. Daily stage height (m) and water temperature (ºC) for the Kwethluk River, Alaska, 2007 - 2008.

Discussion

This effort provides the first estimates of smolt abundance and egg-to-smolt survival in the Kuskokwim River watershed and the Arctic-Yukon-Kuskokwim region. Further, this is one of very few studies to quantify juvenile chum salmon abundance in Alaska. Our survival estimates of 4.6 and 5.2 % fall within the lower range of values previously reported (Table 3). The survival of chum salmon from spawning to emergence and migration varies widely among streams and among years within a stream (Salo 1991; Table 3).

Table 3. Egg-to-smolt survival of chum salmon from this study and published values.

		Survival		
Location	**Years sampled**	**Range (%)**	**Mean (%)**	**Source**
Kwethluk R. AK	2	4.6 - 5.2	4.9	This study
Disappearance Cr. AK	2	8.7 - 16.9	12.8	Wright (1964)[1]
Fraser R. BC	19	5.7 - 35.4	14.2	Beacham and Starr (1982)
Big Qualicum R. BC	4	5.0 - 17.0	11.2	Lister and Walker (1966)
Nile Cr. BC	4	0.1 - 7.0	1.5	Wickett (1952)[1]
Hooknose Cr. BC	14	1.0 - 22.0	8.5	Parker (1962)
Inches Cr. BC	4	1.6 - 18.8	8.9	Fedorenko and Bailey (1980)
Bolshaya R. Russia	7	0.7 - 4.2	2.4	Semko (1954)[1]
Memu R. Japan	3	16.2 - 34.4	27.6	Nagasawa and Sano (1961)[1]

[1]Cited in Salo (1991)

Bradford (1995) reported that egg-to-smolt survival of chum salmon ranges from 7 – 9% and estimates of greater variability result from the analysis of small coastal creeks in Alaska and British Columbia that are subject to extreme fluctuations in flow. Beacham and Starr (1982) used 19 years of chum salmon adult returns, PED, and smolt abundance to examine the relation between environmental variables and egg-to-smolt survival for chum salmon in the Fraser River, British Columbia. Egg-to-smolt survival was inversely related to the amount of winter rainfall, and much of the variability in survival was attributable to interactions among temperature, rainfall, and egg abundance (Beacham and Starr 1982). During the 19 years that Beacham and Starr (1982) quantified egg-to-smolt survival, estimates varied six fold. Similarly, in 14 years of sampling, Parker (1962) reported egg-to-smolt survival ranging from 1.0 - 22.0%. Given this broad range in survival estimates, long-term studies are needed to assess egg-to-smolt survival so that estimates can be reliably used in models of population dynamics.

Fluctuations in water depth (and hence, discharge) appeared to be the largest factor influencing the initiation of migration of juvenile chum salmon (Figure 6). Like other studies on juvenile salmon migration (Hoar 1958, Kobayashi and Ishikawa 1964), Kwethluk River juvenile abundance increased during high water events, and as previously reported (McDonald 1960, Volobuyev 1984), peak migration timing occurred during early morning (02:00 - 06:00). Peak migration occurred from mid-May through mid-June which coincides with timing of juvenile chum salmon migration from Yukon River tributaries (Martin and others 1986). Juvenile chum salmon were captured the first day of trap operation on 26 April suggesting an early to mid April migration time for some juveniles. In 2008, juvenile chum salmon were not captured until 1 May, which was likely due to the later break-up and colder water temperatures during that year (Appendix B). In addition, fluctuation in river height due to late snow melt at higher elevations likely affected the timing of peak juvenile chum salmon migration between sampling years.

In part, this study was intended to develop and test methods for estimating smolt abundances of salmon in a Kuskokwim River tributary. While numerous studies and methods have been developed for use elsewhere (see Volkhardt and others 2007), methods of this type have not been attempted in the AYK region. Differences in duration of ice cover, break-up dates, size of rivers, and difficulty of access within this region prompted the need for modifications to previously developed protocols and methods. Our previous experience operating inclined plane traps in this region led us to make several modifications to the traps as described by Todd (1994). The trap modifications and design were relatively untested previous to this project. After the first year of sampling, there were a few concerns with the sampling protocol that needed to be addressed. Of biggest concern was the variability in individual trap efficiency (Appendix A). In 2007, the trap with the highest catch of juvenile chum salmon caught the lowest number of recaptures. This suggests that upon release the marked juveniles did not mix back into the population effectively, which is problematic for the assumptions of a mark-recapture experiment. During 2007, marked fish were kept in holding pens at the trap site until just prior to release. They were then dip netted into buckets and transported upstream where they were immediately released. As a potential remedy for this problem, during 2008, we placed holding pens on both sides of the river at the release site. Marked fish were allowed to recover for 6 to 8 hours and then allowed to resume migration of their own volition. In 2008, individual trap catches were as expected; the trap with the highest catch also had the highest number of recaptures suggesting that the 2007 trap efficiency issues were due to method of release. This problem also emphasizes the importance of using two traps for this project. If only one trap had been used, the 2007 bias of marked individuals not mixing properly into the main population of downstream migrants would not have been detected and, as a result, abundance estimates would be misleading.

Predation within the live boxes of the traps may have lead to biases in the estimation of trapping efficiency. In 2007, we observed active predation of chum salmon by Chinook and coho salmon. To reduce the potential for predation, we installed predator screens in the live boxes for the 2008 field season. The screens were designed to separate the larger predatory juvenile salmon (age 1+ Chinook and coho) from the age-0 juveniles.

Trap efficiency appeared to vary with changes in water level, both overall and between traps. One trap was more efficient during high water events, while the other trap was more efficient during times of low water. One explanation for this could be during times of high water discharge juvenile chum salmon preferred the shallower water where one trap was positioned; conversely, when water was low and clear, juveniles preferred the deeper channel where the other trap was located. In 2007, more than double the total number of juvenile chum salmon were captured; however the abundance estimate was approximately 1 million fish lower than in 2008. The lower water levels and higher trap efficiencies in 2007 are the likely cause for this result. Similar findings of reduced trap efficiency associated with high water were reported by Todd (1994) who used inclined-plane smolt traps on the Kasilof River, Kenai Peninsula, Alaska.

This project design proved effective for sampling juvenile salmon with an immediate seaward migration, and may be useful in estimating abundance of other salmon species. Application of this method to estimate the abundance of other salmon species with multiple age classes is possible if fish rear exclusively upstream of the trapping location. If juvenile salmon migrate downstream to rear in other locations, estimates of freshwater survival would need to account for survival in non-natal habitats.   In addition, the population size would have to be large enough to provide an adequate number of marks for the abundance estimation.

Bradford (1995), in a review of survival rates of Pacific salmon, found that the freshwater stage is important in determining recruitment of salmon, even for pink and chum salmon that spend most of their life in the sea. Future monitoring of juvenile salmon abundance, coupled with adult salmon monitoring, will provide needed information to expand our ability to determine the relative importance of mortality in freshwater habitats of the Kwethluk River.

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Appendix A.

Mark-Recapture data for trap 1 (T1) and trap 2 (T2), Kwethluk River, 2007 and 2008.

Year	Event	Marks Released	Unmarked Catch	T1Catch	T2Catch	T1 Recaps	T2 Recaps	T1 Efficiency %	T2 Efficiency %
2007	1	782	1870	1148	722	10	2	1.28	0.26
	2	1463	2041	1314	727	15	3	1.03	0.21
	3	1102	2687	1671	1016	13	4	1.18	0.36
	4	2229	7236	4300	2936	21	16	0.94	0.72
	5	1869	6835	2798	4037	10	17	0.54	0.91
	6	3102	2541	1011	1530	66	36	2.13	1.16
	7	1592	1087	251	836	17	5	1.07	0.31
	8	911	4494	1848	2646	14	6	1.54	0.66
	9	3123	4184	1304	2880	24	48	0.77	1.54
	10	1864	2746	884	1862	12	17	0.64	0.91
	11	2192	8632	2833	5799	16	25	0.73	1.14
	12	721	574	329	245	17	1	2.36	0.14
Total		**20950**	**44927**	**19691**	**25236**	**235**	**180**	**1.18**	**0.69**

Appendix A. (Continued)

Mark-Recapture data for trap 1 (T1) and trap 2 (T2), Kwethluk River, 2007 and 2008.

Year	Event	Marks Released	Unmarked Catch	T1Catch	T2Catch	T1 Recaps	T2 Recaps	T1 Efficiency %	T2 Efficiency %
2008	1	1276	858	664	194	6	4	0.47	0.31
	2	793	1069	837	232	5	1	0.63	0.13
	3	1011	1080	841	239	7	1	0.69	0.10
	4	1088	1362	1001	361	4	4	0.37	0.37
	5	1421	1722	1410	312	9	1	0.63	0.07
	6	1576	1690	1149	541	6	4	0.38	0.25
	7	1484	1746	1142	604	13	5	0.88	0.34
	8	1696	1388	815	573	18	9	1.06	0.53
	9	1221	1624	992	632	7	15	0.57	1.23
	10	1524	2021	889	1132	15	2	0.98	0.13
	11	2816	1176	600	576	24	26	0.85	0.92
	12	1871	1006	410	596	19	34	1.02	1.82
	13	1705	1333	812	521	8	17	0.47	1.00
	14	2138	1133	453	680	16	31	0.75	1.45
	15	2244	751	282	469	19	56	0.85	2.50
	16	1295	443	134	309	6	19	0.46	1.47
	17	813	497	154	343	10	7	1.23	0.86
	18	942	2640	1520	1120	9	11	0.96	1.17
	19	2351	2567	1912	655	36	19	1.53	0.81
	20	2871	1279	861	418	60	28	2.09	0.98
	21	1249	508	286	222	25	5	2.00	0.40
	22	644	330	205	125	26	8	4.04	1.24
	23	564	113	71	42	14	4	2.48	0.71
	24	708	601	382	219	6	6	0.85	0.85
Total		**35301**	**28937**	**17822**	**11115**	**368**	**317**	**1.09**	**0.82**

Appendix B.

Daily catches of juvenile chum salmon along with readings for stream gage height, maximum water temperature, and minimum and maximum air temperature, Kwethluk River, 2007 and 2008.

Year	Date	Chum Catch	Max Gage Height (m)	Max Water Temp (ºC)	Min Air Temp (ºC)	Max Air Temp (ºC)
2007	4/26/2007	29				
2007	4/27/2007	46	0.35	3.0	-5	
2007	4/28/2007	495	0.30	1.5	-4	
2007	4/29/2007	509	0.30	2.0	-3	
2007	4/30/2007	563	0.28	3.0		
2007	5/1/2007	510	0.28	6.5		
2007	5/2/2007	641	0.29	6.5	-2	12
2007	5/3/2007	1873	0.33	7.0	0	13
2007	5/4/2007	2815	0.37	4.5	-2	4
2007	5/5/2007	1956	0.33	7.0	-1	9
2007	5/6/2007	1344	0.30	5.0	-1	7
2007	5/7/2007	1592	0.28	4.5	0	5
2007	5/8/2007	2574	0.27	5.0	1	7
2007	5/9/2007	2174	0.29	3.5	0	
2007	5/10/2007	5074	0.41	5.0	1	11
2007	5/11/2007	6852	0.44	7.0	-1	14
2007	5/12/2007	4842	0.40	8.0		
2007	5/13/2007	2557	0.37	5.5		
2007	5/14/2007	1816	0.34		2	0
2007	5/15/2007	3534	0.33	5.0	3	14
2007	5/16/2007	1777	0.32	10.0	-2	20
2007	5/17/2007	1390	0.33	8.0	6	18
2007	5/18/2007	4783	0.39	8.5	5	11
2007	5/19/2007	10074	0.43	8.0	3	13
2007	5/20/2007	4149	0.42	6.0	2	0
2007	5/21/2007	3429	0.42	7.0	3	13
2007	5/22/2007	2959	0.44	7.0	2	18
2007	5/23/2007	2684	0.45	6.0		

Year	Date	Chum Catch	Max Gage Height (m)	Max Water Temp (ºC)	Min Air Temp (ºC)	Max Air Temp (ºC)
2007	5/24/2007	1102	0.45	8.5	7	15
2007	5/25/2007	5088	0.52	9.5	7	0
2007	5/26/2007	8636	0.59	8.0	7	19
2007	5/27/2007	4857	0.66	9.5	7	15
2007	5/28/2007	4612	0.70	9.5	3	16
2007	5/29/2007	1294	0.70		1	16
2007	5/30/2007	574	0.68	7.0	2	15
2007	5/31/2007	211	0.60	10.0	6	16
2008	4/29/2008		0.60		-12	2
2008	4/30/2008		0.28	1.0	0	2
2008	5/1/2008	1	0.26	0.5	-8	1
2008	5/2/2008	1	0.25	1.0	-7	3
2008	5/3/2008	35	0.23	2.0	-2	10
2008	5/4/2008	224	0.27	3.0	0	13
2008	5/5/2008	238	0.37	2.0	-2	13
2008	5/6/2008	525	0.47	3.0	-4	12
2008	5/7/2008	832	0.62	3.0	0	11
2008	5/8/2008	858	0.68	3.5	3	11
2008	5/9/2008	1069	0.67	4.0	3	11
2008	5/10/2008	1080	0.63	5.0	3	11
2008	5/11/2008	1362	0.58	3.5	2	9
2008	5/12/2008	1722	0.58	5.5	2	13
2008	5/13/2008	1690	0.62	5.0	1	11
2008	5/14/2008	1746	0.59	5.5	-1	12
2008	5/15/2008	1388	0.54	7.0	1	14
2008	5/16/2008	1624	0.52	7.0	1	13
2008	5/17/2008	2021	0.51	7.0	-2	13
2008	5/18/2008	1037	0.49	6.5	-2	13
2008	5/19/2008	1176	0.47	7.0	3	9
2008	5/20/2008	1485	0.46	7.5	-4	13
2008	5/21/2008	1006	0.44	9.0	0	16
2008	5/22/2008	733	0.45	8.5	2	16
2008	5/23/2008	1333	0.45	7.5	4	13
2008	5/24/2008	1270	0.46	7.0	2	13
2008	5/25/2008	1133	0.45	6.0	3	9

Year	Date	Chum Catch	Max Gage Height (m)	Max Water Temp (ºC)	Min Air Temp (ºC)	Max Air Temp (ºC)
2008	5/26/2008	1164	0.43	6.0	0	9
2008	5/27/2008	751	0.43	6.0	0	9
2008	5/28/2008	517	0.41	6.0	3	10
2008	5/29/2008	443	0.41	8.0	4	15
2008	5/30/2008	350	0.43	10.0	3	20
2008	5/31/2008	497	0.45	12.0	4	19
2008	6/1/2008	867	0.50	10.0	4	18
2008	6/2/2008	2640	0.54	9.5	4	17
2008	6/3/2008	2567	0.56	9.0	6	15
2008	6/4/2008	2278	0.58	8.0	6	11
2008	6/5/2008	1279	0.60	9.5	4	17
2008	6/6/2008	726	0.60	8.0	1	10
2008	6/7/2008	508	0.60	9.0	0	8
2008	6/8/2008	331	0.60	8.0	1	10
2008	6/9/2008	330	0.61	9.0	2	13
2008	6/10/2008	210	0.59	8.5	1	14
2008	6/11/2008	121	0.56	9.0	1	13
2008	6/12/2008	113	0.54	8.0	2	14
2008	6/13/2008	240	0.56	11.0	1	21
2008	6/14/2008	181	0.59	13.0	7	21
2008	6/15/2008	1080	0.63	10.0	7	13
2008	6/16/2008	601	0.73	9.0	7	17
2008	6/17/2008	477	0.75	9.5	4	
2008	6/18/2008	119				