

Status of Eulachon in Washington:

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Abstract

In 2019, the Washington Department of Fish and Wildlife (WDFW) used state general funds to study and monitor the ESA listed southern Eulachon distinct population segment (DPS). The primary objective was for WDFW to determine the 2019 eulachon spawning stock biomass (SSB) estimates for the Columbia River population based on egg and larval production surveys. We estimated egg and larvae density (n/m^3) at a transect comprised of six sampling stations crossing the Columbia River just upstream of the estuary. The transect was situated in a location to capture a sample of the eggs and larvae produced from all Columbia River spawning areas (mainstem and tributaries) except for the Grays River. We combined mean weekly egg and larvae densities with estimated river discharge (m^3/s) to estimate the total number of eulachon eggs and larvae produced during the winter of 2019. We converted the estimates of total egg and larvae production into SSB using estimated relative fecundity, sex ratio, and fish weight. We used bootstrapping on the Columbia River data to develop confidence limits for those estimates.

In addition to the larval monitoring, we continued to collect samples of adult Eulachon to expand our knowledge about their length, weight, age, sex ratios, and fecundity (information needed to parameterize our SSB estimation model). We explored how the Gonadosomatic Index (GSI) might give us an estimate of fecundity in years like 2019 where egg counts for fecundity estimations could not be completed. We were the first researchers to establish a length at age based von Bertalanffy growth function (VBGF) for the Columbia River Eulachon population.

Combining our SSB estimates with known Eulachon harvest, run estimates were developed for the Columbia River population. Those run estimates were allocated to brood year tables based on year specific age composition and sex ratio data. Using the complete or essentially complete brood year (2011-2016) returns as a measurement of recruitment, and the corresponding SSB for the measurement of parental stock, we were the first researchers to establish a Ricker stock-recruitment equation for the Columbia River Eulachon population. Various fisheries management Target Reference Points (TRPs) were identified for the population. We discussed how environmental factors that we currently use in run predictions, might be incorporated into a conventional density-dependent stock-recruitment approach, or into an unconventional approach like the Sakuramoto stock-recruitment model. We then assessed how many more years of gathering spawner, recruitment, and environmental data is needed to properly understand the dynamics behind the Columbia River Eulachon stock-recruitment relationship.

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Introduction

The National Marine Fisheries Service (NMFS) listed the southern distinct Population Segment (DPS) of *Thaleichthys pacificus*, also known as “Eulachon,” as threatened under the Endangered Species Act (ESA), effective May 17, 2010 (74 FR 13012; 50 CFR Part 223: 13012-13024; March 18, 2010). The southern DPS consists of all eulachon spawning south of the Dixon Entrance/ Nass River, BC. The Columbia River has been identified as one of the primary spawning rivers of the Southern DPS. For over a century, the status of the eulachon run to the Columbia River was measured by the number of pounds of fish landed during commercial fisheries. Larval sampling in the Columbia River was first attempted in 1946 (Smith and Saalfeld 1955). A few other eulachon larval sampling events occurred in the decades that followed (Hymer 1994). In 1994, Washington Department of Fish and Wildlife (WDFW) began to consistently monitor the peak outmigration larval density in the Cowlitz River. Over the next few years monitoring was begun in other tributaries of the Columbia River. The first survey in the Grays River was done in 1998 (Table 19 in JCRMS 2014). In 1995, eulachon larval sampling was initiated in the mainstem Columbia River downstream from the mouth of the Cowlitz River. In 1997, a transect across the lower Columbia River from navigation marker number 35 at Price Island and across the downstream end of Clifton Channel (near Columbia River kilometer 55) was established as an index to be sampled systematically every year (WDFW and ODFW 2001). Until recently, sampling in the mainstem Columbia River and the tributaries was concentrated around the estimated time of peak larval outflow.

In the “Summary of Scientific Conclusions of the Review of the Status of Eulachon (*Thaleichthys pacificus*) in Washington and Oregon” (Status Review; BRT 2008), the Biological Review Team (BRT) concluded that, “...eulachon are a relatively poorly monitored species...” The spawner biomass estimates established in Canadian rivers were, “regarded by the BRT as constituting the best scientific and commercial data available for recent eulachon abundance in the DPS.” The Canadian approach was to systematically sample the eulachon larval density at multiple mainstem sites throughout the whole period of larval outflow, expand that by the river discharge to obtain an estimation of total season outflow of larvae, and then back calculate how many adults must have produced that larval outflow. This adult equivalent was expressed in metric tonnes (megagrams) and hence referred to as the Spawning Stock Biomass (SSB).

In the Federal Recovery Outline for Eulachon Southern DPS of June 21, 2013, NMFS states that it has been difficult to evaluate the status of eulachon “due to the lack of reliable long term data”, and that available abundance data “are confounded by intermittent reporting, fishery-dependent data, and the lack of directed sampling” (NMFS-NWR 2013). The Federal Recovery Outline for Eulachon Southern DPS, identifies “in-river spawning stock biomass surveys to develop long-term

eulachon spawner abundance estimates for all four sub-populations.”, as the first item in the list of recovery tasks to improve potential for recovery.

The Endangered Species Recovery Plan for Southern Distinct Population Segment of Eulachon (*Thaleichthys pacificus*) was published on September 6, 2017 (<http://www.nmfs.wcr.gov>). In this document, the first recovery action is to, “establish a Eulachon Technical Recovery and Implementation Team.” The second action item is to, “Implement outreach and education strategies.” Action 3 is near-term research priorities. The first of the eight research priorities (3.1) is to, “conduct annual in-river spawning stock biomass surveys in spawning areas with high-to-moderate spawning frequency to develop long-term high-resolution abundance estimations for each subpopulation of eulachon.”

Study Objectives and Report Structure

The purpose of this report is to provide information on the status of the Columbia River Eulachon population in 2019, in a format consistent with the 2015-2018 report to NMFS (Langness *et al.* 2018). In this report, we focus on the development of the SSB estimates in the mainstem Columbia River. We will describe the field and laboratory processes to obtain Eulachon plankton (eggs and larvae) densities, and expand that by river discharge to estimate the total egg and larvae outflow. We will then back calculate the minimum number of spawners needed to produce this flux. Adding on the harvested Eulachon will give us the 2019 run size estimate. That run estimate will then be compared to the previous run estimates for the Columbia River, and historical run estimates for other West Coast populations. Finally, we will present a brood year table based on our run estimates and the age structure observed each year.

Methods

Study Design

Fine-mesh plankton nets have been used sporadically in the lower Columbia River basin since 1946 to collect eulachon smelt larvae. Collection methods and gear were refined and standardized in 1994 for survey of the Cowlitz River (Hymer 1994). Subsequent surveys were expanded to include several other tributaries and the mainstem Columbia River beginning in 1995 (WDFW and ODFW 2001). Further refinements were implemented in 2001 for a study designed to characterize the timing and extent of larval migration in the lower Columbia River as part of an assessment of potential effects on eulachon from a project deepening the Columbia River shipping channel (Howell *et al.* 2002). One result of this work was establishment of a single standardize sampling transect for the mainstem Columbia River at river kilometer 55 that has since been used by fishery managers to index annual eulachon larvae production for the lower Columbia River and tributaries, excluding the Grays River, which enters the Columbia River downstream of the transect (JCRMS 2014). The methods and sample locations established in these earlier mainstem lower Columbia River surveys were applied to our 2019 survey.

Daily egg production method (Parker 1985) has been commonly using in pelagic fish spawning biomass assessment since 1983. Jackson and Cheng (2001) modified the method by using nonlinear regression and bootstrapping techniques to improve the estimates of the Shark Bay snapper spawning biomass and Hay *et al.* (2002) modified it to estimate eulachon smelt SSB in the Fraser River. Their approach expands eulachon egg and larvae sample density data by estimated river discharge to generate SSB estimates. In 2010, WDFW expanded upon the existing lower Columbia River eulachon larvae indexing program to implement an SSB estimation survey like that employed by the Canadian Department of Fisheries and Oceans for the Fraser River run (Hay *et al.* 2002; McCarter and Hay 2003; Therriault and McCarter 2005).

Study Area

Previous studies have documented large spawning concentrations of eulachon in the Cowlitz and Lewis rivers, Washington. During field sampling in 2001, Howell *et al.* (2002) found the highest densities of out-migrating larvae in the Columbia River downstream of the confluence with the Cowlitz River at Columbia River kilometer 110 (Figure 1). Other major tributaries know to contain eulachon spawning habitat include the Grays, Elochoman, Kalama, Lewis, and Sandy rivers. All eulachon larval and egg production from the mainstem Columbia River and major tributaries can be encountered at the standardized sampling transect for the mainstem Columbia River at river kilometer 55, except for the Grays River production.

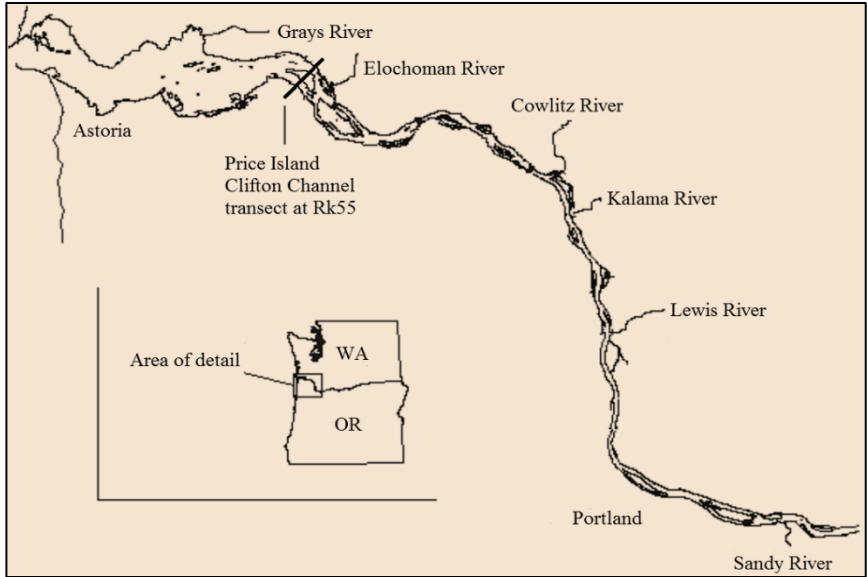


Figure 1. Lower Columbia River eulachon spawning stock biomass study site showing the location of the larval eulachon sampling transect at Columbia River kilometer 55. Included are the primary tributaries containing eulachon spawning habitat.

We sampled the Columbia River at an existing transect at kilometer 55, the index site for larval eulachon sampling that has been monitored by WDFW since 1997 (WDFW 2001, Howell *et al.* 2002). The transect position (perpendicular to the river flow) crosses Clifton Channel from the Oregon shore to Tenasillahe Island and then crosses the shipping channel to Price Island on the Washington shore. Columbia River discharge was measured at the USGS water-monitoring gage 14246900 Columbia River at Port Westward, near Quincy, OR (formerly referred to as the Beaver Army Terminal; Figure 2).

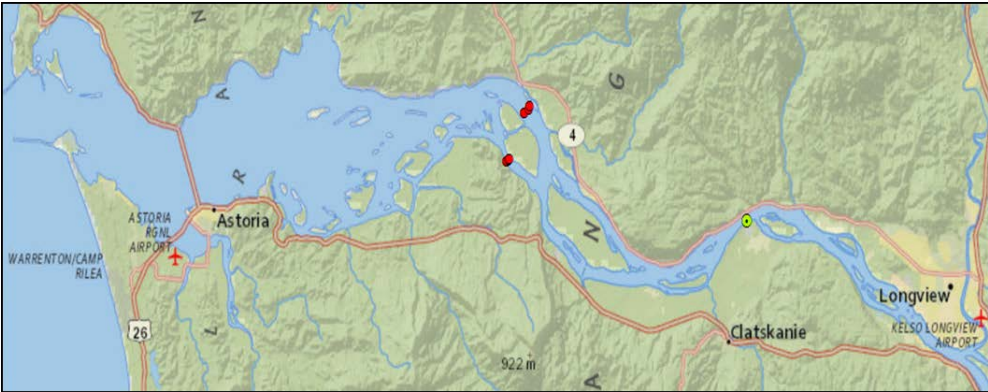


Figure 2. Map of lower Columbia River with mainstem transect sampling stations indicated by red circles, and USGS gauge station indicated by the green circle.

There were no funds available in 2019 to monitor the Grays, Naselle or Chehalis rivers, as had been done previously.

Field Data Collection and Laboratory Processing

We used a plankton net deployed from an anchored vessel to capture eulachon larvae (Figure 3). The net was a typical ring net design comprising a tapered nylon sock (3.35 m length, 300 μm mesh) lashed to a stainless-steel circular frame (0.61 m inside diameter). Samples were collected in an 8.9-cm, two-piece polyvinyl chloride (PVC) collection bucket attached to the end of the sock. Spherical lead weights (2.54 kg, 9.07 kg or both) were attached to the frame base. Water flow was measured with a General Oceanic Model 2030R mechanical flowmeter mounted in the mouth of the net and calibrated to measure the total volume of water in cubic meters that was filtered through the net. Our standard setup was a single flow meter, but we experimented with a two-meter setup in spring 2013. We retained the two flow meter configuration to validate the volume sampled.

All samples were obtained during daylight hours on ebb tides for safety and logistical reasons. A vessel was anchored, and we recorded water temperature, depth, and turbidity readings. A tow consisted of lowering the plankton net to the river bottom and then retrieving it. Therefore, set duration depended on river depth.

Sampling the Columbia River involved separate one-to-seven minutes stationary plankton tows made for each of six stations situated along the standardized sampling transect located at Columbia River kilometer 55. The transect position (perpendicular to the river flow) crosses Clifton Channel from the Oregon shore to Tenasillahe Island and then crosses the shipping channel to Price Island on the Washington shore (Figure 2). Sample frequency on the Columbia occurred twice weekly during the peak out-migration period and weekly during pre and post peak. The Columbia River was sampled at all six sites along the transect, 19 times during the 2019 weeks of the year 5 through 20 (i.e., Sunday January 27th through Saturday May 18th).

Contents of the collection bucket were rinsed into separate bar-coded 1-L Nalgene[®] screw-cap storage bottles for each sample and fixed with dilute (approximately 70%) ethyl alcohol. Samples were stored in bins and analyzed through the season at the WDFW Region 5 laboratory in Ridgefield, Washington.

One hundred percent of each sample was examined. Samples were poured into a black dish, and we used the 5X lens of an Intertek Model LUX 900 dissecting microscope (with 13W lamp) to count all eggs and larvae (Figures 4 and 5). For species identification of larvae and staging of eggs, we used a Labomed Luxeo 4D (Model 414500) stereozoom microscope.

Three or four larvae from each Columbia River sample were placed in 2-ml United Laboratory Plastics cryogenic vials containing DNA preservative solution (100% anhydrous ethanol) and shipped to the WDFW Molecular Genetic Laboratory in Olympia, Washington, for archiving and potential future genetic analyses.

Adult Eulachon samples (Figure 6) were obtained from incidental catch in the Columbia River and Grays River salmonid test fisheries, and from tribal catch in the Cowlitz River. The sampled fish were weighed and measured. Also, the whole gonad (both skeins) were weighed on most female samples. Otoliths were extracted from all fish, and fin clips taken from a random sample for DNA analysis.

Data Processing

We obtained estimated daily river discharge from monitoring stations, in cubic feet per second, and converted those values to daily discharge in cubic meters per day (Appendix A).

We estimated plankton density based on the estimated volume of water filtered through the plankton net (Appendix B) and the laboratory counts of Eulachon eggs and larvae for each sample (Appendix C). Water volume calculations were made using only data from the primary flow meter (there were no significant anomalies between the primary and secondary flow meters in 2019). The daily and weekly eulachon plankton densities can be found in Appendix D.

Catch rates for larvae were estimated as catch per cubic meter of water filtered in each sample. Expansion of the samples to weekly and annual outflow estimates were done in accordance with the procedures described for the Fraser River (Hay *et al.* 2002). The cumulative number of eggs and larvae was estimated for each sample week as the product of the weekly mean density of Eulachon plankton (eggs and larvae) and the river discharge for the week.

The adult Eulachon samples were processed to obtain data to inform the biological parameters (sex ratios, average weights, fecundity, etc.) used in the estimation of SSB. We compared the differences in sex ratios observed in our adult sampling (Table 1) and reviewed past studies for sex ratio information (Table 2). Due to the wide range in values reported and concerns about potential biases (Wagemann 2014), we decided to follow the example reported in Hay *et al.* (2002) and concluded that it was valid to use a 1:1 sex ratio when estimating SSB. We considered the following data when selecting our weight parameters: a 43.67 gram average (10.4 fish per pound; n=938) for sport-dipped fish collected in 2014 from the Cowlitz River (unpublished data); a 40.63 gram average (n=2,352) reported in Hays *et al.* (2002) for the Fraser River; and, a 34.6 gram average (13.1 fish per pound; n=2,500) reported for 1953 Columbia River and tributary commercial fisheries (FCO 1954). Due

to the range in average weights, we elected to use the 40.63 gram value reported by Hay *et al.* (2002) to calculate the 11.16 fish per pound used in our SSB modeling. In summary, Eulachon SSB estimates were made with the following assumptions: 1:1 sex ratio; 40.63 grams average fish weight; 40.84 grams average female fish weight (used in calculating eggs per gram of female fish); 173 millimeters average female fish length; 32,766 average eggs/female; 11.16 eulachon per pound; eggs and larvae are equivalent; and, 100% survival from egg to larvae stage (Table 3).

We employed bootstrapping (Jackson and Cheng 2001) to all raw data for the Columbia River to determine the error structure around annual egg/larvae production (Figure 9), spawner, and SSB estimates. For each bootstrap sample we let $n=1,000$ (Table 3). We pooled all bi-weekly density estimates into one-week periods for each station. The bootstrap procedure randomly selected six weekly egg and larvae density values from the pool of six sampling stations, with replacement. The mean and standard deviation were estimated from the 1,000 bootstrap replications for each week. Bootstrap estimates were generated for each sample week, and summed for the entire Columbia River egg and larval outmigration period surveyed. Each time the model file is open, the bootstrapping of each week is activated, which generates slightly different distributions. To stabilize the SSB estimate for this report, the model file was recalculated 150 times, and the average of those results were used to provide the final estimate distribution.

Results and Discussion

The duration of the larval outflow from the Columbia River typically spans 20 weeks regardless of the magnitude of production (Figure 7). The peak for 2019 came in week 15 (the latest peak since 2014). There is a minor peak in production that appears during early to mid-January, which is associated with the fish that arrive between Thanksgiving and Christmas. Sampling during 2019 did not start until January 30th (Week of the Year 5). None-the-less, more larvae were collected during this first sample date than the subsequent seven weeks of sampling (Table C1).

Mean daily larval and egg density does not show an obvious correlation with mean daily discharge (Figure 8). Other factors, such as water temperature, may play a more significant role in determining larval and egg densities. Temperature can influence the timing of the adult migration, and the time it takes for the eggs to hatch.

Since 2011, limited numbers of eggs have been taken in the plankton net tows. Therefore, mean combined egg and larvae densities have been very similar to the mean larvae densities for the given year. Generally, egg densities peaked earlier than the larvae densities, though this wasn't observed in 2019 (Table D1).

In the Columbia River (Table D1), the tendency for greater plankton densities at the Price Island sites (Stations 4–6) is thought to be related to the fact that most eulachon spawning tributaries are on the Washington shore (Elochoman, Cowlitz, Kalama, and Lewis rivers). The lack of eggs in the samples is likely due to eulachon spawning further upriver (not in the immediate vicinity of the Clifton Channel/Price Island sampling transect). Most eggs encountered at the sample transect location are in a later stage of development, or are dead.

We estimate that the SSB for the Columbia River was approximately 4,182,000 pounds with a 95% confidence interval of 2,275,000 to 6,415,000 pounds (approximately 1,900 metric tonnes with a confidence interval of 1,000 to 2,900 metric tonnes) for 2019 (Table 4). A conservative estimate of the eulachon run to the Columbia River system would consist of adding known harvest to the SSB estimate for the Columbia River. Commercial and Recreational fisheries were closed in 2019. Tribal ceremonial and subsistence fisheries caught 23,660 pounds (10.7 metric tons). Harvest in 2019 amounted to approximately 0.5% of the SSB value, making the run size approximately 4,205,000 pounds. Due to the Grays River occurring below the Columbia River larval index site, one might consider adding the Grays River SSB value to this to get a more complete run estimate; however, past Grays River SSB values have been less than 1% of the corresponding Columbia River SSB. No SSB estimate for the Grays River was done in 2019, so no adjustment was made to the run size estimate.

Accurate eulachon plankton density estimates are dependent upon having correct larvae and egg counts and flow meter measurements. A sticking or slow meter would result in a low estimate of water volume sampled. That would bias the plankton densities high, which subsequently would bias the biomass estimates high. Given the surprisingly high SSB estimates, the use of old flow meters was questioned. Testing the old meter in tandem with a new meter in spring 2013 revealed that two meters performed similarly. We continue to this day to mount two meters on our net. For consistency, we record both meter readings, but have used the readings from the original meter for all analyses.

Missing eggs and larvae at the beginning and end of a survey will result in an underestimation of the annual plankton production, and subsequently bias the SSB estimate low (Moffitt *et al.* 2002). Ideally, one should strive to start and end the season with no eggs or larvae present in the samples. Due to budget constraints, the 2019 Eulachon larval sampling season was shortened. We counted 4 eggs and 290 larvae in the first sample period, and 1 egg and 18 larvae in our last sample period (Table C1). We therefore conclude that the 2019 Columbia River SSB estimate is biased low.

As mentioned in the above paragraph, having correct larvae and egg counts is necessary to assure good estimates of plankton density. During the peak of the run we double our sample days per week to improve our confidence intervals (Figure 9; Weeks of the Year 14, 15, and 16 for the 2019 sampling season). During this time there can be thousands of eggs and larvae to count in a single sample. The temptation is to estimate the counts by expansion of a subsample count, but if the subsample is not representative, the estimation can be off. In 2010 and 2011, we experimented with subsampling, including using a sample splitter device, but found too much variations between the subsamples. As a result, we chose to process the whole sample regardless of the circumstances.

Some larvae and eggs collected in the early and late sampling periods are of different form or size. Subsequently, these larvae and eggs were not included in the eulachon plankton count, but recorded as non-eulachon larvae or eggs. Temporal genetic analysis of the Columbia River Eulachon run revealed that there was still a presence of non-eulachon larvae after removal of the noticeably different larvae (Langness *et al.* 2018). It is likely that in some years the spawning of Longfin Smelt (*Spirinchus thaleichthys*) occurs above the Price Island/ Clifton Channel Eulachon egg and larval outflow sampling stations. The presence of obvious non-eulachon larvae and eggs were always low, probably never exceeding 5 percent of a sample at any time, and almost never occurring during the peak period for eulachon outmigration. Even if these non-eulachon larvae and eggs were included in the determination of density, they would have created a very modest high bias in the SSB estimate.

River discharge was measured at Port Windward (Columbia River kilometer 86.6) which is some distance above the Clifton Channel/Price Island larval sample transect sites (Columbia River kilometer 55). Two rivers flow into this 31.6 km section of the Columbia River – the Elochoman

River (right bank, Columbia River kilometer 62.9) and Clatskanie River (left bank, Columbia River kilometer 80.0). The Elochoman River's mean discharge is 925 ft³/s, 1020 ft³/s, 662 ft³/s for January, February, and March respectively (USGS 14247500 data from 1941–1971, <http://waterdata.usgs.gov>). The Clatskanie River's mean discharge is 349 ft³/s, 383 ft³/s, and 212 ft³/s for January, February and March respectively (USGS 1424700 data from 1950–1954, <http://waterdata.usgs.gov>). These two rivers drain approximately 118.8 miles², which is only 0.05% of the drainage area above the Port Westward gage (256,900 miles²). Monthly mean discharges for the Port Westward site are 301,000 ft³/s, 244,000 ft³/s, and 296,000 ft³/s for January, February and March respectively (USGS 14246900 data from 2011–2013, <http://waterdata.usgs.gov>). The contribution of these two rivers to the daily discharge at the sampling site during eulachon plankton outflow is minor (<0.05%); however, it does mean that the daily production of eggs and larvae was biased low by that percent (daily production is estimated as the daily discharge (m³/sec) times the estimated daily larval and egg density (number/m³)). Not correcting for water inflow downstream of the Port Westward biased our estimates of total eulachon egg and larvae production, which subsequently biased our biomass estimates low by <0.05%.

We assume that the larval densities we observed during our daylight sampling are representative of the larval densities throughout the whole day. Some researchers report larger catches of eulachon larvae at night (Levings 1980; Orr 1984). As Moffitt *et al.* (2002) point out, larger abundance of eulachon larvae migrating at night would bias the biomass estimate low if the samples were only taken during daylight hours. We speculate that diurnal differences in larval densities may be more apparent in smaller and slower bodies of water where the larval collection sites may be closer to the hatching/emergence sites. In larger systems, the passive migrating minuscule eulachon larvae are likely to be well mixed and disbursed by the time they arrive at larval collection sites in the lower reaches of the river. Thus, the bias may be more of an issue for the SSB estimation in the Grays River than for the SSB estimation in the mainstem Columbia River.

We have assumed that there is no egg to larval mortality. This gives us conservative SSB estimates. Had there been stranding due to dewatering, loss from disease, etc. then it would take more females to produce the egg and larvae seen at the collection site. If some egg retention occurs, or eggs fail to be fertilized, then even more females are needed to account for the observed level of production. In our model, we simply divide the number of eggs and larvae produced by the assumed fecundity to derive the estimated number of females.

In the model, we have assumed a sex ratio of 1:1. This assumption may result in a conservative estimate of SSB. Most eulachon studies report a dominance of males in the sample. If we took the weighted average M:F gender ratio from Table 1 of 1.67:1, the estimated number of females would be multiplied by 2.5 rather than doubled to derive the number of spawning smelt. Moffitt *et al.* (2002) warns us that, “all reported sex ratios for eulachon should be interpreted with caution.”

Eulachon sex ratios in the literature probably vary because of gear selectivity, low sample sizes, and the temporal and spatial scale of sample collections.

Moffitt *et al.* (2002) explain how gender differences in behavior near and on the spawning grounds may lead to samples dominated by males. It would seem prudent to continue to focus our adult collections in the estuary and lower reaches of the mainstem Columbia River, where the various components of the run are present and mixed together.

In Figure 10, you can see that on average, the run in the Columbia River is more than an order of magnitude greater than the Fraser River run. It is evident that the two rivers are discordant, and perhaps trend in completely opposite patterns. It is obvious that the Columbia River run is a very significant component of the eulachon southern DPS. Having a consistently funded long-term stock assessment program in the Columbia River, as the Canadians have in the Fraser River, would benefit the recovery effort and fisheries management.

For a more in depth review of the adult Eulachon biodata collection, ageing, and genetic studies, consult Appendix E.

As to our agency's public outreach objective, we have presented information about Eulachon to various commercial and recreational fishery groups, fish commissions and councils, and professional groups during 2019. We have integrated fun activities and new displays focused on Eulachon at the WDFW/City of Vancouver Water Resources Education Center's annual Sturgeon Festival held September 21, 2019, and intend to continue to emphasize Eulachon at the 2020 Festival. Very restricted recreational fisheries (few hours of dip netting in short reaches of the Cowlitz or Sandy rivers) were not held during the 2019 run, due to a poor forecast and late arrival of fish. The pre-season forecast for 2020 is for a moderate run, which may allow managers to open very restricted fisheries in 2020. The associated creel survey process gives us a chance to rekindle the public interest in Eulachon and educate them about their status, biological needs, and role in the Columbia River and ocean ecosystems.

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Figures



Figure 3. Photograph of the plankton net setup deployed to collect eulachon smelt eggs and larvae. Image shows the setup when two General Oceanic flow meters were mounted to the frame.



Figure 4. Photograph of Washington Department of Fish and Wildlife Region 5 laboratory setup to process eulachon larval samples. Laura Lloyd is viewing a portion of the content of sample 00571 under a 5x lens. A multiple counter is used to separately track eulachon and non-eulachon larvae and eggs. Up to ten eulachon larvae will be taken from a sample and transferred to cryogenic vials containing DNA preservative for future genetic analysis (note pipette and red-capped vial in background).



Figure 5. Photograph of a portion of a eulachon larval sample viewed under a 5x lens. Note that the black background facilitates viewing of the thin slightly opaque larvae. This is a very clean sample, without debris and algae. Larvae will cling and become buried in debris and algae, making the task of counting more difficult.



Figure 6. Top photograph of a live male Eulachon (*Thaleichthys pacificus*) (top) and female Eulachon (bottom) caught during trawling operations in the lower Columbia River in 2013. Biological data collected on the adult run is used to parameterize the estimation of Spawning Stock Biomass (SSB). Photograph courtesy of Jeannette Zamon, NMFS Point Adams Research Station. Bottom photograph of a Longfin Smelt (*Spirinchus thaleichthys*) from the Sacramento Bay Delta Distinct Population Segment, USFWS Bay-Delta Fish and Wildlife Office, <https://www.fws.gov/sfbaydelta/EndangeredSpecies/Species/Accounts/LongfinSmelt/LongfinSmelt.htm>

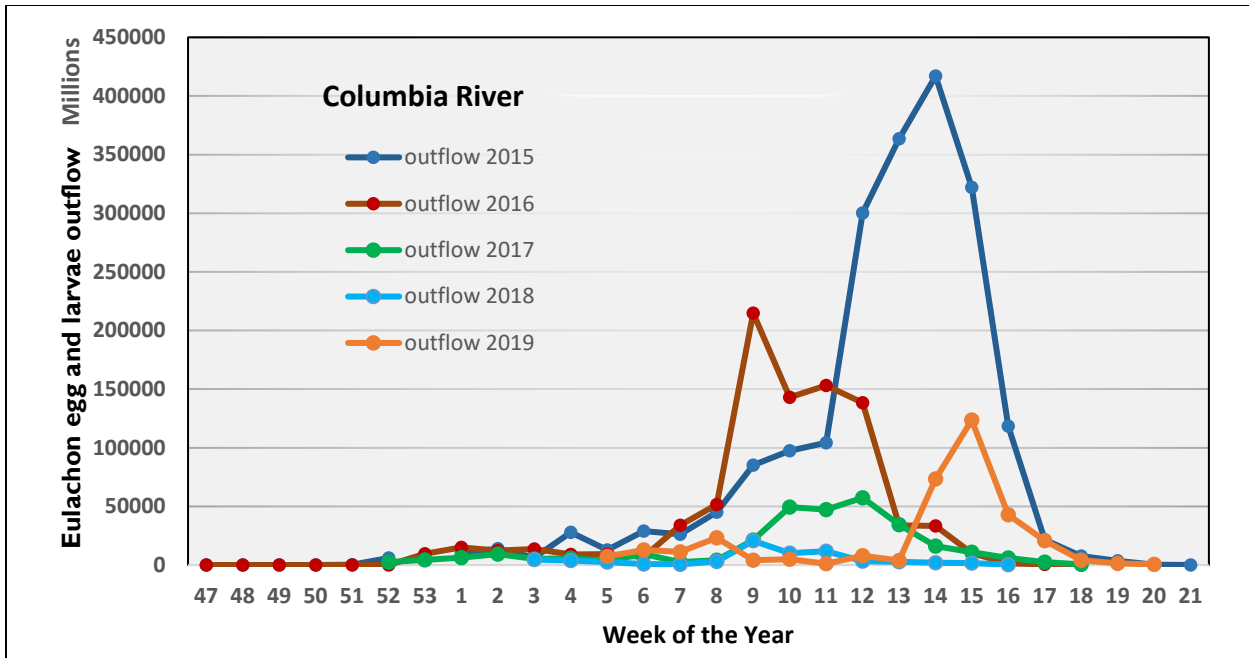


Figure 7. Weekly eulachon egg and larvae sample densities (values averaged if sampled twice in a week) for the Columbia River from sites along the Price Island/Clifton Channel transect, during 2014-15 (weeks 49 through 21), 2015-2016 (weeks 43 through 19), 2016-2017 (weeks 52 through 18), 2018 (weeks 3 through 16) and 2019 (weeks 5 through 20). Charts sized to maintain relatively equal scales.

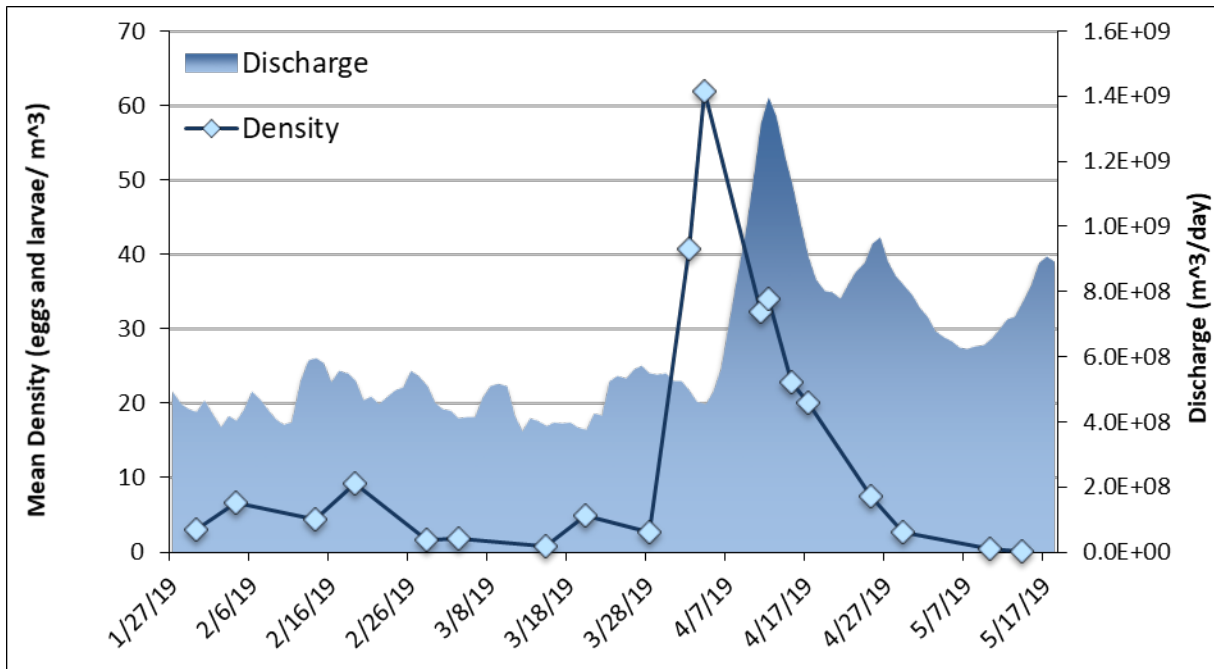


Figure 8. Mean daily Columbia River Eulachon egg and larval sample densities collected at the Clifton Channel/Price Island index from January 27, 2019 through May 18, 2019 (Weeks of the Year 5 through 20) displayed against the calculated daily Columbia River discharge at the USGS Water Gage 14246900 (Columbia River at Port Westward, near Quincy, Oregon).

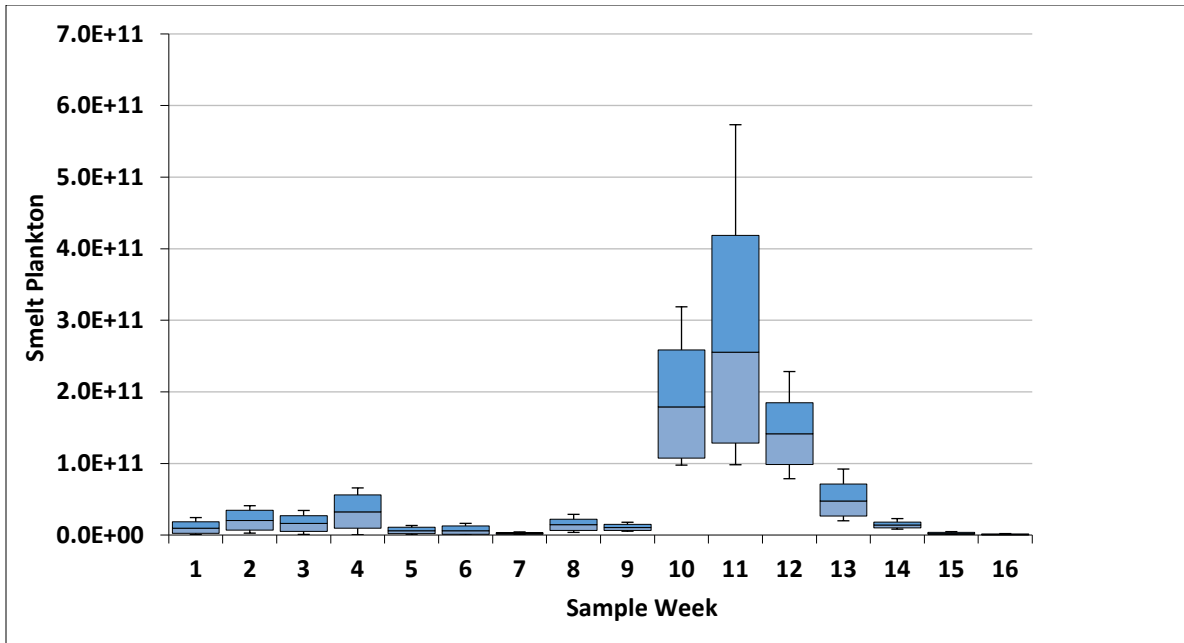


Figure 9. Box plot of weekly outflow (passive outmigration) of Eulachon (smelt) plankton (eggs and larvae) into the Columbia River estuary at the Clifton Channel/Price Island survey transect for fifteen sample weeks during 2019 (Weeks of the Year 5 through 20). Dark Blue represents upper (95%) confidence level, the black line separating the boxes represents the mean, and the light blue represents the lower (95%) confidence level. Includes bootstrap generated minimum and maximum estimates.



Figure 10. Comparison of estimated number of Eulachon spawning in the Columbia River, Fraser River, Chehalis River, Naselle River, and Grays River. Estimates of number of spawners are based on the SSB weight multiplied by a standard 11.16 fish per pound, and rounded to the nearest hundred fish. Estimates for the Fraser River derived from data provided by the Canadian Department of Fisheries and Oceans (DFO).

Tables

Table 1. Summary of adult Eulachon sex ratio data collected for the Columbia and river, 2011-2013.

Date	Source	Study	Collection gear	Number examined	Gender ratio (M:F)
2011-2012	Cowlitz River	Cowlitz Tribe	Fyke net	60	0.32:1
2012-2013	Cowlitz River	Cowlitz Tribe	Fyke net	30	0.33:1
2013 Feb 25	Columbia River	NMFS Pt. Adams	trawl	126	0.64:1
2013 Mar 5	Columbia River	NMFS Pt. Adams	gillnet	1,230	n/a
2013 Mar 7	Columbia River	NMFS Pt. Adams	trawl	6,480	1.86:1
2013 Mar 11	Columbia River	NMFS Pt. Adams	trawl	173	0.57:1
2013 Mar 12	Columbia River	NMFS Pt. Adams	trawl	22	0.05:1
			Total	6,801	
				Range	0.32–1.86:1
				Daily average	0.78:1
				Weighted average	1.67:1

Table 2. Eulachon sex ratio published for the Columbia River, tributaries, and for the Fraser River.

Year	Source	Reference	Collection Gear	Number Examined	Gender Ratio (M:F)
1930's	Columbia R.	Royal (1932) 1	commercial gillnet	ns*	6.8:1
1930's	Cowlitz R.	Royal (1932) 1	commercial dip net	ns*	3.2:1
1930's	Lewis R.	Royal (1932) 1	commercial dip net	ns*	12.3:1
		Royal (1932) 1		mean	4.5:1
1946	Cowlitz R.	Smith and Saalfeld (1955)	commercial dip net	1465	10.5:1
1946	Sandy R.	Smith and Saalfeld (1955)	commercial dip net	992	2.8:1
1946	Cowlitz R.	Smith and Saalfeld (1955)	Dip net	ns*	3.0:1
			1930's – 1946 Range		2.8-12.3:1
1939	Fraser R.	McHugh (1939)	commercial gillnet	1066	1.73:1
1995	Fraser R.	Hay <i>et al.</i> (2002)	commercial gillnet	663	0.88:1
1996	Fraser R.	Hay <i>et al.</i> (2002)	commercial gillnet	459	1.11:1
1997	Fraser R.	Hay <i>et al.</i> (2002)	commercial gillnet	513	0.98:1
1998	Fraser R.	Hay <i>et al.</i> (2002)	commercial gillnet	416	1.67:1
2000	Fraser R.	Hay <i>et al.</i> (2002)	commercial gillnet	201	1.16:1
2001	Fraser R.	Hay <i>et al.</i> (2002)	commercial gillnet	100	1:1
			Total 1995-2001	2352	
				1995-2001 Range	0.88-1.67:1
				1995-2001 Average	1.09:1
	<i>ns* = Not specified</i>				

Table 3. Parameter values used in estimating Columbia River Eulachon spawning stock biomass from 2013-2019.

Parameter	Value
<u>Biological</u>	
sex ratio	1:1
mean female length (mm)	173
mean female weight (gram)	40.84
eggs/gram female	802.3
eggs/ female	32,766
mean fish weight (gram)	40.6
fish/pound	11.16
eggs/gram of fish	401
eggs/fish	16,293
egg to larvae survival	100%
<u>Bootstrap</u>	
Iterations	1,000
Alpha	0.05
Confidence Level	0.95

Table 4. Estimated Columbia River Eulachon mean egg and larvae density, egg and larvae production (smelt plankton outflow), and spawning stock biomass for the period January 27, 2019 through May 18, 2019 (Weeks of the Year 5 through 20), including bootstrap generated mean and 95% confidence limit estimates of plankton outflow, numbers of spawners, and SSB in pounds and in metric tons.

Cumulative Values for:	Plankton Outflow	Number of Spawners	SSB (Pounds)	SSB (megagram)
Days Sampled	19			
n (per sample day)	6			
Mean egg density	0.12			
Mean larvae density	13.45			
Mean egg & larvae density	13.58			
Point estimate	761,897,513,242			
Bootstrap generated values				
Maximum	1,452,313,844,750	89,137,289	7,984,409	3,622
Upper CI	1,166,822,235,608	71,614,941	6,414,857	2,910
Mean	760,634,880,718	46,684,765	4,181,754	1,897
Median	750,656,086,349	46,072,306	4,126,894	1,872
Lower CI	413,736,773,931	25,393,529	2,274,607	1,032
Minimum	314,211,921,073	19,285,087	1,727,448	784

Table 5. Comparison of estimated number of Eulachon spawning in the Columbia River, Fraser River, Chehalis River, Naselle River, and Grays River. Estimates of number of spawners are based on the SSB weight multiplied by a standard 11.16 fish per pound, and rounded to the nearest hundred fish. Estimates for the Fraser River derived from data provided by the Canadian Department of Fisheries and Oceans (DFO), using the standard 7-week Fraser River survey for 2017-2019 (i.e., excluding the early 3 weeks added to surveys since 2017).

	Columbia River	Grays River	Naselle River	Chehalis River	Fraser River
2011	37,000,000	8,200			762,700
2012	36,000,000	9,700			2,952,400
2013	110,000,000	25,800			2,460,300
2014	180,000,000				1,623,800
2015	110,000,000	184,300	41,000	280,000	7,799,300
2016	54,556,500	818,100	36,400	695,900	1,082,500
2017	18,307,100		600	191,700	868,500
2018	4,104,300			13,600	10,038,200
2019	46,684,800				

Appendix A: Discharge for the Columbia River

Table A1. Columbia River discharge, in cubic feet per second reported for the USGS Water Gage 14246900 Columbia River at Port Windward (near Quincy, Oregon), and daily discharge in cubic meters per day, January 27, 2019 through May 18, 2019. Included is river temperature measured during sampling of the Price Island/Clifton Channel transect.

Date	Discharge		Temp °C	Date	Discharge		Temp °C	Date	Discharge		Temp °C
	ft ³ /sec	m ³ /day			ft ³ /sec	m ³ /day			ft ³ /sec	m ³ /day	
19-01-27	203,000	496,655,000		19-03-06	171,000	418,364,000		19-04-13	547,000	1,338,277,000	
19-01-28	187,000	457,510,000		19-03-07	195,000	477,082,000		19-04-14	496,000	1,213,501,000	
19-01-29	180,000	440,384,000		19-03-08	209,000	511,334,000		19-04-15	459,000	1,122,978,000	9.8
19-01-30	177,000	433,044,000	6.2	19-03-09	213,000	521,121,000		19-04-16	413,000	1,010,436,000	
19-01-31	191,000	467,296,000		19-03-10	209,000	511,334,000		19-04-17	371,000	907,680,000	10.1
19-02-01	176,000	430,597,000		19-03-11	173,000	423,258,000		19-04-18	343,000	839,175,000	
19-02-02	158,000	386,559,000		19-03-12	153,000	374,326,000		19-04-19	328,000	802,477,000	
19-02-03	172,000	420,811,000		19-03-13	169,000	413,471,000		19-04-20	326,000	797,584,000	
19-02-04	165,000	403,685,000	5.7	19-03-14	165,000	403,685,000		19-04-21	319,000	780,458,000	
19-02-05	181,000	442,830,000		19-03-15	160,000	391,452,000	4.4	19-04-22	336,000	822,049,000	
19-02-06	202,000	494,208,000		19-03-16	164,000	401,238,000		19-04-23	352,000	861,195,000	
19-02-07	191,000	467,296,000		19-03-17	163,000	398,792,000		19-04-24	364,000	890,554,000	
19-02-08	179,000	437,937,000		19-03-18	164,000	401,238,000		19-04-25	387,000	946,825,000	11.8
19-02-09	167,000	408,578,000		19-03-19	158,000	386,559,000		19-04-26	396,000	968,844,000	
19-02-10	161,000	393,899,000		19-03-20	154,000	376,773,000	6.5	19-04-27	365,000	893,000,000	
19-02-11	164,000	401,238,000		19-03-21	175,000	428,151,000		19-04-28	348,000	851,408,000	
19-02-12	215,000	526,014,000		19-03-22	172,000	420,811,000		19-04-29	335,000	819,603,000	12.4
19-02-13	241,000	589,625,000		19-03-23	216,000	528,460,000		19-04-30	323,000	790,244,000	
19-02-14	244,000	596,964,000	4.4	19-03-24	222,000	543,140,000		19-05-01	308,000	753,545,000	
19-02-15	238,000	582,285,000		19-03-25	219,000	535,800,000		19-05-02	296,000	724,186,000	
19-02-16	214,000	523,567,000		19-03-26	230,000	562,712,000		19-05-03	278,000	680,148,000	
19-02-17	228,000	557,819,000		19-03-27	235,000	574,945,000		19-05-04	270,000	660,575,000	
19-02-18	226,000	552,926,000		19-03-28	226,000	552,926,000	7.0	19-05-05	266,000	650,789,000	
19-02-19	216,000	528,460,000	4.7	19-03-29	224,000	548,033,000		19-05-06	258,000	631,216,000	
19-02-20	192,000	469,743,000		19-03-30	226,000	552,926,000		19-05-07	256,000	626,323,000	
19-02-21	197,000	481,975,000		19-03-31	216,000	528,460,000		19-05-08	259,000	633,663,000	
19-02-22	186,000	455,063,000		19-04-01	215,000	526,014,000		19-05-09	260,000	636,110,000	
19-02-23	197,000	481,975,000		19-04-02	204,000	499,101,000	8.4	19-05-10	269,000	658,129,000	14.6
19-02-24	204,000	499,101,000		19-04-03	190,000	464,849,000		19-05-11	280,000	685,041,000	
19-02-25	207,000	506,441,000		19-04-04	187,000	457,510,000	8.8	19-05-12	293,000	716,847,000	
19-02-26	228,000	557,819,000		19-04-05	203,000	496,655,000		19-05-13	296,000	724,186,000	
19-02-27	222,000	543,140,000		19-04-06	232,000	567,606,000		19-05-14	317,000	775,564,000	14.9
19-02-28	210,000	513,781,000	3.9	19-04-07	287,000	702,167,000		19-05-15	336,000	822,049,000	
19-03-01	188,000	459,956,000		19-04-08	341,000	834,282,000		19-05-16	364,000	890,554,000	
19-03-02	181,000	442,830,000		19-04-09	400,000	978,630,000		19-05-17	371,000	907,680,000	
19-03-03	178,000	435,490,000		19-04-10	467,000	1,142,551,000		19-05-18	366,000	895,447,000	
19-03-04	169,000	413,471,000	3.4	19-04-11	538,000	1,316,258,000	8.9				
19-03-05	170,000	415,918,000		19-04-12	571,000	1,396,995,000	9.1				

Appendix B: Daily Plankton Net Sampling Effort for the Columbia River

Table B1. Daily plankton net sampling effort to collect Eulachon eggs and larvae, in minutes and water volume (cubic meters) sampled, for the six sites situated along the Columbia River Price Island/Clifton Channel transect, January 27, 2019 through May 18, 2019.

Sample 2019 C		Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
Week	Date	Min	Vol	Min	Vol	Min	Vol	Min	Vol	Min	Vol	Min	Vol
5	19-01-30	03:10	42.0	3:32	45.5	3:26	35.9	3:10	25.6	2:25	15.7	2:44	8.6
6	19-02-04	03:31	53.0	3:26	49.2	3:14	41.4	3:14	28.0	2:05	14.5	2:43	8.3
7	19-02-14	02:18	29.3	3:04	38.4	3:11	34.6	2:29	15.9	2:55	19.7	3:07	11.5
8	19-02-19	02:37	38.7	3:18	50.3	3:12	41.6	2:51	23.5	2:28	25.0	3:34	16.7
9	19-02-28	02:21	25.0	3:23	39.8	3:03	34.6	3:03	34.6	2:44	20.9	2:28	21.9
10	19-03-04	02:14	27.9	3:05	37.6	2:51	31.0	2:42	18.9	2:21	9.7	3:57	12.5
11	19-03-15	02:19	23.6	2:56	30.7	2:52	27.8	2:41	17.1	2:06	14.5	3:59	12.2
12	19-03-20	02:36	34.2	3:11	41.5	3:16	41.0	3:23	30.3	2:21	20.7	4:05	17.6
13	19-03-28	02:30	33.2	3:43	49.5	3:17	37.1	2:45	23.2	2:54	33.9	4:06	21.0
14	19-04-02	02:27	36.9	3:01	42.9	2:48	29.2	2:50	29.6	2:46	40.5	3:50	24.4
14	19-04-04	02:28	38.5	3:31	54.1	3:07	37.0	2:39	24.9	2:43	34.9	3:59	21.8
15	19-04-11	02:15	48.6	3:45	75.8	3:25	66.0	2:33	36.6	2:59	63.0	2:38	28.2
15	19-04-12	01:20	26.6	2:31	50.6	2:29	48.9	2:24	32.3	3:54	74.5	2:09	22.3
16	19-04-15	01:10	20.4	2:28	47.1	1:54	31.2	1:23	16.9	2:30	40.8	1:51	16.1
16	19-04-17	01:06	14.7	01:56	31.3	1:40	24.5	1:08	11.5	2:43	32.9	1:55	11.6
17	19-04-25	02:11	29.3	02:45	40.6	2:41	39.8	2:23	22.3	2:59	41.0	2:44	17.2
18	19-04-29	02:21	32.5	03:07	40.2	2:48	31.9	2:37	21.4	2:45	34.1	2:34	14.0
19	19-05-10	02:08	32.6	02:22	36.4	2:18	32.2	2:44	26.4	2:56	37.1	4:04	19.9
20	19-05-14	02:34	40.5	02:56	47.4	3:08	39.3	2:50	32.1	3:05	44.1	2:19	13.0

Appendix C: Lab Counts of Eulachon Eggs and Larvae for the Columbia River

Table C1. Daily numbers of Eulachon eggs and larvae collected during plankton net sampling of the six sites along the Columbia River Price Island/Clifton Channel transect, January 27, 2019 through May 18, 2019.

Sample-2019 C		Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
Week	Date	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs
5	19-01-30	47	3	138	1	41	0	49	0	1	0	14	0
6	19-02-04	44	0	221	0	346	0	199	4	80	0	7	0
7	19-02-14	85	0	168	0	159	0	12	0	6	0	9	0
8	19-02-18	315	2	227	1	461	3	56	0	1	0	5	0
9	19-02-28	75	0	70	0	55	0	2	2	3	0	2	0
10	19-03-04	10	0	64	2	44	0	35	0	0	0	2	0
11	19-03-15	12	0	13	1	12	0	48	0	2	1	2	0
12	19-03-20	180	2	112	7	155	3	280	17	31	0	9	4
13	19-03-28	82	7	153	6	57	7	48	2	71	7	54	1
14	19-04-02	696	4	1090	12	856	1	854	8	3095	15	2129	0
14	19-04-29	740	6	2968	18	872	8	984	5	5927	26	3073	0
15	19-05-10	515	5	1203	19	1079	11	832	12	1940	43	4264	0
15	19-05-14	229	2	619	16	303	7	704	40	1801	58	3290	3
16	19-04-04	136	3	619	18	522	12	325	3	1010	32	981	0
16	19-04-11	129	0	318	0	298	3	240	5	892	4	507	0
17	19-04-12	51	2	112	7	190	0	179	0	422	7	464	0
18	19-04-15	29	3	62	2	27	1	83	2	170	5	115	0
19	19-04-17	2	0	6	0	6	0	19	0	48	0	17	0
20	19-04-25	6	0	4	0	2	0	5	0	1	1	0	0

Appendix D: Daily and Weekly Eulachon Egg and Larvae Sample Densities for the Columbia River.

Appendix E: Adult Information

COLUMBIA RIVER STUDIES OF ADULT EULACHON

(Thaleichthys pacificus)

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Introduction

The Spawning Stock Biomass (SSB) approach requires the estimated egg and larval count to be converted into the biomass of the adult spawners that produced the observed ichthyoplankton outflow. The details of that approach have been described in various documents (Hay *et al.* 2002; McCarter and Hay 2003; Therriault and McCarter 2005). This appendix provides some more detail of the methods used (Wagemann 2014; Langness *et al.* 2016; Langness *et al.* 2018), and a summary of the data from adult sampling that we used to parameterize our SSB estimation model.

Methods

Biological Data

With no commercial or recreational Eulachon fishery in 2019, all adult fish samples were obtained from:

- trammel nets (salmonid test fisheries) in Columbia River commercial Zone 2;
- salmon smolt screw traps in the Grays River;
- and, dip net sampling in the Cowlitz River.

Adult samples were brought back to the WDFW Southwest Regional Office Laboratory in Ridgefield, Washington, for further processing. We used a 30 cm measuring board to obtain fork lengths (to the nearest millimeter). All fish were blotted dry with paper towels before weights were obtained. An electronic balance scale was used to weigh the fish (to the nearest 100th of a gram).

In addition to weights and lengths, fish chosen for the fecundity study had an internal and external visualization done, including examination for the degeneration of teeth, using a Labomed Luxeo (Model 414500) 4d stereozoom microscope. Otoliths were collected for ageing, and fin clips were taken and archived for future genetic studies.

Dentition

In order to have a better understanding of the biological changes that occurred in pre-spawn smelt, we examined a sub-sample of our pre-spawn fish, comprised of 91 males and 61 females, for tooth resorption. Detailed descriptions of the dentition was simplified into three categories: (1) no teeth observed; (2) remnant teeth observed; and, (3) at least one intact tooth observed.

Genetic Samples

About a 6 mm square of fin tissue was removed from each adult sample. The tissue was placed into a 2 ml screw-capped plastic vial, containing 100% ethanol. These vials were stored, at room temperature, in 100-cell plastic storage boxes for later shipment to the WDFW Molecular Genetics Laboratory, Olympia, Washington, where they are archived for future analyses.

Sex Ratios

Sex ratio can be calculated from the Cowlitz River dip net collection, using all fish caught. However, the sex ratio shifts toward a male dominance as one gets further upriver. Given the lack of samples from the Columbia River Commercial Zone 1 (lower estuary), due to no commercial Eulachon fishery in 2019, it is appropriate to assume a 1:1 Male:Female ratio for the 2019 run.

Age and Size Composition

Age Demographics

The sagittal otolith is the recommended structure for ageing Eulachon (Langness *et al.* 2018). Sagittal otolith extractions were performed at the WDFW Southwest Regional Office Laboratory in Ridgefield, Washington, using a 5X lens of an Intertek Model LUX 900 dissecting microscope (with 13W lamp). In order to remove the otoliths with minimal breakage, the fish head was sliced behind the operculum and then further divided cranially by hemisphere. Fine botany tweezers were used to extract the otoliths, and in cases where they were wedged, deionized water was used to flush the otolith out. Otoliths were gently rubbed to remove any outer coating. Both left and right otoliths were placed together in an open well of a plastic tissue culture tray to dry for 48 hours before the well was sealed. When all the wells were full of individual otolith sets, the trays were sent to the WDFW Ageing Laboratory in Olympia, Washington.

Whole otoliths were submerged in ethanol and surface aged under reflective light, using a standard dissecting scope with magnification range of 10-50X. We used the following ageing criteria for run years 2012-2019.

- An annulus was defined as an opaque zone (summer growth) followed by a complete translucent zone (winter growth).
- Annuli need not be proportional. In other words, a smaller growth zone may be followed by a larger growth zone or vice versa.
- An annulus should be visible along most portions of the otolith.
- A January 1 birthday was assumed. Therefore, for a fish captured during a spawning migration (January-March) the edge of the otolith was counted as a year whether the edge was an opaque (summer) zone or was beginning to form a translucent (winter) zone.

Figure E1 shows examples of otoliths determined to be ages 2 through 5, using the above listed ageing criteria.

All age estimates are measured with error. Process error arises when the otolith banding pattern does not exactly portray the period of interest (i.e., annual). Observation error arises when the interpretation of the banding pattern is ambiguous with a specific method or to different readers, so repeated counts are imprecise. Therefore, it is common practice to check for agreement of paired-age samples (McBride 2015). Our goal was to have about 20% of our readable otolith sets read by two readers (Kimura and Anderl 2005). The Evans-Hoenig Test of symmetry (Evans and Hoenig 1998) was used to examine age disagreements between the two readers for evidence of bias.

WDFW is a participant in the Committee of Age Reading Experts (CARE) sponsored by the Pacific States Marine Fish Commission. CARE's task is to document and standardize the ageing procedures used by all age determination facilities on the North American Pacific coast. CARE is also concerned

with setting up mechanisms that make it possible to exchange samples for calibrating the precision of age determinations between agencies. This includes information on how to make up samples for exchange, as well as a way to preserve permanent collections of specimens for precision testing (CARE 2006).

Size Demographics

Length Distributions

The Fork Length (FL) distributions for each year (2013, 2015-2019) were compared to each other using the Kolmogorov-Smirnov Test. The KS Test is a nonparametric and distribution free hypothesis test procedure to determine if two samples of data are from the same distribution. The test statistic D is the supremum (greatest distance) between the empirical distribution functions (cumulative fraction plots) of the two data sets. The level of significance was set at $\alpha = 0.05$. If the p value was less than this level, then the null hypothesis (that the two samples of data came from the same distribution) is rejected.

Growth

The original 3-parameter monophasic von Bertalanffy Growth Function (VBGF; von Bertalanffy 1938, 1957) describes the body growth in length (or weight) of most fish:

$$L_t = L_{\infty} (1 - e^{-K(t-t_0)})$$

Where $L(t)$ is the body length (in our case fork length) at age (t), L_{∞} is the average maximum length or asymptotic (fork) length, K is the rate at which the fish approaches the average maximum length, and t_0 is the time we expect the length to be zero.

We used the r program (R Development Core Team 2016) code developed by Luis A. Cubillos, of the Cambio Climático Pesca y Acuicultura en Chile, to fit our fork length at age data to the standard VBGF. The vector theta (L_{∞} , K , t_0) consists of our *a priori* (initial) parameters. For our initial estimate of length infinity we chose 240 mm (a value slightly above the 235 mm maximum we have seen in our studies). The initial K value was set at a low rate of 0.2 similar to what has been observed in other baitfish (Figure 7). Eulachon larvae are just a few millimeters long, and the egg is only about 1 mm in size. A small negative value for t_0 may have been appropriate, but we chose to set the initial t_0 value to zero. The age vector was (1, 2, 3, 4, 5, 6, 7) corresponding to Ages 1 through 7 for which we have average fork lengths. The corresponding average fork length vector was (85, 166, 178, 183, 183, 182, 192). The average size at ages 2 through 7 came from our length at age observations since 2012. The size at Age 1 was at first assumed to be 83 mm, about half of average Age 2 size. WDFW and the Fisheries and Oceans Canada (frequently referred to as the Canadian Department of Fisheries and Oceans [CDFO]) have used 50-125 mm Standard Length (SL) as the size range associated with Age 1+ Eulachon caught in the Pink Shrimp trawl fishery off the west coast of Vancouver Island (WCVI). The center of this range is 87.5 mm SL. We determined that the SL is approximately equal

to 90% of the FL. That would make the center of the range 97.2 mm FL. The fishery occurs in May, so the average size back in January is likely less. We therefore set our *a priori* average fork length corresponding to Age 1 to 85 mm FL.

The optim function in R was used to solve for the VBGF parameters. The optim function provides a general-purpose optimization based on Nelder–Mead, quasi-Newton and conjugate-gradient algorithms. We chose the Broyden–Fletcher–Goldfarb–Shanno (BFGS) algorithm for our method of optimization. BFGS is a Quasi-Newton second-derivative line search family method, one of the most powerful methods to solve unconstrained nonlinear optimization problem (Al-Baali *et al.* 2014).

Fecundity

Having some female samples where gonad weights were taken in addition to body weights, allowed us to calculate Gonadosomatic Index (GSI) values for those fish:

$$\text{GSI} = \frac{\text{weight of gonad}}{\text{total body weight}} * 100\%$$

Where GSI is the percent of body weight attributed to gonad weight.

The limited funding of this project meant that gonads had to be preserved for a later time when funds become available to count eggs.

Brood Year Strength

Brood Year Tables

The brood year tables are based on the annual run estimates to the Columbia River. To derive the run estimate for a given year, we add the known harvest to our mainstem Columbia River SSB estimate for that year (both expressed as numbers of fish rather than poundage). We then map the ages between the run year and corresponding brood years making up the run. We split the run estimates into male and female components. The gender specific age composition of the run is then used to assign a portion of the run to its corresponding brood year age class. The male and female brood tables are then added together to produce the combined sex brood table.

Stock-Recruitment Models

One of the most difficult problems in the assessment of fish stocks is establishing the relationship between the spawning stock and subsequent recruitment (Hilborn & Walters 1992). The stock reproductive potential (SRP; e.g. number of eggs, number of out-migrating larvae, corresponding number of parental spawners or number of female parental spawners) can be compared to the total return for a brood year to give an index of larvae to adult survival. There are two stock-recruitment models typically used in fisheries management: the Beverton-Holt model (Beverton and Holt 1957),

where recruitment increases asymptotically; and, the Ricker model (Ricker 1975) where recruitment declines at high spawning stock abundance. There are other models, including general ones that incorporate a third fitting parameter, and General Additive Models (GAMs) that also fit spatiotemporal and environmental functions of covariates to the data. At this time, we do not know which model is the best model for our purposes. Iles (1994) recommends that one make a comparison between models, using the error sum of squares as a criterion. There are other model comparison methods available (AIC, Δ AIC, BIC, etc.) that can also be used to select the best model. For further discussion purposes only, we will use the Ricker model:

$$R = e^a S e^{-bS} e^\varepsilon$$

Where R is recruits and S is Stock(SRP). For our purposes we consider the return of mixed (male and female) adults to the mouth of the Columbia River, as our recruits. The SSB estimates are our proxy for the SRP stock values. We chose to use numbers of fish, rather than biomass for R and S.

The a and b parameters were estimated by the log transformation:

$$\ln(R / S) = a - bS + \varepsilon$$

Productivity, for a specified time period, is defined as the natural logarithm of the ratio of recruits to spawners in the absence of density dependent mortality (Neave 1953). For semelparous species in which R and S are in the same units, the slope at the origin for the Ricker models (“a” value) can be directly interpreted as the maximum annual reproductive rate, expressed as recruits per unit spawner abundance (Myers 2001). We assume “a” is a normal random variable, i.e. a random effect. The slope “b” is a fixed effect that depends upon equilibrium population size, and ε is a normal, possibly autocorrelated, residual process error (Myers 2001). The scatter of data around these theoretical curves is allowed for by including this additional random component ε in the model that describes deviation of R from the curve (Iles 1994).

Autocorrelation represents the degree of similarity between a given time series and a lagged version of itself over successive time intervals. A residual series free from autocorrelation satisfies the normal distribution assumption (Chen 2016). Before directly testing for autocorrelation (serial correlation), we first determined that the mean of the residuals was zero. Then we verified normality by examining a normal probability plot (P-P Plot). We plotted the observed cumulative probabilities of occurrence of the standardized residual on the Y-axis and of expected normal probabilities of occurrence on the X-axis, such that the 45-degree line will appear when the observed conforms to normality. To assure that the stock-recruitment relationship (SRR, here described by the Ricker model) is homoscedastic (the same for the entire range of the dependent variable), we plotted the residuals on the Y-axis and the independent variable (S) on the X-axis, such that the points form a random cloud around the zero line. If the SRR is not the same for the entire range of the dependent variable (heteroscedastic), it will show up as trends and patterns in the distribution of points (e.g., a

cone of residual points that gets wider as the number of spawners increases). We also ran a Park test (Park 1966) where the squared residuals are regressed on the independent variable (S). If the independent variable has a significant b coefficient ($p < 0.05$) then we cannot assume homoscedasticity. Finally, we use the Durbin-Watson test for autocorrelation (Durbin and Watson 1950, 1951, and 1971). This test is only applicable to the serial correlation of residuals from the least squares regression based on time and spatial series. The Durbin-Watson formula is constructed with one-order time lag or one-step space displacement. The sum of squares of the residual differences depends on the arrangement of elements (in our stock-recruitment relationship brood years are sequentially arranged in a time series). These restrictions on the use of the Durbin-Watson test identified by Chen (2016) do not prevent us from using the test.

Reference points begin as conceptual criteria which capture in broad terms the management objective for a fishery. To implement Eulachon fishery management, it must be possible for us to convert the conceptual reference points into Technical Reference Points (TRPs), which can be calculated or quantified based on biological or economic characteristics of the fishery (Hoggarth *et al.* 2006). Maunder (2012) found through simulation analysis that the steepness of the Beverton-Holt stock-recruitment relationship is difficult to estimate for most fish stocks, which lead to the use of proxy reference points. In contrast, the Ricker curve can be used to readily calculate various TRPs: the equilibrium point where recruitment equates to the stock ($S_r = R_r$); the point of maximum sustainable recruitment or production (S_{MSR} or S_{MSP}); and, the point of maximum sustainable yield (S_{MSY}) and its corresponding yield value (Y_{MSY}). We used some equations where the TRPs are estimated using the Ricker stock-recruit equation's parameters (mostly from Iles 1994):

- $S_r = a/b$ (recruitment at replacement $R_r = S_r$)
- $S_{MSR} = 1/b$ (also referred to as S_{MSP})
- $S_{MSY} = a(0.5-0.07a)/b$ (Hilborn 1985)
- $Y_{MSY} = R_{MSY} - S_{MSY}$ (R for the 45 degree replacement line at $S_{MSY} = S_{MSY}$)

Population numbers fluctuate around an inter-annual mean carrying capacity that reflects the average environmental conditions over the long term (Johnson and Johnson 2011). Inherent in the concept of carrying capacity is the basic idea of a maximum population that can be supported over a period of time for a particular level of resources (Ayllón *et al.* 2012). The Ricker “b” parameter is often said to define the carrying capacity of a population because as we see in the previous paragraph “b” is in the denominator for S_r , S_{MSR} , and S_{MSY} . A higher “b” value means a steeper slope which would reduce our TRPs. The population equilibrium is thus lowered by increasing density-dependent effects.

Environmental Factors

Prediction of a future Columbia River Eulachon run size is based on the strength of the brood years composing that run year. While large larval outflows are expected from large parent spawner escapement, the adult recruitment is often not as large as the larval outflow suggests. Ocean environmental and biological conditions drive ocean survival, so it is important to consider these factors when making run predictions and should be accounted for in our stock-recruitment models. We discuss whether a conventional density-dependent stock-recruitment model should be used, or the unconventional Sakuramoto Model (Sakuramoto 2018), and how many more years of data gathering will it take to capture the cycle of environmental conditions in the stock-recruitment relationship (SRR).

Results and Discussion

Biological Data

The inability to sample throughout the run creates an unknown sampling bias. Eulachon typically begin arriving the third week of November and depending on water temperatures, will continue spawning until the end of April or beginning of May. Our adult sampling occurs primarily during the commercial fishing season, the length of which is two days a week during the month of February. This leaves a large amount of the run not sampled, and while the sampling occurs during all or most of peak, the eulachon may be better served by monitoring the entire run. In 1954, Smith and Saalfeld (1955) noted that the monitoring of Columbia River eulachon through data collected during just the commercial harvest was inaccurate, as the Columbia was never sampled for the run entirety.

It was noted almost 8 decades ago, that commercial sampling does not satisfy the needs required to obtain a proper sampling of an adult eulachon run (McHugh, 1939, Smith and Saalfeld 1955). In order to ascertain run strength and spawning parameters it is necessary to fund fishery independent monitoring.

Length and Weight

Fourteen adult male Eulachon samples were collected during trammel net operations (salmonid test fisheries) in Columbia River commercial Zone 2 (upper estuary, Table E1). Fork lengths ranged from 156 mm to 191 mm, averaging 170.5 mm. Body weights ranged from 19.15 g to 44.51 g, averaging 30.71 g. No females were collected from the trammel net operations in Columbia River commercial Zone 2.

Ninety-seven adult male Eulachon samples were collected during salmon smolt screw trap operations in the Grays River (Table E1). Fork lengths ranged from 155 mm to 200 mm, averaging 170.8 mm. Body weights ranged from 27.43 g to 62.12 g, averaging 36.41 g. Two adult female Eulachon samples were collected during salmon smolt screw trap operations in the Grays River (Table E2). The two fish measured almost the same, with an average fork length of 166 mm, and an average body weight of 33.58 g.

Three-hundred forty-five male adult Eulachon were dipped from the Cowlitz River (Table E1). Fork lengths ranged from 144 mm to 230 mm, averaging 168.2 mm. Body weights ranged from 20.53 g to 94.63 g, averaging 34.54 g. Two-hundred eight-two female adult Eulachon were dipped from the Cowlitz River (Table E2). Fork lengths ranged from 139 mm to 215 mm, averaging 167.2 mm. Body weights ranged from 19.44 g to 87.09 g, averaging 35.42 g.

Dentition

The prominent canine teeth on the vomer is a distinguishing feature of the Eulachon (Hart 1973); however, in their adult stage at sea Eulachon have substantial teeth throughout their mouth (Hay and McCarter 2000). Tooth resorption has been well documented in eulachon literature (Hart and McHugh 1944; Hay and McCarter 2000; Gustafson *et al.* 2010). This resorption of teeth indicates that they likely stop feeding as they approach their spawning rivers, and resorb minerals in their teeth (and probably scales) to assist with gonadogenesis.

The Eulachon adult examined during the 2013 Columbia River run were largely toothless. Only six, out of the 25 sampled had one partial lower tooth. In addition, of the eight large tongue teeth, 18-fish had resorbed half or more. Twenty-one female Eulachon were examined during the 2015 run for tooth resorption. Six had three or fewer main teeth and half their tongue teeth. The remaining 15 had half or more of their main teeth and half or more of their tongue teeth. Several had double rows remaining of their main teeth. No observations were made during the 2016 run. Twenty-one females from the 2017 run were observed to have their canine teeth gone and only single rows of other teeth remaining. For 2018, forty-nine fish were examined for main tooth resorption. Of these, 26 (53.1%) had no teeth remaining, 20 (40.8%) contained remnants, that is, teeth that were partially to mostly resorbed, and 3 (6.1%) had one tooth remaining.

For 2019, one-third of the adult Eulachon collected (152 fish) were examined for tooth resorption. Of these, 57 (37.5%) had no teeth remaining, 89 (58.6%) contained remnants, and 6 (3.9%) had at least one tooth fully intact. Breaking this down by sex (91 males and 61 females examined), we saw 58.6% of males with no teeth remaining, versus 11.5% of females with no teeth remaining. Remnant teeth were more common in females (86.9%) than in males (39.6%). This means that 5.5% of males and 1.6% of females had at least one tooth intact. Tooth resorption appears to be as important to male as it is to female gonadogenesis.

The lack of teeth in returning adult Eulachon was mostly noted in our 2013, 2018, and 2019 samples. Tooth resorption for gonadogenesis is a known life strategy in eulachon (Hay and McCarter 2000; NOAA, 2010), but typically it involves canines and or a few side teeth. The 2013, 2018, and 2019 fish had very few teeth left. It is possible that the ocean conditions for these three return years were adequate for a younger age demographic, but still not adequate without large amounts of tooth resorption.

Genetic Samples

In addition to the Eulachon larvae samples being retained for genetic studies, fin clips from adult samples were also archived.

The following 2019 adult Eulachon genetic samples collection is archived at the WDFW Molecular Genetics Laboratory in Olympia, Washington:

- Cowlitz River Sample (MGL code 19EA) n = 31

The following 2019 adult Eulachon genetic samples collection was transferred on April 3, 2019 to Rick Gustafson NMFS/NWFSC:

- Grays River (MGL code 19GR) n = 50.

Sex Ratios

As expected, the M:F ratio from the Cowlitz River Eulachon collection was male dominant (1.22:1, n= 627). Due to the range in values reported in the literature, the range in values we have observed, and concerns about potential biases (Moffitt *et al.* 2002), we decided to follow the example reported in Hay *et al.* (2002) and concluded that it was valid to use a 1:1 sex ratio in our 2019 SSB calculation. (Table E4). A comparison of estuary vs fresh water indicates that fish caught in the estuary are near or at 1:1; however fish caught in fresh water have large ranges that are dependent on space and time. This pattern was initially seen in 2013, during the NOAA trawler work (Zamon *et al.*, 2015), and repeated in 2016 during our commercial sampling. Previously reported male-biased ratios (Smith and Saalfeld, 1955; Stockley and Ellis, 1970) may not be truly representative of the Columbia spawning population as a whole, and may instead reflect behavioral or distributional differences between males and females as they migrate into freshwater or enter the spawning grounds (Gustafson *et al.* 2010). Sex-specific differences in migration timing have been observed in the Copper River, Alaska, Eulachon population, where the second half of the run is male-biased (Moffitt *et al.* 2002). Enterline *et al.* (2015) has suggested that male biased ratios in Rainbow Smelt (*Osmerus mordax*) spawning surveys may be the result of female Rainbow Smelt spawning once, while the male Rainbow Smelt tends to spawn multiple times, in 1-3 different rivers. Because sampling above the saltwater wedge leads to a wide array of ratios, we would still recommend obtaining sex ratios below the wedge in order to reduce errors in the calculation of run return.

Age and Size Composition

Age Demographics

During 2019, seven hundred forty sets of Eulachon otoliths (456 male and 284 female) were sent to the WDFW ageing lab for analysis. Ages were obtained on 735 fish (Tables E1-E2). Only 5 sets were unreadable (0.7%). All unreadable sets were from female Eulachon collected from the Cowlitz River. Four of the five fish were of average size (160, 163, 164, and 176 mm). One of these sets had unmatched otoliths, and another had broken otoliths. The largest fish (190 mm) that could not be aged had vateritic otoliths (a deformity in which the aragonite is replaced by vaterite crystals). That equates to 0.1% of our sample having this otolith structure. Vateritic otoliths are not often found in wild fish populations (typically 1%–24% of otoliths). It is believed that fast growth due to

environmental rather than genetic control, leads to vaterite development (Reimer *et al.* 2017). Vaterite replacement results in large, light, brittle, and irregular shaped otoliths. This reduces otolith function, probably causing severe hearing loss, and hence reduces the fish's survival (Reimer *et al.* 2016). In Figure E4, 190 mm would be an outlier for Age 2, but something we have seen. Given its vateritic otoliths, it is possible that our largest fish (in the unreadable category) is an Age 2 fish.

The average age for male Eulachon collected in 2019 was 2.5 years-old. The youngest male observed was Age 2, and the oldest male observed was Age 5 (Table E1). The average age for female Eulachon collected in 2019 was 2.4 years-old. The youngest female observed was Age 2, and the oldest observed female was Age 4 (Table E2). There were no adult Eulachon (male or female) of Age 6 or Age 7 observed during the 2019 run (Figure E2, Table E1, and Table E2).

Both Smith and Saalfeld (1955), and Barraclough (1964) reported that first time spawners were at least 3 years of age. Wilson *et al.* (2006) concluded that while first time spawning could occur at any time between the ages of two and five, most spawners were Age 2 or Age 3. Clarke *et al.* (2007), with the use of a new otolith ageing method, hypothesized that eulachon spawning was limited to no more than two age classes, and possibly just one (Age 2). Many other reports have listed different age demographics for spawning smelt, but many of these observations have been a one to two year snapshot. When we looked at ages over a 6 year period (2013, 2015-2019) we found that the age demographics changed dramatically, with the average age shifting upwards, peaking in 2016, then returned almost to the baseline of 2013 (Figure E2). If age demographics positively correlate to food source and nutrient availability, it would make sense that the age demographic of a run year would be more dynamic. As such, the recommendation would be to continue tracking otoliths, in order to establish a more recognizable age pattern, and identify other potential causes for age fluctuation.

Precision is the degree of reproducibility. In age determination, it relates to the variability between or within readers. Two WDFW age-readers independently aged 120 otolith sets and the percent agreement between readers was 73% for 2019 samples (62% in 2015, 61% in 2016, 75% in 2017, and 58% in 2018). Despite some disagreement between readers, 97% of disagreements were ± 1 year resulting in an average percent error (APE) index of about 5%, with no bias between readers (Evans-Hoenig Test: $p = 0.27$). The generally poor agreement between readers, during the past 5 years, highlights the difficulty of ageing eulachon otoliths and the need to develop more specific ageing criteria, through validation of annuli formation.

Size Demographics

Length Distributions

Length distributions vary year to year (Figure E3). It was not until we began looking at length through an age lens that we were able to grasp the year-to-year changes. There was no significant difference in fork length distributions for return years (RYs) that had similar age structures, like RY

2016 and RY 2017 (Kolmogorov-Smirnov Test: $D = 0.097$, $p = 0.92$). If the age structures were different, such as RY 2018 and RY 2019, there was significant differences in length distributions (Kolmogorov-Smirnov Test: $D = 0.470$, $p < 2.2E-16$).

There is a 10 cm average increase in length that occurs between the 2 and 3 years-old groups (Figure E4). This difference occurs, to a smaller degree, between the 3 and 4 years-old fish, but after this the length median for Ages 4, 5, and 6 are the same. Our hypothesis is that under normal conditions, the Columbia basin Eulachon returns mostly consist of Age 3 and Age 4 fish (Figure E5). Fish above Age 4 will occur when ocean conditions are poor because, they need to stay out and grow to the minimum size required for successful spawning. When comparing ocean conditions to our age demographic we find that during poor ocean conditions the average age for the run year increased up to 1.5 years (Figure E3). If the recent ocean conditions are good, fish can grow to the minimum size required for successful spawning quickly and return as Age 2 spawners.

Within each age class depicted in Figure E5, the sample (return) years that had many data points had somewhat similar length distributions. The sample years that had few data points were often noticeably different in length distribution from the data rich years. Perhaps, if we can reduce sampling error by obtaining more samples, then interannual length distribution differences will be reduced.

Most Eulachon, regardless of brood year (BY) return to spawn at about 166-183 mm FL (average Age 2 length through average Age 4 and 5 length) with an average size of 176 mm FL (Figure E6). For a few brood years, the younger or older age at return size distributions fell outside this normal size range. This is consistent with the distributions in Figure E5. For example, the BY 2014 fish that returned as Age 5 spawners were very large, all exceeding 200 mm FL (Figure E6, Table E1). Those Age 5 fish returned in 2019. We can see in Figure E5 that the Age 5 fish that returned in 2019 were noticeably larger than Age 5 fish in previous return years. Perhaps if we can obtain more samples, then length distributions will be more similar between age classes.

Growth

Growth strategies are central to our understanding of life-history theory, as they determine body size and influence key life-history traits, including survival, development, and reproduction (Mumby *et al.* 2015). We were able to fit a length at age von Bertalanffy growth function (VBGF) to 1,764 paired-samples of fork lengths and ages from our Columbia Basin adult Eulachon collections made during 2012-2019 (Figure E7). The resulting parameters were $L_{\infty} = 184.8$ mm, $K = 1.619$, and $t_0 = 0.63$.

These parameter values are consistent with those reported for other Osmerids (smelt) listed on the FishBase von Bertalanffy spreadsheet (<https://marine.rutgers.edu/~cfree/what-combinations-of->

[von-Bertalanffy-growth-parameters-are-possible/](#)). The L_{∞} values for 18 studies on Pond Smelt (*Hypomesus olidus*), European Smelt (*Osmerus eperlanus*), Atlantic Rainbow Smelt (*Osmerus mordax mordax*), and Capelin (*Mallotus villosus*), ranged from 9.6 cm (96 mm) to 38.3 cm (383 mm), and averaged 23.6 cm (236 mm). The K values for these fish ranged from 0.152 to 1.650 and averaged 0.476. The t_0 values ranged from -0.83 to -0.13, and averaged -0.50. Pond Smelt had almost the same L_{∞} and K values as we found for Eulachon (115 mm and 1.65 respectively, no t_0 value reported). With the exception of some Capelin studies, the VBGF parameters had been based on unsexed fish. We did not develop separate VBGF for male and female Eulachon, but Figure E8 suggests that sex specific growth curves are going to be very similar to each other, and nearly identical to the mixed sample VBGF. Our speculation is also supported by the Capelin studies that indicate that L_{∞} values for males are slightly more than for females, K values are similar, and t_0 values slightly lower for males.

Developing sex specific growth curves is something we expect to do in the near future. We could also develop a weight at age VBGF; however, there may be less value in doing this for a semelparous fish like Eulachon, then for iteroparous fish like Sturgeon. For semelparous species, there is really only determinate growth, since death follows spawning. For iteroparous species, those reproducing more than once, there are two growth strategies available: determinate growth, whereby growth ceases around/slowly considerably after sexual maturity, and indeterminate growth, which, at the most basic level, involves continued growth through life, and is found in the majority of iteroparous animals. This growth after maturity may be expressed differently between males and females, and may only be noticeable in the weight at age growth curve (Mumby *et al.* (2015).

Eventually, Eulachon researchers should look beyond the original monophasic VBGF. Fish pass through several stages (stanzas) as they develop. The length-weight relationship and the growth curve can be different for each developmental stage. During the sexual maturation stage, there is a switch in energy allocation between growth and reproduction. The change in growth rate between the two stages can be either steep or gradual. Ohnishi *et al.* (2012) proposed two models. A biphasic growth model derived by connecting two independent VBGFs at an arbitrary age is one approach used to account for steep inflections in growth. Researchers (such as Araya and Cubillos, 2006) have found that the biphasic VBGF is a more suitable model than the original monophasic VBGF based on the Akaike information criterion (AIC; Akaike 1973). In their second model, Ohnishi *et al.* (2012) took into consideration that the ratio of energy invested to reproduction against total surplus energy $p(t)$, changes continuously (more gradually) throughout an individual's lifetime. This second model can be considered an extended VBGF, with additional parameters, namely age at maturity (t_m), the upper limit of the allocation rate in reproductive energy (v), and rapidity of maturation (a), being added to the three original parameters (L_{∞} , K, and t_0). Ohnishi *et al.* (2012) looked at twelve types of energy allocation schedules, $p(t)$, and the corresponding somatic growth (in length) based on different combinations of the additional parameter values. When $v=0$, the growth curve is identical

to the original VBGF. When $\nu=1.0$, the growth rate after maturation converges to zero because most surplus energy is devoted to reproduction, generating more determinate growth. The curves given by sufficiently high a ($a=100$) represent biphasic VBGF resulting from an abrupt change in growth rate around age t_m . These more advanced approaches to modeling growth in Eulachon is something to pursue later, after monophasic length at age VBGF are developed for males and females.

Fecundity

We have never take gonad weights on male Eulachon, so the following results and discussion only applies to female Eulachon. Sixty-six of the female Eulachon sampled from the Cowlitz River in 2019 had their gonads weighed in addition to body weight (Table E2). Gonad weights ranged from 5.90 g to 20.69 g, averaging 11.75 g. The GSI values calculated for these 66 fish ranged from 22.77% to 34.97%, averaging 27.94% (33.18% if average gonad weight and average body weight are used). Average GSI from 2012-2018, ranged from 19.44% to 25.91%. The 2019 range and average GSI values are higher than those observed during the previous seven years.

For our female samples, the GSI measures the relative size of the ovaries (what percentage of the body weight is attributed to gonad weight). The GSI increases as the fish matures, reaching a peak level at time of spawning (loose and runny eggs). As we observed during the 2012-2018 spawning events, this peak GSI is very similar year to year. Çek *et al.* (2001) found that mean values of GSI increased with increasing mean body weight and length during oogenesis in female Rosy Barb (*Puntius conchoni*). These relationships were significant ($r^2 = 0.96$). Our 2012-2018 Eulachon data showed a positive linear relationship between GSI and mean size (body weight and length); however, our r^2 values were less:

$$GSI_i = 0.6421 (FL_i) + 140.39 \quad [r^2 = 0.72]$$

$$GSI_i = 0.7842 (BW_i) - 11.437 \quad [r^2 = 0.48]$$

Where FL=average fork length for year i , and BW=average total body weight for year i .

The observed GSI for 2019 matched the predicted GSI when the GSI-Fork Length equation was used (Figure E9); however, the observed GSI for 2019 was an extreme outlier from the GSI-Body Weight equation predicted values line (Figure E10). While the 2019 average gonad weight (11.75 g, Table E2 and Figure E11) was similar to 2012-2018 average (10.32 g), the 2019 average fork length (167.2 mm, Table E2 and Figure E9) and body weight (35.42 g, Table E2 and Figure E10) values were considerably less than the 2012-2018 averages (182.4 mm, 44.22 g).

In Figure E11, we see that the variation in GSI values is attributed more to total gonad weight ($r^2 = 0.93$) than total body weight ($r^2=0.48$, see above):

$$GSI_i = 1.6065 (GW_i) + 6.6547 \quad [r^2 = 0.93]$$

Where GW = average total gonad weight for year *i*.

The variation in GSI values is only slightly attributed to age ($r^2 = 0.15$, Figure E12), mostly due to the significant relationship between age and fork length ($r^2 = 0.72$, Figure 13) and that variation in GSI values is significantly attributed to fork length ($r^2 = 0.72$, see above):

$$\text{GSI}_i = -2.3797 (\text{Age}_i) + 31.613 \quad [r^2 = 0.15]$$

$$\text{FL}_i = 150.57 * (\text{Age}_i)^{0.1482} \quad [r^2 = 0.72]$$

Where Age = average age for year *i*.

The minimum fork length observed in 2019 was 139 mm. That 2 years-old fish had a high GSI value of 32.90% (6.40 g gonad weight 19.44 g body weight). Based on the female Eulachon length-weight equation developed in Langness *et al.* (2018), we would expect a Eulachon measuring 139 mm FL to weigh 20.78g:

$$\text{BW} = 0.000145 (\text{FL})^{2.405} \quad [r^2 = 0.70]$$

The average female Eulachon sampled in 2019 was 167.2 mm FL, and 35.42 g body weight. The expected body weight for 167.2 mm FL fish would be 32.38 g. So, while the smallest fish was slender (lighter for its length than expected), the average fish sampled in 2019 would likely be robust (heavier for its length than expected). Since the average age was 2.4 years-old, we think that recent ocean conditions were favorable, allowing the Eulachon to mature early and return in robust condition.

In the female Eulachon length-weight equation above, the exponent (*b*) is less than 3.0, which equates to negative allometric growth. This means that the females are becoming more slender as they grow in length. The *b* parameter is almost always between 1.96 and 3.94, with 90% of cases falling inside the 2.7 to 3.4 range (Froese 2006). On the other hand, the male Eulachon length weight equation has an exponent of 3.11 (Langness *et al.* 2018), which essentially equates to isometric growth ($b = 3.0$, proportions stay the same as the fish grows). This difference in morphology is quite evident in the picture of a male and a female eulachon (Figure 6 in the main report).

The weighed gonads from the 66 sampled fish have been preserved (bagged with the corresponding fish body, labeled, and frozen), and are being held until such time we secure funds to count eggs (determine fecundity). In the absence of actual fecundity values for 2019, we can look at the high average GSI value of 33.18%, and conclude that the 2019 females were likely very fecund (> 43,000 eggs per female, Figure E14):

$$\text{Fec}_i = 999.54 (\text{GSI}_i) + 10275 \quad [r^2 = 0.57]$$

Where Fec = average fecundity for year *i*.

Our measurement of fecundity represents the spawning potential of an average female eulachon. In other words, it is the number of ripening oocytes and mature ova or eggs just prior to spawning. This is different from fertility – the actual number of eggs shed on the spawning ground by the female. In our model to estimate the SSB, we assume that the full spawning potential is met (fecundity equals fertility), all eggs are successfully fertilized, and that there is no egg or larval mortality. This leads to a very conservative SSB estimate. Realistically, it takes more females to produce the larval and egg outflow we observe. We recommend that egg size and quality data continue to be gathered in the next few years. Furthermore, new field and hatchery studies should be developed to help managers address pre-spawn mortality, egg retention, incomplete fertilization, poor egg viability, and egg-larval survival, in their estimation of spawning adults.

Brood Year Strength

Brood Year Tables

While 2014 is a missing year, we have data from 2013 and 2015-2019. The 2014 values were approximated by averaging out 2013 and 2015. For the run reconstruction and brood year tables, sex ratio was assumed to be 1:1 except during years where lower estuary sampling produced a different value (Table E3). Fish sampled above the saltwater wedge were less consistent in their sex ratio, demonstrating the temporal and spatial differences that potentially existing between sexes. Due to this potential bias, numbers above the saltwater wedge were not used for table development.

The brood year tables are based on the annual run estimates to the Columbia River. To derive the run estimate for a given year, we add the known harvest to our mainstem Columbia River SSB estimate for that year. The harvest and SSB numbers are typically expressed in pounds or metric tonnes; however, for this exercise we have converted the poundage to number of fish using our standard 11.16 fish/pound. We then map the ages between the run year and corresponding brood years making up the run (Table E4). Using the sex ratios in Table E3, we split the run estimates into male and female components. The known gender specific age demographics are applied to derive Tables E5 and E6. Because the sex ratios are not a consistent 1:1, and the age demographics vary by gender and run year, the brood year tables are different for each gender. We combine Tables E5 and E6 to create the overall (combined male and female) brood year table (Table E7).

Stock-Recruitment Models

Looking at the brood year tables, one can see that for a few brood years (perhaps BY 2011-BY 2016), we now have a reasonably complete account of how many Eulachon returned for a given brood year. Those brood year returns can be compared to their corresponding parental number of spawners to derive an index of recruits per spawner.

Figure E15 shows the predicted linear relationship from our 2011-2016 brood years:

$$\ln(R / S) = 2.0064 - (3E-8)S \quad [r^2 = 0.71]$$

Productivity is measured here as the y-intercept of the log transformed equation (where the x-value (S) is equal to zero). From Figure 15, the y-intercept is approximately 2 recruits per unit spawner abundance (“a” value is 2.0064). Myers *et al.* (1999) suggest that the maximum annual reproductive rate for most species examined is typically between 1 and 7. This number is relatively consistent within species; however, it may be less for some species and more for others. Productivity ($\ln(R/S)$) for BYs 2011-2016 ranged from – 4.24 to 1.68, and averaged – 1.06 (Figure E15).

Lowerre-Barbieri *et al.* (2016) surmised that spawner-recruit systems differ in their sensitivity to environmental effects and temporal pattern of strong year classes over the expected reproductive lifespan. Temporal patterns of strong year classes is species specific (Pineda *et al.* 2007; Morgan 2014). Lowerre-Barbieri *et al.* (2016) assessed data reported in Pepin (2015) and showed that commercially exploited stocks from primarily temperate habitats had recruitment variability patterns that differed amongst families (Figure E16). They found forage fish (especially Osmerids) to have greater recruitment variability relative to variability in spawner biomass. The $\ln(\text{SD recruitment}/\text{SD SSB})$ calculated from our 2011-2016 data is approximately 0.33 (Standard Deviation of R was 82,244,463 and SD of S was 59,446,010). That is consistent with forage fish in general, but considerably lower than the relative variabilities of other Osmerids.

The structural problems of a model are reflected in the residuals (Chen 2016). The residual process error (ϵ) was examined and found to be normally distributed with a mean of zero, homoscedastic, and not autocorrelated. That is to say that the assumptions of the Ricker model have been met. Normal Probability Plots showed little deviation from the line, and we conclude residuals are normally distributed. Residuals plotted against the independent variable (S) showed no apparent pattern (cone, bowtie, etc.). The Park Test (Park 1966) showed that when the residuals squared are regressed on the independent variable (S) the slope coefficient proved to not be significant ($p = 0.4532$). From the visual examination of the residual plot, and the results of the Park Test, we conclude that size of the error terms do not differ across values of the independent variable (homoscedasticity). The usual process to test for autocorrelation, is to first determine if the more common positive autocorrelation exists. If not, then a check for the less common negative autocorrelation is done. The calculated Durbin-Watson Test statistic for autocorrelation ($d = 1.5378$) was greater than the upper critical point for $\alpha = 0.05$, $n = 6$, and $k' = 1$. We therefore accepted the null hypothesis that there is no positive autocorrelation (an increase seen in one time series leads to a proportionate increase in the other time series). The value $(4 - d) = 2.4622$, was greater than the upper critical point. So, we also accept the null hypothesis that there is no negative autocorrelation (an increase seen in one time series results in a proportionate decrease in the other time series).

The Ricker model (Figure E17) displays compensation at low population sizes (i.e. survival increases). At high spawner abundances, recruitment declines for the Ricker model, which is known as overcompensation. The negative slope of the log transformed equation, or “b” value (0.00000003) defines the intensity of this density dependency.

To test if there is overcompensation, one can compare how well the data fits a Beverton-Holt model versus a Ricker model (Cunningham 2019). In the case of the Beverton-Holt model, the recruitment rate (R/S) declines with increasing S. For the Ricker model, the number of recruits (R) begins to decline with increasing S. The second approach to quantify support for the overcompensation hypothesis is to fit the Deriso-Schnute general model (Deriso 1980; Schnute 1985) to the stock-recruitment data. If the value of the shape parameter approaches or equals -1.0 the data best fits the Beverton-Holt model. If the value of the shape parameter approaches 0 the data best fits the Ricker model, and the overcompensation hypothesis is supported. While we didn’t fit a Beverton-Holt curve or Deriso-Schnute general model to the data, one can see extremely low recruitment values for the higher stock values on the Recruits versus Stock plot. It is highly likely that overcompensation does occur in the population dynamics of the Columbia River Eulachon population. For a population exhibiting overcompensation, surplus escapement may result in reduction in future recruitment (Cunningham 2019).

It is rather easy to conceptualize the TRPs from Figure E17. The spawners at replacement (S_r) is where the 45-degree line intercepts the Ricker curve. The spawners at maximum sustainable Recruitment (S_{MSR}) is the x-axis value associated with the highest point of recruitment along the curve. The spawners at maximum sustainable yield (S_{MSY}) is the point of greatest difference between the curve and the 45-degree line. The maximum sustainable yield (Y_{MSY}) is the difference between the R_{MSY} and S_{MSY} . The calculated values of these TRPs are in Table E8. Figure E18 shows that BYs 2011 and 2012 had recruitment above replacement (in fact above the maximum sustainable recruitment). The more recent BYs (2013-2016) had poor recruitment (below replacement).

For a period of three-quarters of a century prior to run year 1993, commercial landings in the Columbia River were consistently in the tens of million fish (NMFS 2017). Taking into account recreational and tribal harvest, and escapement to spawning areas, the Columbia River Eulachon population was likely functioning at a higher equilibrium level back then. One might consider separately modeling stock-recruitment relationships before and after the great decline. Being species specific, we can assume that the “a” value (the maximum annual reproductive rate) remains the same, but the “b” values will differ pre- and post-decline. The traditional approach to determining carrying capacity for anadromous fish has been through stock-recruitment analysis (Potter *et al.* 2003). The approach has been proven to be imprecise in most cases since it requires long-time data series including a wide range of run sizes, which are usually not available in most populations

(Cramer and Ackerman 2009). Run estimates for 2000-2010 (excluding 2004 due to missing data) were made by Brad James (WDFW retired) and can be found in Figure 2-3 of the Eulachon Recovery Plan (NMFS 2017). We lack essential data to develop run estimates prior to 2000. For 2000-2010, several assumptions had to be made. Larval and egg sampling was only conducted for a few days each year, and those values had to be expanded out to the corresponding “full season” coverage we have had since 2011. Sport fisheries harvest was estimated to be equal to the tributary commercial fisheries, since no creel surveys were conducted. A fixed age structure must be used to breaking down these run estimates into brood year numbers. In summary, we can only add a decade of incomplete and imprecise stock-recruit data to what we have now, and none of that is for years prior to the great decline.

Survival rate indices provide a time series of density independent mortality estimates through deviations of observed R/S from those predicted by the fitted stock recruitment function for a specified time period. Survival rate indices were expressed as the natural log of the ratio of observed R/S to the predicted R/S (Figure E19). The natural log of these ratios transforms the differences, such that they tend to be normally distributed. The trend of the survival rate index for BYs 2011-2016 did indicate an obvious level-shift in survival rate between BY 2014 and BY 2015 (Figure E19). Though BYs 2015 and 2016 have not been fully recruited, their survival rates are likely to remain below the zero line (where the observed R/S matches the predicted R/S from our log transformed Ricker stock-recruit model).

The shift in productivity and survival suggests that complex underlying mechanisms drive the observed productivity, and that additional unmodeled variables that vary over time and location may explain some of the observed variability in the log ratio of recruits to spawners and survival rate index. Chen (2016) states, “Both oversimplification (e.g., explanatory variables are incomplete) and under simplification (e.g., explanatory variables are redundant) of reality can lead to trustless explanation and unfaithful prediction.” Hilborn and Walters (1992) suggested that one should be cautious with the choice of environmental covariates to include in the stock-recruitment model. Iles (1994) took some exception to this advice, and cautioned modelers that the failure to consider those variables, that for biological reasons are known to affect recruitment, will lead to models that are poor in explaining observed variation.

Inference from sparse data is a limitation of the present analysis. Long-term (>20 years) datasets are usually necessary to correctly define the stock-recruitment relationship. That requires extensive planning on the part of Eulachon managers. They must be committed to their sampling plan and find ways to annually fund that work. In the meantime, we might want to take a meta-analytic approach.

Meta-analysis is an analytical technique designed to summarize the results of multiple studies. By combining studies, we can increase the sample size and thus the power to study effects of interest.

To quote the late Ransom Myers (Myers 2001), “A meta-analytic approach is needed because spawner recruitment data are much like Hobbes’ view of primitive man: nasty, brutish, and short: these data are nasty because they often contain outliers, brutish because they have many undesirable statistical properties (e.g. extreme skewness), and short because data have not been collected for hundreds of years.” Meta-analysis has been shown to be a powerful tool; however, the outcome of a meta-analysis depends on the quality of the studies included. Literary review approaches are prone to publication bias. Most journals only publish positive outcomes. Small differences in search strategies can produce large differences in the set of studies found. Furthermore, most reports of individual studies include only summary results, such as means, standard deviations, proportions, limiting the researchers ability to harness the power of increased sample size, etc. If the methods of collecting, processing and analyzing differ significantly between studies, it will likely be inappropriate to combine the data from those studies. Fortunately, researchers like Ransom A. Myers had the insight to establish online repositories of spawner-recruitment data (RAM Legacy Stock Assessment Database; Myers *et al.* 1995, Ricard *et al.* 2012), that might be of value to us if we decide to take a meta-analytic approach to understanding the stock-recruitment relationship of the Columbia River Eulachon population.

Environmental Factors

A run is composed of fish from several brood years. In order to manage Eulachon fisheries, our unit annually compiles environmental correlates that may help in predicting the strength of the brood years contributing to a given run year. Measures of ocean conditions, such as the Pacific Decadal Oscillation (PDO) and Multivariate ENSO Index (MEI; El Nino/ La Nina), were gathered from the internet. In addition, biological information from the American and Canadian governments was obtained such as the number and type of copepods and euphausiids present off the coast. Relative brood year (cohort) strength is thought to be generally determined at the larval and egg stage (Cushing 1990). So, we also incorporate information about Columbia River plume size, water particle travel time, and other factors from the Center for Coastal Margin Observation & Prediction (CMOP), that may affect survival of the out-migrating larvae along the way to their appropriate ocean habitat. Many of these environmental factors, we have been using for prediction purposes, influence the recruitment process and should be considered for incorporation into the stock-recruit model we eventually chose to use. Incorporating environmental factors into the SRR, might require an approach different from the traditional density-dependent based stock-recruitment models.

Sakuramoto (2018) proposes that the recruitment is proportionately reproduced by the stock, and simultaneously affected by environmental conditions. He observed that most environmental factors fluctuate cyclically, and the recruitment also fluctuates cyclically in response to the environmental conditions. The stock varies cyclically according to the fluctuations in the recruitment with a certain time lag, which is mainly determined by the fishes’ weighted mean age at maturity (*m*).

Sakuramoto (2018) used complicated equations relying on length at age and weight at age as well as the number at age to derive biomass by age. Age times the biomass at age were summed and divided by the overall total biomass. Since we chose to look at numbers of fish in our Eulachon stock recruit relationships, we used a similar approach based on the number of fish in the combined brood year table (Table E7). The numbers in this table represents the adult Eulachon returns in seven RYs, 2013-2019. Taking the sum for each age column, and dividing by the total sum, we then multiplied those numbers by the numeric age. Next, we summed these weighted ages to get our estimate of weighted mean age at maturity ($m = 3.01$).

The cycle for the environmental condition in the Pacific Ocean is around 18-22 years according to Sakuramoto (2018). For Eulachon, we are seeing environmental conditions off Washington and Oregon cycling more frequently, perhaps 8-12 years. Sakuramoto (2018) noted that the age at maturity seems to be determined on a species-by-species or stock-by-stock basis. However, even for the same species, the environmental conditions that affect the population fluctuations are different in different habitats.

In Sakuramoto's model, the shape of the SRR (Figure E20) is determined by the ratio of the age at maturity to the cycle of the environmental condition. When the age at maturity is low compared to the cycle of the environmental fluctuations (as for the Columbia River Eulachon population), then the line of regression of $\ln(R)$ on $\ln(S)$ has a positive slope with the brood years sequentially moving around the trajectory line in a clockwise loop. The Eulachon age at maturity is less than half of the environmental cycles we described above. So, a Sakuramoto curve for Columbia River Eulachon will show one clockwise loop for one environmental cycle. At present, we most likely do not have enough data points (S and R) to evaluate Columbia River Eulachon population for even one environmental cycle. By contrast, Sakuramoto (2018) had 66 years of data on the Pacific stock of Japanese sardine (*Sardinops melanostictus*) for which he was able to identify three periods in the trajectories of recruitment and stock: 1951-1972 when the levels of S and R were low; 1973-1993 when the levels of S and R were high; and, 1994-2012 when the levels of S and R were medium. These three periods were of lengths corresponding to Sakuramoto's 18-22 years environmental cycle (Figure E20). For our Eulachon, we probably need at least six more brood years before we see even one of our assumed environmental cycle of 8-12 years.

Whether we chose to go with the traditional density dependent approach, or an unconventional approach like the Sakuramoto model, we simply need several more years of gathering spawner, recruitment, and environmental data in order to properly understand the dynamics behind the Columbia River Eulachon stock-recruitment relationship.

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Figures

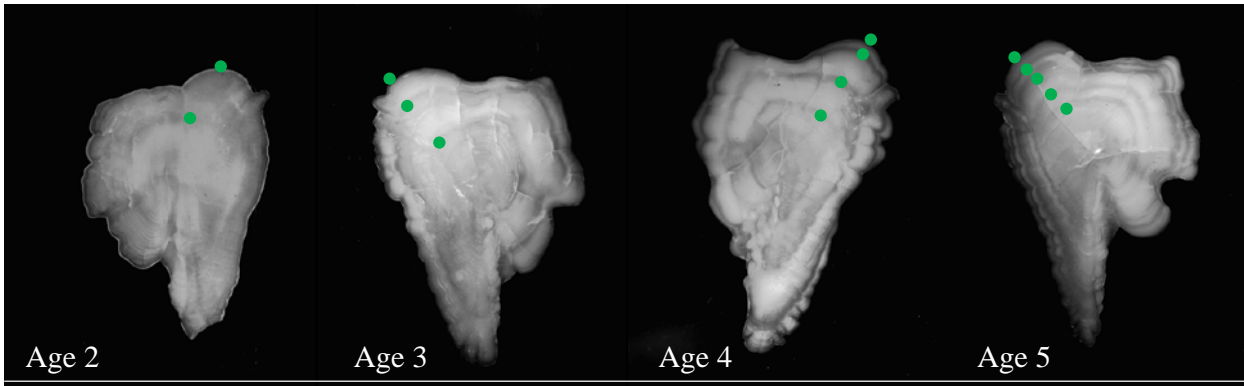


Figure E1. Eulachon otoliths from the primary age classes for fish captured in the Columbia River and tributaries in 2012-2019. Otolith age estimates 2-5 are shown and green dots indicate winter annuli as well as the otolith edge.

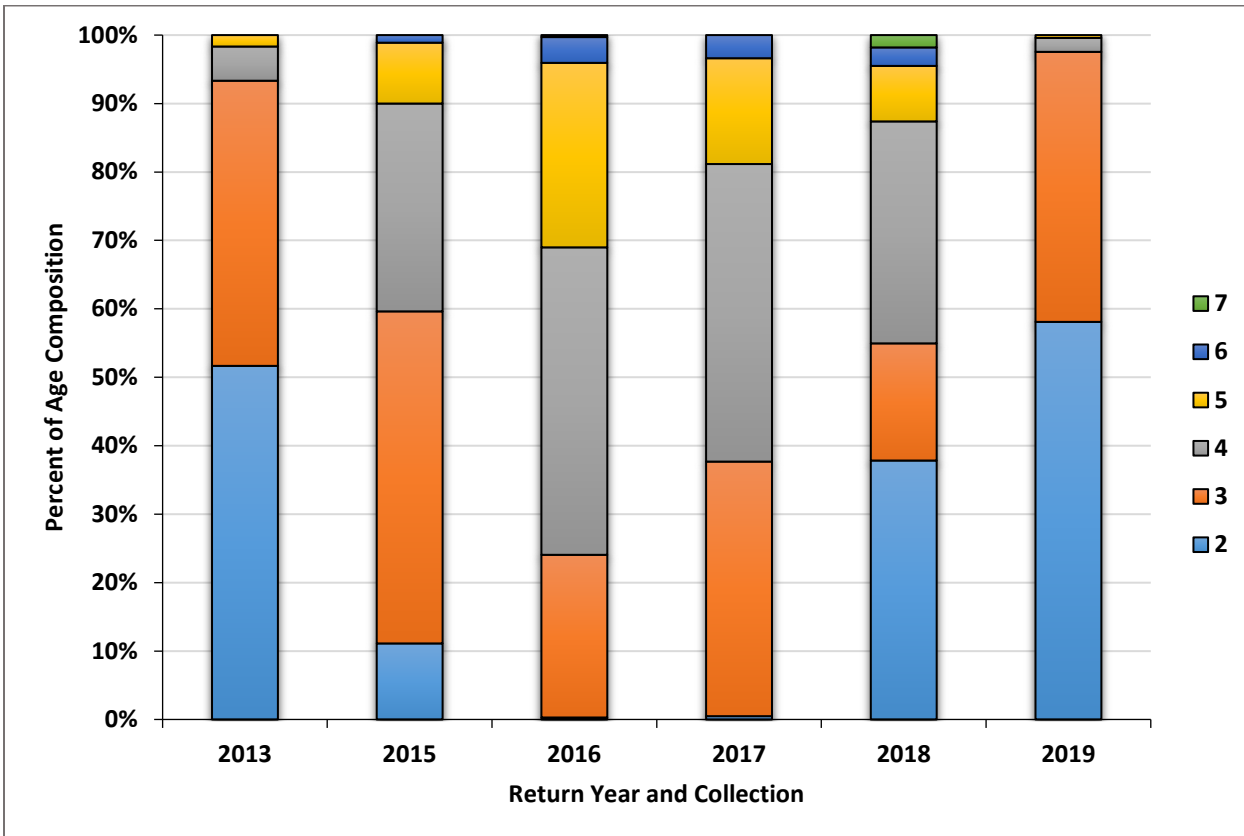


Figure E2. All Years Age Demographics. The number of otolith pairs aged each year are 67, 230, 339, 207, 111, and 735, for return years 2013-2019 respectively.

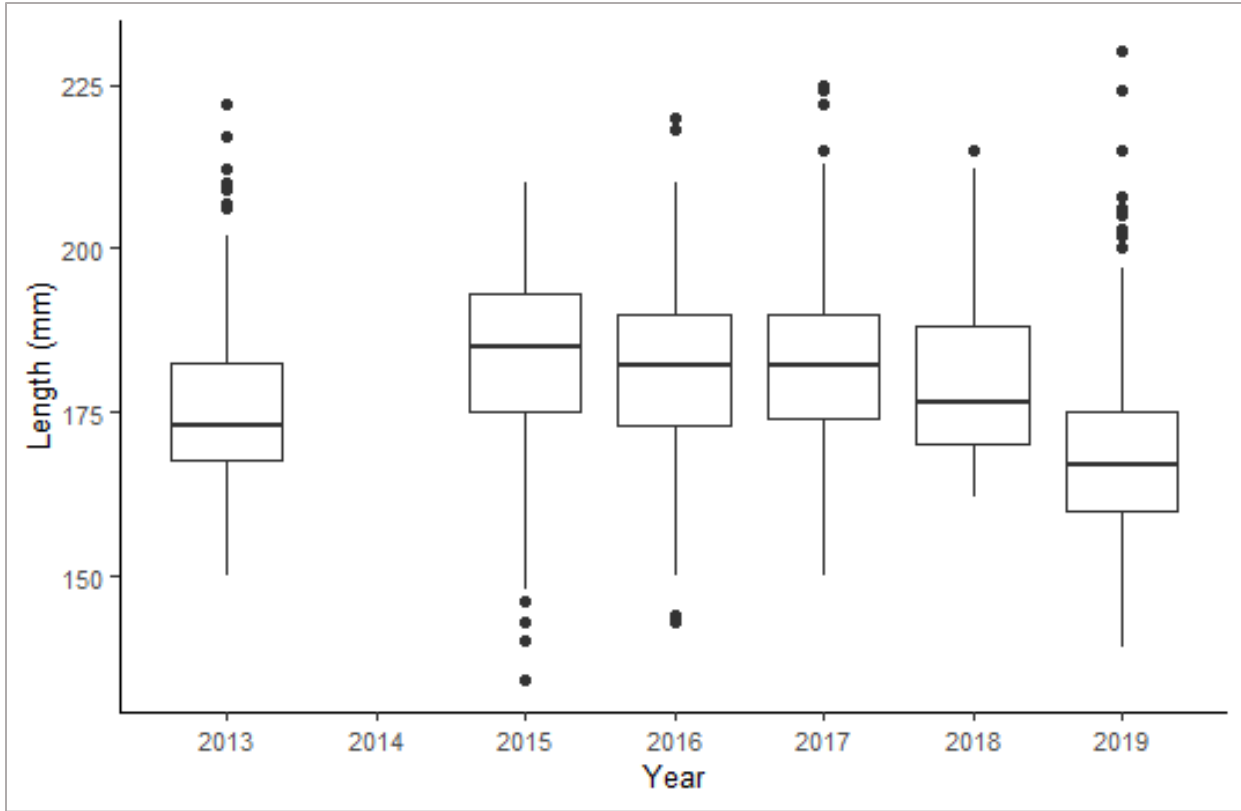


Figure E3. Fork lengths by return year for the Columbia River Eulachon. The black median line separates the upper and lower quartiles. Max and min values are $1.5 * IQR$. Values exceeding that are outliers depicted by dots. Average age at return were 2.56 (2013), 3.40 (2015), 4.11 (2016), 3.84 (2017), 3.26 (2018), and 2.45 (2019).

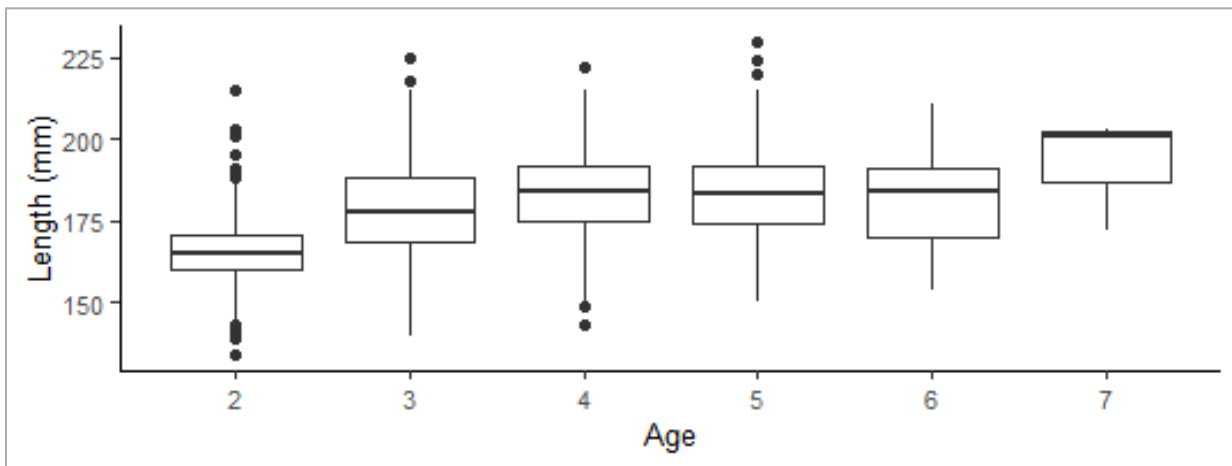


Figure E4. Fork lengths by Age for the Columbia River Eulachon. Data is combined across all years sampled [Age 2 (n=543), Age 3 (n=636), Age 4 (n=393), Age 5 (n=163), Age 6 (n=26), and Age 7 (n=3)]. The black median line separates the upper and lower quartiles. Max and min values are $1.5 * IQR$. Values exceeding that are outliers depicted by dots.

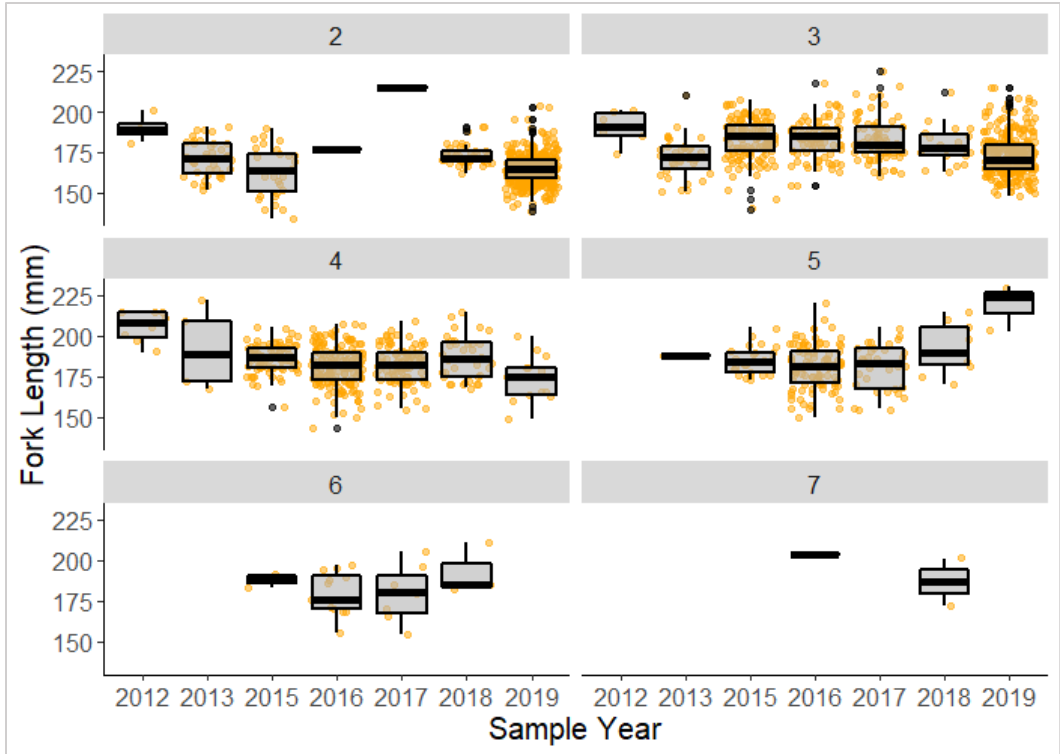


Figure E5. Fork length distribution by sample (return) year for each age group (Ages 2-7).

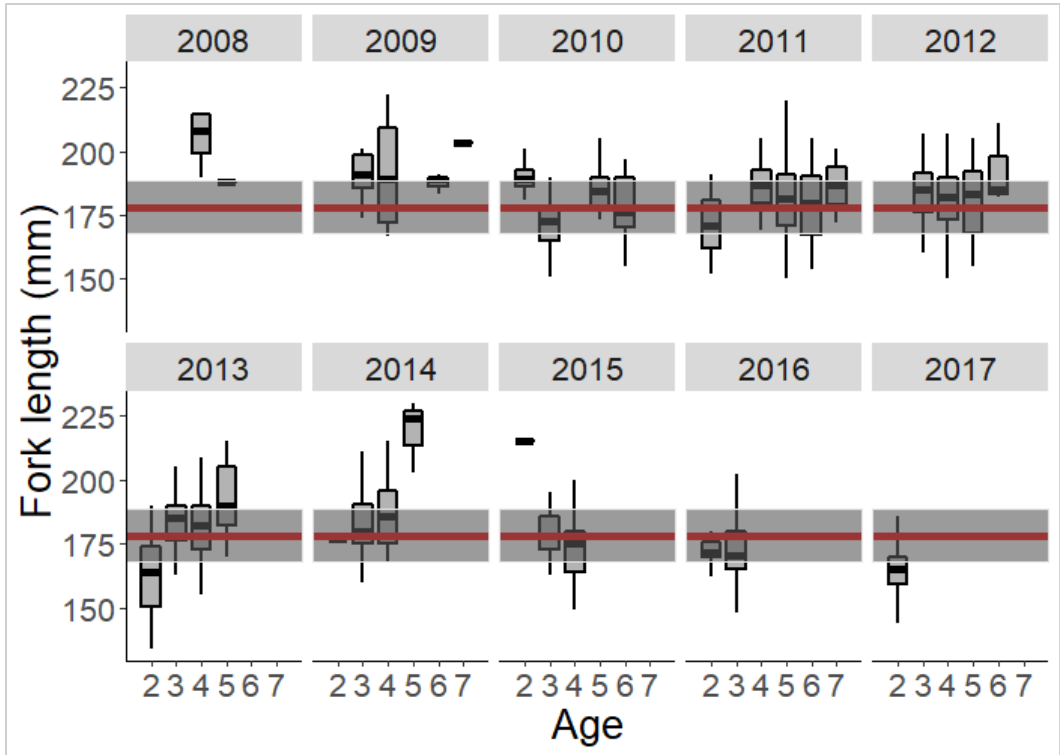


Figure E6. Fork length distribution by age for each brood year (BYs 2008-2017).

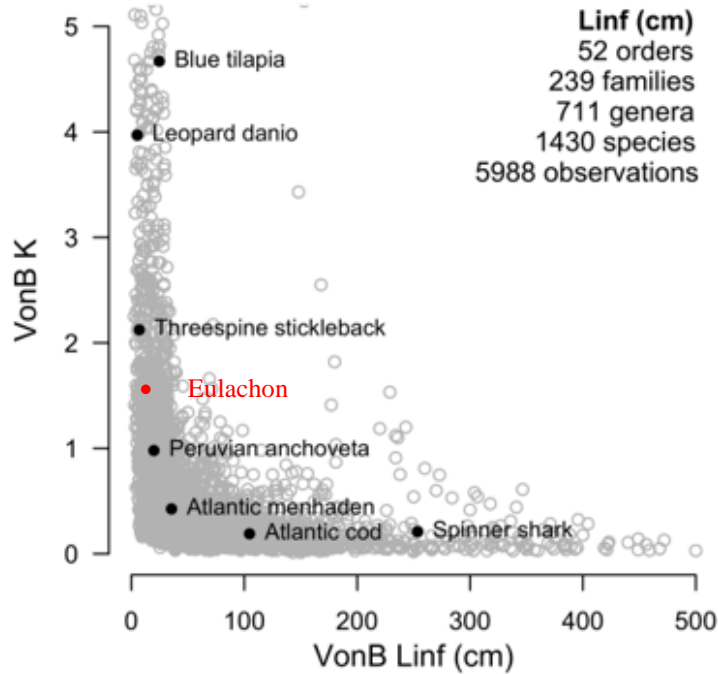


Figure E7. The relationship between the average maximum length (L_{∞}) and the rate (K) at which the fish approaches the average maximum length for 1,430 species. Multiply the length in cm by 10 to get the equivalent length in mm. The source is FishBase’s von Bertalanffy data set (<https://marine.rutgers.edu/~cfree/what-combinations-of-von-bertalanffy-growth-parameters-are-possible/>). Our estimate for Eulachon appears in red lettering.

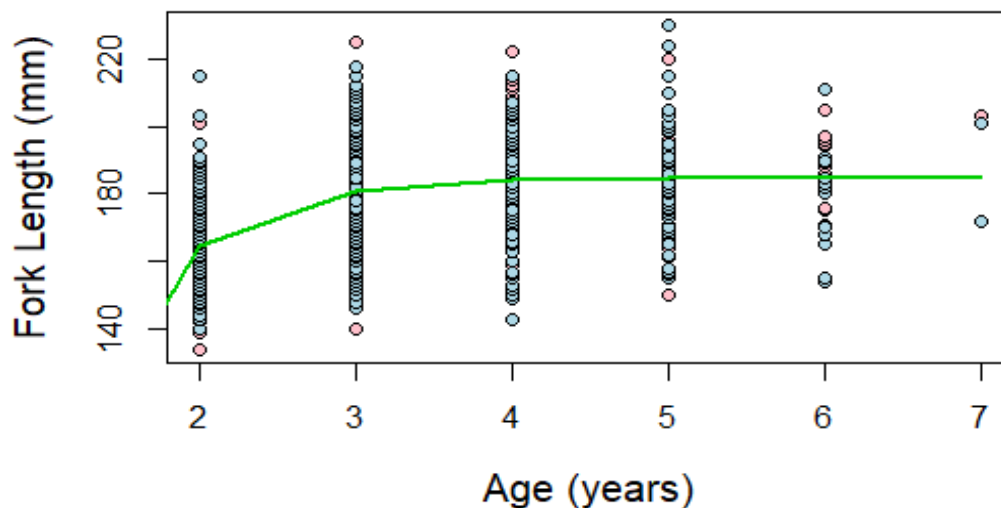


Figure E8. The von Bertalanffy growth function (VBGF) for Columbia Basin Eulachon adults sampled during 2012-2019. Blue circles are males, and red circles are females. $L_{\infty} = 184.8$, $K = 1.6194$, $t_0 = 0.63$, $n = 1,764$.

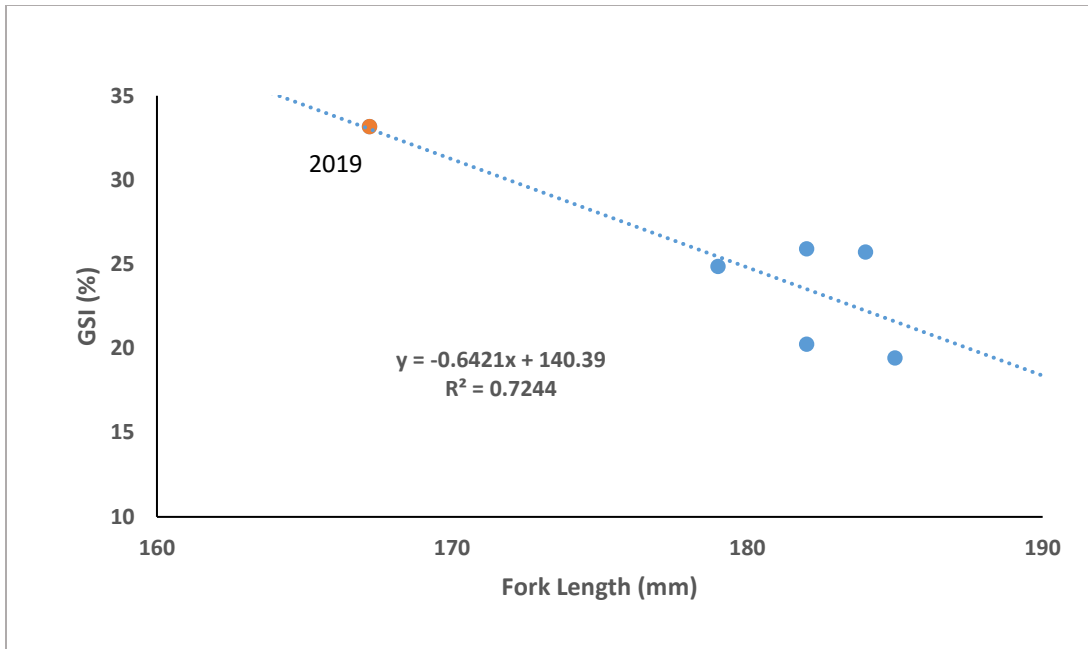


Figure E9. Comparison of average GSI and average fork length for female Eulachon sampled in 2012-2018 versus those sampled in 2019.

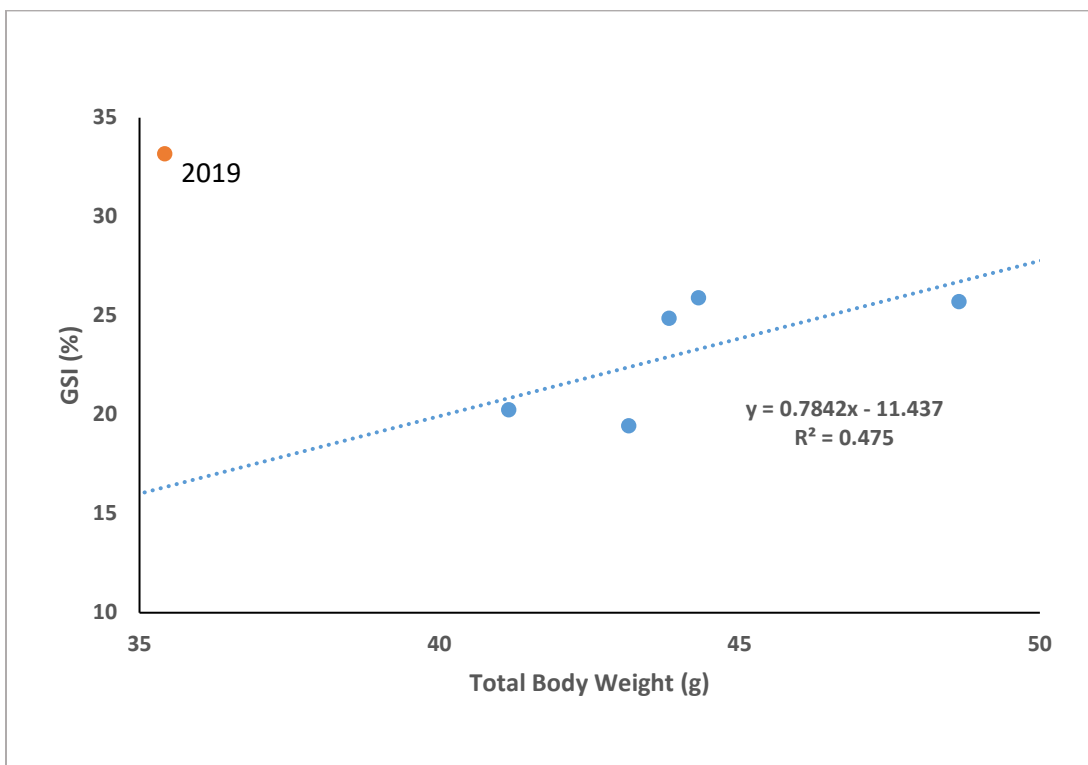


Figure E10. Comparison of average GSI and average total body weight for female Eulachon sampled in 2012-2018 versus those sampled in 2019.

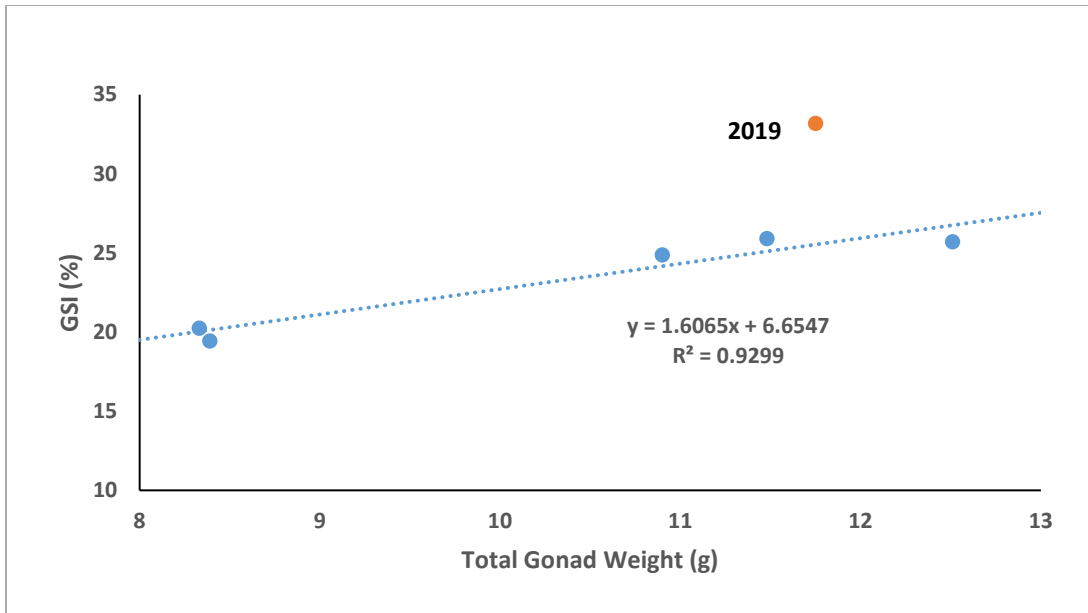


Figure E11. Comparison of average GSI and average gonad weight for female Eulachon sampled in 2012-2018 versus those sampled during 2019.

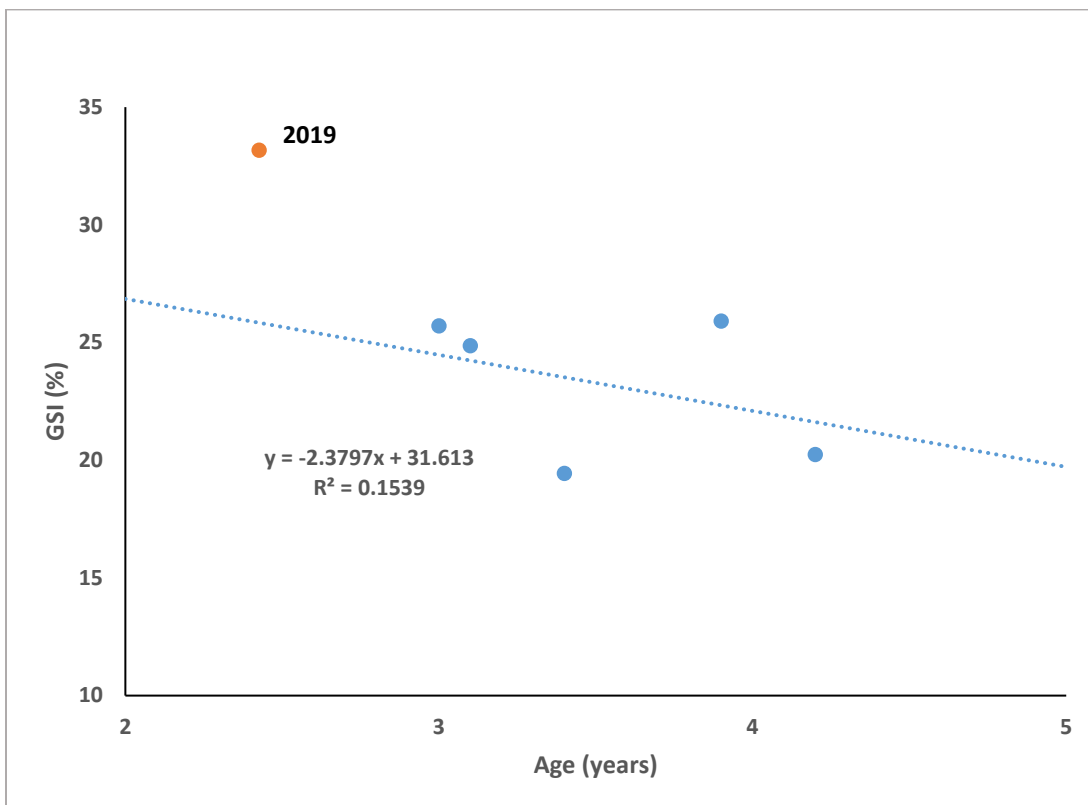


Figure E12. Comparison of average GSI and average age for female Eulachon sampled in 2012-2018 versus those sampled during 2019.

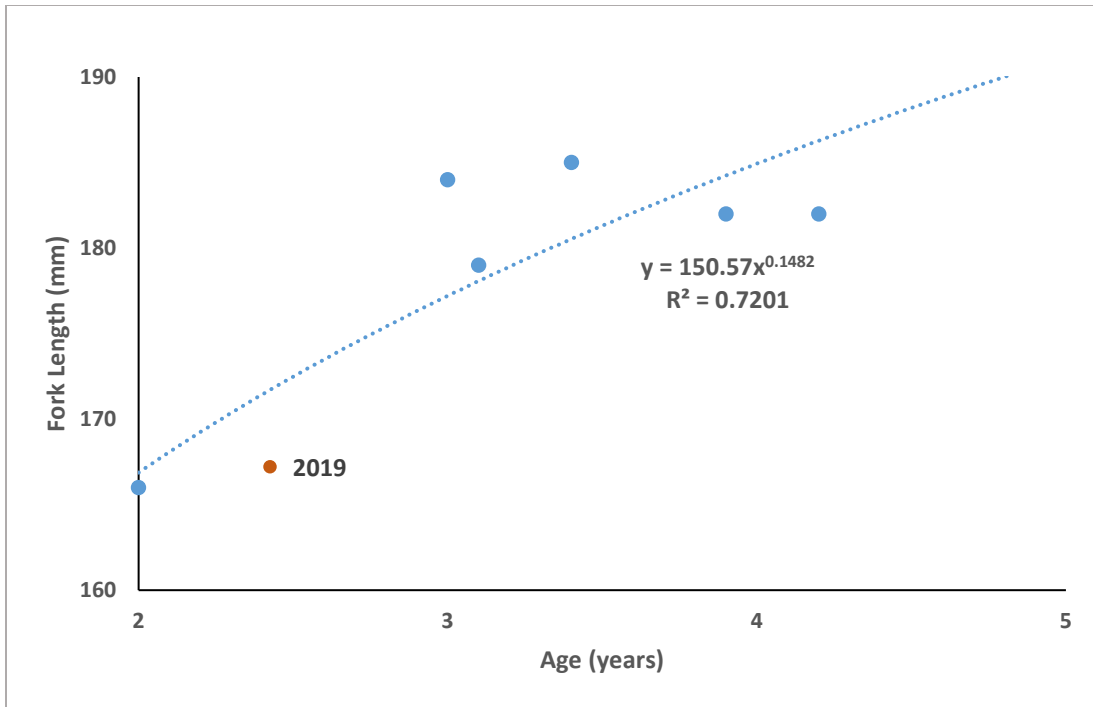


Figure E13. Comparison of average fork length and average age for female Eulachon sampled in 2012-2018 versus those sampled during 2019.

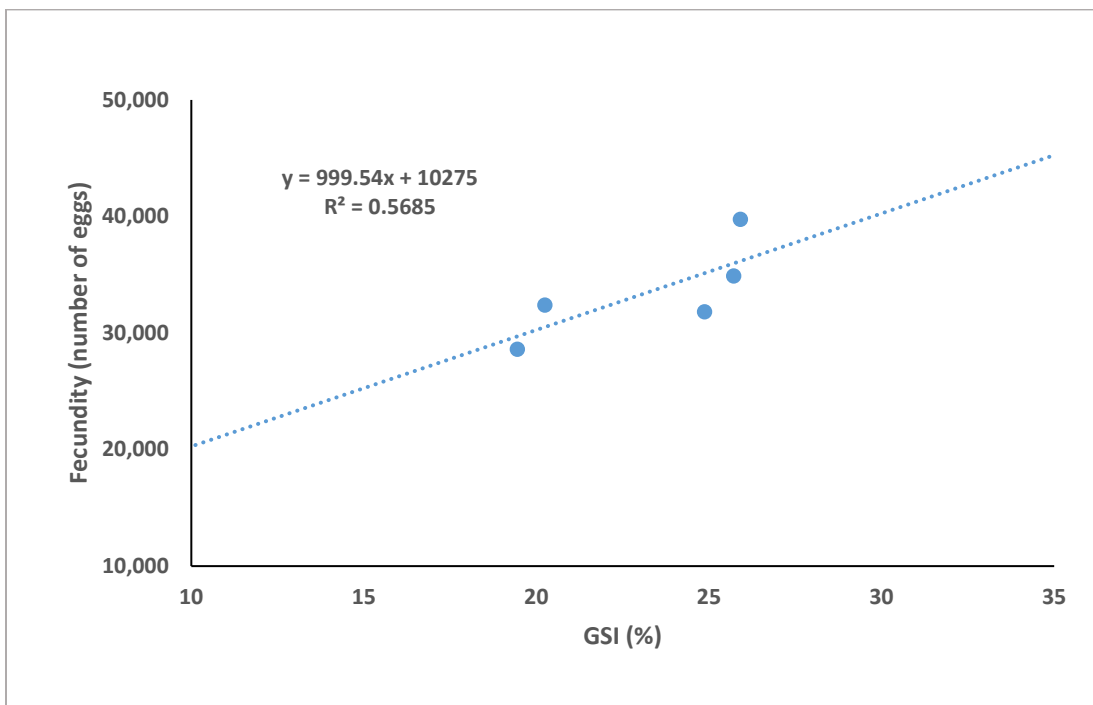


Figure E14. Comparison of average fecundity and average GSI for female Eulachon sampled in 2012-2018. No fecundity data for 2019.

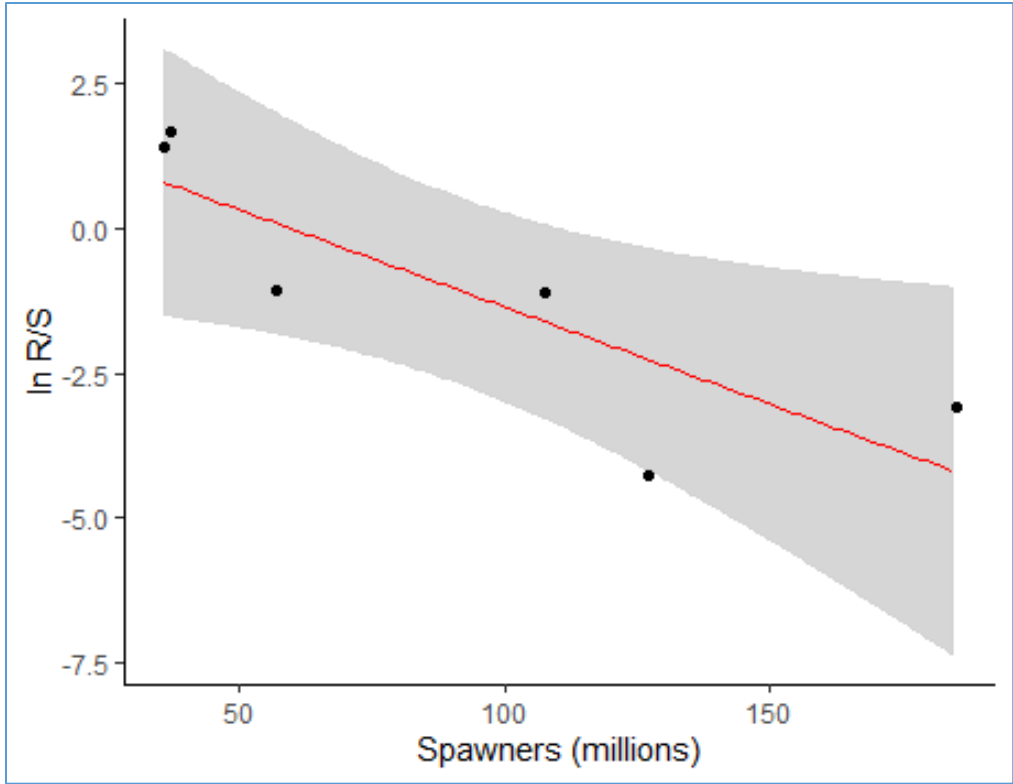


Figure E15. Comparison of productivity [$\ln(R/S)$] and spawners [S] calculated by the Ricker stock-recruitment model, for brood years 2011-2016. As more fish return in Run Years 2020 and 2021, the points below the red fitted line (BY 2015 and BY 2016) will slightly rise toward the Ricker stock-recruitment fitted line. The gray shaded area around the line depicts the 95% Confidence Interval.

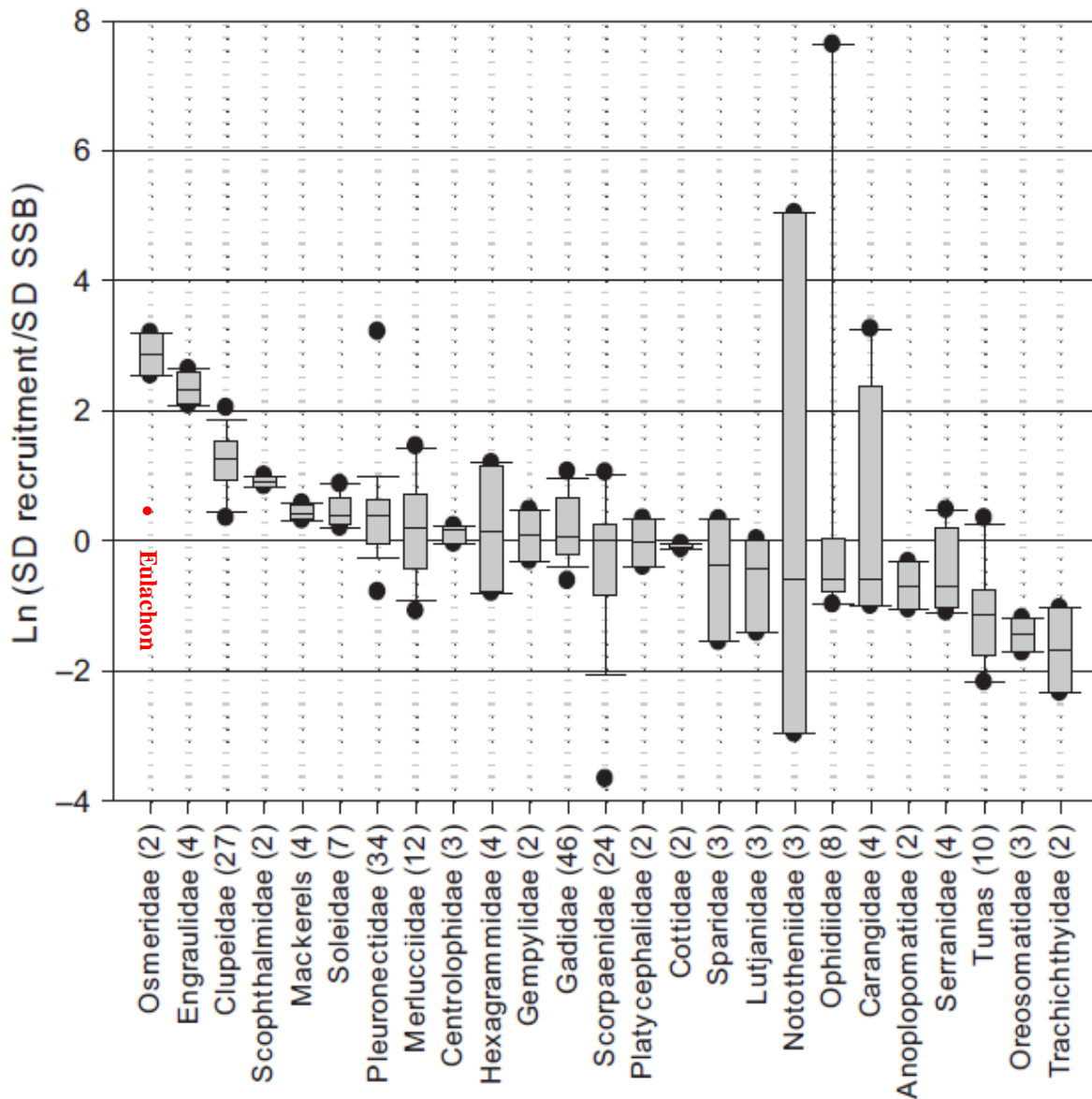


Figure E16. Box whisker plots of variability (SD) in recruitment relative to variability in spawner biomass (SSB) in relation to taxonomic family, with families ordered from highest to lowest median relative variability. Numbers indicate the number of stocks/management units in each family. Scombridae were separated into mackerels and tunas because of clear distinctions in the patterns of relative variability. Grey bars represent the 25th, median and 75th percentiles; error bars represent 5th and 95th percentiles; closed circles represent outliers. Data on fish populations from analytical population assessments collated in the Ransom Myers Legacy database. From Lowerre-Barbieri *et al.* (2016).

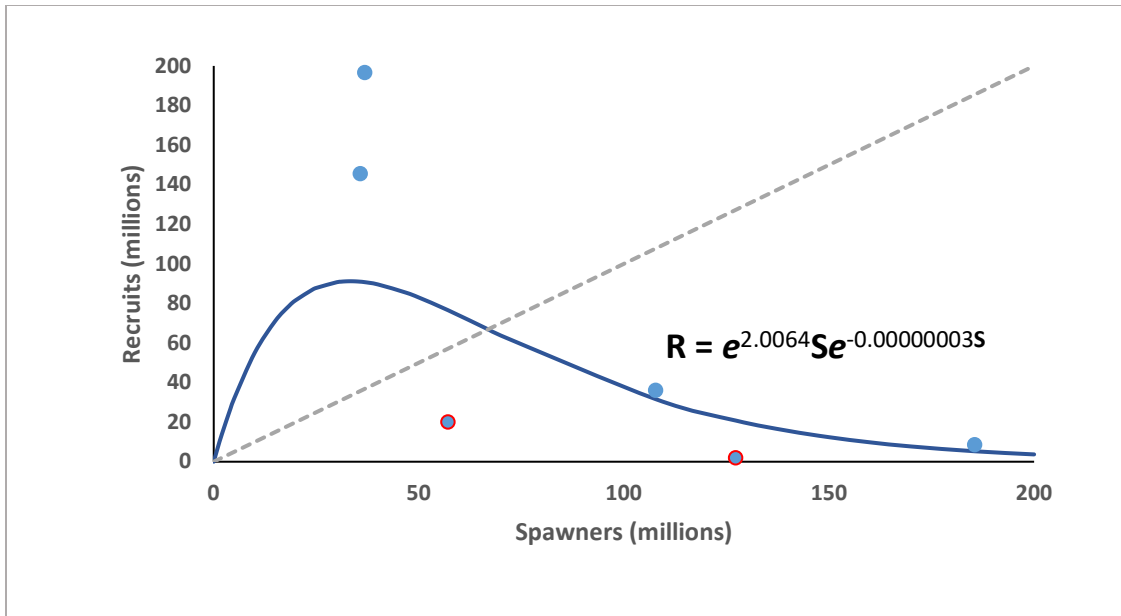


Figure E17. Ricker stock recruitment model fit to Recruits [R] and Spawners [S] for brood years 2011-2016. The red circled data points are for BYs 2015 and 2016. As more fish return in Run Year 2020 and 2021, these points will slightly rise toward the fitted Ricker stock-recruitment line.

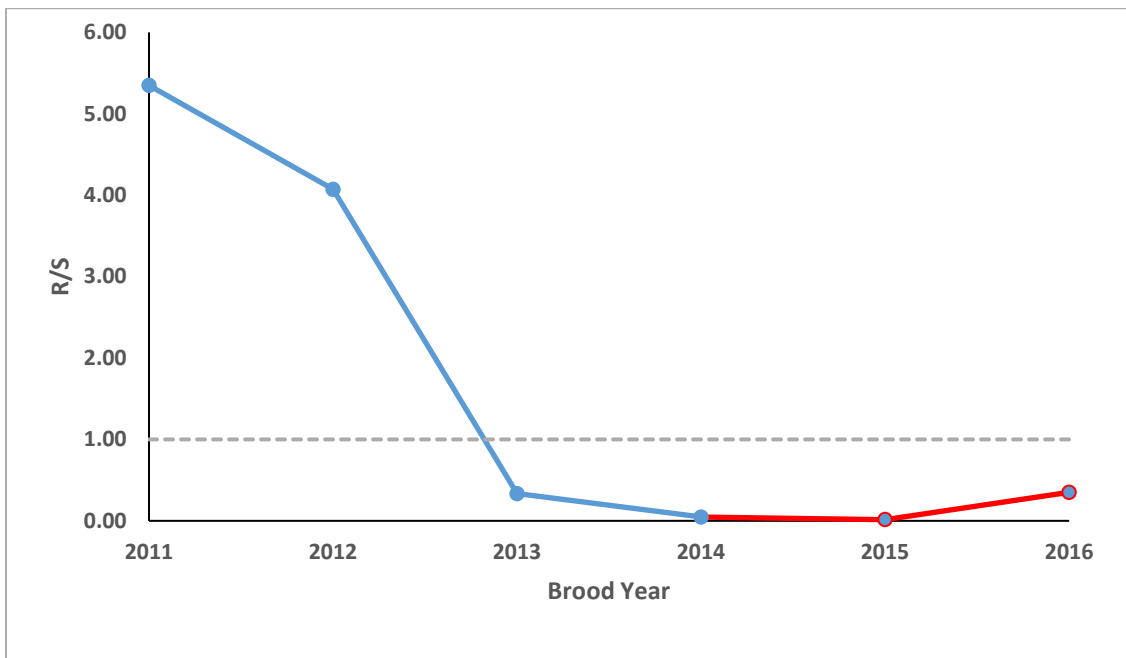


Figure E18. The recruits per spawner by brood year (2011-2016). The dashed line indicates replacement (recruits equal spawners). The red circled data points are for BYs 2015 and 2016 for which potential Age 4 and older returns have not yet been observed. The red line indicates that the trend may change when full recruitment is known for BYs 2015 and 2016.

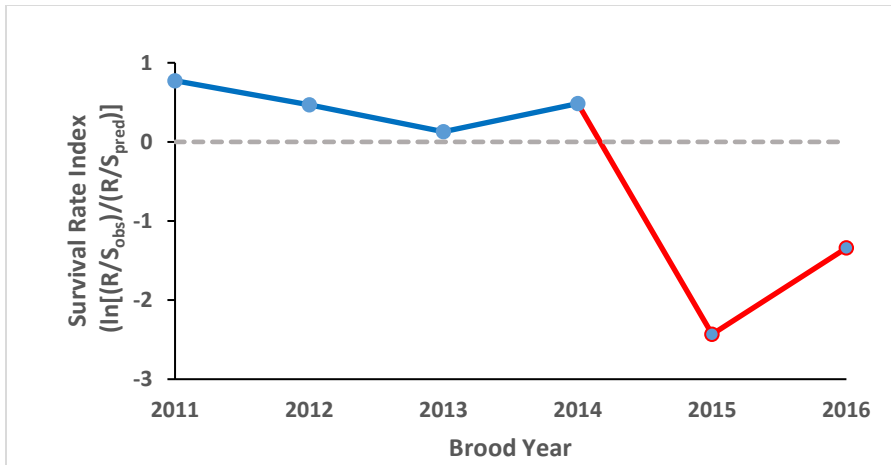


Figure E19. Survival Rate Index for brood years 2011-2016. The blue line indicates survival rate trends above what is predicted by the Ricker stock-recruitment model (the zero line). The red line indicates survival rate trends below what is predicted. The red circled data points are for BYs 2015 and 2016 for which potential Age 4 and older returns have not yet been observed.

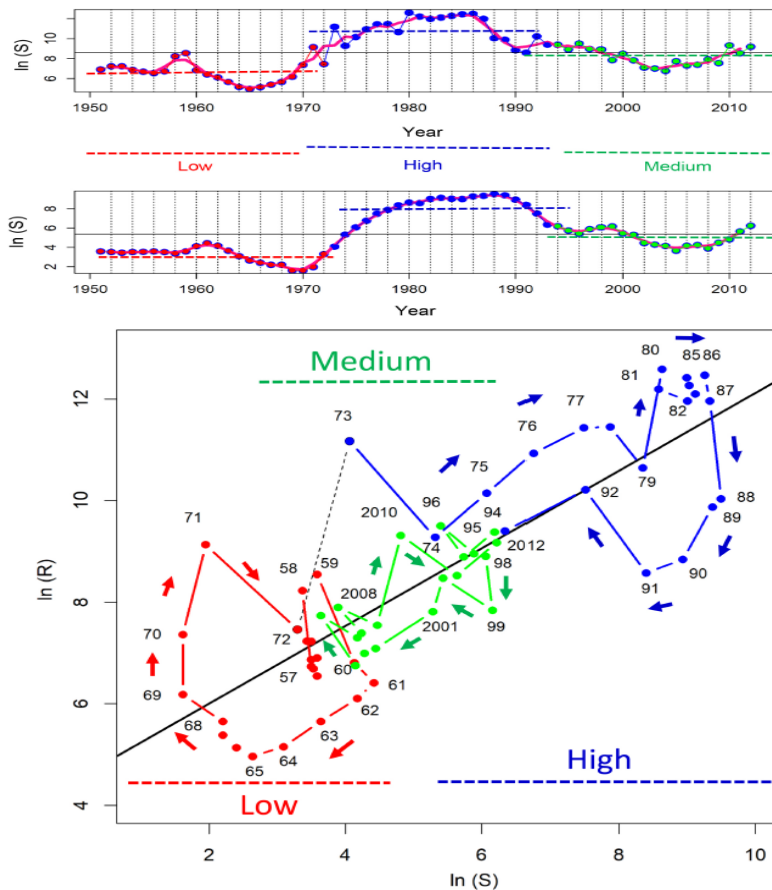


Figure E20. Sakuramoto stock-recruitment model of Pacific stock of Japanese sardine (*Sardinops melanostictus*) based on data from 1952-2012. The trajectory line slope is dependent on the mean age at maturity. Data points move around in clockwise circles when the age the at maturity is low compared to the environmental fluctuations here appearing to be cycling every 18-22 years. Plots from Sakuramoto (2018).

Tables

Table E1. 2019 Eulachon male biological data.

Year	Site	Sex	Age	Fork Length	Weight
2019	Columbia2	Male	3	160	28.35
2019	Columbia2	Male	3	184	42.43
2019	Columbia2	Male	2	174	32.84
2019	Columbia2	Male	3	156	19.15
2019	Columbia2	Male	2	156	23.65
2019	Columbia2	Male	3	165	28.63
2019	Columbia2	Male	3	164	23.97
2019	Columbia2	Male	3	164	27.13
2019	Columbia2	Male	2	172	31.84
2019	Columbia2	Male	3	191	44.51
2019	Columbia2	Male	4	187	24.12
2019	Columbia2	Male	3	175	36.94
2019	Columbia2	Male	3	173	36.72
2019	Columbia2	Male	3	166	29.64
2019	Cowlitz	Male	3	183	48.47
2019	Cowlitz	Male	3	197	54.98
2019	Cowlitz	Male	3	206	68.33
2019	Cowlitz	Male	2	203	69.84
2019	Cowlitz	Male	2	172	38.01
2019	Cowlitz	Male	3	180	41.41
2019	Cowlitz	Male	3	178	44.23
2019	Cowlitz	Male	3	194	57.58
2019	Cowlitz	Male	3	197	58.04
2019	Cowlitz	Male	3	194	54.05
2019	Cowlitz	Male	2	170	39.09
2019	Cowlitz	Male	3	191	59.82
2019	Cowlitz	Male	3	178	46.36
2019	Cowlitz	Male	3	171	38.37
2019	Cowlitz	Male	2	195	55.62
2019	Cowlitz	Male	3	165	35.89
2019	Cowlitz	Male	2	165	32.58
2019	Cowlitz	Male	3	163	30.92
2019	Cowlitz	Male	2	175	43.72
2019	Cowlitz	Male	3	165	32.72
2019	Cowlitz	Male	3	182	47.57
2019	Cowlitz	Male	2	162	33.56

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork Length	Weight
2019	Cowlitz	Male	3	163	35.16
2019	Cowlitz	Male	2	174	40.10
2019	Cowlitz	Male	3	170	39.95
2019	Cowlitz	Male	2	174	40.56
2019	Cowlitz	Male	2	170	34.80
2019	Cowlitz	Male	2	203	56.23
2019	Cowlitz	Male	2	165	35.32
2019	Cowlitz	Male	2	167	34.52
2019	Cowlitz	Male	2	172	42.92
2019	Cowlitz	Male	2	157	29.86
2019	Cowlitz	Male	3	177	37.75
2019	Cowlitz	Male	2	165	35.47
2019	Cowlitz	Male	3	166	31.66
2019	Cowlitz	Male	2	170	39.10
2019	Cowlitz	Male	2	180	48.31
2019	Cowlitz	Male	2	171	37.61
2019	Cowlitz	Male	2	173	37.50
2019	Cowlitz	Male	2	178	41.05
2019	Cowlitz	Male	2	185	50.91
2019	Cowlitz	Male	3	172	36.66
2019	Cowlitz	Male	3	187	51.57
2019	Cowlitz	Male	2	171	38.42
2019	Cowlitz	Male	3	171	34.03
2019	Cowlitz	Male	3	169	35.47
2019	Cowlitz	Male	2	166	30.92
2019	Cowlitz	Male	2	170	39.37
2019	Cowlitz	Male	3	202	56.62
2019	Cowlitz	Male	2	170	37.57
2019	Cowlitz	Male	3	175	40.37
2019	Cowlitz	Male	2	172	40.56
2019	Cowlitz	Male	2	167	34.21
2019	Cowlitz	Male	2	174	38.31
2019	Cowlitz	Male	3	188	50.79
2019	Cowlitz	Male	2	166	31.02
2019	Cowlitz	Male	2	170	37.71
2019	Cowlitz	Male	2	175	46.57
2019	Cowlitz	Male	2	166	32.84
2019	Cowlitz	Male	2	160	25.68
2019	Cowlitz	Male	2	175	36.04
2019	Cowlitz	Male	2	158	27.83
2019	Cowlitz	Male	2	156	23.70

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork Length	Weight
2019	Cowlitz	Male	2	159	24.77
2019	Cowlitz	Male	2	154	25.23
2019	Cowlitz	Male	2	165	30.09
2019	Cowlitz	Male	2	165	25.38
2019	Cowlitz	Male	3	176	31.53
2019	Cowlitz	Male	3	160	27.06
2019	Cowlitz	Male	2	160	25.21
2019	Cowlitz	Male	2	167	29.84
2019	Cowlitz	Male	2	166	30.72
2019	Cowlitz	Male	2	154	22.47
2019	Cowlitz	Male	2	165	30.94
2019	Cowlitz	Male	3	182	42.63
2019	Cowlitz	Male	2	156	24.99
2019	Cowlitz	Male	2	154	25.53
2019	Cowlitz	Male	3	162	32.67
2019	Cowlitz	Male	2	172	34.61
2019	Cowlitz	Male	2	153	22.83
2019	Cowlitz	Male	3	165	32.29
2019	Cowlitz	Male	2	181	43.84
2019	Cowlitz	Male	2	154	28.87
2019	Cowlitz	Male	2	160	27.35
2019	Cowlitz	Male	2	167	28.22
2019	Cowlitz	Male	2	162	31.46
2019	Cowlitz	Male	3	156	26.55
2019	Cowlitz	Male	2	155	23.11
2019	Cowlitz	Male	3	154	25.62
2019	Cowlitz	Male	2	162	29.57
2019	Cowlitz	Male	2	148	22.04
2019	Cowlitz	Male	2	155	26.91
2019	Cowlitz	Male	2	154	26.83
2019	Cowlitz	Male	2	148	21.33
2019	Cowlitz	Male	2	167	29.25
2019	Cowlitz	Male	3	168	30.53
2019	Cowlitz	Male	3	148	26.19
2019	Cowlitz	Male	3	161	30.48
2019	Cowlitz	Male	2	165	32.47
2019	Cowlitz	Male	3	166	31.99
2019	Cowlitz	Male	3	157	27.78
2019	Cowlitz	Male	3	194	49.15
2019	Cowlitz	Male	2	154	24.28
2019	Cowlitz	Male	3	153	26.41

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork Length	Weight
2019	Cowlitz	Male	3	171	39.22
2019	Cowlitz	Male	2	154	24.55
2019	Cowlitz	Male	2	165	33.30
2019	Cowlitz	Male	3	169	38.49
2019	Cowlitz	Male	2	162	29.68
2019	Cowlitz	Male	3	166	30.20
2019	Cowlitz	Male	2	147	23.10
2019	Cowlitz	Male	3	156	27.65
2019	Cowlitz	Male	3	167	33.13
2019	Cowlitz	Male	2	155	24.29
2019	Cowlitz	Male	2	161	30.93
2019	Cowlitz	Male	2	155	24.81
2019	Cowlitz	Male	3	160	30.98
2019	Cowlitz	Male	2	154	27.12
2019	Cowlitz	Male	2	149	25.22
2019	Cowlitz	Male	3	168	30.08
2019	Cowlitz	Male	2	156	24.88
2019	Cowlitz	Male	3	170	37.81
2019	Cowlitz	Male	2	165	31.73
2019	Cowlitz	Male	3	157	27.16
2019	Cowlitz	Male	2	161	28.65
2019	Cowlitz	Male	2	155	24.53
2019	Cowlitz	Male	2	155	25.51
2019	Cowlitz	Male	2	166	30.21
2019	Cowlitz	Male	2	160	29.00
2019	Cowlitz	Male	3	170	33.97
2019	Cowlitz	Male	2	162	30.28
2019	Cowlitz	Male	2	162	32.11
2019	Cowlitz	Male	2	160	29.45
2019	Cowlitz	Male	2	168	34.30
2019	Cowlitz	Male	2	161	29.15
2019	Cowlitz	Male	2	167	37.91
2019	Cowlitz	Male	3	165	33.63
2019	Cowlitz	Male	2	166	33.26
2019	Cowlitz	Male	2	170	34.26
2019	Cowlitz	Male	2	166	36.93
2019	Cowlitz	Male	2	155	27.64
2019	Cowlitz	Male	2	156	27.92
2019	Cowlitz	Male	3	157	28.79
2019	Cowlitz	Male	2	164	30.23
2019	Cowlitz	Male	2	144	20.53

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork Length	Weight
2019	Cowlitz	Male	3	160	30.05
2019	Cowlitz	Male	2	161	26.48
2019	Cowlitz	Male	2	160	28.48
2019	Cowlitz	Male	2	156	29.51
2019	Cowlitz	Male	2	158	29.61
2019	Cowlitz	Male	2	158	26.27
2019	Cowlitz	Male	2	159	29.06
2019	Cowlitz	Male	2	159	27.88
2019	Cowlitz	Male	2	164	30.38
2019	Cowlitz	Male	2	158	25.67
2019	Cowlitz	Male	2	159	28.15
2019	Cowlitz	Male	3	169	38.49
2019	Cowlitz	Male	2	160	29.34
2019	Cowlitz	Male	2	164	29.99
2019	Cowlitz	Male	3	161	31.86
2019	Cowlitz	Male	3	150	25.57
2019	Cowlitz	Male	2	160	29.87
2019	Cowlitz	Male	2	156	29.58
2019	Cowlitz	Male	3	180	46.37
2019	Cowlitz	Male	2	154	23.57
2019	Cowlitz	Male	2	151	24.15
2019	Cowlitz	Male	2	156	27.22
2019	Cowlitz	Male	2	161	34.33
2019	Cowlitz	Male	2	170	37.23
2019	Cowlitz	Male	2	164	30.91
2019	Cowlitz	Male	2	160	28.82
2019	Cowlitz	Male	2	156	26.77
2019	Cowlitz	Male	2	166	34.50
2019	Cowlitz	Male	3	163	31.30
2019	Cowlitz	Male	2	155	28.07
2019	Cowlitz	Male	2	154	23.22
2019	Cowlitz	Male	2	155	27.26
2019	Cowlitz	Male	2	150	21.52
2019	Cowlitz	Male	2	160	28.79
2019	Cowlitz	Male	2	155	25.92
2019	Cowlitz	Male	3	153	24.55
2019	Cowlitz	Male	2	160	33.31
2019	Cowlitz	Male	2	160	30.99
2019	Cowlitz	Male	2	163	27.82
2019	Cowlitz	Male	2	170	29.63
2019	Cowlitz	Male	2	163	29.20

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork Length	Weight
2019	Cowlitz	Male	3	189	44.88
2019	Cowlitz	Male	2	177	32.68
2019	Cowlitz	Male	2	167	25.58
2019	Cowlitz	Male	2	171	25.90
2019	Cowlitz	Male	2	167	31.69
2019	Cowlitz	Male	4	149	22.71
2019	Cowlitz	Male	3	170	34.41
2019	Cowlitz	Male	2	174	30.00
2019	Cowlitz	Male	3	195	49.45
2019	Cowlitz	Male	2	160	26.96
2019	Cowlitz	Male	2	172	34.34
2019	Cowlitz	Male	2	171	30.22
2019	Cowlitz	Male	2	166	30.83
2019	Cowlitz	Male	2	165	32.40
2019	Cowlitz	Male	3	155	26.00
2019	Cowlitz	Male	4	163	28.72
2019	Cowlitz	Male	3	171	35.78
2019	Cowlitz	Male	2	155	23.50
2019	Cowlitz	Male	2	164	29.09
2019	Cowlitz	Male	2	169	35.26
2019	Cowlitz	Male	2	167	31.41
2019	Cowlitz	Male	2	154	24.97
2019	Cowlitz	Male	3	160	28.46
2019	Cowlitz	Male	2	164	31.00
2019	Cowlitz	Male	2	195	54.29
2019	Cowlitz	Male	2	155	24.84
2019	Cowlitz	Male	2	155	26.79
2019	Cowlitz	Male	2	173	37.51
2019	Cowlitz	Male	2	160	27.09
2019	Cowlitz	Male	2	157	26.31
2019	Cowlitz	Male	2	155	25.28
2019	Cowlitz	Male	3	168	28.93
2019	Cowlitz	Male	2	170	35.08
2019	Cowlitz	Male	2	169	28.78
2019	Cowlitz	Male	2	162	30.02
2019	Cowlitz	Male	3	170	27.47
2019	Cowlitz	Male	3	158	26.32
2019	Cowlitz	Male	2	170	33.57
2019	Cowlitz	Male	2	162	27.80
2019	Cowlitz	Male	3	191	48.11
2019	Cowlitz	Male	2	170	32.87

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork Length	Weight
2019	Cowlitz	Male	5	203	55.91
2019	Cowlitz	Male	2	166	30.31
2019	Cowlitz	Male	3	164	28.47
2019	Cowlitz	Male	2	173	34.05
2019	Cowlitz	Male	3	181	42.37
2019	Cowlitz	Male	2	175	37.06
2019	Cowlitz	Male	2	165	28.52
2019	Cowlitz	Male	2	187	47.89
2019	Cowlitz	Male	2	147	22.80
2019	Cowlitz	Male	3	176	41.81
2019	Cowlitz	Male	2	159	27.33
2019	Cowlitz	Male	2	165	29.57
2019	Cowlitz	Male	2	162	28.07
2019	Cowlitz	Male	3	169	31.83
2019	Cowlitz	Male	2	168	30.58
2019	Cowlitz	Male	3	163	30.08
2019	Cowlitz	Male	2	155	24.28
2019	Cowlitz	Male	3	157	26.04
2019	Cowlitz	Male	2	176	35.81
2019	Cowlitz	Male	3	200	58.19
2019	Cowlitz	Male	2	170	33.60
2019	Cowlitz	Male	4	165	32.71
2019	Cowlitz	Male	3	177	41.26
2019	Cowlitz	Male	3	175	39.68
2019	Cowlitz	Male	3	187	50.05
2019	Cowlitz	Male	3	176	39.54
2019	Cowlitz	Male	2	167	30.18
2019	Cowlitz	Male	3	178	44.14
2019	Cowlitz	Male	3	170	38.00
2019	Cowlitz	Male	2	160	28.80
2019	Cowlitz	Male	3	180	44.97
2019	Cowlitz	Male	3	167	32.28
2019	Cowlitz	Male	3	188	48.70
2019	Cowlitz	Male	3	175	40.92
2019	Cowlitz	Male	2	160	28.93
2019	Cowlitz	Male	3	181	44.33
2019	Cowlitz	Male	3	178	40.87
2019	Cowlitz	Male	2	175	36.52
2019	Cowlitz	Male	2	158	28.61
2019	Cowlitz	Male	3	169	32.04
2019	Cowlitz	Male	3	170	34.82

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork Length	Weight
2019	Cowlitz	Male	3	177	34.94
2019	Cowlitz	Male	2	174	34.70
2019	Cowlitz	Male	3	175	38.70
2019	Cowlitz	Male	3	185	44.98
2019	Cowlitz	Male	2	167	33.60
2019	Cowlitz	Male	3	183	46.45
2019	Cowlitz	Male	3	170	36.46
2019	Cowlitz	Male	2	188	50.92
2019	Cowlitz	Male	2	174	37.46
2019	Cowlitz	Male	2	170	35.14
2019	Cowlitz	Male	2	164	30.88
2019	Cowlitz	Male	2	165	33.48
2019	Cowlitz	Male	3	173	36.72
2019	Cowlitz	Male	3	192	52.65
2019	Cowlitz	Male	3	185	45.24
2019	Cowlitz	Male	2	173	37.02
2019	Cowlitz	Male	3	179	41.59
2019	Cowlitz	Male	3	182	45.76
2019	Cowlitz	Male	2	175	38.98
2019	Cowlitz	Male	2	168	34.63
2019	Cowlitz	Male	3	178	44.28
2019	Cowlitz	Male	3	165	32.46
2019	Cowlitz	Male	2	159	28.75
2019	Cowlitz	Male	2	169	33.54
2019	Cowlitz	Male	4	180	41.62
2019	Cowlitz	Male	3	155	29.35
2019	Cowlitz	Male	3	196	54.13
2019	Cowlitz	Male	3	165	31.69
2019	Cowlitz	Male	3	170	34.25
2019	Cowlitz	Male	3	165	33.34
2019	Cowlitz	Male	2	160	27.41
2019	Cowlitz	Male	2	171	36.10
2019	Cowlitz	Male	3	168	34.78
2019	Cowlitz	Male	2	165	32.41
2019	Cowlitz	Male	3	160	28.55
2019	Cowlitz	Male	3	166	29.56
2019	Cowlitz	Male	3	181	47.77
2019	Cowlitz	Male	5	230	94.63
2019	Cowlitz	Male	2	168	32.84
2019	Cowlitz	Male	3	181	40.13
2019	Cowlitz	Male	3	180	41.26

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork Length	Weight
2019	Cowlitz	Male	2	181	45.37
2019	Cowlitz	Male	3	191	52.26
2019	Cowlitz	Male	2	161	28.76
2019	Cowlitz	Male	2	180	37.72
2019	Cowlitz	Male	3	215	75.96
2019	Cowlitz	Male	3	157	25.39
2019	Cowlitz	Male	5	224	75.93
2019	Cowlitz	Male	3	171	31.71
2019	Cowlitz	Male	2	170	32.69
2019	Cowlitz	Male	3	166	27.83
2019	Cowlitz	Male	3	182	38.11
2019	Cowlitz	Male	3	176	36.37
2019	Cowlitz	Male	2	160	29.26
2019	Cowlitz	Male	4	166	29.17
2019	Cowlitz	Male	2	152	26.91
2019	Cowlitz	Male	3	188	52.07
2019	Cowlitz	Male	2	165	28.18
2019	Cowlitz	Male	2	171	33.68
2019	Cowlitz	Male	3	165	27.79
2019	Cowlitz	Male	4	180	38.09
2019	Cowlitz	Male	3	179	38.30
2019	Cowlitz	Male	2	160	27.68
2019	Cowlitz	Male	2	171	30.01
2019	Cowlitz	Male	3	205	62.23
2019	Cowlitz	Male	3	172	31.13
2019	Cowlitz	Male	3	169	28.60
2019	Cowlitz	Male	3	188	46.02
2019	Cowlitz	Male	3	177	41.55
2019	Cowlitz	Male	2	176	35.97
2019	Cowlitz	Male	2	167	30.39
2019	Cowlitz	Male	3	175	35.74
2019	Cowlitz	Male	2	170	29.36
2019	Cowlitz	Male	2	170	32.75
2019	Cowlitz	Male	3	173	30.43
2019	Cowlitz	Male	3	169	33.49
2019	Cowlitz	Male	3	183	45.84
2019	Grays	Male	2	160	28.86
2019	Grays	Male	2	170	36.25
2019	Grays	Male	2	172	37.66
2019	Grays	Male	3	180	39.36
2019	Grays	Male	2	163	31.37

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork_Length	Weight
2019	Grays	Male	2	175	33.02
2019	Grays	Male	2	165	32.58
2019	Grays	Male	2	169	33.03
2019	Grays	Male	2	168	35.8
2019	Grays	Male	2	161	31.19
2019	Grays	Male	3	179	41.76
2019	Grays	Male	2	175	41.9
2019	Grays	Male	3	167	33.22
2019	Grays	Male	2	163	34.33
2019	Grays	Male	3	185	47.31
2019	Grays	Male	3	167	33.65
2019	Grays	Male	4	200	62.12
2019	Grays	Male	2	175	39.71
2019	Grays	Male	2	166	35.65
2019	Grays	Male	2	171	34.41
2019	Grays	Male	2	166	30.55
2019	Grays	Male	3	174	39.2
2019	Grays	Male	3	170	32.52
2019	Grays	Male	3	165	31.69
2019	Grays	Male	2	165	33.29
2019	Grays	Male	3	169	31.32
2019	Grays	Male	3	174	40.21
2019	Grays	Male	2	164	29.1
2019	Grays	Male	3	186	51.3
2019	Grays	Male	2	168	35.8
2019	Grays	Male	2	176	41.24
2019	Grays	Male	2	165	34.9
2019	Grays	Male	3	170	33.83
2019	Grays	Male	3	167	35.62
2019	Grays	Male	2	161	33.97
2019	Grays	Male	3	175	41.26
2019	Grays	Male	2	155	27.64
2019	Grays	Male	3	175	37.74
2019	Grays	Male	2	166	31.11
2019	Grays	Male	3	175	40.08
2019	Grays	Male	2	177	40.78
2019	Grays	Male	2	171	37.27
2019	Grays	Male	3	164	35.03
2019	Grays	Male	2	162	33.19
2019	Grays	Male	2	180	42.28
2019	Grays	Male	2	165	32.39

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork_Length	Weight
2019	Grays	Male	2	166	33.18
2019	Grays	Male	3	165	29.99
2019	Grays	Male	3	180	44.83
2019	Grays	Male	2	166	33.11
2019	Grays	Male	2	161	30.83
2019	Grays	Male	3	164	31.86
2019	Grays	Male	2	167	30.21
2019	Grays	Male	3	190	50.49
2019	Grays	Male	2	170	33.32
2019	Grays	Male	2	163	32.6
2019	Grays	Male	2	170	35.08
2019	Grays	Male	4	175	36.63
2019	Grays	Male	3	182	41.97
2019	Grays	Male	2	168	30.76
2019	Grays	Male	3	162	36.04
2019	Grays	Male	2	180	48.33
2019	Grays	Male	2	163	29.06
2019	Grays	Male	2	169	38.44
2019	Grays	Male	2	177	37.73
2019	Grays	Male	3	180	38.68
2019	Grays	Male	3	175	43.9
2019	Grays	Male	2	175	44.32
2019	Grays	Male	3	180	42.51
2019	Grays	Male	3	163	27.7
2019	Grays	Male	2	164	33.13
2019	Grays	Male	3	177	41.45
2019	Grays	Male	2	167	32.49
2019	Grays	Male	2	160	27.72
2019	Grays	Male	2	162	27.43
2019	Grays	Male	3	175	37.26
2019	Grays	Male	2	169	35.09
2019	Grays	Male	3	166	33.5
2019	Grays	Male	2	166	31.9
2019	Grays	Male	3	170	37.27
2019	Grays	Male	3	164	31.42
2019	Grays	Male	2	179	42.93
2019	Grays	Male	2	175	40.31
2019	Grays	Male	2	176	41.46
2019	Grays	Male	3	170	32.34
2019	Grays	Male	3	174	37.95
2019	Grays	Male	3	180	41.32

Table E1. 2019 Eulachon male biological data, cont.

Year	Site	Sex	Age	Fork_Length	Weight
2019	Grays	Male	3	180	40.37
2019	Grays	Male	3	162	29.48
2019	Grays	Male	2	163	30.08
2019	Grays	Male	2	180	43.14
2019	Grays	Male	4	192	50.53
2019	Grays	Male	3	171	32.19
2019	Grays	Male	2	168	34.64
2019	Grays	Male	3	179	41.92
2019	Grays	Male	2	161	30.23
2019	Grays	Male	3	170	36.31
2019	Columbia2	Average	2.9	170.5	30.71
2019	Cowlitz	Average	2.4	168.2	34.54
2019	Grays	Average	2.5	170.8	36.41
2019	Combined	Male	2.5	168.8	34.82

Table E2. 2019 Eulachon female biological data.

Year	Site	Fish Number	Sex	Age	Fork Length	Weight	Gonad Weight	GSI
2019	Grays	19-545	Female	2	165	32.42		
2019	Grays	19-546	Female	2	167	34.74		
2019	Cowlitz	19-001	Female	2	166	36.36	9.21	25.33
2019	Cowlitz	19-009	Female	3	180	44.95	12.28	27.32
2019	Cowlitz	19-010	Female	3	165	35.03		
2019	Cowlitz	19-011	Female	2	172	37.66	9.45	25.09
2019	Cowlitz	19-014	Female	3	179	41.92	9.92	23.66
2019	Cowlitz	19-015	Female	2	180	48.44		
2019	Cowlitz	19-016	Female	2	156	30.01	8.16	27.19
2019	Cowlitz	19-017	Female	2	170	37.60	9.68	25.74
2019	Cowlitz	19-018	Female	3	215	87.09	19.83	22.77
2019	Cowlitz	19-019	Female	2	155	26.79		
2019	Cowlitz	19-020	Female	2	158	31.11	8.13	26.13
2019	Cowlitz	19-021	Female	3	160	31.61		
2019	Cowlitz	19-024	Female	2	152	26.17		
2019	Cowlitz	19-025	Female	2	168	37.27		
2019	Cowlitz	19-026	Female	2	186	57.52	15.24	26.50
2019	Cowlitz	19-027	Female	2	160	29.58		
2019	Cowlitz	19-028	Female	2	171	40.31		
2019	Cowlitz	19-029	Female	2	170	38.16	11.53	30.21
2019	Cowlitz	19-030	Female	2	156	30.11	8.29	27.53
2019	Cowlitz	19-031	Female	2	163	36.27	9.17	25.28
2019	Cowlitz	19-032	Female	2	161	31.26	8.91	28.50
2019	Cowlitz	19-033	Female	2	152	26.77		
2019	Cowlitz	19-035	Female	3	208	74.94	20.69	27.61
2019	Cowlitz	19-036	Female	2	170	41.07	9.75	23.75
2019	Cowlitz	19-037	Female	2	169	34.12	9.65	28.29
2019	Cowlitz	19-038	Female	2	167	36.68	9.52	25.95
2019	Cowlitz	19-039	Female	2	160	32.74	11.45	34.97
2019	Cowlitz	19-040	Female	3	175	41.86		
2019	Cowlitz	19-041	Female	2	170	39.28		
2019	Cowlitz	19-042	Female	2	167	37.37		
2019	Cowlitz	19-043	Female	3	166	34.49		
2019	Cowlitz	19-044	Female	3	172	39.56		
2019	Cowlitz	19-052	Female	3	177	38.90		
2019	Cowlitz	19-061	Female	3	200	63.94	16.42	25.68
2019	Cowlitz	19-062	Female	3	170	38.46		
2019	Cowlitz	19-063	Female	3	183	49.67	12.75	25.67
2019	Cowlitz	19-064	Female	2	168	31.31		
2019	Cowlitz	19-065	Female	2	150	23.12		

Table E2. 2019 Eulachon female biological data, cont.

Year	Site	Fish Number	Sex	Age	Fork Length	Weight	Gonad Weight	GSI
2019	Cowlitz	19-066	Female	3	166	33.96		
2019	Cowlitz	19-067	Female	2	179	44.54	11.44	25.68
2019	Cowlitz	19-068	Female	2	175	42.30		
2019	Cowlitz	19-069	Female	3	193	50.40	13.81	27.40
2019	Cowlitz	19-070	Female	3	162	32.87		
2019	Cowlitz	19-071	Female	3	165	32.70		
2019	Cowlitz	19-072	Female	3	180	48.89		
2019	Cowlitz	19-073	Female	2	160	28.53		
2019	Cowlitz	19-074	Female	3	163	31.41		
2019	Cowlitz	19-075	Female	4	163	31.43		
2019	Cowlitz	19-076	Female	2	164	31.16		
2019	Cowlitz	19-077	Female	2	166	35.30		
2019	Cowlitz	19-078	Female	2	173	39.77		
2019	Cowlitz	19-079	Female	2	163	29.57		
2019	Cowlitz	19-080	Female	3	162	35.80		
2019	Cowlitz	19-081	Female	3	165	32.25		
2019	Cowlitz	19-082	Female	2	160	31.78		
2019	Cowlitz	19-083	Female	2	160	30.27		
2019	Cowlitz	19-084	Female	2	181	50.68	15.07	29.74
2019	Cowlitz	19-085	Female	2	175	36.36		
2019	Cowlitz	19-086	Female	2	180	44.89	12.87	28.67
2019	Cowlitz	19-087	Female	3	200	60.00	16.65	27.75
2019	Cowlitz	19-088	Female	3	167	34.11		
2019	Cowlitz	19-089	Female	3	170	40.53		
2019	Cowlitz	19-090	Female	3	167	36.54		
2019	Cowlitz	19-091	Female	3	203	65.26	18.34	28.10
2019	Cowlitz	19-092	Female	3	165	33.61		
2019	Cowlitz	19-093	Female	2	160	27.89		
2019	Cowlitz	19-100	Female	3	202	61.27	15.69	25.61
2019	Cowlitz	19-101	Female	3	160	32.41		
2019	Cowlitz	19-102	Female	2	159	31.21		
2019	Cowlitz	19-103	Female	2	160	28.93		
2019	Cowlitz	19-104	Female	2	166	31.36		
2019	Cowlitz	19-105	Female	3	175	45.36		
2019	Cowlitz	19-106	Female	3	182	48.94	13.67	27.93
2019	Cowlitz	19-107	Female	2	170	48.55		
2019	Cowlitz	19-108	Female	2	178	45.33	14.46	31.90
2019	Cowlitz	19-109	Female	3	163	32.77		
2019	Cowlitz	19-110	Female	3	165	38.60		
2019	Cowlitz	19-111	Female	3	157	31.25		

Table E2. 2019 Eulachon female biological data, cont.

Year	Site	Fish Number	Sex	Age	Fork Length	Weight	Gonad Weight	GSI
2019	Cowlitz	19-112	Female	2	170	37.37		
2019	Cowlitz	19-113	Female	3	158	29.07		
2019	Cowlitz	19-114	Female	3	172	37.68		
2019	Cowlitz	19-131	Female	2	164	33.11		
2019	Cowlitz	19-132	Female	3	188	55.91	15.19	27.17
2019	Cowlitz	19-133	Female	3	170	35.69		
2019	Cowlitz	19-134	Female	2	165	30.90		
2019	Cowlitz	19-135	Female	3	208	76.07	20.01	26.30
2019	Cowlitz	19-136	Female	3	170	40.38		
2019	Cowlitz	19-137	Female	2	157	30.51		
2019	Cowlitz	19-138	Female	3	168	34.71		
2019	Cowlitz	19-139	Female	3	171	41.79		
2019	Cowlitz	19-140	Female	2	155	30.36		
2019	Cowlitz	19-141	Female	3	179	45.10		
2019	Cowlitz	19-142	Female	2	160	30.91		
2019	Cowlitz	19-143	Female	2	163	30.67		
2019	Cowlitz	19-144	Female	2	171	38.44		
2019	Cowlitz	19-145	Female	3	185	54.74	15.38	28.10
2019	Cowlitz	19-146	Female	3	188	54.51		
2019	Cowlitz	19-147	Female	3	185	51.52		
2019	Cowlitz	19-148	Female	3	149	23.25		
2019	Cowlitz	19-149	Female	2	166	34.40		
2019	Cowlitz	19-150	Female	2	173	38.28		
2019	Cowlitz	19-151	Female	2	170	36.81		
2019	Cowlitz	19-152	Female	2	166	30.81		
2019	Cowlitz	19-153	Female	2	165	33.80		
2019	Cowlitz	19-154	Female	2	170	28.80		
2019	Cowlitz	19-155	Female	2	155	27.48		
2019	Cowlitz	19-156	Female	2	165	34.40		
2019	Cowlitz	19-157	Female	2	160	30.86		
2019	Cowlitz	19-158	Female	2	160	30.64		
2019	Cowlitz	19-159	Female	-	176	47.86		
2019	Cowlitz	19-160	Female	2	175	43.20		
2019	Cowlitz	19-161	Female	2	170	40.70		
2019	Cowlitz	19-162	Female	3	174	39.60		
2019	Cowlitz	19-163	Female	2	170	35.28		
2019	Cowlitz	19-164	Female	3	170	34.32		
2019	Cowlitz	19-165	Female	3	190	54.67	13.24	24.22

Table E2. 2019 Eulachon female biological data, cont.

Year	Site	Fish Number	Sex	Age	Fork Length	Weight	Gonad Weight	GSI
2019	Cowlitz	19-166	Female	2	170	34.36		
2019	Cowlitz	19-167	Female	2	164	36.76		
2019	Cowlitz	19-168	Female	2	184	45.76		
2019	Cowlitz	19-169	Female	3	176	41.43		
2019	Cowlitz	19-170	Female	2	151	28.70		
2019	Cowlitz	19-171	Female	2	166	33.63		
2019	Cowlitz	19-172	Female	3	165	33.41		
2019	Cowlitz	19-180	Female	2	155	26.80		
2019	Cowlitz	19-181	Female	3	160	31.49		
2019	Cowlitz	19-182	Female	2	165	34.78		
2019	Cowlitz	19-183	Female	2	167	24.09		
2019	Cowlitz	19-184	Female	3	170	36.49		
2019	Cowlitz	19-185	Female	3	190	57.89	16.39	28.31
2019	Cowlitz	19-186	Female	2	164	34.54		
2019	Cowlitz	19-187	Female	3	187	49.05	13.66	27.85
2019	Cowlitz	19-188	Female	3	167	34.74		
2019	Cowlitz	19-189	Female	2	165	31.94		
2019	Cowlitz	19-190	Female	3	170	34.87		
2019	Cowlitz	19-191	Female	3	188	52.45	14.80	28.22
2019	Cowlitz	19-192	Female	2	158	28.36		
2019	Cowlitz	19-193	Female	2	155	24.88		
2019	Cowlitz	19-194	Female	2	165	29.70		
2019	Cowlitz	19-195	Female	3	175	37.56		
2019	Cowlitz	19-196	Female	3	165	37.14		
2019	Cowlitz	19-197	Female	2	160	32.70		
2019	Cowlitz	19-198	Female	2	168	34.47		
2019	Cowlitz	19-199	Female	3	185	48.17		
2019	Cowlitz	19-200	Female	4	175	35.91		
2019	Cowlitz	19-201	Female	2	175	25.64		
2019	Cowlitz	19-202	Female	2	160	32.60		
2019	Cowlitz	19-203	Female	3	172	35.47		
2019	Cowlitz	19-204	Female	3	156	29.15		
2019	Cowlitz	19-205	Female	3	189	40.59	12.52	30.85
2019	Cowlitz	19-206	Female	2	160	29.15		
2019	Cowlitz	19-207	Female	2	160	28.38		
2019	Cowlitz	19-208	Female	2	156	26.72		
2019	Cowlitz	19-209	Female	-	164	31.96		
2019	Cowlitz	19-210	Female	3	170	37.13		
2019	Cowlitz	19-211	Female	3	180	47.69		
2019	Cowlitz	19-212	Female	2	165	33.00		

Table E2. 2019 Eulachon female biological data, cont.

Year	Site	Fish Number	Sex	Age	Fork Length	Weight	Gonad Weight	GSI
2019	Cowlitz	19-213	Female	2	168	33.52		
2019	Cowlitz	19-214	Female	4	178	40.92		
2019	Cowlitz	19-215	Female	3	167	37.46		
2019	Cowlitz	19-216	Female	2	167	32.85		
2019	Cowlitz	19-217	Female	2	156	29.86		
2019	Cowlitz	19-218	Female	3	176	33.53		
2019	Cowlitz	19-221	Female	3	205	72.82	19.51	26.79
2019	Cowlitz	19-222	Female	3	185	53.12		
2019	Cowlitz	19-223	Female	2	175	39.72		
2019	Cowlitz	19-224	Female	3	180	45.74		
2019	Cowlitz	19-225	Female	3	175	39.44		
2019	Cowlitz	19-226	Female	2	161	30.92		
2019	Cowlitz	19-227	Female	2	170	40.98		
2019	Cowlitz	19-228	Female	2	190	55.61	15.71	28.25
2019	Cowlitz	19-229	Female	3	168	36.91		
2019	Cowlitz	19-230	Female	-	190	58.05	15.87	27.34
2019	Cowlitz	19-231	Female	3	162	33.79		
2019	Cowlitz	19-232	Female	2	156	28.07		
2019	Cowlitz	19-233	Female	2	188	53.54		
2019	Cowlitz	19-234	Female	2	170	34.56		
2019	Cowlitz	19-235	Female	4	175	38.59		
2019	Cowlitz	19-236	Female	4	160	32.67		
2019	Cowlitz	19-237	Female	3	162	30.92		
2019	Cowlitz	19-238	Female	2	167	29.27		
2019	Cowlitz	19-239	Female	3	180	45.58		
2019	Cowlitz	19-240	Female	3	190	52.63		
2019	Cowlitz	19-241	Female	3	168	37.27		
2019	Cowlitz	19-242	Female	2	165	34.14		
2019	Cowlitz	19-243	Female	2	146	21.45		
2019	Cowlitz	19-244	Female	3	200	65.72	18.72	28.48
2019	Cowlitz	19-245	Female	2	170	36.73		
2019	Cowlitz	19-246	Female	3	196	63.29	18.24	28.82
2019	Cowlitz	19-248	Female	3	170	39.33		
2019	Cowlitz	19-249	Female	3	159	31.13		
2019	Cowlitz	19-250	Female	2	171	37.22		
2019	Cowlitz	19-251	Female	2	165	34.23		
2019	Cowlitz	19-252	Female	3	170	33.64		
2019	Cowlitz	19-253	Female	3	175	43.42		
2019	Cowlitz	19-254	Female	3	170	34.54		

Table E2. 2019 Eulachon female biological data, cont.

Year	Site	Fish Number	Sex	Age	Fork Length	Weight	Gonad Weight	GSI
2019	Cowlitz	19-255	Female	2	156	29.14		
2019	Cowlitz	19-256	Female	2	160	31.44		
2019	Cowlitz	19-257	Female	3	180	43.40		
2019	Cowlitz	19-258	Female	2	154	25.83		
2019	Cowlitz	19-259	Female	2	158	28.89		
2019	Cowlitz	19-260	Female	2	163	31.68		
2019	Cowlitz	19-261	Female	2	170	33.74		
2019	Cowlitz	19-262	Female		163	36.22		
2019	Cowlitz	19-263	Female	3	164	23.90		
2019	Cowlitz	19-264	Female	3	166	29.05	7.28	25.06
2019	Cowlitz	19-265	Female	2	156	31.84		
2019	Cowlitz	19-266	Female	3	189	51.64		
2019	Cowlitz	19-267	Female	2	160	30.88		
2019	Cowlitz	19-268	Female	3	152	22.17		
2019	Cowlitz	19-269	Female	3	176	37.15		
2019	Cowlitz	19-270	Female	2	164	33.72		
2019	Cowlitz	19-271	Female	3	156	31.71		
2019	Cowlitz	19-272	Female	2	139	19.44	6.40	32.90
2019	Cowlitz	19-294	Female	3	200	56.74	15.20	26.78
2019	Cowlitz	19-295	Female	2	160	34.33		
2019	Cowlitz	19-296	Female	2	154	22.71		
2019	Cowlitz	19-297	Female	2	160	24.66		
2019	Cowlitz	19-298	Female	2	165	37.76		
2019	Cowlitz	19-299	Female	3	151	20.26		
2019	Cowlitz	19-300	Female	3	155	28.29		
2019	Cowlitz	19-301	Female	2	146	24.31		
2019	Cowlitz	19-302	Female	2	164	24.21		
2019	Cowlitz	19-303	Female	2	170	28.01		
2019	Cowlitz	19-304	Female	2	164	29.87		
2019	Cowlitz	19-305	Female	2	157	28.99		
2019	Cowlitz	19-306	Female	2	178	41.13		
2019	Cowlitz	19-307	Female	2	145	21.01		
2019	Cowlitz	19-308	Female	2	150	19.83		
2019	Cowlitz	19-309	Female	3	165	34.15		
2019	Cowlitz	19-310	Female	2	168	39.60		
2019	Cowlitz	19-311	Female	3	163	26.29		
2019	Cowlitz	19-312	Female	2	166	31.45		
2019	Cowlitz	19-313	Female	2	153	22.82		
2019	Cowlitz	19-314	Female	2	147	19.92		
2019	Cowlitz	19-315	Female	2	157	23.86		

Table E2. 2019 Eulachon female biological data, cont.

Year	Site	Fish Number	Sex	Age	Fork Length	Weight	Gonad Weight	GSI
2019	Cowlitz	19-316	Female	3	151	26.50		
2019	Cowlitz	19-317	Female	2	151	24.23		
2019	Cowlitz	19-346	Female	2	156	21.78		
2019	Cowlitz	19-356	Female	2	172	33.63		
2019	Cowlitz	19-423	Female	2	166	25.55		
2019	Cowlitz	19-424	Female	2	151	22.79		
2019	Cowlitz	19-425	Female	3	156	22.15		
2019	Cowlitz	19-426	Female	2	151	21.35		
2019	Cowlitz	19-427	Female	2	151	20.01		
2019	Cowlitz	19-428	Female	2	164	28.00		
2019	Cowlitz	19-429	Female	2	156	19.56		
2019	Cowlitz	19-430	Female	2	165	24.67		
2019	Cowlitz	19-431	Female	2	160	24.03		
2019	Cowlitz	19-432	Female	-	160	23.50		
2019	Cowlitz	19-433	Female	2	156	24.70		
2019	Cowlitz	19-434	Female	2	150	20.01		
2019	Cowlitz	19-435	Female	2	178	34.00		
2019	Cowlitz	19-436	Female	2	165	35.32	11.11	31.46
2019	Cowlitz	19-437	Female	2	151	25.65	8.80	34.31
2019	Cowlitz	19-438	Female	2	157	28.02		
2019	Cowlitz	19-439	Female	2	160	30.54		
2019	Cowlitz	19-440	Female	2	160	30.80		
2019	Cowlitz	19-441	Female	3	168	27.51		
2019	Cowlitz	19-442	Female	2	144	20.92	6.54	31.26
2019	Cowlitz	19-443	Female	3	155	26.74	9.34	34.93
2019	Cowlitz	19-444	Female	2	160	31.18		
2019	Cowlitz	19-445	Female	2	153	25.76	8.60	33.39
2019	Cowlitz	19-446	Female	2	163	25.79		
2019	Cowlitz	19-447	Female	2	170	36.52	11.08	30.34
2019	Cowlitz	19-448	Female	3	159	33.64		
2019	Cowlitz	19-449	Female	2	158	29.03		
2019	Cowlitz	19-450	Female	2	150	25.98	5.92	22.79
2019	Cowlitz	19-451	Female	2	155	27.43	8.08	29.46
2019	Cowlitz	19-452	Female	3	151	27.82	6.62	23.80
2019	Cowlitz	19-453	Female	2	157	32.33	9.95	30.78
2019	Cowlitz	19-454	Female	2	142	21.48	6.14	28.58
2019	Cowlitz	19-455	Female	3	151	23.05	5.90	25.60
2019	Cowlitz	19-456	Female	2	170	27.45		
2019	Cowlitz	19-457	Female	3	166	35.04	10.86	30.99
2019	Cowlitz	19-458	Female	2	150	24.53	6.73	27.44

Table E2. 2019 Eulachon female biological data, cont.

Year	Site	Fish Number	Sex	Age	Fork Length	Weight	Gonad Weight	GSI
2019	Cowlitz	19-459	Female	2	155	27.05	7.00	25.88
2019	Cowlitz	19-460	Female	3	181	37.81	9.88	26.13
2019	Cowlitz	19-461	Female	2	165	31.49	9.29	29.50
2019	Cowlitz	19-462	Female	2	153	24.68	6.61	26.78
2019	Cowlitz	19-463	Female	3	165	32.94	9.81	29.78
2019	Cowlitz	19-464	Female	2	154	27.23	7.42	27.25
2019	Cowlitz	19-465	Female	2	160	30.07	9.68	32.19
2019	Grays	Average	Female	2	166	33.58		
2019	Cowlitz	Average	Female	2.4	167.2	35.42	11.75	27.94
2019	Combined	Average	Female	2.4	167.2	35.41	11.75	27.94

Table E3. Sex Ratio assumed for a given run year based on ratios observed in the Columbia River Commercial Management Zone 1 (lower estuary). Default value is 1:1 Male to Female ratio.

Run Year	M:F	Run Year	M:F
2011	1:1	2016	0.88:1
2012	1:1	2017	1:1
2013	1.07:1	2018	1:1
2014	1:1	2019	1:1
2015	1:1		

Table E4. Mapping of age to brood year and run year. Bolded values represent ages that were present during sampling for that given run year.

Age Mapping Table									
BY \ RY	2012	2013	2014	2015	2016	2017	2018	2019	
2005	7								
2005	6	7							
2007	5	6	7						
2008	4	5	6	7					
2009	3	4	5	6	7				
2010	2	3	4	5	6	7			
2011		2	3	4	5	6	7		
2012			2	3	4	5	6	7	
2013				2	3	4	5	6	
2014					2	3	4	5	
2015						2	3	4	
2016							2	3	
2017									2

Table E5. Brood Year Table for estimated total numbers of female Eulachon in the run (SSB plus Harvest). Gray cells with italicized type indicate a non-sampling year where the numbers shown are an average of two opposing years. Yellow cells indicate preliminary values from the 2019-run year.

BROOD YEAR TABLE (Female) Total Fish							
BROOD YEAR	2	3	4	5	6	7	Total
2005						0	0
2006					0	<i>0</i>	0
2008				0	<i>0</i>	0	0
2009			2,598,440	<i>1,932,292</i>	0	223,362	4,754,093
2010		28,582,840	<i>19,709,375</i>	2,652,083	893,447	0	51,837,745
2011	20,787,520	<i>48,693,750</i>	23,868,750	8,264,385	195,745	0	101,810,150
2012	<i>22,414,583</i>	31,825,000	14,741,876	978,723	41,849	<i>0</i>	70,002,032
2013	5,304,167	6,254,129	4,110,638	167,396	<i>0</i>		15,836,330
2014	0	3,914,894	544,037	<i>0</i>			4,458,930
2015	0	418,490	<i>420,251</i>				838,741
2016	878,829	<i>9,077,419</i>					9,956,248
2017	<i>13,952,330</i>						13,952,330

Table E6. Brood Year Table for estimated total numbers of male Eulachon in the run (SSB plus Harvest). Gray cells with italicized type indicate a non-sampling year where the numbers shown are an average of two opposing years. Yellow cells indicate preliminary values from the 2019-run year.

BROOD YEAR TABLE (Male) Total Fish							
BROOD YEAR	2	3	4	5	6	7	Total
2005						0	0
2006					0	<i>0</i>	0
2008				2,653,867	<i>1,159,375</i>	0	3,813,242
2009			2,653,867	<i>6,845,833</i>	1,591,250	0	11,090,950
2010		15,923,200	<i>16,893,750</i>	6,365,000	252,102	0	39,434,052
2011	34,500,267	<i>33,345,833</i>	20,155,833	6,554,649	283,077	66,148	94,905,808
2012	<i>34,505,208</i>	27,581,667	11,848,789	1,556,923	66,148	<i>0</i>	75,558,735
2013	7,956,250	7,815,158	4,246,154	165,371	<i>0</i>		20,182,933
2014	252,102	2,972,308	727,632	<i>154,276</i>			4,106,318
2015	141,538	330,742	<i>514,254</i>				986,535
2016	694,558	<i>9,359,430</i>					10,053,988
2017	<i>13422039</i>						13,422,039

Table E7. Brood Year Table for estimated total numbers of both male and female Eulachon in the run.

BROOD YEAR TABLE (Combined Male and Female) Total Fish							
BROOD YEAR	2	3	4	5	6	7	Total
2005						0	0
2006					0	<i>0</i>	0
2008				2,653,867	<i>1,159,375</i>	0	3,813,242
2009			5,252,307	<i>8,778,125</i>	1,591,250	223,362	15,845,043
2010		44,506,040	<i>36,603,125</i>	9,017,083	1,145,549	0	91,271,797
2011	55,287,787	<i>82,039,583</i>	44,024,583	14,819,034	478,822	66,148	196,715,958
2012	<i>56,919,792</i>	59,406,667	26,590,665	2,535,646	107,997	<i>0</i>	145,560,767
2013	13,260,417	14,069,288	8,356,792	332,767	<i>0</i>		36,019,264
2014	252,102	6,887,201	1,271,669	<i>154,276</i>			8,565,249
2015	141,538	749,232	<i>934,505</i>				1,825,275
2016	1,573,387	<i>18,436,849</i>					20,010,236
2017	<i>27,374,369</i>						27,374,369

Table E8. Target Reference Points (TRPs) for managing the Columbia River Eulachon fisheries based on the application of the Ricker Stock-Recruitment Model to Brood Years 2011-2016.

Ricker Model	Maximum Sustained Yield			Maximum Sustained Recruitment		Replacement	
	S _{msy}	R _{msy}	Yield	S _{msr}	R _{msr}	S _r	R _r
numbers	24,046,838	86,920,888	62,874,050	33,333,333	91,186,564	66,880,000	66,880,000
pounds	2,154,735	7,788,610	5,633,875	2,986,858	8,170,839	5,992,832	5,992,832
tonnes	977	3,533	2,555	1,355	3,706	2,718	2,718