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Grays Harbor Fall Chum Salmon (Oncorhynchus keta) Abundance and Distribution- Final Report, 2015-2020

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Executive Summary

Background

Pacific Salmon (*Oncorhynchus* spp.) are an important economic and ecological resource in the lower Chehalis River system (Nelson and Reynolds 2014). The goals of this project were to improve estimates of Grays Harbor Fall Chum Salmon (*O. keta*) spawner abundance and describe the distribution of this species throughout the sub-basins of Grays Harbor. Grays Harbor Chum Salmon populations include spawners within the Chehalis River Basin, Humptulips River Basin, and smaller tributaries that empty into the south of Grays Harbor. Washington Department of Fish and Wildlife (WDFW) and the Aquatic Species Enhancement Plan Technical Committee of the Chehalis Basin Strategy (Aquatic Species Enhancement Plan Technical Committee 2014) identified spawner abundance, distribution, and mapping areas of key spawning habitats of Grays Harbor Fall Chum Salmon as key information gaps in the Chehalis River basin. The current method for estimating Chum spawner abundance, developed in the 1970s, is based on a biased and assumed correlation between the overall escapement goal and the relative proportion of spawners in each index section. The method does not account for changes in spawning habitat or distribution of Chum Salmon within the basin.

Pacific Salmon (*Oncorhynchus* spp.) are an important economic and ecological resource in the lower Chehalis River system (Nelson and Reynolds 2014). Chum Salmon spawn in large aggregations and provide important marine-derived nutrients to the ecosystem. Identifying Chum Salmon spawning “hot spots” in the Chehalis River basin can inform restoration activities by:

1. Ensuring that restoration activities enhance these critical “hot spots”.
2. Highlighting areas that will benefit Chinook and Coho Salmon and Steelhead juvenile production through protection of habitats with large nutrient imports.
3. Targeting areas for Chum Salmon restoration to sustain populations in the future.

Methods

Several approaches were employed to determine Chum Salmon escapement. These included (1) area-under-the-curve (AUC), a method of using periodic counts over the entirety of the Chum Salmon run to generate season totals in set areas, (2) carcass mark-recapture (CMR), a method for independently generating an estimate from tagging and tag recovery based on a Jolly-Seber abundance estimator for open populations, and (3) peak expansion, a method of comparing Chum Salmon observed within the weekly index surveys with supplemental surveys (one-time surveys) during peak spawning performed throughout the rest of basin to expand the estimate from the indexes.

Survey life is the apparent residence time of Chum Salmon in the observed stream and includes both the actual residence time of the fish and the observer’s efficiency. Estimates of survey life are crucial for escapement estimation. By pairing AUC and CMR methods in the same indexes we were able to generate independent estimates of survey life. The independent survey life values were then used in combination with the other AUC indexes to generate an estimate for all indexes within the basin.

$$Escapement\ Estimate = \frac{AUC\ Fish - days}{Survey\ Life}$$

Three approaches were used to refine escapement estimates. First, index reaches were selected to estimate survey life in variable stream size classes – side channel, small, medium, and large. These were then applied to the remainder of AUC indexes based on their stream size. Second, live counts were separated into spawner and holder counts or total live counts. Spawner counts represented Chum Salmon holding or actively spawning on spawning habitat, while holders represented Chum Salmon holding in pools or not actively spawning. Total live counts represented a combination of holder and spawner counts and were used when counts were not separated. Escapement was calculated from spawner counts and total live counts separately.

Finally, due to the size of the Grays Harbor basin, it was divided into four sub-basins: Humptulips, Wynoochee, Satsop, and “Other” (i.e., all other Chum Salmon streams including Wishkah, Hoquiam, Cloquallum, and Black rivers, and South Bay tributaries). One sub-basin was selected as the focus each year; in 2020 that was the “Other” sub-basin. In the non-focus basins, annual indexes were surveyed for other species, but Chum Salmon counts were leveraged from these surveys and distribution information applied from a previous year when the basin was the focus to apply a ratio of Chum Salmon inside these indexes to those not covered.

Results

The new or “updated” 2020 escapement estimate for Grays Harbor Basin Chum Salmon spawner abundance was 48,294 (CV = 2.2%) with 95% probability interval of 44,597 and 52,250. The historic or “current” method produced a point estimate of 23,457 with no estimate of precision. The “current” method was 49% lower than the “updated” method. Of the 2020 focus streams using the “updated” method, Wishkah sub-basin had the highest contribution with just over 4,300 Chum Salmon, while Hoquiam and Cloquallum sub-basins both contributed less than 500 chum each. Both Black River and the South Bay tributaries each contributed less than 30 fish to the total Chum Salmon abundance estimate.

Important Study Findings

- Results from monitoring Chum Salmon over the study period suggest that the historic, or “current” method used to produce Grays Harbor Chum Salmon spawner abundance over the last 40 years may underestimate escapement by up to 50%.

- Chum Salmon distribution is widespread in the lower basin, however 90% of the population is spawning within the Humptulips, Wynoochee, and Satsop sub-basins.

- Survey life (measured in days) is the value used to define Chum Salmon residence time in streams and is a parameter in the AUC equation used to calculate abundance (fish). We found survey life was typically smaller in larger streams with greater average bankfull widths; survey life values in larger streams were nearly half those in smaller streams. Values of survey life incorporate residence time and observer efficiency.

- Using counts of fish on spawning habitat (spawner counts) as opposed to counts of all fish (total live counts) produced more accurate survey life estimates; therefore, we recommend that all counts separate spawners and holders.

- It is possible to generate escapement estimates in a large basin like Grays Harbor (4,184 km of river) with precision by measuring density, distribution, and unique survey life values at the sub-basin scale, then updating those values regularly to account for spawning abundance and distribution changes over time.

The findings from 2020 and previous years of the study may be used to inform restoration efforts for other salmon species within Grays Harbor. High-density Chum Salmon spawning locations should be considered when planning and implementing restoration activities. Low-density areas should be candidates for improving habitat for all salmon species. High density spawning areas provide important ecological role by spawning in high densities and providing marine-derived nutrients which benefit all aquatic species. Our work demonstrates that there are alternative methods that are accurate and repeatable with a measure of precision for estimating Chum Salmon spawner abundance in the Grays Harbor basin. In particular, this work indicates that studies based on carcass mark-recapture generate more accurate estimates of survey life and spawner abundance then the historic, or “current” method, and updating distribution information regularly is needed to maintain accuracy. This work provides critical guidance for practitioners looking to update and improve Chum Salmon escapement estimation methodology for management and conservation purposes, especially in large basins where intensive surveys are often impractical.

Introduction

Escapement estimates for the Grays Harbor Chum Salmon (*Oncorhynchus keta*) population have been derived by the Washington Department of Fish and Wildlife (WDFW) each year for the past 40 years. When the method was developed in the 1970s, it was considered hastily put together out of necessity and it was recommended that the method be updated as soon as possible (Brix 1978). Nevertheless, it continues to be used as the “current” method for estimating Chum Salmon escapement. The method assumes an escapement goal of 21,000 and measures abundance in four index reaches (Fig. 1). Overall escapement is then calculated from an assumed relationship between the overall escapement goal and the relative proportion of spawners in each index section.

In the year that the Chum Salmon escapement goal was set, the four survey indexes were assumed to contain 10.8% of the population. However, the original methods and data for determining both the escapement goal and the percent of population in the four indexes are no longer available, so the accuracy of these assumptions (escapement goal of 21,000 and proportion of spawning occurring in the four index reaches) cannot be evaluated. If the assumptions were accurate when the method was developed, to remain effective, the distribution of Chum Salmon and quality of spawning habitat in the reaches would have had to remain unchanged over 40 years. Yet, deviations in channel morphology show that changes have occurred in at least one of the four index reaches (Fig. 2).

This work presents an “updated” escapement methodology that is being developed for the Grays Harbor Chum Salmon population and relies on information collected at additional index surveys that cover the majority of spawning habitat, and supplemental surveys over the entire Chum Salmon spawning distribution in Grays Harbor. The “updated” method uses area-under-the-curve (AUC) calculations and results from carcass mark-recapture (CMR) studies to estimate escapement. This new method allows for potential changes in spawning distribution and habitat use over time and accounts for interannual variation in abundance and distribution due to environmental conditions. The updated escapement methodology presented in this study has broad applications across coastal Chum Salmon populations.

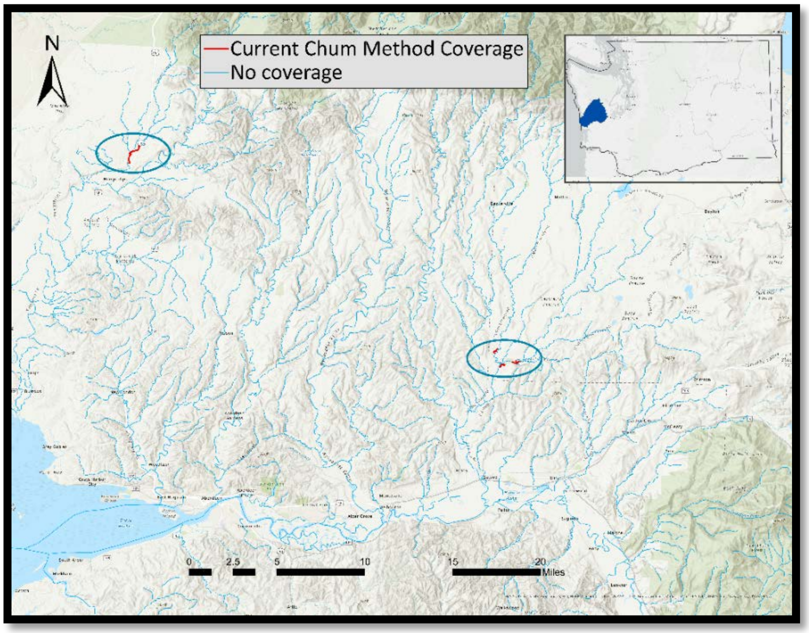


Figure 1. The coverage for current methodology for estimating Chum Salmon abundance. No coverage area includes the lower Chehalis River basin area where Chum Salmon either currently or historically have been reported.

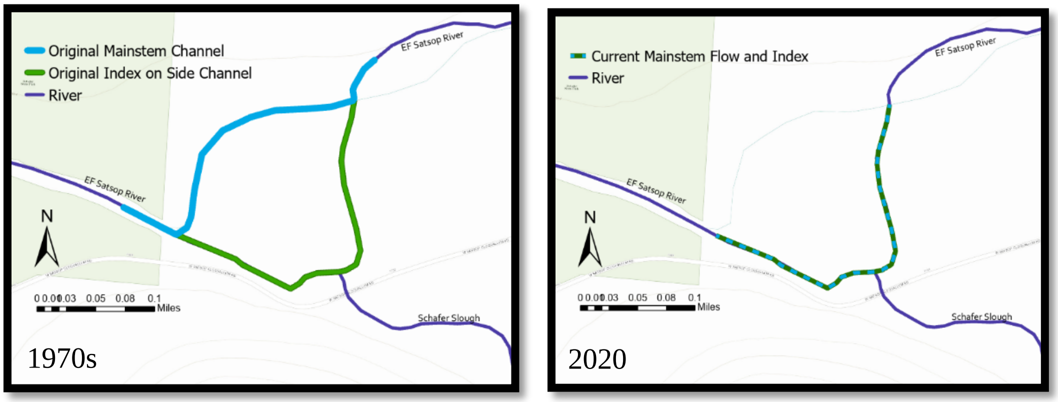


Figure 2. Original side channel index at time of current methodology implementation became the mainstem flow in the 1990's. EF Satsop River side channel is one of the four indexes used to determine abundance in current method.

Chum Salmon are important economically and ecologically in the lower Chehalis River system (Nelson and Reynolds 2014). Chum Salmon spawn in large aggregations and provide important marine-derived nutrients to the ecosystem (Naiman et al. 2002). Data on Chum Salmon abundance and distribution collected during Chinook and Coho Salmon surveys over the past 40 years, commercial catch, and angler observations in streams all indicate that the "current" escapement method consistently underestimated the annual number of Chum Salmon returning to Grays Harbor. In some years, low Chum Salmon abundance was cited as the reason to limit fishing opportunity in Grays Harbor.

A multi-year study was initiated in 2015 to improve methods for spawner abundance estimation and to better describe distribution of Chum Salmon in the lower Chehalis River Basin. After a year of preliminary data, a new escapement survey design was developed and implemented in 2016 and 2017 in the Wynoochee and Satsop sub-basins (Fig. 3) (Edwards and Zimmerman 2018). In 2018 and 2019, a further revised methodology was applied in the Humptulips sub-basin (Ronne et al. 2019). In 2020, the period covered in this report, focus shifted to the remaining sub-basins where Chum Salmon spawn but had not yet been surveyed using the updated methodology. For all years of the study, escapement estimates calculated using the "updated" methodology were consistently higher (150%-200%) than escapement estimates for the entire Grays Harbor Chum Salmon population using the "current" methodology.

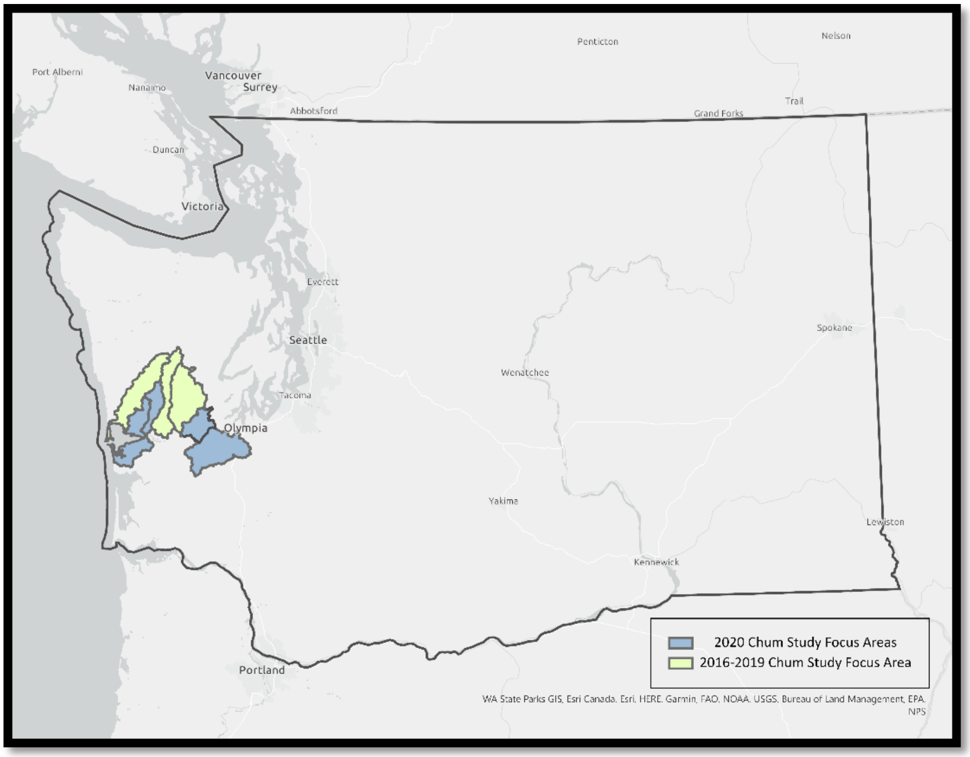


Figure 3. Overview map of Chum Salmon study focus areas.

Unlike Grays Harbor, Puget Sound uses an AUC escapement estimation methodology to determine Chum Salmon spawning escapement annually. The method was also developed in the 1970s (Ames 1984) but relies on weekly visual counts of live Chum Salmon in index reaches over the spawning timeframe. The Puget Sound AUC method assumes a 10-day survey life (days Chum Salmon are present in the survey area) regardless of steam size or environmental conditions, an assumption that is likely violated (English et al. 1992). Accurate survey life estimates in escapement calculations are important since AUC calculations generate the number of fish-per-day that are observed in a survey section. The AUC escapement equation is as follows:

$$Escapement\ Estimate = \frac{AUC\ Fish - days}{Survey\ Life}$$

For the “updated” escapement method, we identified survey life as an important value to consider. One of our main objectives in developing the “updated” escapement methodology was to determine whether survey life differs among different sized streams. In 2020, we generated survey life estimates in a new sub-basin (Wishkah River) using both a medium-large stream and a small stream. We strove to describe distribution in the remainder of the small sub-basins and creeks (South Bay, Hoquiam, Cloquallum, and Black rivers) that have potential for Chum Salmon presence.

Methods

Study Design

In 2020, we used a carcass mark-recapture (CMR) study to inform AUC and survey life calculations from index and supplemental surveys (Table 1, Fig. 4). The focus was South Bay, Wishkah, Hoquiam, Cloquallum, and Black rivers. Data generated from this work and previous distribution and survey life work in the Humptulips, Wynoochee and Satsop Rivers, were used to determine Chum Salmon escapement estimates in the Grays Harbor basin.

Table 1. Types of surveys conducted for Chum Salmon

Survey	Type	Frequency	Count Data	Biological Data
AUC (AUC only)	Index	Weekly (Oct – Dec)	Lives, Carcasses	Sex, Length, Scales
CMR (AUC and Carcass Mark-Recapture)	Index	Weekly (Oct – Dec)	Lives, Carcasses, Carcass Tag Recaptures	Sex, Length, Scales
Peak Count	Supplemental	Once (early to mid-Nov)	Lives, Carcasses	---

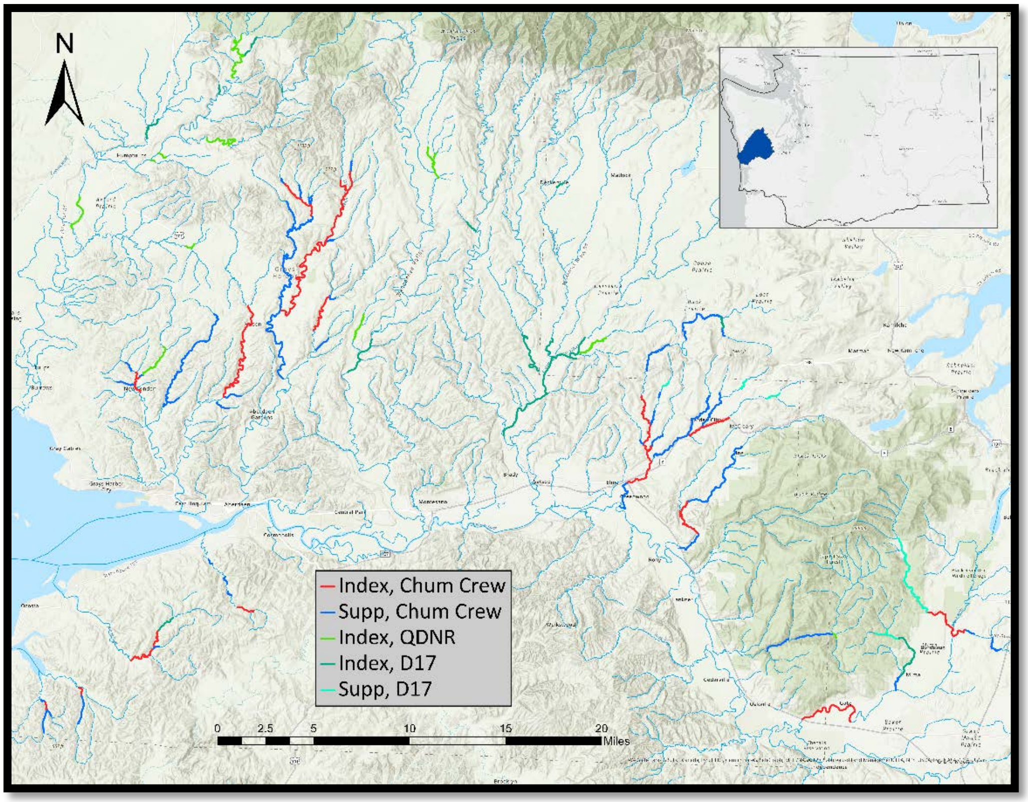


Figure 4. Index and Supplemental Surveys used for the "updated" methodology for escapement estimates. The Quinault (QDNR) and WDFW District 17 staff (D17) contributed chum counts in areas they surveyed for Chinook or Coho.

Area-Under-the-Curve (AUC)

Surveys in AUC indexes were conducted to obtain an estimate of fish-days for the selected reaches. Fish days were then divided by the survey life (combination of residence time of fish in the index and observer efficiency) to generate an estimate of abundance for that index. Surveys collected weekly counts of live and dead Chum Salmon. Live counts were split into two categories; “spawners” and “holders” based on their behavior and the type of substrate where they were observed. If Chum Salmon were holding, either they had yet to reach their spawning location or were not biologically ready to spawn. Fish designated as “spawners” are usually easier to identify and count accurately than “holders" because they are found in shallower water on spawning substrate. Using “spawner only” counts has been suggested as one way to reduce the error and increase the precision of the AUC estimates (Cousens et al. 1982, Parken et al. 2003, Rawding et al. 2014) as well as improve consistency from year to year and between basins. We produced two estimates of abundance in the Wishkah, Hoquiam and Cloquallum sub-basins, one using “spawners only” and the other the more traditional “total live” (spawner + holder) counts. Counts of Chum Salmon from other WDFW and the Quinault Division of Natural Resources (QDNR) crews surveying for Chinook Salmon or Coho Salmon were leveraged to increase the number of AUC indexes available for analysis. This data is collected on an annual basis, but currently there is no process for incorporating these counts into the ‘current’ Chum Salmon escapement method.

Carcass Mark-Recapture

The purpose of the studies within the CMR index reaches was to obtain simultaneous and independent estimates of fish-days and spawner abundance in order to derive estimates of survey life:

$$Survey\ Life = \frac{AUC\ Fish - days}{CMR\ Estimate}$$

Within CMR index reaches, AUC methods were employed for the live counts. Dead Chum Salmon were counted and utilized in a mark-recapture study for an independent estimate of survey life. An open population mark-recapture study design has several assumptions (Seber 1982):

1. *Equal Catchability*: Each carcass that is present during a sampling event, tagged or untagged, has the same probability of being sampled.
2. *Equal Persistence*: Each carcass, tagged or untagged, has the same probability of survival (i.e., persisting in the study areas to following sampling period).
3. *Tag Loss and Recovery*: Tagged carcasses do not lose their marks and all marks are recognized and recorded properly on recovery.
4. *Instantaneous Sampling*: The samples are instantaneous, (i.e., the time it takes to sample and release the sample is negligible).

Sampling methods were designed to minimize, as much as possible, any violations to these assumptions. Each dead fish was examined for tags placed the previous week and if no tags were present, fish condition was assessed to see if the fish was suitable for tagging (Fig. 5).

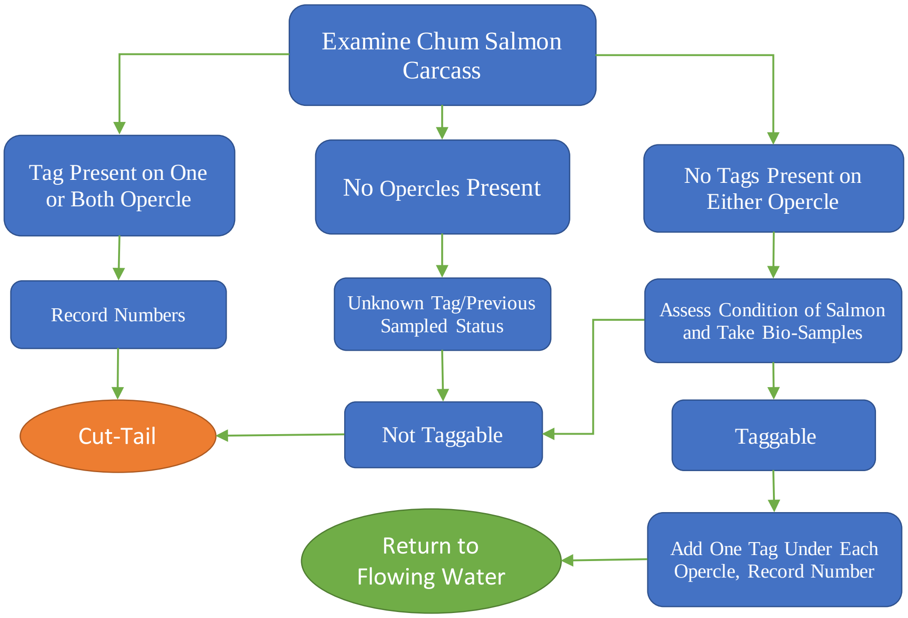


Figure 5. Chum Salmon carcass sampling flowchart.

It was important to examine both opercles for tags and note if a) tags were present, b) no tag was present but opercle was present, or c) if the opercle was missing. If a fish was recovered with one tag present on one opercle but no tag present on the other opercle, it was considered a tag loss on recapture. If the opercle was missing it was not considered a loss on recapture. If the fish was not tagged it was assessed to determine if the carcass was likely to survive until the next survey event.

Carcass condition was rated as follows and only conditions 1-3 were considered taggable:

1. Fresh, clear eyes, red gills, firm flesh, both opercles intact
2. Clear eyes, mostly firm flesh but may have some softening, white gills, both opercles intact
3. Cloudy eyes, flesh softer but intact, both opercles intact
4. Cloudy eyes, flesh very soft
5. Falling apart, skeleton

Carcasses considered taggable had one tag stapled under each opercle (Fig. 6) and the tagged carcasses were returned to a moving body of water so that they could mix with the remaining populations, termed “active mixing”. This was a change that occurred to the methodology in 2019. Prior to 2019, carcasses were returned to the locations where they were recovered and allowed to mix naturally; we termed this “passive mixing”. Surveys in CMR indexes were intentionally conducted in varying stream sizes in order to generate independent survey life estimates for large, medium, and small streams as well as a separate survey life to be used in the side channels.

Figure 6. Tag placement for carcass mark-recapture study of Chum Salmon.

Peak Counts

Peak counts, or supplemental surveys, were performed once at the peak of spawning. Supplemental surveys were designed to cover the distribution of Chum Salmon throughout a sub-basin not feasible to survey on a weekly basis. The intent was to perform all supplemental surveys within a sub-basin in a short period of time and at the same time as the index surveys within that sub-basin, to generate comparable values of density and distribution between the supplemental surveys and index surveys.

Distribution

Chum Salmon distribution throughout the 2020 survey frame was determined by both index and supplemental surveys. Index sections were selected in areas with the highest likelihood of Chum Salmon presence based on habitat, location, and presence observed or reported from local knowledge. The remaining distribution was determined during a one-time peak survey (supplemental survey) in as many areas as possible within the peak spawning period, given the resources available. In sub-basins with index surveys, the supplemental surveys were used to expand for fish seen in the index relative to the supplemental survey. In 2020, abundance estimates were calculated for the Humptulips, Wynoochee and Satsop sub-basins using 2020 index live counts and 2019 or 2017 distribution data (Ronne et al. 2019, Ashcraft et al. 2017).

Analysis

Spawner Abundance in CMR Index Reaches

Carcass tagging data were used to estimate spawner abundance in CMR index reaches. The carcass tagging data were analyzed with a Jolly-Seber (JS) estimator. The JS estimator is an open population mark-recapture model used to estimate abundance in situations where individuals immigrate and emigrate from the population over the course of the study (Seber 1982; Pollock et al. 1990). The JS model has been successfully applied to mark-recapture data of live fish and carcasses in other salmon populations (McIssac 1977; Sykes and Botsford 1986; Schwarz et al. 1993, Bentley et al. 2018). When the estimator assumptions are met, the JS model produces an unbiased estimate of abundance with known precision.

The JS estimator of spawner abundance estimate for each reach was based on the “super population” model (Schwarz et al. 1993) and parameterized in a Bayesian framework. A conceptual schematic of the JS model is shown in Figure 7 and a comprehensive description of this JS model, including summary statistics, fundamental parameters, derived parameters, and likelihoods can be found in Rawding et al. (2014) and Bentley et al. (2018). For this model, spawner escapement is the sum of gross births (i.e., arrival of new carcasses) that enter the system over the study period and includes the estimated number of carcasses present during each sampling period and the carcasses estimated to have entered the system after one sampling period and removed from the system prior to the next sampling period.

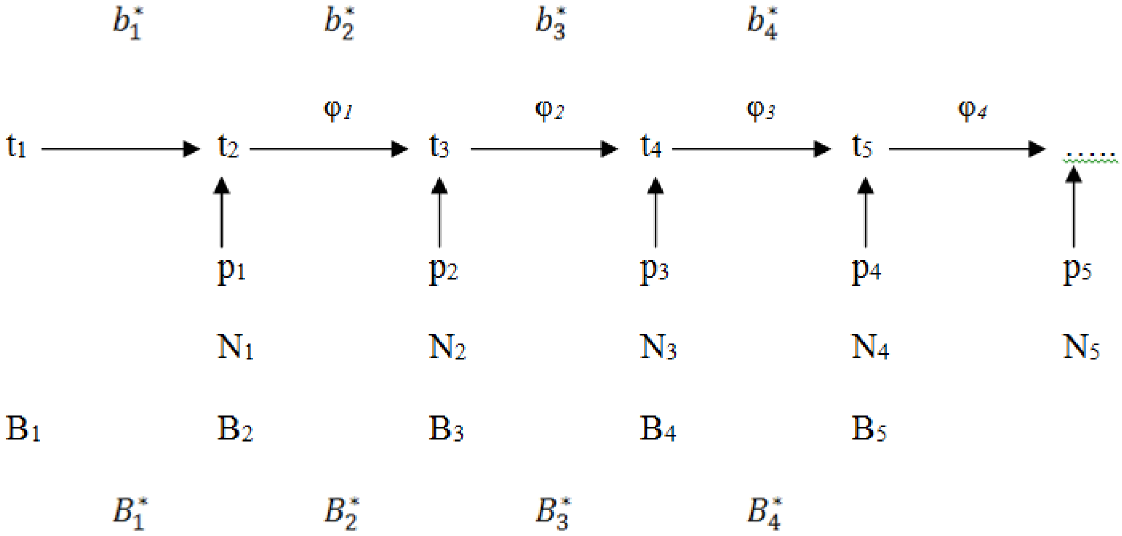


Figure 7. WinBUGS schematic for Jolly-Seber abundance estimation developed by D. Rawding (WDFW). Parameters include sample period (t_i), probability of capture at sample period *i* ($\boldsymbol{p_i}$), probability that a fish enters the population between sample period *i* and *i* +1 ($\boldsymbol{b_i^*}$), probability that a fish alive at sample period *i* will survive and remain in the population between sample time i and sample time i + 1 (φ_i), population size at sample period i (N_i), number of fish that enter after sample time *i* and survive to sample time *i* +1 (B_i), and the number of fish that enter between sampling occasion *i-1* and *i* ($\boldsymbol{B_i^*}$). Total abundance (*N*) is the sum of $\boldsymbol{B_i^*}$ over all sample periods.

Under the Bayesian framework, parameters were calculated from the posterior distribution, calculated from a prior distribution and the data collected (posterior = prior * data). Samples from the posterior distribution were obtained using Markov Chain Monte Carlo (MCMC) simulations (Gilks et al. 1996) in the WinBUGS software package. WinBUGS implements MCMC simulations using a Metropolis with a Gibbs sampling algorithm (Spiegelhalter et al. 2003). Two chains were run with the Gibbs sampler in WinBUGS saving a total of 8,000 iterations of the posterior distribution of each parameter after a 2,000-iteration burn-in. A vague prior was used for the calculations (Bayes-LaPlace uniform prior). The sensitivity of the prior was based on the overlap between a uniform prior and the posterior distribution (Gimenez et al. 2009) and convergence was assumed for parameters with a Brook-Gelman-Rubin statistic value less than 1.1 (Su et al. 2001).

Four potential JS models were evaluated using Deviance Information Criteria (DIC) (Spiegelhalter et al. 2002). DIC is similar to AIC criteria in that both criteria include a model error estimate (posterior mean deviance) penalized for the number of terms in the model. Each of the four models estimate capture probability (p_i - likelihood of detecting a carcass that was present during sample period i), survival probability (φ_i - likelihood that a carcass present in one sample period *i* would remain in the stream until the next sample period), and entry probability (b^*_i - likelihood that a carcass would arrive in at a given sample period). The four models (e.g., ttt, stt, tst, sst) included a combination of static

(s) or time varying (t) capture and survival probabilities among survey periods; the entry probabilities among survey periods were considered to be time varying in each of the three models.

Survey Life Estimates

Survey life ($\widehat{SL}$) in each CMR index reach was the AUC value divided by the JS spawner abundance estimate, where both estimates were independently derived for that index reach. This derivation of survey life represents both the duration of time that live Chum Salmon were present and the observer efficiency in the spawning index reaches. AUC values were treated as true values because no information on observer consistency was available, but JS spawner abundance was included as a distribution of values that incorporated the mean (μ_N) and standard deviation (σ_N) of the JS model estimate of spawner abundance. A Monte Carlo simulation (10,000 model simulations) provided the distributions of values for this calculation:

$$(1)\ \ \widehat{N}^{CMR} \sim norm(\mu_N, \sigma_N)$$

$$(2)\ \ \widehat{SL} = {}^{AUC^{CMR}}/_{\widehat{N}^{CMR}}$$

Area-Under-the-Curve Calculations

AUC was estimated in ‘fish-day’ units based on live counts and the number of days over which the live counts occurred. Data were organized by statistical week ensuring that a zero-count occurred at the beginning and end of the time series and fish-days were calculated as:

$$(3)\ \ \widehat{AUC} = 0.5 * \textstyle\sum_1^n (t_d - t_{d-1}) * (p_d - p_{d-1})$$

where $t_d - t_{d-1}$ is the number of days between surveys, p_d is the number of live Chum Salmon observed on a given survey date, and p_{d-1} is the number of live Chum Salmon observed in the previous survey (English et al 1992; Bue et al. 1998). Under this method, no fish were observed on the first (d = 1) or last survey (d = n). For most datasets, the count on the first and last survey week was zero; however, in the few cases where non-zero counts occurred at the beginning or end of the dataset, a zero count was added the week prior to the first surveyed week or after the last recorded survey for the purpose of calculation. AUC was estimated for total live counts (holders, spawners) and for live counts of spawners only.

Spawner abundance ($\widehat{N}^{AUC}$) in each AUC index reach was the AUC divided by the survey life estimate, where the AUC was calculated from live counts in the AUC index reach and survey life was selected from the CMR index reach of the corresponding stream size classification. AUC values were treated as true values because no information on observation consistency of fish counts was available, but survey life was included as a distribution of values that incorporated the mean (μ_{SL}) and standard deviation (σ_{SL}) of the estimate (see equation 3). A Monte Carlo simulation (10,000 model simulations) provided the distribution of values for this calculation:

$$(4)\ \ \widehat{SL} \sim norm(\mu_{SL}, \sigma_{SL})$$

$$(5)\ \ \widehat{N}^{AUC} = {}^{AUC^{AUC}}/_{\widehat{SL}}$$

Peak Count Expansion

The proportion of spawning that occurred within the index reaches was calculated based on data collected during the peak spawning week when both index and supplemental reaches were surveyed. The proportion of spawning in the index reaches was calculated from live counts (holders, spawners) in all index reaches, divided by live counts summed across all reaches (index, supplemental). The estimated proportion assumed a binomial variance:

$$(1)\quad n_{i} \sim binomial(p_{i}, N)$$

where n_i is the sum of live counts summed across all index reaches (i), p_i is the proportion of spawning in the index reaches, and N is the sum of live counts summed across all index and supplemental reaches.

Total Spawner Abundance

Total spawner abundance was calculated separately for each watershed. Total spawner abundance was the summed abundance in all index reaches (CMR, AUC) divided by the proportion of spawning ($\hat{p}_i$) that occurred within the index reaches. The proportion of spawning that occurred in the index reaches was calculated from peak count data in index and supplemental reaches (see equation 1). This approach has been demonstrated to be effective for estimating population abundance of salmonids, especially if spawning numbers within the index reaches are a high proportion of total spawning in the strata (Liermann et al. 2015). Index reach abundance ($\hat{N}_i$) was included as a distribution of values that incorporated the mean (μ_N) and standard deviation (σ_N) of the summed estimates (JS model for CMR indexes, equation 6 for AUC indexes). The proportion of spawning in index reaches was also included as a distribution of values that incorporated the mean (μ_p) and standard deviation (σ_p) of the estimated proportion (equation 1). A Monte Carlo simulation (10,000 model simulations) provided the distribution of values for this calculation:

$$(2)\quad \hat{N}_{w,s,i} = \sum(\hat{N}^{CMR}_{w,s,i},\, \hat{N}^{AUC}_{w,s,i})$$

$$(3)\quad \hat{N}_{w,s} = {}^{\hat{N}_{w,s,i}}\!\big/_{\hat{p}_{w,s,i}}$$

The final estimate was reported as abundance (mean of the simulated distribution), standard deviation (also calculated from the simulated distribution), and coefficient of variation (standard deviation divided by the mean abundance). Coefficient of variation is a measure of precision that is scaled to the magnitude of the values included in the estimate.

Results

The focus sub-basins of 2020 were Wishkah, Hoquiam, Cloquallum, Black rivers and the tributaries of the south Grays Harbor. In total 54 miles were surveyed on a weekly basis (index surveys) and an additional 80 miles of potential Chum spawning habitat during the peak Chum Salmon spawning (supplemental surveys). Counts of Chum salmon taken by the QDNR and WDFW Chinook spawning ground crews, added an additional 13.4 miles of index surveys in the Humptulips River, 20.4 miles in the Satsop River, and 5.4 miles in the Wynoochee River.

Survey Life

A carcass mark-recapture (CMR) study in 2020 allowed us to determine abundance estimates in two new reaches within the Wishkah River sub-basin. These additional survey life estimates accomplished two things. First, we increased the sample size of survey life estimates within the Grays Harbor basin from 10 to 12. Second, we were able to generate survey life estimates that considered environmental changes specific to 2020 to then apply to the 2020 AUC abundance estimations. Overall, abundance estimates using the AUC method covered 48 index reaches in the Chehalis River basin in 2020 (Appendix B). The CMR method is considered more robust than the AUC method for determining spawner abundance because it considers observer efficiency (Rawding et al. 2014) but is more labor intensive and expensive. Therefore, a combination of AUC and CMR methods were used to generate unique survey life estimates that accounted for interannual variation in stream conditions and observer efficiency.

Survey life was calculated for two of the four CMR indexes originally targeted in the 2020 surveys within Grays Harbor. Two of the CMR indexes in the Hoquiam River sub-basin had very poor carcass recovery and we were unable to generate accurate CMR results (Appendix A). However, survey life estimates for Wishkah River and Cedar Creek, a small tributary to Wishkah, were generated (Table 2). Previous years of the study provided an additional ten independent survey life estimates from varying sized streams. A change to the CMR surveys occurred in 2019 to encourage active mixing of carcasses and improve the likelihood of meeting the equal catchability assumption. Both before and after this adjustment we observed an inverse relationship between the length (days) of apparent survey life and the size of stream (Fig. 8, Appendix C).

Two of the survey life estimates produced in tributaries of the Satsop River over the course of the study came from side channels and were not included in the final survey life to stream size comparison. Side channels tend to be unique and often do not maintain continuous connectivity or flow at the top of the channel and can have a different Chum Salmon residence time than the main river flow. Because of this, the bankfull width to survey life comparison tends to be more erratic and therefore was not included. However, these survey life estimates were used for the AUC estimates within other side channels when counts were intentionally separated.

Table 2. Carcass tagging indexes that resulted in a survey life estimate. Nˆ= Jolly Seber Abundance Estimate, SD = Standard Deviation, AUC = Area-Under-the-Curve Estimate, (SL)ˆ= Survey Life Estimate.

				Spawners Only		**Total Live**	
Index Reach Name	**Size Class**	**Year**	$\widehat{N}$ **(SD)**	**AUC**	$\widehat{SL}\ (SD)$	**AUC**	$\widehat{SL}\ (SD)$
Satsop Tributary 0462 0.0-0.2	Side Channel*	2016	953(45)	5,438	5.7(0.3)	5,547	5.8(0.3)
Dry Bed Creek 0.0-1.0	Small	2016	808(51)	5,304	6.6(0.4)	7,753	9.6(0.6)
Satsop Tributary 0462 0.0-0.2	Side Channel*	2017	186(9)	1,667	9.0(0.4)	1,667	9.0(0.4)
Schafer Creek 0.0-4.3	Medium	2017	721(72)	6,393	9.0(0.9)	8,906	12.5(1.3)
Elwood Creek 0.0-0.6	Small	2018	164(15.6)	1,550	9.5(0.9)	2,178	13.4(1.3)
Stevens Creek 4.5-7.1	Medium	2018	4,229(91)	31,832	7.5(0.2)	43,671	10.3(0.2)
Stevens Creek 6.2-7.1	Medium	2019	807(16.1)	4,488	5.6(0.2)	7,137	8.8(0.1)
Donkey Creek 0.0-0.5	Medium	2019	606(16.3)	5,999	9.9(0.3)	7,452	12.3(0.3)
West Fork Humptulips River 40.6-43.6	Large	2019	854(54.4)	5,383	6.8(0.5)	8,506	10.7(0.8)
Humptulips River 23.1-28.1	Large	2019	732(81.8)	4,197	5.8(0.7)	6,320	8.8(1.1)
Cedar Creek 0.0-0.6	Small	2020	231(31.0)	1,409	6.2(0.9)	2,761	12.2(1.2)
Wishkah River 26.1-29.4	Medium	2020	896(84.5)	5,192	5.8(0.6)	6,540	7.3(0.7)

*Engineered side channel

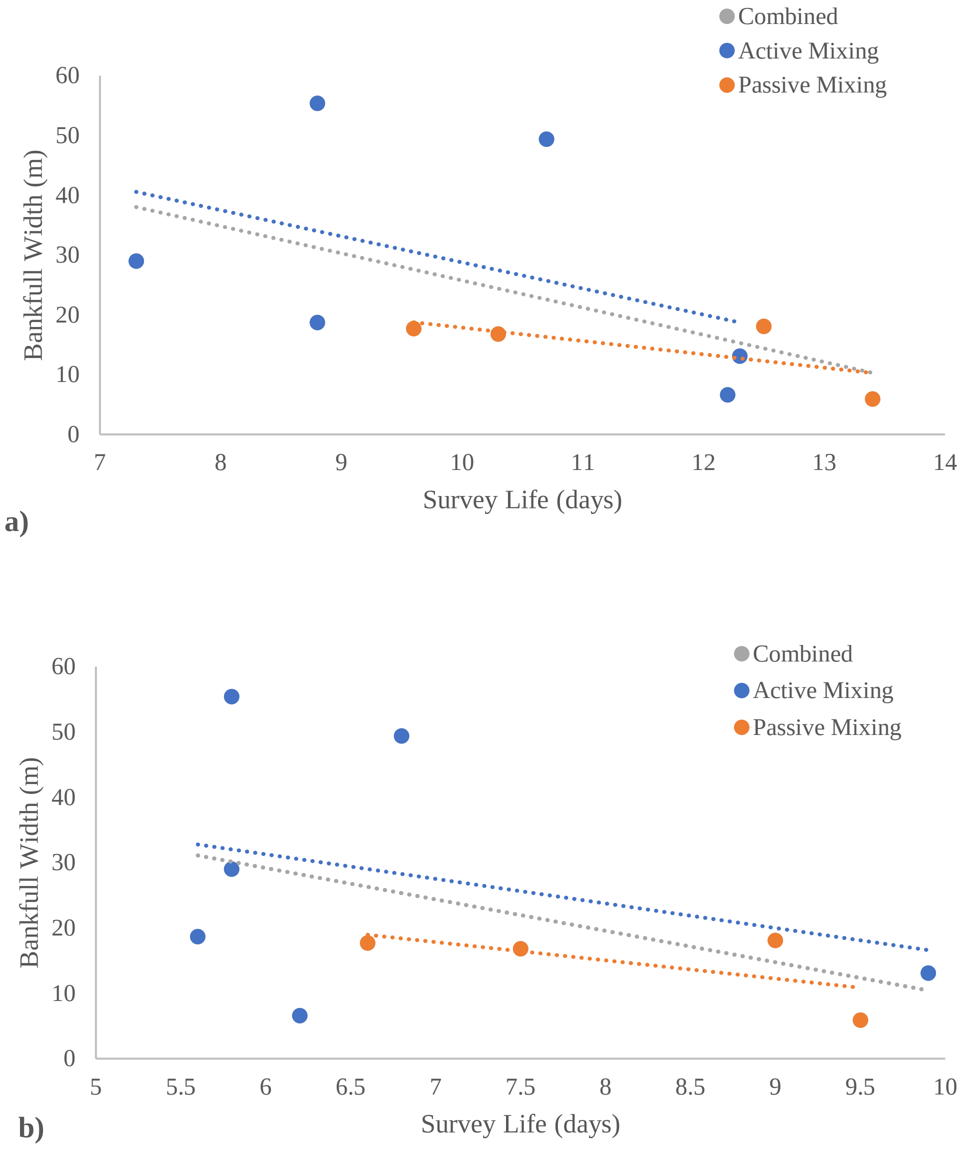


Figure 8. Estimated survey life (days) of live Chum Salmon by average bankfull width of river (m) for both total live counts (a) and spawner only counts (b). “Passive” and “active” mixing methodologies plotted separately and combined. “Passive” mixing refers to freshly tagged carcasses that were returned to the location where they were found, and “active” mixing refers to carcasses that were returned to the nearest flowing water.

The difference in estimates using the AUC method with the current 10-day survey life and CMR method ranged from 19% for a small sized stream and -27% for a medium-large stream. (Table 3).

Table 3. Comparison in the same river section of two estimate methods: carcass mark-recapture (CMR) and area-under-the-curve (AUC). For each section, the AUC estimate was calculated using a standard **10-day** survey life (used for Puget Sound tributaries) and shown as lower or higher than the CMR estimate.

Index Reach	**CMR Estimate (SD)**	**AUC Estimate**	**% Difference**
Cedar Creek 0.6-0.0	231(31)	276	19%
Wishkah 29.4-26.1	896(84.5)	654	-27%

Estimate

Based on the "updated" methodology, Grays Harbor basin in 2020 had a Chum Salmon spawner abundance estimate of 48,294 (CV = 2.2%) with 95% probability interval of 44,597 and 52,250 (Table 4). This was based on total live counts since spawner only counts were not consistently enumerated for all sub-basins. The spawner abundance estimates for Wishkah, East Fork Hoquiam, and Cloquallum sub-basins were calculated using a combination of index AUC and supplement expansion for both spawners-only counts and total live counts (Appendix D). Low presence of fish in the Black River and South Harbor sub-basins prevented accurate AUC and supplemental expansion. Therefore, the total was based on counts of Chum Salmon seen within the sub-basin. Humptulips, Satsop, and Wynoochee sub-basin estimates were calculated using distribution information from previous years (Ashcraft et al. 2017; Edwards and Zimmerman 2018; Ronne et al. 2019) and peak counts to generate a ratio of index to supplemental surveys based on the indexes surveyed in 2020.

Table 4. Estimated 2020 Chum Salmon spawner abundance by sub-basin using the updated methodology compared to the entire Grays Harbor Chum Salmon abundance estimated using the current method. **Nˆ=** Abundance Estimate**,** **SD =** Standard Deviation

	Spawner Only Estimate		**Total Live Estimate**		**Current Grays Harbor Estimates**	
	$\hat{N}$	**SD**	$\hat{N}\ (SD)$	**SD**	$\hat{N}$	**SD**
Wishkah	4,348	93.4	4,354	92.8	-	-
Hoquiam	361	15.0	323	12.2	-	-
Cloquallum	505	66.1	378	45.2	-	-
South Harbor	-	-	29*	-	-	-
Black River	-	-	25*	-	-	-
Humptulips	-	-	24,770	703.4	-	-
Wynoochee	-	-	13,222	737.3	-	-
Satsop	-	-	5,193	292	-	-
Total			**48,294**	**1065.2**	**23,457**	**N/A**

*Number of unique fish seen both live and dead.

The "current" method has no error associated with it whereas the "updated" method allows for error estimation and includes an associated coefficient of variation (CV) of 2.2%.

Biological Diversity

Chum Salmon carcasses were recovered in 2020 near the expected ratio of 1:1 male to female. There were similar percentages of scale age-3 and age-4 Chum Salmon that returned to the basin in 2020 but only a small proportion (2.2%) of age-5 Chum Salmon and no age-2 or age-6 Chum Salmon based on scale analysis (Fig. 9). The average fork length for female Chum Salmon ranged from 63.7 cm for age-3 fish to 69.3 cm for age-5 fish; average male fork lengths ranged from 69.0 cm for age-3 fish to 77.8 cm for age-5 fish.

During the entire duration of the study (2015-2020) age composition fluctuated (Fig. 10) primarily between age-3 or age-4, with age-5 making up a lower percentage (0.8-27%) than either age-3 or age-4 Chum Salmon (73-99%), except in 2016 when there was an extremely poor return of age-3 Chum Salmon (3%).

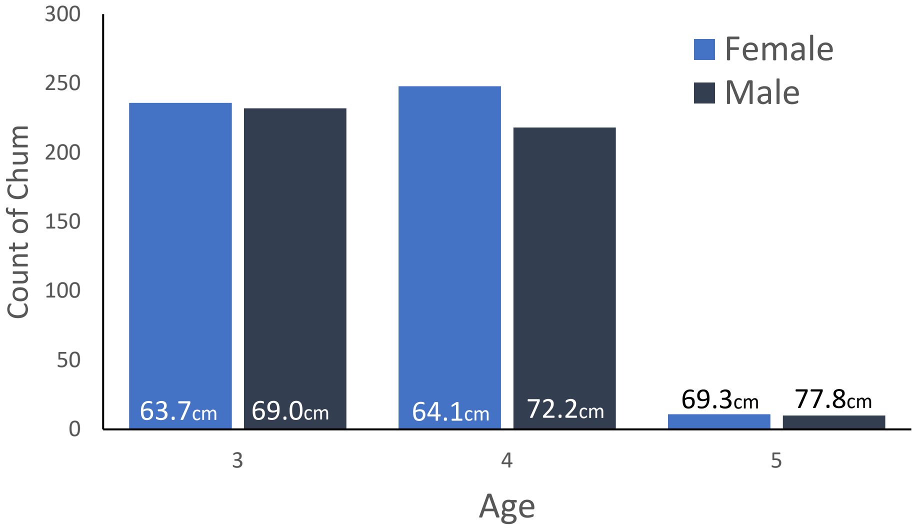


Figure 9. Counts of 2020 Chum Salmon in the Grays Harbor basin by sex and age with average fork length (cm).

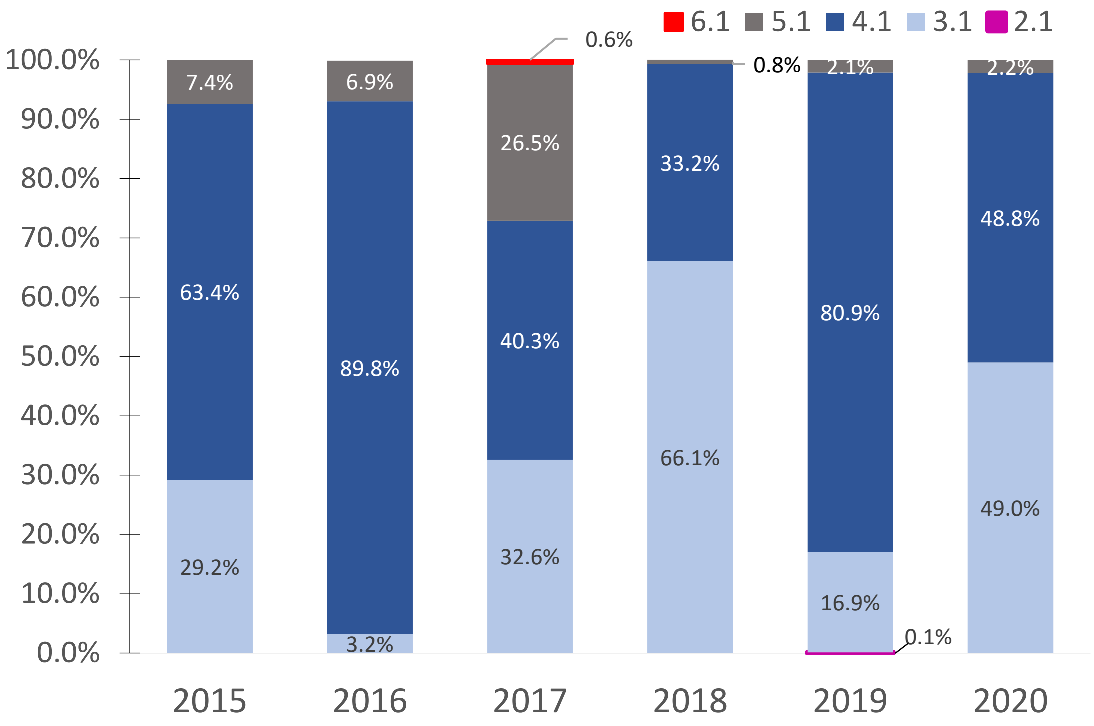
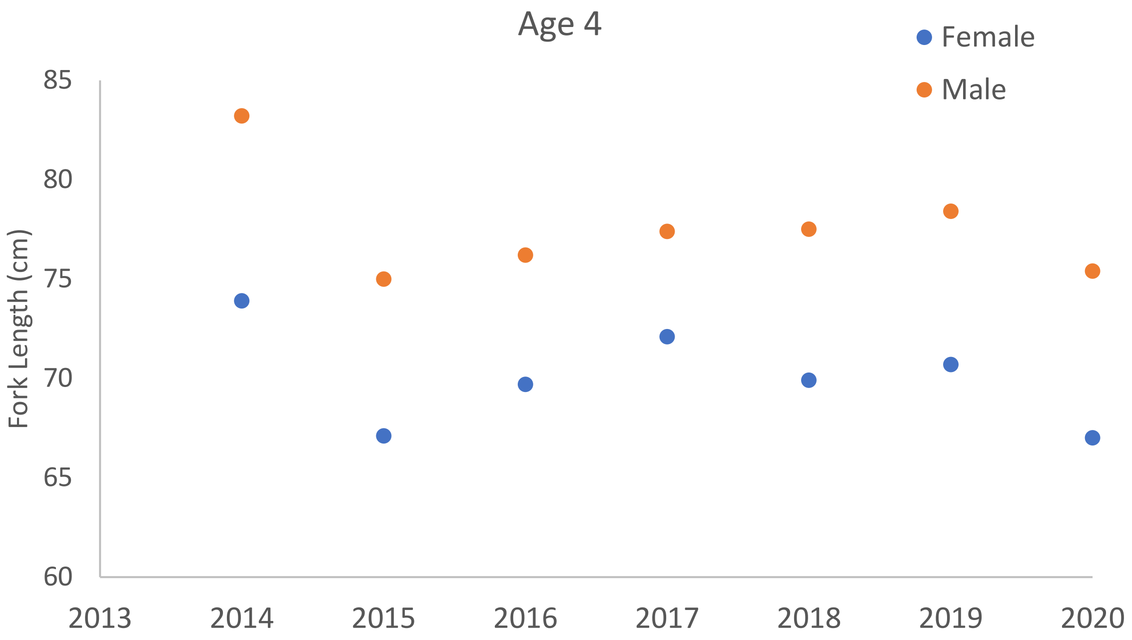


Figure 10. Grays Harbor Chum Salmon age composition by year from data collected in all sub-basins, including those not directly in the study focus area for that year.



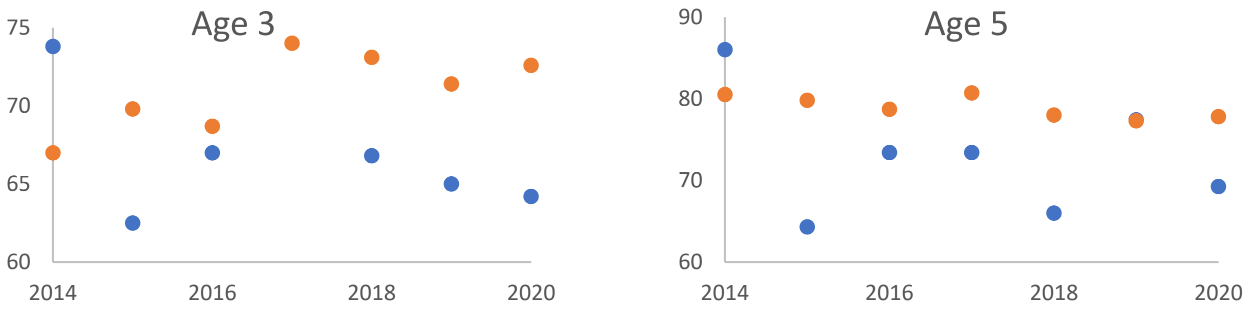


Figure 11. Average fork length (cm) of age-3, age-4, and age-5 Chum Salmon by sex and year in Grays Harbor. There was limited fork length data (n ≤ 10) for age 3 (years 2014-2017) and age 5 (years 2014-2020). No trends were developed for ages 2 or 6 as not all years had samples. Includes all sub-basins where data was collected.

Distribution

The distribution of Chum Salmon in the Grays Harbor basin (Chehalis River basin + Humptulips River basin) is currently isolated to the lower basin downstream of Black River. Although there has been an occasional sighting in tributaries of the Chehalis River basin as far upstream as the Newaukum River, a spawning population has not been documented that high in the basin. In 2020, the focus was on the Hoquiam, Wishkah, Cloquallum and Black rivers as well as several South Bay streams. Of the sub-basins that were surveyed in 2020, the Wishkah River had the highest concentration of Chum Salmon (Fig. 12). However, all the sub-basins in the 2020 focus area only contributed ~10% to the whole Grays Harbor Chum Salmon spawning population.

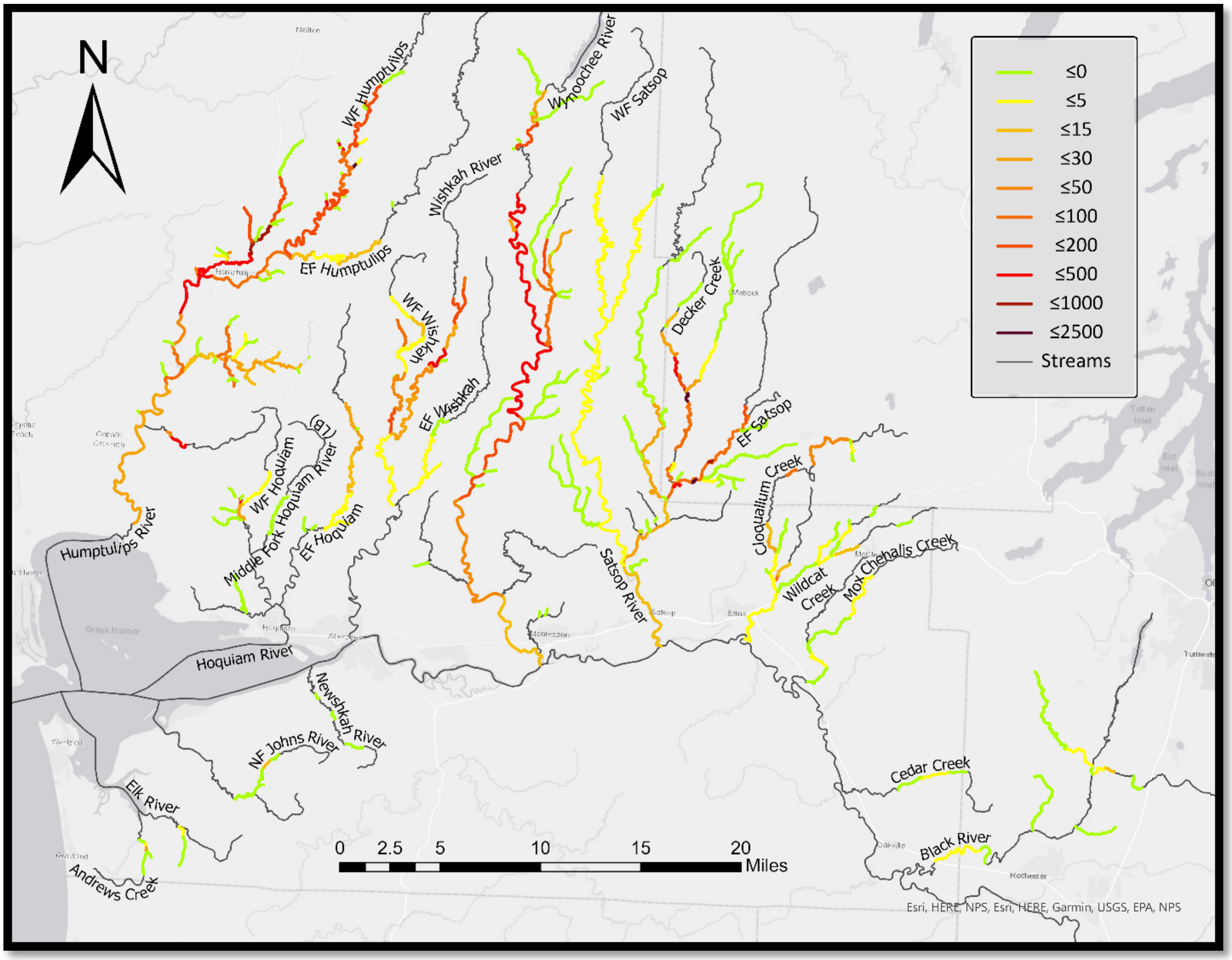


Figure 12. Density (fish/mile) and distribution of Chum Salmon based on peak counts in the 2020 focus study areas. Map also includes 2019 Humptulips, 2017 Wynoochee, and 2017 Satsop density and distribution based on the peak counts from those years.

Discussion

The 2020 Grays Harbor basin Chum Salmon estimate using the “updated” method (48,294, CV = 2.2%) was 2 times that of the “current” methodology (23,457) indicating that the current methodology is underestimating Chum Salmon abundance and there is an urgent need to update how spawner abundance estimates are calculated in the Grays Harbor River basin. These results have been consistent over the course of the study, indicating that a correction factor could be applied retroactively for the population (Table 5; Edwards and Zimmerman 2018; Ronne et al. 2019). In addition, the “updated” method gives a 95% prediction interval of the estimate being between 44,597 and 52,250 for 2020 Chum Salmon spawners in the Grays Harbor basin, providing important information on escapement uncertainty that the “current” method lacks. To update the “current” methodology, several gaps in knowledge needed to be filled. One is the assumption of a 10-day survey life estimate, as used in Puget Sound Chum Salmon AUC estimates. Based on our CMR studies in small, medium, and large streams throughout Grays Harbor, this assumption appears inappropriate for the Grays Harbor Chum Salmon population. The second is better understanding of the distribution of Chum

Salmon within the basin. Finally, better quantification of spawning proportions within and outside of surveyed index sections is needed since full spatial coverage is impractical over such a large and diverse basin.

Table 5. Comparison of Chum Salmon study escapement estimates, and escapement estimates currently used for management purposes, 2017-2020. Study estimates for 2017-2019 does not include all basins with Chum Salmon spawning.

Watershed	2017	2018	2019	2020
Wynoochee	13,852	19,964	20,801	13,222
Satsop	14,460	7,824	8,724	5,193
Humptulips		20,258	14,333	24,770
Wishkah				4,354
Other sub-basins				755
Study Total	**28,312**	**48,046**	**43,858**	**48,294**
All Basin Managing Estimate	18,627	28,413	27,930	23,475

Using a 10-day survey life value for the AUC abundance calculations in Grays Harbor, as is the convention for Puget Sound for Chum Salmon estimates, is likely not the ideal replacement methodology. While it may still be an improvement over the current methodology, a 10-day survey life value does not allow for inter-annual variation due to changes in flow or observer efficiency. During this study it appeared that larger rivers with larger average bankfull widths generally had shorter survey life values than smaller rivers with smaller average bankfull widths. A large proportion (>50%) of Chum Salmon spawn in the main stem or larger forks of the rivers within the basin. However, a 10-day survey life for AUC calculations (where survey life is the denominator) may underestimate Chum Salmon in these sections by as much as 50% since actual survey life may be closer to five. Conversely, some of the smaller streams where Chum Salmon spawn are likely overestimated when using the 10-day survey life values, albeit not to the same degree that larger streams underestimate values (survey life range for small streams = 7.3 to 13.4). Generating unique survey life values each year would account for inter-annual variation caused by flow regimes, environmental change, as well as changes in observer efficiency, and more accurately reflect Chum Salmon abundance.

Distribution of Chum Salmon in the Satsop and Wynoochee rivers was examined in 2016 and 2017. During those years, Decker Creek and East Fork Satsop had some of the highest densities (>1,000 fish/mile) within the Satsop sub-basin, while the Wynoochee had highest densities (100-500 fish/mile) in the main stem and Schafer Creek. Distribution within the Humptulips River was examined during the 2018 and 2019 seasons. Stevens Creek, main stem Humptulips, and West Fork Humptulips had some of the highest densities (500-1,000 fish/mile) of Chum Salmon in the Humptulips sub-basin. Interestingly, several smaller streams, or previously accessed areas of the sub-basin, that had high densities (>50 fish/mile) in 2018 had much lower (< 10 fish/mile) or no presence in 2019. This was also observed in the Satsop basin where several of the engineered side channels did not have water flow until later in the season. This indicates that reduced flow during the early spawning period may have reduced the distribution of Chum Salmon and prevented them from accessing productive habitat in small streams, while simultaneously increasing competition for spawning habitat in large streams. Diverse use of spawning habitat may provide a stabilizing influence of fry production over varying winter conditions (Schuett-Hames et al. 2000). Reduced spawning habitat diversity may have a long-term destabilizing effect on Chum Salmon within the Grays Harbor Basin.

During the last year of the study in 2020, we examined the distribution of spawning populations of Chum Salmon in less studied areas of the Grays Harbor basin. Although we were unable to cover every possible spawning area, we did survey areas where spawning was most probable. Based on low densities (0-10 fish/mile) in the streams that were surveyed, we concluded that the remaining (unsurveyed) streams were unlikely to have large spawning populations, despite having favorable Chum spawning habitat. However, a continued and ongoing effort to monitor lower order streams is recommended since abundance and flow regime seem to affect spawning distribution. Of the streams surveyed in 2020, the Wishkah River had the highest densities (200-500 fish/mile). However, Wishkah River has a small hatchery program of unmarked Chum Salmon releases, and any returns from those releases are included in the escapement estimate which may be artificially inflating the density (Table 6).

Table 6. Chum fry hatchery releases in the Wishkah River from 2016-2020.

Release Year	Release Numbers
2016	135k
2017	120k
2018	100k
2019	0
2020	140k

The South Bay streams and Black River had the lowest densities (<20 fish/mile) and low densities (< 30 fish/mile) in the Hoquiam River may indicate an area where restoration that benefits Chum Salmon might be beneficial The distribution information gained during this study adds credence to the need to update the Chum Salmon estimate methodology given that the “current” methodology only covers four small indexes (Figure 1), or approximately 0.9% of the observed spawning distribution determined by this study (Figure 12).

During each year of this six-year study, a sub-basin was selected for extensive monitoring including one-time supplemental surveys in areas not included as weekly indexes within each sub-basin. This resulted in a spawner abundance ratio between index reaches and supplemental reaches that was used to expand the AUC estimates to the entire sub-basin. Specifically, relationships between abundance in indexes and supplemental surveys allowed for estimate expansion in the Satsop and Wynoochee sub-basins in 2018, 2019, and 2020 as well as the Humptulips sub-basin in 2020. Indexes that were surveyed for Chinook and Coho Salmon were also leveraged as AUC indexes for Chum Salmon, if Chum Salmon observations were recorded, since the spawning season for these species overlap. Counts of Chum Salmon have historically been recorded in all index reaches surveyed by WDFW staff, but previously no protocol existed to incorporate these data into escapement estimates for Chum Salmon in Grays Harbor. The new “updated” method allows information from other surveys to be incorporated into the dataset. However, distribution can change based on flow regimes so the proportions may not be accurate in a year when the flow regimes differ from the year in which the original proportions were determined. In addition, we have noted that changes to the stream channels and substrate can alter the distribution over time. These limitations suggest that a static approach to these ratios is not ideal. We recommend an annual rotating effort to estimate survey life by sub-basin because of the size of the Grays Harbor basin. The sub-basins that rely on expansion based on the index to supplemental relationship should be prioritized to ensure indexes cover enough of the spawning distribution to generate accurate results. The efficacy of expanding index sections from supplemental surveys could be further aided by the addition of several Chum Salmon focused index reaches. For example, several areas of dense Chum Salmon spawning habitat were identified through the course of this project, but those areas are not typically surveyed. Since the index-supplemental expansion functions best when the majority of spawning occurs within index reaches, estimates would be greatly improved by adding reaches with high densities of Chum Salmon.

During this study a few issues related to abundance estimation became apparent. The ability to accurately count spawners as opposed to holders (spawners + holders = total lives) has been shown in other regions of Washington to be more reliable and consistent (Rawding et al. 2014, Bentley et al. 2018). For example, it is easier to see and accurately identify and count fish on spawning habitat then if they are holding in deep pools. When spawner counts get paired with the survey life estimates based on spawner only counts, results generate a more accurate estimate that can then be compared between sub-basins and years. Another benefit to using the spawner counts instead of total live counts is that fish holding in pools are more likely to be counted more than once as they wait to spawn before migrating to the spawning habitat. Since we were using Chum Salmon counts leveraged from surveys of other projects to generate estimates outside the sub-basin(s) of focus, counts of spawners separated from total lives was inconsistent. To continue to leverage other surveys, protocols and training should be standardized between entities collecting data. This training and standardization need became especially apparent in 2018 when the Chum Salmon survey crews overlapped with other crews collecting similar data. The Chum Salmon survey crew and one other crew, primarily focused on Chinook and Coho Salmon, had Chum Salmon counts in the same section on the same day that were within 3% of each other. However, the third crew doing counts in the basin, were 30% lower on their Chum Salmon counts than the other crews. Standardizing protocols through inter-agency training would help minimize count differences and ensure consistency among surveyors.

Recommendations for Grays Harbor Basin Chum Salmon Monitoring

In large river basins where it is impractical to conduct full basin carcass mark-recapture annually, there are several steps that could be done to improve Chum Salmon spawner estimates with some measure of accuracy. Within Grays Harbor basin, the first goal should be to move away from an arbitrary escapement goal with unverified significance. The second goal should be to adopt a method that utilizes AUC indexes to generate abundances, with supplemental peak surveys to expand those abundances to full sub-basins and incorporate Chum Salmon counts from existing Chinook and Coho Salmon surveys in addition to establishing new indexes in areas where spawning occurs. The third goal should be generating annual survey life estimates that are specific to a basin or sub-basin that represent the varying stream sizes within the surveyed area. The last goal should be to update escapement goals and abundances, using retrospective analysis, for forecast modeling.

Carcass mark-recapture (CMR) is the preferred method for determining the spawner abundance of Chum Salmon, however the method is labor intensive and costly. It is also challenging in areas with low fish densities where carcass recovery is difficult. In a large basin with many sub-basins, it may not be feasible to generate estimates using CMR. We propose a tiered approach for estimating spawner abundance in large basins across the Pacific Northwest that support Chum Salmon. First, divide up your basin into relevant ecological regions or sub-basins (Fig. 13). One sub-basin should be the focus sub-basin each year and the focal sub-basin rotated annually.

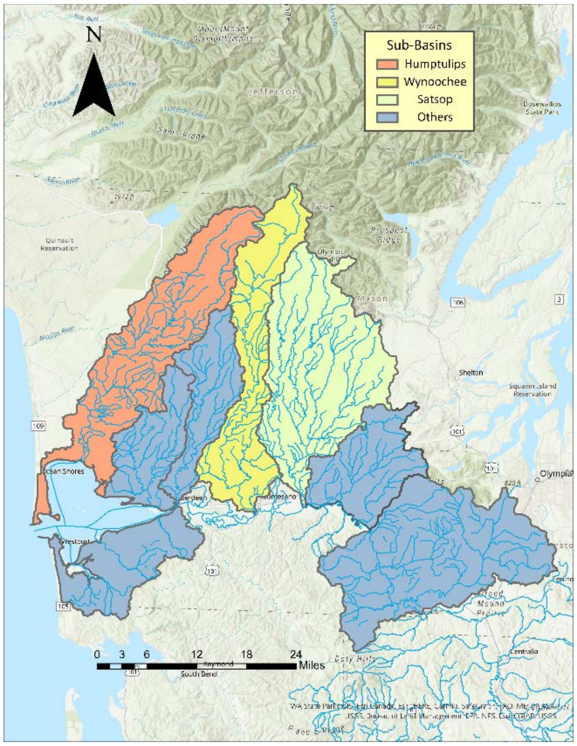


Figure 13. The lower Chehalis basin divided into four "sub-basins" that can reasonably be fully surveyed (focus basin) in a season.

Next, conduct strategic index area-under-the-curve (AUC) surveys in all sub-basins annually. We recommend leveraging any concurrent surveys (Chinook or Coho surveys) that cover the Chum Salmon spawning time frame to collect data with minimal additional effort. The more indexes surveyed will result in a more comprehensive understanding of Chum Salmon spawning distribution and abundance and lead to a more accurate estimate.

Finally, in the focal sub-basin, use the following approach annually to estimate spawner abundance:

1. Conduct weekly surveys in index AUC sections of stream to generate values with supplemental surveys conducted only during the peak week of spawning in the focus sub-basin.
2. Conduct CMR study to generate estimates of abundance using separate CMR index sections of the stream and pair with AUC fish days to generate a unique estimate of the residence time of spawning Chum Salmon in an index section of the focus sub-basin (i.e., survey life in days).
3. Use previously determined spawner distribution information paired with AUC indexes to expand escapement estimates into sub-basins where supplemental surveys were not possible in other areas.

Things to consider:

- All live counts for AUC estimates and supplemental surveys should be based on fish observed on spawning habitat (spawner only counts), not counts of fish holding in pools or boulder gardens (i.e., areas where it is more difficult to get accurate counts).
- CMR indexes should be selected with caution to minimize violations to the assumption that the system is a closed population (e.g., carcass drift into the index from above).

  - Unique survey life estimates are best separated into large and small (or large, medium, small) if there is a range of stream sizes within the basin based on bankfull width. The larger the stream, the shorter the survey life estimate is likely to be.
  - Comprehensive distribution information in each basin is needed to generate estimates in non-focus basins.

Limitations:

The method for estimating spawner escapement in non-focus sub-basins does not consider annual changes in distribution because of flows or abundance, but by rotating the focal sub-basin each year, updated distribution data based on changes to streams can be generated that more accurately reflects interannual variability in spawner distribution. These peak supplemental surveys can be challenging to accomplish, often requiring additional staff and volunteers to assist with covering additional stream surveys during the narrow timeframe of the Chum Salmon spawning period. Accounting for annual changes in distribution can be best done by strategically selecting the annual AUC indexes in those sub-basins that include locations most likely to be subject to flow regime changes and near the edges of the distribution range based on previous observations.

Tiers of Recommended Improvements

Preferred Monitoring Effort Improvement	**Intermediate Improvement**	**Minimum Necessary Improvement**
Methodology	Methodology	Methodology
Update escapement estimate methodology using Bayesian AUC calculation.	Update escapement estimate methodology using Bayesian AUC calculation.	Update escapement estimate methodology using Bayesian AUC calculation.
Analysis would use ratio of indexes to supplemental counts developed from chum study instead of escapement methodology currently used.	Analysis would use ratio of indexes to supplemental counts developed from chum study instead of escapement methodology currently used.	Analysis would use ratio of indexes to supplemental counts developed from chum study instead of escapement methodology currently used.
Analysis would use survey life estimates updated annually.	Analysis would use survey life estimates generated from 2016-2020 chum study.	Analysis would use survey life estimates generated from 2016-2020 chum study
Separate spawners from holder counts of live chum.	Separate spawners from holder counts of live chum.	Separate spawners from holder counts of live chum.
Develop new chum index survey strata to represent spawning distribution and capture interannual variability.	Develop new chum index survey strata to represent spawning distribution and capture interannual variability.	Develop new chum indexes through incorporation of data already collected in other salmonid indexes to calculate escapement.

Comprehensive AUC indexes in each major basin.	Include AUC indexes in all major sub-basins chum spawn.	Utilizing the same effort currently for field collection.
Rotating CMR indexes annually to update and validate survey life estimates and efficiencies for chum streams/subbasins.	Include full distribution supplemental surveys rotating annually in all major basins.	
Comprehensive AUC indexes in each major basin.		
Supplemental surveys covering full distribution in all major basins.		
Exploratory surveys in basins with chum spawning potential but not covered regularly or minimal abundances.		
Standardization and training cross agencies of counts of live (spawner, holder) and dead chum.	Standardization and training cross agencies of counts of live (spawner, holder) and dead chum.	
Establish new escapement goals through retrospective analysis.	Establish new escapement goals through retrospective analysis.	Establish new escapement goals through retrospective analysis.
Data Management	Data Management	Data Management
Move to new database that holds all necessary information in one place.	Move to new database that holds all necessary information in one place.	Move to new database that holds all necessary information in one place.
Electronic Data Collection	Electronic Data Collection	
Benefits	Benefits	Benefits
Abundance estimate with best known precision.	Abundance estimate with increased known precision	Abundance estimate with limited known precision
Representation of **actual** spatial distribution	Improved representation of spatial distribution	Some representation of spatial distribution.
Statistically robust		

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Appendix

Appendix A. Summarized carcass tagging data used as inputs in the Jolly-Seber open population abundance estimate.

n = number captured at sample time, previously tagged and untagged.
m = number captured at sample time that were previously tagged
R = number of tagged releases at sample time
r = number of R releases, recaptured in a future period.
z = number of R releases recovered not at the next period but a later period
u = number captured at sample time, unmarked

a) Wishkah

Period	Date	n	m	R	r	z	u
1	11/8/2020	14	0	11	2	0	14
2	11/23/2020	285	1	68	40	1	284
3	11/30/2020	142	41	71	29	0	101
4	12/9/2020	158	28	62	1	1	130
5	12/15/2020	9	2	0	0	0	7

b) Cedar Creek

Period	Dates	n	m	R	r	z	u
1	11/15/2020	18	0	11	4	0	18
2	11/23/2020	59	3	26	15	1	56
3	11/30/2020	46	11	20	12	5	35
4	12/7/2020	43	16	6	2	1	27
5	12/14/2020	8	3	0	0	0	5

c) Davis Creek

Insufficient data to run Jolly-Seber for developing survey life estimates.

Period	Dates	n	m	R	r	z	u
1	11/23/2020	9	0	9	5	0	9
2	12/1/2020	15	5	7	1	0	10
3	12/7/2020	1	1	0	0	0	0

d) East Fork Hoquiam

Insufficient data to run Jolly-Seber for developing survey life estimates.

Period	Dates	n	m	R	r	z	u
1	11/21/2020	18	0	12	2	0	18
2	11/30/2020	16	1	9	0	1	15
3	12/9/2020	13	1	4	1	0	12
4	12/14/2020	2	1	0	0	0	1

Appendix B. Area-under-the-curve in fish-day units for Chum in index reaches, fall 2020. Fish-days were calculated for 'spawners' only and total live count (holders, spawners). Index reaches were surveyed by either foot or boat (strata) and were surveyed using one of two survey types (AUC = live counts, CMR = live counts (for AUC) and carcass tagging).

					Fish Days	
Sub-Basin	**Index Reach Name**	**Strata**	**Type**	**Size Class**	**Spawners Only**	**Total Lives**
Cloquallum	Bush Creek_0-0.5	Foot	AUC	Small	561	628
	Rock Creek_0.4-1	Foot	AUC	Small	58	43
	Cloquallum Creek_1.9-4.1	Foot	AUC	Medium	7	31
	Cloquallum Creek_4.1-5	Foot	AUC	Medium	22	55
	Cloquallum Creek_5-7	Foot	AUC	Medium	117	140
	East Fork Wildcat Creek_2.3-3.5	Foot	AUC	Medium	40	50
	East Fork Wildcat Creek_3.5-4.8	Foot	AUC	Medium	91	110
	Mox Chehalis Creek_4.3-5.3	Foot	AUC	Medium	16	35
Hoquiam	Davis Creek_0-0.3	Foot	AUC	Small	635	1,007
	East Fork Hoquiam_7.5-16	Foot	AUC	Medium	1,454	1,511
	West Fork Hoquiam_10.4-10.7	Foot	AUC	Medium	20	20
	WF Hoquiam River_10.9-13.3	Foot	AUC	Medium	0	105
	West Fork Hoquiam_9.4-10.4	Foot	AUC	Medium	0	88
Humptulips	Brittain Creek_0.0-0.2	Foot	AUC	Small	*	1,138
	Elwood Creek_0.0-0.6	Foot	AUC	Small	*	804
	O`Brien Creek_0-0.5	Foot	AUC	Small	4,589	6,332
	Donkey Creek_0.8-1.5	Foot	AUC	Medium	1,553	2,446
	Donkey Creek_0-0.5	Foot	AUC	Medium	3,586	4,773
	Stevens Creek_4.5-5.2	Foot	AUC	Medium	12,100	15,584
	Stevens Creek_5.2-6.2	Foot	AUC	Medium	8,484	11,934
	East Fork Humptulips River_1.6-4.4	Foot	AUC	Large	*	624
	Humptulips River_16.7-19.2	Foot	AUC	Large	*	881
	Humptulips River_36.7-40.6	Foot	AUC	Large	*	3,152
Satsop	Decker Creek_0.5-1.1	Foot	AUC	Medium	920	890
	Decker Creek_1.1-1.8	Foot	AUC	Medium	1,144	1,448
	Creamer Slough_0-0.3	Foot	AUC	Side Channel	212	210
	Schafer State Park Slough_0-0.4	Foot	AUC	Side Channel	351	2,366
	Maple Glen Slough_0-0.3	Foot	AUC	Side Channel	801	790
	West Fork Satsop River_7.3-17	Boat	AUC	Medium	324	330
	Satsop River_10-11	Boat	AUC	Large	118	201
	Satsop River_11-12.4	Boat	AUC	Large	130	296
	Satsop River_12.4-14.7	Boat	AUC	Large	711	924
	Satsop River_6.3-10	Boat	AUC	Large	471	702

South Bay	Johns River_9.5-10.7	Foot	AUC	Medium	0	77
	West Branch Elk River_0-0.6	Foot	AUC	Medium	10	15
Wishkah	Cedar Creek_0-1.0	Foot	CMR	Small	1,409	2,761
	East Fork Wishkah River_3.2-4.5	Foot	AUC	Medium	45	66
	West Fork Wishkah River_8.1-9.8	Foot	AUC	Medium	390	348
	West Fork Wishkah River_9.8-10.8	Foot	AUC	Medium	46	67
	Wishkah River_17.7-21.5	Boat	AUC	Medium	821	1,350
	Wishkah River_21.5-24.5	Boat	AUC	Medium	1,597	2,441
	Wishkah River_24.5-26.1	Boat	AUC	Medium	8,204	9,748
	Wishkah River_26.1-29.4	Boat	CMR	Medium	5,192	6,541
Wynoochee	Shafer Creek Tributary 0298_0.0-0.3	Foot	AUC	Small	*	1,732
	Unnamed Creek 0299_0.0.-0.1	Foot	AUC	Small	*	328
	Shafer Creek_3.1-4.3	Foot	AUC	Medium	*	4,174
	Wynoochee River_13.7-15.4	Boat	AUC	Large	*	2,098
	Wynoochee River_29.1-31.2	Boat	AUC	Large	*	4,631

* Spawners were not separated from total counts, so no AUC was developed for spawners only.

Appendix C. Average bankfull width for streams where unique survey life estimates were generated.

Index Reach Name	Size Class	Average Bankfull Width (m)
Satsop Tributary 0462 0.0-0.2	Side Channel	8.0
Dry Bed Creek 0.0-1.0	Small	7.7
Elwood Creek 0.6-0.0	Small	5.9
Cedar Creek 0.6-0.0	Small	6.6
Schafer Creek 4.3-0.0	Medium	18.1
Donkey Creek 0.5-0.0	Medium	13.1
Stevens Creek 6.2-4.5	Medium	16.8
Stevens Creek 7.1-6.2	Medium	18.7
Wishkah River 29.4-26.1	Medium	29.0
West Fork Humptulips River 43.6-40.6	Large	49.4
Humptulips River 28.1-23.1	Large	55.4

Appendix D. Number of 2020 Chum Salmon counted during peak spawning surveys for both index and supplemental reaches.

Sub-Basin	Reach	Survey Type	Strata	Spawners	Total Lives	Deads
South Bay Sub-basin	Johns River_6.2-7.8	Index	Foot	0	0	0
	Johns River_9.5-10.7	Index	Foot	7	7	0
	West Branch Elk River_0-0.6	Index	Foot	1	1	2
	Andrews Creek_0.1-0.8	Supp	Foot	0	0	0
	Andrews Creek_0.8-1	Supp	Foot	1	1	0
	Andrews Creek_1-1.3	Supp	Foot	3	4	1
	Andrews Creek_1.3-2.3	Supp	Foot	0	0	0
	Florence Creek_0-0.3	Supp	Foot	0	0	0
	Newskah Creek_6.6-7.6	Supp	Foot	0	0	0
	North Fork Johns River_7.8-9.5	Supp	Foot	0	0	0
	Trib to Andrews 1370_0-0.45	Supp	Foot	0	0	0
	West Branch Elk River_0.6-1	Supp	Foot	0	0	0
	Newskah Creek_2.5-2.8	Supp	Foot	0	0	0
	Newskah Creek_4.2-4.6	Supp	Foot	0	0	0
	North Fork Johns River_10.1-10.7	Supp	Foot	0	0	0
	West Branch Elk River_1-2.2	Supp	Foot	0	0	0
Black River Sub-basin	Black River_4.1-6	Index	Boat	0	0	2
	Black River_6-7.1	Index	Boat	1	1	3
	Black River_7.1-8.1	Index	Boat	0	0	0
	Black River_8.1-8.6	Index	Boat	0	0	0
	Beaver Creek_0-1	Index	Foot	0	0	2
	Waddell Creek_0-1.9	Index	Foot	0	0	1
	Black River_18-18.5	Supp	Foot	0	0	0
	Beaver Creek_1-1.8	Supp	Foot	8	8	4
	Beaver Creek_2.5-3.5	Supp	Foot	0	0	0
	Mima Creek_0-0.9	Supp	Foot	0	0	0
	Waddell Creek_1.9-6.7	Supp	Foot	0	0	0
	Tributary 0664_0-1.8	Supp	Foot	0	0	0
	Cedar Creek_3.6-5.5	Supp	Foot	0	0	0
	Cedar Creek_5.5-7.4	Supp	Foot	0	0	0
Cloquallum Sub-Basin	Cloquallum Creek_1.9-4.1	Index	Boat	1	1	4
	Cloquallum Creek_4.1-5	Index	Foot	1	1	1
	Cloquallum Creek_5-6	Index	Foot	0	0	1
	Cloquallum Creek_6-7	Index	Foot	3	11	6
	Cloquallum Creek_7-8	Index	Foot	0	0	8

Sub-Basin	Reach	Survey Type	Strata	Spawners	Total Lives	Deads
Cloquallum Sub-Basin	East Fork Wildcat Creek_2.3-3.5	Index	Foot	4	5	0
	East Fork Wildcat Creek_3.5-4.8	Index	Foot	8	8	0
	Bush Creek_0-0.5	Index	Foot	33	38	9
	Rock Creek_0-0.4	Index	Foot	0	0	0
	Rock Creek_0.4-1	Index	Foot	3	3	0
	Mox Chehalis Creek_4.3-5.3	Index	Foot	2	3	0
	Mox Chehalis Creek_5.3-6.6	Index	Foot	0	0	0
	Cloquallum Creek_0-1.9	Supp	Foot	0	0	2
	Cloquallum Creek_11.4-12	Supp	Foot	21	38	0
	Cloquallum Creek_13-16.4	Supp	Foot	96	104	12
	Wildcat Creek_0-0.8	Supp	Foot	0	0	0
	Wildcat Creek_0.3-3	Supp	Foot	0	0	0
	West Fork Wildcat Creek_0-1.5	Supp	Foot	3	3	0
	West Fork Wildcat Creek_1.5-2.6	Supp	Foot	0	0	0
	East Fork Wildcat Creek_7.4-8.1	Supp	Foot	0	0	0
	East Fork Wildcat Creek_8.1-8.4	Supp	Foot	0	0	0
	Middle Fork Wildcat Creek_0-1	Supp	Foot	0	0	0
	Middle Fork Wildcat Creek_1-2.1	Supp	Foot	0	0	1
	Middle Fork Wildcat Creek_2.4-3.4	Supp	Foot	0	0	0
	Tributary 0508_0-0.2	Supp	Foot	0	0	0
	Bush Creek_0.5-1.5	Supp	Foot	5	10	0
	Falls Creek_0-0.3	Supp	Foot	0	0	0
	Power Creek_0-0.7	Supp	Foot	0	0	0
	Power Creek_0.7-1	Supp	Foot	0	0	0
	Power Creek_1.7-2.3	Supp	Foot	0	0	0
	Rock Creek_1-1.4	Supp	Foot	0	0	0
	Mox Chehalis Creek_1.2-4.3	Supp	Foot	0	0	1
	Mox Chehalis Creek_6.6-9	Supp	Foot	0	0	0
	Mox Chehalis Creek_9-12	Supp	Foot	0	0	2
Wishkah Sub-basin	Cedar Creek_0-1	Index	Foot	100	151	16
	East Fork Wishkah River_3.2-4.5	Index	Foot	5	6	0
	East Fork Wishkah River_4.5-5.9	Index	Foot	0	0	0
	West Fork Wishkah River_8.1-9.8	Index	Foot	16	19	0
	West Fork Wishkah River_9.8-10.8	Index	Foot	4	5	0
	Wishkah River_17.7-21.5	Index	Boat	19	55	5
	Wishkah River_21.5-24.5	Index	Boat	50	101	9
	Wishkah River_24.5-26.1	Index	Boat	489	520	13
	Wishkah River_26.1-27.6	Index	Boat	26	40	2
	Wishkah River_27.6-29.4	Index	Boat	257	294	8

Sub-Basin	Reach	Survey Type	Strata	Spawners	Total Lives	Deads
Wishkah Sub-basin	Big Creek_0-0.5	Supp	Foot	0	0	0
	Cedar Creek_1-1.8	Supp	Foot	50	50	5
	East Fork Wishkah River_1-3.2	Supp	Foot	5	6	0
	East Fork Wishkah River_5.9-6.5	Supp	Foot	0	0	0
	Ramey Creek_0.6-1.6	Supp	Foot	86	96	3
	Ramey Creek_0-0.6	Supp	Foot	48	50	0
	Tributary 0203_0-1	Supp	Foot	1	2	2
	Unnamed Trib to WF Wishkah_0-0.1	Supp	Foot	0	0	0
	West Fork Wishkah River_0-1.8	Supp	Foot	119	176	8
	West Fork Wishkah River_1.8-5.2	Supp	Foot	105	108	
	West Fork Wishkah River_10.8-11.3	Supp	Foot	0	1	
	West Fork Wishkah River_5.2-8.1	Supp	Foot	2	10	
	Wishkah River_11.8-17.7	Supp	Boat	4	11	2
Hoquiam Sub-basin	West fork Hoquiam_10.9-13.3	Index	Boat	0	5	0
	West Fork Hoquiam_9.4-10.4	Index	Boat	0	17	0
	West Fork Hoquiam_10.4-10.7	Index	Boat	0	3	0
	East Fork Hoquiam_7.5-9.9	Index	Boat	0	3	0
	East Fork Hoquiam_9.9-12.6	Index	Boat	28	28	0
	East Fork Hoquiam_12.6-16	Index	Boat	72	72	1
	Davis Creek_0-0.3	Index	Foot	57	61	0
	Davis Creek_0.6-0.8	Index	Foot	0	0	0
	Lytle Creek_0-0.3	Supp	Foot	0	0	0
	Berryman Creek_0-1	Supp	Foot	1	1	0
	Tributary 0146_0-0.1	Supp	Foot	0	0	0
	North Fork Little Hoquiam_0-0.1	Supp	Foot	0	0	
	North Fork Little Hoquiam_2.2-2.4	Supp	Foot	0	0	0
	Middle Fork Hoquiam_1.4-1.8	Supp	Foot	0	0	0
	Middle Fork Hoquiam_1.8-2.8	Supp	Foot	0	0	0
	Middle Fork Hoquiam_2.8-4.2	Supp	Foot	0	0	0
	Tributary 0143_0-0.3	Supp	Foot	0	0	0
	Polson Creek_0-2	Supp	Foot	0	0	0
	Hoover Creek_0-1	Supp	Foot	0	0	0
	Davis Creek_0.8-1.2	Supp	Foot	0	0	0
	Tributary 0181_0-0.2	Supp	Foot	0	0	0