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Characteristics of Fall Chum Salmon *Oncorhynchus keta* in the Kuskokwim River Drainage

by

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Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

Fishery managers became aware in the mid 1990s that the Kuskokwim River hosts a run of fall chum salmon *Oncorhynchus keta* distinct from the more common summer chum salmon population. Between 1993 and 2002, Kuskokwim River commercial and subsistence harvests averaged 205,600 chum salmon per year caught in directed fisheries and as incidental catch in coho salmon *O. kisutch* directed fisheries; however, harvest statistics do not distinguish fall run from the summer run of chum salmon. Furthermore, the escapement of fall chum salmon is not monitored, although escapement is monitored for several summer chum populations. Distinctive characteristics in the morphology, age and sex composition, and spawning distribution of fall chum salmon are unknown or undescribed. In this project we describe some of these characteristics by comparing 336 fall chum salmon sampled from the South Fork Kuskokwim River with 1,964 summer chum salmon sampled from the Kwethluk, George, and Takotna rivers. In 2004, fish were sampled and examined for length from mideye-to-tail-fork (METF), maximum dorsal-ventral height, and maximum width. Age and sex was determined for each fish, and fecundity parameters were measured for 15 to 20 females from each of the 4 sample groups. Spawning distribution of fall chum salmon was determined through review of historical aerial surveys and augmented with additional surveys in 2004. Multivariate analysis demonstrated a significant difference in the morphology between fall and summer chum salmon, with fall chum salmon generally having greater length from METF, smaller maximum height, and smaller maximum width. The fall chum salmon population had a greater percentage of age-0.2 fish than summer chum salmon populations, but sex ratios were similar and there was no significant difference in fecundities; however, these results may have been influenced by sampling biases. Spawning distribution of fall chum salmon appeared to be limited to a subset of tributary streams in the upper Kuskokwim basin characterized by braided channels and glaciated headwaters. Analysis of 31 single nucleotide polymorphisms in 9 populations in the Kuskokwim River demonstrated sufficient genetic differences between fall and summer chum salmon populations to distinguish the two runs in mixed stock analyses with a high degree of accuracy (>92%). Analysis of mixed stock chum salmon catches from fish wheels operated near Kalskag indicated a low occurrence of fall chum salmon in 2004, but no definitive conclusion could be made about run timing of fall chum salmon from the limited subsample analysis. Greater resolution about run timing may be possible thorough analysis of the remaining mixed stock samples that have been archived.

Key words: Age, sex, length (ASL), distribution, fall chum salmon, fecundity, fish wheel, George River, Kuskokwim River, Kwethluk River, morphology, *Oncorhynchus keta*, run timing, South Fork Kuskokwim River, summer chum salmon, Takotna River, weir.

INTRODUCTION

In September 2000, the Alaska State Board of Fisheries (BOF) classified Kuskokwim River chum salmon *Oncorhynchus keta* (Walbaum) as a "stock of concern" due to the chronic inability, despite the use of specific management measures, to maintain expected harvest above escapement needs (5 AAC 39.222; Burkey et al. 2000a). This finding applied to all Kuskokwim River chum salmon. No distinction was made between the summer and fall runs, which is not surprising given that fall chum salmon in the Kuskokwim River have only been recognized by biologists as a distinct run since the mid 1990s (Seeb et al. 1997a; 2004).

The "stock of concern" finding was the culmination of measures taken in response to a string of disastrously low chum salmon runs that began in 1992 (Burkey et al. 2000b; 2002), and was continued by the BOF following deliberation in 2004 (Bergstrom and Whitmore 2004). The finding prompted conservation measures aimed at reducing chum salmon harvest and improving escapement (Burkey et al. 2002). The northern boundary of District 4 in Kuskokwim Bay was moved south several miles in order to distance commercial fishermen from the Kuskokwim River; managers hoped that the added buffer zone would reduce the interception of chum salmon bound for the Kuskokwim River during the District 4 sockeye salmon *O. nerka* directed fishery. In the Kuskokwim River, commercial fishing was closed in June and in part or all of July during 2001 through 2004. Concurrent with these closures, and for the first time in history, subsistence fishermen were placed on a 4-day per week fishing schedule. These conservation measures were relaxed each year at some point in late June or in July when indicators, such as the Bethel test fishery and tributary escapement projects, showed run abundance and escapements were adequate. In each of these years, commercial fishing for coho salmon *O. kisutch* began by late July or early August with concurrent incidental chum salmon harvest.

Managers have not known to what extent the conservation measures might benefit Kuskokwim River fall chum salmon, if at all. It was thought that these fish might begin entering the Kuskokwim River after the conservation measures were relaxed in late June or July, and that fall chum salmon may derive their greatest harvest reductions through the harvest limits imposed by commercial fish buyers who had only a fraction of their normal processing capacity during the coho directed fishery. However, genetic analysis of an opportunistic sample from the commercial fishery (17 ~~June~~ July 1996; ADF&G, Gene Conservation Laboratory, Anchorage, unpublished data) contained 12% (± 4%) fall chum salmon, while another sample from the Bethel test fishery (25 July to 1 August 2003; ADF&G, Gene Conservation Laboratory, Anchorage, unpublished data) contained 0% (± 3%) fall chum salmon. Still, any discussion about run timing, abundance, or escapement of fall chum salmon has been speculative because, unlike in the Yukon River, harvest and escapement of Kuskokwim River fall chum salmon are not monitored.

Citation date changed 2/28/2007 to correct typographical error.

Residents of the upper Kuskokwim River have historically recognized the presence of fall chum salmon and harvested them for subsistence use (e.g. Stickney 1980; Stokes 1985). Long-time residents asserted that fall chum salmon were much more abundant in decades past (R. Collins, resident, McGrath, personal communication; N. Mellick, resident, Sleetmute, personal communication). The recollections of local residents echoed trends reported of sockeye salmon in Bristol Bay, where minor producers during one climatic regime were much more dominant during other times (Hilborn et al. 2003). In Bristol Bay, the resilience of the area's sockeye salmon is credited to a sustainable fisheries management plan that emphasizes conservation of the biocomplexity within fish stocks. Although genetic evidence of distinct sets of chum salmon populations in the Kuskokwim River has been reported (Seeb et al. 1997a; 2004), information about the distribution, morphology, and behavior of Kuskokwim River fall chum salmon is missing. In the meantime, overlapping multispecies runs and the harvesting of mixed stocks could result in over harvesting of fall chum salmon in relation to their abundance.

In order to begin closing this information gap, we set out to describe biological characteristics of fall chum salmon in the Kuskokwim River. The objectives were to: 1) describe the distribution, morphology, and biology of adult fall chum salmon in comparison to summer chum salmon; 2) assess the run timing and relative abundance of adult fall chum salmon in the lower Kuskokwim River. This information is essential for including fall chum salmon in a sustainable salmon fishery management program for the Kuskokwim River.

METHODS

STUDY AREA

The Kuskokwim River is the second largest river in Alaska, draining an area of approximately 130,000 km^2, or 11% of the land area of Alaska (Figure 1; Brown 1983). The river arises on the northwestern slope of the Alaska Range, running approximately 1,500 km westward to empty into the Bering Sea in Kuskokwim Bay. Each year 5 species of Pacific salmon *Oncorhynchus spp.* return to the river and its tributaries to spawn, thereby supporting important commercial and subsistence harvests. Subsistence harvests remain a fundamental component of local culture, and the subsistence salmon fishery in the Kuskokwim Area is second only to the Yukon River in the annual number of chum salmon harvested (ADF&G 2003; Coffing 1991, *Unpublished* a, *Unpublished* b; Coffing et al. 2000).

AGE, SEX, AND MORPHOLOGY

Summer chum salmon were captured with fish traps incorporated into weirs used to monitor escapement on the Kwethluk (190 rkm), George (453 rkm), and Takotna (835 rkm) rivers (Figure 1; Costello et al. *In prep*; Roettiger et al. *In prep*; Stewart and Molyneaux *In prep*). Fall chum salmon were captured in a live box at a fish wheel located on the South Fork Kuskokwim River near the village of Nikolai (941 rkm; Figure 1). These 4 locations were each a similar distance to their respective spawning grounds. At least 3 pulse samples were collected during each of the summer and fall chum salmon runs, each pulse timed using past escapement data to sample each third of the run. A target amount of 170 fish were captured in each pulse sample, ($\alpha = 0.05$, $d = 0.10$, $k = 6$; Bromaghin 1993), though this sample size was not always achieved. Three scales were taken for age determination according to standard scale analysis procedures (DuBois and Molyneaux *Unpublished*), and sex was recorded for each fish. Using calipers and a meter stick, fish were measured to the nearest millimeter for 3 morphometric features: 1) maximum width (Katayama 1935), 2) maximum dorsal-ventral height (Finn et al. 1998), and 3) length from mideye–to-tail-fork (METF) (DuBois and Molyneaux *Unpublished*).

Age and sex compositions and morphology were analyzed for differences between groups and over time. Sex and age compositions were compared using chi square tests of independence (Sokal and Rohlf 1995). Variability in morphometric measurements of both males and females from summer and fall chum salmon stocks were examined using a multivariate analysis of variance (MANOVA; Green 1978). Similarities in morphology measurements between individual populations were examined using a MANOVA and cluster analyses (Everitt 1980). The effects of run timing on age and sex were examined using logit model analyses (Hosmer and Lemeshow 2000). A linear regression was applied to examine changes in morphology over time and relationships between morphology measurements (Sokal and Rohlf 1995).

Ages are reported using European notation, which is composed of 2 numerals separated by a decimal. The first numeral indicates the number of winters the juvenile spent in freshwater and the second numeral indicates the number of winters spent in the ocean (Groot and Margolis 1991). Total age of a fish is equal to the sum of these 2 numerals, plus one year to account for the winter when the egg was incubating in gravel. For example, a chum salmon described as an age-0.2 fish is actually 3 years of age.

FECUNDITY

A total of 15–20 unspawned females were collected per sampling site, 5 drawn from each pulse sample. Whole skeins (ovaries) were collected from each fish and individually preserved in labeled vials containing 70% ethyl alcohol until processing. Total number of eggs (absolute fecundity) was estimated for each female by weighing 3 random subsamples of 100 eggs to the nearest 0.01 g on a digital balance (Mettler Toledo, PG503-S[1]). Fecundity of individual fish was

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[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

estimated by dividing the total egg skein weight by the subsample weight, then multiplying by the number of eggs in the subsample (100) similar to Nemeth et al. (2003). This was replicated for each of the subsamples, and the number of eggs per female was estimated as the average of the 3 replicates (Equations 1 and 2):

$$f_{ij} = \frac{G_j * 100}{g_{ij}}; \qquad (1)$$

$$F_k = \frac{\sum f_{ij}}{n_k} \qquad (2)$$

where:

$f_{ij} =$ estimated fecundity based on subsample *i* from ovary *j*;

$G_j =$ weight of ovary *j*;

$g_{ij} =$ weight of subsample *i* from ovary *j*;

$F_k =$ mean fecundity of individual fish *k*; and

$n_k =$ number of egg group subsamples taken from fish *k*.

Since fecundity is reported to vary with fish length, relative fecundity was also calculated by dividing the fecundity by body length to obtain the number of eggs per cm of body length (Lovetskaya 1948; Nemeth et al. 2003). For this report, absolute fecundity refers to the total number of eggs estimated for each fish, and relative fecundity refers to the number of eggs per cm of body length. Average egg weight was calculated by dividing total skein weight by the absolute fecundity.

Mean and variance in absolute fecundity were reported for each site and for the pooled summer chum salmon samples. These statistics were calculated, by site and pooled summer run, for both the entire sample and for separate age categories. The effects of length, age, and run timing on absolute and relative fecundity were examined using linear regression and ANOVA (Sokal and Rohlf 1995). Females that could not be aged were dropped from further analyses. Fecundities and egg weights of summer and fall chum salmon and of individual populations were compared using ANOVA (Sokal and Rohlf 1995). Fecundities of Kuskokwim River chum salmon were compared with fecundities from other chum salmon populations reported by Salo (1991) and Nemeth et al. (2003).

SPAWNING DISTRIBUTION

Historical Alaska Department of Fish and Game (ADF&G) aerial and ground-based survey data were summarized to compare the timing of spawning and distribution of spawning grounds utilized by summer and fall chum salmon in the Kuskokwim River basin. This information, along with local knowledge, was used to form an itinerary for an aerial survey of fall chum salmon in the upper Kuskokwim River basin on 27 September 2004. The aerial survey was designed to search for and formally document fall chum salmon spawning areas.

RUN TIMING

The run timing of fall chum salmon was originally intended to be investigated through a mark–recapture tagging project using catches from fish wheels operated on the mainstem Kuskokwim River near the village of Kalskag (rkm 263; Figure 1). However, funding shortfalls limited the number of tags deployed and resulted in insufficient tag recoveries, so passage of fall chum salmon could not be estimated by this means. As an alternative, the run timing of fall chum salmon in the mainstem Kuskokwim River was estimated from mixed stock analyses of samples taken from the Kalskag fish wheels. The genetic baseline of allozyme markers developed in the mid 1990's (Seeb et al. 1997b) could not be used for this analysis as it requires samples of several tissues from each fish that must be preserved in a frozen state. Because only axillary process tissues were collected from tagged chum salmon as part of this project, it was necessary to develop and test a baseline of DNA-based genetic markers for chum salmon populations in the upper Kuskokwim River in order to apply genetic stock identification. The genetic markers used were single nucleotide polymorphisms (SNPs) recently developed by the ADF&G Gene Conservation Laboratory for use with chum salmon.

Sample Collection

The baseline was derived from samples of archived tissues collected as part of previous work involving allozymes (Seeb et al. 1997b) and stored frozen at -80˚C. Collections were selected to represent both summer and fall runs of chum salmon from the upper Kuskokwim River drainage. Whenever possible, 95 individuals were selected from each population for analysis.

Axillary processes were clipped from chum salmon caught in the Kalskag fish wheels (Figure 1) and the tissues were stored in ethanol in individually labeled 2 ml vials. The following data were recorded for each individual: date, time, bank, condition, and tag number. For each of 4 periods (14 June–5 July, 6–27 July, 28 July–17 August, 18 August–8 September) 190 individuals were randomly subsampled from the available samples. Of these subsamples, 125 were chosen from fish sampled from the right bank wheel and 65 were chosen from the left bank wheel. This sampling scheme was designed to compensate for the apparent preference of upriver chum salmon stocks for right bank areas (Kerkvliet et al. 2004).

Laboratory Analysis

Genomic DNA was extracted and purified using DNA easy 96 columns (QUIAGEN, Valencia, CA) from individuals from each collection. Thirty-one SNP loci were genotyped following the methods described in Smith et al. (2005). Of the 31 SNP loci, 11 were previously published in Smith et al. (2005), and the remaining 20 SNP loci were developed by the ADF&G Gene Conservation Laboratory and are not yet published (Table 1).

Statistical Analysis

Individual genotypes were recorded for each of the 31 SNP loci. Indeterminate assays (the genotype could not be assigned with certainty), failed polymerase chain reactions, and failed DNA extractions were recorded as failures. Genotype linkage methods (GENEPOP version 3.2; Raymond and Rousset 1995) were used to test for significant association between loci. Four of the SNP loci were located in the mitochondrial DNA, 3 in the control region (*Oke_CR30*, *Oke_CR231*, and *Oke_CR386*) and one in the ND3 region (*Oke_ND3-69*). If genotypes at these loci were not independent of each other (linkage), the locus with the fewest failures was chosen for use in the remaining analyses and the others were excluded. In addition, 6 of the nuclear

SNP loci (3 pairs) were located in close proximity: *Oke_GnRH-373/Oke_GnRH-527*, *Oke_IL8r-272/Oke_IL8r-406*, and *SNP15/SNP16*. Independence between genotypes at each locus in a pair was investigated by testing for gametic disequilibrium with GENEPOP. Association of genotypes within these pairs of loci was adjusted for in the mixture analysis by combining individual genotypes for both loci in the pair into a composite genotype (incomplete composite genotypes were treated as failures) and the locus pair was treated as a single locus with unique multi-locus genotypes considered as alleles.

Population allele frequencies for each SNP locus were computed from individual genotype data for both diploid and haploid loci. When more than one collection was available from a given population the allele frequencies were compared using the log likelihood ratio test of homogeneity, (G-test; Sokal and Rohlf 1995) collections that were not significantly different ($\alpha = 0.05$) were pooled for the remaining analyses. Cavalli-Sforza and Edwards (1967) chord distances were computed from population allele frequencies after adjusting for linked loci. Genetic similarity between populations was visualized using the multidimensional scaling methods in *NtSYS* (Exeter Software, Setauket, NY).

Mixture Analysis

Simulation analyses were conducted to determine the accuracy and precision with which mixture components could be assigned to the summer and fall runs. In these simulations, hypothetical mixtures (N = 400) were derived entirely from the run or population under study, and a mixed stock analysis was performed with the baseline being parametrically resampled. Average estimates of the proportion of each run (summer and fall) in the mixture were derived from 1,000 simulations. To determine the 90% confidence intervals the estimates were sorted and the 51st and the 950th estimates indicated the bounds of the confidence interval. Simulations were performed using the Statistical Package for Analyzing Mixtures (SPAM version 3.5; Debevec et al. 2000), and baseline and mixture genotypes were randomly generated from the baseline allele frequencies using Hardy-Weinberg expectations. This method was repeated for each population in the baseline as well as for each of the two runs (summer and fall). Mean estimates greater than 90% indicated that populations could be identified as summer or fall run and that the run components in mixtures could be identified with a high level of accuracy and precision.

Samples of chum salmon (N = 190) encountered in the fish wheels during each of the 4 periods were genotyped at each of the 31 SNP loci. The relative contribution of each run of chum salmon encountered during each period was estimated from the baseline allele frequencies and the multi-locus genotypes for each individual in the sample. All calculations were carried out using the SPAM analysis package.

RESULTS

AGE COMPOSITION

A total of 1,964 summer and 336 fall chum salmon were sampled for morphometric features and age and sex composition. Of these, ageable scales with all associated information were available from 1,791 summer and 280 fall chum salmon.

There was a significant difference in age compositions between South Fork Kuskokwim River fall chum salmon and pooled summer chum salmon (chi square = 224.2, df = 2, P < 0.0001). There was a higher proportion of younger (age-0.2) fish in the fall chum salmon population compared to pooled summer chum salmon stocks (54.6% and 15.7%, respectively; Figure 2).

The age composition of the South Fork Kuskokwim River fall chum salmon population was significantly different from individual summer chum salmon populations (chi-square = 34.8, df = 4, $P < 0.0001$) however, there were also differences between the 3 summer chum salmon populations. The age compositions of George and Kwethluk river fish were significantly different (chi-square = 30.6, df = 2, $P < 0.0001$), as were George and Takotna river fish (chi-square = 11.1, df = 2, $P < 0.005$), but there was no significant difference between Kwethluk and Takotna river fish. There was a higher proportion of older (age-0.4) fish in the George River summer chum salmon population compared to other summer populations (Figure 2).

Older (age-0.3 and -0.4) fish were more prevalent later in the run for both fall and summer chum salmon populations (Figure 3). The change was not significant between time periods for South Fork Kuskokwim River fall chum salmon; however, it was significant for Kwethluk, George, and Takotna river populations (all $P < 0.0001$). All populations displayed an increase in younger (age-0.2) fish over time, and a subsequent decrease in older (age-0.3 and -0.4) fish over time.

SEX COMPOSITION

There was no significant difference in sex compositions between South Fork Kuskokwim River fall chum salmon and pooled summer chum stocks (chi-square = 0.23, df = 2, $P > 0.05$). There were 45.5% females for the fall chum salmon population and 47.0% females for pooled summer chum salmon stocks (Figure 4). When examined by population, the percentage of females in the Kwethluk River summer chum salmon population was significantly lower than that of both George and Takotna river summer chum salmon (chi-square = 15.0, df = 1, $P < 0.001$ and chi-square = 5.8, df = 1, $P < 0.05$, respectively). There was no significant difference in sex ratios between any other populations ($P > 0.05$).

The percentage of female chum salmon tended to vary over time in each of the 4 populations (Figure 5), although the trend was only significant for George River summer chum (chi-square = 17.4, df = 4, $P < 0.005$). For this population, the percentage of females increased over time.

MORPHOLOGY

South Fork Kuskokwim River fall and pooled summer chum salmon had significantly different morphology measurements among most age and sex classes in 2004 (MANOVA; Tables 2, 3; Figures 6, 7, 8). The fall chum salmon had significantly smaller maximum width than pooled summer chum salmon for all female age classes ($P < 0.001$), but there was no difference in maximum width among male age classes ($P > 0.05$). In addition, the fall chum salmon had significantly smaller maximum dorsal-ventral height than pooled summer chum salmon among all sex and age classes ($P < 0.005$). Fall chum salmon had significantly greater lengths from METF than pooled summer chum salmon for all sex and age classes ($P < 0.025$) except age 0.3 males.

Significant morphology differences were observed between individual populations for some sex and age classes (Table 4). Multivariate analyses demonstrated generally greater lengths from mideye-to-tail-fork for South Fork Kuskokwim River fall chum compared to each summer chum population ($P < 0.005$), although this relationship did not always hold. There was no significant difference in lengths between fall chum and Kwethluk River summer chum salmon for age 0.2 and age 0.3 females, and age 0.3 males ($P > 0.05$). There was no significant difference in lengths between fall chum and Takotna River summer chum for age 0.2 males ($P > 0.05$), and there was no significant difference between fall chum and George River summer chum for age 0.3 males ($P > 0.05$). In general, fall chum salmon had smaller maximum height than individual summer chum populations ($P < 0.0001$). However, differences were not significant between fall chum and Takotna age-0.4 female and age-0.2 male summer chum salmon. Fall chum salmon had smaller maximum widths than summer chum salmon populations only for females ($P < 0.0001$), although the difference was not significant between fall chum and Takotna age-0.2 and -0.4 female summer chum salmon. There was no significant difference in maximum width between males for individual fall and summer chum salmon populations. When all morphology characteristics were combined in a cluster analysis, South Fork Kuskokwim River fall and Takotna River summer chum salmon were similar, both populations were different from George River summer chum, and all populations were different from Kwethluk River summer chum (Figure 9).

Morphology measurements varied with distance of the sampling location from the mouth of the Kuskokwim River. As distance from the mouth increased, there was a decrease in maximum width for all females and for male summer chum salmon (Figure 10). Similarly, there was a decrease in maximum dorsal-ventral height as distance from the mouth increased for both males and females (Figure 11). Length measurements decreased as distance from the mouth increased, but was slightly higher for the uppermost river populations (Figure 12).

There were no universal trends in morphology measurements over time for Kuskokwim River chum salmon populations (Figures 13 through 20). No clear trends were apparent for Kwethluk River summer chum (Figures 13 and 14), but George River male and female summer chum demonstrated a decrease in length from METF, maximum height, and maximum width for most sex and age groups (Figures 15 and 16). Takotna River female summer chum salmon demonstrated a decrease in length from METF and maximum height, but a slight increase in maximum width for all age classes (Figure 17) however, results were mixed for males (Figure 18). No clear trends were apparent in South Fork Kuskokwim fall chum (Figures 19 and 20).

There was a positive correlation between all morphometric measurements (Figures 21, 22, 23). The strongest correlations were observed for males for all comparisons, and for the relationship between length from METF and maximum dorsal-ventral height.

FECUNDITY

There was no difference in absolute and relative fecundities between South Fork Kuskokwim River fall chum salmon and pooled summer chum salmon ($P > 0.05$; Table 5). Average absolute fecundity for fall chum salmon was 2,446 eggs and ranged from 1,789 to 3,453 eggs. In comparison, average absolute fecundity for pooled summer chum salmon females was 2,362 eggs, and ranged from 1,527 to 3,270 eggs. Likewise, absolute and relative fecundities were similar between individual populations ($P > 0.05$, Tables 6, 7). There was no effect of age on fecundity for Kuskokwim River fall and summer chum salmon. However, fecundity tended to increase with increasing length from METF ($F = 2.17$, $df = 68$, $P < 0.05$; Figure 24). Though fecundity appeared to decrease over time for both fall and summer chum salmon, this relationship was not significant ($P > 0.05$). When compared to distance upriver, absolute fecundity increased with increasing distance, and relative fecundity increased only for summer chum salmon populations (Figure 25); however, these relationships were not significant ($P > 0.05$).

There was a significant difference in average egg weight between South Fork Kuskokwim River fall and pooled summer chum salmon (F = 26.85, df = 69, P < 0.0001; Table 5). Average egg weight for fall chum salmon was 141 mg, and ranged from 93 to 213 mg. In comparison, average egg weight for pooled summer chum salmon females was 193 mg, and ranged from 120 to 270 mg. Additionally, there was a significant difference between all populations (P < 0.05) except between George and Kwethluk river populations (Table 8); the greatest differences occurred between fall chum salmon and each individual summer chum salmon population (P < 0.025). As distance from the river mouth increased, the average weight of eggs decreased, with a highly significant decrease for the fall chum salmon (Figure 26).

SPAWNING DISTRIBUTION

Residents of the Kuskokwim River drainage have historically acknowledged the presence of fall chum salmon. Residents near Nikolai and McGrath have long harvested fall chum salmon for subsistence use, though they assert that their abundance was much greater in decades past (R. Collins, resident, McGrath, personal communication; T. Alexia, resident, Nikolai, personal communication). Residents of Nikolai have not harvested as many chum salmon recently, likely due in part to the decrease in dependence on dog teams (N. Alexia, resident, Nikolai; personal communication). People in the lower river near Aniak also have acknowledged the presence of fall chum salmon, noting their difference in flesh color and texture, finer gill rakers, smaller eggs, and rounder shape (B. Aloysius, resident, Kalskag; personal communication). Both residents near Aniak and residents in the upper Kuskokwim River drainage had different names in native languages for bright and colored fish, and implied that these were summer and fall chum salmon, respectively.

The earliest known documentation of Kuskokwim River fall chum salmon by ADF&G was during salmon resource investigations in 1976, in which “bright” (i.e. not in spawning condition) chum salmon were noted migrating up the Pitka Fork of the Middle Fork Kuskokwim River in mid-August (Schaefer 1977). Subsistence reports allude to chum salmon harvested after early August in the South Fork Kuskokwim River near the village of Nikolai (Stickney 1981; Stokes 1982, 1985). Aerial surveys and genetic sampling in 1996 marked the first concentrated effort to document fall chum salmon in the upper Kuskokwim River basin. A sampling trip in late August targeting collection of tissues for genetic stock identification (GSI) found a few bright chum salmon in the Pitka Fork and Sullivan Creek, but the crew appeared to have arrived prior to the bulk of the fall chum salmon (Figure 1; L. Dubois, Commercial Fisheries Biologist, ADF&G, Anchorage; personal communication). Aerial surveys in late September 1996 documented fall chum salmon in the South Fork, Windy Fork, and Big Rivers, and GSI samples were collected from fish in a side channel of Big River in late September. Approximately 60% of the chum salmon were spawned out at this time (L. Dubois, Commercial Fisheries Biologist, ADF&G, Anchorage; personal communication). Interviews with residents of the area confirmed the annual presence of these populations (L. Dubois, Commercial Fisheries Biologist, ADF&G, Anchorage; personal communication). Aerial and ground-based surveys since 2000 have consistently documented fall chum salmon in the South Fork Kuskokwim River, as well as the Big and Windy Fork Rivers in September (Table 9) (Clark and Molyneaux 2003; Schwanke and Molyneaux 2002; Schwanke et al. 2001). Available information suggests that the distribution of fall chum salmon is confined to the upper reaches of the Kuskokwim River drainage.

This area was the focus of the aerial survey conducted on 27 September 2004. A partial survey was conducted on many upper Kuskokwim River tributaries, but many streams were too colored, turbid, or small for observations and others were frozen over. Spawning aggregates were seen only in the South Fork Kuskokwim, upper Pitka Fork, Middle Fork, Windy Fork, and Big Rivers (Figure 1). These streams are characterized by braided channels and glaciated headwaters and may contain areas where groundwater upwells. There are also unconfirmed reports of fall chum salmon in the Aniak and Stony Rivers, where they may co-occur with summer chum salmon (D. Cannon, resident, Aniak; personal communication).

RUN TIMING

Sample Collection

A baseline of allele frequencies for 31 SNPs was developed for 9 spawning aggregates of Kuskokwim River chum salmon (Table 10; Figure 27). At least 95 individuals were available from 7 spawning locations. Two additional locations, the Holokuk and neighboring Oskawalik rivers, with sample sizes of 48 and 58 respectively, were included to complete the geographic representation.

Mixed stock genetic samples were collected from 2,717 chum salmon caught at the Kalskag fish wheels between 14 June and 8 September 2004. These samples were divided into 4 temporal periods (14 June–5 July, 6–27 July, 28 July–17 August, and 18 August–9 September). A total of 190 individuals were randomly sampled from each period, with a target of 125 individuals sampled from the right bank and 65 sampled from the left bank. For the fourth period, however, only 53 individuals were available from the right bank, so the remaining 137 samples were chosen from the left bank.

Laboratory Analysis

Genomic DNA was successfully extracted from 827 individuals in the baseline collections and 756 individuals in the mixture samples. At the time that this project was proposed, only 20 SNP loci were available for chum salmon. Subsequently, 11 more SNP loci were available and the ADF&G Gene Conservation Laboratory added these loci at no additional cost to this project. Thus, all individuals were assayed for genotypes at 31 SNP loci (Table 1). The combined average failure rate for obtaining usable genotypes was 1.4% (range: 0.0% to 5.1%).

Statistical Analysis

Complete linkage was found between 3 of the mtDNA SNP loci, *Oke_CR30*, *Oke_CR386*, and *Oke_ND3-69*. *Oke_CR386* and *Oke_ND3-69* were dropped from further analyses and *Oke_CR30* was retained because it had the most complete set of genotypes. Linkage was not complete between *Oke_CR30* and *Oke_CR231* (8 of 827 genotypes showed alternate alleles), but *Oke_CR231* showed no allelic variation in the baseline, so it was dropped from the remaining analyses without loss of information.

Of the 27 SNPs located in the nuclear DNA, 3 pairs were located in close proximity to each other: *Oke_GnRH-373/Oke_GnRH-527*, *Oke_IL8r-272/Oke_IL8r-406*, and *SNP15/SNP16*. Significant gametic disequilibrium was found in each of the pairs ($P > 0.0001$) indicating that genotypes at one locus of a pair were not independent of the genotypes at the other locus of the pair. Genotypes for both loci in a pair were combined into composite genotypes for each locus-pair and treated as a single locus.

Population allele frequencies for each SNP locus were computed from individual genotype data, both diploid and haploid loci. Allele frequencies in collections taken from the same location at different times were compared using the log-likelihood ratio statistic: Kogrukluk River 1992 and 1993 collections (G = 24.7, df = 28, P = 0.64) and Stony River early (1 August 1994) and late (25 September 1994) collections (G = 27.4, df = 28, P = 0.49). Allele frequencies for these collections were not significantly different, and they were pooled for the remaining analyses. Computation of Cavalli-Sforza and Edwards (1967) chord distances from population allele frequencies showed evidence of genetic distinction between summer and fall run populations of chum salmon and more genetic diversity between the fall run populations than among summer run populations (Figure 28).

Mixture Analysis

Simulation analyses conducted to determine the accuracy and precision of assignment to the summer and fall runs indicate that each of the populations in the baseline could be identified to the correct run with a high degree of accuracy (summer ≥ 95% and fall ≥ 91%; Table 11). Additional simulations showed that mixtures of chum salmon from the same run could be identified to the correct run with a high degree of accuracy (summer 98% and fall 92%). Stock composition estimates of chum salmon encountered by the fish wheels at Kalskag during each of the 4 periods indicate that fall chum salmon contributed 5% of the chum salmon encountered during the early portion of the analysis, 14 June to 5 July 2004 (90% CI: 0.00 to 0.15; Table 12). In the remaining periods, fall chum salmon were almost absent from samples taken at the fish wheels (90% CI: 0.00 to 0.11).

DISCUSSION

AGE COMPOSITION

Unusually high numbers of returning age-0.2 chum salmon occurred throughout the Kuskokwim Area in 2004 (Costello et al. *In prep*; Molyneaux and Folletti 2005; Roettiger et al. *In prep*; Stewart and Molyneaux *In prep*), however, fall chum salmon from the South Fork Kuskokwim River had significantly more age-0.2 fish than any summer chum salmon population (Figure 2). While age-0.3 and -0.4 fish usually dominate chum salmon populations (Bakkala 1970; Beacham 1984; Clark and Weller 1986; Helle 1979), fall chum salmon have been reported to have a greater proportion of age-0.2 fish compared to summer chum salmon in both Asian and North American stocks (Beacham 1984; Helle 1960; Sano 1966). No significant difference was reported, however, in age composition between fall and summer runs in the Yukon River based on samples collected from commercial catches (Buklis and Barton 1984).

The difference observed in age composition between fall chum salmon from the South Fork Kuskokwim River and the summer chum salmon populations could be influenced by differences in the gear types used to collect samples. If there is some offshore stratification by size due to differences in current and swimming ability, then the fish wheel used to collect samples in the South Fork Kuskokwim may be biased towards collecting smaller, and therefore younger, chum salmon compared to the weirs that were used for sample collection in determining age composition for the summer chum salmon. The lack of significant change in age composition over time for the fall chum salmon may support this, although a trend of decreasing average age did occur (Figure 3).

Another potential confounding influence was the greater occurrence of scale reabsorption in South Fork Kuskokwim River fall chum salmon (D. Folletti, Fish & Wildlife Technician, ADF&G, Anchorage; personal communication). This may have resulted in overestimating the percentage of age-0.2 fish, especially since fish rejected during the aging process tended to have greater lengths from METF and greater maximum dorsal-ventral height than aged fish ($P < 0.005$ and $P < 0.0025$, respectively; ANOVA). This may indicate that older (larger) fish were rejected during aging more often than younger (smaller) fish, resulting in a lower average age overall. The extent of these biases is unknown, but further investigations are warranted.

SEX COMPOSITION

No differences in sex ratios were observed between the South Fork Kuskokwim River fall population and the pooled summer chum salmon stocks, although a significant difference was observed within the summer chum salmon populations (Figure 4). Again, it is possible that use of the fish wheel on the South Fork Kuskokwim River introduced some bias towards collecting smaller, and perhaps female, chum salmon, but no difference in sex composition has been reported between summer and fall chum salmon in other populations.

MORPHOLOGY

Significant differences in overall morphology indicate that South Fork Kuskokwim River fall chum salmon tend to be longer and thinner than Kuskokwim River summer chum salmon, at least when near their spawning area (Table 3; Figures 6, 7, 8). Other studies have reported morphological differentiation in *Oncorhynchus spp.* according to distance of upstream migration, with more interior populations having less robust body shapes (Eniutina 1954; Taylor and McPhail 1985). The less robust longer and thinner body shape seen in Kuskokwim River fall chum salmon may be an adaptation to longer migrations, helping these fish to minimize energy consumption during upstream migration (Beacham and Murray 1987; Beacham et al. 1988). This is supported by trends within the summer chum populations relative to migration distance. For example, maximum width of female summer chum salmon decreased as migration distance increased (Figure 10) and maximum dorsal-ventral height decreased as distance increased for both sexes (Figure 11). Thus, observed differences between summer and fall chum populations examined here may be due to migration distance, and not to spawning time. These differences are likely a result of populations adapting to the most favorable local conditions for survival (Taylor 1991).

Differences reported here between Kuskokwim River fall and summer chum salmon reflect the comparative morphology of fish sampled in close proximity to their respective spawning grounds. These differences in morphology may not transfer to the same populations of fish if measurements were made when they first enter the Kuskokwim River. Indeed, because fall chum salmon have farther to travel, they could be larger than summer chum salmon when they first enter the Kuskokwim River, but experience disproportionate weight loss by the time they arrive at the spawning grounds. This hypothesis would best be explored by conducting a morphometrics study of chum salmon near the mouth of the Kuskokwim River coupled with genetic stock identification or tagging that would determine stream of origin.

Differences observed in morphological measurements might also be influenced by at least three potential sources of bias, including subtle differences in measurement techniques between sampling crews, differences in collection methods (weirs versus fish wheel), and the limitation of having only one spawning population representative of fall chum salmon. Measurement technique could largely be controlled; however, the other two sources of bias could not have been overcome without considerable expense.

Notwithstanding these potential sources of bias, other studies have found that fall chum salmon differ morphologically from summer chum salmon in ways similar to those seen in the Kuskokwim River. Fall chum salmon have greater lengths than summer chum salmon in many river systems, including the Amur River (Berg 1934; Grigo 1953; Lovetskaya 1948), Yukon River (Buklis 1981; Buklis and Barton 1984), and in Prince William Sound (Helle 1960). However, in southern British Columbia, no consistent differences in mean length-at-age for early and late spawning populations were found (Beacham 1984; Beacham et al. 1983). The smaller maximum height and width for Kuskokwim River fall relative to summer chum salmon is similar to that seen in the Amur River, Russia (Birman 1951; Grigo 1953).

FECUNDITY

There was an increase in both absolute fecundity and relative fecundity with increasing distance to spawning ground; however, there was no statistically significant difference between any individual chum salmon populations, or between pooled summer chum salmon stocks and the South Fork Kuskokwim River fall chum salmon population (Tables 6, 7; Figure 25). Absolute and relative fecundities of Kuskokwim River chum salmon were similar to those reported for chum salmon in other river systems (Figure 29; Beacham and Murray 1993; Nemeth et al. 2003; Salo 1991). However, in many systems fall chum salmon typically have a greater fecundity than summer chum salmon (Bakkala 1970; Berg 1934; Helle 1960; Lovetskaya 1948; Sano 1966), although this is not the case in the Yukon River (Andersen 1983a, 1983b; Beacham et al. 1988; Elson 1975; Raymond 1981; Trasky 1974).

South Fork Kuskokwim River fall chum salmon consistently had significantly smaller average egg weights than all summer chum salmon populations (Table 8; Figure 26). This was similar to other studies, which have shown that fall populations and populations spawning in upper portions of drainages tend to have smaller average egg size than summer populations and populations spawning in lower portions of drainages (Beacham and Murray 1987, 1993). A difference in egg size may be a mechanism to regulate fry emergence timing and may be related to incubation temperature. Beacham and Murray (1993), however, suggest that this is more likely an effect of migration distance, whereby upper river fish allocate more of their energy to migration and less to gonad development. The egg weights reported here are similar to those reported in other river systems, though Kuskokwim River fall chum salmon tend to have smaller egg sizes than those reported for the Amur River, British Columbia, and the Yukon River (Beacham and Murray 1987; Beacham et al. 1988; Smirnov 1975).

There was no significant effect of age on fecundity, and only a marginally significant effect of length on fecundity for pooled summer chum salmon samples (Figure 24). There was no effect of age or length on fecundity of fall chum salmon. Salo (1991) and Nemeth et al. (2003) both reported an effect of length on fecundity of chum salmon, but not age. The reasons for the difference between summer and fall chum salmon are unknown, although it is important to note that the Kuskokwim sample sizes, particularly for fall chum salmon, were small and only included collections from 1 year.

SPAWNING DISTRIBUTION

After reviewing historical data, talking with residents, and conducting additional surveys in 2004, it appeared that spawning distributions of Kuskokwim River fall chum salmon were confined to the upper Kuskokwim River basin, while summer chum salmon populations occurred primarily in lower and middle basins (Table 9; Figure 1). Furthermore, fall and summer chum salmon did not appear to co-occur in the same spawning areas. These findings were similar to other studies, where summer chum salmon were reported to spawn in lower basin tributaries while fall chum salmon spawn in upper basin tributaries (Grigo 1953; Lovetskaya 1948; Sano 1966). According to Birman (1951), fall chum salmon were adapted to reproduce in areas of upwelling groundwater and to negotiate river migrations under high water conditions. In the Yukon River, summer chum salmon generally spawned in runoff tributaries of the lower river, while fall chum salmon spawned primarily in upper drainage channels, sloughs, springs, and heads of main tributaries where upwelling groundwater prevents freezing in most years (Buklis and Barton 1984; Milligan et al. 1986). It is likely that Kuskokwim River fall chum salmon utilized similar areas of groundwater upwell, where relatively warmer water would allow for a shorter incubation period compared to summer chum salmon. Because of their later spawning time, a shorter incubation period would be necessary for outmigrating fall chum salmon fry to take advantage of ocean conditions optimal for survival.

These findings describe the known spawning areas of fall chum salmon in the Kuskokwim River drainage; however, it is possible that other spawning areas exist. For example, in October of 2004 chum salmon were seen spawning in the Aniak River drainage (D. Cannon, resident, Aniak; personal communication). This may be an undocumented population of distinct fall chum salmon, or simply the waning end of summer chum salmon, which are abundant in the Aniak River. If the Aniak River fish found in October were indeed genetically distinct fall chum salmon, then this may be the only spawning area in the Kuskokwim River drainage where fall and summer runs co-exist. Interestingly, for many years residents near Aniak have been aware of small numbers of chum salmon in the Aniak River during September and October, and note that these late spawning fish have a higher oil content and finer gill rakers than the Aniak River chum salmon seen during July (B. Aloysius, resident, Aniak; personal communication). Tissue samples were collected from a small number of the October Aniak River fish for use in genetic analysis, though the sample size was too small to definitively determine whether these fish were genetically distinct dominant summer chum salmon of the Aniak River. Elsewhere in the Kuskokwim basin more extensive aerial surveys would help identify the location of additional fall chum salmon spawning areas, but characterizing spawning fish as "fall" or "summer" chum salmon will require verification through genetic analyses.

RUN TIMING

Run timing was investigated through genetic analysis of mixed stock samples collected near Kalskag. Only 2 populations of fall chum salmon were available for inclusion in the baseline, Big River and South Fork Kuskokwim River, but incidental historical data indicate that these may be 2 of the main populations of fall chum salmon (Table 9). Suspected fall chum salmon have been observed in 5 other rivers late in the season (after August), and the numbers observed in the Pitka Fork and Windy Fork rivers of the Middle Fork Kuskokwim River were similar to those seen in the Big River and South Fork Kuskokwim River, although the Pitka Fork and Windy Fork populations are not represented in the genetic baseline.

Differences in allele frequency at 28 SNP loci were found between summer and fall chum salmon as demonstrated by the multidimensional scaling plot of genetic distances (Figure 28). The similarity between populations within a run in relation to the distinction between the runs was also indicated by the simulations of genetic stock identification (Table 11). These 100% simulations demonstrated that baseline populations can be identified to the correct run with a high degree of accuracy (mean correct allocation ≥ 91%). In addition, mixtures of chum salmon from the same run could also be correctly allocated to either summer run (98%) or fall run (92%). Disparity in correct allocation between the two runs may be due to the unequal number of populations in the baseline; cumulative small misallocation to populations of the wrong run can sum to several percent over 7 populations. Another possibility is the greater genetic divergence between the fall run compared to summer run, which could lead to more misallocation to populations outside the fall run as a group.

Mixture estimates indicated that fall chum salmon were not a large component of the chum salmon sampled by the Kalskag fish wheels in 2004. The greatest relative contribution was seen during the earliest period (5%), dropping to effectively 0% during the remainder of the season (Table 12). The percentage of fall chum salmon seen in this study was lower than results from an opportunistic sample collected from the commercial fishery on 17 July 1996. This mixed sample, which was analyzed with the allozyme marker baseline, was composed of 12% (± 4%) fall chum salmon (ADF&G, Gene Conservation Laboratory, Anchorage, unpublished data). However, another mixed stock analysis of samples taken in Bethel between 25 July and 1 August 2003 assigned 99% of the samples as summer run fish (ADF&G, Gene Conservation Laboratory, Anchorage, unpublished data). These mixed stock analyses supported the hypothesis that fall chum salmon were present earlier in the season, despite their late spawning time. Additional resolution of the run timing of fall chum salmon in the lower Kuskokwim River may be possible through the genetic analysis of archived fish scales that were annually collected from the commercial fishery near Bethel. Such analysis would also characterize the relative contribution of fall chum salmon to the overall commercial catch.

It is assumed that unrepresented fall chum salmon populations will be genetically more similar to other fall chum than to summer chum, but this cannot be tested before more baseline samples of fall populations are collected. Genetic distances indicate that fall chum populations are distinct from each other as well as being distinct from summer chum, and it is possible that an unrepresented component of the fall run is genetically more similar to summer chum than either of the two fall chum populations in the baseline. For example, the early and late samples from the Stony River were collected from spawning aggregates more than a month apart, yet allele frequencies for the two collections were not significantly different. If this is the case, unrepresented fall chum salmon in the mixture could be misallocated to the summer run. Improving the representation of additional fall chum salmon populations in the baseline will lead to greater ability to detect fall chum in the mixed stock samples and greater confidence in the estimates. In addition, only about a quarter of the mixed stock samples collected from Kalskag were analyzed, so greater resolution in the proportion of fall chum salmon in the 4 mixed stock samples collected in 2004 could be achieved by increasing the number of fish analyzed.

CONCLUSIONS

While genetic evidence of fall run chum salmon in the Kuskokwim River basin was found in the late 1990s, this project was the first to formally document morphological and life history characteristics of fall chum salmon in comparison to summer chum salmon populations within the basin. There did not appear to be differences in sex composition or fecundity between the two runs. Fall chum salmon appeared to be distinct from summer chum salmon by having spawning distribution limited to upper river tributaries, having younger average age at return, and a less robust body shape at least when near the spawning grounds. There appeared to be gradation of change in morphology and fecundity among all chum salmon spawning populations that is concurrent with the gradation of increasing distance from the mouth of the Kuskokwim

River to respective spawning grounds. This spatial gradation may be the primary influence in the morphological differences between fall and summer chum salmon in the Kuskokwim River basin. A definitive conclusion about the run timing of fall chum salmon was not achieved in this study; however, fall chum salmon were detected in the earliest mixed stock sample, which is unexpected given that in other rivers, such as the neighboring Yukon River, fall chum salmon entered freshwater late in the season. Genetic stock identification of the mixed stock samples showed that fall chum salmon constituted a relatively small fraction of the overall Kuskokwim River chum salmon run in 2004, though larger proportions were found in the opportunistic sample collected in 1996. Future investigations should incorporate characterization of other Kuskokwim River fall chum salmon populations, examine possible interannual variation within populations, characterize spawning habitats, and investigate the potential to analyze archived fish scales from the commercial fishery in order to determine run timing and relative contribution of fall chum salmon in the lower Kuskokwim River fishery.

Although fall chum salmon currently constitute a small proportion of the overall Kuskokwim River chum salmon run, this unique group of fish is an important component of the overall biodiversity and should be maintained in order to foster long-term sustainable harvest of salmon against changing environmental conditions. This preliminary description of the biology, distribution, and run timing of Kuskokwim River fall chum salmon is the first step in including these distinct populations in sustainable chum salmon management.

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TABLES AND FIGURES

Table 1.–Single nucleotide polymorphisms (SNPs) assayed in Kuskokwim River chum salmon.

Name				
Published	**Temporary**		**DNA Type**	**Source**
Oke_CKS-389			nDNA	Smith et al. 2005
Oke_Cr30		1	mtDNA	Smith et al. 2005
Oke_Cr231			"	Smith et al. 2005
Oke_Cr386		1	"	Smith et al. 2005
Oke_DM20-548			nDNA	Smith et al. 2005
Oke_GnRH-373		2	"	Smith et al. 2005
Oke_GnRH-527		2	"	Smith et al. 2005
Oke_lL8r-272		3	"	Smith et al. 2005
Oke_IL8r-406		3	"	Smith et al. 2005
Oke_ND3-69		1	mtDNA	Smith et al. 2005
Oke_u1-519			nDNA	Smith et al. 2005
	SNP12		"	ADF&G Unpublished
	SNP13		"	ADF&G Unpublished
	SNP14		"	ADF&G Unpublished
	SNP15	4	"	ADF&G Unpublished
	SNP16	4	"	ADF&G Unpublished
	SNP17		"	ADF&G Unpublished
	SNP18		"	ADF&G Unpublished
	SNP19		"	ADF&G Unpublished
	SNP20		"	ADF&G Unpublished
	SNP21		"	ADF&G Unpublished
	SNP22		"	ADF&G Unpublished
	SNP23		"	ADF&G Unpublished
	SNP24		"	ADF&G Unpublished
	SNP25		"	ADF&G Unpublished
	SNP26		"	ADF&G Unpublished
	SNP27		"	ADF&G Unpublished
	SNP28		"	ADF&G Unpublished
	SNP29		"	ADF&G Unpublished
	SNP30		"	ADF&G Unpublished
	SNP31		"	ADF&G Unpublished

Note: Locus names have not yet been established for 20 loci, so temporary names are given

Source Note: ADF&G Gene Conservation Laboratory (Unpublished data)

1 These mitochondrial loci were found to be completely linked.

2 These loci were linked.

3 These loci were linked.

4 These loci were linked.

Table 2.–Morphometric statistics for Kuskokwim River summer and fall chum salmon, 2004.

		Age		METF length (mm)				Maximum Height (mm)				Maximum Depth (mm)			
Project	**Sex**	**Class**	**N**	**Mean**	**SD**	**95% CI**	**SE**	**Mean**	**SD**	**95% CI**	**SE**	**Mean**	**SD**	**95% CI**	**SE**
Kwethluk	M	0.2	59	547.0	20.9	5.3	2.7	141.1	9.1	2.3	1.2	68.5	5.5	1.4	0.7
(S)		0.3	139	567.3	27.7	4.6	2.4	148.6	28.9	4.8	2.5	72.3	5.6	0.9	0.5
		0.4	111	588.4	29.5	5.5	2.8	151.7	12.8	2.4	1.2	75.0	5.3	1.0	0.5
		Total	309	571.0	31.1	3.5	1.8	148.3	21.5	2.4	1.2	72.5	41.0	4.6	2.3
	F	0.2	46	529.6	19.5	5.6	2.9	118.2	5.9	1.7	0.9	75.5	5.9	1.7	0.9
		0.3	105	546.8	26.7	5.1	2.6	123.7	8.0	1.5	0.8	78.2	7.0	1.3	0.7
		0.4	66	557.9	24.4	5.9	3.0	124.8	8.7	2.1	1.1	79.6	6.8	1.6	0.8
		Total	217	546.5	26.5	3.5	1.8	122.8	8.2	1.1	0.6	78.1	6.9	0.9	0.5
Total			**526**	**560.9**	**31.6**	**2.7**	**1.4**	**137.8**	**21.4**	**1.8**	**0.9**	**74.8**	**6.9**	**0.6**	**0.3**
George	M	0.2	57	523.1	29.9	7.8	4.0	132.6	11.0	2.9	1.5	63.8	7.2	1.9	0.9
(S)		0.3	148	568.7	35.7	5.8	2.9	142.5	12.2	2.0	1.0	70.8	7.2	1.2	0.6
		0.4	256	583.3	34.5	4.2	2.2	145.7	12.8	1.6	0.8	72.4	6.8	0.8	0.4
		Total	461	571.2	39.3	3.6	1.8	143.0	13.1	1.2	0.6	70.9	7.5	0.7	0.3
	F	0.2	67	501.5	29.1	7.0	3.5	111.1	8.2	2.0	1.0	70.8	7.1	1.7	0.9
		0.3	207	528.4	30.6	4.2	2.1	119.6	11.6	1.6	0.8	74.7	6.7	0.9	0.5
		0.4	187	540.3	31.8	4.6	2.3	121.5	11.5	1.7	0.8	77.3	7.0	1.0	0.5
		Total	461	529.3	33.3	3.0	1.6	119.1	11.6	1.1	0.5	75.2	7.2	0.7	0.3
Total			**922**	**550.3**	**42.0**	**2.7**	**1.4**	**131.1**	**17.2**	**1.1**	**0.6**	**73.0**	**7.6**	**0.5**	**0.3**
Takotna	M	0.2	21	535.4	21.2	9.1	4.6	129.8	11.2	4.8	2.5	64.7	6.1	2.6	1.3
(S)		0.3	75	558.1	32.4	7.3	3.7	134.8	11.7	2.7	1.4	66.3	7.3	1.7	0.8
		0.4	75	583.7	31.4	7.1	3.6	141.2	13.1	3.0	1.5	68.7	7.4	1.7	0.8
		Total	171	566.5	34.9	5.2	2.7	137.0	12.9	1.9	1.0	67.2	36.5	5.5	2.8
	F	0.2	31	509.5	20.1	7.1	3.6	110.1	9.6	3.4	1.7	67.7	6.2	2.2	1.1
		0.3	85	538.3	27.9	5.9	3.0	115.4	11.7	2.5	1.3	72.1	6.8	1.4	0.7
		0.4	53	548.0	23.6	6.4	3.2	115.6	8.9	2.4	1.2	72.7	9.3	2.5	1.3
		Total	169	536.1	28.5	4.3	2.2	114.5	10.7	1.6	0.8	71.5	7.8	1.2	0.6
Total			**340**	**551.4**	**35.3**	**3.8**	**1.9**	**125.8**	**16.3**	**1.7**	**0.9**	**69.3**	**7.8**	**0.8**	**0.4**
All Summer	M	0.2	136	535.1	27.2	4.6	2.3	135.9	11.2	1.9	1.0	65.9	6.5	1.1	0.6
(pooled)		0.3	362	566.0	32.3	3.3	1.7	143.2	20.8	2.1	1.1	70.5	7.0	0.7	0.4
		0.4	443	584.7	32.8	3.1	1.6	146.4	13.3	1.2	0.6	72.4	6.8	0.6	0.3
		Total	941	570.3	36.0	2.3	1.2	143.7	16.8	1.1	0.5	70.7	7.2	0.5	0.2
	F	0.2	145	511.9	27.4	4.5	2.3	113.1	8.6	1.4	0.7	71.6	7.1	1.2	0.6
		0.3	398	535.4	30.0	2.9	1.5	119.8	11.1	1.1	0.6	75.1	7.1	0.7	0.4
		0.4	307	545.5	29.8	3.3	1.7	121.2	10.9	1.2	0.6	77.0	7.7	0.9	0.4
		Total	850	535.1	31.6	2.1	1.1	119.1	11.0	0.7	0.4	75.2	7.6	0.5	0.3
Total			**1791**	**553.6**	**38.3**	**1.8**	**0.9**	**132.0**	**18.8**	**0.9**	**0.4**	**72.8**	**7.7**	**0.4**	**0.2**
South Fork	M	0.2	64	549.3	28.3	6.9	3.5	123.0	11.9	2.9	1.5	65.8	8.4	2.1	1.0
(F)		0.3	39	572.3	26.0	8.2	4.2	128.6	12.5	3.9	2.0	69.7	7.3	2.3	1.2
		0.4	34	599.1	33.7	11.3	5.8	134.5	13.6	4.6	2.3	72.2	7.5	2.5	1.3
		Total	137	568.2	35.3	5.9	3.0	127.5	13.3	2.2	1.1	68.5	8.3	1.4	0.7
	F	0.2	89	528.3	20.7	4.3	2.2	106.1	7.9	1.6	0.8	66.8	5.4	1.1	0.6
		0.3	36	549.7	25.9	8.5	4.3	109.9	10.1	3.3	1.7	68.3	10.7	3.5	1.8
		0.4	18	562.8	25.3	11.7	6.0	113.0	12.6	5.8	3.0	69.6	11.7	5.4	2.7
		Total	143	538.0	26.1	4.3	2.2	107.9	9.5	1.6	0.8	67.5	8.0	1.3	0.7
Total			**280**	**552.8**	**34.4**	**4.0**	**2.1**	**117.5**	**15.1**	**1.8**	**0.9**	**68.0**	**8.1**	**1.0**	**0.5**

Note: S = summer and F = fall.

Table 3.–Multivariate analysis results of morphology characteristics for Kuskokwim River summer and fall chum salmon, 2004.

	Age	Measurement	Summer Chum			Fall Chum							
Sex	**Class**	**(mm)**	**N**	**Mean**	**CV**	**N**	**Mean**	**CV**	**F Value**	**P**	**Wilks' λ**	**F Value**	**P**
F	0.2	METF length	145	511.9	0.054	89	528.3	0.039	22.87	**<0.0001**	0.539	65.38	**<0.0001**
		max height		113.1	0.076		106.1	0.075	39.73	**<0.0001**			
		max width		71.6	0.099		66.8	0.081	30.52	**<0.0001**			
	0.3	METF length	389	535.4	0.056	36	549.7	0.047	7.58	**0.0061**	0.808	33.92	**<0.0001**
		max height		119.8	0.093		109.9	0.092	26.14	**<0.0001**			
		max width		75.1	0.095		68.3	0.157	27.43	**<0.0001**			
	0.4	METF length	307	545.5	0.055	18	562.8	0.045	5.84	**0.0162**	0.855	18.1	**<0.0001**
		max height		121.2	0.090		113.0	0.112	9.35	**0.0024**			
		max width		77.0	0.100		69.6	0.168	14.69	**0.0002**			
M	0.2	METF length	136	535.1	0.051	64	549.3	0.051	11.44	**0.0009**	0.494	67.03	**<0.0001**
		max height		135.9	0.083		123.0	0.097	54.84	**<0.0001**			
		max width		65.9	0.099		65.8	0.127	0.01	**0.9247**			
	0.3	METF length	362	566.0	0.057	39	572.3	0.045	1.37	**0.2422**	0.916	12.27	**<0.0001**
		max height		143.2	0.146		128.6	0.097	19.66	**<0.0001**			
		max width		70.5	0.099		69.7	0.105	0.74	**0.3911**			
	0.4	METF length	443	584.7	0.056	34	599.1	0.056	6.05	**0.0142**	0.816	35.46	**<0.0001**
		max height		146.4	0.091		134.5	0.101	25.34	**<0.0001**			
		max width		72.4	0.094		72.2	0.104	0.03	**0.8638**			

Note: "Summer chum" includes fish sampled at the Kwethluk, George, and Takotna river weirs, "Fall chum" includes fish sampled from the South Fork Kuskokwim River fish wheel.

Table 4.–Multivariate analysis results of morphology characteristics for individual populations of Kuskokwim River summer and fall chum salmon, 2004.

Sex	Age Class	Location	N	METF Length Mean	METF Length Group	Max Height Mean	Max Height Group	Max Width Mean	Max Width Group
F	0.2	Kwethluk (S)	45	556.6	A	124.2	A	80.0	A
		George (S)	59	517.6	B	114.9	B	72.4	B
		Takotna (S)	31	509.5	B	110.1	C	67.7	C
		South Fork (F)	89	528.3	C	106.1	D	66.8	C
		df			*3*		*3*		*3*
		F value			*25.17*		*41.25*		*45.18*
		P			***<0.0001***		***<0.0001***		***<0.0001***
	0.3	Kwethluk (S)	96	546.9	AB	123.2	A	78.9	A
		George (S)	184	531.2	C	119.0	B	75.6	B
		Takotna (S)	84	538.7	BC	115.4	C	72.1	C
		South Fork (F)	36	549.7	A	109.9	D	68.3	D
		df			*3*		*3*		*3*
		F value			*7.93*		*17.46*		*25.11*
		P			***<0.0001***		***<0.0001***		***<0.0001***
	0.4	Kwethluk (S)	72	545.3	A	122.6	A	76.5	A
		George (S)	224	530.4	B	120.0	AB	75.9	AB
		Takotna (S)	53	548.0	A	115.6	BC	72.7	BC
		South Fork (F)	18	562.8	C	113.0	C	69.6	C
		df			*3*		*3*		*3*
		F value			*11.64*		*6.20*		*6.03*
		P			***<0.0001***		***0.0004***		***0.0005***
M	0.2	Kwethluk (S)	60	568.0	A	151.6	A	71.6	A
		George (S)	64	568.0	A	142.9	A	68.0	B
		Takotna (S)	21	535.4	B	129.8	B	64.7	C
		South Fork (F)	64	549.3	B	123.0	B	65.8	BC
		df			*3*		*3*		*3*
		F value			*7.23*		*15.32*		*8.04*
		P			***<0.0001***		***<0.0001***		***<0.0001***
	0.3	Kwethluk (S)	148	568.4	A	146.6	A	72.5	A
		George (S)	171	574.5	A	144.3	A	71.7	AB
		Takotna (S)	75	558.1	B	134.8	B	66.3	C
		South Fork (F)	39	572.3	A	128.6	C	69.7	B
		df			*3*		*3*		*3*
		F value			*4.63*		*32.78*		*15.79*
		P			***0.0033***		***<0.0001***		***<0.0001***
	0.4	Kwethluk (S)	105	575.1	AB	148.4	A	73.7	A
		George (S)	219	570.0	B	142.4	B	70.9	BC
		Takotna (S)	75	583.7	A	141.2	B	68.7	C
		South Fork (F)	34	599.1	C	134.5	C	72.2	AB
		df			*3*		*3*		*3*
		F value			*8.46*		*12.00*		*8.15*
		P			***<0.0001***		***<0.0001***		***<0.0001***

Note: S = summer and F = fall. Means with the same letter are not significantly different (LSD t-tests).
Source: Sokal and Rohlf 1995.

Table 5.–Fecundity and egg weight statistics for female Kuskokwim River summer and fall chum salmon, 2004.

	Age		Total (absolute) Fecundity (No. Eggs)				Relative Fecundity (No. Eggs/cm)				Egg Weight (mg)			
Project	**Class**	**N**	**Mean**	**95% CI**	**SD**	**SE**	**Mean**	**95% CI**	**SD**	**SE**	**Mean**	**95% CI**	**SD**	**SE**
Kwethluk	0.2	2	2,269	155	112	79	41.9	4.7	3.4	2.4	192	142	103	73
(S)	0.3	8	2,244	310	447	158	40.5	5.8	8.4	3.0	207	26	37	13
	0.4	4	2,231	372	379	190	40.5	7.8	8.0	4.0	211	43	44	22
	Total	14	2,244	197	377	101	40.7	3.8	7.3	2.0	206	24	45	12
George	0.2	2	2,255	985	710	502	44.0	12.0	8.6	6.1	166	11	8	6
(S)	0.3	10	2,365	227	366	116	44.2	4.0	6.4	2.0	201	16	25	8
	0.4	7	2,328	364	491	186	43.7	5.8	7.9	3.0	203	13	18	7
	Total	19	2,340	189	420	96	44.0	3.0	6.7	1.5	198	11	24	5
Takotna	0.2	6	2,476	386	483	197	48.7	6.4	8.0	3.3	157	16	20	8
(S)	0.3	9	2,548	268	410	137	47.6	5.0	7.7	2.6	175	22	34	11
	0.4	3	2,263	420	371	214	41.9	8.0	7.1	4.1	222	23	21	12
	Total	18	2,476	193	418	98	47.0	3.5	7.7	1.8	177	16	35	8
All Summer	0.2	10	2,390	277	446	141	46.4	4.6	7.4	2.3	166	25	40	13
(pooled)	0.3	27	2,390	154	409	79	44.3	2.9	7.7	1.5	194	13	34	7
	0.4	14	2,286	215	410	109	42.4	3.8	7.3	1.9	209	14	27	7
	Total	51	2,362	113	411	58	44.2	2.1	7.5	1.1	193	10	36	5
South Fork	0.2	9	2,530	265	406	135	48.2	4.5	6.8	2.3	124	15	24	8
(F)	0.3	2	2,026	465	335	237	36.3	8.1	5.9	4.1	166	79	57	40
	0.4	2	2,491	52	38	27	42.8	3.9	2.8	2.0	193	39	28	20
	Total	13	2,446	214	393	109	45.6	4.1	7.5	2.1	141	21	38	11

Note: S = summer and F = fall. “All Summer” includes fish sampled at the Kwethluk, George, and Takotna river weirs.

Table 6.–Results of ANOVA to examine differences in absolute fecundity between Kuskokwim River summer and fall chum salmon, 2004.

		Mean Absolute Fecundity	Kwethluk		George		Takotna	
Project	**N**	**(No. Eggs)**	**F value**	**P**	**F value**	**P**	**F value**	**P**
Kwethluk (S)	14	2,244						
George (S)	19	2,340	0.46	**0.5031**				
Takotna (S)	18	2,476	2.65	**0.1135**	0.98	**0.3286**		
South Fork (F)	13	2,446	1.87	**0.1840**	0.52	**0.4765**	0.04	**0.8396**

Note: S = summer and F = fall.

Table 7.–Results of ANOVA to examine differences in relative fecundity between Kuskokwim River summer and fall chum salmon, 2004.

		Mean Relative Fecundity	Kwethluk		George		Takotna	
Project	**N**	**(No. Eggs/cm)**	**F value**	**P**	**F value**	**P**	**F value**	**P**
Kwethluk (S)	14	40.7						
George (S)	19	44.0	1.79	**0.1906**				
Takotna (S)	18	47.0	5.53	**0.0255**	1.61	**0.2133**		
South Fork (F)	13	45.6	2.87	**0.1025**	0.37	**0.5500**	0.28	**0.5981**

Note: S = summer and F = fall.

Table 8.–Results of ANOVA to examine differences in egg weight between Kuskokwim River summer and fall chum salmon, 2004.

		Mean Egg Weight	Kwethluk		George		Takotna	
Project	**N**	**(mg)**	**F value**	**P**	**F value**	**P**	**F value**	**P**
Kwethluk (S)	14	206						
George (S)	19	198	0.44	**0.5125**				
Takotna (S)	18	177	4.28	**0.0472**	4.12	**0.0362**		
South Fork (F)	13	141	16.11	**< 0.0005**	27.18	**< 0.0001**	7.19	**0.0120**

Note: S = summer and F = fall.

Table 9.–Historical ADF&G aerial and boat survey observations of Kuskokwim River fall chum salmon.

Major Tributary	Stream	Date	No. Chum	Method	Conditions	Comments
Holokuk River	mainstem	9/8/1966	?	aerial	poor	some salmon; silvers and chums
Holitna River	Hoholitna River	9/14/1980	4	boat	NA	8 nights fishing with set net
Big River	mainstem	9/29/1980	4	boat	NA	16 nights fishing with set net
	mainstem	9/24/1996	304	aerial	good	isolated group in one side channel
	mainstem	9/28/2003	23	aerial	fair	clear side channels only
Middle Fork Kuskokwim	Pitka Fork	9/9/1977	5700	aerial	good	helicopter; above Sullivan Creek; fish still in schools
	Windy Fork	9/24/1996	400	aerial	fair	started at 62.32.53N, 154.20.52W; ended at 62.43.87N, 154.37.44W
North Fork Kuskokwim	mainstem	9/19/1971	1	boat	NA	gill net catch, 7 miles above confluence with McKinley Fork
Swift Fork Kuskokwim	Highpower Creek	10/2/1971	3	boat	NA	gill net catches made between 9/21 and 10/2
South Fork Kuskokwim	mainstem	9/23/1996	845	aerial	fair	seen in side channels, Farewell to 30 mi downstream
	mainstem	9/27/2000	100	aerial	fair	most side channels and sloughs only; Rohn to mouth surveyed
	mainstem	9/22/2002	4150	aerial	fair	10 mi N of Fairwell to confluence; all salmon found in one slough
	mainstem	9/28/2003	1280	aerial	fair	clear side channels only; most chums in slough at 62.54.37N, 154.05.81W
	unnamed tributary	9/23/2001	130	aerial	good	actively spawning; 62.51.28N, 153.59.93W
	unnamed tributary	9/23/2001	480	aerial	good	actively spawning; 62.54.37N, 154.05.81W

Table 10.–Kuskokwim River collections analyzed for genetic stock identification of chum salmon using SNP markers, 2004.

Collection	Spawn Timing	Population		Sample Size
Baseline	Summer	Aniak River		95
		Holokuk River		48
		Oskawalik River		58
		Kogrukluk River		
			1992	45
			1993	50
		George River		95
		Takotna River		95
		Stony River		
			Early	95
			Late	56
	Fall	Big River		95
		South Fork Kuskokwim River		95
			Subtotal	**827**
Kalskag mixtures		*1*: 14 June–5 July		190
		2: 6 July–27 July		190
		3: 28 July–17 August		190
		4: 18 August–8 September		190
			Subtotal	**756**
		Total		1,587

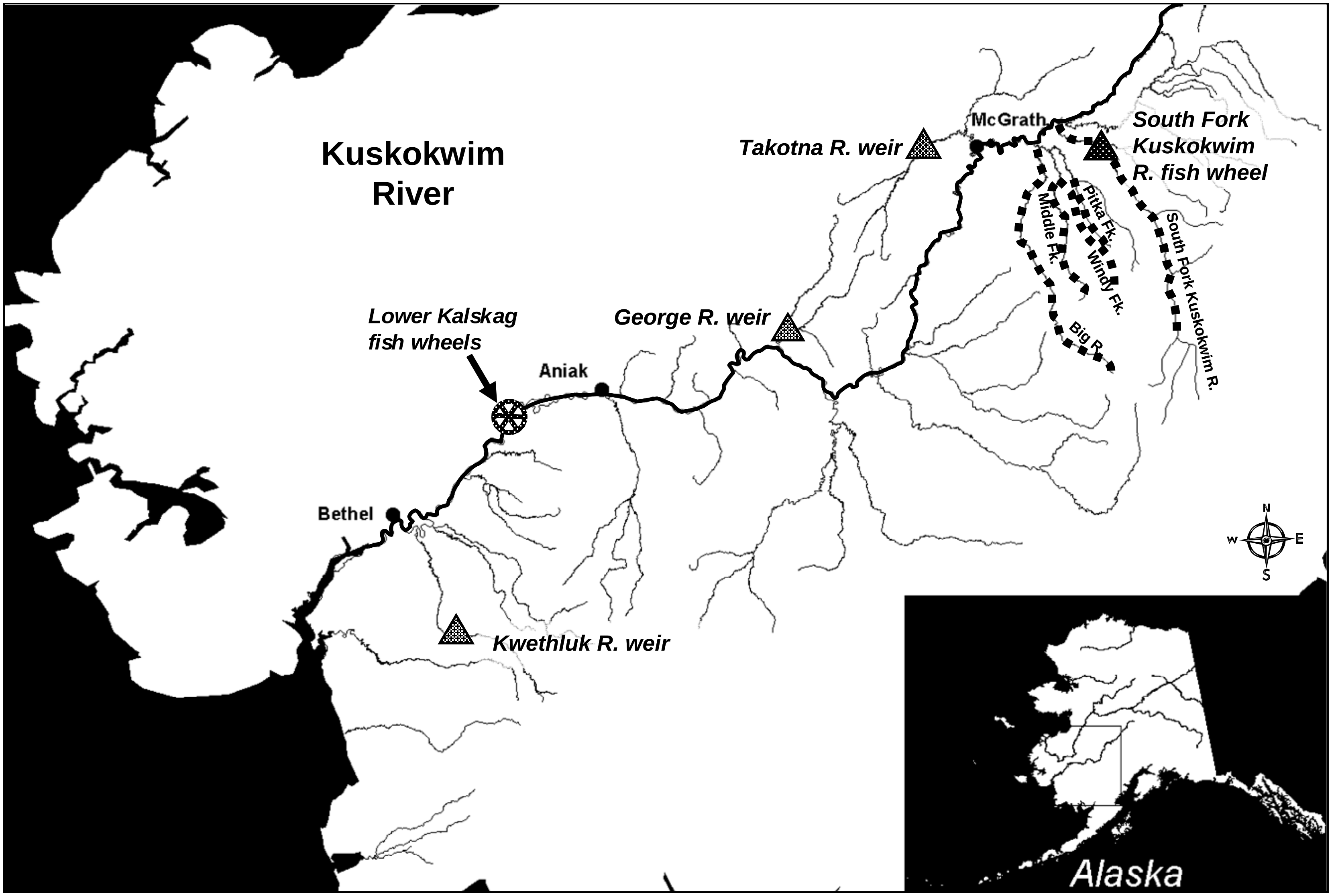
Table 11.–Percent correct allocation to run time and 90% confidence intervals for mixed stock analysis simulations in which each population comprised 100% of the hypothetical mixtures.

Run	Population	Estimate	90% CI
Summer		**0.98**	**(0.93 - 1.00)**
	Aniak River	0.99	(0.96 - 1.00)
	Holokuk River	0.97	(0.91 - 1.00)
	Oskawalik River	0.97	(0.90 - 1.00)
	George River	0.99	(0.95 - 1.00)
	Kogrukluk River	0.98	(0.94 - 1.00)
	Stony River	0.98	(0.95 - 1.00)
	Takotna River	0.95	(0.89 - 1.00)
Fall		**0.92**	**(0.85 - 0.98)**
	Big River	0.94	(0.87 - 1.00)
	South Fork Kuskokwim	0.91	(0.83 - 0.98)

Table 12.–Relative contribution and 90% confidence intervals of Kuskokwim River summer and fall chum salmon encountered at the Kalskag fish wheels during 4 periods in 2004.

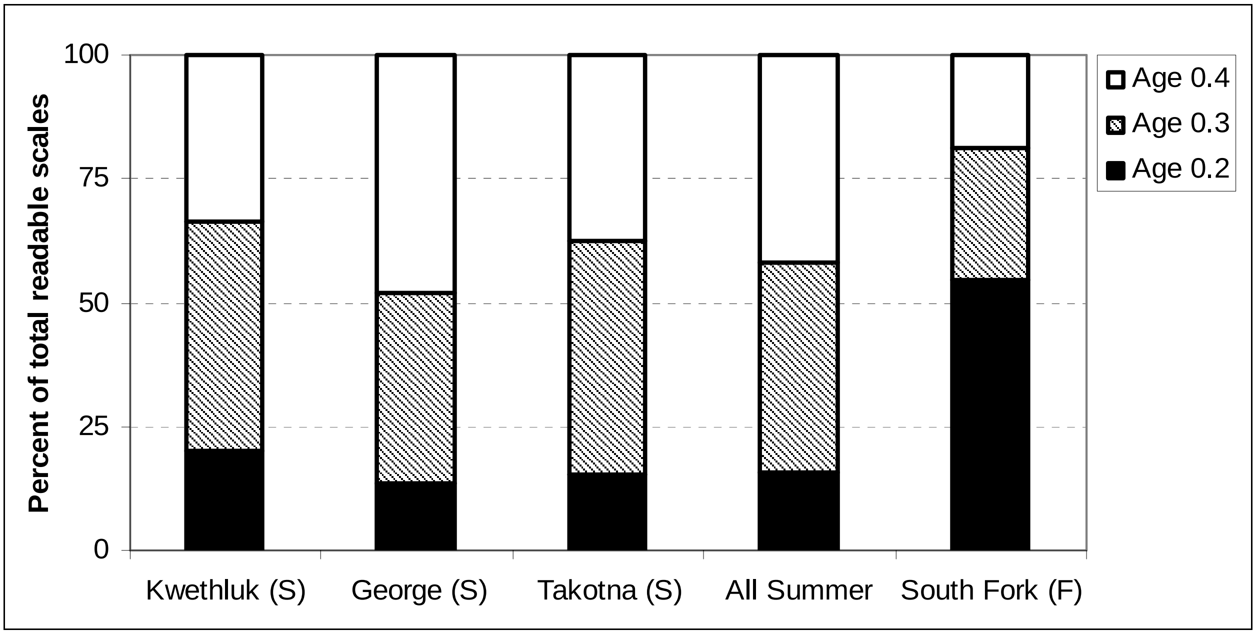
			Summer		**Fall**	
	Period	**N**	**Est.**	**90% CI**	**Est.**	**90% CI**
1:	June 14–July 5	190	0.95	(0.85 - 1.00)	0.05	(0.00 - 0.15)
2:	July 6–27	189	0.98	(0.91 - 1.00)	0.01	(0.00 - 0.08)
3:	July 28–August 17	190	1.00	(0.96 - 1.00)	0.00	(0.00 - 0.04)
4:	August 18–September 8	187	0.99	(0.88 - 1.00)	0.01	(0.00 - 0.11)

Note: Proportions may not sum to 1.0 due to rounding error.



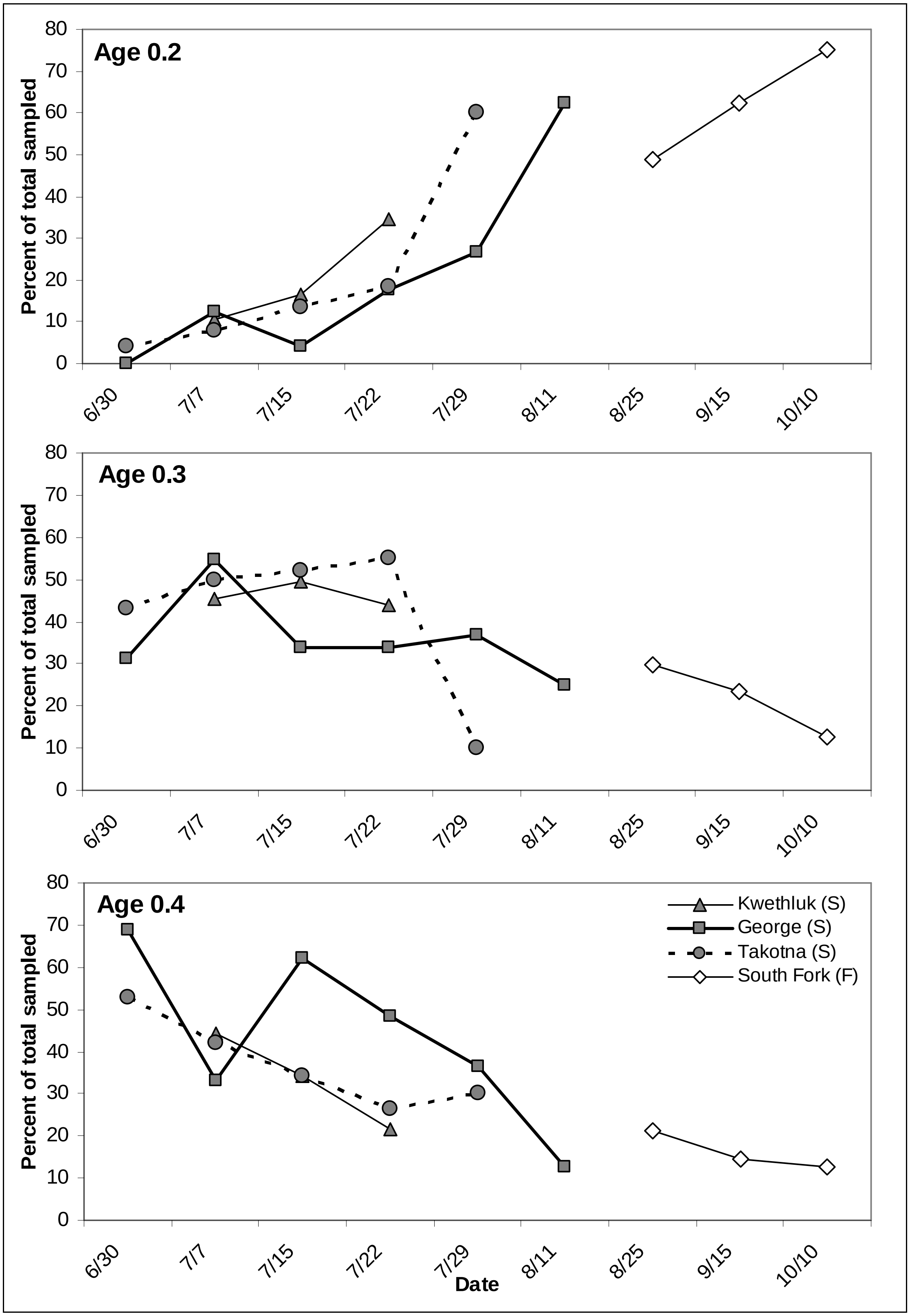
Note: Rivers with known spawning fall chum salmon are marked with a dashed line.

Figure 1.–The Kuskokwim River drainage, showing sampling locations for summer (Kwethluk, George, and Takotna river weirs) and fall (South Fork Kuskokwim River fish wheel) chum salmon, 2004.



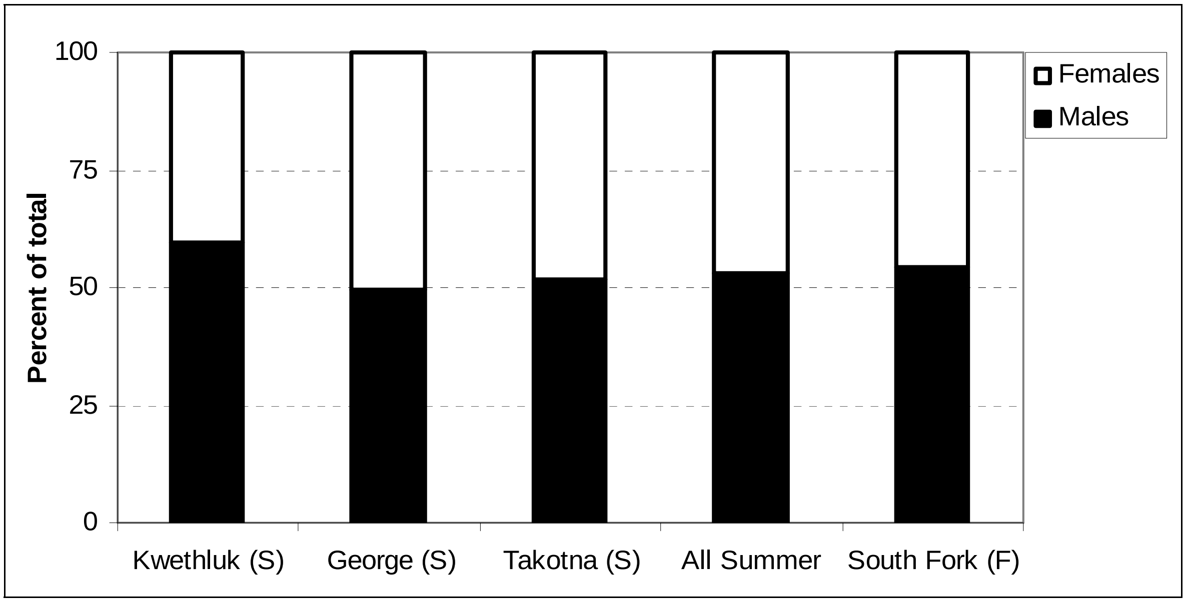
Note: "All Summer" includes fish sampled at the Kwethluk, George, and Takotna river weirs. S = summer and F = fall chum salmon.

Figure 2.–Age composition of Kuskokwim River summer and fall chum salmon, 2004.



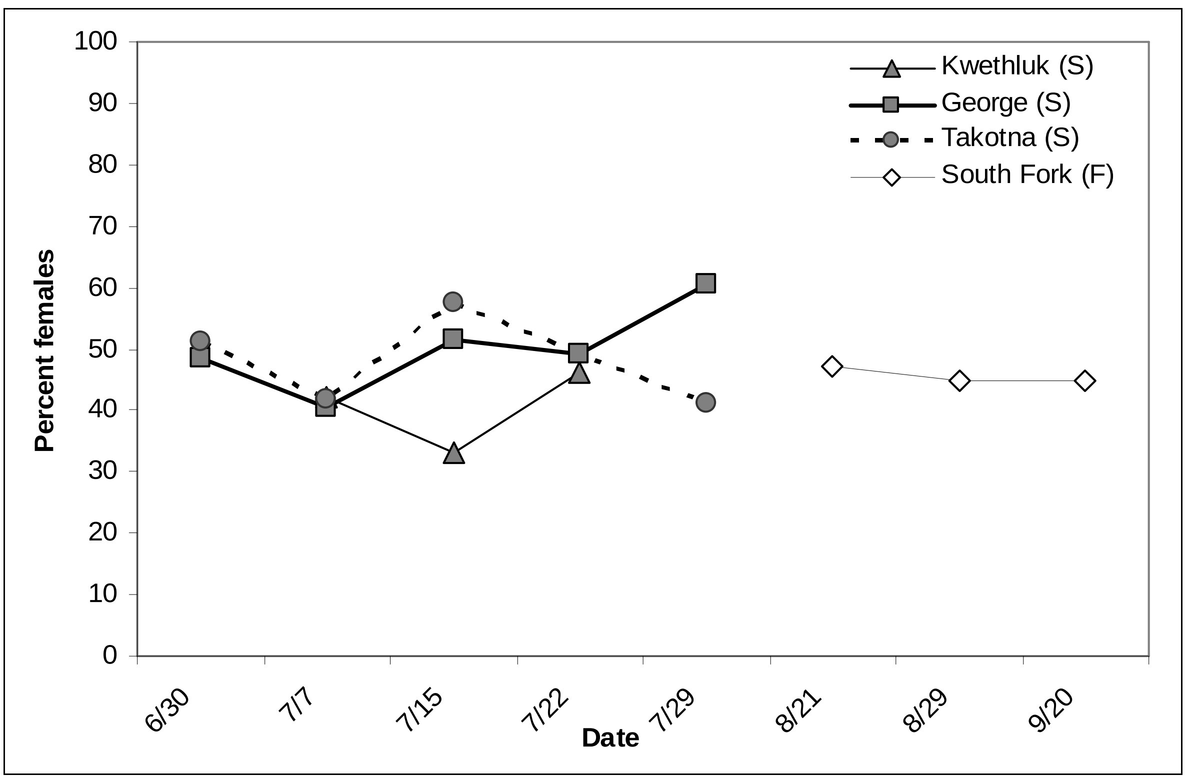
Note: S = summer and F = fall.

Figure 3.–Change in age composition over time for Kuskokwim River summer and fall chum salmon, 2004.



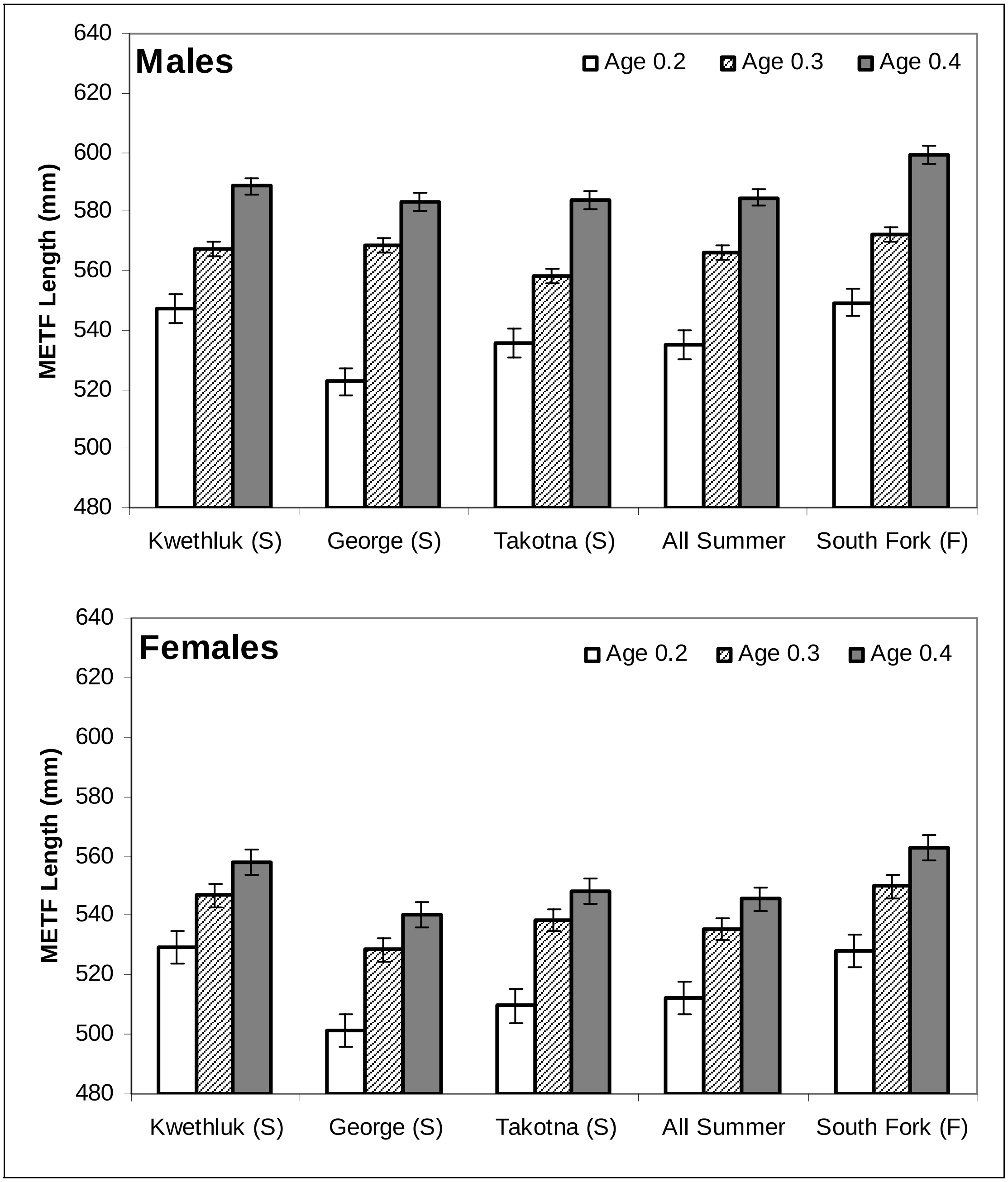
Note: "All Summer" includes fish sampled at the Kwethluk, George, and Takotna river weirs. S = summer and F = fall.

Figure 4.–Sex ratios of Kuskokwim River summer and fall chum salmon, 2004.



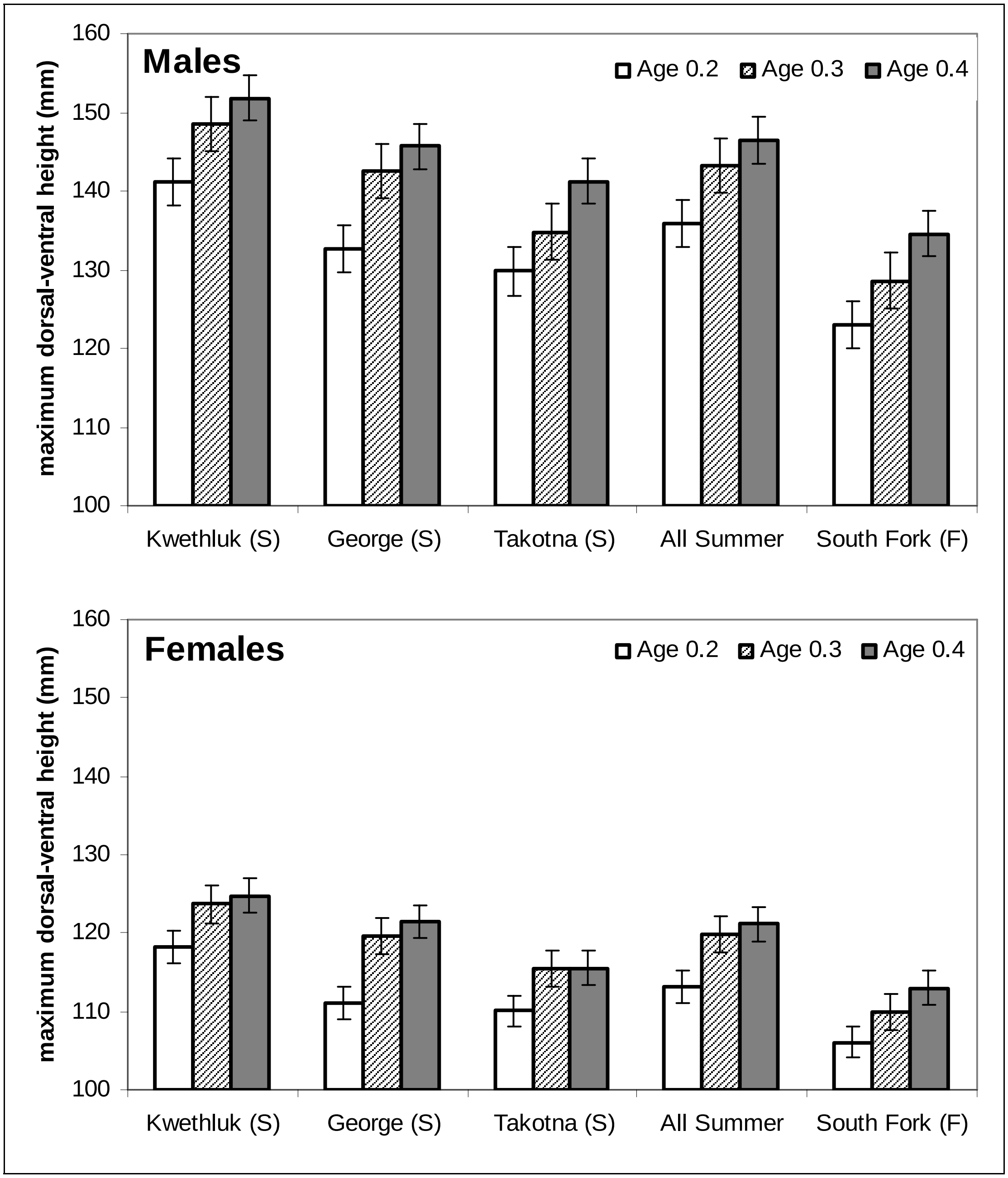
Note: S = summer and F = fall.

Figure 5.–Change in percentage of females over time of sampled Kuskokwim River summer and fall chum salmon populations, 2004.



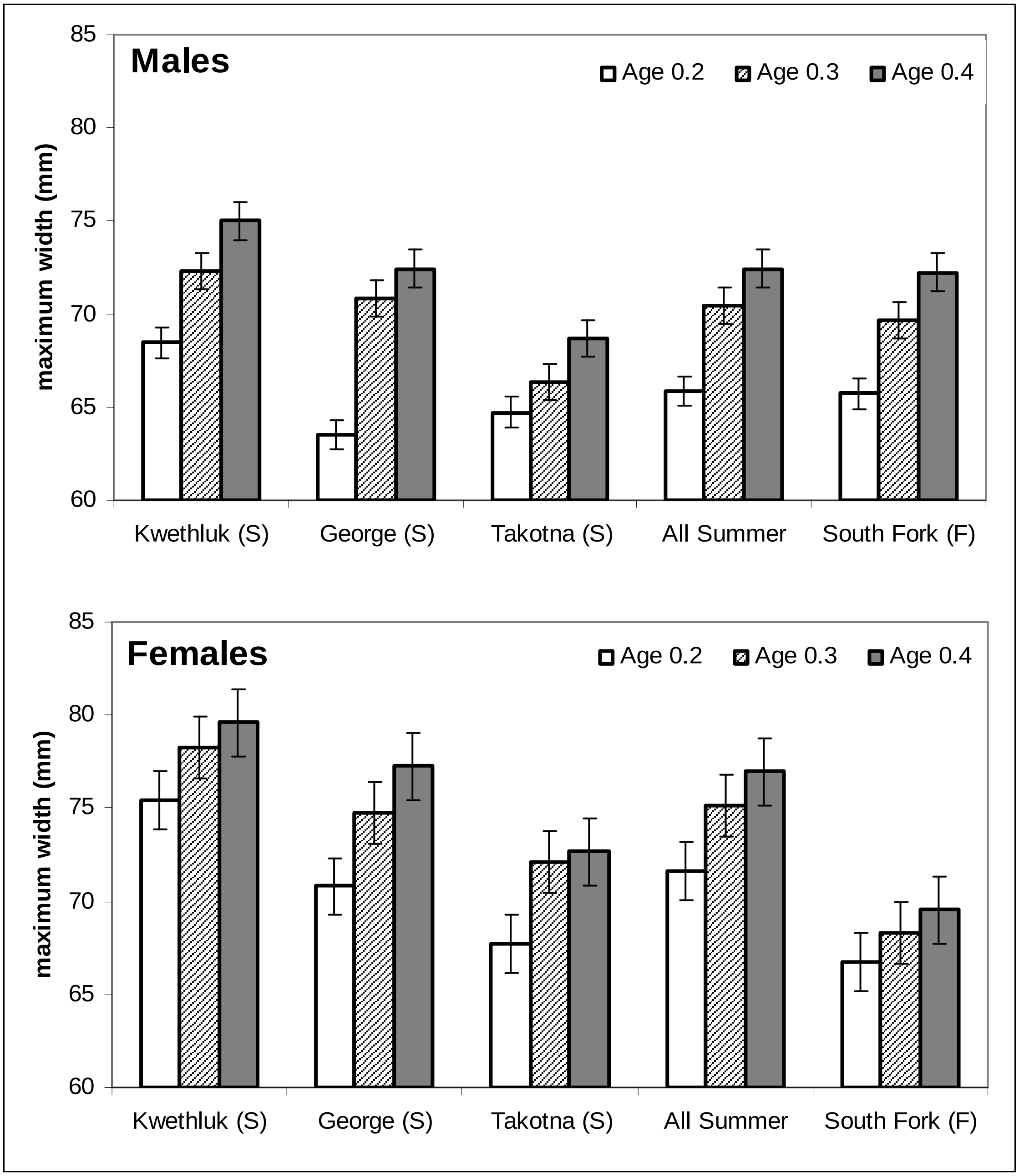
Note: "All Summer" includes fish sampled at the Kwethluk, George, and Takotna river weirs. S = summer and F = fall.

Figure 6.–Average length from mideye-to-tail-fork (METF) among age groups of male and female Kuskokwim River summer and fall chum salmon, 2004.



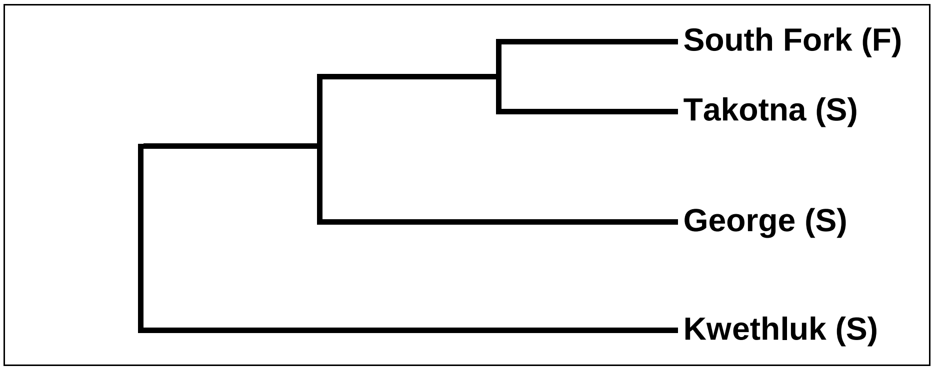
Note: "All Summer" includes fish sampled at the Kwethluk, George, and Takotna river weirs. S = summer and F = fall.

Figure 7.–Average maximum dorsal-ventral height among age groups of male and female Kuskokwim River summer and fall chum salmon, 2004.



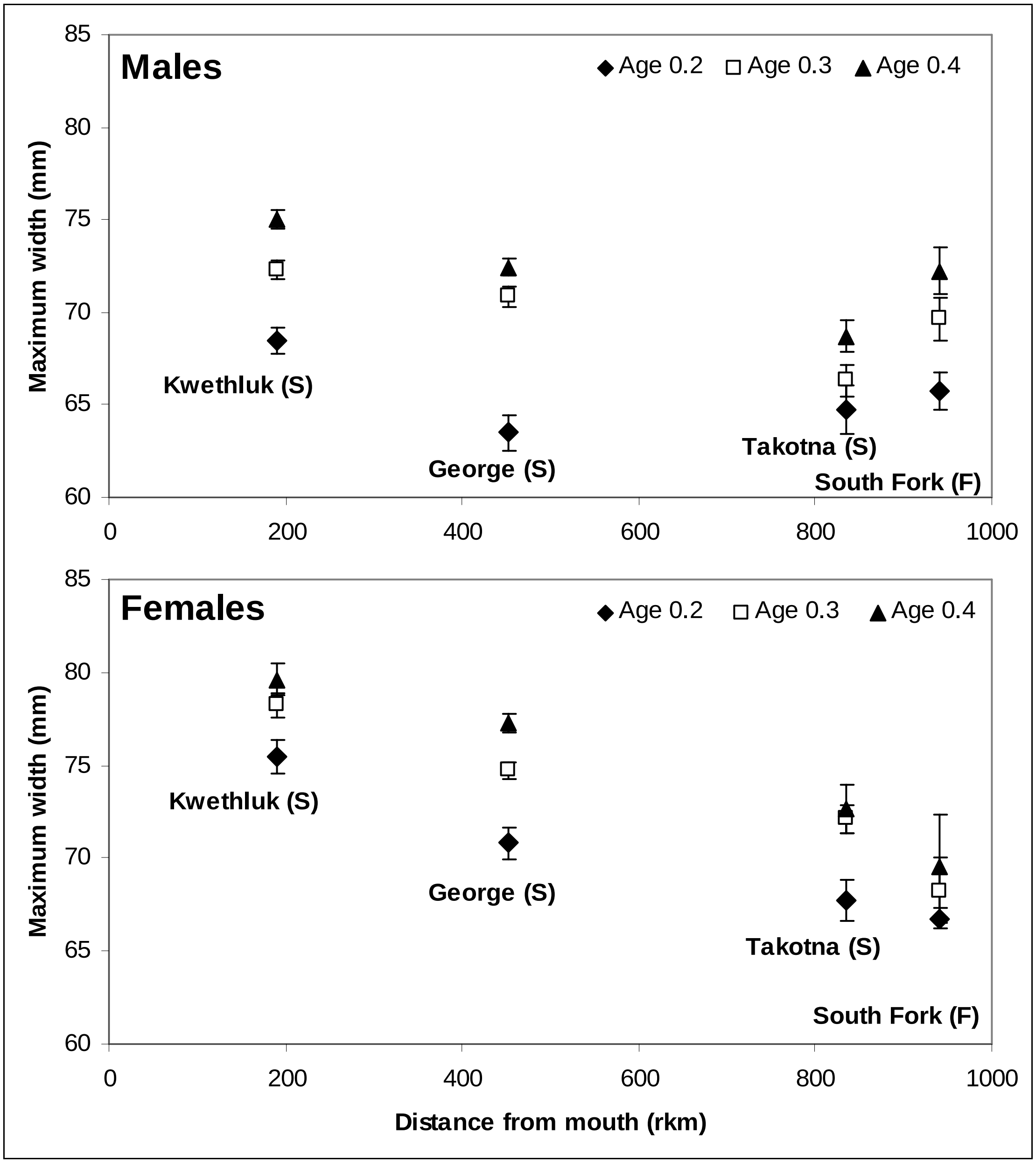
Note: "All Summer" includes fish sampled at the Kwethluk, George, and Takotna river weirs. S = summer and F = fall.

Figure 8.–Average maximum widths among age groups of male and female Kuskokwim River summer and fall chum salmon, 2004.



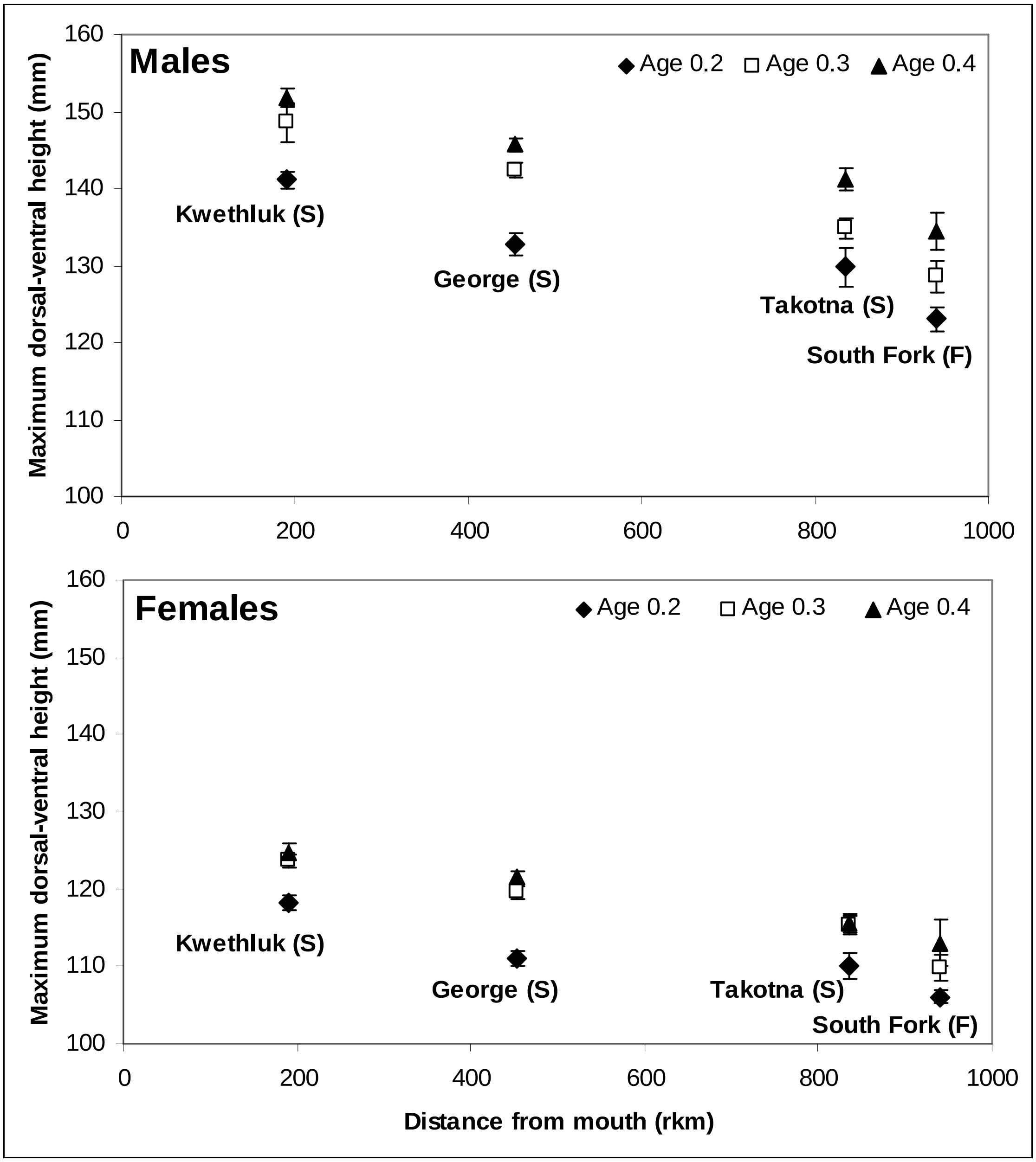
Note: S = summer and F = fall.
Source: Everitt 1980.

Figure 9.–Average linkage cluster analysis showing relationship between Kuskokwim River summer and fall chum salmon for morphology characteristics, 2004.



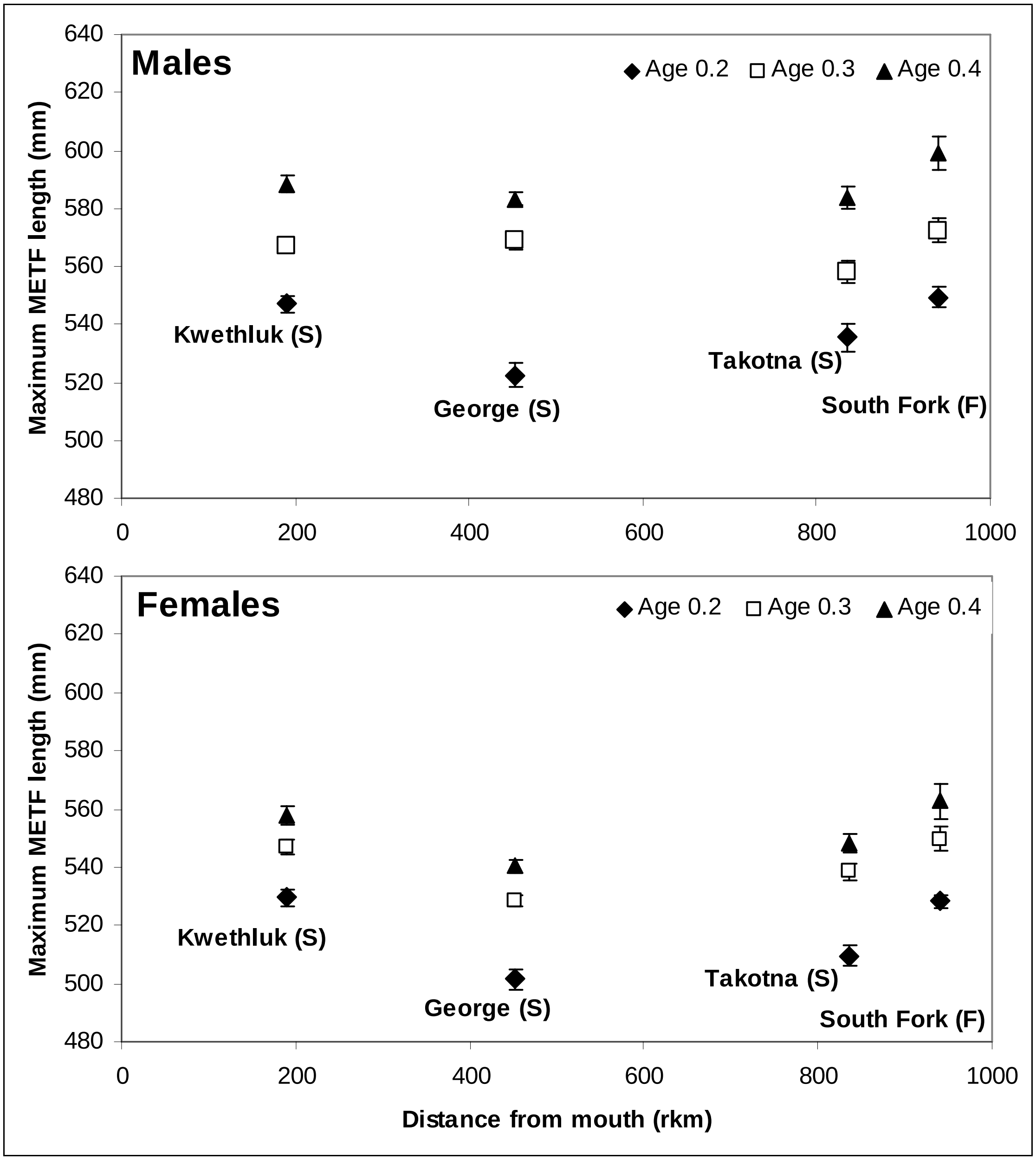
Note: S = summer and F = fall. Error bars are ± 1 SE.

Figure 10.–Relationship between migration distance and average maximum width for male and female Kuskokwim River summer and fall chum salmon, 2004.



Note: S = summer and F = fall. Error bars are ± 1 SE.

Figure 11.–Relationship between migration distance and average maximum dorsal-ventral height for male and female Kuskokwim River summer and fall chum salmon, 2004.



Note: S = summer and F = fall. Error bars are ± 1 SE.

Figure 12.–Relationship between migration distance and average length from mideye-to-tail-fork (METF) for male and female Kuskokwim River summer and fall chum salmon, 2004.

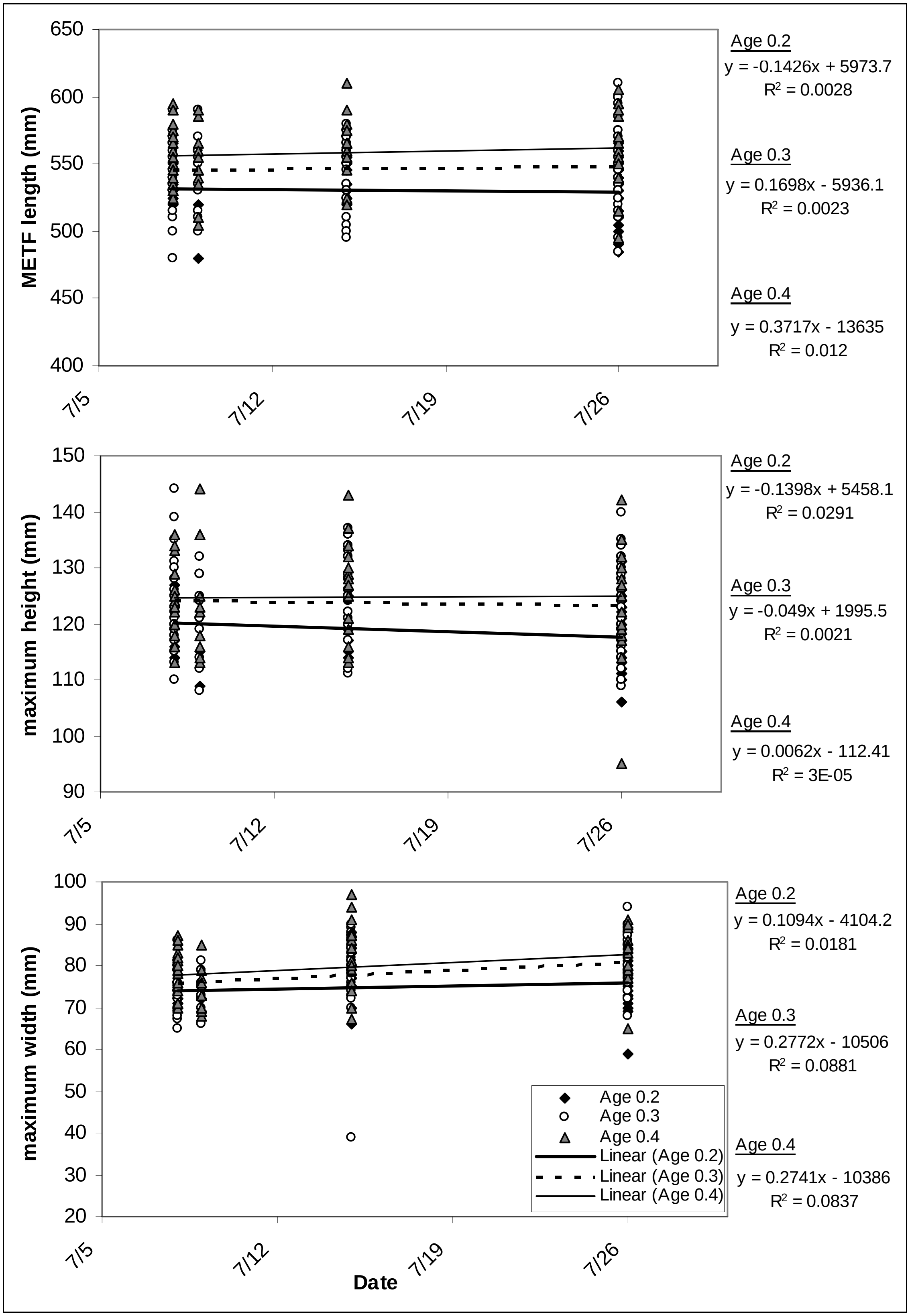


Figure 13.–Change in morphology measurements over time for female summer chum salmon at the Kwethluk River weir, 2004.

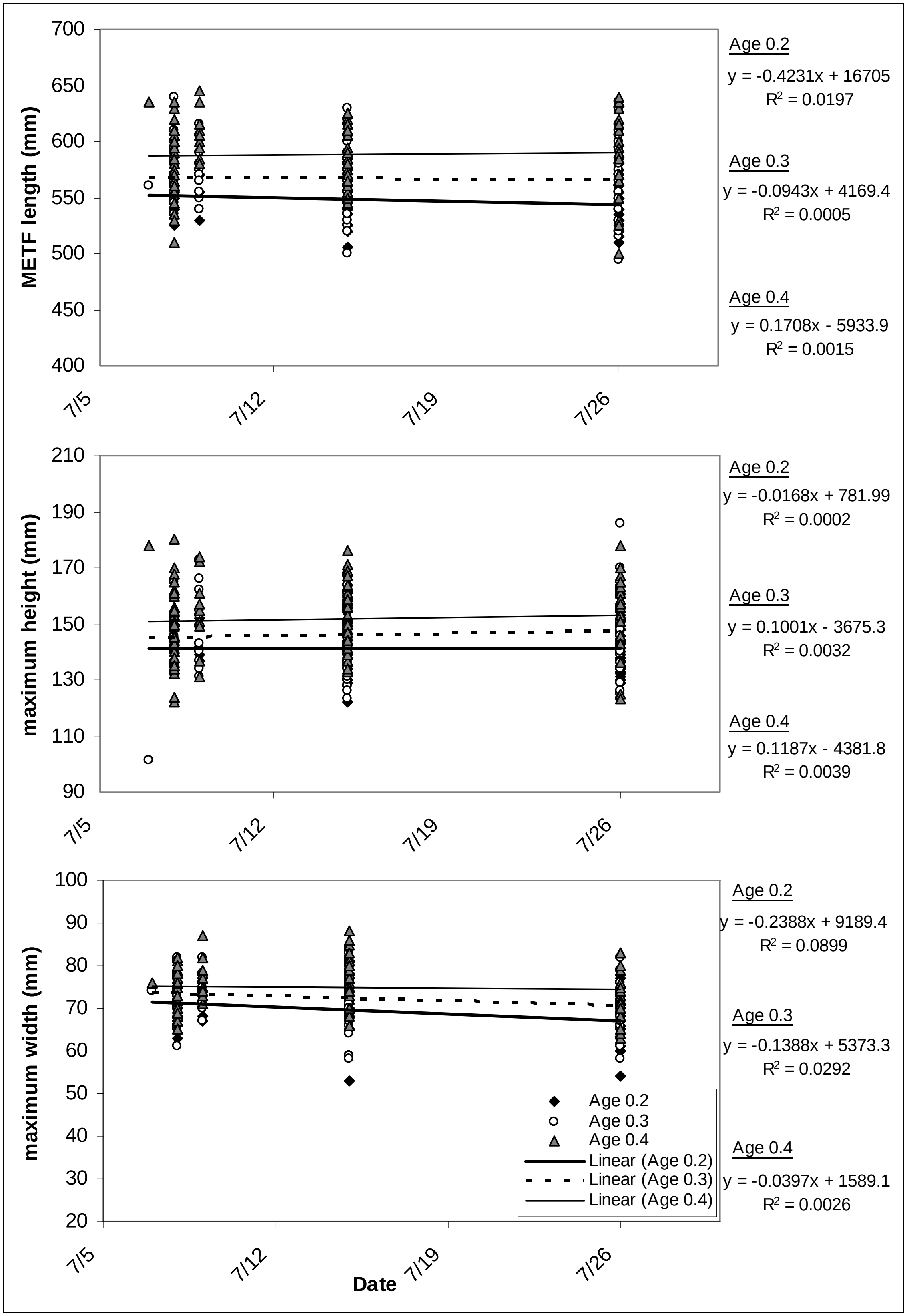


Figure 14.–Change in morphology measurements over time for male summer chum salmon at the Kwethluk River weir, 2004.

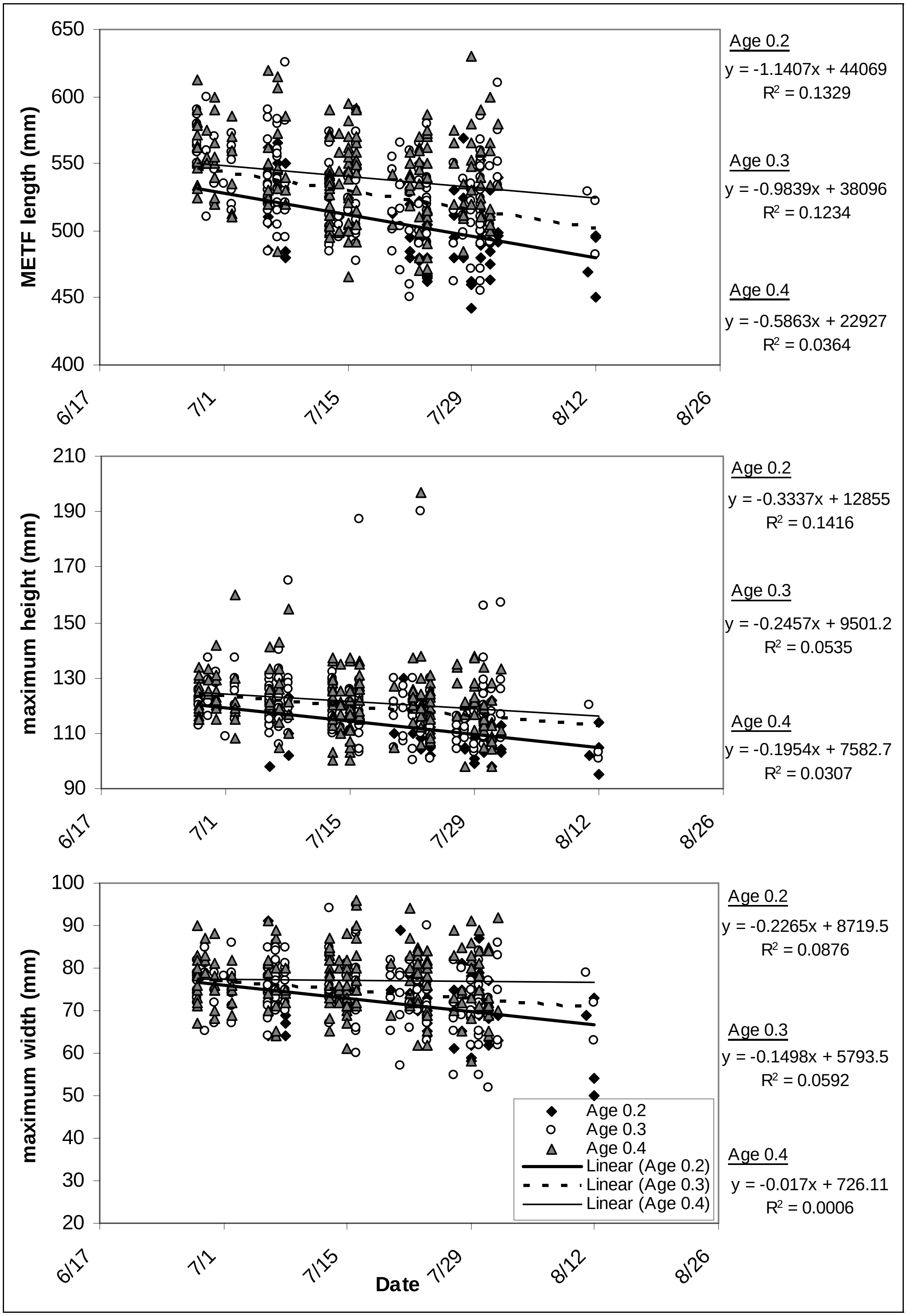


Figure 15.–Change in morphology measurements over time for female summer chum salmon at the George River weir, 2004.

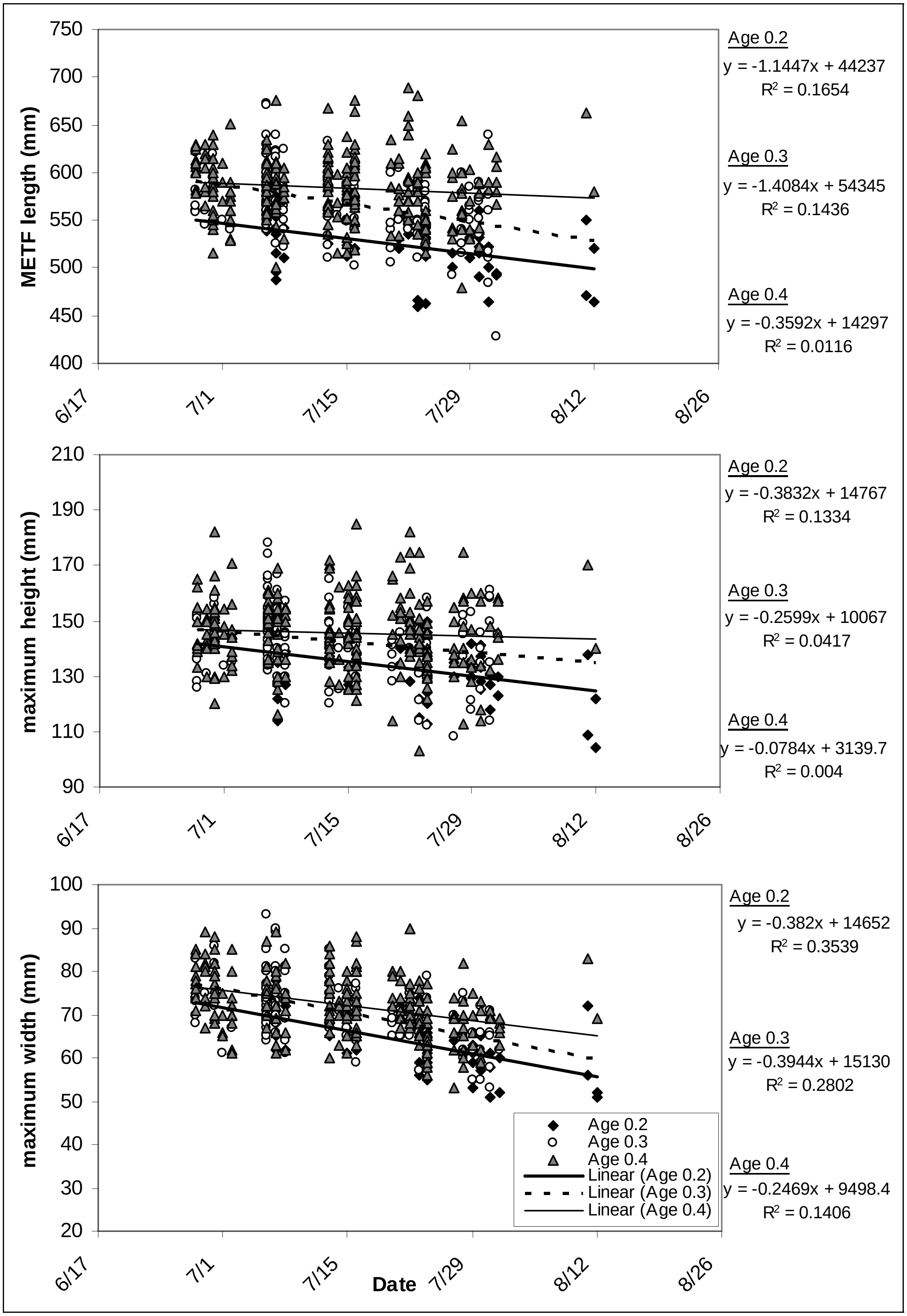


Figure 16.–Change in morphology measurements over time for male summer chum salmon at the George River weir, 2004.

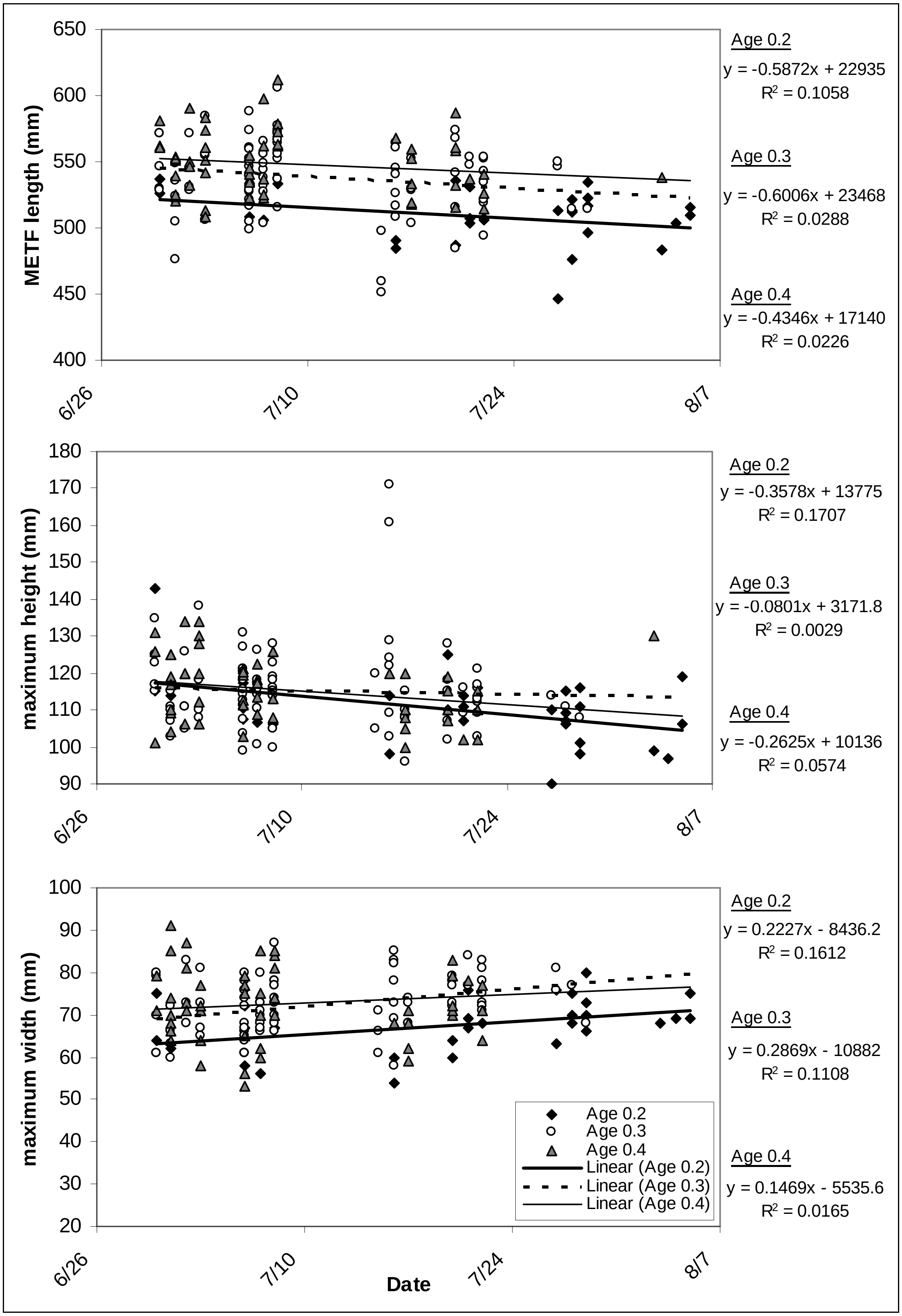


Figure 17.–Change in morphology measurements over time for female summer chum salmon at the Takotna River weir, 2004.

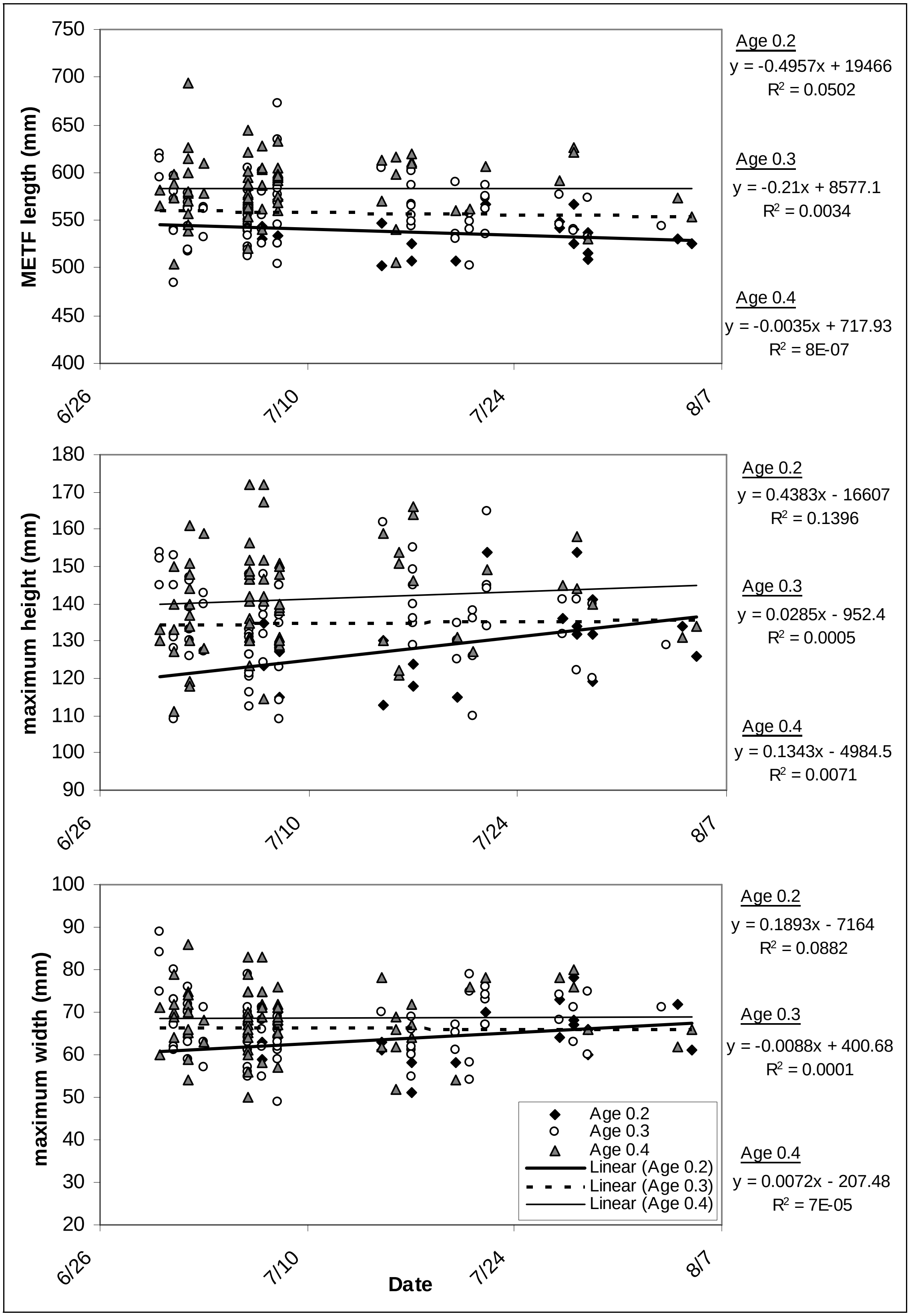


Figure 18.–Change in morphology measurements over time for male summer chum salmon at the Takotna River weir, 2004.

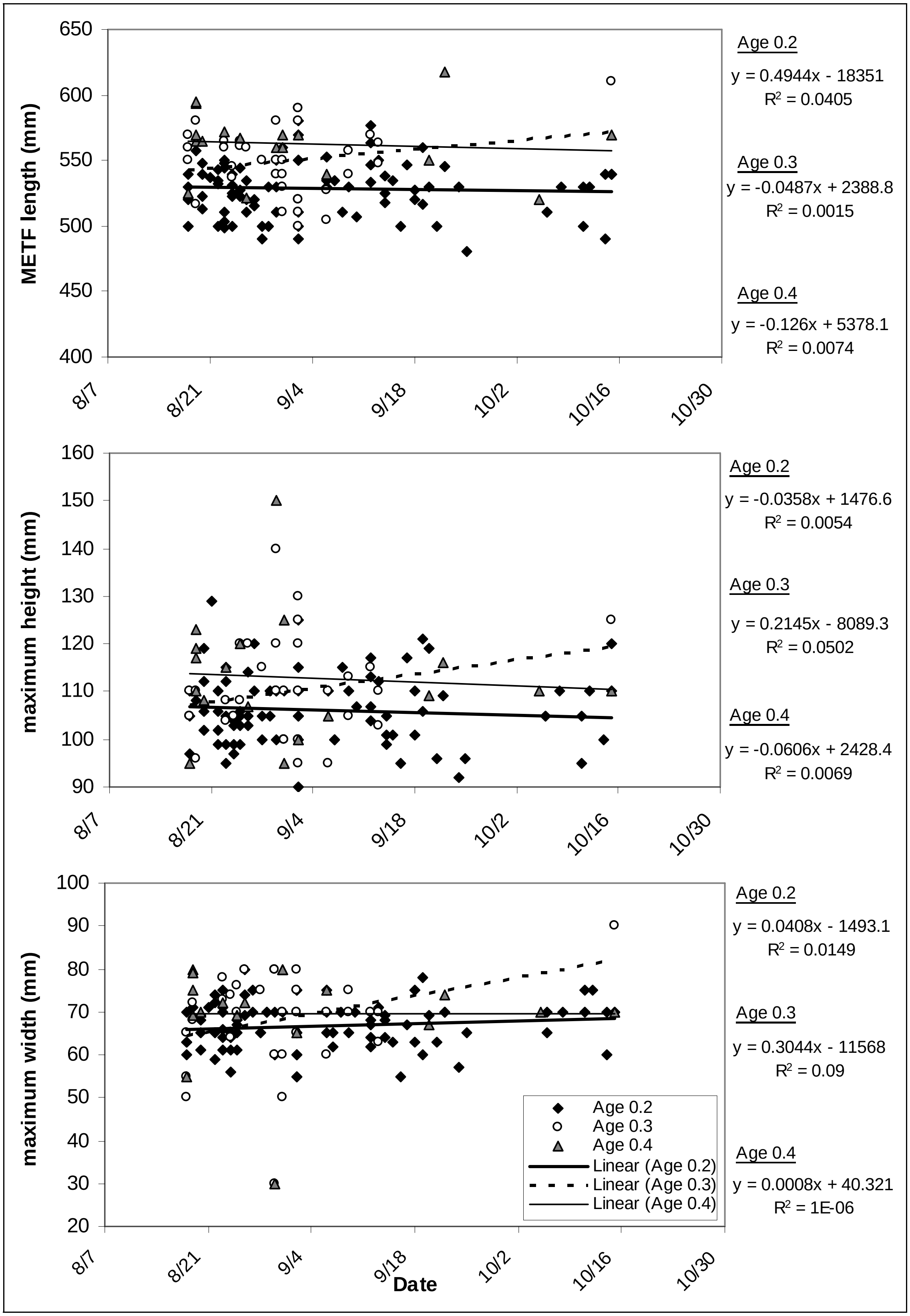


Figure 19.–Change in morphology measurements over time for female fall chum salmon at the South Fork Kuskokwim River fish wheel, 2004.

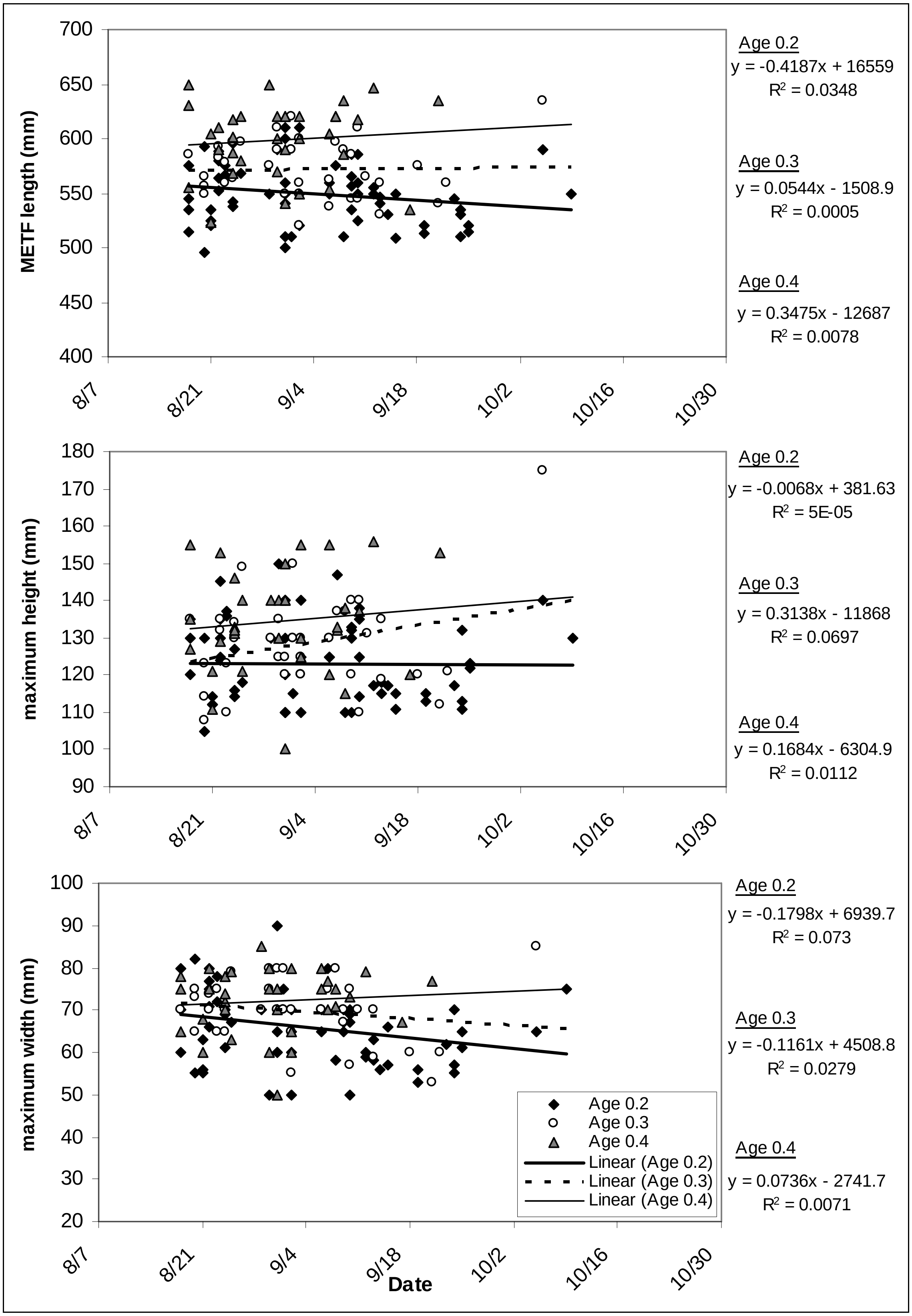
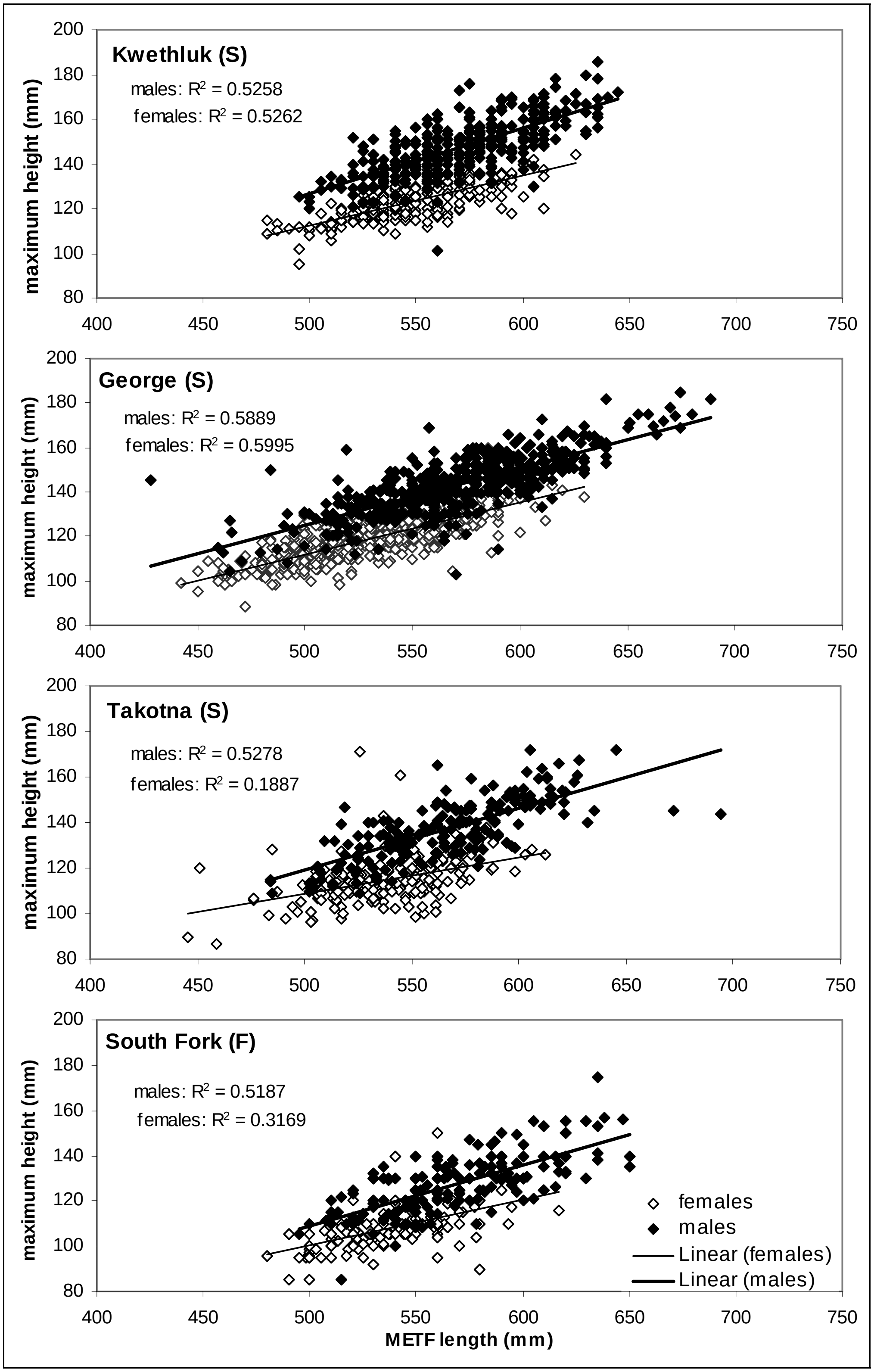
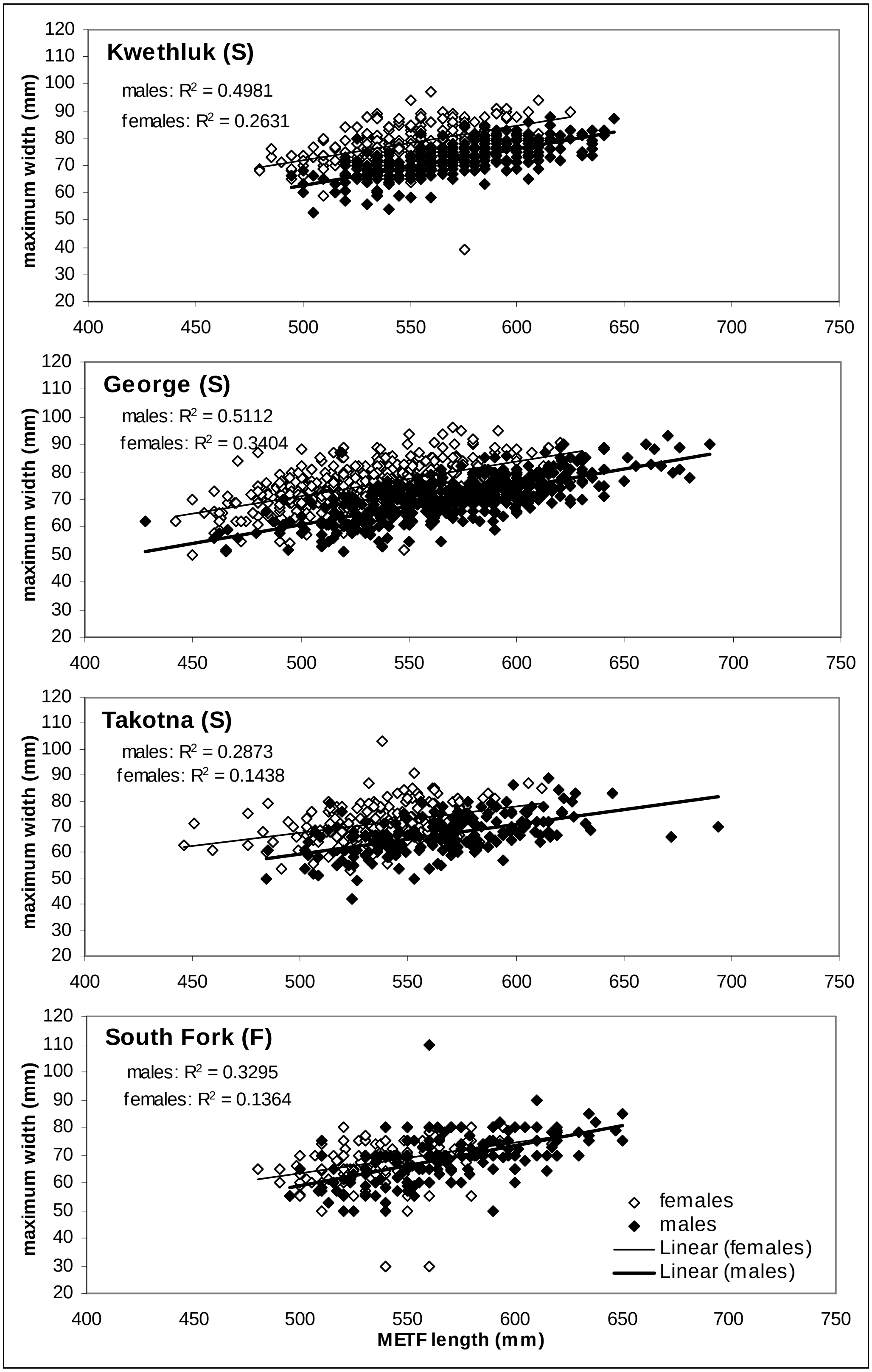


Figure 20.–Change in morphology measurements over time for male fall chum salmon at the South Fork Kuskokwim River fish wheel, 2004.



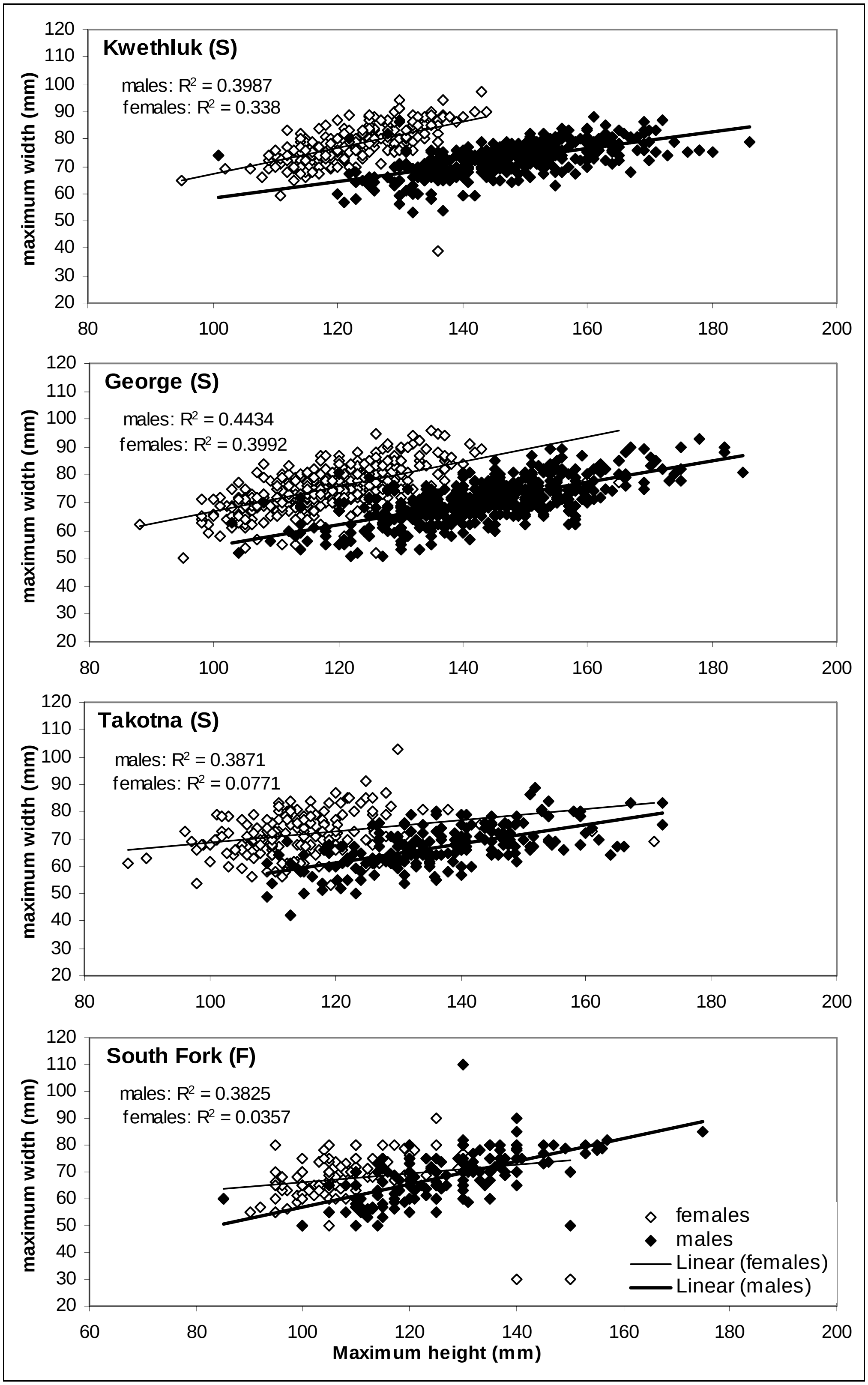
Note: S = summer and F = fall.

Figure 21.–The relationship between maximum dorsal-ventral height and length from mideye-to-tail-fork (METF) for male and female Kuskokwim River summer and fall chum salmon, 2004.



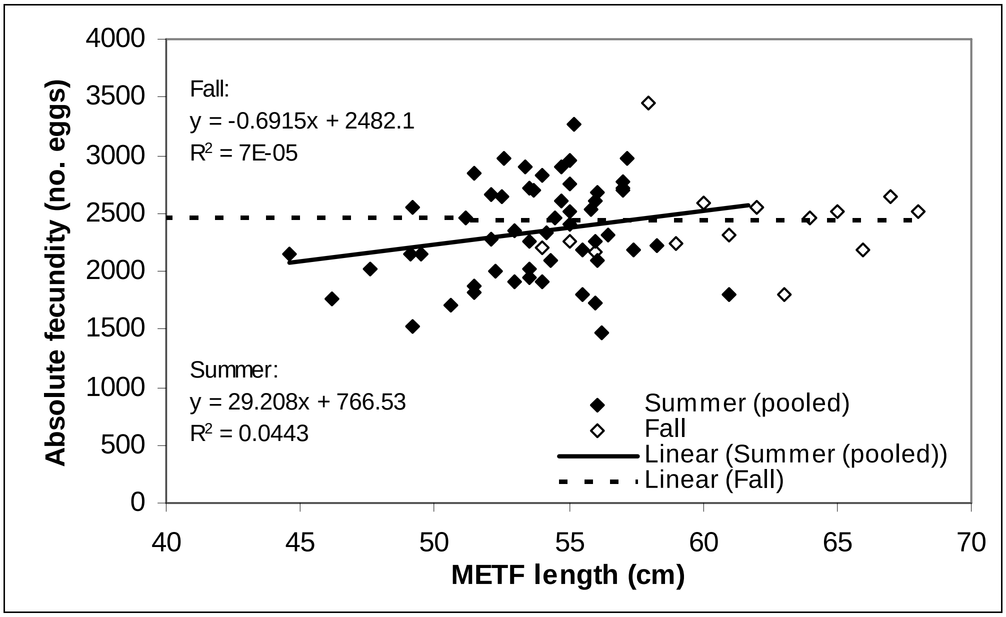
Note: S = summer and F = fall.

Figure 22.–The relationship between maximum width and length from mideye-to-tail-fork (METF) for male and female Kuskokwim River summer and fall chum salmon, 2004.



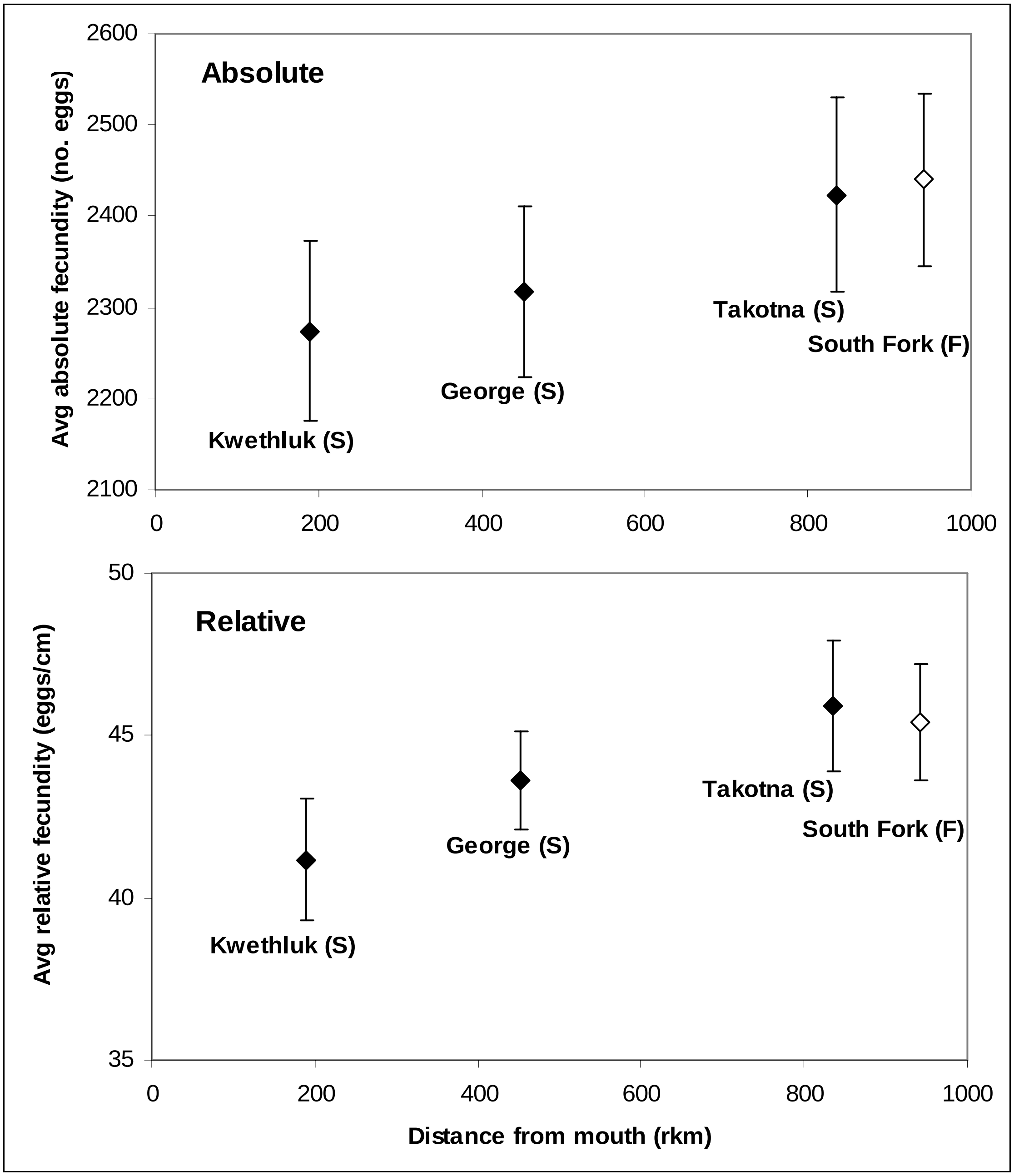
Note: S = summer and F = fall.

Figure 23.–The relationship between maximum dorsal-ventral height and maximum width for male and female Kuskokwim River summer and fall chum salmon.



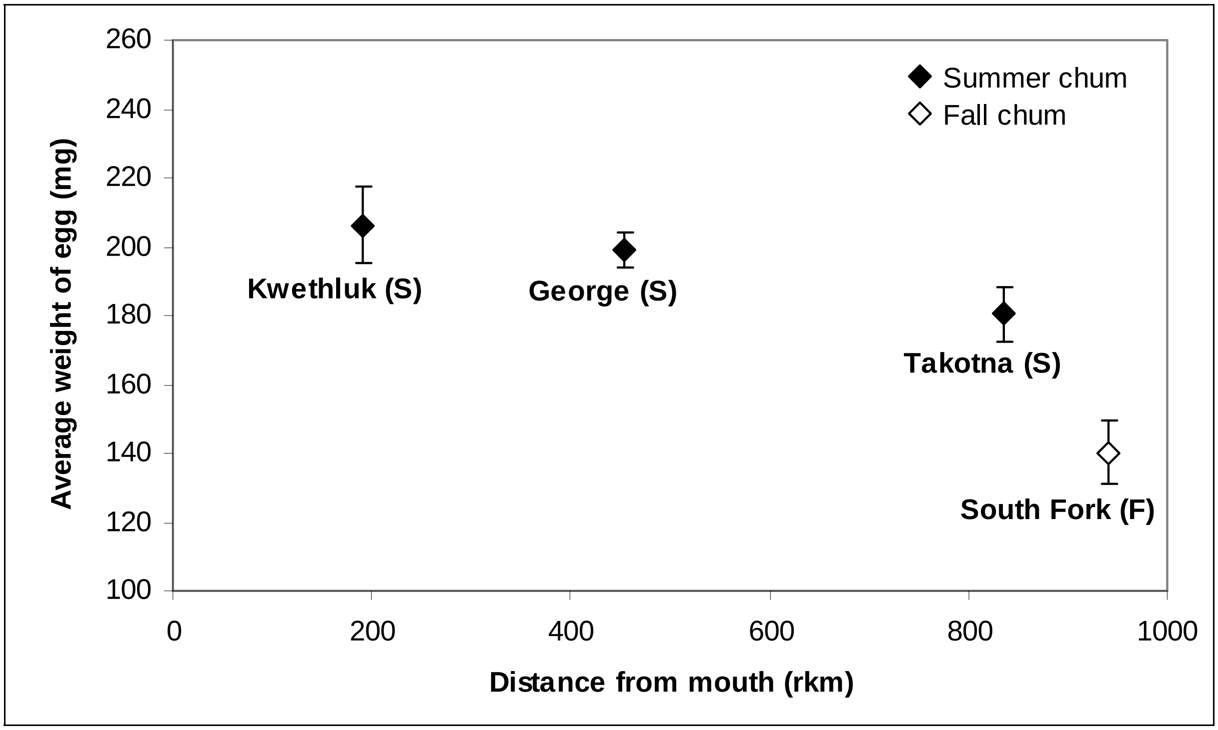
Note: Pooled summer samples include fish from the Kwethluk, George, and Takotna river weirs, and fall samples include fish from the South Fork Kuskokwim River fish wheel.

Figure 24.–Relationship between absolute fecundity and length from mideye-to-tail-fork (METF) of female chum salmon sampled from the Kuskokwim River, 2004.



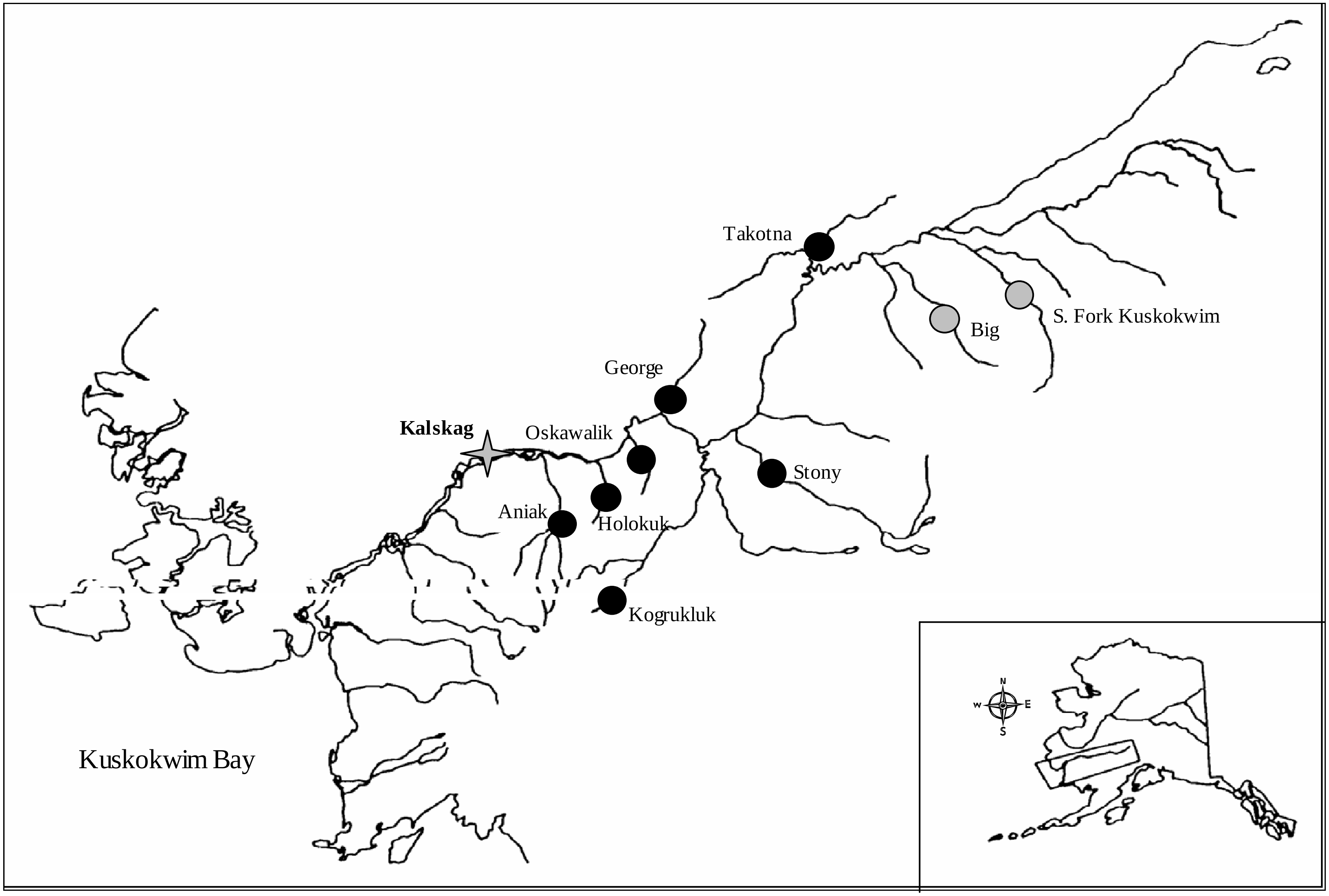
Note: S = summer and F = fall. Error bars are ± 1 SE.

Figure 25.–Relationship between migration distance and absolute fecundity (number of eggs) and relative fecundity (number of eggs per cm) for Kuskokwim River summer and fall chum salmon, 2004.



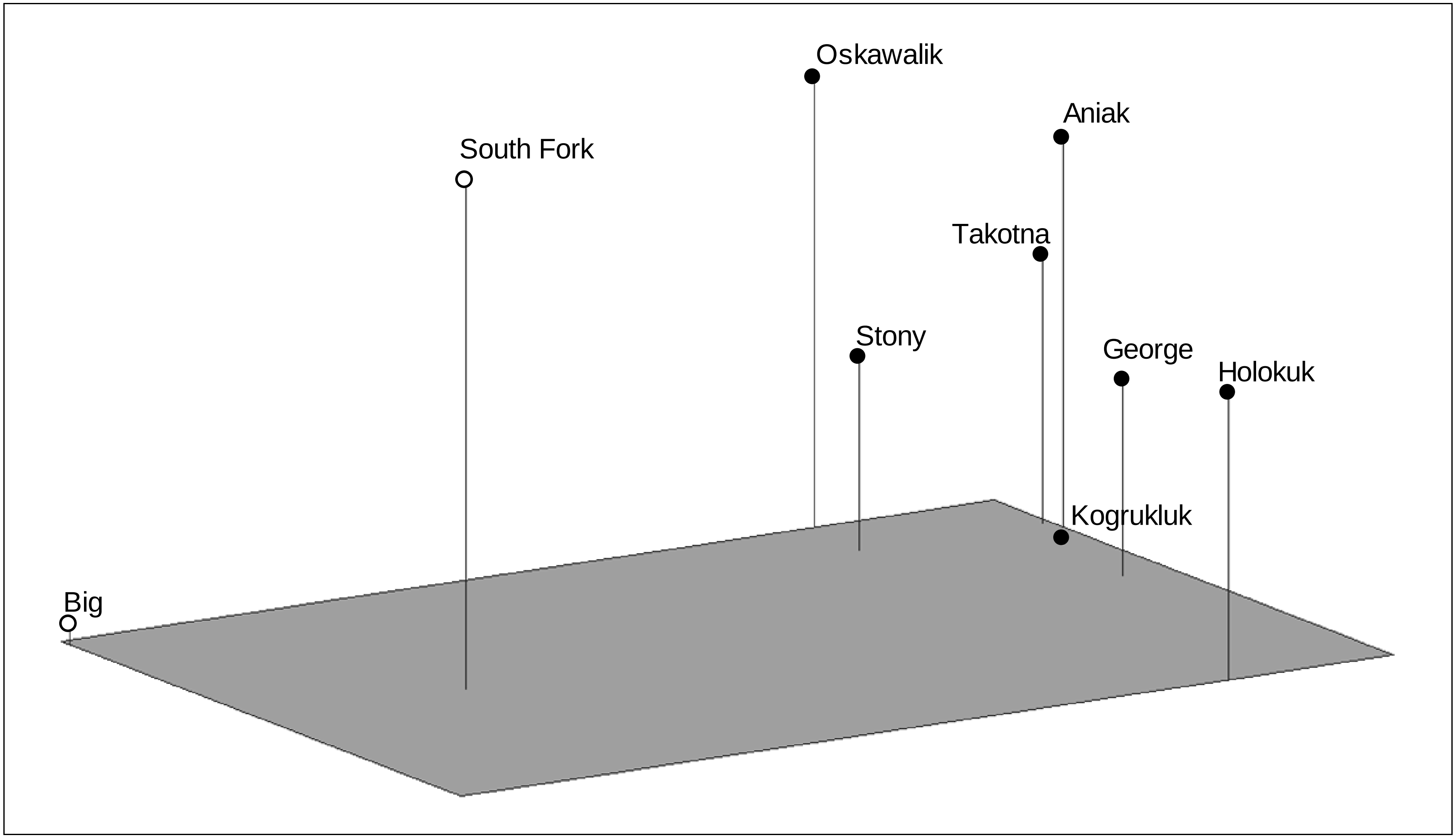
Note: S = summer and F = fall. Error bars are ± 1 SE.

Figure 26.–Relationship between migration distance and average weight of single egg for Kuskokwim River summer and fall chum salmon, 2004.



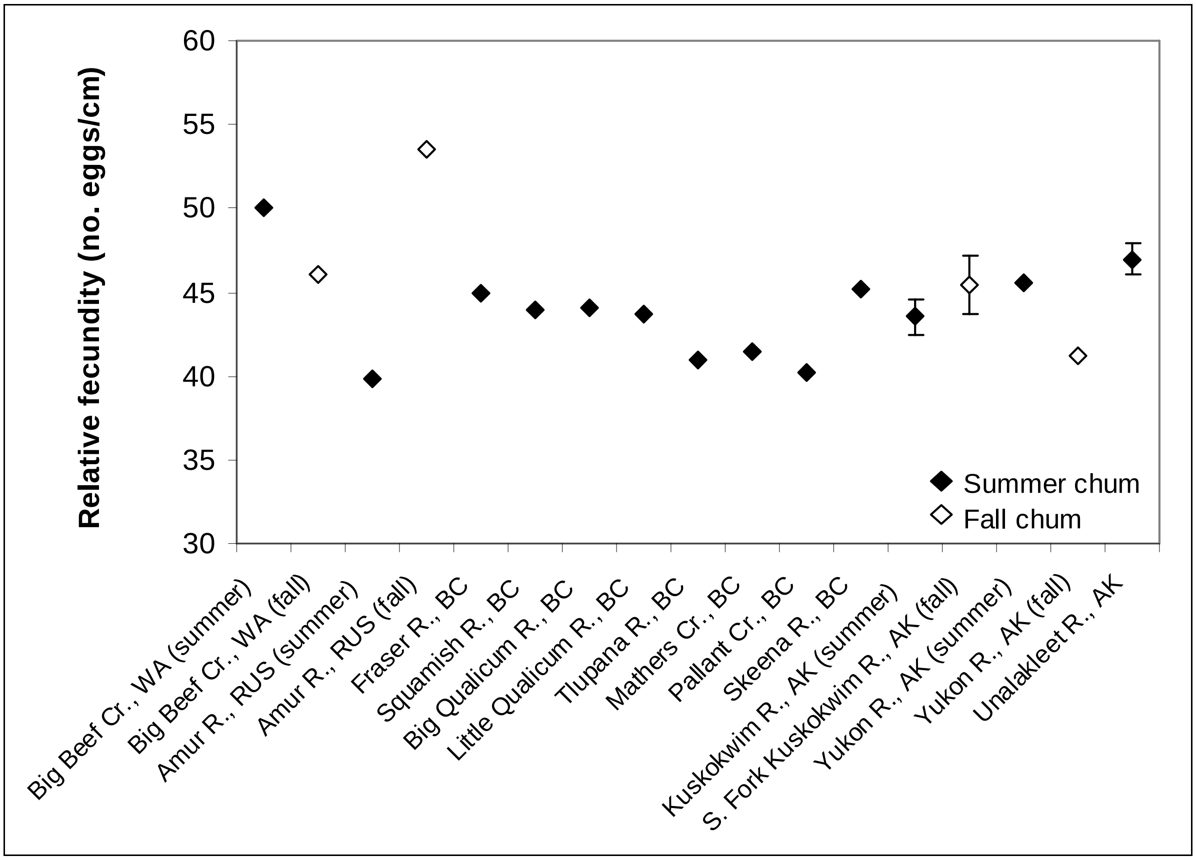
Note: Black circles indicate summer chum populations, gray circles represent fall chum populations.

Figure 27.–Sampling locations of Kuskokwim River collections analyzed for genetic stock identification of chum salmon using SNP markers, 2004.



Note: Closed circles indicate summer chum populations, open circles represent fall chum populations.

Figure 28.–Multidimensional scaling plot of genetic distances showing differences in allele frequencies at 28 SNP loci between Kuskokwim River summer and fall chum salmon populations.



Note: Point marker represents mean, whisker extends ± 1 SE from mean (value available only for Kuskokwim and Unalakleet river samples). Samples are arranged from southern to northern populations.

Figure 29.–Mean relative fecundities of chum salmon from the Kuskokwim River compared to those from other rivers reported by Salo (1991) and Nemeth et al. (2003).