Emigration timing, abundance, and egg-to-smolt survival of juvenile chum salmon at Clear Creek, Alaska and comparisons to other systems

Christian E. Zimmerman and Sean E. Burril

U.S. Geological Survey

Alaska Science Center

4210 University Dr.

Anchorage, Alaska, USA

czimmerman@usgs.gov

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Abstract

To describe the emigration timing and gain a better understanding of survival partitioning among life stages of chum salmon, *Oncorhynchus keta* (Walbaum), near the northern extent of their range, we used incline plane smolt traps and mark recapture methods to monitor seaward emigration, estimate abundance, and determine egg-to-smolt survival in Clear Creek (2002 through 2005) and the Kwethluk River (2007 and 2008), Alaska; two freshwater habitats contrasting in size and latitude. Emigration occurred from May 7 through June 8 and from April 29 through June 18 for Clear Creek and the Kwethluk River, respectively. For both sampling sites, the first pulse in emigration was associated with a warming in water temperature from 0.0 to 1.5 ^{o}C. Greater than 50% of all juvenile chum salmon were caught in Clear Creek while water temperatures ranged between 1.0 and 2.0 ^{o}C, but >50% of the Kwethluk River juveniles were caught while temperatures ranged from 5.0 to 8.0 ^{o}C. Abundance peaked between mid-to-late May for all years at both sites, and overall abundance ranged from 0.5 to 3.0 million in Clear Creek and 2.0 to 2.9 million in the Kwethluk River. Egg-to-smolt survival was higher (range = 10.5 – 20.5%) but more variable in Clear Creek than the Kwethluk River (range = 4.6 – 5.2%). This study is one of only a few studies to describe the emigration, and the first study to estimate abundance and egg-to-smolt survival for wild juvenile chum salmon in Alaska.

Introduction

Chum salmon, *Oncorhynchus keta* (Walbaum), inhabit a broad geographic range around the North Pacific Ocean. Within this range, data are limited concerning freshwater life history and primarily comes from populations near the southern extent. Due to environmental extremes associated with high latitude environments, especially during winter months corresponding to incubation, constraints on the egg-to-smolt life stage are likely different from those experienced by southern populations. A better understanding of the early life history is needed to help predict abundance and evaluate the relative role of freshwater vs. marine mortality in estimating abundance of salmon returns, an important step in the sustainability of this resource.

Chum salmon, in many of northwestern Alaska's watersheds, have experienced unexplained declines in recent years (NRC 2005; AYK SSI 2006). Due to lack of general knowledge concerning salmon populations and their habitat in these areas, it is difficult for fisheries managers to determine appropriate management actions in response to such declines (Shotwell & Adkison 2004; NRC 2005). Escapement goals, within the Artic-Yukon-Kuskokwim (AYK) watershed, are established based on stock-recruit relationships of returning adult chum salmon counts (Clark *et al.* 2009; Linderman & Bergstrom 2009). Because these relationships are constructed using only adult counts, they combine mortality across all life stages and habitats. Estimates of abundance at early life-stages would enable a more detailed partitioning of survival among all life-stages and facilitate hypothesis development for restoration and management actions (Moussalli & Hilborn 1986; Mobrand *et al.* 1997; Beamish & Sweeting 2009). In addition, knowledge of environmental constraints on emigration timing can give insight into how a changing environment might affect chum salmon near the northern extent of their range.

Typically, estimation of egg-to-adult survival is determined by construction of age data from adult scale samples. An estimate of egg-to-adult survival gives no information about variation in survival between the different early life history stages of salmon (i.e. egg-to-fry, fry-to-smolt, estuarine residence). An estimate of egg-to-smolt/fry survival can be difficult to obtain, and often times invasive, as it requires disruption of spawning habitat to obtain counts of surviving fry from redds (Beland 1996). Inclined-plane traps and other smolt trapping methods allow estimation via mark recapture methods; this technique is less invasive and allows for immediate estimation of abundance and survival if adult abundance estimates are available. In addition to providing short-term feedback on the effect that changes in spawning habitat have on survival, mark-recapture data also allow researchers to partition mortality between freshwater (egg-to-smolt) and marine life stages (smolt-to-adult; Volkhardt *et al.* 2007).

In this study, we described the emigration and estimated the survival of juvenile chum salmon from egg-to-smolt in Clear Creek and the Kwethluk River, Alaska. Our goal was to determine the emigration timing and environmental constraints influencing emigration behavior and compare survival rates between Clear Creek and the Kwethluk River, two rivers contrasting in size and latitude.

Study Area

Clear Creek is a clear water tributary that originates in the Zane Hills of northwestern Alaska, and flows approximately 40 km to the east before entering the Hogatza River (Koyukuk River Drainage; Figure 1). In addition to chum salmon, Clear Creek provides habitat for Chinook salmon, *O. tshawytscha* (Walbaum), and 6 other non-salmonid fish including: Sculpin (Cottidae), Arctic grayling (*Thymallus arcticus*), Burbot (*Lota lota*), whitefish (Coregonidae), Arctic char (*Salvalinus alpinus*), and Alaska blackfish (*Dalia pectoralis*). To monitor adult salmon returns on Clear Creek, the Bureau of Land Management and the U.S. Fish and Wildlife Service operate a resistance board weir at approximate river km 1.2 (N 60^{o} 13’17.0”, W 155^{o} 30’20.0”). Seven-year averages of salmon passing the weir are: 14,323 chum salmon, 9 Chinook salmon, and 7 sockeye salmon (5-year average).

The Kwethluk River is a clear water/tannin-stained run-off system that originates in the Kilbuk Mountains of southwest Alaska and flows northeast approximately 230 km before joining the Kuskokwim River 31 km upstream of Bethel (Figure 1). This watershed drains approximately 3,400 km^2. The Kwethluk River provides habitat for chum, Chinook, coho, *O. kisutch* (Walbaum), sockeye, *O. nerka* (Walbaum), and pink, *O. gorbuscha* (Walbaum) salmon. Other fish species occurring within the watershed include: rainbow trout (*O. mykiss*), Dolly Varden (*Salvelinus malma*), Alaska blackfish, Arctic grayling, Northern pike (*Esox lucius*), whitefish spp., burbot, and nine-spine stickleback (*Pungitius pungitius*). 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 approximate river km 88 (N 60^{o} 29’44.7” , W 161^{o} 05’54.8” W). 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 *et al.* 2009).

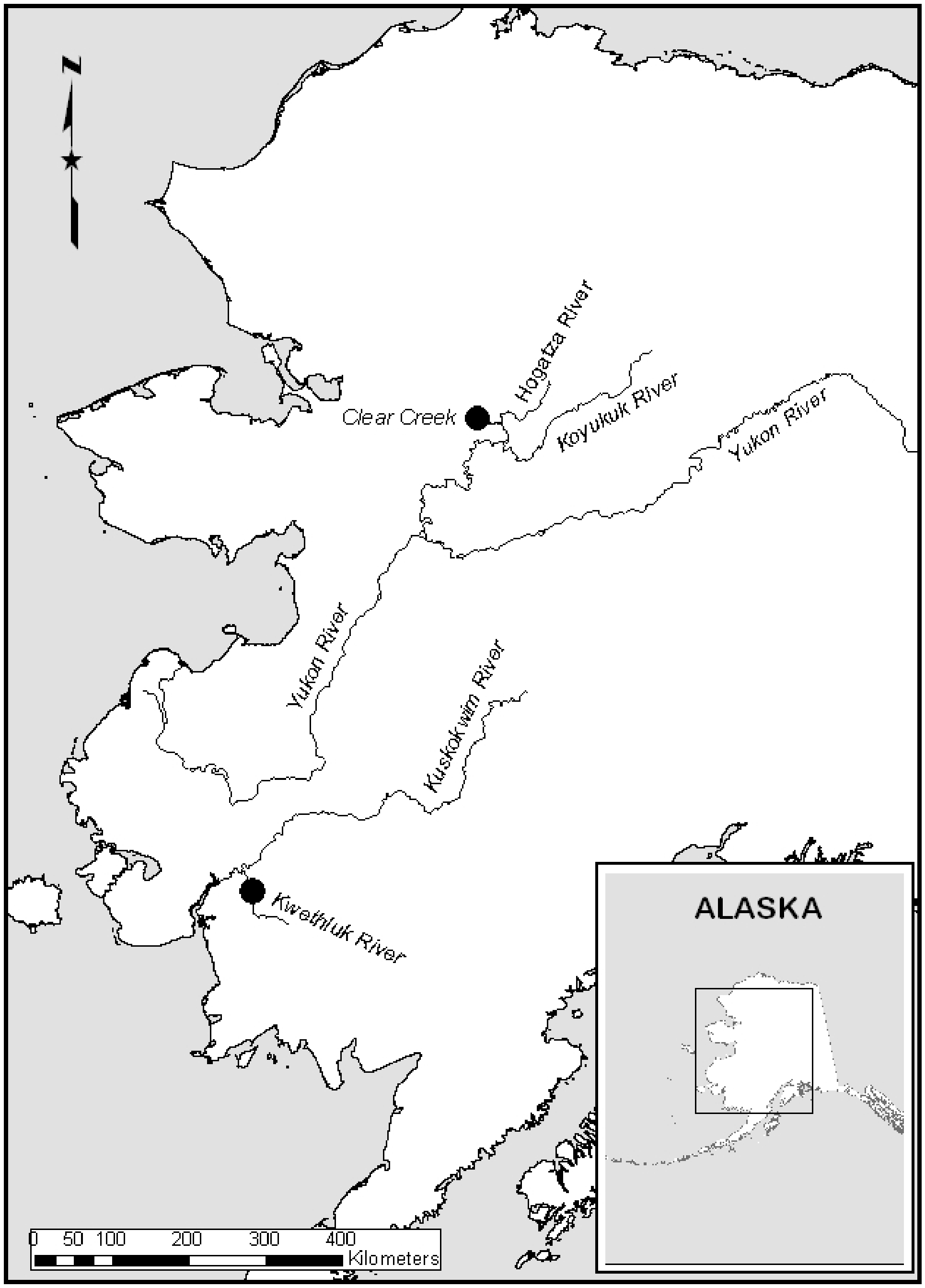

Figure 1. Map of the study area with sampling sites indicated by shaded circles.

Methods and Materials

Emigration Timing

In both Clear Creek and the Kwethluk River, incline-plane smolt traps were used to capture juvenile chum salmon during their seaward migration (Todd 1994). We used a "One Trap" scenario (Carlson *et al.* 1998) which consisted of two traps positioned on opposite banks. Trap checks were made every 4 hours in a 24-hour period. During periods of high flow or debris loads, traps were checked every 2 hours to avoid reductions in flow. Unless a sample of fish was held for marking, all fish were released after counting.

Upon arrival at both Clear Creek and the Kwethluk River field location, we installed a staff gage to monitor changes in water stage height. A staff gage reading was taken twice daily, once in the morning (08:00 hours) and evening (20:00 hours). Air and water temperature were recorded daily. Air temperature was recorded using a min/max thermometer, and water temperature was recorded using 3 Tidbit Temperature loggers (set at 15 minute intervals) suspended one from each trap, and one to a solid bank structure.

To describe yearly migration timing, the 25, 50, and 75% quartiles were calculated for Clear Creek and the Kwethluk River. In addition, dates of the first emigration pulse and peak emigration were recorded. First pulse is described as the first sustained increase in daily abundance, and peak emigration is described as the date with the largest daily catch. To investigate the effects of water temperature on emigration timing, daily minimum water temperature was grouped into six categories: ≤0, 1 to 2, 3 to 4, 5 to 6, 7 to 8, and ≥9 ^{o}C, and the percent of total juvenile chum salmon catch that occurred within each category was calculated. Also calculated was the percentage of total sampling days in which water temperatures were within each category.

Abundance Estimation

To estimate abundance of juvenile chum salmon we used mark recapture methodology. To mark fish we used a solution of Bismarck Brown Y dye, 0.5 g dye/15 liters of water. The maximum holding time in the dye solution was 2 hours. Chum salmon smolts were allowed to recover in holding tubs for a minimum of 2 hours prior to release. The manner in which marked smolts were released followed a one trap method. Fish were transported upstream approximately 1 km by boat and released. Release was timed as close to midnight as possible during all release events. The frequency of marking events was driven by: changes in the trap position (when a trap was moved we needed to re-estimate efficiency), and changes in the stream flow (ideally trap efficiency was evaluated whenever there was 10 cm change in the stream gage height). The target number of marked smolts for any marking period was a function of trap efficiency and the desired level of precision (Carlson *et al.* 1998).

Abundance estimates of chum salmon smolts followed the mark-recapture estimators and design developed by Carlson *et al.* (1998). Estimates of total fish passage were dependant on trapping efficiency (i.e., the proportion of recaptures to total marks released). Trapping efficiency was estimated over the range of flows experienced during the season.

Survival Estimation

Percent survival of juvenile chum salmon was estimated using potential egg deposition (PED, i.e., the maximum number of eggs brought into the system by spawning females) and abundance as determined above. Estimates of PED were calculated using adult female chum salmon age distribution and abundance data from Clear Creek and Kwethluk River weirs

(Kretsinger, unpublished data; Miller *et al.* 2009), in addition to fecundity data from literature values of stock specific age/fecundity relationships (Finn *et al.* 1998; Gilk *et al.* 2005). After each field season, we used the smolt abundance estimates in conjunction with the previous year (parental year) female escapement and fecundity estimates to calculate survival. Survival estimates were calculated as:

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

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

Egg-to-adult survival estimates were obtained using available weir data and age-sex-length (ASL) data to back calculate survival. Clear Creek data were obtained from personal communication with Carl Kretsinger (Bureau of Land Management), and the Kwethluk River data were obtained from United States Fish and Wildlife Service weir data. Only one year from Clear Creek (2000) and the Kwethluk River (2003) had sufficient data to perform a complete calculation.

Table 1. Dates of emigration events for juvenile chum salmon.

	First Pulse	Peak Emigration	Emigration Quartile 25%	50%	75%
Clear Creek					
2002	19 May	21 May	20 May	23 May	30 May
2003	11 May	23 May	22 May	24 May	26 May
2004	11 May	24 May	15 May	17 May	23 May
2005	12 May	15 May	15 May	18 May	21 May
Kwethluk River					
2007	28 April	19 May	10 May	18 May	24 May
2008	4 May	2 June	14 May	22 May	2 June

Results

Emigration Timing

In Clear Creek, juvenile chum salmon emigrated between May 7 and June 8 in all years. The first major pulse of emigrating juveniles occurred between May 11 and May 19 in all years (Table 1). The majority of juvenile chum salmon (75%) emigrated within a 15-day period from May 15 to May 30 in all years, and peak emigrations occurred between May 15 and May 24 (Table 1).

In the Kwethluk River juvenile chum salmon emigrated between April 29 and June 18 for 2007 and 2008. The first pulse of emigrating juveniles occurred on April 28 and May 4 for 2007 and 2008 respectively (Table 1). The majority (75%) of juveniles emigrated within a 14-day period from May 10 to May 24 (2007) and from May 14 to June 2 (2008; Table 1). In 2007, the emigration was near its end by June 1, but continued until June 18 in 2008. Peak emigration of juvenile chum salmon occurred on May 19 and June 2 for 2007 and 2008 respectively.

Emigration in response to environmental conditions was variable within and between watersheds. In Clear Creek, greater than 50% of all juvenile chum salmon were caught while water temperatures were between 1.0 and 2.0 ^{o}C, except in 2002 when most juveniles were captured at temperatures between 3 to 4 ^{o}C (Table 2). The first pulse in emigration was associated with a warming in water temperature between 0 to 1.0 ^{o}C, with the exception of 2002 (Figure 2; Table 1).

Emigration in the Kwethluk River occurred over a range in water temperature from 0.0 to 12.0 ^{o}C, with greater than 50% of all juvenile chum salmon being caught at temperatures between 5.0 and 8.0 ^{o}C (Table 2). The first pulse in emigration was associated with a warming in water temperature between 0.0 to 1.5 ^{o}C (Figure 3, Table 1).

Abundance Estimation

Estimated abundance of juvenile chum salmon in Clear Creek ranged from 0.5 million in 2002 to 3.0 million in 2005, and followed an even/odd year cycle, with larger estimates on odd years (Table 3). Abundance estimates of juvenile chum salmon on the Kwethluk River were 2.0 million in 2007, and 2.9 million in 2008 (Table 3). In both Clear Creek and the Kwethluk River, estimates of juvenile chum salmon were higher in years with a higher PED, with the exception of 2005 on Clear Creek (Table 3).

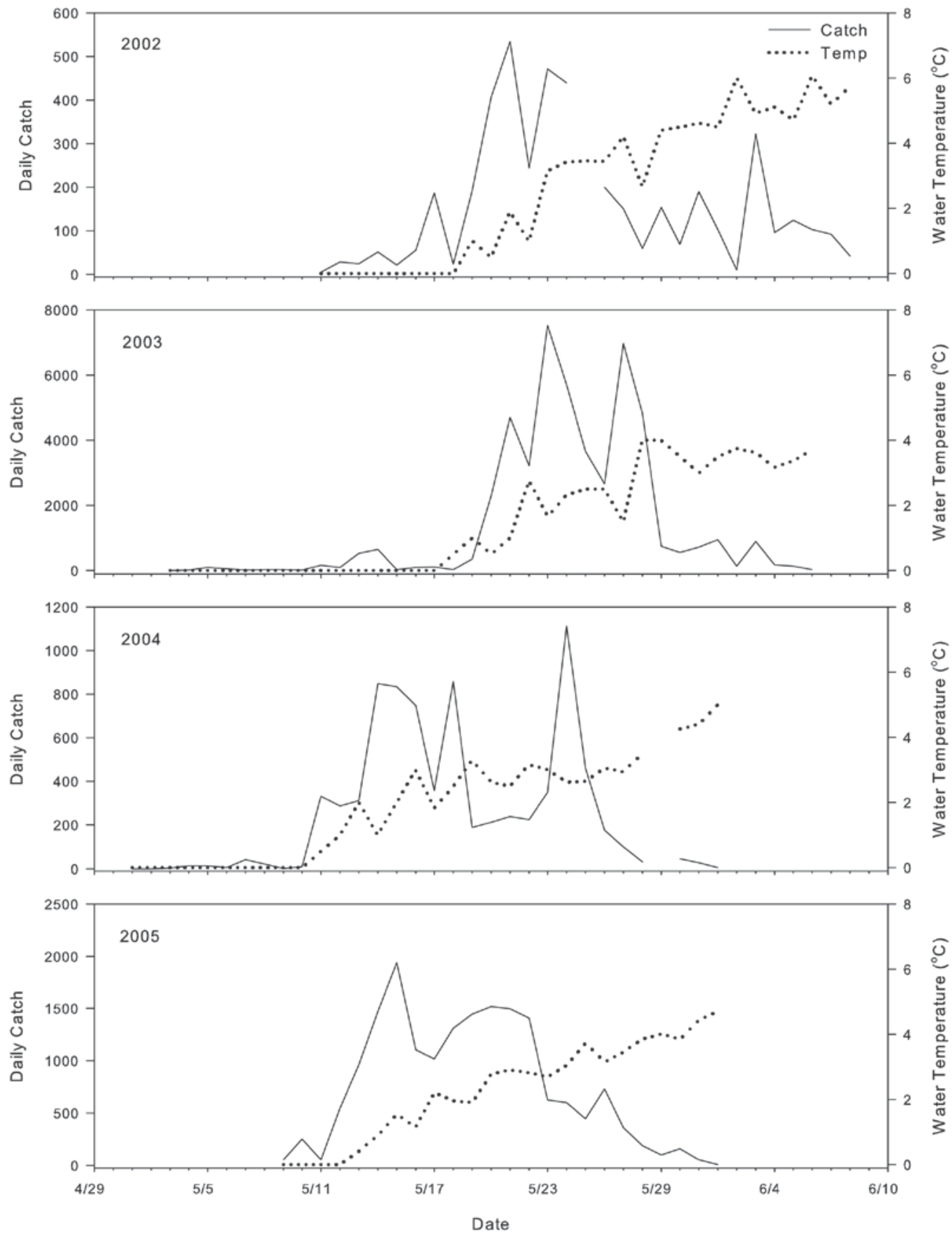

Figure 2. Daily catch of juvenile chum salmon and daily water temperature for years sampled on Clear Creek, Alaska.

Table 2. Percentage of total juvenile chum salmon that emigrated within each water temperature range. Value in parenthesis indicates percentage of total days water temperature was within given range.

	Temperature Category					
	≤0 °C	1 to 2 °C	3 to 4 °C	5 to 6 °C	7 to 8 °C	≥9 °C
Clear Creek						
2002	18 (31)	23 (10)	51 (34)	8 (17)	-	-
2003	9 (49)	72 (23)	19 (29)	-	-	-
2004	5 (33)	68 (37)	23 (27)	<1 (3)	-	-
2005	19 (25)	67 (38)	15 (33)	-	-	-
Average	13 (35)	58 (27)	27 (31)	4 (10)	-	-
Kwethluk River						
2007	<1 (3)	1 (6)	7 (11)	27 (31)	52 (36)	13 (14)
2008	1 (8)	3 (6)	14 (10)	32 (22)	22 (24)	27 (27)
Average	1 (6)	2 (6)	11 (11)	30 (27)	37 (30)	20 (21)

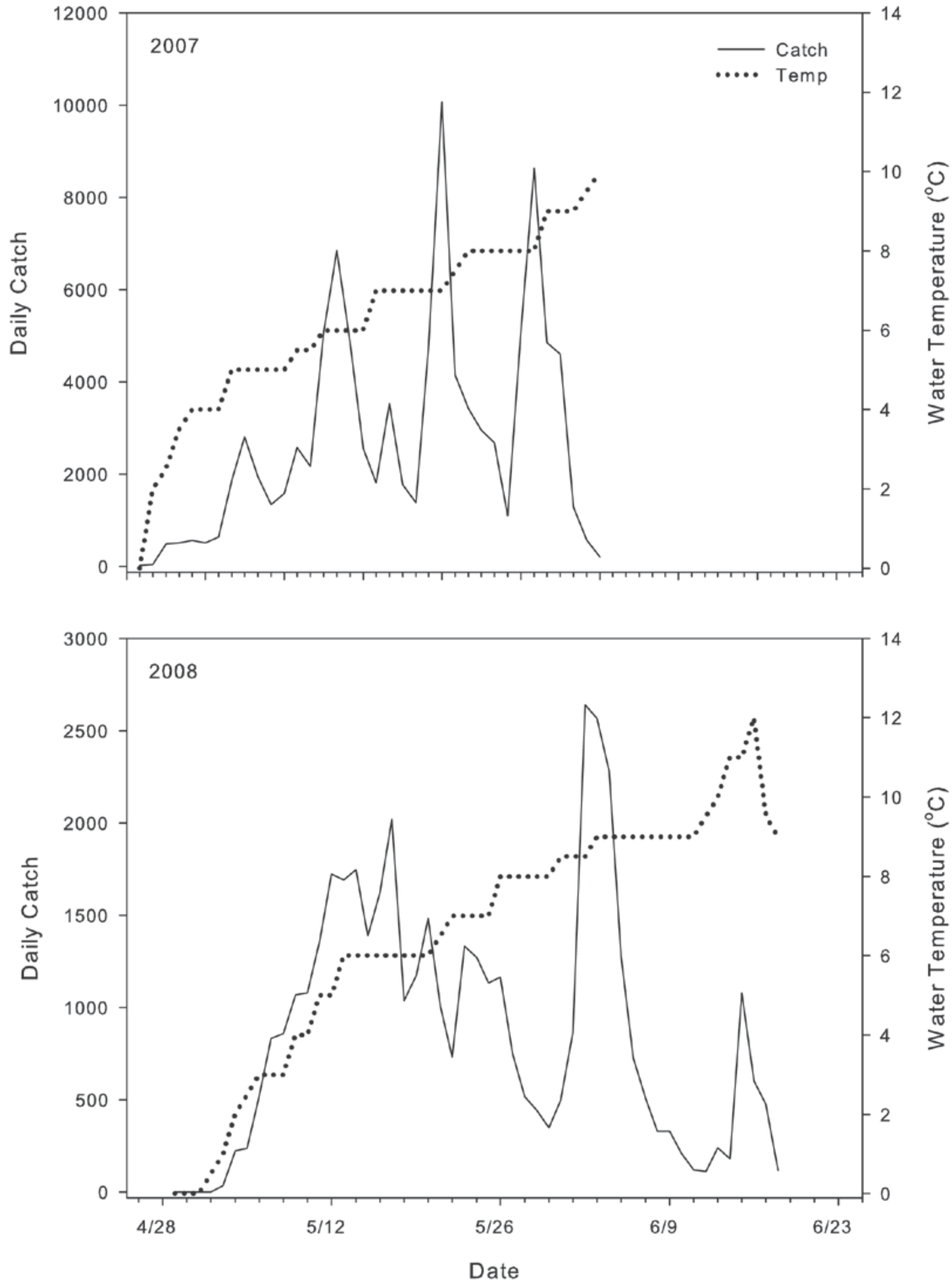

Figure 3. Daily catch of juvenile chum salmon and daily water temperature for years sampled on the Kwethluk River.

Table 3. Estimated abundance (S) of juvenile chum salmon with bootstrap 95% confidence intervals (CI), estimate of eggs deposited (E) by parental year females, and percent egg-to-smolt survival (S/E) of juvenile chum salmon.

Clear Creek	S	95% CI	E	SD(E)	S/E%	SD(S/E)%
2002	545,169	124,161 - 1,111,179	2,678,492	587,584	20.4	10.4
2003	2,212,747	1,857,447 - 2,656,442	15,604,654	3,352,805	14.2	3.3
2004	577,897	442,802 - 822,255	5,530,000	1,266,086	10.5	2.9
2005	3,029,656	2,210,262 - 4,755,188	14,813,740	2,678,291	20.5	5.5
Kwethluk River						
2007	2,004,691	1,714,381 - 2,140,580	43,691,193	5,966,514	4.6	0.7
2008	2,925,384	2,803,109 - 3,210,697	56,094,477	8,992,062	5.2	0.9

Survival Estimation

Egg-to-smolt survival for juvenile chum salmon varied between years and was lowest in 2004 (10.5%) and 2003 (14.2%), and highest in 2005 (20.5%) and 2002 (20.4%; Table 3). The lowest percent survival in 2004 resulted from a PED of 5.5 million. In contrast the highest percent survival resulted from an estimated PED of 14.8 million (Table 3). PED in 2003 was the highest recorded at 15.6 million, but resulted in the third poorest survival percentage. Kwethluk River juvenile chum salmon had consistent survival estimates of 4.6 (2007) and 5.2% (2008), but these estimates were lower than all estimates for Clear Creek (Table 3). PED was 43.8 and 55.9 million in 2007 and 2008 respectively. Egg-to-adult survival estimates for chum salmon from

Clear Creek in 2000 and the Kwethluk River in 2003 were similar at 0.08 and 0.10% respectively.

Discussion

This study is one of only a few studies to describe the migration timing and to estimate the abundance of emigrating wild juvenile chum salmon in Alaska. From this data we provide the first estimate of egg-to-smolt survival within the AYK region. Chum salmon inhabiting the AYK region are near the northern extent of their range and are subject to environmental constraints unlike those experienced by populations from more southern ranges.

Density dependant mortality is a common factor affecting egg-to-smolt survival in many freshwater habitats. In a system where density dependant mortality is present there is a threshold reached when the number of spawning adults begins to negatively affect juvenile survival. In a study by Fukushima et al. (1998) on pink salmon in Auke Creek, Alaska, redd superimposition, due to spawner density, was found to be a major factor affecting survival. In our study, neither Clear Creek nor the Kwethluk River exhibited evidence of density dependence. In all years, larger estimates of PED were associated with higher estimates of juvenile chum salmon abundance, with the exception of 2005 in Clear Creek (Table 3). These results emphasize the importance of adult escapement to juvenile recruitment for both systems.

Results from our study support large scale trends for juvenile chum salmon across their range. For instance, timing and duration of emigration for juvenile chum salmon in Clear Creek and the Kwethluk River are consistent with latitudinal trends reviewed by Salo (1991) in which migration timing occurs earlier as you move north to south. On a smaller scale, however, overall emigration timing was similar between Clear Creek and the Kwethluk River. The only notable variation was that observed on the Kwethluk River in 2008, and was likely a result of the later than usual break-up and ice-out compared to 2007. Although emigration timing was similar between Clear Creek and the Kwethluk River, the effect of variation in water temperature on emigration behavior varied. A slight increase in water temperature above zero degrees Celsius appeared to be the main factor influencing the first pulse in emigration for both systems (Figures 2 and 3; Table 1). Variation in water temperature during the emigration period has the potential to influence the onset and duration of emigration to a great extent. In a study on juvenile chum salmon in Carnation Creek, B.C., by Holtby et al. (1989) a 1.0 to 2.0 ^{o}C change in water temperature, as a result of logging, caused a change in migration timing up to 6 weeks. The range in water temperature at which the majority of juvenile chum salmon migrated was narrower and lower in Clear Creek than in the Kwethluk River (Table 2). Estuarine arrival is believed to be closely timed with optimum feeding conditions in estuarine habitats (Cushing 1990), a change in freshwater temperature not reflected in estuarine productivity may result in a mismatch between estuarine residence and optimum feeding conditions.

As previously reported survival of chum salmon from egg deposition to emergence and seaward migration is widely variable between streams and sampling years (Salo 1991; Table 4). Our range of survival estimates for Clear Creek (10.5 – 20.5%) fell within the mid to upper range of values previously reported for wild juvenile chum salmon, however, survival estimates for the Kwethluk River (4.6 and 5.2%) fell within the lower range (Table 4). Among the studies presented in Salo (1991), with some exceptions, year-to-year variation in egg-to-smolt survival

Table 4. Egg-to-smolt survival of wild juvenile chum salmon from this study and published values.

Location	Years sampled	Survival Range (%)	Survival Mean (%)	Source
Memu R. Japan	3	16.2 - 34.4	27.6	Nagasawa and Sano (1961) [1]
Disappearance Cr. AK	2	8.7 - 16.9	12.8	Wright (1964)[1]
Inches Cr. BC	4	1.6 - 18.8	8.9	Fedorenko and Bailey (1980)
Hooknose Cr. BC	14	1.0 - 22.0	8.5	Parker (1962)
Nile Cr. BC	4	0.1 - 7.0	3.3	Wickett (1952)
Big Qualicum R. BC	4	5.0 - 17.0	11.2	Lister and Walker (1966)
Clear Cr. AK	4	10.5 – 20.5	16.4	This study
Fraser R. BC	19	5.7 - 35.4	14.2	Beacham and Starr (1982)
Kwethluk R. AK	2	4.6 - 5.2	4.9	This study
Bolshaya R. Russia	7	0.7 - 4.2	2.4	Semko (1954) [1]

appears to increase from north to south (Table 4). Due to small sample sizes among studies this trend may be spurious. Alternatively, it may provide evidence for less variability in survival in sub-arctic habitats with stable incubation environments. Variation in juvenile chum salmon survival between Clear Creek and the Kwethluk River can likely be explained by geographic or environmental differences. Due to lack of data it is unclear what mechanisms are influencing survival at both Clear Creek and the Kwethluk River. However, similarities in historic chum salmon survival trends in the AYK region were present over a broad geographic area, suggesting large scale environmental influence, such as temperature, as a main mechanism effecting survival (Shotwell & Adkison 2004; Shotwell *et al.* 2005). In addition, Beacham & Starr (1982) concluded from 19 years of data on chum salmon from Fraser River, British Columbia, that much of the variation in egg-to-smolt survival was attributed to interactions among temperature, rainfall, and egg abundance. Lastly, predation can significantly influence the freshwater survival of juvenile chum and pink salmon during their downstream migration (Hunter 1959; Beall 1972; Fresh & Schroder 1987).

It is possible that the magnitude of variation in egg-to-smolt survival between Clear Creek and the Kwethluk River is, in part, a result of the distance travelled from emergence to the trap location and the additive effects of natural mortality and predation over that course. The Kwethluk River is larger in size and has a spawning distribution of over 200 river km more than Clear Creek. Spawning habitat within Clear Creek is confined to an area stretching approximately 25 km upstream of the trap location, with the majority of spawning occurring within 5 to 15 km (Christian Zimmerman, unpublished data). Chum salmon on the Kwethluk River are known to spawn as far as 236 km upriver of the trap location (Anadromous Waters Catalogue).

Predation is another factor known to influence the survival of juvenile salmon, and may affect juvenile chum salmon survival in the Kwethluk River to a greater extent than Clear Creek. The Kwethluk River has a greater abundance and diversity (i.e. sculpin, burbot, rainbow trout, whitefish spp., pike, Dolly Varden, arctic grayling, and juvenile Chinook and coho salmon) of predators known to feed on migrating juvenile salmon than does Clear Creek (Christian

Zimmerman, unpublished data). The salmon population of the Kwethluk River is in large part composed of coho salmon (Miller *et al.* 2009). In a study on juvenile pink and chum salmon from Hooknose Creek, British Columbia, Hunter (1959) estimated an average mortality of 45% for juveniles migrating 2.6 km to sea; the main predators were found to be juvenile coho and sculpin. Similarly, Beall (1972) and Fresh & Schroder (1987) found significant predation on juvenile chum salmon in Big Beef Creek, Washington, by juvenile coho salmon and trout.

In conclusion, some results from our study are consistent with broad scale trends observed over the range of chum salmon populations. The effect of water temperature on the emigration behavior of juvenile chum salmon, however, varied over a short geographic scale, and was more pronounced in Clear Creek than in the Kwethluk River. Due to lack of data, it is unclear what factor, or combination of factors is influencing egg-to-smolt survival on Clear Creek and Kwethluk River. It is possible that difference in watershed size and diversity of predators plays a big role in yearly variation in survival between both systems, and that environmental variation is a key factor influencing survival among these populations. Due to the different environmental constraints on chum salmon near the northern extent of their range, opposed to more southern populations, it is apparent that more baseline data are needed to develop populations dynamics models better suited for the arctic and sub-arctic regions. Shotwell & Adkison (2004) point out that the current models used to estimate abundance indices for Yukon and Kuskokwim River salmon populations are inadequate compared to what is needed to derive a quantitative assessment for these returns. Our findings not only strengthen our current knowledge on the freshwater ecology of juvenile chum salmon in the AYK region, but will benefit researchers and fisheries managers in the management and sustainability of subsistence and commercial fisheries of the AYK region.

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