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[Article]

Accuracy of Using Scales to Age Mixed-Stock Chinook Salmon of Hatchery Origin

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Abstract.—Despite a long history of using scales to age Pacific salmon, there have been few attempts to validate scale-derived ages. This is particularly true for Chinook salmon *Oncorhynchus tshawytscha*, a species exhibiting a wide range of life histories across stocks. This has led to continuing questions regarding the accuracy of scale-based age determination for Chinook salmon. This study assessed the accuracy of Chinook salmon scale age data produced by multiple readers from multiple agencies, who aged hatchery fish of known age from mixed-stock, nonterminal fisheries conducted along the Pacific coast of Canada from 1991 to 2003. The test sample consisted of scales from 434 fish from both stream- and ocean-type stocks marked with coded wire tags (i.e., fish origin and total age were known). Sample stocks originated from Oregon, Washington, and British Columbia. Five readers from three federal or state Pacific Northwest fisheries agencies participated in the study. The readers possessed various levels of experience, which was classified as (1) deep or shallow (depth) depending on the number of years the reader was involved in aging Chinook salmon scales and (2) broad or narrow (breadth) depending on the variety of stocks the reader had previously encountered. Accuracy ranged from 84% to 94%, although readers with both deep and broad experience consistently achieved accuracies greater than 90%, while those with a narrower breadth of experience tended to show age bias. Overall, the results suggest that aging Chinook salmon scales from ocean-caught hatchery fish can be accurate and that readers' previous exposure to stocks comprising a wide range of life history types may be at least as important as the number of years of experience in achieving a high level of aging accuracy.

Knowing the age composition of catch in a fishery is critical to accurately estimating brood year exploitation rates and other stock-specific biological parameters that provide for informed management decisions for many commercially important salmon species. Under- or overestimation of brood year abundance can lead to inappropriate harvest decisions. While accurate age determination is therefore essential, adequate validation of fish aging methods is often lacking (Beamish and McFarlane 1983).

Since the early 1900s, salmon have typically been aged by means of scales (Gilbert 1913), which are easy to collect in a noninvasive manner. Salmon are not long-lived, particularly when compared with non-anadromous marine species. While Chinook salmon *Oncorhynchus tshawytscha* can live longer than 6 years, more commonly their maximum life span is 3–5 years (Healey 1991). They spend from several months to years in freshwater before migrating to the ocean. Salmon scales (Figure 1) form a concentric series of ridges called circuli that vary in thickness and spacing depending on rate of growth (time of year) and the environment (fresh- or saltwater) in which they are formed (Clutter and Whitesel 1956; Barber and Walker 1988). An annual zone is composed of the circuli that make up the fast "summer" growth and the slower "winter" growth zones.

As with all age determination methods, interpretation of annual growth zones on salmon scales presents its own unique challenges. When a scale is lost and then regenerated, the central region that represents previous growth is blank (Blair 1942). In addition, maturation can lead to resorption of the outer margin of scales, sometimes resulting in lost annuli (Clutter and Whitesel 1956; Chilton and Bilton 1986). In both cases, underestimation of age is likely unless criteria are developed to account for such conditions. Variability in early life history (i.e., freshwater residency) can lead to myriad variations in scale patterns, thus contributing to aging errors. Physiological stress due to changes in food availability or temperature can produce freshwater "checks" that can be misinterpreted as annuli (Clutter and Whitesel 1956). A misjudgment could mean an error of 1 year, which constitutes a serious error for such a short-lived species (Beamish and Fournier 1981).

Salmon scale reading laboratories have developed criteria over the years to assist readers in making decisions regarding scale pattern interpretation. These criteria reflect the training and experience of laboratory personnel. The most common problem faced by a Chinook salmon scale reader is resolving whether an

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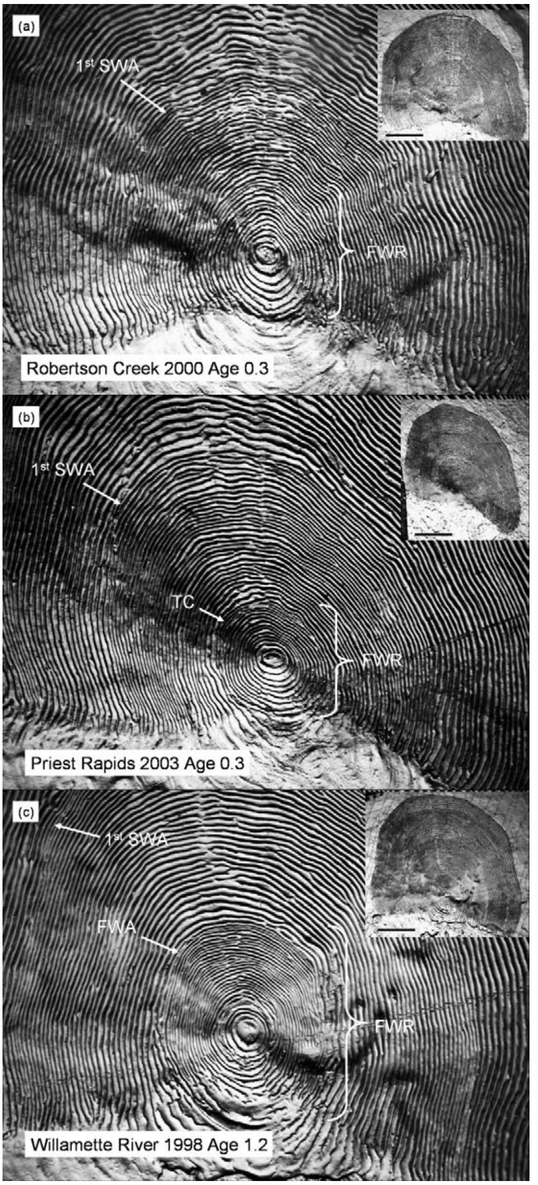

FIGURE 1.—Images of Chinook salmon scales from the different study stocks, comparing freshwater regions (FWRs) with clear (a, c) and ambiguous (b) freshwater pattern characteristics (inset scale bars = 1.6 mm, SWA = saltwater annulus, FWA = freshwater annulus). Note the small, unambiguous FWR with no FWA from (a) the ocean-type Robertson Creek stock compared with the distinctly larger FWR with a FWA of (c) the stream-type Willamette River stock. The first annual growth zone of (b) the Priest Rapids stock demonstrates multiple checks, including a transition check (TC) that is prominent enough to cause some readers to identify a FWA, resulting in overestimation of age.

annulus is present in the freshwater region of the scale. Various researchers (Koo and Isarankura 1967; Yole 1989) have attempted to standardize criteria that objectively, consistently, and accurately establish freshwater age. Although a number of useful criteria have been identified and used, there seems to be no "one size fits all" set of criteria that can be applied to all Chinook salmon stocks. This means that a Chinook salmon scale reader must rely on experience to make best judgments.

Chinook salmon are one of the few fish species for which validation of scale-derived ages is readily possible for multiple stocks. Millions of juvenile Chinook salmon from stocks along the Pacific Northwest are marked with coded wire tags (CWTs) as an essential component of coastwide management of this species (Hankin et al. 2005). Coded wire tags are small pieces of magnetized wire that are injected into the nasal tissue of a proportion of released juveniles from select stocks. The CWTs are uniquely coded to enable identification of a fish's stock origin and total age. As fish are harvested in commercial, recreational, and aboriginal fisheries, CWTs are extracted and decoded. When combined with samples taken in spawning escapements, these tag data provide stock- and brood-year-specific estimates of exploitation, harvest, and ocean survival rates. Apart from sampling or code reading errors, a CWT provides virtually 100% accuracy in establishing total age of the fish from which it is extracted. The presence of these tags in thousands of harvested Chinook salmon each year provides an excellent opportunity for validating the accuracy of scale aging performed by agencies and their personnel coastwide. However, despite the long history of aging Chinook salmon from scales and the availability of CWT-marked fish for over three decades, few studies have attempted to validate the criteria used to interpret their scale growth patterns. While some studies have examined variability among scale readers in determining ages from known-age fish (Godfrey et al. 1968; Bilton et al. 1983; Yole 1989), only one study has attempted to correlate reader experience with aging accuracy for highly mixed stock assemblages (Yole 1989). Furthermore, there has been little cross-verification between agencies to test the reproducibility of Chinook salmon age data among laboratories coastwide. This has led to continuing questions regarding the accuracy of scale age determination in Chinook salmon (Hankin et al. 2005).

To address such questions, this study set out to assess (1) the accuracy of using scales to age CWT-marked, hatchery-origin Chinook salmon caught in nonterminal fisheries harvesting highly mixed stock assemblages and (2) how scale age accuracy may be

TABLE 1.—Release stage (Sub = subyearling; Yr = yearling) of hatchery Chinook salmon from which scale samples were collected, and the stock and predominant life history type (S = stream type, O = ocean type) they represent (aggregate age composition: age 1 = 0.5%; age 2 = 26.0%; age 3 = 52.8%; age 4 = 18.9%; age 5 = 1.8%).

Province or state	Geographic area	Stock	Life history type	Release stage	Number of samples
British Columbia	North Coast	Kitsumkalum River	S	Sub, Yr	20
		Babine River	S	Yr	23
		Kinkolith River	S	Yr	16
	Central Coast	Atnarko River	O	Sub, Yr	21
	East Coast Vancouver Island	Quinsam River	O	Sub	20
		Big Qualicum River	O	Sub	20
	West Coast Vancouver Island	Robertson Creek	O	Sub	19
		Nitinat River	O	Sub	18
	Fraser River	Dome Creek	S	Yr	13
		Nicola River	S	Sub, Yr	19
		Lower Shuswap River	O	Sub	16
		Harrison River	O	Sub	17
		Chilliwack River	O	Sub	18
Washington	Puget Sound	Skagit River (spring and summer stocks)	S, O	Sub, Yr	19
		White River	S	Sub, Yr	19
		Stillaguamish River	O	Sub	16
		Samish River (Friday Creek)	O	Sub	21
	Washington coastal	Sooes Creek	O	Sub	18
		Queets River	O	Sub	19
	Columbia River	Willamette River	S	Yr	11
		Santiam River (North and South forks)	O	Sub, Yr	12
		Priest Rapids	O	Sub	23
		Lewis River	S	Yr	15
Oregon	Oregon coastal	Salmon River	O	Sub	21
Total					434

influenced by the type of experience of personnel from several agencies.

Methods

Scales were primarily collected from hatchery-produced Chinook salmon caught from 1991 to 2003 in Canadian troll fisheries (northern British Columbia and west coast of Vancouver Island); a smaller number of scales were taken from fish caught in nonterminal, ocean net fisheries (coastal British Columbia). Terminal fisheries were deliberately excluded as a source of samples to avoid the possibility of aging error related to scale resorption. This allowed readers to focus on annulus interpretation rather than whether annuli were missing. Only adipose-fin-clipped fish with decoded CWTs and readable scale samples were included in this study. These fish had been released from hatchery facilities as either subyearlings or yearlings. A total of 495 Chinook salmon representing 24 stocks from Oregon, Washington, and British Columbia (Table 1) were selected. Total ages ranged from 1 to 5 years. Samples were chosen based on the life history they were meant to represent: ocean type (no freshwater annulus [FWA]) or stream type (one FWA). The stage at release of a hatchery fish does not necessarily determine the length of freshwater residency; for many stocks, fish go to sea as subyearlings within several months of release, whereas other fish typically spend their first winter in freshwater before migrating to the ocean (e.g., McNicol 1999).

Five Chinook salmon scale readers agreed to participate in this study during 2004–2005. Three (readers A, B, and C) were from Fisheries and Oceans Canada (DFO), one (reader D) was from the Washington Department of Fish and Wildlife, and one (reader E) was from the Alaska Department of Fish and Game. The three readers from DFO aged samples completely independent of one another. Participants were chosen based on the "depth" and "breadth" of their experience in aging Chinook salmon scales. Depth of experience was assessed based on the number of years the reader had been aging Chinook salmon. Deep experience was defined as 10 or more years of Chinook salmon aging, while shallow experience was defined as 3 years or less. Broad experience was defined as familiarity with many stocks of both ocean- and stream-type fish, while narrow experience was defined as familiarity largely with one of the two life history types and a limited number of stocks. Designation of the level of experience was relational among participants based on the background supplied by each (Table 2). Readers A, B, D, and E were considered to have deep experience as they had been aging Chinook salmon for more than 10 years. By comparison, reader C, with 3 years of experience, was considered to have shallow experience. Readers A and

TABLE 2.—Depth and breadth of Chinook salmon scale aging experience among readers (see Methods for further description of categories).

Reader	Depth of experience aging Chinook salmon (years)	Breadth of experience (regions of stock familiarity)	Life history type familiarity	Experience rating (depth/breadth)
A	21	Oregon, Washington, British Columbia, Yukon, Alaska	Both ocean and stream type	Deep/broad
B	20	Oregon, Washington, British Columbia, Yukon, Alaska	Both ocean and stream type	Deep/broad
C	3	Washington, British Columbia, Yukon	Both ocean and stream type	Shallow/moderate
D	26	Oregon, Washington and southern British Columbia	Mostly ocean type	Deep/moderate
E	17	Southeast Alaska to Yakutat and northern British Columbia transboundary	Mostly stream type	Deep/narrow

B were considered to have very broad experience, being exposed to the most stocks across life history types, while readers C and D were considered to have moderate experience and reader E was considered to have narrow experience based on the more limited exposure to different life history types.

When assessing age, the only information readers had available to them was scale card number and catch date. They were supplied with prenumbered data sheets that identified scale card format and which fish they were to age on each card. Readers were asked to record age in European designation (Koo 1962) for each scale and to provide a single age for each fish that would be used for comparisons. Each reader was instructed to age the sample once in their usual manner and speed, without revisiting any samples. Results from all five readers were compared with the CWT-decoded age (considered the true age). Only total age was used for the comparison because true freshwater age versus marine age cannot be accurately determined using CWTs for fish released as subyearlings since it is not known with certainty when such fish migrate to sea. Regardless, total age is more important from a stock assessment perspective as it identifies the brood year origin, even if the life history type is incorrectly assigned. Nevertheless, differences in the interpretation of freshwater regions among readers were noted.

As a measure of inter-reader variability (precision) in estimating scale ages, two statistics were calculated for each sample: the absolute percent error and the coefficient of variation (APE, CV; Beamish and Fournier 1981; Chang 1982; Campana 2001). The APE for the jth fish was calculated as:

$$\mathrm{APE} = 100 \times 1 \Bigg/ R \sum_{i=1}^{R} \frac{|X_{ij} - T_j|}{T_j}, \qquad (1)$$

where X_{ij} is the age determination made by the ith reader for the jth fish; T_j is the true age of the jth fish as indicated by a CWT, and R is the number of readers. The CV for the jth fish was calculated as:

$$\mathrm{CV} = 100 \times 1 \Bigg/ R \frac{\sqrt{\sum_{i=1}^{R} \frac{(X_{ij} - T_j)^2}{R-1}}}{T_j}. \qquad (2)$$

Mean APE and CV were then calculated across all samples.

To test for the presence of bias among readers, a simple, two-cell chi-square test was conducted for each reader across all scale ages. This test determined whether a reader tended to over- or underestimate the age of a fish when an incorrect age was assigned. Bias tests were made on all ages combined as sample sizes for individual ages tended to be small.

Results

Of the 495 samples selected, 434 could be aged by all five readers. Of the 61 fish that could not be aged by all readers, 19 (31%) were due to human error (lost samples, incorrect sample sent), 40 (66%) were considered regenerated or otherwise unreadable by one or more readers, and 2 (3%) were considered irresolvable due to an ambiguous freshwater region. The latter two groups reflect slight differences among agencies in the criteria used to decide whether to provide an age. Total ages ranged from 1 to 5 years, with the majority being 2–4 years (Table 1). The eliminated samples did not significantly change the age composition of samples used in this analysis. Readers A, B, and D (deep and moderately broad to broad experience) correctly aged 94.0, 91.7, and 92.3% of the samples, respectively (Table 3). Reader E, with deep but narrow experience, was less accurate, correctly aging 84.3% of the samples, while reader C (shallow but moderately broad experience) correctly aged 92.6%. Precision of estimates among readers was quite high, with a mean APE of only 3.3%, while the mean CV was 4.4%. Bias was detected for two readers, both with deep Chinook salmon aging experience but less

TABLE 3.—Summary of Chinook salmon scale aging accuracy results for each reader. Total number of samples correctly aged (C), overaged (O), and underaged (U) are reported for each stock examined by each reader.

Stock location	Reader A			Reader B			Reader C			Reader D			Reader E			Total number per stock
	C	O	U	C	O	U	C	O	U	C	O	U	C	O	U	
Atnarko River	20		1	17	3	1	18	2	1	18	1	2	18	2	1	21
Babine River	22		1	22		1	21		2	21		2	23			23
Big Qualicum River	18	1	1	18	2		18	2		19	1		18	2		20
Chilliwack River	18			17	1		18			18			15	3		18
Dome Creek	12		1	13			12		1	13			13			13
Harrison River	15	2		15	2		14	3		17			10	7		17
Kinkolith River	15		1	13	1	2	14		2	7		9	14		2	16
Kitsumkalum River	19		1	19		1	18		2	18		2	13	6	1	20
Lower Shuswap River	16			15	1		16			15		1	16			16
Lewis River	13	2		15			15			15			13	2		15
Nicola River	16		3	14	1	4	16		3	12	1	6	14	2	3	19
Nitinat River	18			18			18			18			18			18
Priest Rapids	21	2		19	4		18	5		22	1		16	7		23
Queets River	19			18	1		19			19			8	11		19
Quinsam River	19	1		19		1	20			20			17	3		20
Robertson Creek	17	1	1	18		1	18		1	18		1	18		1	19
Salmon River	19	1	1	18	1	2	20		1	19	2		13	7	1	21
Samish River	20	1		20	1		20	1		20	1		20	1		21
Santiam River	11		1	11		1	10		2	10		2	11		1	12
Skagit River	19			19			19			18	1		19			19
Sooes Creek	18			17		1	18			16	2		17	1		18
Stillaguamish River	15	1		16			15	1		16			13	3		16
White River	18		1	18		1	19			19			18	1		19
Willamette River	10	1		9	2		8	3		11			11			11
Grand total	408	13	13	398	20	16	402	17	15	399	10	25	366	58	10	434
Percent of total	94.0	3.0	3.0	91.7	4.6	3.7	92.6	3.9	3.5	91.9	2.3	5.8	84.3	13.4	2.3	

than broad experience. Among incorrectly aged samples, reader D tended to underestimate total age ($\chi^2 = 6.43$, df $= 1$, $P = 0.011$), while reader E tended to overestimate age ($\chi^2 = 33.9$, df $= 1$, $P < 0.001$). Readers A–C did not exhibit any significant bias. All five readers agreed on the correct total age for 322 (74%) of the samples. For 17 (5%) of these fish, one or more readers disagreed on life history type (i.e., whether the first annulus was formed in fresh- or saltwater). Almost all disagreements between reader estimates and CWT age were by 1 year. There were only five cases where one of the five readers disagreed with the CWT age by 2 years. Life history interpretation was the source of disagreement for about 80% of all total age differences generated. Figure 1 illustrates how ambiguity in the freshwater region of a scale can lead to differing age designations.

The Nitinat River stock was the only Chinook salmon stock for which the five readers correctly aged all fish. All readers had problems interpreting scales from the Nicola River stock, usually underestimating age as a result of identifying fish as ocean type rather than stream type. Reader D, in particular, had trouble with Kinkolith River stock scales, underestimating age for 9 of the 16 samples by designating them as ocean-type fish instead of stream-type fish. Reader E tended to overestimate age for Harrison, Kitsumkalum, Priest Rapids, Queets, and Salmon River stocks, in most cases identifying a FWA in samples from ocean-type stocks.

Discussion

Chinook salmon are one of the most difficult salmon species to age due to their complex and variable life history. Seaward migration of juveniles can begin immediately after emerging from the gravel or be delayed by one or more years; saltwater residency can then last from months to six or more years (Healey 1991). Stocks, races, and individual fish exhibit a diverse array of scale growth patterns that readers must become skilled at interpreting to accurately and consistently assess age. Readers must learn to differentiate annuli from checks, which result from natural or hatchery-induced disruptions in growth. Often, their biggest challenge is correctly classifying the first annulus as being formed in fresh- or saltwater. Chinook salmon undergo stresses during their migration in freshwater and estuarine waters; these stresses lead to deposition of what is defined as a transition check (TC) in the scale's transition zone (Clutter and Whitesel 1956) that in character satisfies some of the criteria used to identify annuli (Koo and Isarankura 1967). By far, the most common problem in aging Chinook salmon scales of unknown stock origin is correctly differentiating a TC from a FWA. If a TC is incorrectly interpreted as a FWA, overestimation of age occurs.

The results of this study suggest that hatchery-origin Chinook salmon scales taken from mixed-stock ocean fisheries can be aged with a high degree of accuracy even when stock origin is not known. This appears to be true across agencies even though there was no attempt to standardize criteria and how they were applied. Although all but one reader correctly aged over 92% of the samples, accuracy would probably have been even higher if agencies had been allowed to employ quality control procedures typically used to reduce errors and bias, such as having a second reader independently age a portion of samples, performing accuracy tests using CWTs a posteriori, and addressing any biases such measures might uncover. Surprisingly, there are few previously published studies that have attempted to test Chinook salmon aging accuracy using samples of known age. Bilton et al. (1983) examined scale aging accuracy among five scale readers (of unspecified experience) for a limited number of known-age samples ($n = 34$) from four New Zealand Chinook salmon stocks. Those investigators found that while accuracy varied among readers (74–97%), on average the readers were correct 86% of the time. Godfrey et al. (1968) assessed scale aging accuracy among four "experienced" scale readers, who examined 400 Chinook salmon samples from the Columbia River with no accompanying biological information. Accuracy within this group averaged 75%. More recently, Copeland et al. (2007) found that Chinook salmon scales collected terminally in the Snake River were accurately aged 80% of the time, although scales were from terminally caught fish and only ocean ages were assessed. Only one other published study (Yole 1989) was comparable with ours. Yole (1989) reported aging accuracy results for Chinook salmon scale samples caught in highly mixed stock fisheries. Five scale readers of varying years' experience (breadth of experience unspecified) from the same agency examined scales of known total age collected in mixed-stock fisheries from California to southern Alaska and accurately aged 88–99% of the samples ($n = 280$).

Previous studies have demonstrated that the depth of experience influences aging accuracy. Yole (1989) demonstrated that, overall, novice readers were not as accurate in aging Chinook salmon scales as experienced readers. However, even among experienced readers, the degree of accuracy can vary significantly (Godfrey et al. 1968; Yole 1989). Bilton et al. (1983) made a similar observation, concluding that if all readers had the same experience reading scales from the stocks examined (i.e., equal breadth of experience), agreement among readers would have been higher. However, none of these studies explained how they defined experience or rated the quality of reader experience. In our study, the results suggest that breadth of experience may be as important as years of experience for explaining the variation in agreement among the readers. This suggests that to achieve a high degree of aging accuracy for Chinook salmon scale samples of unknown stock origin, a reader should have experience examining samples from a wide a variety of stocks of varying life history types.

While this study demonstrates that hatchery-reared Chinook salmon scales can be accurately aged, accuracy of scale age for Chinook salmon of wild origin encountered in mixed-stock fisheries has generally not been assessed. Such testing would be much more problematic. First, very little CWT marking of wild Chinook salmon occurs south of Alaska. While passive integrated transponder (PIT) tags have been used to validate ages of wild fish, such marking has been conducted on a limited number of stocks, primarily located in the Columbia River basin (Copeland et al. 2007). Any accuracy measures based on these stocks would probably not be representative of wild stocks coastwide. Thus, directly assessing whether aging accuracy among stocks of wild origin would be equal to the accuracy observed among hatchery Chinook salmon stocks remains a challenge. However, fish aging laboratories typically establish criteria for aging Chinook salmon scales based on both wild- and hatchery-origin samples collected from multiple stocks and generally do not distinguish between the two while determining age. These criteria are thus considered robust, at least for the stock assemblages typically encountered. Within a stock, there may be some differences between hatchery and wild smolt scale patterns due to early rearing conditions (e.g., first annulus formation in hatchery yearling releases versus wild yearling smolts). Among the Canadian stocks familiar to the authors, such circumstances do not require the use of different aging criteria. While scale characteristics of individual stocks will vary, particularly among stream-type stocks or stocks with mixed life history types, these differences are more typically due to stock-specific rearing circumstances rather than to wild or hatchery origin per se. Nevertheless, while this study has demonstrated that the criteria used to age hatchery Chinook salmon can be accurate, the use of such criteria to age wild-origin Chinook salmon needs to be validated before scales can be considered as an accurate method of aging all (wild and hatchery) Chinook salmon encountered in mixed-stock fisheries. This would require the use of marks applied to out-migrating wild smolts (e.g., CWTs, PIT tags, chemical tags, thermal otolith marks) or the use of genetic markers (e.g., parental genotyping) to identify stock and brood year origin. However, unlike CWT marking of hatchery-reared Chinook salmon, marking of wild Chinook salmon is not yet widespread. Thus, validation of scale aging in wild fish would require new marking programs, which would be a costly undertaking on a coastwide basis. Nevertheless, marking a more limited number of stocks representing the more common life history types would allow an initial test of the accuracy of current aging criteria used to age wild as well as hatchery Chinook salmon.

While overall aging accuracy was high in this study, age errors were clearly higher for some stocks than for others. In most cases, stocks with greater age error were predominately stream-type fish, and the errors were associated with interpretation of the freshwater region of the scale. Experienced Chinook salmon readers acknowledge that they do create more "specific" freshwater growth criteria for terminal samples. However, for mixed-stock samples of unknown origin, readers default to a more basic form. Knowing the stock origin of a scale sample before aging allows readers to narrow their focus on the distinguishing scale characteristics for that specific stock. Hence, knowing the stock origin before aging (via CWTs or genetics) would probably have improved the accuracy results in our study. While scale samples have not been collected for all Chinook salmon stocks coastwide, archives exist for the majority of North American stocks of moderate to high abundance. Therefore, information on the freshwater characteristics specific to many stocks already exists. Thus, in many cases, knowing the stock origin of a scale could allow a reader to use more stock-specific criteria to determine age. The challenge is to make these archives available to all agencies.

In summary, this study demonstrates that total ages of hatchery-produced Chinook salmon caught in Canadian mixed-stock fisheries can be determined from scales with greater than 90% accuracy. While depth of experience has previously been demonstrated to affect accuracy, the present study suggests that the breadth of scale readers' exposure to the wide variation in freshwater growth characteristics found on Chinook salmon scales from stocks of all life history types and freshwater rearing experiences may be equally as important. We suggest that accurate scale aging of mixed-stock Chinook salmon samples is achievable if readers have been aging Chinook salmon for an appropriate length of time, but just as importantly, have been exposed to as wide a diversity of life history types as possible. However, until testing is conducted on scales from fish of wild origin, some uncertainty will remain as to whether such accuracy can be achieved among stock aggregates composed of both hatchery- and wild-origin fish.

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