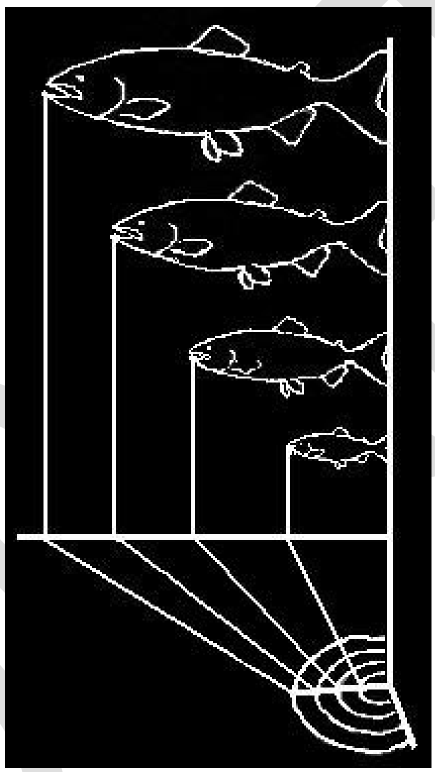
FISH LIFE HISTORY ANALYSIS PROJECT: METHODS FOR SCALE ANALYSIS

March 2014



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MANUAL OUTLINE

PURPOSE

The purpose of this manual is twofold: 1) to provide guidelines for scale analyses for new, supporting and collaborating staff, and 2) to form a repository for historical and accumulated knowledge of methods utilized by the Oregon Department of Fish and Wildlife's Fish Life History Analysis Project (FLHAP). These methods include: 1) age notation; 2) nomenclature and scale anatomy; 3) species- and region-specific biological trends; 4) reference samples and means for age validation in relation to estimates derived from reading fish scales, and 5) size-at-age trends and estimations. Background information on the FLHAP can be found in Clemens et al. 2013a. Information on standard operating procedures for scale collection and preparation and data management can be found in Clemens et al. 2013b.

Species accounts and their unique, age-specific characteristics follow at the end of this manual, in appendices.

INTRODUCTION

Why analyze fish scales? Fish scales provide a relatively inexpensive means of estimating life history characteristics of fishes — age, origin, life history type, growth; size-at-age; and repeat spawning. Fish scales are also relatively easy to collect, store, and with lots of practice, read. These characteristics can serve as a proxy for the health of a particular stock, the age structure of that stock; proportion of hatchery spawners; growth trajectories, and life history diversity in that stock (Figure 1).

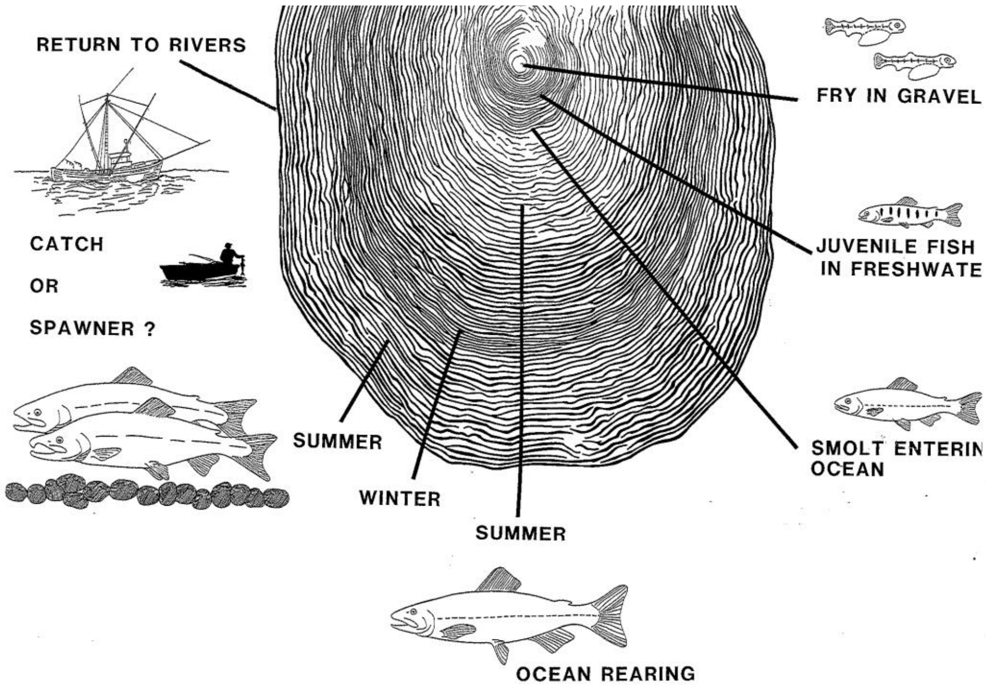

Figure 1. Schematic showing the life cycle of a salmonid in relation to its scales, growth, and age (Image: S. Torvik).

Advantages of using scales to age fish:

- Don't have to kill the fish.
- Can be sampled at multiple times during life.
- Easy and inexpensive to collect (therefore easy to get respectable sample sizes).
- Easy to process.
- Some salmonid populations have coded wire tags (CWTs), so the age of those fish can be validated.

Disadvantages of using scales to age fish:

- Not appropriate for fish that may be older than 8-10 years and spawn many times. For these it is better to use otoliths or other bony structures. Salmonids and centrachids are usually under this age limit, though largemouth and smallmouth bass may reach upper age limits.
- Annuli may be difficult to recognize because they require interpretation of the pattern of multiple circuli.
- Scales can be lost and regenerated. A scale regenerated later in life cannot be read.
- Scales can be resorbed prior to spawning and information can be lost.

- Some fish do not have scales (e.g., lamprey, catfish, sturgeon). Aging scales is only possible for species with cycloid and ctenoid scales.

SCALE ANATOMY

Scale anatomy is shown in Figure 2. A circulus is visible as a “ring” on the scale, though is actually a circular layer. As the fish grows the scale grows another, larger, layer. The plural form is circuli. Circuli spacing and number can be a rough proxy for growth rate and time. We know that during the summer when the fish is growing quickly, the circuli are thicker and more widely spaced than they are during the winter when the fish is growing slowly. Over a short period of time, such as a summer during the juvenile phase, a circulus can be related to time. However, the relationship will not hold up over the entire life of the fish.

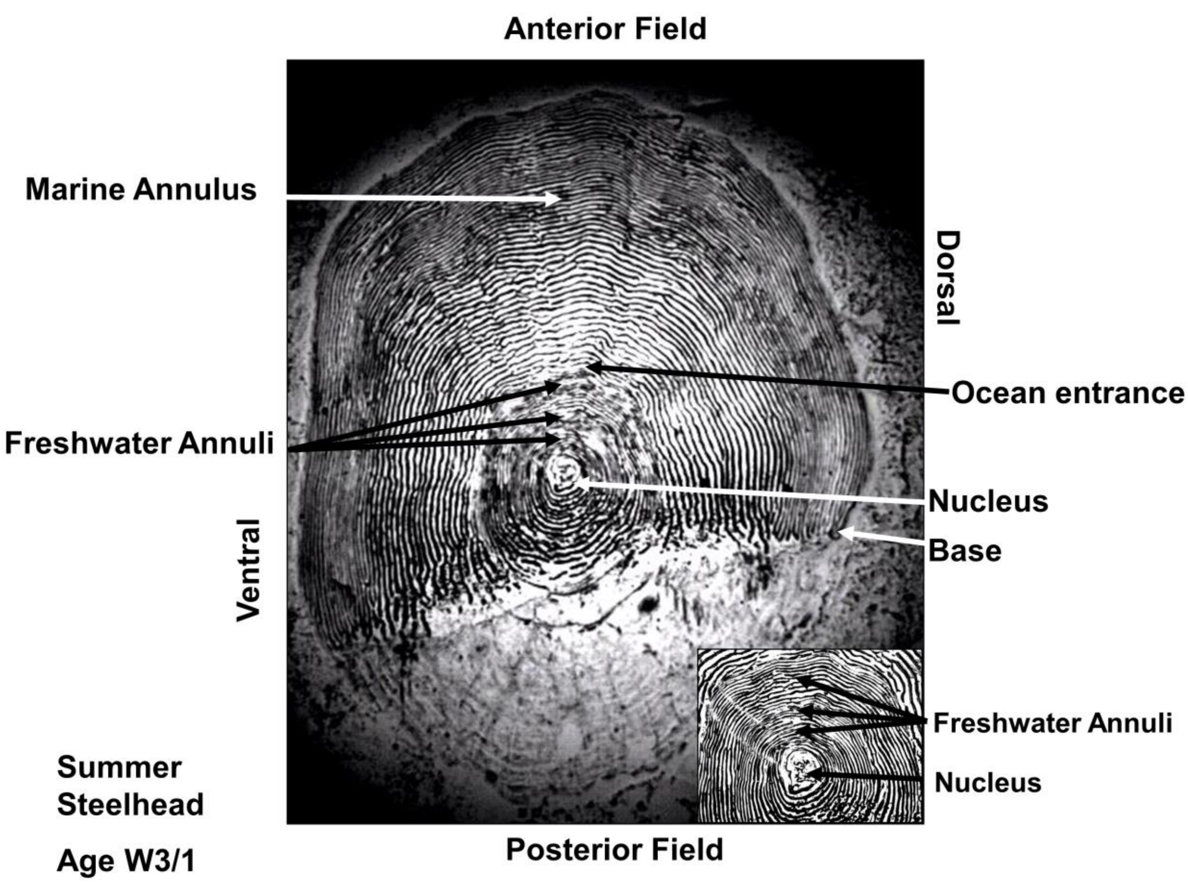

Figure 2. Scale anatomy, inset highlights the freshwater zone. The example shown here is for steelhead. Age notations will differ based upon species (see text).

An annulus is a band of thin, narrowly spaced circuli laid down during a winter, slow-growth period. Plural form is annuli. During the juvenile, freshwater phase, successive annuli are spaced relatively far apart. Once the salmonid migrates to the ocean, successive annuli are usually closer together.

The anterior field is the portion of the scale that, *in situ*, lies closest to the head of the fish and is within the pocket of skin and not visible. The anterior portion of the scale contains the circuli. The posterior field, the portion of the scale that, *in situ*, lies closest to the tail of the fish, is covered with pigmentation cells and comprises the visible portion of the scale. When you grasp a scale with forceps to remove it from the fish, it is the posterior field that is grasped. Salmonid scales from the key area are not symmetrical. You will notice that the circuli extend further into the posterior field on the ventral side than on the dorsal side.

Within FLHAP, we refer to the center-most circulus as the nucleus. Other projects may refer to the portion of the scale formed in freshwater as the nucleus.

SCALE READING PROTOCOL

New scale readers are trained by experienced readers. First a trainee and experienced reader estimate the age of the fish together, then the trainee reads another, similar group (same species and basin) of scales and compares results with those of the experienced reader, discussing their differences. In addition the trainee will read scales read by previous readers.

The FLHAP uses the following protocol:

a. **Accrue background information.** Knowledge of the biology, basin, and hatchery practices (releases, sizes, marks, etc.) for the fish stocks for which scale reads are conducted are gleaned from local biologists, district reports, ODFW hatchery plans, or other sources to inform the scale readers of what life histories and emigration strategies the fish might exhibit.

b. **Examine reference collections.** These constitute scales from known-age fish (CWT-validated) and historic collections that were previously aged. Note that life history characteristics often differ within species (e.g., stocks, life history diversity, and basins), and so wherever possible, reference scale samples from specific origins, stocks, and basins should be used. Similarly, reference samples from the same types of surveys should be used because particular survey methods (and timing of those surveys) may result in unique selection bias with regards to life history type, stock, sex, body size, and age (e.g., see Clutter and Whitesel 1956).

c. **Conduct two initial reads.** Two trained readers conduct reads on the fish scales, independent of each other. These reads are usually conducted “blind” in that each reader is unaware of the biological data (i.e., length, mark, date, etc.) associated with each scale sample. However, basin, species and stock information is considered by the reader. It is also important for the scale reader to be aware of the general date—a scale reader may interpret a band of narrow circuli on the edge of the scale differently if the scale was collected in the spring or in the fall.

d. **Conduct a consensus read.** The two readers conduct a final, consensus read together for scales in which they had disagreements. “Body length”, “sex”, and “stock of origin” are considered at this stage to help achieve a consensus.

e. **Identify possible outliers.** The body lengths of the fish are then plotted against the ages estimated from scales, and scales from the fish that are outliers are re-examined. Sometimes this will result in an adjusted age estimate, but often it simply results in a “flagging” of a potential data discrepancy (possible mis-measurement of the fish’s length or other problem). OR sort the file by age, then length. The largest and smallest fish of each age can be flagged as seems appropriate and re-examined.

f. **Validate age estimates.** If the fish being aged possess CWTs, then these data are accessed and used to validate the age estimates from scale reads.

Occasionally a collection will be read by only one reader. While not the ideal situation, sometimes work load and staff expertise will necessitate reading a collection by only one reader. The single reader should still read the collection twice and the collection should contain some known age (CWT) samples to use to estimate reading accuracy.

Background information for each scale collection to be read helps the scale readers understand the age structure, origin, life history diversity, degree of scale resorption, etc., that they might expect. Nevertheless, biology, environmental factors, and hatchery rearing practices are dynamic and cryptic or subtle diversity of life history strategies can exist. The scale reader, therefore, should endeavor to keep an open mind.

Validation and Corroboration

It is important to realize that estimates of fish age, origin or life history by scales are just that: estimates. These estimates can be viewed with more confidence if the dataset can be validated or corroborated. Age validation means to compare estimated ages with known (true) ages to indicate a degree of accuracy within the dataset. Age validation is an important requirement in age estimates of fishes (Beamish and McFarlane 1983). For example, FLHAP most frequently uses coded wire tagged (CWT) fish as a method of validation. Brood year, and therefore known age, is queried from the interagency CWT database providing a ‘true’ measure of age. Of course the CWT database has errors in it, too, so it should be examined carefully to insure no egregious errors are swaying what is otherwise taken to be the true, valid age. Other methods of validation include utilizing natural marks (e.g., patterns caused by oceanic regime shifts), chemically- or temperature-induced marks on hard tissues of the fish, or brood year identified by genetic pedigree.

Corroboration is a measure of the consistency or repeatability of an age determination method and enables an estimate of precision. To corroborate means to use multiple age estimation methods to arrive at the same estimate. For example, age and origin of a fish can be estimated using both scales and a bony structure such as an otolith or from independent reads by scale readers from other laboratories.

The foregoing description is meant to underscore the practice of rigor in fish life history analysis by scale readers. This high degree of rigor includes redundancy (more than one reader), use of ancillary biological data to find potential errors in scale reads; use of reference samples and other means of corroboration to improve the readers' ability to recognize life history characteristics. We carefully use particular language such as "estimates", "validation" (accuracy), and "corroboration" (precision) to clearly and accurately communicate age data (Figure 3).

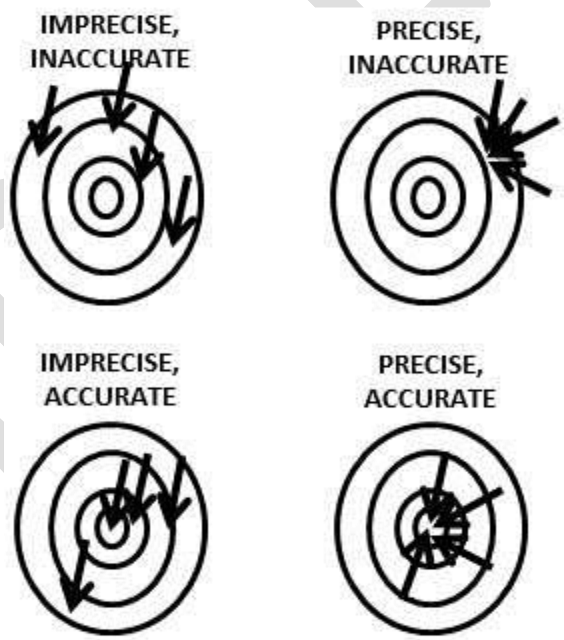

Figure 3. Arrow-to-target analogy for age estimates, showing combinations of precision (consistency), related to a true or accurate age.

AGE NOTATION

Salmon (Chinook, Coho, Chum):

- Gilbert-Rich (Gilbert and Rich 1927) notation: N_n.
  - N = the total age of the fish.
  - n = the age at which the smolt migrates to the ocean.

- For fall-spawning fishes like salmon, add "1" to the FW age (and therefore the total age). They experience their first winter as an egg or sac fry in the gravel before they grow scales. All fish turn 1 year older on January 1st.

- For spring-spawning fishes like steelhead, trout, and warmwater fishes, nothing is added to the annuli observed on the scales; the total annuli count for these fishes = the total age, again with each fish turning 1 year older on January 1st.

- Juveniles referred to as "zeroes" or "sub-yearlings" will have an "n" = 1; they are in their 1st year at migration.

- Juveniles referred to as "yearlings" will have an "n" = 2; they are in their 2nd year at migrations. Used for spring Chinook caught in the spring.

- Capture year – N = Brood year.

- Outmigration year- n = Brood year.

Steelhead:

For most coastal steelhead trout we follow the notation used by the old Coastal Steelhead Research Project in the 1980's – mid-1990's, with the exception of Rogue River. For Rogue steelhead a different notation is used which accommodates the "half-pounder" life history.

- Origin n/N and Origin n/N S.N S for repeat spawners
  - Origin= H for hatchery, W for wild.
  - n = number of annuli formed in freshwater before 1st ocean migration.
  - Slash "/" = 1st ocean migration.
  - N = number of "salt years" prior to first spawning. On winter steelhead, the final annulus may be barely showing on the edge so it is easier to count summer growth periods.
  - S = a spawning run and will follow a number representing the winter annulus that was resorbed or damaged during spawning. Most adult steelhead will be on their 1st spawning run so will not have an "S" in their age notation. Repeat spawners on their second spawning run will have one S, usually attached to their 2nd salt year, though they may have

spawned as a “1-salt” or a “3-salt”. Fish on a third run will have two “S” in their notation.

- The freshwater zone of summer and winter steelhead is aged the same way for both races. However, for summer steelhead after initial ocean entrance (/) only visible saltwater annuli are counted, though a fish caught late in the summer or fall may resorb most of the previous annulus (which is to be counted). Summer steelhead experience another winter period in freshwater before spawning. Since the fish is not feeding and putting resources into gonad development instead of somatic growth, a normal annulus is not formed on the scale. If summer steelhead are aged at spawning (in the next calendar year from when they returned to freshwater), the resorption on the scale edge caused by the effort of spawning, the spawning check, is counted as the annulus for that winter.

- In past data sets, fish of hatchery origin may be denoted as just H/N without the number of freshwater annuli given. Because virtually all hatchery smolts were yearlings (released with one freshwater annulus) a reader can assume an “H” means the same as “H1”.

- The old Rogue River Research Project (1980s-1990s) used slightly different notation. Rogue steelhead may go on a non-spawning “half-pounder” run after their 1st summer in the ocean. They return to the river briefly during the winter and then migrate back out to the ocean. The fish are considered to weigh about a half pound (though they often weigh up to 2 lbs) and they contribute to a popular fishery. The half pounder run causes an annulus that has some resorption but is occurring on a fish that is too small to be spawning. This is a well-documented life history. The half-pounder annulus was denoted by an “H” <u>after</u> the slash in the notation (Table 1). The half pounder life history occurs only in the Rogue, Klamath, and Eel rivers

Trout:

- Age = number of annuli.
- We note spawning runs in the comment column.

Warmwater fishes:

- Age= number of annuli.
- In tables, annuli (or age) is often denoted in Roman numerals

Table 1. Comparison of age notations for coastal and Rogue River steelhead. Number to the left of the "/" indicate freshwater age; numbers to the right of it indicate saltwater age. The FLHAP uses the notation typical of coastal steelhead, and we use an "H" to the left of the "/" to indicate hatchery origin. W = wild.

Common Age For 2 yr Old Smolt	Coastal Steelhead	Rogue River Steelhead	Total Age at Time Scale Collected
1-salt	W2/1	W2/1	3
Half pounder		W2/H	3
Half pounder + 1 salt yr		W2/H1	4
2-salt	W2/2	W2/2	4
Repeat spawner-2nd run	W2/2s.3	W2/2S	5
Repeat spawner-3rd run	W2/2s.3s.4	W2/2SS	6

ORIGIN IDENTIFICATION

FLHAP is often asked to identify hatchery fish from wild fish, based on circuli pattern, as a sort of control for intentionally unclipped or otherwise mis-clipped hatchery fish. Accordingly, project staff often estimate origin with various levels of confidence, considering species, condition of the fish scales, basin geography, and hatchery rearing practices (release dates and sizes; rearing conditions). There has to be significant differences between the scale patterns of the hatchery and wild fish to be able to identify origin. There are many groups of fish for which it is not possible to identify origin by their scale patterns.

The following brief description of our mode for identifying hatchery fish from wild fish is a general description only, and there are exceptions to the generalization we describe. Scale readers should obtain scales from several fish of *known* origin from the species and basin of interest, and then familiarize themselves with those scale patterns.

The premise for identifying hatchery fish from wild fish is that the former are reared in a relatively constant environment often with near-optimum opportunities (temperature and feed) for growth. Relative to the scales of wild fish, hatchery conditions *typically* result in scales with large freshwater zones, uniform circuli spacing, and thick circuli. In contrast, wild fish may experience highly variable rearing conditions seasonally that cause/allow periods of slower and faster growth. The difference in spacing and thickness of ciruli formed during winter versus spring by a wild fish can be striking and help identify the fish as wild In the past, the FLHAP has used statistical tools like discriminant function analysis to discern between hatchery and wild coho. However the ability to discern origin is dependent upon really good and representative "training" scale collections to accurately and precisely guide this analysis.

SIZE-AT-AGE ESTIMATIONS

Occasionally we are asked to estimate the size of the fish at a previous age or event using back calculation methods (Figure 5). Most often this type of analysis occurs with trout but a salmon example would be estimating the size of the fish at ocean migration. There is a lot of literature available to explain and discuss the formulas and methods to make these calculations (DeVries and Frie 1996). Contemporary literature agrees that proportional methods are more appropriate that linear regression. However, the method most often used by FLHAP in the past was linear regression because the proportional methods all require a measurement of the total scale radius. In past analyses involving estimation of size at ocean entrance, we were working with adult salmon scales sampled from spawned out carcasses. The scales were in poor condition without intact edges so an accurate measurement of the total scale radius was not possible. We believe that better results are achieved if the linear regression is developed from fish of similar size of the fish at the point of the back calculation (i.e. use smolts to develop the linear regression that will estimate size at ocean entrance measured on scales of returning adults.)

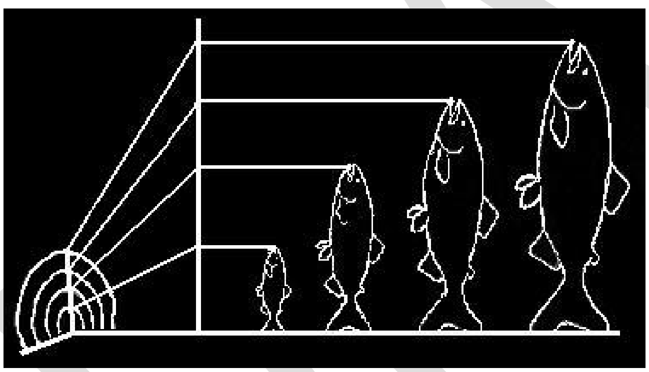

Figure 5. Schematic showing fish size by age estimated by scale reads. (Image: Trish Nickelson)

The Fraser-Lee method (Fraser 1976, Lee 1920) is useful when the length of the fish in the regression of fish length (y-axis) against scale radius (x-axis) does NOT originate at the y-intercept, and so a correction factor is needed to adjust the y-intercept.

- $L_i = [(L_c - a) * S_c^{-1}] * S_i + a$
  - L_i = body length at time of interest
  - L_c = body length of fish at capture (y-axis).
  - S_i = scale radius at point of interest
  - S_c = total scale radius at capture (x-axis).

- **a** = y-intercept correction factor for an even distribution of numbers of fish across a broad range of body sizes for a particular species and a particular population. Also known as the “intercept parameter” and the length that a particular fish species, for a particular population exhibits onset of scale formation (the fish is growing prior to forming scales).

- **$[(L_c – a) * S_c^{-1}]$** = slope of regression line of L regressed against S.

- The regression averages out the slope of the line created by the plotting of data points of each fish, where the coordinate of the first point of each fish is (S_c, L_c), and the second point is (0, a).

Table 2. Values of ‘a’ for various salmon species

Species	‘a’ (cm)	source
Chinook	3.0-3.5	Project regressions
Coho	~3.0	Project regressions
Bull Trout	~4.5	personal observation, L. Borgerson
Sockeye	4.0	Koo 1955

SCALE MEASUREMENTS

FLHAP uses a microscope connected to a computer and ImagePro software to conduct measurements of scale radius and circuli count of the scales. When conducting circuli counts (cc), the FLHAP counts the circuli along the 20^{o} ventral angle, and if measuring the scale radius, the FLHAP also measures along this same angle (Figure 6). All of these measurements are done on the largest mounted scale. When FLHAP staff conduct comparisons of scale size, as measured by a ruler on the microfiche projection, we standardize those measurements with the extent of magnification of the projected image by each microfiche (prior to 2012, all microfiche measures were conducted at 88X magnification). During 2012 and onward, the magnification has changed slightly from 88X for each microfiche. However, whenever not merely approximating, the FLHAP uses the ImagePro software to conduct standardized measurements of fish scales.

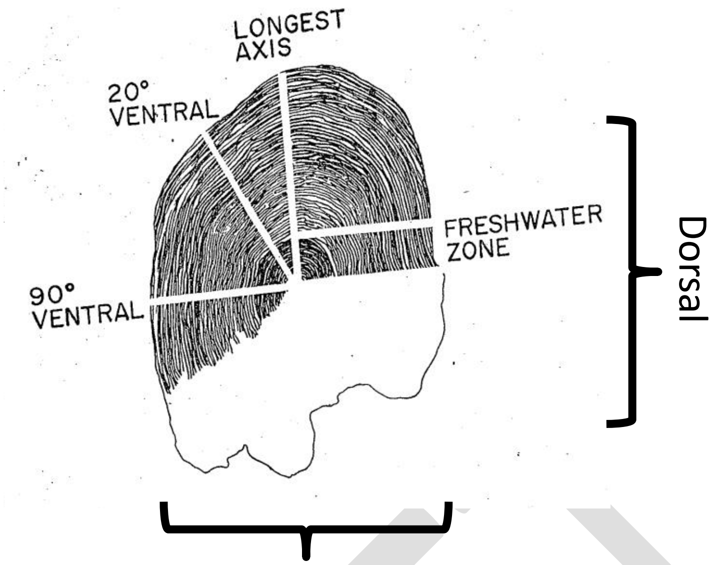

Figure 6. Scale axis and angles. Also shown are the dorsal side and posterior fields of the scale.

PROBLEMS EXPERIENCED WITH SCALES

When one considers the fish from which scales are sampled and read to estimate life history information (age, origin, or life history) are often a subset of all fish available for a particular survey or project, it is clear that scale reads are an "estimate (of age) of an 'estimate' (of the population)". Data from the scale reads are often used for escapement estimates, run forecasts, and general age structure trends. This consideration makes it all the more clear why it is important that we strive for both high accuracy and precision in scale reads. Failure to do so may result in a grossly-biased estimate of the overall population and management of that population.

The following problems are often experienced and if not appropriately addressed may affect the quality of life history estimates based on scale analysis:

1) **Too few scales**. The FLHAP likes to use 3 or more scales for estimates; 2 will suffice; 1 leads to concerns about bias. Those scales are selected for reading from 8 – 10 scales collected from fish at sampling (see Clemens et al. 2013b).

2) **Regenerated scales**. Occurs when a fish experiences an injury that results in the loss of scales. Newly formed (regenerated) scales that form in place of lost scales will have a void area (no circuli or annuli) for the time period prior to scale loss. See Clemens et al. 2013b for an example.

3) **Resorbed scales**. ("Resor*p*tion" = noun; "resor*b*" = verb). Maturing, migrating, spawning and otherwise stressed fish will leach calcium from their scales. As the

calcium is leached from the scales, the remaining material, especially on the edge will erode. The scales will be smaller than they would be otherwise, and the edges will be wavy, ragged, and indented, with circuli and annuli missing. See Clemens et al. 2013b for an example.

4) **Disintegrating scales**. Possibly related to microbial decay, scales can become highly degraded and brittle and will rip when one tries to remove them from other, similar condition scales upon which they are often stuck. We have found this condition in scales from both spawning ground carcasses and fresh, ocean-caught fish.

5) **Lateral line scales and other non-key scales**. Do not contain the most complete life history information from the fish (Clutter and Whitesel 1956) (see Clemens et al. 2013b).

6) **Dirty scales**. Periphyton, dirt, sand, and scale debris that are not sufficiently cleaned during the mounting process (Clemens et al. 2013b), obscure scale features. Scales sandwiched between Post-it notes or other non-waterproof paper may stick to the paper and make them more difficult to clean, process, and read. However, some waterproof papers (e.g., glossy) are also particularly problematic, as they become tightly glued to the scale.

7) **Scales mounted upside-down**. Only 1 of the 2 sides of a scale shows the circuli and annuli features useful in ageing. This is the “rough” side (Clemens et al. 2013b). If this rough side is mounted down on a gummed card, then the circuli will not be impressed on the plastic card and the scale cannot be aged.

8) **Poor data quality control**. Everyone makes mistakes and some errors are to be expected. For example, mis-alignment of ancillary biological data; disagreements between sex, date, or body length on the scale envelope and the electronic data, etc. Use of spreadsheet formulae that can become corrupted and then lead to mis-numbering of samples. Excessive and persistent errors are particularly troublesome as they take a significant amount of time to check and remedy, and they raise concerns over broader, more insidious problems that may exist with the data or the samples collected.

SPECIES INDENTIFICATION

Most samples will have the correct species labeled on the envelope or card. Occasionally, a spawning ground carcass will be is such poor shape that we may be asked to identify the species based on scale characteristics. Occasionally, a sampler either mis-identifies a fish or records the wrong species on the envelope. In this event FLAHP staff will need to recognize an incorrect species within a collection. Table 3 compares scale features that help identify the correct species. Details are from Mosher(1969) and staff observation.

Table 3. Comparison of scale features used in species identification.

Scale feature	Coho	Chinook	Chum	Steelhead
Common # FW annuli	1	0 coastal 0, 1 Willamette 1 inland	0	1-4
Common # SW annuli	0, 1	1-6	1-4	1-4
Globular reticulation	Rare	Some	Extensive	Common
Circuli appearance	Coarse,	Fine, regular	Coarse	Coarse, broken
Scale shape	Oval, long anterior-posterior axis	Round	Oval, long ventral-dorsal axis	Rectangular
Margin of circuli and posterior field	Uneven, with “danglers”	Very straight	Covered by globular reticulation	Uneven
Complete circuli around nucleus	>6	6-8	<7	>12
Most distinguishing feature(s)	FW annulus, coarse circuli	Multiple SW annuli, fine circuli	Globular reticulation, “flat” shape	Scale shape, multiple FW annuli

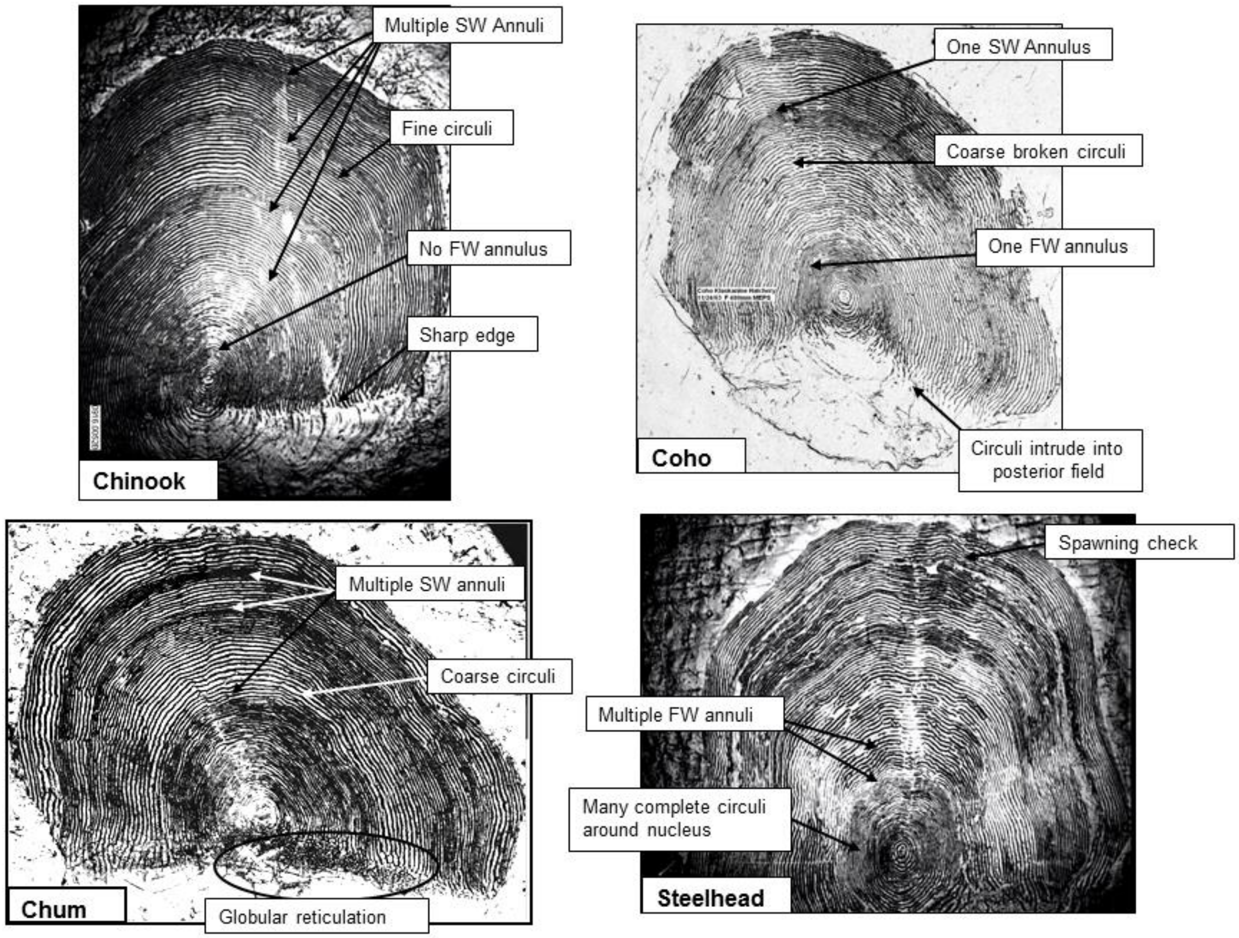

Figure 7. Identifying features of Chinook, coho, chum salmon and steelhead trout scales.

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GLOSSARY

Accuracy – The process of achieving an age estimate (or other measure) that equates with the actual age (or other measure). A true measure.

Annuli – Plural for annulus. Group of circuli that are bunched together; indication of slowed growth during the winter by the fish as visualized on the scale; indication of 1 year of life.

Annulus – Singular for annuli.

Anterior field – Portion of a fish scale growing closest to the head of the fish; shows circuli and annuli. In live fish, this part is covered up by other scales.

Axis (of scale) – Plane of view or measurement from the posterior field of the scale to the anterior field of the scale, to its tip.

Base (of scale) – Nexus of the posterior and anterior fields.

Check – Pseudo-annulus caused by conditions that are stressful to the fish and reflected by decreased growth; represented on the scale as several circuli spaced closer together than surrounding circuli. See "mid-summer check" and "spawning check" for examples.

Circuli – Concentric growth increments radiating out from the nucleus of the scales that form over the course of weeks.

Circulus – Growth increment (singular).

Concordance – Agreement rate on an age estimate between two different types of methods (e.g., scale reads and genetic pedigree analyses). Note that each method is not infallible, hence the usage of this term, as compared with "validation" or "accuracy". Nevertheless, concordance can be considered as being more scientifically sound than "corroboration".

Corroboration – Back-up evidence supporting a particular age estimate or other scientific measure that is NOT irrefutable, and therefore does not replace "validation".

Ctenoid – Scale type particular to warmwater fishes (basses, sunfishes, etc.). Similar to cycloid scales with some anatomical differences, most notably having a spiny posterior margin.

Cycloid – Scale type particular to coolwater fishes (trout, salmon, whitefish, etc.). Similar to ctenoid scales with some anatomical differences, most notably having a smooth posterior margin.

Disintegrating scales – Brittle scales that pull apart into many pieces upon attempts to mount them on gum cards. Appears to be the result of significant decomposition or be a reaction to acid in the paper envelopes.

Dorsal field – That part of the scale that, *in situ*, lies closest to the top of the fish (the fish's back).

Estimate – Best approximation of the true value of something (e.g., age), given the available data (the fish scales, background information, reference samples, observations, etc.).

Estuary type – Life history strategy used by some Chinook salmon of rearing relatively low in a particular basin, specifically in the estuary, before emigrating to the ocean and subsequently returning freshwater. For example, some coastal CHF enter an estuary early in the summer and wait until fall to enter the ocean as a large smolt. Compare and contrast with "Ocean type" and "Stream type".

Fall Chinook – Chinook that enter freshwater during the fall to spawn. Because they are in freshwater for the least amount of time relative to spring and summer Chinook, their scales are usually in the best condition. Their scales record a pseudo-annulus or "gonad check" on the scale edge that should NOT be counted in age estimates.

Freshwater zone – The center of the scale comprising the nucleus and other circuli that radiate out from the nucleus and are a biological record of the fish's age and relative growth rate in fresh water.

Gilbert-Rich notation – Form of age notation (Gilbert and Rich 1927) used by ODFW in ageing salmonid scales: N_n, wherein N = the total age of the fish and n = age at which the fish went to the ocean.

Globular reticulation – Essentially "bumps" or "nodules" on a scale. Mostly observed in chum salmon and steelhead scales, at the scale base. Therefore, useful as one means of discerning species by scales.

Gonad check – Psuedo-annulus or narrowing between circuli on the outside edge of fall Chinook scales at return to freshwater. Indicative of slower growth during gonad development.

Gonad development – The physiological process of sexual maturation: spermatogenesis for males and oogenesis for females. During this period fish put more resources into development of eggs and sperm and less into somatic growth.

Hatchery fish – Fish spawned and reared in a hatchery environment. Hatchery origin fish often experience even and significant growth prior to release (freshwater phase) due to consistent and ideal environmental conditions in the hatchery. Contrast with wild fish, which have uneven and usually less growth during the fresh water rearing phase, but which undergo compensatory growth rapidly upon entering fresh water.

Hatchery residual – Hatchery steelhead that has 2 clear annuli in the fresh water zone. While released as an age-1 juvenile, it spent an additional year rearing in freshwater before ocean migration.

Iteroparity / Iteroparous – Life history strategy of repeat spawning (typical in trout).

Jack – Precocious male with a total age of 2 for coho and fall Chinook salmon, and a total age of 3 for a spring Chinook with a yearling or "sub-2" juvenile life history. A mini-jack is a fish that is smolt-sized but did not go to the ocean and is sexually mature.

Jill – Precocious female of the same age as a jack.

Key scales / Key area – The preferred sampling area for scales of salmonids. Used by ODFW. This area is located at the intersection of an imaginary line connecting the posterior insertion point of the dorsal fin and the anterior insertion point of the anal fin, and just above the lateral line. These scales are the preferred (key) scales to use because studies have shown on sockeye salmon that these are the first scales to form and therefore record the most complete age and growth trajectories of salmonids, therefore leading to a higher chance of scale reading personnel generating non-biased age estimates.

Lateral line scales – Non-key area scales collected from the lateral line. Identified by obvious lateral line pores along the scale axis.

Mid-summer check – Psuedo-annulus representing a period of reduced growth in the ocean during the warm summer period. When present, exists between the first and second annuli. Usually obvious by its few circuli and spacing relative to the first and second annuli. When present, it can sometimes, but not always, be strong. Can be found on coho and Chinook salmon and steelhead.

Non-key scales – Those scale sampled outside of the key sampling area on the fish.

Nucleus –The center of the fish scale surrounded by the first circulus, in the middle of the fresh water zone.

Ocean entrance – The portion of the scale following the fresh water zone. Delineated by the transition from the (usually) relatively slow growth of the fresh water zone to the rapidly increasing growth of the ocean environment. Represented by an increase in spacing of circuli.

Ocean maturing – Coho, chum, and fall Chinook salmon and winter steelhead all develop near-mature eggs and sperm in the ocean. They spawn very soon after returning to freshwater.

Ocean type – Life history strategy used by some Chinook salmon of rearing relatively low in a particular basin, for a short period of time (see "Sub-yearling") before emigrating to the ocean. Most of the first summer is spent in the ocean.

Plus growth – Sometimes referred to just as "growth" by FLHAP. Indication of growth following an annulus on the edge. Depending on the situation (species, life history, basin), this observation can be used to justify counting the annulus preceding this growth in the age estimation, and in some cases, in adding another, not visible annulus into the age estimation (resorbed). Guidance for doing this has been provided by reference samples, including those from lower in basins with more complete scales and information from hatchery fish that were CWT, and therefore validate age estimates generated by FLHAP personnel.

Posterior field – Portion of the scale showing on a live fish and does NOT record circuli or annuli. Usually the first part on the scale to resorb, followed by the anterior field. This knowledge is useful in determining the status of a scale and estimating whether crucial age information (annuli) are missing.

Precision – The repeatability of a given measure or age estimate.

Psuedo-annulus – Check or false annulus formed by a biological or environmental stressor to the fish causing a slow-down in its growth. Observed as a congregation of a few circuli that is often less substantial than an actual annulus.

Rainbow trout – Non-anadromous *Oncorhynchus mykiss* identified as such by the lack of saltwater annuli.

Reference samples – Scales taken from a known location and time, sometimes with age estimates attached to them, sometimes with age validation by CWT information or other; sometimes with a more complete scales collected from fish lower in a particular basin. Used by scale readers as a means to "calibrate" subsequent reads by a scale reader from other, newer scales from the same species of fish and the same basin, with the express goal of attaining a high level of accuracy and precision.

Regenerated – “Voided” area of a scale caused by a previous injury to the fish that resulted in its losing that scale. The fish quickly grows a blank scale. When the blank scale reaches the size of adjacent, non damaged scales, it will again form circuli.

Resident – Fish that are not anadromous, but their cohorts may be. Examples include sockeye (kokanee); steelhead (rainbow trout); and previously under-appreciated species that can residualize such as Chinook (Chinook) and coho (coho). Resident fish are identified as such by the lack of saltwater annuli and may be smaller compared to the same age anadromous fish.

Residual – A behavior in which an anadromous hatchery fish (e.g., steelhead) resides in freshwater for another year (FW age 2) before emigrating to the ocean. Observed as a clear hatchery pattern with even circuli spacing, extremely large freshwater zone, with two distinct annuli.

Resorbed – Scales that have attained this state through the process of resorption, in which the fish is using its somatic energy reserves to fuel gonadal maturation, migration, and spawning, therefore leading to a loss of somatic tissue (like scale edges). If the fish continues to grow after the event that caused the resorption, the scale will have a “blank” band without circuli

Saltwater zone – That location including ocean entrance outward towards the edges of the scale, exemplified by good growth — relative to the freshwater zone.

Scale base – See “Base”.

Semelparity / Semelparous – Life history strategy of single spawning followed by death (salmon; some steelhead).

Somatic – Any bodily tissue other than gonadal.

Spawning check – Pseudo-annulus resulting from a spawning event, present on scales of iteroparous fishes. Usually appears as a band of resorbed scale material. The spawning check may resorb over the most recent annulus of a winter steelhead and forms instead of the most recent annulus of a summer steelhead.

Spring Chinook – Chinook that enter fresh water very early, in the spring, to spawn the following fall.

Stream maturing – Summer steelhead and spring Chinook salmon enter freshwater with immature gonads. They spend months in freshwater prior to spawning and during this time the eggs and sperm mature.

Stream type – Life history strategy used by some Chinook salmon of rearing higher up in a particular basin, for a longer period of time (see “Yearling”) before emigrating to the ocean. The first summer and winter occur in freshwater.

Sub-yearling – Chinook life history strategy of emigrating to the ocean prior to reaching its first year of life post-hatch. The same as a sub-1.

“Sub-1” – Chinook life history strategy of emigrating to the ocean prior to reaching its second year of life post-hatch. Also called a sub-yearling. “Sub” refers to the subscript value of the Gilbert-Rich notation – a sub-1 is in its first year at ocean entrance.

“Sub-2” – Chinook life history strategy of emigrating to the ocean after its second year of life post-hatch. Also called a yearling. “Sub” refers to the subscript value of the Gilbert-Rich notation – a sub-2 is in its second year at ocean entrance.

Summer Chinook – Chinook that enter freshwater during the summer (intermediate timing relative to spring and fall Chinook) to spawn in the fall.

Summer steelhead – Steelhead that enter freshwater during the summer to spawn the following spring. The salt water zone on the scales from these fish is aged by counting the winter periods (annuli).

Validation – Practice of using irrefutable proof to backup or ground truth the estimated ages of fish from scales. An example is the use of CWTs to ground truth age estimates by scale readers. However, it should be noted that CWT data, being collected by humans, and can sometimes have errors associated with it.

Ventral field – That part of the scale that, in situ, lies closest to the bottom of the fish (the fish’s “belly”). Compared with the dorsal field, the ventral field is somewhat tapered.

Winter steelhead – Steelhead that enter freshwater late (during the winter) to spawn the following spring. The salt water zone on the scales from these fish is aged by counting the summers (growth periods between annuli).

Yearling – Chinook life history strategy of emigrating to the ocean after reaching its second year of life post-hatch.

APPENDIX 1: ACRONYMS

cc: Circuli count.

CCRMP: Coastal Chinook Research and Monitoring Program.

CROOS: Collaborative Research on Oregon Ocean Salmon.

CWT: Coded-wire tags.

CWTIT: Coded-Wire-Tag Improvement Team.

FLHAP: Fish Life History Analysis Project.

MEPS: Mid-eye to posterior scale.

OASIS: Oregon Adult Salmonid Inventory and Sampling.

ODFW: Oregon Department of Fish and Wildlife

OSCRP: Ocean Salmon and Columbia River Program.

PIT tags: Passive-integrated transponder tags.

MRP: Marine Resources Program.

RMIS: Regional Mark Information System.

SARs: Smolt-to-Adult Ratios.

APPENDIX 2. CHINOOK SALMON

The Fish Life History Analysis Project (FLHAP) analyzes scales of more Chinook salmon than any other species. Whereas we have read Chinook scales from all parts of Oregon, our focus is on coastal, and Willamette, and Sandy, and Hood River stocks. The Oregon Department of Fish and Wildlife (ODFW) research group in LaGrande reads Chinook and steelhead scales from the NE region, although in the past we have assisted in training their staff and lend support as needed. The Deschutes River Research projects read their own scales with occasional support from FLHAP. Scales collected during Columbia River management activities are usually read by staff in Clackamas.

Juvenile life histories of Chinook salmon have been characterized by Rich (1920) as ocean or stream type. Ocean type juveniles migrate to the ocean as sub-yearlings, usually early enough in the year that part of their first summer is spent in the ocean. Stream type juveniles stay in the freshwater through their entire first year and migrate during their second spring. In Oregon, most of our coastal Chinook fall in between these two life histories. They tend to drop down out of freshwater similar to an ocean type juvenile but then they spend the summer in the estuary with ocean migration occurring in the fall. We are calling these estuary type.

Oregon has both spring and fall stocks of Chinook salmon. Both races occur in coastal rivers and those that are tributaries of the Columbia River (inland stocks). Generally, coastal spring Chinook migrate to the ocean as estuary-type sub-yearlings and mature at ages 2-6. Inland spring Chinook tend to migrate to the ocean as yearling or stream type juveniles and mature at ages 3-5. Coastal fall Chinook migrate to the ocean as estuary-type sub-yearlings and mature at ages 2-7. Inland fall Chinook migrate to the ocean as ocean-type sub-yearlings and mature at ages 2-6.

There are 63 coastal rivers of which 16 support large Chinook salmon populations and another 10-15 have small populations. The Willamette River has five important subbasins with Chinook populations and is possibly the most complex river in our state due to the variability of the Chinook populations and the degree of human impact on the river. To analyze Chinook scales, it is important to understand the life history of each system. Keep in mind that any fish can do anything, but most will follow a common life history and knowing this will make analysis easier. For example, most coastal fish will be estuary-type sub-yearlings at ocean migration but you may find a fish that followed a yearling life history in every population.

COASTAL CHINOOK

Background Information

Life History: A brief summary of life histories observed in coastal fish is given in Table A2.1. A discussion of how information in the columns effects scale interpretation follows the table. A more detailed discussion of this information is given by Nicholas and Hankin (1988).

Table A2.1. Life history characteristic of coastal Chinook salmon stocks.

Basin	Race	Juvenile life history	Estuary rearing	Extended river rearing	Time of ocean entrance	Ocean migration	Misc.
Nehalem	Fall	Sub-yearling	Yes	Some	Late summer/ Fall	North	Spring or summer run exists
Wilson	Fall	Sub-yearling	Yes	Yes	Late summer/ Fall	North	
Trask	Fall	Sub-yearling	Yes	Yes		North	
Trask	Spring	Sub - yearling	Yes			North	Spring run juveniles mix with CHF
Nestucca	Fall	Sub-yearling	Yes	Yes	Late summer/ Fall	North	
Nestucca	Spring	Sub-yearling	Yes			North	
Salmon	Fall	Sub-yearling	Yes		Summer/ Fall	North	
Siletz	Fall	Sub-yearling	Yes	Yes	Late summer/ Fall	North	
Siletz	Spring	Sub-yearling	Yes			North	Spring run juveniles mix with CHF
Yaquina	Fall	Sub-yearling	Yes		Late summer/ Fall	North	
Alsea	Fall	Sub-yearling	Yes	Some	Late summer/ Fall	North	
Alsea	Spring	Sub-yearling	Yes			North	
Siuslaw	Fall	Sub-yearling	Yes		Late summer/ Fall	North	
Umpqua	Fall	Sub-yearling	Yes			North	

Basin	Race	Juvenile life history	Estuary rearing	Extended river rearing	Time of ocean entrance	Ocean migration	Misc.
Umpqua	Spring	Yearling, sub-yearling	Yes	Yes	Spring and fall	North and South	
Coos	Fall	Sub-yearling	Yes		Late summer/ Fall	North	
Coquille	Fall	Sub-yearling	Yes		Late summer/ Fall	North	
Sixes	Fall	Sub-yearling	Yes		Late summer/ Fall	North	
Elk	Fall	Sub-yearling	Slight	Some	Summer	North, some south	Adult run extremely late fall
Rogue	Fall	Sub-yearling	Slight	Yes	Summer	South	
Rogue	Spring	Sub-yearling	Slight	Yes	Summer	South	Some yearlings
Chetco	Fall	Sub-yearling	slight	Yes	Late summer	South	

Race: It is necessary to know the race of the fish so that the scale analyst can know how to interpret the edge of the scale. Because spring Chinook return to freshwater (FW) in the spring, there will be an annulus and possibly a few circuli of “spring” growth on the edge of the scale at that time. As the spring Chinook holds in FW until time to spawn in late summer-fall, they do not grow and will resorb their scale edges so the spring growth and possibly the last annulus will be lost. Fall Chinook enter FW in the fall and will have grown during their last summer, though by late summer they are putting more energy into gonad production. The edge of their scale will have a band of wide spaced, summer circuli ending with a band of narrowing circuli representing the gonad check. The gonad check looks a lot like an annulus but should not be counted as such. “Summer” growth on the edge of a ragged scale from a spring Chinook usually means an annulus has been resorbed (and should be added to the annuli count) while summer growth on the edge of a ragged scale from a fall Chinook means the gonad check has been resorbed and no adjustment to the annuli count is needed

Time of ocean migration: For scale analysis, it is useful to know time of ocean migration to be able to predict space between ocean entrance check and the first annulus. The earliest, ocean type fish may have so much summer growth between ocean entrance and the annulus that you might be tempted to count that annulus as the second annulus—it may be as far out on the scale as a second annulus on a late sub-yearling or a yearling. Late summer to fall migrants may not have any summer growth between ocean entrance and the first annulus. Without the change in circuli spacing, the beginning of the annulus is not obvious. The annulus may be a vague band that is difficult to define—but it’s there.

A big variation on time of ocean migration for coastal stocks is the spring migrating (stream-type) yearling. These may occur in any basin but are more common in Umpqua spring Chinook. They are best identified by a “tight” FW zone followed by “good” ocean summer growth and a well formed SW annulus that is “far” out on the scale. They will not have the vague band of “medium” spaced circuli following ocean entrance like the fall migrating, estuary-type migrants.

River and Estuary Rearing: Being aware of amount of river or estuary rearing may help understand FW patterns. Coastal fish that rear in a river where conditions become limiting early in the summer (such as in Siuslaw or Yaquina), then pass into the estuary may have a pattern that looks a lot like the FW pattern of a NE Oregon yearling (or a coho). It looks like a band of tight circuli followed by much wider circuli which is a lot like a FW annulus followed by “spring” growth. Because the life history has been documented in these fish (Nicholas and Hankin 1988), we know it is not an annulus but a combination of river and estuary growth. Alternately, coastal fish that have extended river rearing may seem small at ocean entrance and lack improved estuary growth.

It is useful to know ocean migration patterns for each Chinook stock to set work priorities: management meetings for North migrators usually happen before the meetings of the South migrators in the Klamath Management Zone (KMZ). In many years, north migrators have more obvious annuli compared to south migrators but this depends on ocean conditions. Appearance of ocean annuli will be somewhat consistent between all populations that go to the same area in the ocean.

Size-at-age trends: Chinook have good size-at-age length trends, meaning there is a correlation with size and age. Of course, these trends can be offset by life history, with spring Chinook that have yearling life histories and lack the last summer of ocean rearing tending towards smaller body sizes than fall Chinook of the same age. Also note that substantial overlap in body size can occur across age classes. Table 2 provides some size-by-age associations that should be viewed as a rough approximation only.

Table A2.2. General size-by-age associations for Chinook.

Total age	MEPS length (mm)	FL (mm)
2	< 500	*Add ~8 to MEPS (bigger fish, bigger diff.)
3	500 – ~700	*Add ~10 to MEPS (bigger fish, bigger diff.)
4	>700 – low 800s	*Add ~12 to MEPS (bigger fish, bigger diff.)
5	Lots of overlap with 4s	*Add ~15 to MEPS (bigger fish, bigger diff.)
5 and 6	No discernible difference	*Add ~15 to MEPS (bigger fish, bigger diff.)

Origin: We can estimate hatchery vs. wild origin with some confidence only in the Chetco, Winchuck, and Elk rivers because these basins have minor to no estuaries so

FW growth is mostly riverine and the wild juveniles tend to enter the ocean in mid-summer. The hatchery source for these basins is Elk River hatchery which releases juveniles in the fall at relatively large body sizes, causing them to have fairly different scale patterns from the local, wild juveniles (Figure A2.1).

The scale patterns of wild and hatchery fish in the other coastal basins are not sufficiently different to allow confident identification of origin. The hatchery fish are released at the same time the wild juveniles are migrating to the ocean and the estuaries in the other coastal basins allow wild juveniles to be comparable in size to the hatchery juveniles at ocean entrance.

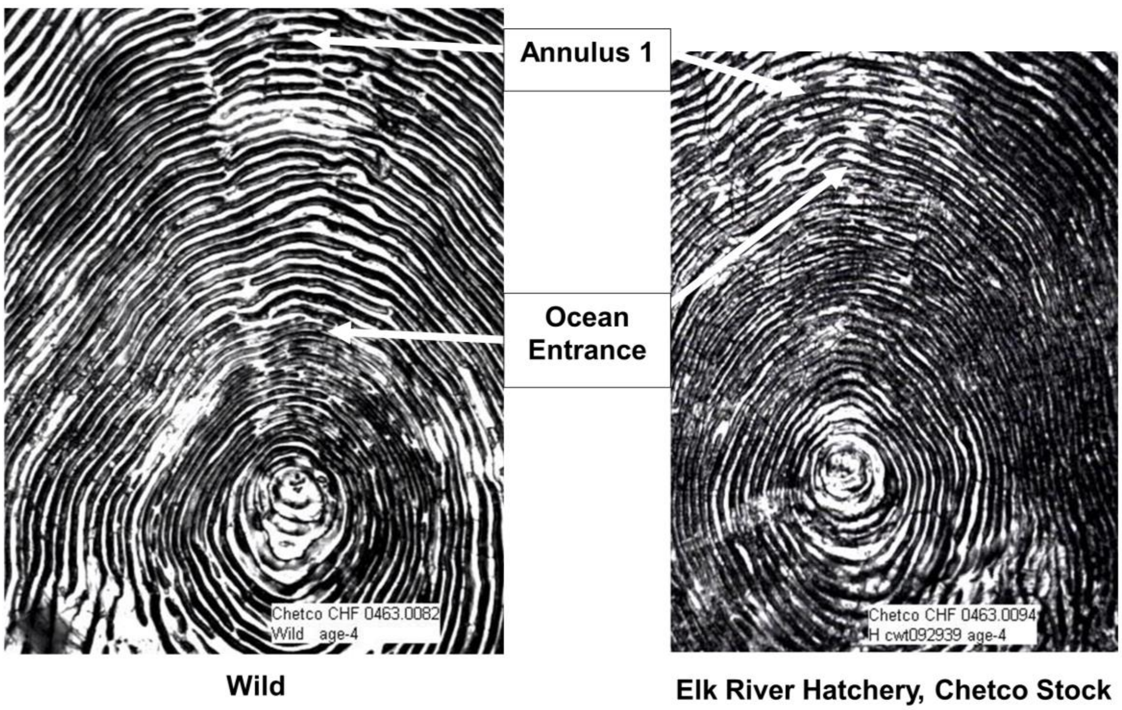

Figure A2.1. Scale patterns from wild and (CWT) hatchery Chinook from the Chetco River.

Basin specific observations:

- Miller et al. (2012), working with OSU colleagues, report on evidence of a genetic difference between the early-run (fall) and late-run (spring or summer) Chinook in Nehalem.
- The following are considered important basins for monitoring for the Pacific Salmon Treaty:
    - North Oregon Coast (NOC) aggregate
        - Nehalem (Escapement Indicator)
        - Siletz (Escapement Indicator)
        - Siuslaw (Escapement Indicator)
        - Salmon River (Exploitation Rate Indicator)
    - Mid Oregon Coast (MOC) aggregate
        - Coquille (Proposed Escapement Indicator)
        - South Umpqua (Proposed Escapement Indicator)
        - Elk River (Proposed Exploitation Rate Stock)
- Siuslaw: Has some of the biggest smolts around (tremendous growth with resultant huge freshwater zones). The fish are relatively large at the 1st marine annulus.

- Umpqua, Coos, and Coquille basins tend to have some of the most degraded fall Chinook scales, including the final annulus missing on some of the fish scales.

<u>Validation</u>

Age: Wherever possible, FLHAP seeks to obtain scales from CWT-fish as a means of validating our age estimates from scales. Typical agreement rates between ages determined from CWT information and age estimates from scales for the FLHAP are > 91 – 97%, and typically 95 – 97%. With two exceptions, all fish with CWTs and thus known ages have been hatchery fish. In 2002, wild fish were captured and tagged in the Siuslaw River; scale ages agreed with CWT ages at the rate of 98%. In 2012, the CCRMP began implanting CWTs in wild fish in the Salmon River. The earliest returns of these fish will be in 2014. CWT fall Chinook are released from Salmon River and Elk River hatcheries as well as various STEP programs. CWT spring Chinook are released from Trask Hatchery, Cedar Creek Hatchery, Rock Creek Hatchery, and Cole M. Rivers Hatchery.

Origin: Our origin validation has been one-sided, usually with validation of hatchery fish only, due to the recovery of a CWT. As noted above, only once, Siuslaw River tagged in 2002, have we had wild Chinook with CWTs. In that case, there were no hatchery releases, so again it was a one-sided validation. In the Elk and Chetco rivers, where there are releases of "100%" fin-clipped hatchery fish from Elk River Hatchery we cannot assume that all unmarked fish are wild for validation purposes. A small percentage of hatchery fish are poorly clipped or regenerate their fins so there will always be some doubt about the origin of fish with intact fins.

Reference scales: We have multi-year scale collections of CWT hatchery fish from Salmon River Hatchery and Elk River Hatchery sampled from sport fisheries, spawning grounds, and hatchery returns. We also have scales from miscellaneous STEP activities that have reared juveniles to smolt stage and CWT them before release. Because we have documented the juvenile life-histories in most of the coastal basins to be mostly sub-yearlings, the same age as the hatchery fish, we feel that we can use hatchery fish from the same return year as a reference for ocean age of wild fish.

Willamette River Basin Chinook

Life History Background Information

In his work on Chinook from the Willamette River, Mattson (1962) reported the first data on age estimates, growth and outmigration timing from 1947 – 1951. This data is considered the closest approximation to a "baseline" for populations of Willamette Chinook. However, when considering the potential for a baseline comparison of Mattson's data to more contemporary dates, some considerations are necessary:

- Some river impoundment within the Willamette Basin had already occurred at the time of Mattson's studies.
- Only 2 sampling stations were used, including:
    - "A station for 'residents' in the Molalla River, ~ 2 miles below the mouth of the North Fork Molalla; and
    - A station for 'migrants' to the ocean in the lower, mainstem Willamette above Oswego."
- Mattson (1962) sampled *outside* of the preferred key scale sampling location described in Nicholas and Van Dyke (1982).
- The angle of measurement for circuli differs from the 20^o angle typically used for scale analyses (see elsewhere in this manual).

Pertinent observations from Mattson (1962 and 1963).: Three periods of emigration to the ocean:

- Late winter-spring (1^{st} spring or summer = "FINGERLINGS"; 8-10 months old [FL = 37 – 100 mm]), ≤ 55% of a year class;

- Fall-early winter (≥ 1 year old; October – December [FL = 100 – 150 mm]), ≤ 50% of a year class; and
- 2nd spring migration (15 – 19 months; February – first of May [FL = 100 – 140 mm]), ≤ 33% of a year class.

- [These three distinct migratory periods may equate with “ocean” (CH-0), “estuary” (CH-1), and “stream” migrants (CH-1+).]
- Freshwater annuli occur between 10th and 20th circuli
- Freshwater annuli formed by 4 – 6 circuli.
- Distinguishing between yearlings and sub-yearlings:
    - Fingerling: Mean number of FW circuli at time of emigration = 9 – 11.
    - “Sub-yearling”: Mean number of FW circuli at time of emigration = 20 – 35.
    - Yearlings: Mean number of FW circuli at time of emigration = 19 – 25.
- “Depending upon their size at time of movement, some migrants exhibited accelerated scale growth, comparable to brackish or marine growth found on adult scales; this has been termed ‘superior freshwater growth’. Comparisons were made of migrant and adult scale growth patterns to show similarities, which were striking in many cases.”
- “Rich (1920) observed an accelerated type of freshwater growth on scales of young salmon from the lower reaches of the Columbia which he called ‘intermediate’. These intermediate rings represent a period of growth more rapid than normal growth in freshwater and yet not as vigorous as true ocean growth.”
- “Age and weight data were obtained from sport-caught salmon because later in the summer the scales are absorbed, aging becomes impossible, and weight is lost.”
    - Age-3 mean FL = 25.0” (635 mm)….~50% yearlings, 50% sub-yearlings
    - Age-4 mean FL = 30.6” (777 mm)….~70% yearlings, 30% sub-yearlings
    - Age-5 mean FL = 33.9” (861 mm)….92% yearlings, 8% sub-yearlings
    - Age-6 mean FL = 37.3” (947 mm)….MOST were yearlings.
- “In eight marking experiments using Willamette River stocks and involving 421 recoveries, Rich and Holmes (1929) found that 5 year old adults predominated, 6 year olds returned in larger numbers than 4 year olds, and only a few 3 year olds were recovered.”

We believe the juvenile life histories described by Mattson still exist in Willamette subbasins. Currently, there is not a viable population in the Molalla River where he sampled but Clackamas, North Santiam, South Santiam, McKenzie, and the Upper

Willamette subbasins support populations with fingerling, sub-yearling, and yearling juvenile life histories. Because of slight changes in current methods (key area collection, different reference line), circuli counts differ between Mattson's and our recent work. The age compositions of returning adults in the current 5 subbasins and the Sandy river have changed since Mattson's study. The age-4 and age-5 fish fluctuate in dominance by subbasin and year. Age-3 fish are still sparse while age-6 are barely more plentiful that 3 year olds and nowhere near as plentiful as 4 year olds as they were in 1929.

In 1997, using analyses of fish scales, ODFW's Fish Life History Analysis Project originally reported on life history diversity of Willamette River Chinook, including a life history pattern that appears to be remarkably similar to what ODFW personnel have more recently been identifying as "reservoir-reared juveniles": "The most common pattern…indicated a large size at ocean entrance with the freshwater annulus and ocean entrance superimposed as if the fish had migrated in the winter" (Lindsay et al. 1997). A high proportion of these potential "reservoir-reared juveniles" were age-4 adults returning to the McKenzie River. They concluded that the prevalence of this life history type could not be fully attributed to hatchery releases or strays (Lindsay et al. 1997). More recent work on otolith microchemistry (Caudill et al. 2011; Bourret 2013) and various other data sources (Keefer et al. 2012) have confirmed that some juveniles do rear in reservoirs. A recent encouraging comparison of scale morphology and otolith microchemistry suggests a high concordance. This suggests that scale analyses can be used to effectively identify life history (rearing) types of juveniles (Caudill et al. 2011; Bourret 2013). In spite of this corroborative evidence, this pattern remains controversial.

Further insight of life history diversity has come from comparisons of age estimates from scale reads with genetic pedigree analyses; collections of scales from juveniles in reservoirs, and screw traps at the base of dams; and scales from late fall juveniles from Leaburg Dam (McKenzie River) corresponding with reservoir draw-down.

While trying to work out if the large pattern with superimposed FW annulus and ocean entrance check was related to reservoir rearing, it was dubbed, pattern "X". The FLHAP has slowly realized through different lines of evidence that this pattern is correlated with reservoir-rearing for one year. Therefore, pattern "XX" = reservoir rearing for two years; and pattern "SX" = rearing in cooler streams in the upper watershed(**s**tream) for one year, plus subsequent rearing in the reservoir during a second year (Figure A2.2).

Areas needing validation

Based on McKenzie Chinook, we have found that yearlings generally have ≥ 50 circuli between the nucleus and the last circulus on the 1st marine annulus. Therefore, if one counts ~50 circuli (± ~5 circuli) to the end of the 1st marine annulus, then there *should* be a FW annulus prior to this marine annulus. This is a rule of thumb only, and we have found exceptions to it. Nevertheless, we have also found fairly good agreement between this relationship of circuli count, 1st marine annulus, and the presence of a FW annulus among stocks of Willamette and coastal Chinook.

The FLHAP is working with researchers to help validate the life history patterns noted above. Specifically, we are working with researchers who are using otolith microchemistry to assess saline signatures, through strontium ion profiles in the otoliths, and we are working with colleagues at ODFW to bolster scale information with tag-recapture data and with known reservoir-rearing fish. Finally, we are exploring different scale measurements to identify diversity in freshwater rearing — both growth and age — through graphical comparisons of an invariant number. Preliminary examinations indicate that this approach shows promise in identifying diversity in freshwater rearing. The invariant number is calculated as:

(Fork length * scale radius to freshwater annulus 1^{-1}) * Circuli count for annulus 1.

Finally, we will soon be purchasing otolith equipment for processing and reading salmonid otoliths. We will be exploring techniques to use these otoliths to supplement and complement our age estimates and identification of putative life history types.

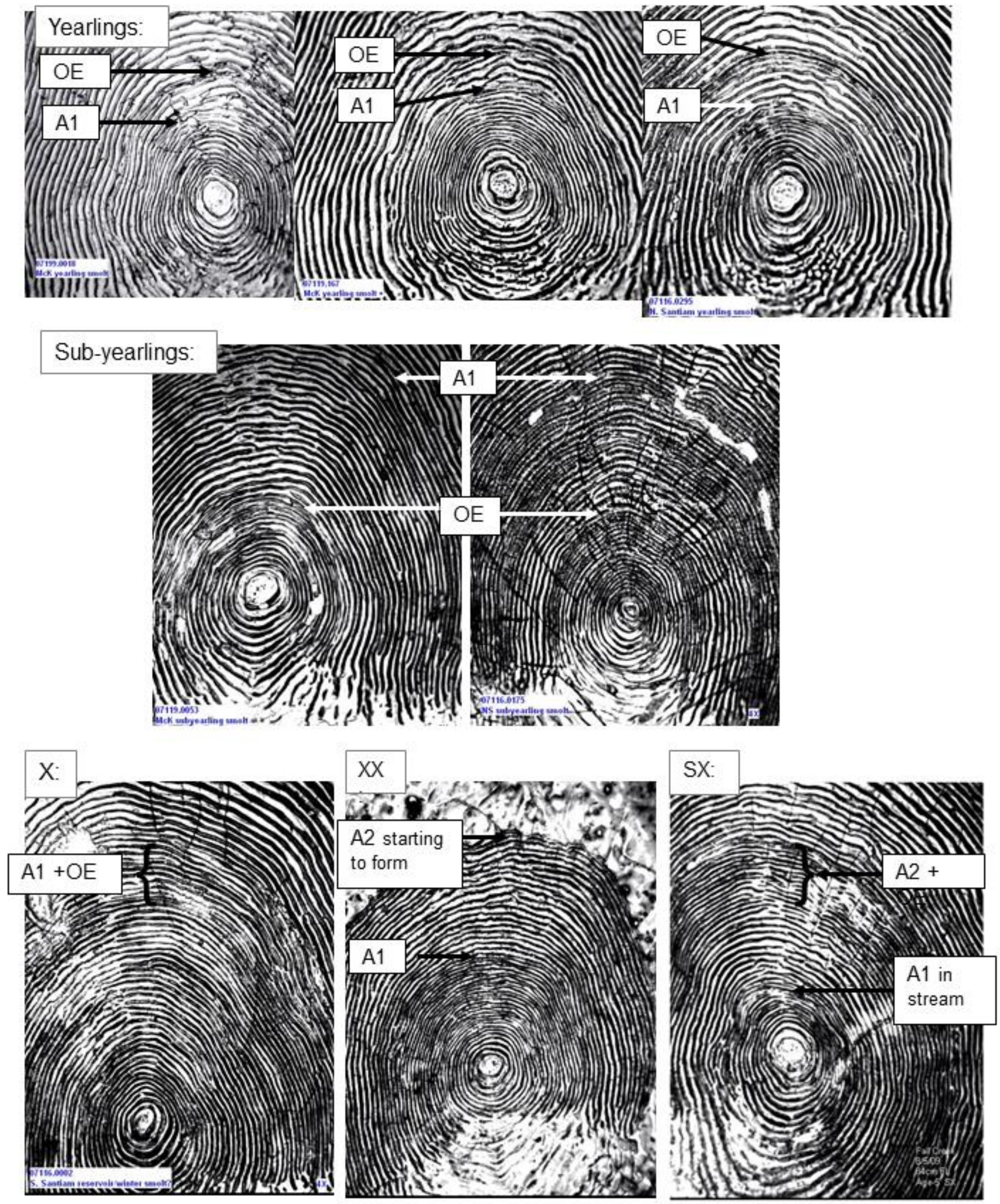

Figure A2.2. Five different freshwater life histories observed within the Willamette basin. Patterns “X”, “XX”, and “SX” are different FW life histories that are defined in the text. OE = ocean entrance, A1= Annulus 1, A2=Annulus 2.

Reference samples

Reference samples from lower Willamette fishery below Willamette Falls are provided by Kevleen Melcher of Clackamas ODFW. These scales reveal an annulus near the edge of the scale. This seems to agree with Mattson's observation that, "Some of the scales from spent fish were approximately half their original size, and possibly 1 or even 2 annuli may have disappeared." (1963).

Identification of unclipped fish via thermal marks on otoliths

Currently otolith samples are sent out to the Washington Department of Fish and Wildlife to assess the presence of hatchery thermal marks to thereby identify hatchery fish that may possess adipose fins. We anticipate taking over this work as we get settled in using our otolith processing and reading equipment.

Age validation

Coded Wire Tagged Fish

Validation between age determination by CWTs and age estimation by fish scales yields an ~91% agreement rate; this is lower than for coastal Chinook, perhaps for three reasons: 1) the greater diversity of life history types in the Willamette (Figure 4); 2) the greater presence of hatchery fish, some of which may be unclipped; and 3) the more degraded nature of the Willamette scales.

More recently Willamette BiOp personnel have been getting the otolith scores for all unclipped fish to verify their origin (hatchery fish in the Willamette will have thermal bands from temperature variation designed to create those bands for the purposes of origin identification). This is helpful in parsing out hatchery from wild fish so that the scale reads for putative life history types can be focused only on wild fish (FLHAP has not had success in identifying hatchery fish from wild fish based on scales alone).

Genetic pedigrees

Chinook salmon trapped at Cougar Dam on the SF McKenzie River are released above the dam in Cougar Reservoir. These fish are fin clipped for a genetic pedigree study. Given these are live fish, otolith scores are not available. The Genetic Pedigree study matched adult offspring to parents that had been placed above Cougar Reservoir to spawn. The adult offspring were trapped immediately downstream of Cougar Dam upon return from the ocean. Because the parents and offspring were sampled on known dates, we can determine the brood year and age of the adult offspring to validate the scale ages. Validation rate for scale reads has been in the high 70 to high 80 percentiles for age-4 and age-5 fish for 2011 and 2012. Further comparisons and data QA and QC are currently underway, including examining potential sources of error for the pedigrees. While the results of the pedigree study can't corroborate the length of time the offspring spent in the reservoir or the juvenile life history, it does prove that they survived passage through Cougar Dam

Hood River Chinook

Spring and Fall races of Chinook salmon exist in Hood River. The fall Chinook population is considered extirpated though strays and a small amount of natural production still spawn each year. The juvenile life history of the spawners is a subyearling that appears to be an early summer migratory (ocean-type). We were unable to discern hatchery patterns from wild patterns. The wild spring Chinook salmon migrate to the ocean as both subyearlings and yearlings. Hatchery fish are released as yearlings and are "100%: finclipped. All hatchery fish carry an adipose fin clip as well as a maxillary clip or ventral clip specific to a single release year. The double clips, while not as exact as CWT, corroborate the scale age.

John Day River

Criteria were developed in 1987 for reading scales from John Day spring Chinook. When these scales are collected from spawners, there is a high degree of resorption. There are no hatchery fish released in the John Day River.

John Day Spring Chinook 1987

Criteria for when to add an annulus

SITUATION:

1. Add 1 to visible annulus count. The last visible annulus is not on the scale edge. Several complete circuli of summer growth exist between last visible annulus and scale edge.

2. Do not add to count of visible annuli. The annulus or part of the annulus might be on the edge. The edge might have narrowing for annulus or "pre"-annulus. Last full annulus is far from edge and what could be a full summer's growth zone exists between last full annulus narrowing on edge. Part of the posterior field should still exist and radial striations may also show. Count narrowing on edge as the last annulus.

Many scales do not neatly match the above situations. Here are some guidelines to follow when its not clear which situation you are dealing with.

a. If any summer circuli are complete around the entire scale edge, this is situation #1.

b. If there might be summer circuli beyond an annulus on the edge but you're not sure, consider this situation #2.

c. The edge of the scale is so broken that in some places the annulus is on the edge and in other places summer circuli are on the edge. If the posterior edge is virtually gone and summer sirculi show along 4 inches or more of the scale edge, consider this as situation #1 and add 1 to annulus count.

d. If part of the posterior field is still present and summer circuli show along less than 4 inches of the scale edge, consider this as situation 2 and do not add to the annulus count. Count the last visible annulus as the last annulus.

When to throw out a scale

Since the vast majority of these spring chinook are yearling migrants, you can still age the scale if there is regeneration in the freshwater zone. Assume there is a freshwater annulus.

If the regeneration extends beyond the freshwater zone and you feel that you may be missing a saltwater annulus, throw the scale out.

If the scale is so resorbed that the posterior field is completely gone and the "bottoms" of the circuli are worn off, consider throwing the scale out. Two annuli may be missing. If the scale is in really bad shape and the fish length is way too large for the age you've assigned, look carefully at the posterior field and bottoms of the circuli.

Upper Columbia and Snake River Chinook

Spring and summer races exist. All juveniles seem to migrate as yearlings with a FW annulus followed by spring growth on their scales. In the past we identified hatchery or wild origin using discriminant analysis on samples collected for the Lower Snake Compensation Plan (Messmer et al. 1990) and for NOAA Fisheries' barging study (Borgerson and Bowden 1993)

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