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Yukon River Chinook Salmon Aging Consistency

by

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and

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June 2010

Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries

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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

Accurate and consistent age estimation is an inherent assumption of historical age trend analysis. During the years that the Alaska Department of Fish and Game (ADF&G) has collected scales from Yukon River Chinook salmon *Oncorhynchus tshawytscha* many different readers have interpreted scale growth patterns and assigned ages. Age validation studies for wild Yukon Chinook salmon are not available; therefore the accuracy of these ages cannot be addressed. Recent studies have suggested a decline in older-aged fish, but these studies are predicated on the assumption that aging has been precise and consistent. This study assessed the percent agreement and temporal consistency by ADF&G in estimating Chinook salmon ages from scales. A subset of aged scale impressions were selected over a 43-year span (1964–2006). These scale impressions were aged by 3 independent scale readers. Age estimates by ADF&G were compared to the readers' estimates for consistency in age composition, systematic differences, and agreement. Results from these analyses suggest that ADF&G has consistently aged Chinook salmon over the past 43 years as no significant differences were found in the estimates of age composition among ADF&G and the independent readers. In general, agreement was high between ADF&G and each independent reader. More importantly, age-specific differences and the levels of agreement were temporally consistent. Differences were identified in age-2 freshwater and age-5 saltwater estimates where ADF&G tended to assign more of these ages than the other readers. In Yukon River Chinook salmon, these ages comprise older-aged fish. Differences in estimating these ages allow us to put the estimated proportions of older-aged fish in Yukon River Chinook salmon populations into context.

Key Words: Yukon River, Chinook salmon, age estimation, aging consistency, scale aging

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) is responsible for managing Pacific salmon *Oncorhynchus* spp. for long-term sustainability and maximum sustained yield in Alaskan waters. Towards this end, age-structured information ranks among the most influential biological variables in fisheries management, as it forms the basis for measures of population dynamics and productivity (Quinn and Deriso 1999; Campana 2001). The collection of high quality unbiased (i.e. accurate and precise) age-structured information is at the core of the State of Alaska's salmon research and management programs. For example, stock-specific age-structured information is routinely used to reconstruct salmon runs, forecast future runs, establish harvest management guidelines, and evaluate escapement goals.

Age, sex, and length (ASL) trends in Yukon River Chinook salmon *O. tshawytscha* have most recently come to the forefront in fishery-related meetings as research, anecdotal information, and local and traditional knowledge suggest the proportion of older and larger Chinook salmon has declined (Yukon River Joint Technical Committee [JTC] 2006). Hyer and Schleusner (2005) demonstrated a declining trend in the proportion of large Yukon River Chinook salmon but observed no trends in sex composition, length, or length-at-age. One possible factor that may be affecting the observed change in salmon age composition is statistical bias, where inconsistent age estimates are manifested as changes in age composition over time. Appropriate age estimation is an inherent assumption of historical ASL trend analysis. Age trend study results depend on unbiased consistent historical age data; however, this is rarely examined.

Estimating an age for salmon from scales, either freshwater or saltwater can be subjective. Age is estimated by viewing the magnified scale impression and interpreting the circuli and their patterns of growth. Circuli are concentric ridges on the outer surface of the scale separated by valleys. A year's growth typically has a zone of widely spaced circuli, the summer growth, and a zone of closely spaced circuli, the winter growth (Mosher 1968). Scale readers must be able to recognize a check, a zone of slower growth characterized by a set of circuli being more closely spaced than the adjacent circuli. These checks can vary in appearance from easily recognizable, clear-cut zones to diffuse zones that are not much different from the adjacent zones (Mosher 1968). Furthermore, the reader must interpret each check as either a false or true annulus based upon their experience and familiarity (Bilton 1972). Scale readers often classify annuli as true or false in a subjective manner and that leads to age disagreements. A true annulus is that set of closely spaced circuli formed during the slower growth in the winter. Other checks, or false annuli, may form during any time of year, and these are often attributed to an abrupt change in physical or environmental conditions. The reader's experience with a particular stock or aggregate of stocks will affect their ability to recognize and interpret patterns that may be unique to a particular stock.

ADF&G has collected ASL information annually from Chinook salmon in commercial, sport, subsistence, and test fisheries as well as from escapement monitoring and other salmon research projects throughout the Yukon River since 1960. During these years, many different readers have interpreted scale growth patterns and assigned ages. Methods used to address age data quality were not well documented. Based on anecdotal information, it is assumed that aging techniques were passed along from reader to reader. In general, the supervisor or another experienced reader would train the new reader and check their ages until an acceptable agreement level was reached. Good percent agreement, that minimized between-reader differences, is likely lacking from some years.

The need to verify that ADF&G has estimated Chinook salmon ages consistently was identified by the JTC Salmon Size Subcommittee (JTC 2006). The work presented here addresses the Yukon River Panel priority 3: *determine the quality of stock escapement, wherever possible continue to document age, sex, and length of fish harvested*; because any documentation of age requires consistent assignment of ages (Yukon River Panel 2006[1]).

OBJECTIVE

The objective of this study was to assess the level of temporal consistency exhibited by ADF&G when estimating Yukon River Chinook salmon ages from scales.

METHODS

ADF&G SCALE COLLECTION, PROCESSING, AND AGE NOTATION

Chinook salmon scales were collected from the preferred area of the fish as described by Mosher (1963) and mounted onto gum cards. Up to 40 scales could be mounted onto a single gum card. From 1964 to 1981 one scale was collected from each fish. Consequently, a single gum card could represent ages for up to 40 (generally 30) individual fish. Aging the freshwater portion of Chinook salmon scales can be difficult or impossible if the scale has been damaged or regenerated. To reduce uncertainties, primarily in the freshwater growth area, sampling protocol changed beginning in 1982, requiring 3 scales to be collected from each fish, hence; a single gum card could represent ages for up to 10 individual fish (3 scales per fish; 30 scales per card). The additional scales increased the chance of collecting a scale with a complete freshwater growth pattern and provided readers with more information to determine the appropriate age estimate.

[1] Yukon River Panel. 2006 (Unpublished). Budget Priorities Framework. Budget Priorities Subcommittee, Restoration and Enhancement Committee.

The scales, mounted on gum cards, were impressed in clear cellulose acetate using methods described by Clutter and Whitesel (1956). Scale impressions were magnified and examined using a Microfiche reader or projected from a microscope. Error codes were used to identify various reasons that a scale, or portions of a scale, could not be read, such as: presence of debris, damage, regenerated freshwater growth, or absorbed saltwater annuli.

ADF&G had only reported an age estimate when the total age was estimated, including both freshwater and saltwater ages. Most Yukon River Chinook salmon are stream-type, spending one or more years in freshwater, and 1 to 6 years in the ocean. Total age from the parent brood year can range from 3 to 8 years old. Ages were recorded using European notation, the freshwater age separated by a decimal from the saltwater age (Koo 1962). Total age from the brood year is the sum of freshwater and saltwater age plus one to account for time spent in the gravel before hatching and growth before scale formation. For the purpose of this report, subscripts were used to refer to 3 age types: freshwater (age_{fw}), saltwater (age_{sw}) and total (age_{t}). The authors contend the notation recommended by Koo, where freshwater or saltwater ages are denoted by the placement of the period, such as ages 1., 2., .1, .2, .3, .4, .6; may confuse the reader.

The original gum cards and acetate impressions were archived by ADF&G. Age information for each fish was archived along with corresponding metadata and additional biological data, such as sex and length. These historical data, in various formats, were compiled into a database (Brannian et al. 2007).

STUDY DESIGN

The study was designed to evaluate aging consistency from the entire range of Chinook salmon ages. The emphasis focused on scale impressions representing age_{t}-7 or -8 fish because the suggested decline in older-aged fish is a concern among researchers, managers, and fishermen. Acetate cards that had at least one scale impression from an older-aged fish were selected from the ADF&G Yukon River Chinook salmon archives. Selecting acetate cards with older-aged fish ensured a sufficient sample size of these target ages because of their relative low abundance during some years. These scale impressions were sent to 3 independent scale readers for aging. Age estimates by ADF&G were compared to estimates from the independent readers.

Chinook salmon scale impressions in the ADF&G archives where at least one fish was estimated to be age_{t}-7 or -8 were identified from the database. Age records were selected from fish sampled from large-mesh (≥8-inch) gear in lower river commercial harvests in District 1 and 2, and test fisheries at Flat Island, Big Eddy, and Middle Mouth (Figure 1). Using lower river fisheries data for this study was appropriate because: 1) these fisheries represent the most abundant, continuous dataset since 1964 (a 43-year span), and 2) salmon scales collected nearer the ocean exhibit minimal absorption, where the outer scale margin is increasingly absorbed as freshwater spawning migration progresses. A total of 9,013 older-aged fish were available for inclusion in this study (Table 1).

ADF&G staff were able to identify the approximate years worked by individual readers of Yukon River Chinook salmon since 1982. The older-aged fish were pooled spatially and divided into 5 temporal strata that reflected changes in ADF&G scale readers, collection methods, and the number of older-aged fish available in each stratum and year. The 18 years where individual readers could not be identified were divided equally into 9-year segments: 1964–1972 was stratum 1 and 1973–1981 was stratum 2 (Table 1). Stratum 3 was assigned to years 1982–1990 when at least 2 readers aged scales and 1 of the readers began about 1982. More than one-third of the older-aged fish available were in this stratum. A change in readers occurred in 1990–1991 and stratum 4 was assigned to years 1991–1996 where at least 3 readers aged scales. The last stratum was assigned to 1997–2006 when 3 readers aged scales; a change in readers occurred in 1996–1997.

The minimum sample size objective of 120 older-aged fish per stratum was set to ensure adequate numbers would be available for statistical analysis. The annual sample objective for these fish in each year was proportional to the total number of older-age fish in each corresponding stratum. Therefore, each stratum objective was 120 samples and the objective for each year within the stratum was determined by the number of older-aged fish by year (Table 1).

SCALE SELECTION

All older-aged fish that were available for inclusion in the study were compiled into a chronological list (List 1) that related an age record with specific acetate card information. The stratum objective (120) was divided into the total number of older-aged fish available by stratum to systematically select every n^{th} record available. For example, in the first stratum, 1,108/120≈9; therefore the first and every 9^{th} record thereafter in stratum 1 was selected for inspection and possible inclusion in the study. Following similar methods, every 6^{th}, 26^{th}, 17^{th}, and 16^{th} record was selected for further inspection in stratum 2, 3, 4, and 5; respectively. This resulted in weighting each year, within a stratum, by the number of older-aged fish available.

A second list was compiled (List 2) that contained all the ages for each acetate card that was included in List 1 as well as specific acetate card information, such as; date, location, mesh size, fishery type, ages, fish number, and card number. During the inspection process, every effort was made to select high quality readable acetates and those where age records corresponded with the database. Acetates and the two lists were examined for:

1) Completeness;
2) Acetate label matches information in List 2;
3) Information from List 1 and List 2 match;
4) Records in List 2 and fish number matches between acetate and List 2;
5) Acetate is not overly damaged or scratched;
6) Scales are in correct orientation;
7) Pressing is uniform across acetate; and
8) Unreadable scale impressions are minimal.

When an older-age record was judged unacceptable, the records and corresponding acetate cards above and below the unacceptable record (from List 1) were examined until an acceptable record was found. The selection process of examining every n^{th} record continued until the sample objective was reached for each year.

The selection process was modified for acetates with more than 20 fish (1 scale/fish) such that an acceptable older-aged record from an acetate card before 1982 may be counted more towards the annual sample objective. Where an older-age record (from List 1) was present on an acetate card that contained records from 21 to 30 fish, that record would count as 2, and from an acetate card with 31 to 40 fish, that record would count as 3 towards the sample objective. This was done assuming that additional older-aged acceptable records would be present on the selected acetate.

Although older-aged fish were preferentially included in this study, all scale impressions on the selected acetates were to be aged, yielding a variety of freshwater, saltwater, and total age estimates. All age records and associated information from the selected acetates were compiled into a third chronological list (List 3). Each acetate card was assigned and labeled with a unique study number (1-491). Each fish record in List 3 was assigned a unique number (1-7301). List 3 became the source for the aging study.

The scale selection process resulted in archived age data from 5 temporal strata over 43 years, which consisted of 491 acetates impressed with 14,681 scales from 7,301 individual Chinook salmon (Tables 1 and 2). Of these, 1,149 (15.7%) fish were estimated by ADF&G to be $age_t \geq 7$ (Table 1). A total of 6,393 (87.6%) of the Chinook salmon represented on the selected acetates were successfully aged by ADF&G (Tables 1 and 2).

INDEPENDENT SCALE READERS

Three independent aging laboratories were recommended by senior ADF&G staff for participation in this study: Canadian Department of Fisheries and Oceans (DFO), the Washington Department of Fish and Wildlife (WDFW), and the ADF&G Age Laboratory in Juneau (*note*: the ADF&G Age Laboratory in Juneau is independent from the ADF&G staff responsible for estimating Yukon River Chinook salmon ages). Each reader was highly experienced in aging Chinook salmon scales.

The same set of selected acetates was sent to each reader along with a data entry file that was created from List 3 in which to record age estimates and error codes. No additional information was provided about the selected acetates or expected ages to avoid biased estimates. Readers were not aware that older-aged fish were preferentially selected for inclusion in the study. Independent readers estimated freshwater age only, saltwater age only, both fresh and saltwater ages, or neither. An error code was assigned when one or both ages were not estimated. Other than the age reporting method, the readers used their own established criteria, methods, and equipment to estimate ages. Once each reader had completed their aging, their estimates were added to List 3 such that each fish record had estimates from ADF&G paired with each reader.

One reader used the method described by Rowse et al. (1990) to determine freshwater age. This method standardized some of the criteria presented by Yole (1989) by scoring 3 parameters: the presence of a freshwater annulus, comparing 2 caliper measurements, and circuli spacing (Appendix A1). This method may be more germane to the Pacific Northwest, where age_{fw}-0 Chinook salmon frequently occur, than to Yukon River stocks that are predominately age_{fw}-1.

Two of the readers estimated ages independently and operated solely on their own using a Microfiche reader to magnify and view the scale images. The other reader which was actually 2 participants, estimated the ages with a more rigorous procedure employed by the respective aging laboratory. Each participant aged one-half of the scale impressions and randomly checked 20% of the other participant's scales. Of those that were checked, any disagreements in ages or error codes were discussed between the 2 and resolved. Equipment used at the 2 participants' aging laboratory was a Neo-Promar microscope, with multiple objectives, which projected the image onto a large flat surface. The microscope provides a superior image quality compared with the Microfiche reader likely helping better determine age estimates, especially in the freshwater zone.

DATA ANALYSIS

Two types of datasets were compiled from ADF&G's and the readers' ages and analyzed separately, unpaired and paired. Unpaired datasets were robust as they incorporated all successful age estimates of a given type (i.e., if the reader assigned an age it was included in the dataset). Paired datasets allowed for direct comparison of age estimates between ADF&G and the readers. Paired datasets included only successful age estimations of a given type common to ADF&G and reader-1, ADF&G and reader-2, and ADF&G and reader-3. These paired datasets were investigated for agreement, age frequency, and age-difference plots for freshwater, saltwater, and total age estimates. Comparisons were not made among or between the independent readers. Analytical approaches do not address aging accuracy because the true age of each fish was not known.

Age Composition

Unpaired datasets were used to represent estimates of age composition between ADF&G and the readers. Chi-square goodness-of-fit analyses (α=0.05) were used to detect differences between estimates of saltwater and total age composition generated by ADF&G and the readers for each temporal stratum (Chilton and Bilton 1986; Copeland et al. 2007). These analyses tested the null hypothesis that the relative frequency distribution of saltwater and total age classes did not differ between ADF&G and the readers. Chi-square was not used to compare freshwater age compositions because of the limited range of the freshwater ages and small sample sizes for all but age_{fw}-1 fish.

Percent Agreement

Percent agreement was used to describe the repeatability of age estimates between ADF&G and the readers. Paired datasets were used to evaluate percent agreement (Godfrey et al. 1968; Chilton and Bilton 1986) by reader, age type, and temporal stratum. In this study, agreement was evaluated when an age estimate was available from both readers. Error codes, describing why an age estimate was not made for a particular scale, were not available from the database for some years and were therefore excluded from agreement calculations.

Age-Difference Plots

Age-difference plots, a variation of the age-bias plot recommended by Campana (et al. 1995), were used to provide a robust visual detection of any systematic age differences between ADF&G and each reader by age type and stratum. Age-difference plots compare age estimates between ADF&G and each reader through reference to an equivalence line (i.e. age estimate by ADF&G equals age estimate by reader). In this representation, age estimates by each reader and stratum are presented as the mean age and 95% confidence intervals (CI) corresponding to each age category reported by ADF&G. The intent of the CI is not to assign statistical significance to the mean age, but to allow informed interpretation of any difference between the reader's mean age and the equivalence line. The age-difference plots are useful for detecting systematic differences across strata, temporal patterns by reader, and recognizing any patterns among the 3 readers. Visual examinations of the relative variation in the directions and magnitudes of any detected differences across strata were used to infer aging consistency by ADF&G. The strength of the difference was inferred by the magnitude of the difference between the readers' mean age and the ADF&G assigned age. The scales of the y-axes were set to facilitate comparisons across ages and maximize detection of temporal patterns. The y-axes scales are not necessarily biologically relevant.

The use of age-bias plots may be superior to more traditional parametric analysis when diagnosing systematic differences between 2 sets of age estimates (Campana et al. 1995). This is because many standard tests are unable to detect non-systematic (e.g., under aging at one end and over aging at the other end of the age continuum) biases. In addition, parametric tests often yield significant differences that are meaningless in a biological context (e.g., a mean difference of 0.05 years). This is especially true when sample sizes are large and the number of age classes available is small, as in this study.

RESULTS

AGE ESTIMATION

The percentage of completely and partially readable scales varied among readers. Overall, the readers successfully aged a majority of the selected scale impressions. Readers-1, -2 and -3 estimated 80.5%, 65.1%, and 84.9% of both freshwater and total ages, and 92.4%, 95.1%, and 96.5% of saltwater ages, respectively (Table 2). The percentage of successfully estimated freshwater ages was less than that of saltwater ages across all readers and strata. This trend was most pronounced in the first 2 strata where readers estimated from 50.4% to 77.2% of the freshwater ages and from 87.9% to 94.6% of the saltwater ages (Table 2). Consequently, the readers' ability to estimate total age was largely limited by their ability to estimate freshwater age. Relative to age estimates by ADF&G, all readers estimated fewer freshwater ages in the first 2 strata. The readers estimated more saltwater ages than ADF&G in all strata which is an artifact of ADF&G not aging the saltwater age without a freshwater age.

The number of paired age estimates between ADF&G and any reader ranged from 4,658 to 6,372 by age type (Table 3). Averaged among all strata, 88.2%, 72.9%, and 93.3% of ADF&G's estimates were paired with age estimates by Reader-1, -2 and -3, respectively (Table 3). The percentage of paired freshwater age estimates were lower in the first 2 strata compared to the later strata for all readers. Nearly all (≥99.4%) of the age estimates by ADF&G also had a saltwater age assigned by each reader (Table 3). The number of paired total age estimates between ADF&G and each reader was identical to or slightly less than that for freshwater age in each stratum.

AGE COMPOSITION

The saltwater age compositions among ADF&G and the 3 readers were similar in each stratum (Figure 2 and Appendix A2). No statistical differences in saltwater age compositions were present in any stratum (χ^2=3.13, p=0.96; χ^2=6.78, p=0.66; χ^2=7.96, p=0.54; χ^2=2.47, p=0.98; χ^2=8.15, p=0.52; df=9; stratum 1–5; respectively; Figure 2).

The total age compositions among ADF&G and the 3 readers were similar in each stratum (Figure 3 and Appendix A3). No statistical differences in total age compositions were present in any stratum (χ^2=11.23, p=0.26; χ^2=9.70, p=0.38; χ^2=10.83, p=0.29; χ^2=2.32, p=0.99; χ^2=9.70, p=0.38; df=9; stratum 1–5; respectively; Figure 3).

PERCENT AGREEMENT

Overall, the percent agreement was high and temporally consistent across readers and strata. Percent agreement was highest in estimating freshwater age, followed closely by saltwater age and total age, respectively.

The average percent agreement of freshwater ages was 97.3% (Table 4). This high level of agreement was because age_{fw}-1 was the predominant freshwater age and where ADF&G had assigned an age_{fw}-1, readers, on average, determined that same age for 99.2% of the fish (Table 4). Conversely, percent agreement was low (average 12.1%) between ADF&G and each reader in all strata where ADF&G had determined an age_{fw}-2 (Table 4).

The average percent agreement of saltwater ages was 92.4% (Table 5). Age_{sw}-2 had the highest percent agreement (93.8%), followed closely by age_{sw}-4 (93.4%), -3 (91.6%) and -5 (90.1%). Percent agreement of age_{sw}-1 and -6 fish was 100% and 50.0%, respectively (Table 5). Although, inference is limited for these 2 ages as sample sizes were very low to absent in all strata.

The average percent agreement of total ages was 90.0% (Table 6). Age_t-4 had the highest percent agreement (93.1%), followed closely by age_t-6 (92.0%), -5 (91.2%) and -7 (83.2%). Percent agreement of age_t-1 and -6 fish was 100% and 8.6%, respectively; although, inference was limited as sample sizes were very low to absent in most strata (Table 6).

AGE-DIFFERENCE PLOTS

The age-difference plots showed temporally consistent differences in estimating freshwater, saltwater, and total age. Overall, the directions and magnitudes of the differences were consistent across all strata. In addition, the observed patterns of differences were similar across each combination of ADF&G and reader. With few exceptions, the magnitudes of these differences were very small and likely not biologically meaningful.

Where ADF&G assigned an age_{fw}-2, the mean age of all readers was considerably lower in all strata (range 1.00-1.23, Figure 4). Conversely, where ADF&G assigned an age_{fw}-1, the readers' mean ages were slightly greater in most strata; however, the maximum difference was very small, 0.02 (Figure 4). In stratum 2 there were not any age_{fw}-2 estimates available from ADF&G for comparing with the readers.

In general, when ADF&G assigned an age_{sw}-2 or -3, the readers' mean ages were greater, although not consistently across strata. Age-difference plots of age_{sw}-4 showed considerable variability across strata and readers; however, the maximum mean age difference was 0.03 (Figure 5), and the level of inconsistency inferred by this variability was negligible and does not support a meaningful age_{sw}-4 difference. The pattern of age_{sw}-5 difference was the most pronounced and consistent for any saltwater age. Age-difference plots of age_{sw}-5 showed the readers' mean ages were always less than the assigned age, ranging from 4.83 to 4.95, with the lowest mean age occurring in stratum 2 (Figure 5). Age-difference plots for age_{sw}-6, which included 2 fish, showed the readers agreed with one estimate and disagreed with the other.

The directions and magnitudes of differences associated with total age estimates varied by age, and the temporal patterns were consistent among the 3 readers. In general, the readers' mean ages were greater for age_t-4 and -5, similar for age_t-6, and less for age_t-7 and -8. The age-difference plots for age_t-7 show the readers' mean ages ranged from 6.71 to 6.93 (Figure 6). The overall mean age among readers was 6.84 (±0.01), however strata 1 and 3 had a lower mean age

6.77 (±0.02) than strata 2, 4, and 5, with a mean age of 6.84 (±0.01, Figure 6). The difference plots for age_t-8 show the readers' mean ages ranged from 6.9 to 7.3, the largest difference of any mean age (Figure 6). This is not surprising given most of the age_t-8 estimates by ADF&G had an age_{fw}-2 component.

AGE FREQUENCY

Age frequency tables show the age assigned by each reader when ADF&G assigned a specific age (Appendices A4, A5, and A6). Age frequency tables alone are not well suited for detection of aging bias between readers (Campana et al. 1995). However, they do provide a convenient and acceptable approach to presenting paired datasets and summarizing paired age estimates.

DISCUSSION

The results of this study suggest that ADF&G has consistently aged lower Yukon River Chinook salmon from scales over the past 43 years. This conclusion is supported by 1) an age composition that did not differ among ADF&G and the independent readers in any temporal stratum, 2) the directions and magnitudes of the age differences between ADF&G and the readers were consistent and very small and 3) the percent agreement between ADF&G and the readers was high and consistent across strata.

AGE ESTIMATION

The high percentages of successfully aged fish resulted in large sample sizes for both unpaired and paired age comparisons, which contributed to the robustness of this study. The difference in each reader's ability to estimate age in the first 2 strata compared to the later strata was due, in part, to the number of scale impressions available for each fish. Additional scales, that were available from 1981 to present, effectively increased the number of successfully aged fish and reduced aging differences between ADF&G and the readers. When a scale is lost during a salmon's life, a new scale will be quickly grown to replace the missing scale and freshwater circuli may not be present; however, the saltwater age can often be estimated. Consequently, the effects of collecting 3 scales per fish were greater for freshwater age estimation.

The numbers of successful age estimates were variable by age type. The readers estimated fewer freshwater ages and more saltwater ages than ADF&G. In general, readers estimated fewer ages than ADF&G when assigning a freshwater age from a single scale. However, with 3 scales per fish in the later strata the percentage of freshwater age estimates was similar among readers. The readers' higher percentage of saltwater age estimates relative to ADF&G was an artifact of the study design. The readers were directed to estimate incomplete ages when possible, whereas the ADF&G aging method did not assign incomplete ages. The freshwater age was less likely to be estimated than the saltwater age in all strata; therefore, freshwater age was the limiting factor in estimating total age.

AGE COMPOSITION

The chi-square test results had no significant differences in saltwater and total age composition among ADF&G and the readers in any of the 5 strata, which suggest that ADF&G has consistently estimated Lower Yukon River Chinook salmon age composition over the past 43 years. The small stratum-specific differences in the age composition between ADF&G and the readers followed no clear pattern across strata. Saltwater and total age composition patterns were similar among readers and strata because the total age compositions were mostly influenced by the frequency of saltwater ages. The total age compositions were more variable among readers than the saltwater age compositions because the differences are primarily due to freshwater ages.

PERCENT AGREEMENT

Percent agreement was high for all age types in all strata. Percent agreement by age was variable but generally high and consistent across readers and strata except for age_{fw}-2. The percent agreement for total age was largely due to the saltwater age component, while the difference between these age types was a function of the freshwater age agreement. Comparisons of percent agreement across age types must be considered with some latitude because the probability of assigning the same age is unequal.

Beamish and Fournier (1981) illustrated that the utility of percent agreement was limited in that precision is not evaluated equally for all species or growth phases, making comparisons difficult. For example, Yukon River Chinook salmon freshwater age can range between 0-3 years and the saltwater age can range between 1-6 years; consequently, a 95% agreement has different implications with respect to the 2 age types. Percent agreement has lost favor in the literature in recent years (Campana et al. 1995 and Campana 2001).

A considerable difference was found between the readers and ADF&G in age_{fw}-2 estimates. When ADF&G recorded an age_{fw}-2 fish, readers disagreed most of the time and estimated the fish to be an age_{fw}-1, suggesting a consistent systematic difference. For all practical purposes, freshwater age was either 1 or 2 years, because few age_{fw}-0 and no age_{fw}-3 fish were represented on the acetates. Estimating an age_{fw}-1 was, by chance alone, almost always correct. This was reflected in the high agreement associated with this age. Conversely, estimating an age_{fw}-2 requires a reader to have the criteria and ability to identify this less common age. In stratum 2 there were not any age_{fw}-2 estimates available from ADF&G for comparing with the readers. This infers inconsistency in age_{fw}-2 estimates by ADF&G in stratum 2 given that other readers did estimate some age_{fw}-2.

In estimating freshwater age, the potential for considerable disagreement exists among readers interpreting the freshwater plus growth, transitional growth, and presence of a migration check. New growth may occur in freshwater after the formation of the last freshwater annulus. This growth, termed freshwater plus, can be substantial and quite variable because of physical and environmental factors, seaward migration distance from the over-wintering location, and timing of migration. After the fish arrives in the estuary and before starting its recognizable marine growth, transitional growth may occur, consisting of a variable number of circuli that are intermediate in appearance between fresh and marine growth (Mosher 1968). During this transitional growth a migration check, or false annulus, can occur that may be mistaken for a freshwater annulus. Mosher (1968) categorizes 3 types of freshwater to saltwater transition zones in salmon as abrupt, gradual, and diffuse. Each of these transition zone types can have variable amounts of freshwater plus growth as well as transitional growth. An abrupt transition zone coupled with extensive freshwater plus growth has the greatest potential to be misidentified as another freshwater annulus (Mosher 1968). This study includes many scales from salmon with a long seaward migration distance (Canadian stocks) and substantial freshwater growth. Along with various appearances of a migration check, can lead to disagreements in assigning a second freshwater annulus.

AGE-DIFFERENCE PLOTS

The age-difference plots for age_t-7 showed the readers' mean ages were lower in strata 1 and 3. Because this pattern was not observed in the age_{sw}-5 plots, the decreased age_t-7 mean age can only be attributed to the age_{fw}-2 component in the age_t-7. The readers' tendency to assign a younger age for age_{sw}-5 and age_{fw}-2 were additive with respect to age_t-7 estimates. Therefore, the readers' mean ages in the age_t-7 plots were less in all strata because of their age_{sw}-5 estimates, and were even less in strata 1 and 3 because of their decreased age_{fw}-2 estimates.

The magnitudes of the saltwater age-specific differences were small, a function of the high percent agreement in estimating these ages. The largest difference was associated with age_{sw}-5 fish. The magnitudes of the total age-specific differences were also small, yet slightly larger than that of saltwater. The percent agreement and consistency in estimating total age was largely a function of the saltwater component because most of the total age estimates included an age_{fw}-1 estimate. However, those ages with a substantial age_{fw}-2 component had the greatest age-specific differences.

HISTORICAL OLDER-AGED FISH

This study targeted older-aged fish because recent studies have suggested a decline in this age group and to determine if inconsistent aging was a contributing factor. Collectively, percent agreement and age-difference plots support the conclusion that ADF&G has consistently estimated Lower Yukon River Chinook salmon over the past 43 years. ADF&G and the independent readers were generally in high agreement and most observed differences were not biologically meaningful. Specific values associated with the observed levels of difference and percent agreement were not the focus of this study; it was the temporal patterns of these values that were used to infer aging consistency.

Of interest is how the results of this study may affect our perception of the estimated historical age composition of Yukon River Chinook salmon, and specifically, inferences upon the older-aged fish. These older-aged fish historically represent only a small percentage of the Yukon River age composition and it has been suggested their numbers have declined further over the past 20-plus years (JTC 2006). Although most age estimates were consistent, a substantial difference was found in the readers' mean ages when ADF&G assigned an age_{fw}-2 and a small difference when ADF&G assigned an age_{sw}-5. Age_{fw}-2 fish were not abundant in the selected acetates chosen for this study and the difference associated with age_{sw}-5 fish was small. A concern is that these represent older age_t-7 and -8 fish. Consequently, a small difference in the contribution of these older aged-fish may be biologically meaningful.

The older ages include 4 age classes, in age notation recommended by Koo (1962): age_t-7 composed of age-1.5 and -2.4 and age_t-8 composed of age-1.6 and -2.5. Estimates by age class were not specifically addressed in the study. However, results for age_{sw}-5 may be considered analogous with age-1.5. Even though all readers' mean ages were lower for age_{sw}-5 estimates and agreement was 90%, ADF&G's estimates for age-1.5 were likely acceptable for the purpose of estimating overall age composition. The age-1.5 component makes up the majority of age_t-7; however percentages of age-2.4 fish have varied over the years. The low agreement found for age_{fw}-2 fish suggests historical estimates for age_t-7 Chinook salmon, in years with relatively abundant estimates for age-2.4 fish, lack precision. It is unclear whether this interpretation for age-2.4 would translate into meaningful changes in the historical age_t-7 composition. The majority of the age$_t$-8 fish are age-2.5. Consequently, the low agreement in age$_{fw}$-2 estimates coupled with the small difference identified in age$_{sw}$-5 estimates may have considerable implications with respect to the historical estimates for age-8 Chinook salmon.

CONCLUSIONS

ADF&G has consistently estimated Lower Yukon River Chinook salmon ages from scales over the past 43 years. No statistical difference in age composition was found among ADF&G and the independent readers in any temporal stratum. Differences in freshwater, saltwater, and total age estimates were generally small and temporally consistent. Percent agreement in estimating saltwater and total age was high and temporally consistent. Percent agreement in estimating age$_{fw}$-1 was high and temporally consistent. Percent agreement in estimating age$_{fw}$-2 was low and temporally consistent. Differences in age$_{fw}$-2 and age$_{sw}$-5 estimates between the readers and ADF&G may have considerable implications in the estimated number of older-aged fish.

RECOMMENDATIONS

A standardized method should be clearly identified to estimate Yukon River Chinook salmon ages from scales, especially with respect to freshwater age. Collaboration with other aging laboratories experienced with aging Chinook salmon scales, and further review of age validation studies may help define criteria. A reasonable assumption is that because scale readers employed by ADF&G age thousands of Yukon River Chinook salmon scales annually, their estimates are most appropriate. However, aging differences between ADF&G and each reader were evident in each stratum and should not be ignored. Further studies may be initiated to address the differences in estimating older-aged Yukon River Chinook salmon with emphasis on age$_{fw}$-2 and age$_{sw}$-5 fish. Understanding how the observed differences in aging scales could affect historical estimates of age$_t$-7 and -8 fish is critical to understanding the dynamics of these age classes in the Yukon River through time.

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TABLES AND FIGURES

Table 1.–Numbers of older-aged fish, sample objective, acetates, records, and aged fish by year.

	Ages Available in Database		Age Records in Study			
	Age$_t$≥7					
Year	Number	Sample Obj.	Acetates	Records	Aged Fish	Age$_t$≥7
1964	97	11	6	164	130	23
1965	132	14	9	204	179	42
1966	131	14	7	202	173	24
1967	156	17	9	251	181	27
1968	294	32	17	475	404	92
1969	170	18	10	278	260	36
1970	28	3	3	42	38	4
1971	17	2	2	50	43	2
1972	83	9	5	122	104	11
1973	111	18	10	261	223	20
1974	117	19	10	300	239	27
1975	151	24	13	361	298	52
1976	47	8	4	120	105	6
1977	37	6	4	92	82	6
1978	73	12	6	170	151	11
1979	153	25	13	372	327	58
1980	27	4	2	60	52	5
1981	31	5	3	87	76	6
1982	384	15	10	180	122	22
1983	251	10	8	110	89	20
1984	266	10	10	100	84	19
1985	180	7	7	70	55	16
1986	570	22	22	220	193	52
1987	398	15	15	150	133	30
1988	663	26	26	260	234	100
1989	258	10	10	100	90	17
1990	133	5	5	50	47	7
1991	196	11	11	110	102	20
1992	98	6	6	60	51	7
1993	302	17	17	170	143	24
1994	336	19	19	190	165	24
1995	155	9	9	90	81	12
1996	992	57	52	520	491	133
1997	58	4	4	40	39	5
1998	266	16	16	160	149	23
1999	92	6	6	60	58	6
2000	182	11	11	110	100	16
2001	179	11	11	110	101	20
2002	506	31	31	310	296	62
2003	318	19	19	190	183	24
2004	180	11	11	110	106	11
2005	124	8	18	180	177	23
2006	71	4	4	40	39	4
1964–1972	1,108	120	68	1,788	1,512	261
1973–1981	747	120	65	1,823	1,553	191
1982–1990	3,103	120	113	1,240	1,047	283
1991–1996	2,079	120	114	1,140	1,033	220
1997–2006	1,976	120	131	1,310	1,248	194
Total	9,013	600	491	7,301	6,393	1,149

Table 2.–Number and percent of Chinook salmon freshwater age (Age_{fw}), saltwater age (Age_{sw}), and total age (Age_t) by reader and stratum.

			Number and Percent Aged									
			ADF&G[a]	Reader-1			Reader-2			Reader-3		
Stratum	Years	Number of Fish	Age_t	Age_{fw}	Age_{sw}	Age_t	Age_{fw}	Age_{sw}	Age_t	Age_{fw}	Age_{sw}	Age_t
1	1964–1972	1,788	1,512	1,117	1,586	1,116	902	1,648	901	1,380	1,692	1,380
			84.6%	62.5%	88.7%	62.4%	50.4%	92.2%	50.4%	77.2%	94.6%	77.2%
2	1973–1981	1,823	1,553	1,305	1,603	1,305	930	1,670	929	1,402	1,706	1,402
			85.2%	71.6%	87.9%	71.6%	51.0%	91.6%	51.0%	76.9%	93.6%	76.9%
3	19821990	1,240	1,047	1,135	1,192	1,135	937	1,219	937	1,124	1,220	1,124
			84.4%	91.5%	96.1%	91.5%	75.6%	98.3%	75.6%	90.6%	98.4%	90.6%
4	1991–1996	1,140	1,033	1,050	1,084	1,050	912	1,115	912	1,043	1,127	1,043
			90.6%	92.1%	95.1%	92.1%	80.0%	97.8%	80.0%	91.5%	98.9%	91.5%
5	1997–2006	1,310	1,248	1,266	1,279	1,266	1,073	1,286	1,070	1,246	1,299	1,246
			95.3%	96.6%	97.6%	96.6%	81.9%	98.2%	81.7%	95.1%	99.2%	95.1%
	Total	7,301	6,393	5,876	6,748	5,875	4,757	6,942	4,752	6,198	7,048	6,198
			87.6%	80.5%	92.4%	80.5%	65.1%	95.1%	65.1%	84.9%	96.5%	84.9%

[a] ADF&G estimates were only reported when both age_{fw} and age_{sw} were determined. ADF&G's number and percent aged were identical for age_{fw}, age_{sw}, and age_t).

Table 3.–Number and percent of paired Chinook salmon freshwater age (Age_{fw}), saltwater age (Age_{sw}), and total age (Age_t) by reader and stratum.

			Number and Percent of Paired Age Estimates								
			ADF&G vs Reader-1			ADF&G vs Reader-2			ADF&G vs Reader-3		
Stratum	Years	No. Aged by ADF&G	Age_{fw}	Age_{sw}	Age_t	Age_{fw}	Age_{sw}	Age_t	Age_{fw}	Age_{sw}	Age_t
1	1964–1972	1,512	1,067	1,492	1,066	856	1,500	856	1,319	1,501	1,319
			70.6%	98.7%	70.5%	56.6%	99.2%	56.6%	87.2%	99.3%	87.2%
2	1973–1981	1,553	1,277	1,539	1,277	911	1,544	911	1,363	1,544	1,363
			82.2%	99.1%	82.2%	58.7%	99.4%	58.7%	87.8%	99.4%	87.8%
3	1982–1990	1,047	1,032	1,045	1,032	925	1,044	925	1,037	1,045	1,037
			98.6%	99.8%	98.6%	88.3%	99.7%	88.3%	99.0%	99.8%	99.0%
4	1991–1996	1,033	1,016	1,032	1,016	903	1,031	903	1,016	1,031	1,016
			98.4%	99.9%	98.4%	87.4%	99.8%	87.4%	98.4%	99.8%	98.4%
5	1997–2006	1,248	1,240	1,245	1,240	1,063	1,240	1,060	1,224	1,247	1,224
			99.4%	99.8%	99.4%	85.2%	99.4%	84.9%	98.1%	99.9%	98.1%
	Total	6,393	5,635	6,357	5,634	4,661	6,363	4,658	5,963	6,372	5,963
			88.2%	99.4%	88.1%	72.9%	99.5%	72.9%	93.3%	99.7%	93.3%

Table 4.–Freshwater age (Age_{fw}) percent agreement of Chinook salmon for ADF&G and reader, by stratum.

Percent Agreement					
			Age_{fw}		
Stratum	Years	Reader	1	2	Total[a]
1	1964–1972				
		1	98.2	22.7	95.1
		2	99.0	9.8	94.7
		3	99.9	5.7	96.1
2	1973–1981				
		1	98.8		98.8
		2	99.3		99.3
		3	99.8		99.8
3	1982–1990				
		1	99.6	17.0	95.8
		2	98.2	22.2	94.5
		3	99.7	4.3	95.4
4	1991–1996				
		1	99.1	5.9	97.5
		2	98.5	18.8	97.1
		3	100	0.0	98.3
5	1997–2006				
		1	99.7	11.1	99.0
		2	97.9	11.1	97.2
		3	100	0.0	99.3
Average (reader)[b]		1	99.1	17.1	97.4
		2	98.6	16.2	96.6
		3	99.9	4.0	97.9
Average[c]					
			99.2	12.1	97.3

[a] Total is the weighted average percent agreement across all age classes.

[b] Average (reader) is the weighted average percent agreement across all strata by reader.

[c] Average is the weighted average percent agreement across all strata and readers.

Table 5.–Saltwater age (Age_{sw}) percent agreement of Chinook salmon for ADF&G and reader, by stratum.

Percent Agreement									
			Age_{sw}						
Stratum	Years	Reader	1	2	3	4	5	6	Total[a]
1	1964–1972								
		1		100.0	96.0	96.4	90.3		95.5
		2		100.0	93.6	95.7	89.5		94.5
		3		100.0	94.8	95.9	87.2		94.5
2	1973–1981								
		1		97.2	89.1	92.3	87.4		91.1
		2		95.8	89.5	92.8	83.8		91.0
		3		97.2	88.6	93.3	89.5		91.8
3	1982–1990								
		1		100	95.8	94.5	90.7	0.0	93.8
		2		84.6	95.8	91.8	87.4	0.0	91.2
		3		92.3	94.6	93.9	92.7	0.0	93.6
4	1991–1996								
		1	100.0	76.5	93.3	89.8	92.3	100.0	91.3
		2	100.0	82.4	93.0	89.8	89.9	100.0	90.8
		3	100.0	82.4	91.2	90.1	93.8	100.0	91.1
5	1997–2006								
		1		86.7	90.4	93.2	93.6		92.4
		2		86.7	91.3	92.6	89.3		91.7
		3		86.7	86.3	91.8	94.7		90.8
Average (reader)[b]		1	100.0	94.3	92.2	93.7	90.8	50.0	92.9
		2	100.0	92.9	92.1	93.0	88.0	50.0	92.0
		3	100.0	94.3	90.4	93.4	91.5	50.0	92.4
Average[c]									
			100.0	93.8	91.6	93.4	90.1	50.0	92.4

[a] Total is the weighted average percent agreement across all age classes.

[b] Average (reader) is the weighted average percent agreement across all strata by reader.

[c] Average is the weighted average percent agreement across all strata and readers.

Table 6.–Total age (Age_t) percent agreement of Chinook salmon for ADF&G and reader, by stratum.

Percent Agreement									
			Age_t						
Stratum	Years	Reader	3	4	5	6	7	8	Total[a]
1	1964–1972								
		1		100.0	93.3	94.1	77.7	0.0	90.8
		2		100.0	94.2	93.8	70.5	0.0	89.4
		3		100.0	94.2	95.1	72.1	0.0	90.7
2	1973–1981								
		1		96.8	87.8	91.1	87.8		90.1
		2		97.6	89.7	92.1	84.2		90.7
		3		98.4	88.3	93.1	88.8		91.6
3	1982–1990								
		1		100.0	95.6	93.0	81.0	0.0	89.9
		2		80.0	95.1	89.9	78.9	0.0	87.4
		3		91.7	93.7	92.5	81.7	0.0	89.4
4	1991–1996								
		1	100.0	76.5	92.6	88.1	87.7	25.0	89.1
		2		78.6	92.9	88.8	81.9	33.3	88.4
		3	100.0	82.4	91.6	89.4	88.8	25.0	89.7
5	1997–2006								
		1		86.7	90.5	92.7	90.7		91.8
		2		85.7	90.9	89.5	87.1		89.4
		3		86.7	86.5	91.5	92.6		90.4
Average (reader)[b]		1	100.0	93.3	91.4	92.0	84.6	8.3	90.4
		2		91.0	92.2	90.9	80.4	10.0	89.0
		3	100.0	94.4	90.2	92.7	84.1	7.7	90.4
Average[c]									
			100.0	93.1	91.2	92.0	83.2	8.6	90.0

[a] Total is the weighted average percent agreement across all age classes.

[b] Average (reader) is the weighted average percent agreement across all strata by reader.

[c] Average is the weighted average percent agreement across all strata and readers by stratum.

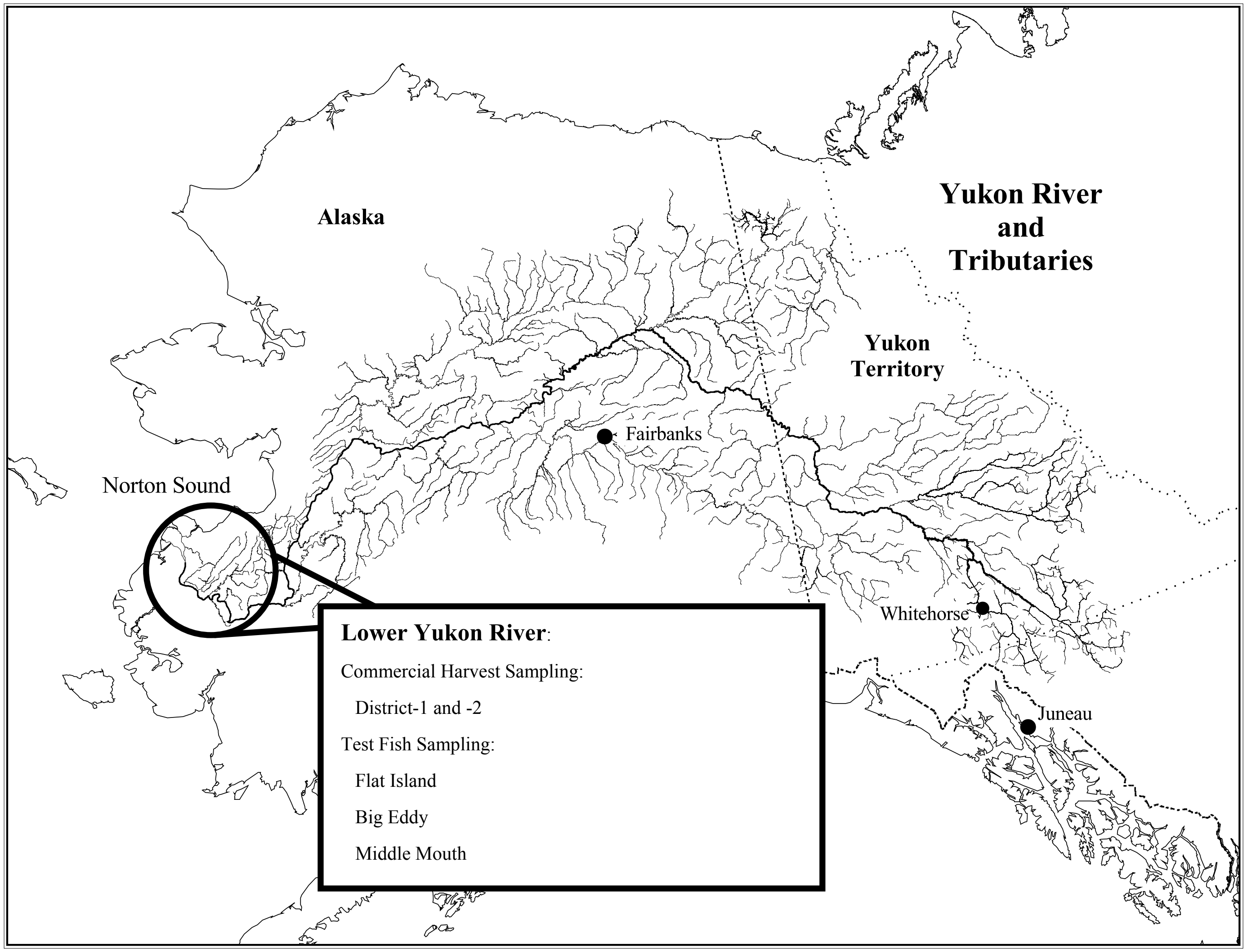
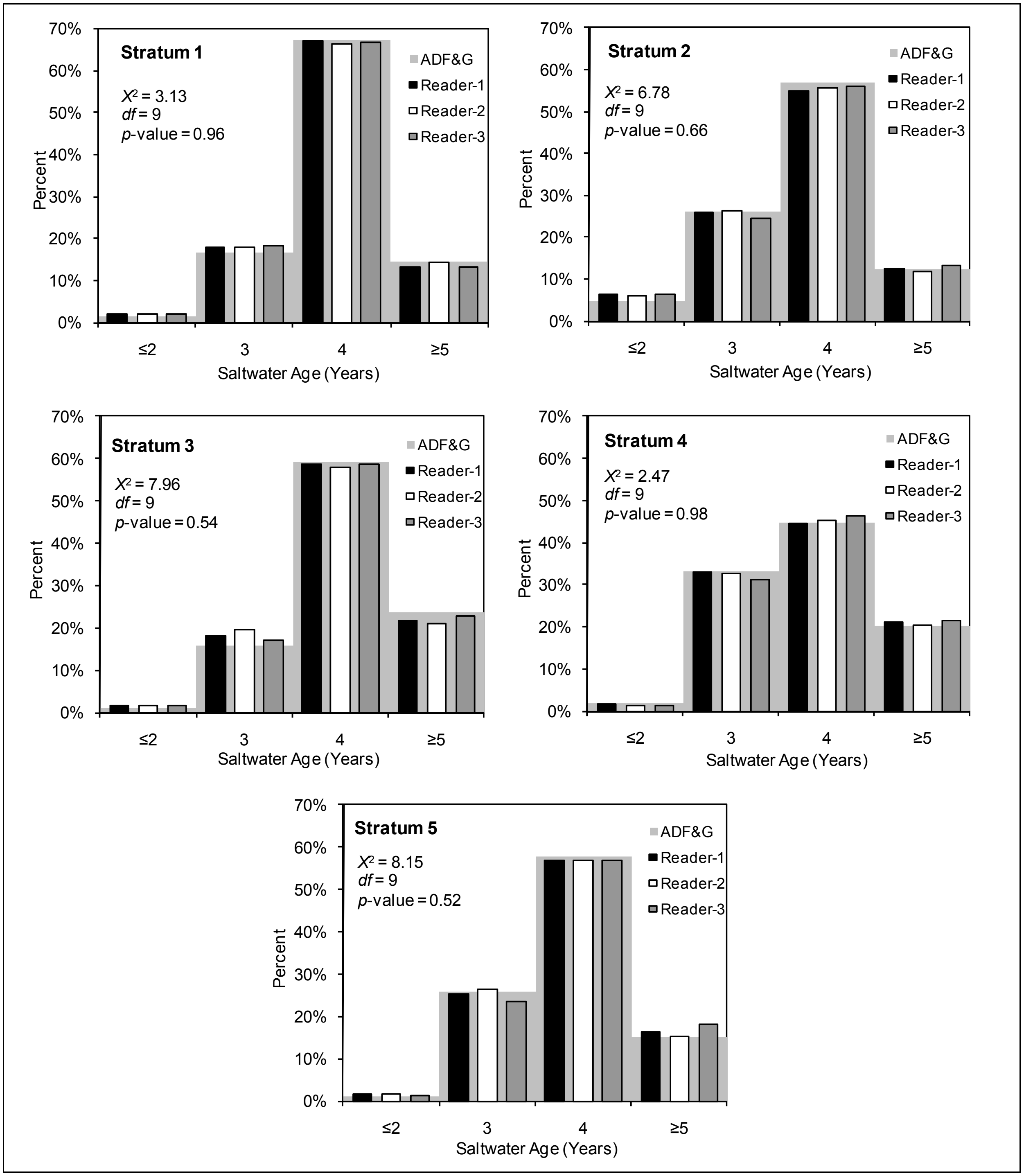
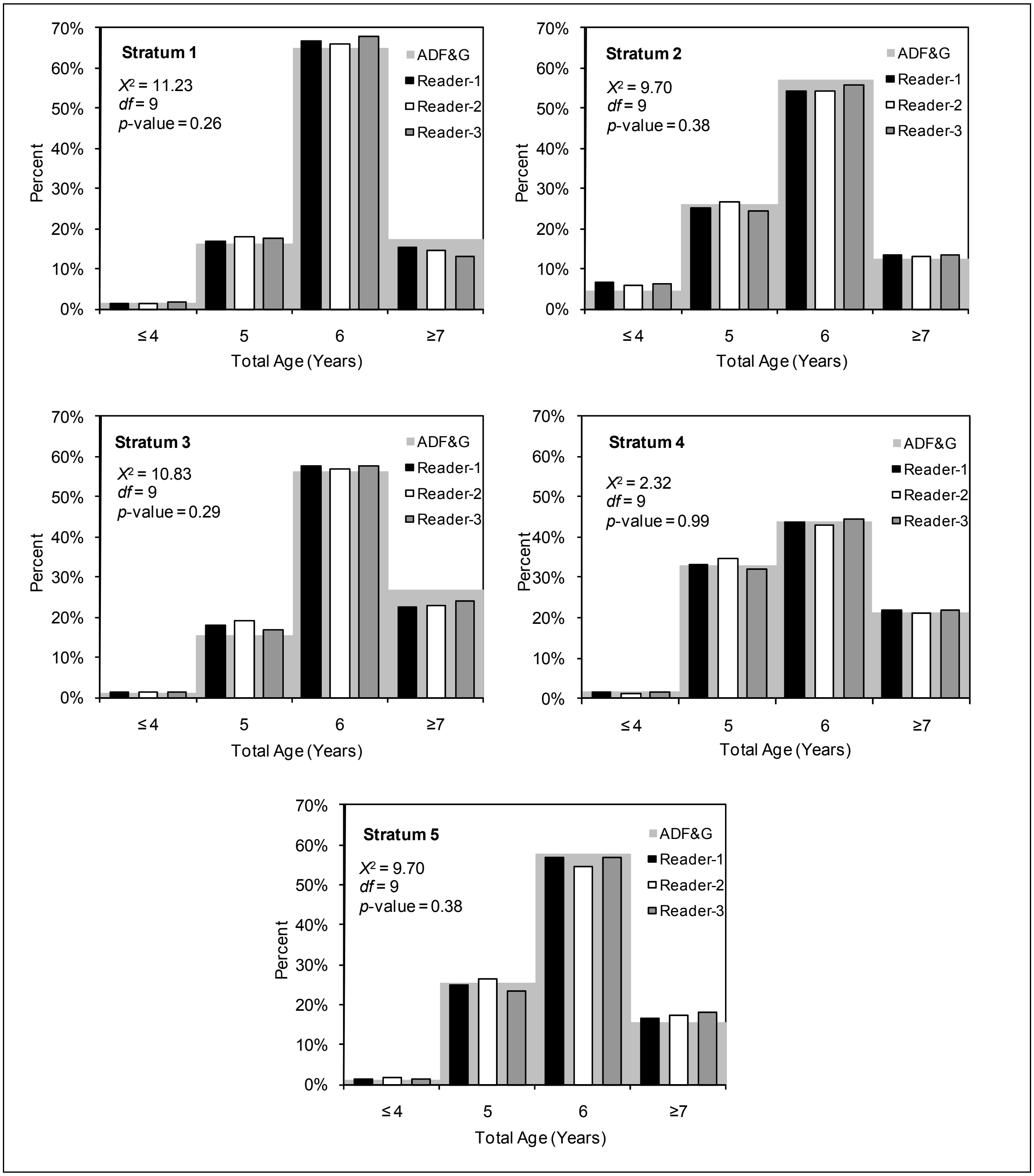


Figure 1.–Lower Yukon River sampling area from where Chinook salmon scales were selected for study.



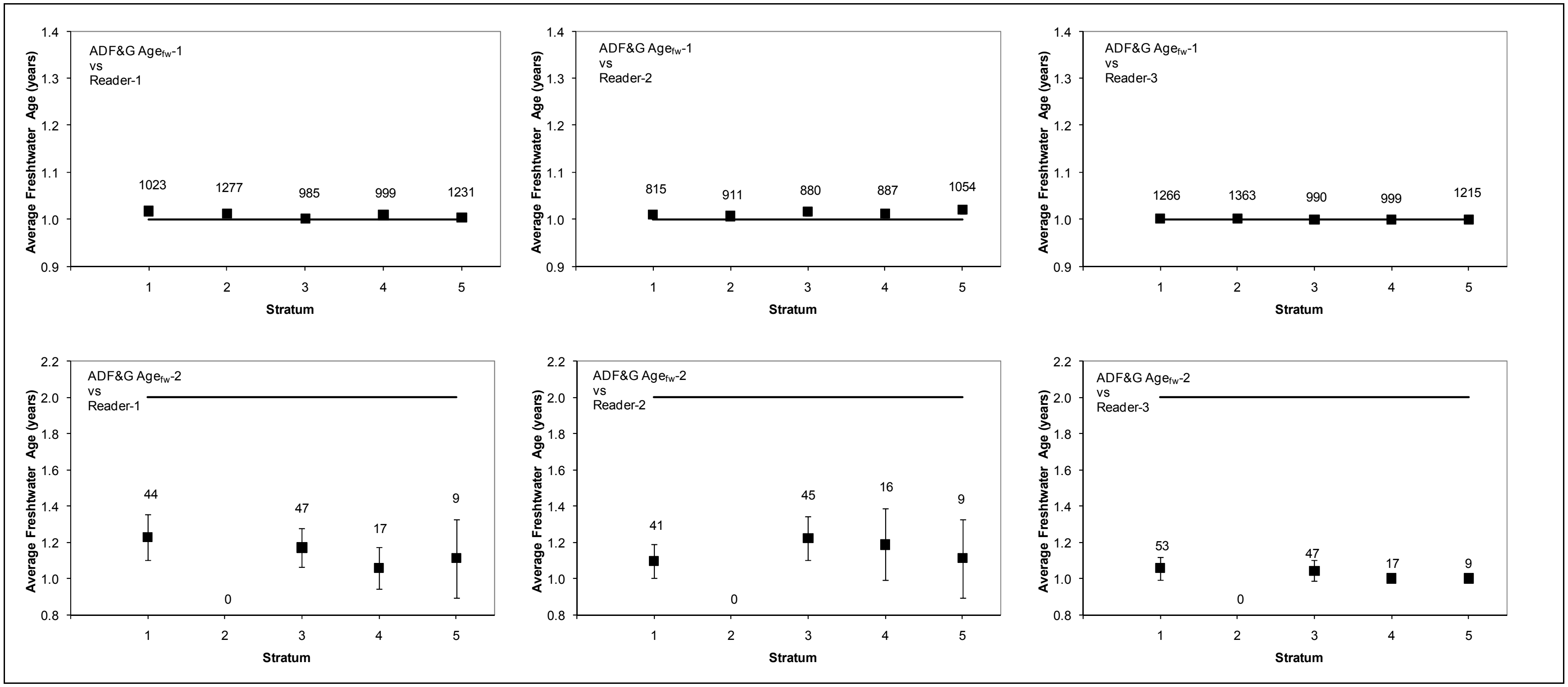
Note: Chi-square goodness of fit statistics are shown, α=0.05. The saltwater age compositions were from unpaired datasets.

Figure 2.–Chinook salmon saltwater age composition among ADF&G and readers, by stratum.



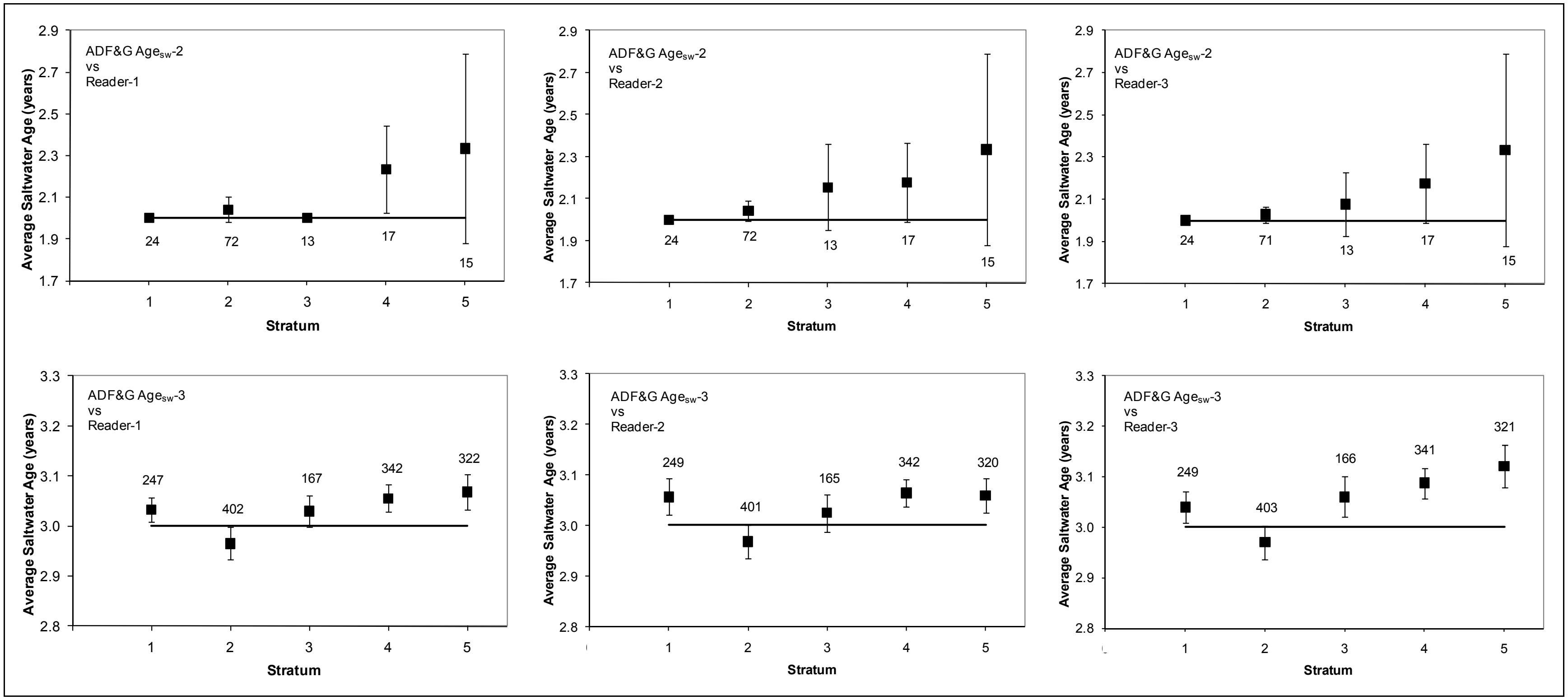
Note: Chi-square goodness of fit statistics are shown, α=0.05. The saltwater age compositions were from unpaired datasets.

Figure 3.–Chinook salmon total age composition among ADF&G and readers, by stratum.



Note: Error bars represent 95% confidence intervals around the mean age assigned by readers for all fish assigned a given age by ADF&G. The equivalence line (solid line) is shown.

Figure 4.–Freshwater age-difference plots of Chinook salmon between ADF&G and reader, by stratum.



Note: Error bars represent 95% confidence intervals around the mean age assigned by readers for all fish assigned a given age by ADF&G. The equivalence line (solid line) is shown.

Figure 5.–Saltwater age-difference plots of Chinook salmon between ADF&G and reader, by stratum.

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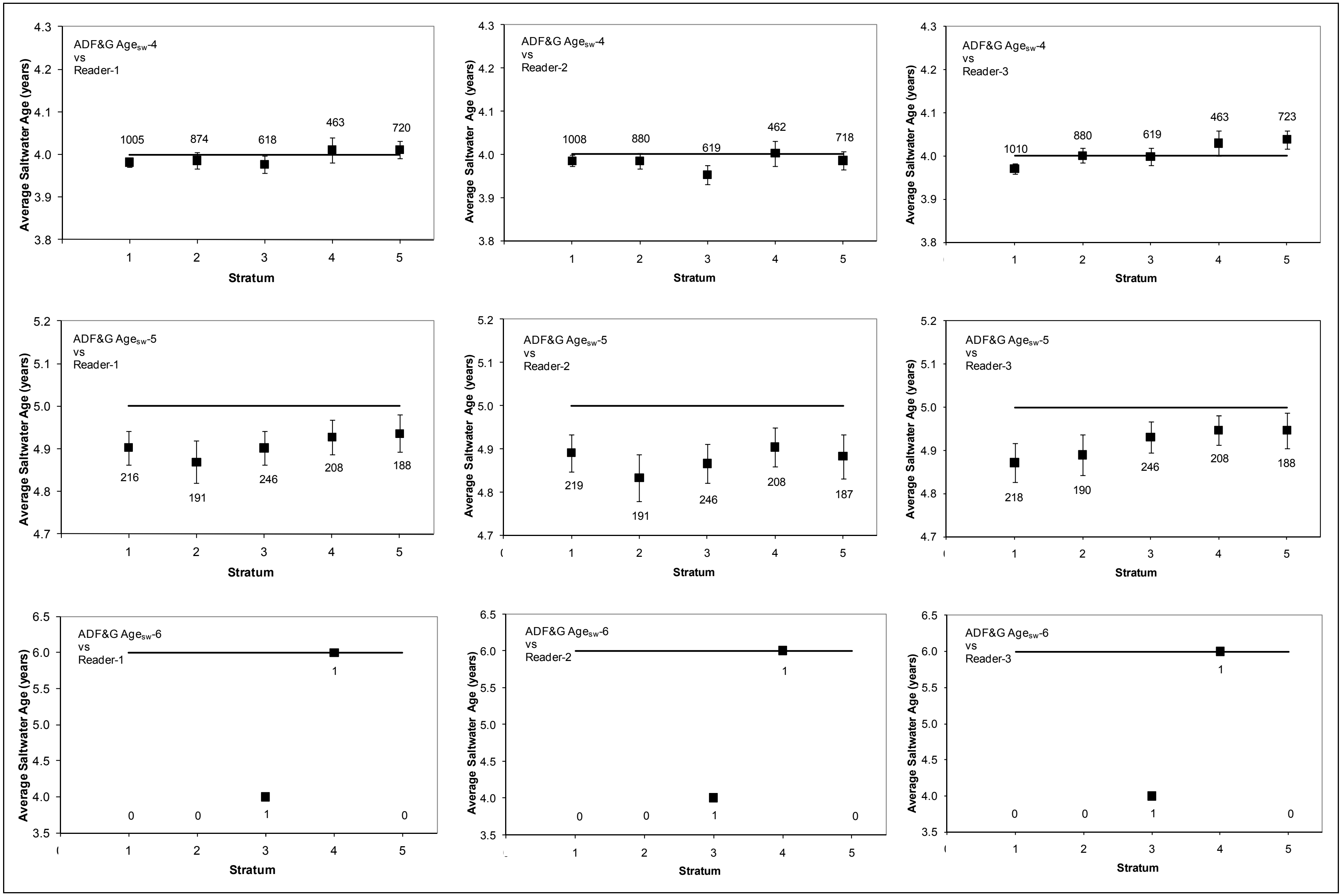
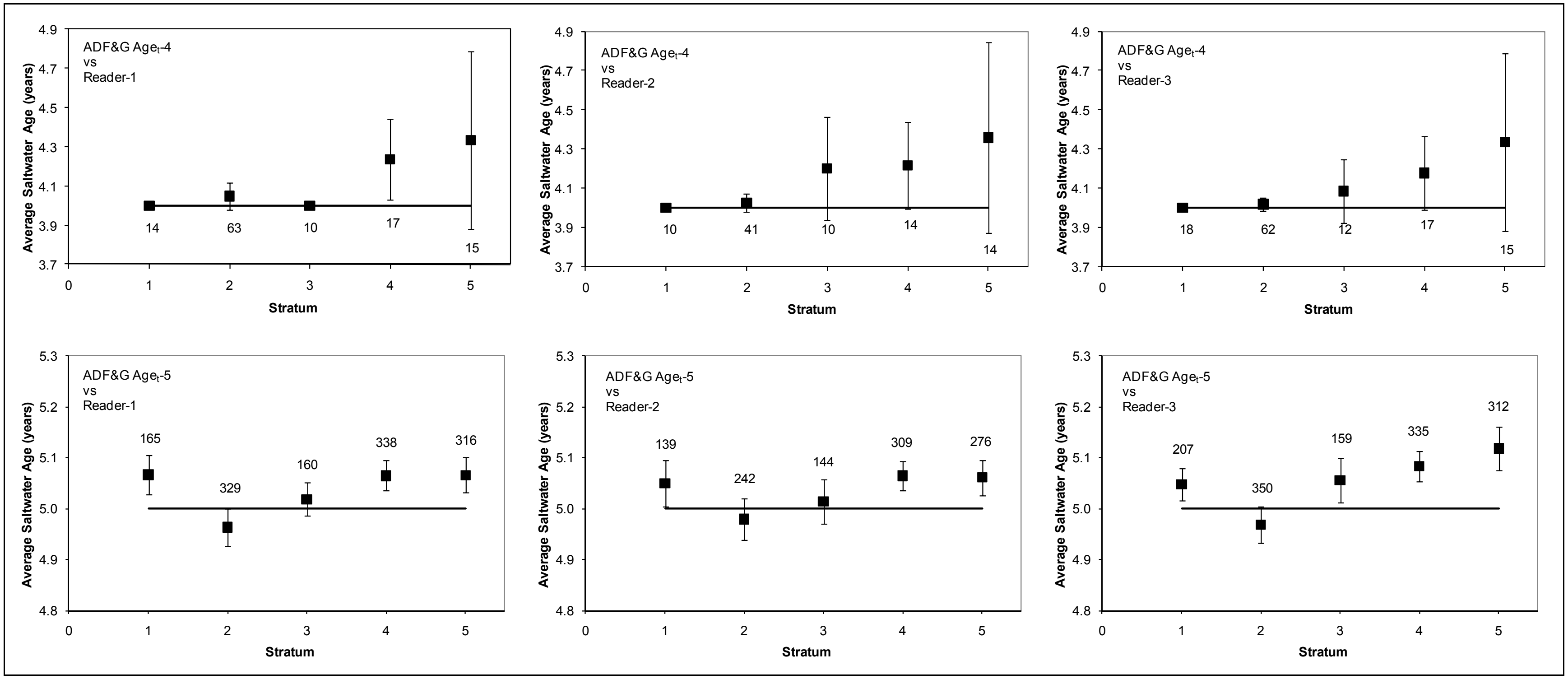


Figure 5.–Page 2 of 2.



Note: Error bars represent 95% confidence intervals around the mean age assigned by readers for all fish assigned a given age by ADF&G. The equivalence line (solid line) is shown.

Figure 6.–Total age-difference plots of Chinook salmon between ADF&G and reader, by stratum.

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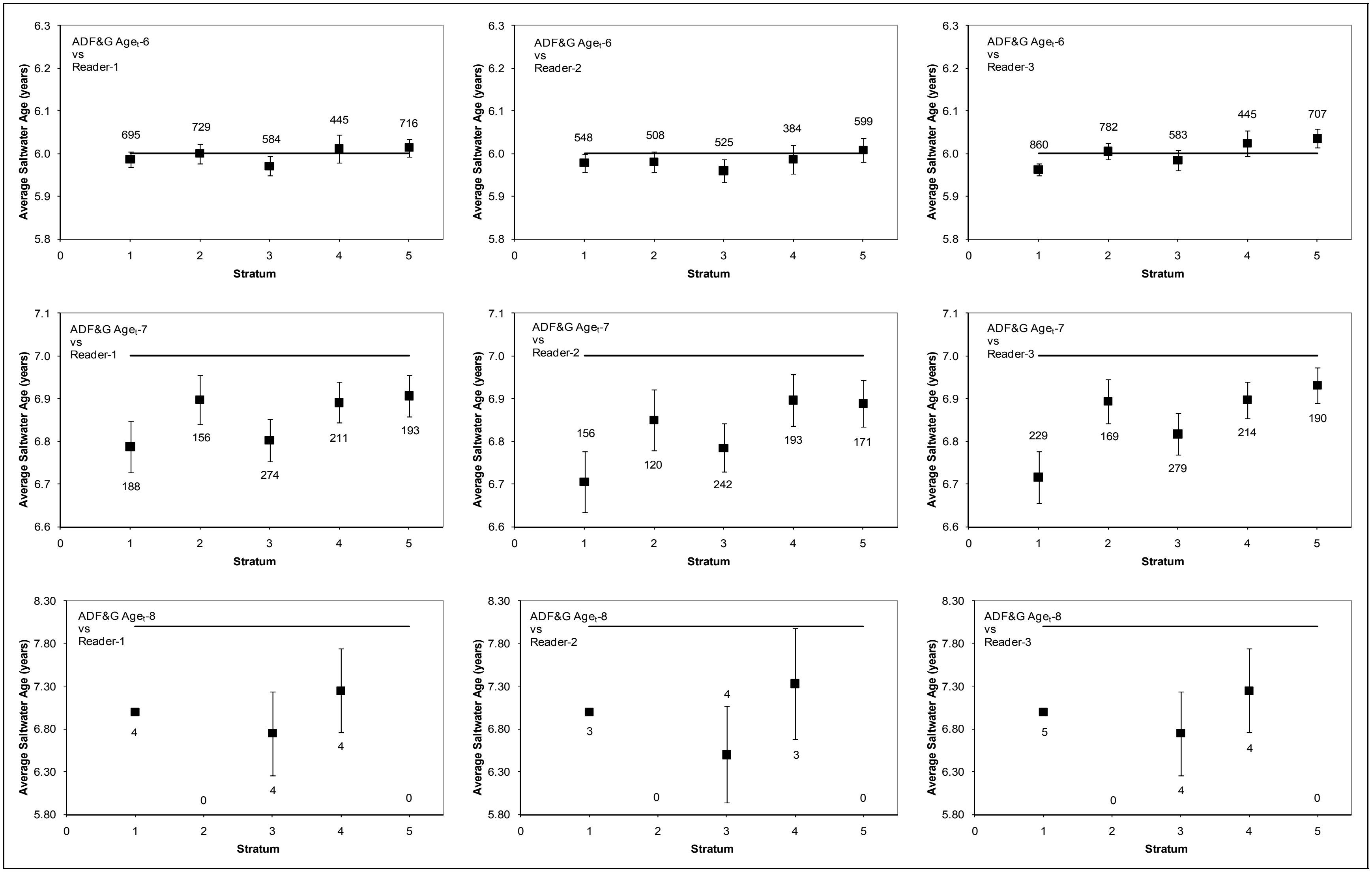

Figure 6.–Page 2 of 2.

APPENDIX A

Appendix A1.–Criteria for determining freshwater age of Chinook salmon.

Sum of scores < 0 = Age 0. and > 0 = Age 1.					
	Age 0.		Inconclusive	Age 1.	
Criteria	-2	-1	0	+1	+2
Freshwater Annulus	-No freshwater annulus visible inside of transition zone -Freshwater circuli evenly spaced	-Slight irregularities in circuli width and spacing without the obvious narrowing, pinching, and brading typical of a clear freshwater annulus	-Several checks in the fresh-water zone, none strong enough to indicate an annulus	-One or more moderately strong checks in the freshwater zone -Possible FW annulus confused w/ tran-sition check. -FW circuli are dif-ferent (finer and den-ser) than circuli of marine growth	-Distinct FW annulus as evidenced by narrowing, pinching, and braiding circuli distinct from circuli in the transition zone -FW circuli are dis-tinctly different than marine growth circuli, this is exemplified in a "cut out" pattern
Caliper Measurement -The distance between the 1st and 2nd marine annuli (measured on a radius bisecting the focus), moved inward one scale year, and scored according to placement of the focal endpoint	-Measurement falls on or beyond focus on all radii measured	-Measurement falls less than half the distance from the focus to the last FW circuli -Measurement may fall on or beyond the focus on some radii		-Measurement falls over half way between focus and the strongest FW check	-Measurement falls on or near strong FW check
Distance and Spacing -Comparison of circuli in 1st marine summer with those in second marine summer	-Circuli on the inside of the 1st marine summer are distinctly closer and narrower than those in the 2nd marine summer -Indistinct 1st marine annulus which circuli resembles those in 1st marine summer -Often two or more checks inside of 1st marine annulus	-Circuli on either side of the 1st marine an-nulus are different but not as distinct as in the -2 category -Non-uniform growth through 1st marine year, occasionally growth differs between dorsal and ventral sides of the scale		-Circuli are generally equal/uniform between the 1st and 2nd marine summers -Moderately distinct 1st marine annulus	-Circuli are equal between the 1st and 2nd marine annular zones -Distinct 1st marine annulus

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Definitions of Aging Terms:

Annuli - winter growth as evidenced by a decrease in width and spacing of circuli and pinching and braiding of circuli.

Check - any alteration in curculi spacing including narrowing, pinching, and braiding. Checks include annuli, transition zones, and other growth disturbances resulting from food limitations, injury, changing hatchery rearing conditions, etc.

Cut out pattern - when there are many (>20) freshwater circuli that are distinctly narrower and denser than circuli of the 1st marine summer growth.

FW - freshwater growth zone from the focus to the last circuli in freshwater.

Plus growth zone - the scale growth zone from the end of the last freshwater annulus to the last circuli of freshwater.

Transition zone - the scale zone coinciding with migration from freshwater to marine environments.

Source: Van Alen and McPherson, ADF&G, Division of Commercial Fisheries, Juneau, Alaska, personal communication.

Appendix A2.–Chinook salmon saltwater age (Age_{sw}) composition by reader and stratum.

	Saltwater Age Composition (Percent)				
	Age_{sw}	ADF&G	Reader-1	Reader-2	Reader-3
Stratum 1	2	1.6	1.8	1.8	1.9
1964–1972	3	16.7	17.8	17.8	18.1
	4	67.2	67.0	66.2	66.8
	5	14.6	13.4	14.2	13.2
Stratum 2	2	4.6	6.4	6.1	6.2
1973–1981	3	26.1	26.1	26.4	25.5
	4	57.0	54.8	55.6	55.7
	5	12.3	12.7	11.9	12.6
Stratum 3	2	1.2	1.8	1.5	1.5
1982–1990	3	16.0	18.0	19.6	17.1
	4	59.2	58.7	58.1	58.8
	5	23.6	21.6	20.8	22.6
Stratum 4	2	1.7	1.5	1.4	1.3
1991–1996	3	33.2	32.8	32.8	31.1
	4	44.8	44.6	45.3	46.3
	5	20.2	21.1	20.4	21.3
Stratum 5	2	1.2	1.5	1.5	1.4
1997–2006	3	25.8	25.3	26.4	23.6
	4	57.9	56.8	57.0	56.8
	5	15.1	16.4	15.2	18.2

Note: The individual Chinook salmon aged for the saltwater age composition were based on unpaired datasets that incorporated all successful age estimates for each reader. Percentages sum to 100 by stratum and reader.

Appendix A3.–Chinook salmon total age (Age_t) composition by reader and stratum.

	Total Age Composition (Percent)				
	Age_t	ADF&G	Reader-1	Reader-2	Reader-3
Stratum 1	4	1.6	1.3	1.3	1.6
1964–1972	5	16.2	16.8	17.9	17.5
	6	64.9	66.7	66.1	67.8
	7	17.3	15.3	14.7	13.1
Stratum 2	4	4.6	6.7	5.9	6.3
1973–1981	5	26.1	25.2	26.6	24.4
	6	57.0	54.5	54.5	56.0
	7	12.3	13.6	13.0	13.3
Stratum 3	4	1.1	1.4	1.2	1.4
1982–1990	5	15.4	18.1	19.2	17.0
	6	56.4	57.9	56.8	57.7
	7	27.0	22.6	22.8	23.8
Stratum 4	4	1.7	1.5	1.3	1.4
1991–1996	5	32.9	33.1	34.6	31.9
	6	44.0	43.6	43.0	44.6
	7	21.3	21.7	21.1	22.1
Stratum 5	4	1.2	1.5	1.6	1.4
1997–2006	5	25.6	25.0	26.4	23.4
	6	57.7	56.8	54.7	57.0
	7	15.5	16.7	17.4	18.1

Note: The individual Chinook salmon aged for the total age composition were based on unpaired datasets that incorporated all successful age estimates for each reader. Percentages sum to 100 by stratum and reader.

Appendix A4.–Chinook salmon paired age frequency for ADF&G and Reader-1 by stratum.

ADF&G	Reader-1 Age														
	Age_{fw}			Age_{sw}						Age_{t}					
Age	0	1	2	1	2	3	4	5	6	3	4	5	6	7	8
Stratum 1 (1964–1972)															
1		1,005	18												
2		34	10		24										
3					1	237	9								
4						27	969	9			14				
5							21	195				154	11		
6												25	654	16	
7													41	146	1
8														4	
Stratum 2 (1973–1981)															
1		1,262	15												
2					70	1	1								
3					29	358	15								
4					1	38	807	28			61	1	1		
5						1	23	167			26	289	14		
6											1	32	664	30	2
7												1	16	137	2
8															
Stratum 3 (1982–1990)															
1	1	981	3												
2		39	8		13										
3					1	160	6								
4					2	21	584	11			10				
5						1	22	223			2	153	5		
6							1				2	26	543	13	
7												2	50	222	
8													1	3	
Stratum 4 (1991–1996)															
1		990	9	1											
2		16	1		13	4									
3					2	319	21			1					
4						21	416	26			13	4			
5						1	14	192	1		2	313	22	1	
6									1			24	392	29	
7												1	23	185	2
8														3	1
Stratum 5 (1997–2006)															
1		1,227	4												
2		8	1		13		1	1							
3					5	291	25	1							
4					1	19	671	29			13		1	1	
5						2	9	176	1		5	286	24	1	
6											1	20	664	30	1
7												2	15	175	1
8															

Appendix A5.–Chinook salmon paired age frequency for ADF&G and Reader-2 by stratum.

ADF&G	Reader-2 Age														
	Age_{fw}			Age_{sw}						Age_t					
Age	0	1	2	1	2	3	4	5	6	3	4	5	6	7	8
							Stratum 1 (1964–1972)								
1		807	8												
2		37	4		24										
3					2	233	12	2							
4						29	965	14			10				
5						1	22	196			1	131	6	1	
6												23	514	11	
7													46	110	
8														3	
							Stratum 2 (1973–1981)								
1		905	6												
2					69	3									
3				1	26	359	15								
4						38	817	25			40	1			
5						1	30	160			15	217	10		
6												25	468	15	
7												1	17	101	1
8															
							Stratum 3 (1982–1990)								
1	1	864	15												
2		35	10		11	2									
3					2	158	4	1							
4						40	568	11			8	2			
5						2	29	215			3	137	3	1	
6							1					37	472	16	
7												3	47	191	1
8													2	2	
							Stratum 4 (1991–1996)								
1	1	874	12	1											
2		13	3		14	3									
3					1	318	23								
4						23	415	24			11	3			
5						1	19	187	1		1	287	21		
6									1			24	341	19	
7												1	26	158	8
8														2	1
							Stratum 5 (1997–2006)								
1		1,032	22												
2		8	1		13		1	1							
3					5	292	22	1							
4					1	30	665	22			12		1	1	
5						2	18	167			4	251	21		
6											1	28	536	33	1
7												1	19	149	2
8															

Appendix A6.–Chinook salmon paired age frequency for ADF&G and Reader-3 by stratum.

ADF&G	Reader-3 Age														
	Age_{fw}			Age_{sw}						Age_t					
Age	0	1	2	1	2	3	4	5	6	3	4	5	6	7	8
Stratum 1 (1964–1972)															
1		1,265	1												
2		50	3		24										
3					2	236	10	1							
4						35	969	6			18				
5							28	190			1	195	11		
6												37	818	5	
7												1	63	165	
8														5	
Stratum 2 (1973–1981)															
1	1	1,360	2												
2					69	2									
3					29	357	17								
4						29	821	30			61	1			
5						1	19	170			26	309	15		
6												25	728	29	
7												1	17	150	1
8															
Stratum 3 (1982–1990)															
1	2	987	1												
2		45	2		12	1									
3						157	8	1							
4					1	18	581	19			11	1			
5						1	16	228	1		1	149	8	1	
6							1				1	25	539	18	
7												2	48	228	1
8													1	3	
Stratum 4 (1991–1996)															
1		999		1											
2		17			14	3									
3						311	30			1					
4						16	417	30			14	3			
5							12	195	1			307	28		
6									1			18	398	29	
7													23	190	1
8														3	1
Stratum 5 (1997–2006)															
1		1,215													
2		9			13		1	1							
3					4	277	37	3							
4					1	14	664	44			13	0	1	1	
5						2	7	178	1		4	270	35	3	
6											1	16	647	43	
7												1	12	176	1
8															