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Kuskokwim River Sockeye Salmon Investigations, 2006 and 2007

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CHAPTER 2. HABITAT AND GROWTH OF RIVER-TYPE SOCKEYE SALMON IN THE KUSKOKWIM WATERSHED, ALASKA

by

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ABSTRACT

The Kuskokwim River supports a substantial population of sockeye salmon that inhabit riverine habitats for one year post-emergence before migrating to sea. We investigated the types of habitat utilized by these "river-type" juvenile sockeye salmon in a major tributary of the Kuskokwim River and tested the hypothesis that growth of river-type sockeye salmon (back-calculated from adult salmon scales) was comparable to that of "lake-type" sockeye salmon within the Kuskokwim watershed and in other Alaskan lakes. Within riverine habitats, catch per river-seine set (CPUE) was significantly greater in lentic slough habitats compared with flowing side channel and mainstem habitats; although, sockeye salmon inhabiting mainstem habitats were significantly longer than those in side channel and slough habitats. CPUE and length data suggest that juvenile sockeye salmon were actively migrating downstream as they grew older and larger. Telaquana Lake produced the largest juvenile sockeye salmon in the Kuskokwim watershed and lake-rearing sockeye salmon were significantly longer than those inhabiting river habitats. Nevertheless, comparison of juvenile scale growth from adult Kuskokwim salmon (mostly river-type) versus scale growth from lake-rearing sockeye salmon in seven areas of Alaska indicated salmon growth in the Kuskokwim drainage was similar to that of some major sockeye salmon populations and greater than others. Overall, our research indicated that slough habitat, such as that produced by old river oxbows, is especially important to river-type sockeye salmon during early freshwater life (spring) in the Kuskokwim watershed, whereas habitats downstream of the spawning areas are important during later freshwater life. Although lake-type sockeye salmon grew faster than river-type sockeye salmon in the Kuskokwim watershed (primarily in response to growth in Telaquana Lake), growth of river-type sockeye salmon is comparable to or greater than growth of lake-type sockeye salmon in other watersheds.

Key words: Kuskokwim River, Holitna River, Kogrukluk River, Telaquana Lake, river-type sockeye salmon, chum salmon, coho salmon, Chinook salmon, scale growth, habitat.

INTRODUCTION

Three types of juvenile sockeye salmon life history strategies have been described in the literature. The most common is the "lake-type" strategy in which juveniles typically spend one to two years in a lake before emigrating to the ocean. Recent radiotelemetry research (Chapter 1 this document) indicated that most Kuskokwim sockeye salmon follow a "river-type" strategy where they spawn in areas without access to lakes, thus are using riverine habitats, typically rearing and overwintering in river channel and slough areas where water velocity is slow (Wood et al. 1987). Some watersheds also produce a third type of sockeye salmon, known as the "sea-type," which inhabit river habitats for approximately three months or less when no lake rearing habitat is available, [e.g., Harrison River (Fraser watershed), Stikine River, Puget Sound rivers, and Nushagak River] (Schaefer 1951; Wood et al. 1987; Gustafson and Winans 1999; Westing et al. 2005).

"River-type" sockeye salmon are not abundant across the Pacific Rim. Small populations have been observed in the Kamchatka River, Bolshaya River, Mulchatna River (Nushagak drainage), Stikine River, and Taku River (Wood et al. 1987; Burgner 1991; Eiler et al. 1992). This variation in sockeye salmon juvenile life history strategies reflects successful adaptations by sockeye salmon to a variety of freshwater habitat types. However, across the Pacific Rim the relatively low abundance of river-type and sea-type sockeye salmon compared with lake-type salmon (Burgner 1991) suggest productivity of river and sea-type sockeye salmon is lower.

Sampling of the Kuskokwim commercial catch since 1984 indicated that approximately 80% of returning adult sockeye salmon spent one winter in freshwater as juveniles before migrating to sea, and 1% or less of the sockeye salmon migrated to sea during their first year (Molyneaux and Folletti 2005). Chapter 1 of this document demonstrated that most adult sockeye salmon in the Kuskokwim River basin spawn in areas that are not associated with lake habitats. Thus, most juvenile sockeye salmon in the Kuskokwim watershed appear to inhabit riverine habitats for approximately one year after emergence.

The goals of our investigation were to examine habitats used by juvenile river-type sockeye salmon in a major tributary system of the Kuskokwim River (Holitna and Kogrukluk rivers) and to estimate and compare freshwater growth of river-type and lake-type sockeye salmon in major tributaries throughout the Kuskokwim watershed. Habitat types utilized by juvenile sockeye salmon (and other fishes) were examined in the lower Holitna River and one of its major upriver tributaries, the Kogrukluk River (Figure 2.1), during June through September 2006. The Holitna River is known to support river-type sockeye salmon (Baxter[3] 1979) and up to 60,000+ adult sockeye salmon per year have been counted at the Kogrukluk weir (Liller et al. 2008). Salmon growth, which is important to salmon survival (Beamish and Mahnken 2001; Ruggerone et al. 2007), was back-calculated from scales of adult salmon that were radiotracked to tributaries throughout the watershed (Chapter 1 this document) or sampled at weirs and other projects during 2005–2007.

OBJECTIVES

The following specific hypotheses about sockeye salmon habitat and growth were tested:

HABITAT USE BY SOCKEYE SALMON:

1. Juvenile sockeye salmon and other juvenile salmonids randomly utilize river habitat types in the upper and lower Holitna River.
2. Distribution of juvenile sockeye salmon and other salmonids along the upper and lower river and within habitat types remains constant from late June through early September.
3. Mean size of sockeye salmon at a given time period does not differ by main channel versus off channel habitat types or from upper to lower river reaches.

SOCKEYE SALMON GROWTH BY TRIBUTARY:

4. Smolt length and spring growth of sockeye salmon does not differ among smolts originating from each major spawning area and river in the watershed, including clear water, glacial, or turbid rivers, or upper versus lower watershed rivers.
5. Sockeye salmon smolt size does not differ among smolts originating from river-rearing versus lake-rearing habitats, including salmon from other Alaskan watersheds.

METHODS

JUVENILE SALMON ABUNDANCE AND HABITAT

Juvenile salmon were sampled by river seine in the Kogrukluk River, which is a major tributary of the upper Holitna River 709 river kilometers (rkm) from the ocean, and in the lower Holitna River, approximately 491 rkm from the ocean (Figure 2.1). Sampling in the Kogrukluk River occurred primarily within 20 rkm upstream of the ADF&G weir (rkm 710). Sampling in the lower Holitna River primarily occurred within 60 rkm of its confluence with the Kuskokwim River near the village of Sleetmute. Numerous sockeye salmon are known to spawn in the Kogrukluk River (Liller et al. 2008 and Chapter 1 this document), whereas little, if any, spawning occurs in the lower Holitna River (few gravel areas). Sampling occurred from late June

[3] Baxter, R. Unpublished. Hoholitna River reconnaissance survey, 1977. Alaska Department of Fish and Game, Division of Commercial Fisheries, AYK Region Kuskokwim Salmon Resource Report No. 3, Anchorage.

through early September, 2006. Sampling frequency was approximately every two weeks in the Kogrukluk River and once per month in the lower Holitna River.

The river seine was designed to sample juvenile salmon in low to moderate velocity rivers (Ruggerone et al. 2007). The net was 20 m long, 2 m deep at the center, 1 m deep at the wings, and mesh size ranged from 12 mm at the wings to 3 mm at the center. When deploying the river seine, the upstream end was walked downstream at the same speed as the river current while the boat carried the lower end of the net to another biologist approximately 33 m downstream (Appendix 2.A). Surface area sampled by the river seine is approximately 400 m^2.

Upon retrieval of the river seine, all fish were placed in one or more buckets. Fishes were identified and counted. The salmon catch was randomly sampled for length measurements until approximately 30 sockeye salmon of each age class was obtained during each sampling period. A portion of the salmon were preserved in 10% buffered formalin and then sent back to the lab where species identification was checked and corrected when necessary. Scales were removed from sockeye salmon for measurement (see below) and fish length was re-measured.

Juvenile sockeye salmon and other salmonids were sampled in three habitat types: mainstem, flowing side channel, and slack water slough. Slough habitats included both spring fed and river back-water areas. Diversity of habitat types was much greater in the Kogrukluk River compared with the lower Holitna River, a wide (~150 m) low gradient river (Appendix 2.A). Most catch per effort statistics are reported as geometric mean values (as opposed to arithmetic mean) because salmon catch data are positively skewed (many small catches and few large catches). Application of the log-transformation normalized the frequency distribution of catch data, a requirement for statistical analyses. The geometric mean catch is smaller than the arithmetic mean catch, and it is a better representation of central tendency when data are strongly positively skewed. ANOVA of log-transformed catch data was used to test hypotheses related to habitat types occupied by sockeye salmon of various sizes (Zar 1996). Although sockeye salmon is the targeted species of this investigation, we also present abundance and habitat data for other salmonids.

SOCKEYE SALMON LENGTH VERSUS SCALE RADIUS RELATIONSHIP

We attempted to collect at least 10 juvenile sockeye salmon per 10 mm length interval in order to develop a relationship between body length and scale radius (Henderson and Cass 1991; Fukuwaka and Kaeriyama 1997) that could be used to back-calculate length of juveniles from scales collected from adult sockeye salmon in each tributary of the Kuskokwim watershed. Juvenile sockeye salmon collected from the Holitna drainage were supplemented with juvenile sockeye salmon (mostly smolts) collected while migrating downstream from the outlet of Telaquana Lake during June 13–15, 2006. Scales were removed from the preferred area (Koo 1962), placed on a numbered gum card, and pressed into heated acetate cards at the laboratory. Scale measurements followed procedures described by Davis et al. (1990) and Hagen et al. (2001). After selecting a scale for measurement, the scale was scanned from a microfiche reader and stored as a high resolution digital file. High resolution (3352 x 4425 pixels) allowed the entire scale to be viewed and provided enough pixels between narrow circuli to ensure accurate measurements of circuli spacing (Figure 2.2). The digital image was loaded in $Optimas_1$ 6.5 image processing software to collect measurement data using a customized program. The scale image was displayed on a high resolution monitor and the scale measurement axis was consistent with that for adult scales (approximately 22° from the longest axis). Distance (mm) between circuli was measured within each growth zone [i.e., from the scale focus to the outer edge of the first freshwater annulus (FW1) and to the outer edge of the spring plus growth zone (FWPL), which represents growth during smolt migration in freshwater and/or estuarine habitats].

A variety of approaches have been used to back-calculate fish lengths from scale radii measurements (Francis 1990). We explored the Fraser-Lee procedure recommended by Ricker (1992). However, the Fraser-Lee procedure was not appropriate to back-calculate juvenile salmon length from adult scales because some adult scales were resorbed along the outer edge, and allometry of scales and salmon length changes from juvenile to adult life stages (Fisher and Pearcy 2005). Therefore, as recommended by Fisher and Pearcy (2005), we utilized geometric mean regression of juvenile salmon length (mm) on total scale radius (mm) to back-calculate juvenile length from adult scales collected in the watershed. Pierce et al. (1996) concluded that various back-calculation methods produced equivalent results, especially when variability in the fish length versus scale radius relationship was low. The slope of the geometric mean regression was calculated from the ratio of length standard deviation to scale radius standard deviation. The Y-intercept of the regression could then be calculated using algebra because the regression crosses mean Y and mean X values. All lengths are reported as live lengths. Preserved fish lengths were multiplied by 1.042 to account for shrinkage when preserved in 10% buffered formaldehyde (Rogers 1964). Reported values are mean ±1 standard error (SE) unless noted otherwise.

JUVENILE SOCKEYE SALMON LENGTH BY WATERSHED

Scales were collected from the preferred scale area of age-1.3 adult sockeye salmon (one winter in freshwater, three winters in ocean) returning to known tributaries in the Kuskokwim watershed during 2005 (pilot study), 2006, and 2007. Numerous salmon scales were collected each year from sockeye salmon captured with fish wheels operated near Kalskag (rkm 270; Figure 2.1), then live-released after tagging with an esophageal radio transmitter (Chapter 1 this document). Spawning area of tagged salmon was determined by aerial surveys and by ground-based receiver stations located in select drainages (note: some tagged fish did not successfully escape into spawning tributaries, and these fish were pooled into a "Kuskokwim River" group which represented a mix of sockeye salmon of unknown origin). Scales from tagged salmon were supplemented with age-1.3 sockeye salmon scales collected from weirs on the Kwethluk, George, Tuluksak, Kogrukluk and Salmon rivers, and a sonar project operated on the Aniak River (Figure 2.1). Additional adult scales were collected from fish captured by beach seine in Telaquana Lake and in the upper Telaquana River (0.5 km from lake) as adults approached the lake. Some scales collected from weir and sonar projects exhibited resorption along the outer margin of the scale, therefore ocean age was determined from length frequency distributions of ocean age-2 (two winter annuli) and ocean age-3 (three winter annuli) male and female salmon whose scales had not resorbed.

Adult scales were selected for measurement only when salmon age was in agreement between two scale readers. Scales having an abnormal focus were excluded (e.g., unusually great growth to first circuli). Methods for measuring adult salmon scales were the same as for juvenile salmon. The scale measurement axis was determined by a perpendicular line drawn from a line intersecting each end of the first salt water annulus approximately 22° from the longest axis (Figure 2.2). Growth zones corresponding to seasonal and annual scale growth were measured. Growth zone FW1 is the area between the scale focus and the outer edge of the first freshwater annulus, growth zone FWPL represented growth between FW1 and the beginning of ocean growth, growth zones SW1, SW2, and SW3 represented annual ocean growth, and growth zone SWPL represented growth after the last ocean annulus. The distance (mm) between circuli was measured within each growth zone. The habitat in which FWPL growth occurs is unknown, but it likely includes both freshwater and possibly estuarine habitats. Data associated with the scale (i.e., date of collection, location, sex, length, and capture method) were included in the dataset. Only data associated with FW1 and FWPL growth are reported here.

Juvenile sockeye salmon length at the end of the first year in freshwater (FW1) and at the end of the smolt transition period (FW1 and FWPL) was estimated from the aforementioned fish length-scale radius relationship and adult salmon scales. Preliminary analyses indicated the ranking of back-calculated lengths among the watersheds was not consistent each year (significant interaction effect); therefore, estimated lengths in each watershed were compared using ANOVA for each year of data. Adult salmon scales reflect growth of fish that survived rather than the total population inhabiting the watershed as juveniles. Smaller salmon tend to experience higher mortality; therefore, back-calculations of size from adult scales likely over-estimated average salmon size and underestimated variability in size.

COMPARISON OF KUSKOKWIM SOCKEYE SALMON GROWTH WITH OTHER STOCKS

Adult sockeye salmon were randomly sampled from the Kalskag fish wheel catch (Chapter 1 this document); therefore, juvenile lengths estimated from these adult scales represent a random sample of sockeye salmon primarily rearing in the middle upper watershed and upstream. Freshwater scale growth of adults sampled at Kalskag was compared with scale growth from age-1.3 sockeye salmon sampled from seven other watersheds in Alaska (Kvichak, Egegik, Nushagak District, Black Lake, Kasilof, Kenai, Coghill) during the past 30 to 40 years (Ruggerone and Rogers 1998). These watersheds represent four regions of Alaska where most lake-type sockeye salmon are found (e.g., Bristol Bay, Chignik, Cook Inlet, and Prince William Sound). Methods used to measure scale annuli and freshwater spring growth of sockeye salmon from these other watersheds was the same as that used for Kuskokwim sockeye salmon.

RESULTS

HABITAT UTILIZATION IN THE KOGRUKLUK RIVER

Subyearling sockeye salmon were the most abundant fish sampled in the Kogrukluk River during late June through late September, 2006, averaging approximately 158 fish per seine set. Geometric mean (g.m.) catch per seine set (CPUE) of juvenile sockeye salmon was consistently high from late June through early August (g.m.=47 sockeye salmon), then declined sharply to approximately 3 salmon per set during late August through late September (Figure 2.3). No yearling sockeye salmon were captured indicating most yearlings had moved downstream prior to late June.

CPUE of subyearling sockeye salmon was significantly greater in slough habitats (g.m.=35.5 fish; $P<0.001$) and side channel habitats (g.m.=16.1 fish; $P=0.014$) compared with mainstem habitats (g.m.=4 fish; two factor ANOVA: df=2, 62; $F=11.415$, $P<0.001$) (Figure 2.4; Table 2.1). Catch of sockeye salmon was 100% greater in slough versus side channel habitats, but the difference was not statistically significant ($P=0.126$), owing to the high variability in catch.

Chum salmon fry were highly abundant in late June (g.m.=74 chum salmon), but catch declined precipitously to two chum salmon per set in early July and to 0.4 chum salmon per set for the remainder of the season (Figure 2.3). CPUE of subyearling chum salmon did not vary significantly by habitat type (P>0.05), although CPUE tended to be greatest in side channel habitats during late June and mainstem habitats during early July (i.e. the period when chum salmon were most abundant) (Figure 2.4; Table 2.1).

Identification of Chinook versus coho salmon could not be confirmed during late July and August (no samples preserved), although fish identifications from other dates were confirmed. Subyearling Chinook salmon were relatively abundant in the Kogrukluk River and CPUE declined from 19.0 Chinook salmon per set in late June to 13.7 per set in late July (unconfirmed identification) and to approximately 1.5 Chinook salmon per set during early August through late September (Figure 2.3). Yearling Chinook salmon were rarely captured. In contrast with sockeye salmon, subyearling Chinook salmon were significantly more abundant in mainstem habitats (g.m.=27.5 fish; P<0.001) compared to slough habitats (g.m.=5.9 fish; P<0.001) during late June and early July (Figure 2.4; Table 2.1). Chinook salmon catches in side channel habitats were intermediate (g.m.=11 fish).

Subyearling coho salmon were rarely captured during late June and early July. CPUE of subyearling coho salmon increased to 16.5 fish per set in early August (unconfirmed identification) followed by less than one coho salmon per set during late August and September. Most subyearling coho salmon were captured in mainstem habitats (Figure 2.4; Table 2.1). Yearling coho salmon were rarely captured during late June through September (0.3 fish per set).

Juvenile whitefish *Coregonidae* spp. averaged less than one fish per set during late June through September and there was no difference in CPUE between habitats. CPUE of other fishes (sculpins *Cottidae* spp., juvenile grayling *Thymallus arcticus*, and northern pike *Esox lucius*) peaked in late July (Figure 2.3), and there was no difference in CPUE between habitats (Table 2.1). No rainbow trout *Oncorhynchus mykiss* and only 4 char *Salvelinus* spp. were captured in the Kogrukluk River.

HABITAT UTILIZATION IN THE LOWER HOLITNA RIVER

Subyearling sockeye salmon were the third most abundant species group sampled by beach seine in the lower Holitna River from late June through mid-September, 2006. CPUE increased from 0.7 fish per set in late June to 5.7 fish per set in late July, and then declined to 0.4 fish per set in August and September (Figure 2.5). CPUE of sockeye salmon in the lower Holitna River was much less than CPUE in the Kogrukluk River.

Side channel and slough habitats were less common in the lower Holitna River compared to the Kogrukluk River. During late July, when nearly all sockeye salmon fry were captured, sockeye salmon fry were significantly more abundant in mainstem habitats compared with side channel habitats (df=1, 20; F=5.399, P=0.031). Slough habitats were not sampled during this period.

CPUE of chum salmon peaked in late June (33.5 fish per set), were rarely captured in late July (0.2 fish per set), and were not captured in August and September (Figure 2.5). CPUE of chum salmon did not differ between mainstem and side channel habitats.

Chinook salmon fry and yearlings were rarely captured in the lower Holitna River, averaging less than 0.1 fish per set (Figure 2.5). No coho salmon were captured. Other fishes, numerous young-of-the-year and some older whitefish, sucker *Catostomidae* spp., grayling, northern pike, and sculpin, were exceptionally abundant in the lower Holitna River, especially during late July and mid-September (Figure 2.5). No char or rainbow trout were captured. Numerous large sheefish *Stenodous Leucichthys* were observed in mid-channel, but none were captured in the seine.

JUVENILE SALMON SIZE IN THE KOGRUKLUK AND HOLITNA RIVERS

Length of subyearling sockeye salmon captured in the Kogrukluk River increased from approximately 32 mm in late June to 50 mm in early August, and remained relatively constant from early August to late September (Figure 2.6) when few sockeye salmon were captured (Figure 2.3). The increase in length per day (approximate growth rate) from late June through late July was 0.56 mm (Figure 2.7). Sockeye salmon length in the lower Holitna River was approximately 8 mm greater in late June and 13 mm greater in late July compared with sockeye salmon in the Kogrukluk River.

Length of sockeye salmon in mainstem, side channel, and slough habitats of the Kogrukluk River was compared during late June and early July when measurements were available in each habitat. Sockeye salmon length was significantly longer in mainstem versus side channel habitats (Figure 2.8; two factor ANOVA, df=2, 199, F=37.569, $P<0.001$). Sockeye salmon length was smaller in slough habitats versus mainstem and side channel habitats. Sufficient length data were not available in each habitat during subsequent periods for statistical comparisons, but length tended to be greater in mainstem habitats compared with side channel and slough habitats.

Length of chum salmon steadily increased from 42 mm in late June to 57 mm in late July, or an average daily increase of 0.6 mm (Figures 2.6 and 2.7). Chum salmon size was nearly identical in the Kogrukluk and Holitna rivers.

Length of subyearling Chinook salmon in the Kogrukluk River increased from approximately 41 mm in late June to 64 mm in late July then remained relatively stable for the remaining season when few Chinook salmon were captured (Figure 2.6). The increase in length per day from late June through late July was 0.8 mm (Figure 2.7). Coho salmon were slightly smaller, on average, compared to Chinook salmon and the increase in length per day was 0.9 mm. Too few Chinook and coho salmon were captured in the Holitna River to calculate mean size.

SOCKEYE SALMON LENGTH-SCALE RADIUS RELATIONSHIP

Juvenile sockeye salmon length was correlated with total scale radius (r=0.91). The following geometric mean regression was used to back-calculate juvenile length from adult scale measurements (Figure 2.9):

$$\text{Live length (mm)} = 27.77 + 152.51\ (\text{scale radius (mm)}), \quad (1)$$

n=293, R^2=0.82, overall $P<0.001$. The 95% confidence interval about a predicted salmon length of 100 mm is ±13 mm.

This relationship was compared to the same relationship developed with juvenile sockeye salmon from the Chignik watershed (Alaska Peninsula; Ruggerone and Rogers 1998). Back-calculation of sockeye salmon length using the Kuskokwim model was 4% greater (2 mm) than that predicted by the Chignik model when the predicted length was small (e.g., 52 mm), but it was 2.2% less (2.5 mm) when the predicted length was large (e.g., 112 mm). When comparing length back calculations from the 1,088 freshwater scale measurements of adult Kuskokwim sockeye salmon using the 2 models, sockeye salmon length was 1.5% less (1.4 mm), on average, at the end of the first growing season (FW1) and 2.2% less (2.4 mm) at the end of spring plus growth (FWPL) when applying the Kuskokwim versus Chignik scale model. These findings provide initial evidence that salmon length to scale radius relationships is somewhat robust between stocks and between years.

SOCKEYE SALMON LENGTH BY WATERSHED

Sockeye salmon scales were examined from adult salmon returning to 16 drainages within the Kuskokwim watershed. These drainages ranged from the Kwethluk River in the lower watershed (rkm 131) to Telaquana Lake in the upper watershed (rkm 756). Juvenile sockeye salmon lengths were back-calculated from 1,088 adult sockeye salmon scales collected during 2005 (56 scales), 2006 (568 scales), and 2007 (464 scales). These fish reared in freshwater during 2001, 2002, and 2003, then emigrated to sea during 2002, 2003, and 2004, respectively. Text that follows refers to the juvenile salmon by the year in which they returned as adults (i.e., four years after the first growth season and three years after the spring growth (smolt) season).

Mean back-calculated length of sockeye salmon at the end of the first growing season (FW1) ranged from 81 ± 2.3 mm in Two Lakes (Stony River watershed) to 108 ± 1.4 mm in Telaquana Lake (also Stony River dainage) when samples from all years were combined (Figure 2.10). Mean length of sockeye salmon at the end of the spring smolt period (FW1 and FWPL) ranged from 96 ± 2.3 mm in upper Aniak River to 117 ± 1.3 mm in Telaquana Lake (Figure 2.10). Back-calculated mean growth during spring transition (FWPL) ranged from 2 ± 1.1 mm in the Tuluksak River to 27 ± 3.0 mm among juveniles produced by adults from the unspecified Kuskokwim River group (note: the “Kuskokwim River” group represented a mixture of tagged sockeye salmon for which spawning tributary/habitat could not be determined). It is important to note that these mean length estimates are influenced by unequal sample sizes and growth during each year (Table 2.2; see additional analyses that follow).

Growth of juvenile sockeye salmon was compared between Kuskokwim tributaries in 2006 and 2007. During 2006 and 2007 (2002 and 2003 growth years) Telaquana Lake produced the largest juvenile sockeye salmon at the end of the first growing season (FW1), averaging 110 mm and 106 mm, respectively (Figure 2.11, Table 2.2; $P<0.05$). Telaquana Lake sockeye salmon were also significantly longer, on average, than most other stocks at the end of spring growth during the smolt period (when sample size exceeded 10 fish) ($P<0.05$, Table 2.2). Spring growth (FWPL) of Telaquana Lake sockeye salmon during the smolt migration period was less than other stocks in 2007, but typical of other stocks in 2006.

SOCKEYE SALMON LENGTH BY HABITAT TYPE

Back-calculated lengths of river-rearing sockeye salmon were compared with back-calculated lengths of lake-rearing sockeye salmon. Nearly all lake-rearing sockeye salmon were from Telaquana Lake. Across the 3 years of study, the average length of sockeye salmon at the end of the first growing season (FW1) was significantly smaller among river-rearing sockeye salmon (89 mm) compared with lake-rearing salmon (103 mm; Figure 2.12; two factor ANOVA (year, location): df=2, 1083; $F=45.56$; $P < 0.001$). Likewise, the average length at the end of the spring transition period (FW1 and FWPL) for river-rearing sockeye salmon (105 mm) was significantly smaller than lake-rearing salmon (118 mm; Figure 2.12; two factor ANOVA: df=2, 1083; $F=25.24$; $P<0.001$). Growth during the spring smolt period (FWPL) was not significantly different between river- and lake-rearing sockeye salmon ($P>0.05$).

SOCKEYE SALMON LENGTH BY STUDY YEAR

Juvenile lengths back-calculated from adult salmon scales collected from the Kalskag fish wheel represent a random sample of sockeye salmon primarily rearing in the middle and upper Kuskokwim River watershed, as noted above. Mean lengths of these juvenile sockeye salmon at the end of the first season were 89 ± 1.6 mm in 2005, 93 ± 0.8 mm in 2006, and 87 ± 0.8 mm in 2007. Mean length of sockeye salmon in 2006 (93 mm) was significantly greater than lengths in 2005 and 2007 (multiple range test, $P < 0.02$). Mean lengths of juvenile sockeye salmon at the end of spring growth (FW1 and FWPL) were significantly different during each year ($P < 0.001$): 107 ± 2.3 mm in 2005, 97 ± 0.9 mm in 2006, and 115 ± 1.2 mm in 2007. Significant differences in length at the end of the spring growth period were strongly influenced by significant differences in spring growth (FWPL). FWPL was low in 2006 (4 ± 0.6 mm), moderate in 2005 (18 ± 2.7 mm), and high in 2007 (27 ± 1.4 mm). These data indicated that sockeye salmon that grew slowly during the first season in freshwater (e.g., 2007) experienced relatively large growth during the following spring; whereas, salmon that grew fast during the first season (e.g., 2006) experienced relatively little growth during the following spring. Greater growth of 2006 salmon may have been related to relatively high air temperature at Bethel from May to September 2002 (avg. 51.6°F) compared with adjacent years (47.6–50.6°F). Spring growth of salmon appeared to be influenced by temperature, which was high during May and June in 2004 (51.5°F) and relatively low during 2003 (48.6°F).

COMPARISON OF KUSKOKWIM SOCKEYE SALMON GROWTH WITH OTHER STOCKS

Scale growth in Kuskokwim sockeye salmon (based on Kalskag samples) during the first year (FW1) was smaller, on average, than that of Egegik and Kvichak salmon, similar to that of Nushagak, Kenai, and Kasilof salmon, and larger than that of Black Lake and Coghill sockeye salmon (Figure 2.13). Growth of Kuskokwim sockeye salmon at the end of the following spring transition period (FW1 and FWPL) was similar to that of Egegik, Kvichak, Nushagak, and Black Lake sockeye salmon, and greater than that of Kenai, Kasilof, and Coghill Lake sockeye salmon. These data provide evidence that growth of Kuskokwim sockeye salmon in freshwater was similar to that of some major sockeye salmon populations and greater than others. Kuskokwim sockeye salmon tagged at Kalskag were dominated by sockeye salmon that spawned in rivers without access to lake habitat (94% of total), indicating that scale growth of river-type sockeye salmon in the Kuskokwim watershed (FW1: 0.41 mm; FW1 and FWPL: 0.51 mm) was comparable to scale growth of lake-rearing sockeye salmon located on other regions of Alaska (FW1: 0.23–0.55 mm; FW1 and FWPL: 0.25–0.55 mm).

DISCUSSION

JUVENILE SOCKEYE SALMON HABITAT

Subyearling sockeye salmon were especially abundant in slough habitats of the Kogrukluk River during spring. Slough habitats include both mainstem backwater areas and lentic areas supported by spring water. Many of the sloughs were old oxbows that were created when the river changed course. Some sloughs also supported spawning habitat and easy access for their progeny. Slough habitat was prevalent in the Kogrukluk and Holitna rivers (Appendix 2.A). Water velocity in these habitats was minimal and provided shallow lentic habitat that was similar to lake habitat where juvenile sockeye salmon are typically found.

Abundance of juvenile sockeye salmon in the Kogrukluk River declined sharply after early August, apparently in response to emigration (rather than mortality). Emigration of sockeye salmon from habitats near the spawning grounds may have been influenced by declining water levels that reduced availability of slough habitat. However, the relatively large size of sockeye salmon in mainstem versus slough habitats and in the lower Holitna River versus the Kogrukluk River suggests the emigration may have been active rather than passive. Larger salmon in mainstem habitats and in the lower river likely reflect somewhat older salmon (in terms of days), but they could have also been faster growing individuals.

Juvenile sockeye salmon abundance in the lower Holitna River peaked in late July. This area supports few if any spawning sockeye salmon, therefore sockeye salmon in this area originated from upstream areas, including the Kogrukluk River. In the lower Holitna River, juvenile sockeye salmon were typically observed in shallow low velocity areas of the mainstem and within side channels. The decline of sockeye salmon abundance in the Kogrukluk and Holitna rivers after late July raises the question: where do juvenile sockeye salmon reside during fall and winter? Some sockeye salmon may have dispersed offshore and into the river beyond the reach of the river seine as water level and velocity declined. Other salmon may have dispersed further downstream in the mainstem Kuskokwim River and associated habitats.

The Kuskokwim River supports one of the largest populations of coho salmon in Alaska, therefore predation by coho salmon on emerging sockeye salmon fry was considered. However, unusually few subyearling and yearling coho salmon and no 2-year old coho salmon smolts were observed while sampling for sockeye salmon from late June through September. A few yearling coho salmon were observed in large pools and beaver ponds adjacent to the Kogrukluk River during late June, but few if any sockeye salmon fry were present in these habitats. These observations suggest predation by coho salmon on sockeye salmon fry, which can be significant in lakes (Ruggerone and Rogers 1992), was not significant in these riverine areas.

Sockeye Salmon Length by Watershed

A geometric mean regression was developed to estimate juvenile Kuskokwim sockeye salmon length from scale radii measurements of adult salmon returning to 16 areas of the Kuskokwim watershed. Back-calculated lengths of juvenile sockeye salmon at the end of the first year in freshwater (range of means: 81–108 mm) were relatively great compared with lengths of sockeye salmon smolts (e.g., 87 mm for age-1 Kvichak smolts (Ruggerone and Link 2006), or 90 mm for Telaquana Lake smolts in 2006). The relatively large back-calculated length of Kuskokwim sockeye salmon likely reflects size-selective mortality of smaller sockeye salmon. Back-calculated length of sockeye salmon at the end of the spring transition period should not be directly compared with length of smolts because FWPL scale growth may include growth that occurred in the estuary in addition to the river during smolt migration. Back-calculated length of sockeye salmon should not be directly compared with lengths of juvenile sockeye salmon captured in the Kogrukluk River and in the lower Holitna River because these samples were not random, as indicated by the lack of length increase after late July (Figure 2.6).

Lengths of lake-type sockeye salmon in the Kuskokwim River were significantly greater than lengths of river-type salmon. This finding reflects the large size of Telaquana Lake sockeye salmon relative to other sockeye salmon in the watershed. Telaquana Lake, which likely supports the largest populations of lake-rearing sockeye salmon in the Kuskokwim watershed, produces relatively large sockeye salmon even though the lake is often glacial. Conceivably, the long back-calculated lengths of Telaquana sockeye salmon could reflect size-selective predation as smolts migrate a tremendous distance to the ocean (756 rkm). However, back-calculated lengths of sockeye salmon from Two Lakes (also in the Stony River watershed) were smaller than most river-type sockeye salmon populations, indicating size-selective predation was not especially high for upriver populations.

Sockeye salmon scales from the Kuskokwim River were similar or larger in size to those of other major sockeye salmon populations in Alaska, suggesting growth of river-type sockeye salmon in the watershed is favorable. Growth of sockeye salmon is typically density-dependent, but the effects of density on growth of river-type sockeye salmon in the Kuskokwim watershed have not been examined. Kuskokwim sockeye salmon appear to maintain favorable growth while shifting their distribution from slough habitats in the upper watershed during spring to downstream habitats during late summer and fall.

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TABLES AND FIGURES

Table 2.1.–Geometric mean catch per river seine haul of age-0 salmon, non-salmonids, and whitefish in the Kogrukluk River during 2006.

Habitat	n	Geometric mean	Lower SE	Upper SE
Sockeye Salmon (June to late September)				
Mainstem	22	4.0	1.6	10.4
Side channel	28	16.1	5.9	41.1
Slough	33	32.5	11.0	81.4
Chum Salmon (late June & early July)				
Mainstem	8	28.3	15.1	87.7
Side channel	9	13.5	8.7	49.0
Slough	8	9.1	5.2	28.9
Chinook Salmon (late June & early July)				
Mainstem	10	27.5	11.0	73.0
Side channel	15	11.1	4.3	29.0
Slough	10	5.9	2.9	16.7
Coho Salmon (late July & early August)				
Mainstem	5	48.0	25.9	150.9
Side channel	10	4.3	2.3	12.7
Slough	7	9.2	5.9	32.4
Non-salmonids (June to late September)				
Mainstem	22	5.1	1.5	12.1
Side channel	28	3.5	0.9	8.1
Slough	33	4.6	1.2	10.8
Whitefish (June to late September)				
Mainstem	22	0.4	0.2	1.0
Side channel	28	0.1	0.1	0.4
Slough	33	0.0	0.0	0.1

Note: CPUE during periods when species were relatively abundant. Sample periods excluded if overall catch rates were low.

Table 2.2.–Mean back-calculated length of sockeye salmon at the end of the first growth year (FW1) and after spring growth during the following year (FW1 & SWPL), and growth during spring of the smolt migration (FWPL).

Life stage	Adult year	Growth year	Location	River km [a]	Length (mm)	SE	n	Skewness
FW1	2005	2001	Stony R [b]	536	117.9		1	
FW1	2005	2001	Kuskokwim R [c]	270	110.2	6.2	2	0.00
FW1	2005	2001	Telaquana Lk	756	94.4	6.1	6	-1.04
FW1	2005	2001	Holitna (Chukowan)	709	93.2		1	
FW1	2005	2001	Hoholitna	538	90.9	3.4	7	0.01
FW1	2005	2001	Holitna [e]	491	88.3	2.0	16	-0.82
FW1	2005	2001	Kogrukluk R	709	86.5	3.3	13	1.09
FW1	2005	2001	Aniak R [d]	307	81.5	2.9	6	0.08
FW1	2005	2001	Stony (Two Lakes)	740	69.6	2.1	3	0.71
FW1	2006	2002	Telaquana Lk	756	110.5	1.7	63	-1.04
FW1	2006	2002	Tuluksak R	192	**97.2**	1.3	78	0.25
FW1	2006	2002	Hoholitna	538	**96.5**	2.1	40	0.24
FW1	2006	2002	George R	446	**95.3**	2.6	32	0.24
FW1	2006	2002	Holitna [e]	491	**94.6**	1.3	86	0.11
FW1	2006	2002	Kwethluk	131	**94.3**	1.4	72	0.16
FW1	2006	2002	Upper Aniak (Salmon)	390	**91.4**	2.2	41	0.68
FW1	2006	2002	Stony R [b]	536	**91.1**	4.9	14	-0.19
FW1	2006	2002	Holokuk/Oskawalik R	380	**90.4**	4.5	10	0.57
FW1	2006	2002	Aniak R [d]	307	**90.2**	1.8	37	0.53
FW1	2006	2002	Kuskokwim R [c]	709	**89.9**	2.1	40	0.29
FW1	2006	2002	Holitna (Chukowan)	709	**89.8**	3.0	20	0.22
FW1	2006	2002	Kogrukluk (Shotgun)	720	**89.1**	3.4	14	0.07
FW1	2006	2002	Kuskokwim R	270	**86.3**	5.5	8	-0.36
FW1	2006	2002	Stony (Two Lakes)	740	**84.8**	3.8	13	0.09

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Table 2.2.–Page 2 of 5.

Life stage	Adult year	Growth year	Location	River km [a]	Length (mm)	SE	n	Skewness
FW1	2007	2003	Telaquana Lk	756	105.8	2.5	28	-0.15
FW1	2007	2003	Kogrukluk (Shotgun)	720	**90.3**	4.1	7	-0.55
FW1	2007	2003	Aniak R [d]	307	**88.8**	1.3	79	0.45
FW1	2007	2003	Holitna [e]	491	**88.1**	1.4	49	-0.17
FW1	2007	2003	Hoholitna	538	**87.8**	1.6	39	0.20
FW1	2007	2003	Kuskokwim R [c]	270	**87.4**	2.2	38	0.01
FW1	2007	2003	Holitna (Chukowan)	709	**87.3**	3.3	18	-0.09
FW1	2007	2003	Stony R [b]	536	**87.3**	8.8	6	0.37
FW1	2007	2003	Kwethluk	131	**84.8**	1.1	139	0.98
FW1	2007	2003	Holokuk/Oskawalik R	380	**84.3**	5.7	4	0.47
FW1	2007	2003	Kogrukluk R	709	**82.6**	1.6	44	0.99
FW1	2007	2003	Stony (Two Lakes)	740	**80.8**	2.8	11	1.34
FW1	2007	2003	Upper Aniak (Salmon)	390	**69.6**	1.0	2	0.00
FW1 & FWPL	2005	2002	Kuskokwim R [c]	270	127.6	11.2	2	0.00
FW1 & FWPL	2005	2002	Telaquana Lk	756	118.8	7.1	6	-0.14
FW1 & FWPL	2005	2002	Stony R [b]	536	117.9		1	
FW1 & FWPL	2005	2002	Kogrukluk R	709	115.4	3.6	13	-0.50
FW1 & FWPL	2005	2002	Stony (Two Lakes)	740	109.0	1.5	3	-0.65
FW1 & FWPL	2005	2002	Holitna [e]	491	101.0	4.8	16	1.19
FW1 & FWPL	2005	2002	Aniak R [d]	307	97.8	7.2	6	0.01
FW1 & FWPL	2005	2002	Hoholitna	538	94.5	4.0	7	-0.18
FW1 & FWPL	2005	2002	Holitna (Chukowan)	709	93.2		1	
FW1 & FWPL	2006	2003	Telaquana Lk	756	116.1	1.4	63	-0.41
FW1 & FWPL	2006	2003	Kwethluk	131	**100.3**	1.9	72	0.59
FW1 & FWPL	2006	2003	Hoholitna	538	**100.0**	2.5	40	0.35
FW1 & FWPL	2006	2003	Tuluksak R	192	**99.3**	1.5	78	0.54
FW1 & FWPL	2006	2003	George R	446	**99.1**	3.1	32	0.59

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Table 2.2.–Page 3 of 5.

Life stage	Adult year	Growth year	Location	River km [a]	Length (mm)	SE	n	Skewness
FW1 & FWPL	2006	2003	Kogrukluk (Shotgun)	720	**98.2**	3.6	14	0.24
FW1 & FWPL	2006	2003	Stony R [b]	536	**98.0**	4.5	14	-0.52
FW1 & FWPL	2006	2003	Holitna [e]	491	**96.8**	1.4	86	0.19
FW1 & FWPL	2006	2003	Kuskokwim R [c]	270	**96.2**	9.2	8	0.40
FW1 & FWPL	2006	2003	Upper Aniak (Salmon)	390	**95.6**	2.4	41	0.37
FW1 & FWPL	2006	2003	Aniak R [d]	307	**95.3**	2.4	37	0.54
FW1 & FWPL	2006	2003	Kogrukluk R	709	**93.3**	2.3	40	0.63
FW1 & FWPL	2006	2003	Stony (Two Lakes)	740	**92.3**	3.5	13	0.78
FW1 & FWPL	2006	2003	Holokuk/Oskawalik R	380	**90.4**	4.5	10	0.57
FW1 & FWPL	2006	2003	Holitna (Chukowan)	709	**89.8**	3.0	20	0.22
FW1 & FWPL	2007	2004	Holokuk/Oskawalik R	380	127.4	7.0	4	-0.13
FW1 & FWPL	2007	2004	Stony R [b]	536	120.9	6.0	6	0.11
FW1 & FWPL	2007	2004	Telaquana Lk	756	119.9	2.8	28	0.60
FW1 & FWPL	2007	2004	Kuskokwim R [c]	270	119.1	2.7	38	0.06
FW1 & FWPL	2007	2004	Kogrukluk (Shotgun)	709	118.4	7.0	7	-1.04
FW1 & FWPL	2007	2004	Holitna [e]	491	115.5	2.7	49	0.08
FW1 & FWPL	2007	2004	Stony (Two Lakes)	740	114.3	4.0	11	0.36
FW1 & FWPL	2007	2004	Kwethluk	131	**112.5**	1.4	139	-0.46
FW1 & FWPL	2007	2004	Holitna (Chukowan)	709	111.6	3.9	18	0.51
FW1 & FWPL	2007	2004	Aniak R [d]	307	**110.0**	2.2	79	0.05
FW1 & FWPL	2007	2004	Hoholitna	538	**109.7**	2.6	39	0.01
FW1 & FWPL	2007	2004	Kogrukluk R	709	**109.0**	3.0	44	-0.26
FW1 & FWPL	2007	2004	Upper Aniak (Salmon)	390	98.2	5.9	2	0.00
FWPL	2005	2002	Stony (Two Lakes)	740	39.4	3.5	3	-0.70
FWPL	2005	2002	Kuskokwim R [c]	709	29.0	5.0	13	-0.68

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Table 2.2.–Page 4 of 5.

Life stage	Adult year	Growth year	Location	River km [a]	Length (mm)	SE	n	Skewness
FWPL	2005	2002	Telaquana Lk	756	24.4	11.8	6	0.46
FWPL	2005	2002	Kuskokwim R	270	17.5	17.5	2	0.00
FWPL	2005	2002	Aniak R	307	16.4	7.7	6	0.30
FWPL	2005	2002	Holitna [e]	491	12.7	5.0	16	0.97
FWPL	2005	2002	Hoholitna	538	3.5	3.5	7	2.04
FWPL	2005	2002	Holitna (Chukowan)	709	0.0		1	
FWPL	2005	2002	Stony R [b]	536	0.0		1	
FWPL	2006	2003	Kuskokwim R [c]	270	9.9	6.5	8	1.19
FWPL	2006	2003	Kogrukluk (Shotgun)	720	9.1	4.9	14	1.42
FWPL	2006	2003	Stony (Two Lakes)	740	7.5	4.1	13	1.59
FWPL	2006	2003	Stony R [b]	536	6.9	3.7	14	1.53
FWPL	2006	2003	Kwethluk	131	6.0	1.5	72	1.87
FWPL	2006	2003	Telaquana Lk	756	5.6	1.6	63	1.89
FWPL	2006	2003	Aniak R [d]	307	5.1	2.0	37	2.07
FWPL	2006	2003	Upper Aniak (Salmon)	390	4.2	1.6	41	2.21
FWPL	2006	2003	George R	446	3.9	1.7	32	2.14
FWPL	2006	2003	Hoholitna	538	3.5	1.7	40	2.91
FWPL	2006	2003	Kogrukluk R	709	3.4	1.7	40	3.11
FWPL	2006	2003	Holitna [e]	491	2.3	0.9	86	3.44
FWPL	2006	2003	Tuluksak R	192	2.1	1.1	78	4.16
FWPL	2006	2003	Holitna (Chukowan)	709	0.0	0.0	20	
FWPL	2006	2003	Holokuk/Oskawalik R	380	0.0	0.0	10	
FWPL	2007	2004	Holokuk/Oskawalik R	380	**43.0**	3.2	4	0.31
FWPL	2007	2004	Stony R [b]	538	**33.6**	12.2	6	0.07
FWPL	2007	2004	Stony (Two Lakes)	740	**33.6**	2.5	11	-0.56
FWPL	2007	2004	Kuskokwim R [c]	270	**31.7**	3.2	38	-0.11
FWPL	2007	2004	Upper Aniak (Salmon)	390	28.6	5.0	2	0.00
FWPL	2007	2004	Kogrukluk (Shotgun)	720	28.1	8.5	7	-0.04

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Table 2.2.–Page 5 of 5.

Life stage	Adult year	Growth year	Location	River km [a]	Length (mm)	SE	n	Skewness
FWPL	2007	2004	Kwethluk	131	**27.7**	1.8	139	-0.13
FWPL	2007	2004	Holitna [e]	491	**27.4**	3.0	49	0.01
FWPL	2007	2004	Kogrukluk R	709	**26.5**	3.3	44	0.04
FWPL	2007	2004	Holitna (Chukowan)	709	24.3	5.8	18	0.30
FWPL	2007	2004	Hoholitna	538	21.9	3.1	39	0.18
FWPL	2007	2004	Aniak R [d]	307	21.2	2.2	79	0.24
FWPL	2007	2004	Telaquana Lk	756	14.1	3.8	28	1.11

Note: Values that were significantly different ($P < 0.05$) from the value in the box from the same life stage and year (e.g., Telequana Lake) are highlighted in bold. Values are shown in descending order within each life stage and year. The "Kuskokwim River" group represented a mixture of tagged fish sockeye salmon for which tributary / habitat could not be determined.

[a] Distance from the mouth of the Kuskokwim River to the mouth of the spawning tributary.

[b] Includes entire Stony River drainage except the associated lake systems (i.e., Telaquana Lk and Stony (Two Lakes)).

[c] Kuskokwim R location represents all sockeye salmon that were not tracked to a spawning tributary. River kilometer provided is consistent with the location of tagging. Spawning activity in the mainstem was not confirmed.

[d] Includes entire Aniak River drainage except the Upper Aniak (Salmon).

[e] Includes entire Holitna River drainage except the Hoholitna, Kogrukluk R, Kogrukluk (Shotgun) and Holitna (Chukowan).

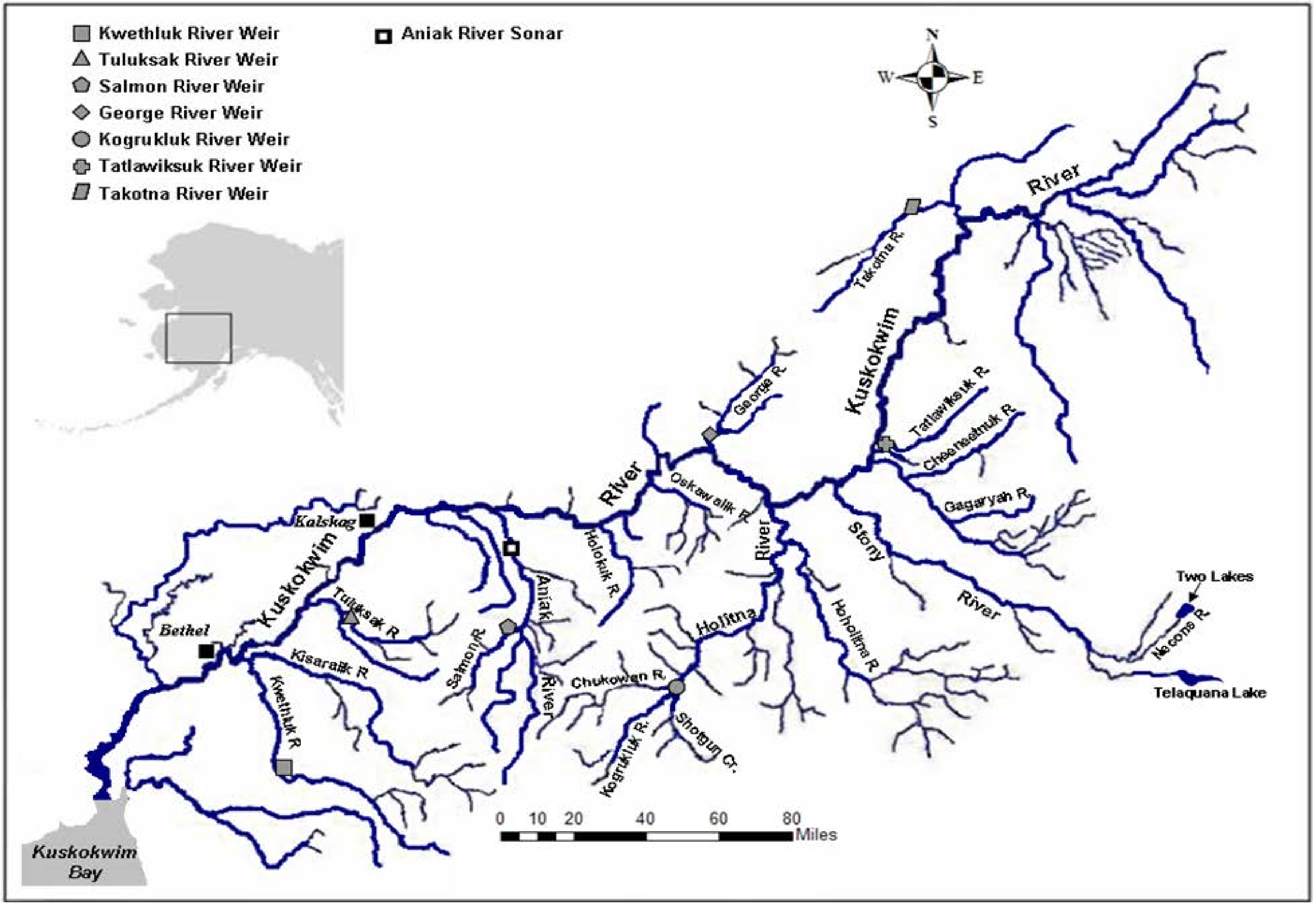
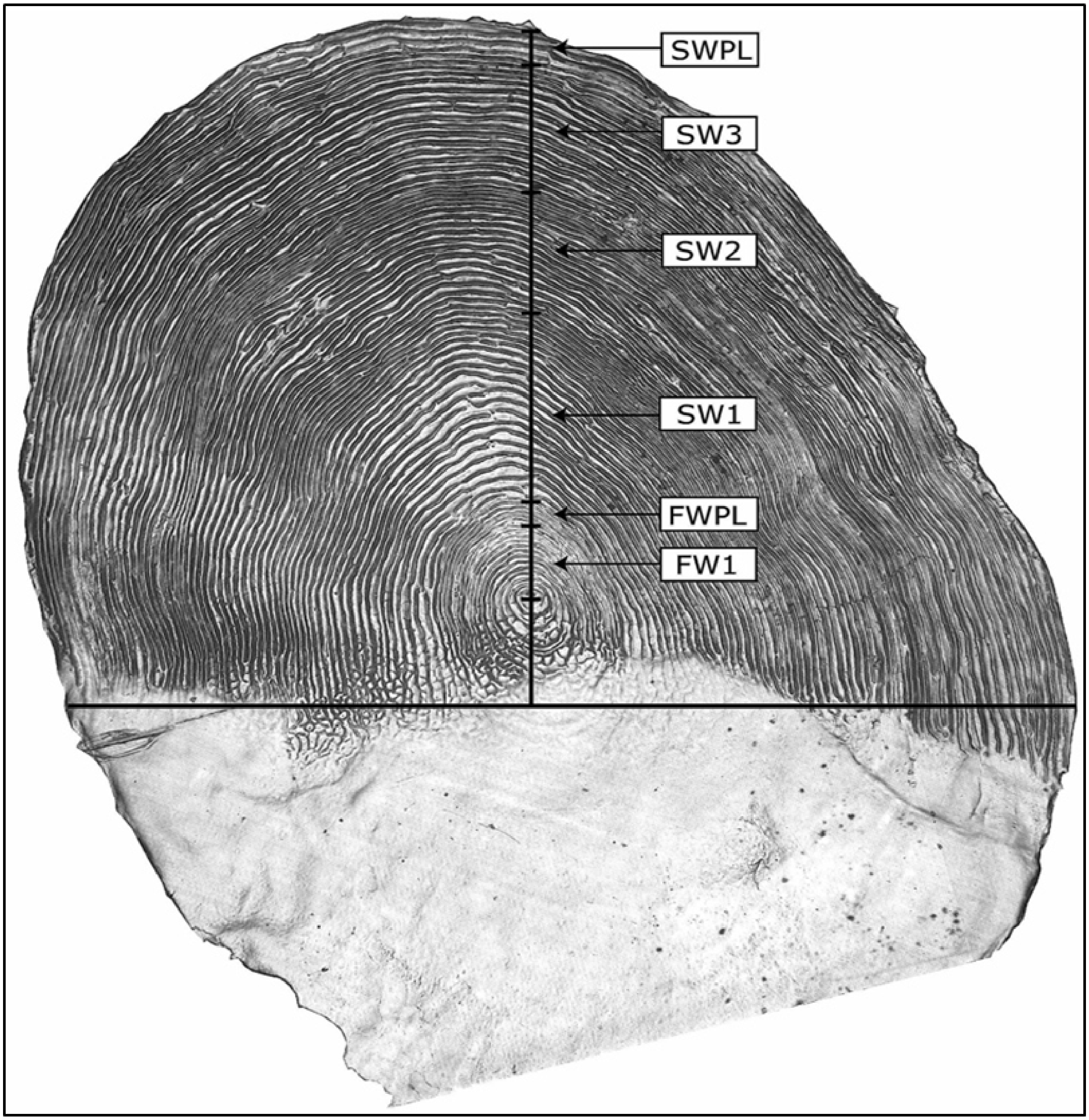


Figure 2.1.–Kuskokwim River watershed with location of major tributaries, adult salmon weirs, and Kalskag tagging location.



Source: Ruggerone et al. 2007

Figure 2.2.–Age-1.3 sockeye salmon scale showing the perpendicular measurement axis and the life stage zones corresponding to growth during the first year in freshwater (FW1), spring growth during the year of smoltification (FWPL), growth during each year at sea (SW1, SW2, SW3), and growth during the homeward migration (SWPL).

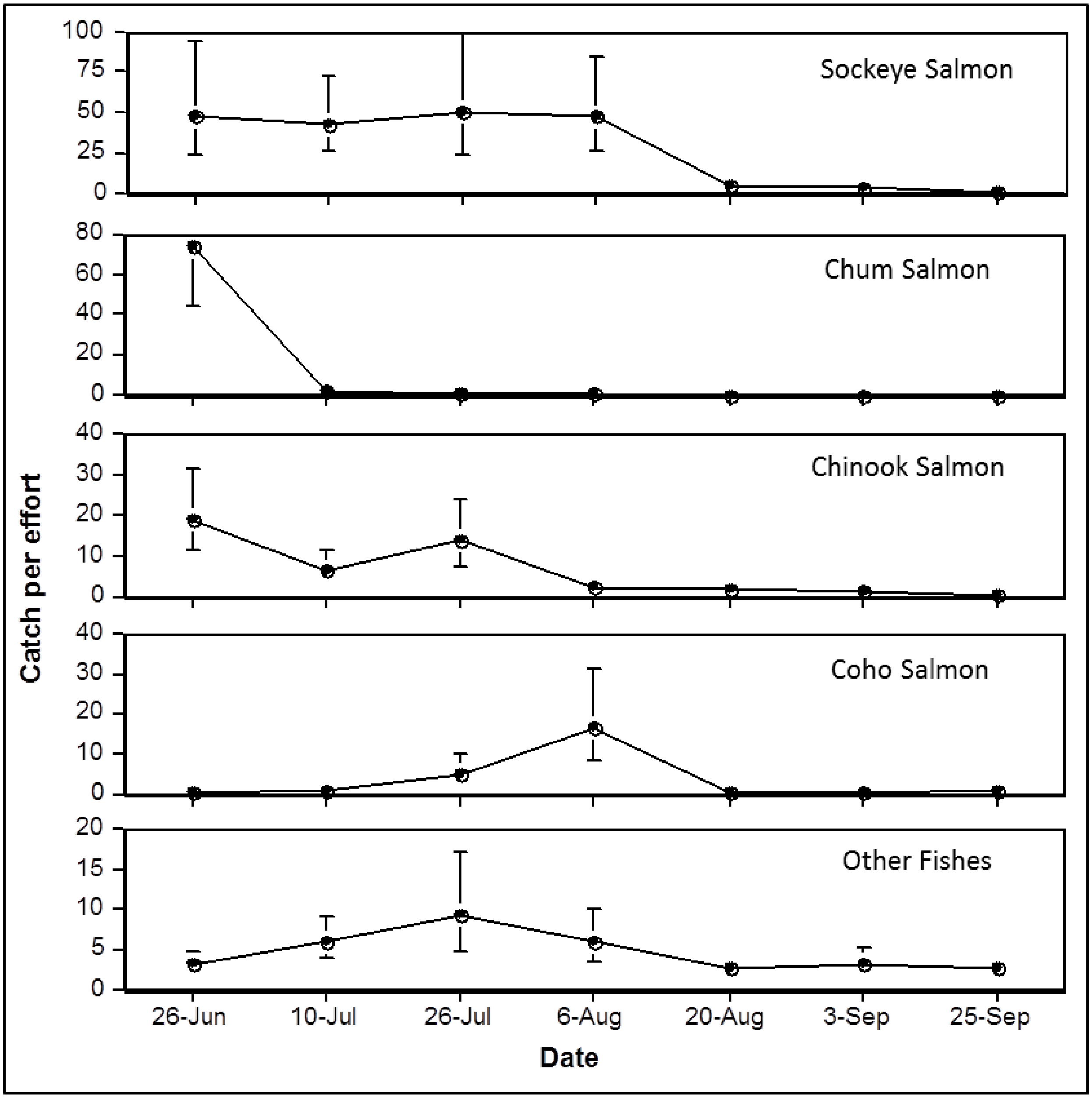


Figure 2.3.–Geometric mean beach seine catch (±1 SE) of age-0 salmon and other fishes in the upper Holitna River (Kogrukluk R) during late June to late September, 2006.

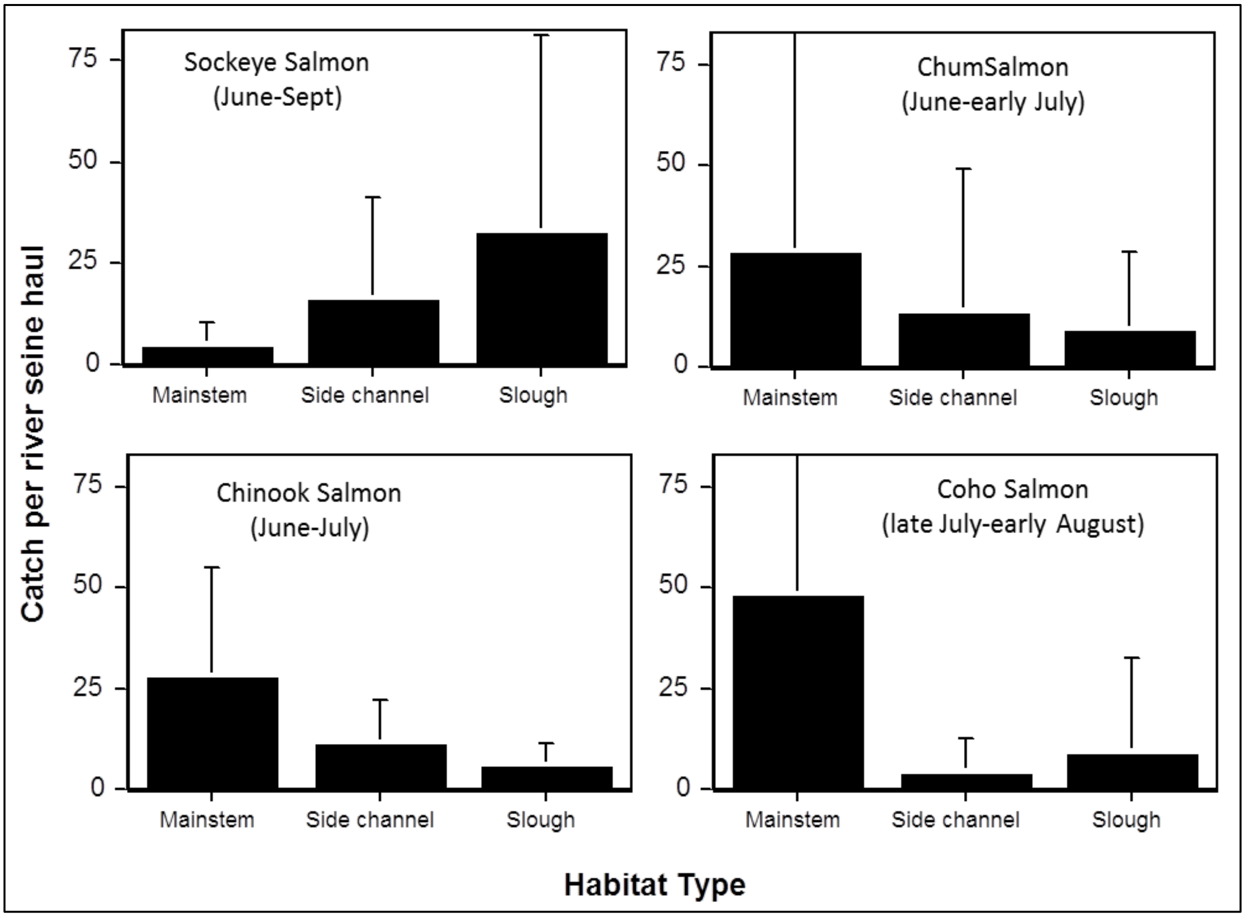


Figure 2.4.–Geometric mean catch per river seine haul of age-0 salmon the upper Holitna River (Kogrukluk R) during 2006.

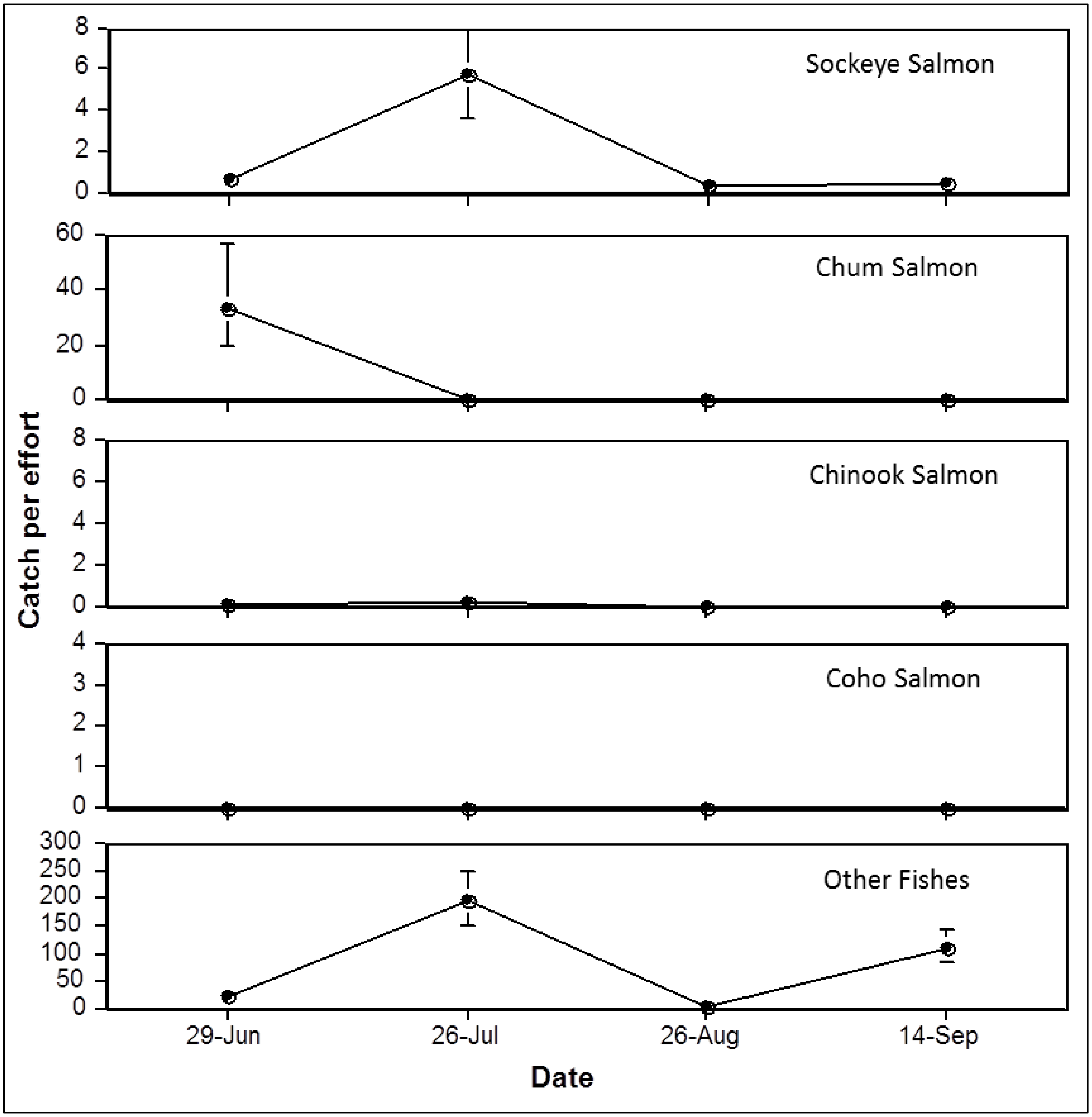


Figure 2.5.–Geometric mean beach seine catch (±1 SE) of age-0 salmon and total non-salmonids in the lower Holitna River during late June to late September, 2006.

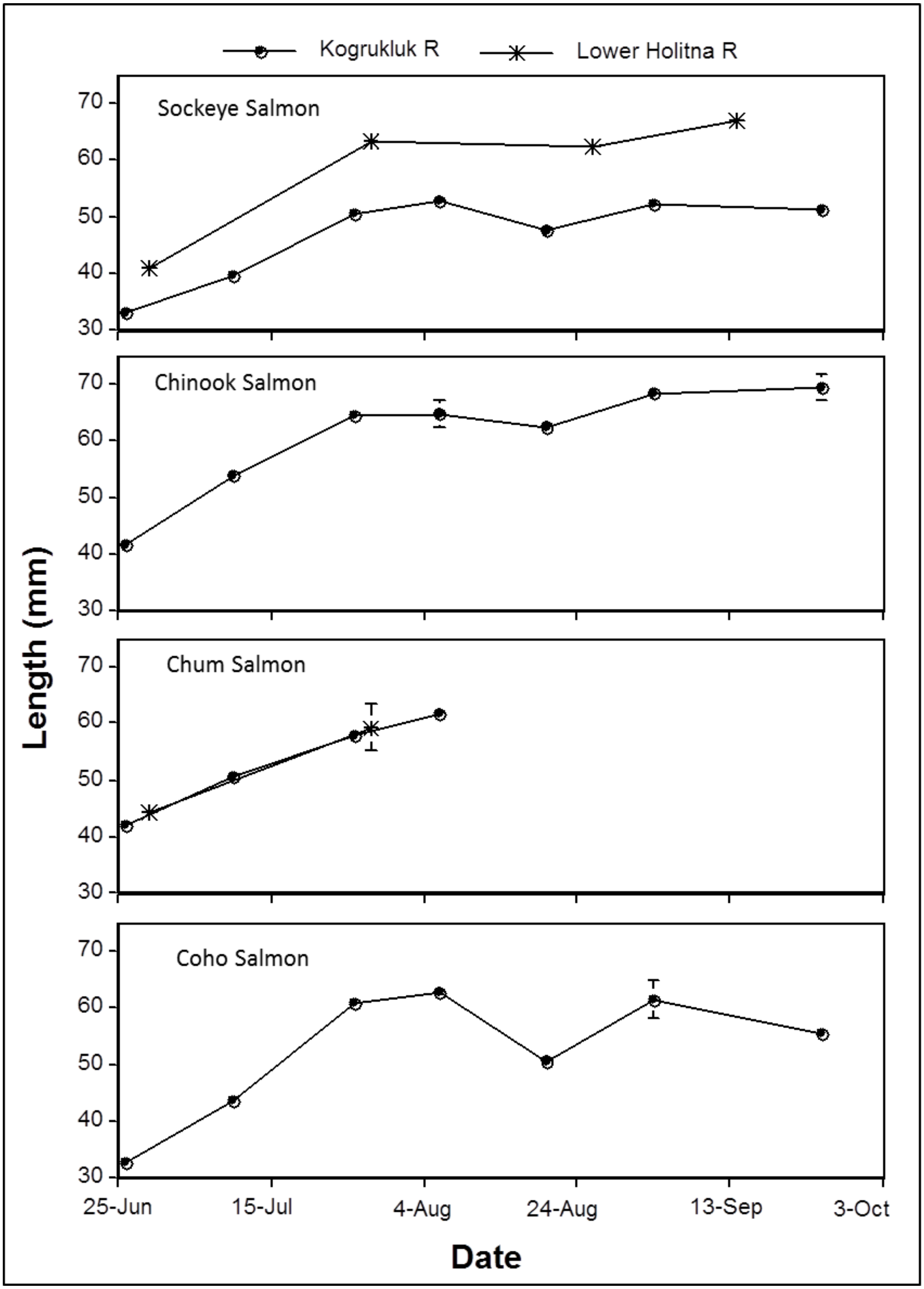
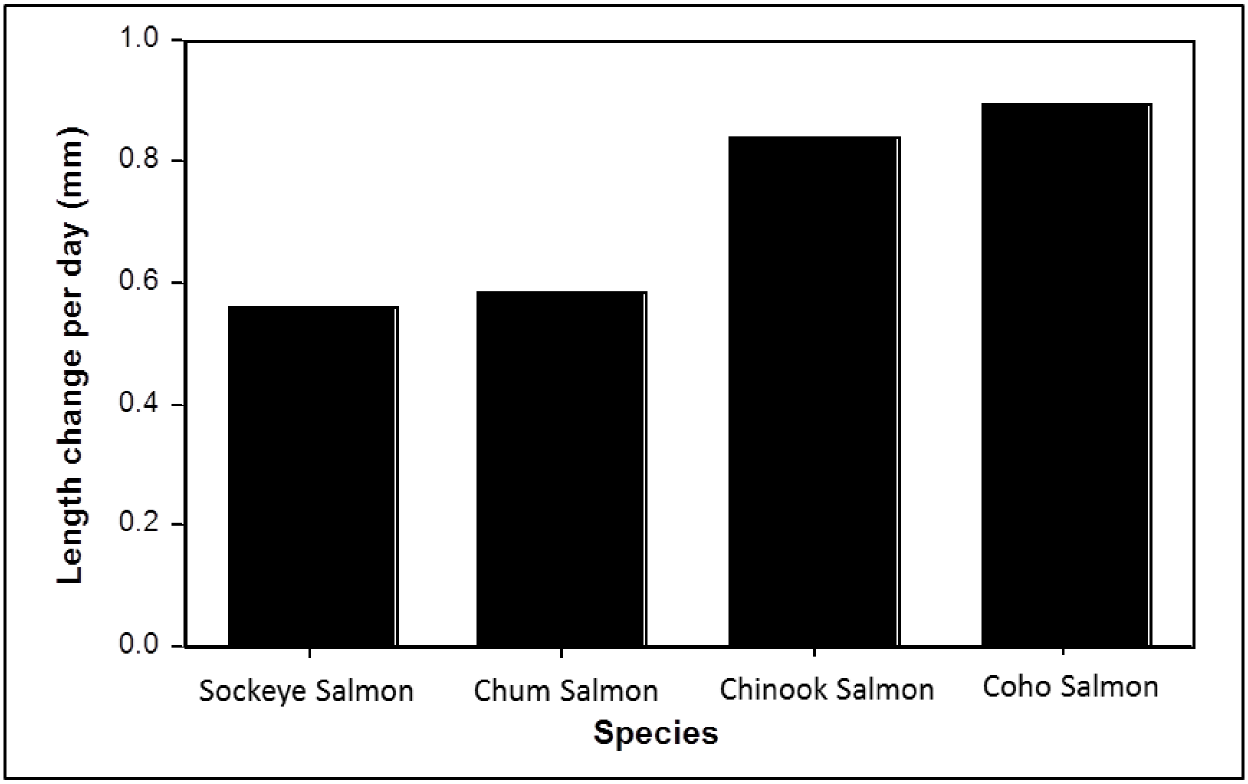


Figure 2.6.–Mean live length (±1 SE) of age-0 salmon in the upper and lower Holitna River from late June to late September, 2006.



Note: Values are based on change in mean length during the period when change was relatively consistent and catch rates were relatively high. Values reflect growth and movement of individuals into and out of the study area.

Figure 2.7.–Approximate mean growth per day of juvenile salmon in the upper Holitna River (Kogrukluk R) during June and July 2006.

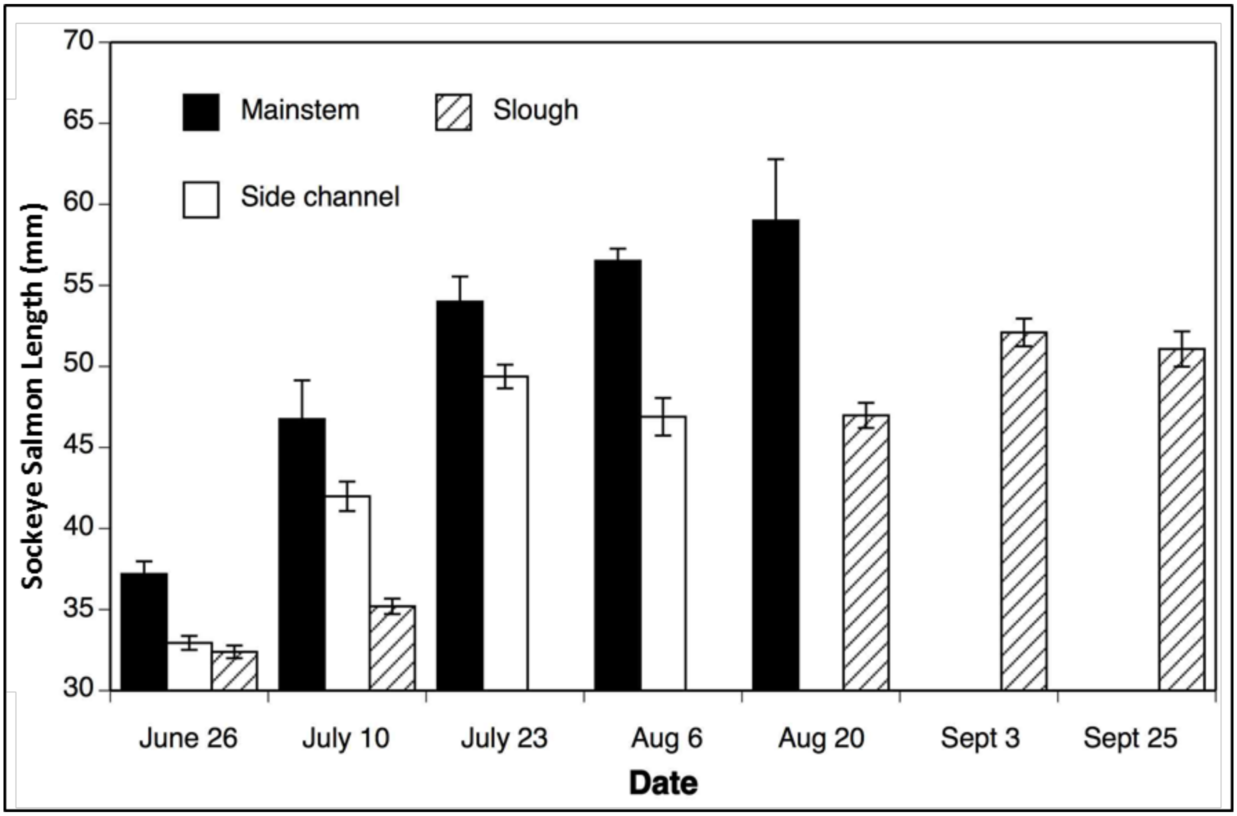
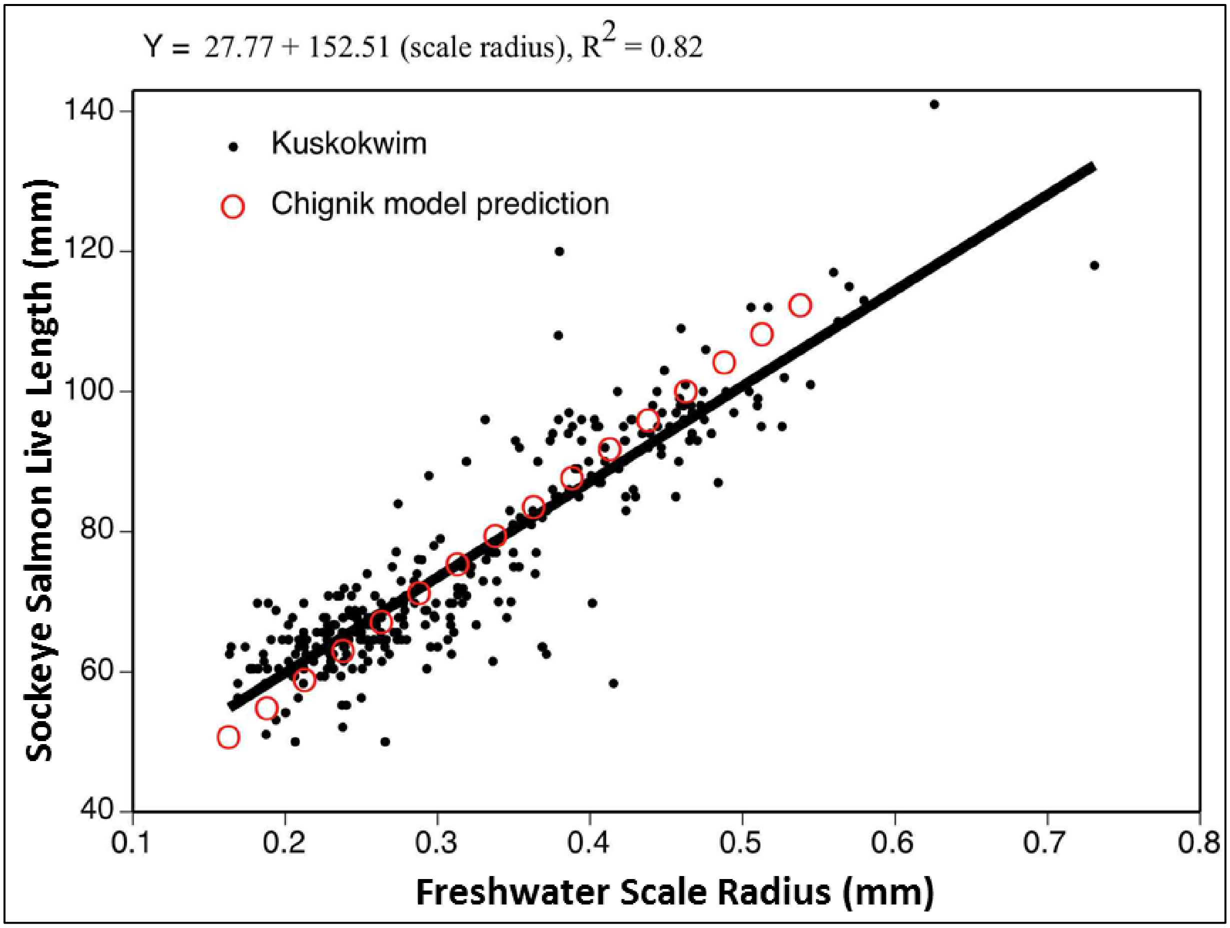
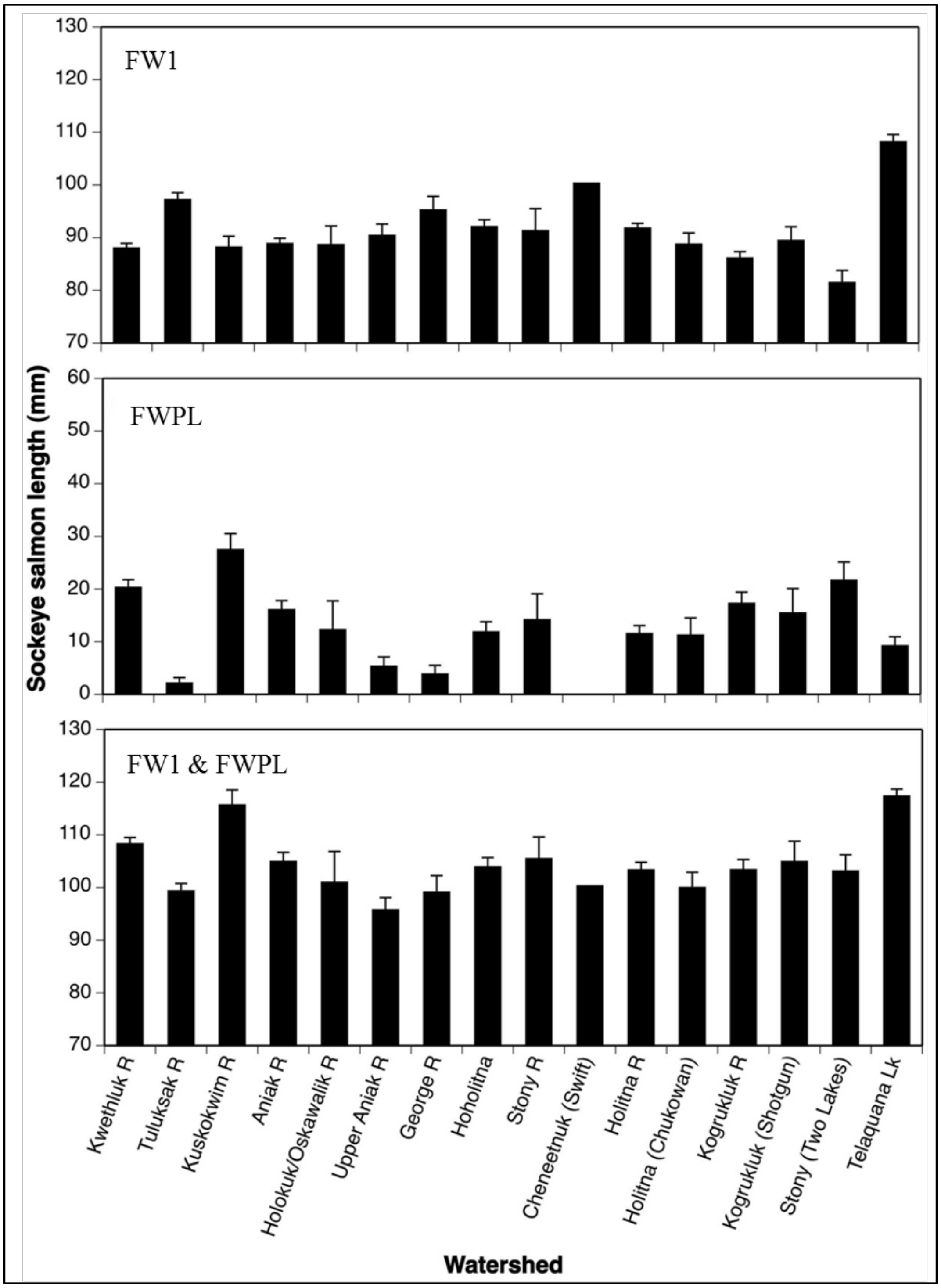


Figure 2.8.–Mean length mean (±1 SE) of subyearling sockeye salmon captured in mainstem, side channel, and slough habitats of the upper Holitna River (Kogrukluk R) during late June through September 2006.



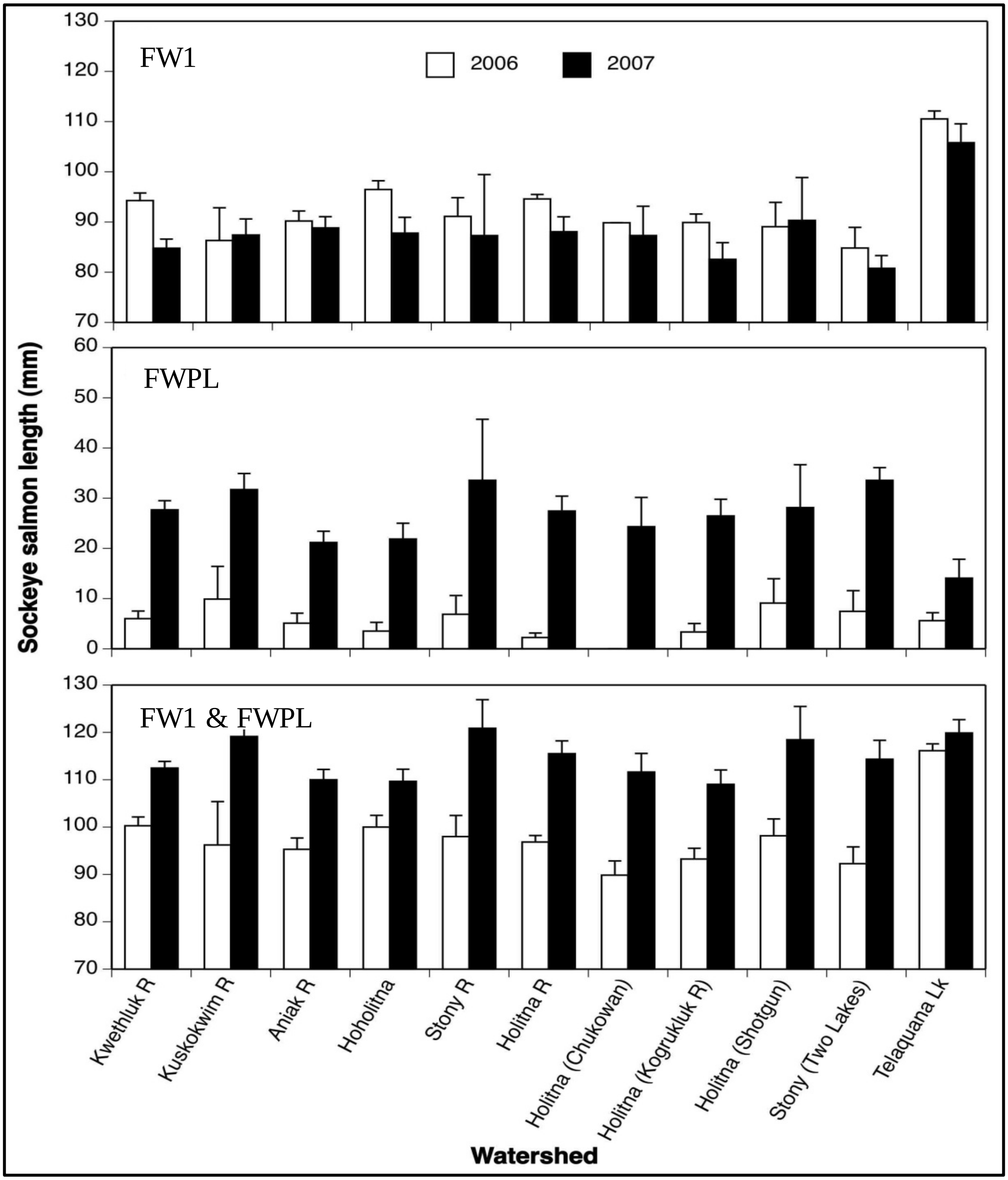
Note: The geometric mean regression for juvenile sockeye salmon from the Chignik watershed, Alaska, is shown for comparison.

Figure 2.9.–Geometric mean regression of juvenile Kuskokwim River sockeye salmon back calculated length on their freshwater scale radius (FW1 & FWPL).



Note: Values include all data from adult return years 2005, 2006, and 2007. The "Kuskokwim River" group represented a mixture of tagged fish sockeye salmon for which tributary / habitat could not be determined.

Figure 2.10.–Mean (±1 SE) back-calculated length of sockeye salmon from areas within the Kuskokwim River drainage at the end of the first growing season, and the end of the smolt transition period during the following spring, and the incremental growth during the smolt period.



Note: Watersheds having few scales or scales during only one year were excluded. The "Kuskokwim River" group represented a mixture of tagged fish sockeye salmon for which tributary / habitat could not be determined.

Figure 2.11.–Comparison of mean (±1 SE) back-calculated length of sockeye salmon from each area and life stage in the Kuskokwim River drainage during adult return years 2006 versus 2007.

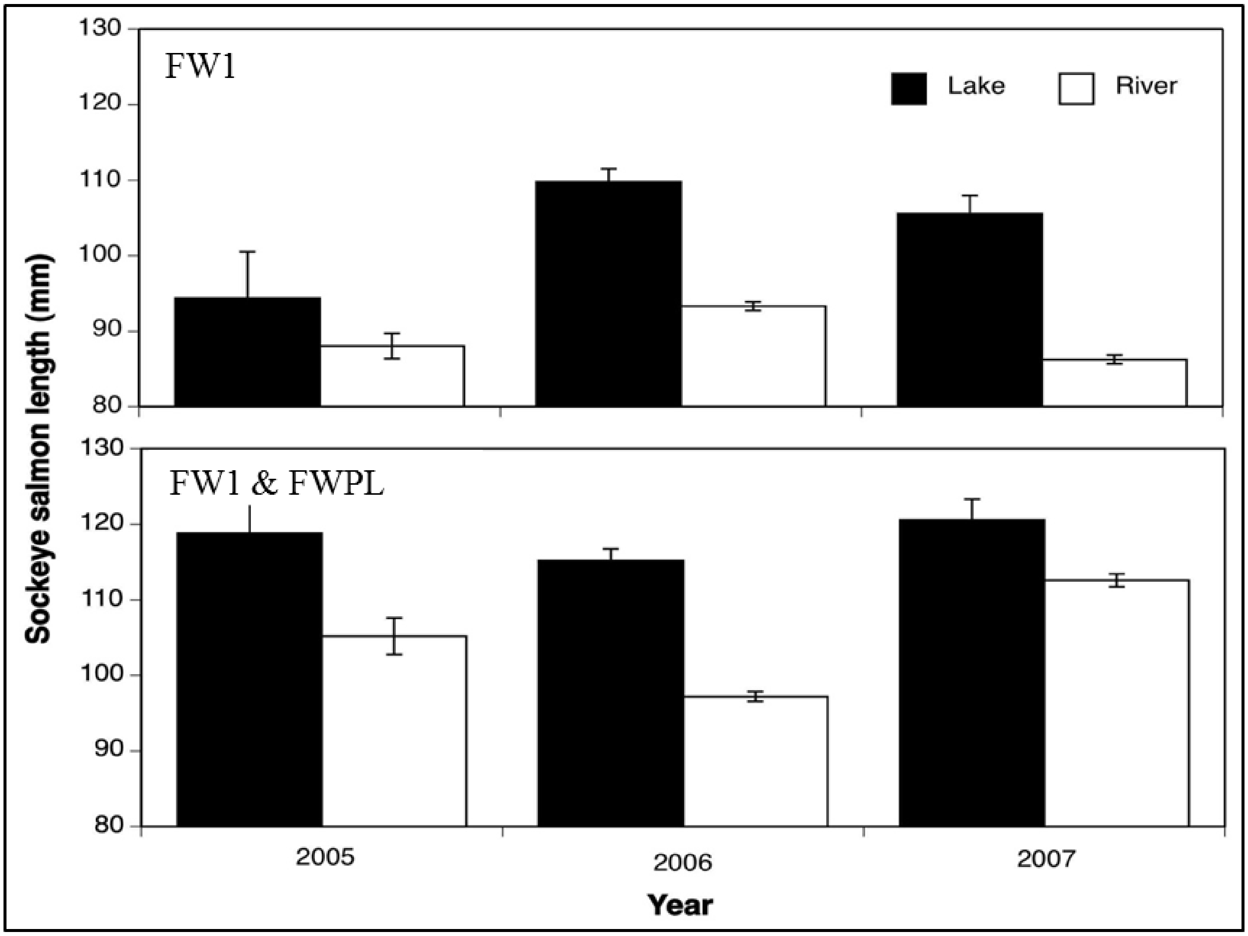


Figure 2.12.–Comparison of back-calculated mean length (±1 SE) of river- versus lake-rearing sockeye salmon during each life stage, adult years 2005–2007.

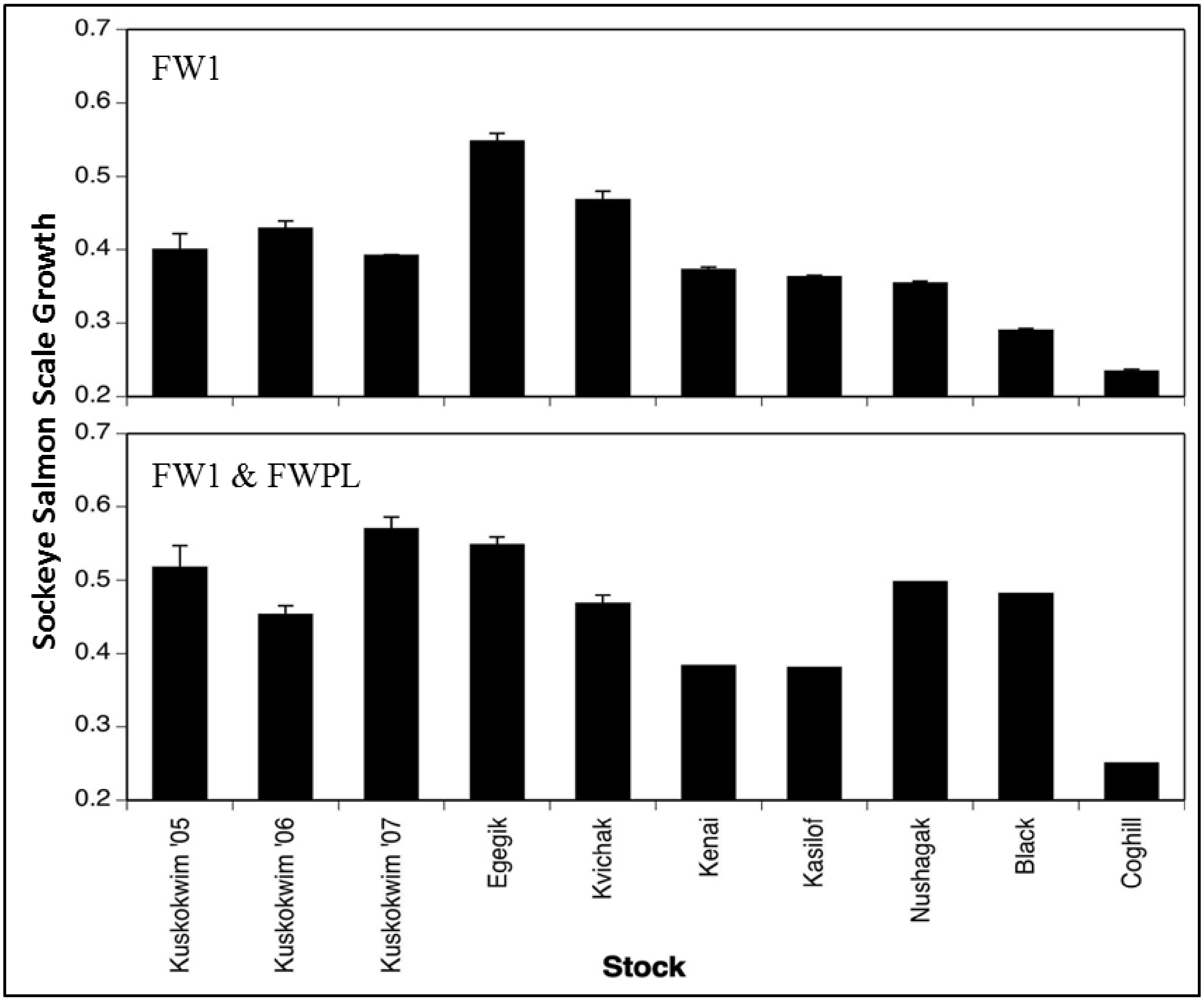


Figure 2.13.–Comparison of mean (±1 SE) of sockeye salmon scale growth in the Kuskokwim River (adult return years 2005–2006) versus age-1.3 lake-rearing sockeye salmon from other regions of Alaska (Ruggerone and Rogers 1998).

APPENDIX 2.A: PHOTOGRAPHS OF FISH SAMPLING AND HABITAT

Appendix Figure 2.A.1.–Setting the river seine along the mainstem (top) and slough (bottom) of the Kogrukluk River.

Appendix Figure 2.A.2.–Examples of slough habitat in the Kogrukluk River.

Appendix Figure 2.A.3.–Setting the river seine in the lower Holitna River.

Appendix Figure 2.A.4.–Chum (upper) and sockeye (lower) salmon fry.