Willapa Bay Coho Forecast Methodology

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Introduction

Each year, the Scientific and Statistical Committee (SSC) and the Salmon Technical Team (STT) of the Pacific Fishery Management Council (PFMC) complete a methodology review to help assure that any new or significantly modified methods use the best available science to estimate impacts of the Council's salmon management. In September 2019, the Council approved the methodology review for the abundance forecast approach used for Willapa Bay natural coho salmon (*Oncorhynchus kisutch*). Abundance forecasts are important for setting annual harvest control rules and for evaluating stock status. Willapa Bay coho is not managed under an international agreement; therefore, it is not exempt from the annual catch limit (ACL) requirements of the Magnuson Stevens Act (MSA) as other Washington coho stocks.

The intent of this document is to provide the SSC and the STT with the information required to conduct their review of the methodology used by the Washington Department of Fish and Wildlife (WDFW) in developing its annual forecast of natural and hatchery coho abundance for the Willapa Bay management unit. We will describe the proposed method used to forecast ocean age-3 (OA3) abundance of wild coho originating from Willapa Bay in 2020 and to compare the accuracy of the proposed method to two alternative naïve models using cross-validation. The document is organized into three sections followed by two appendices: background, a forecasting section, and a discussion. Appendix A is a table listing environmental variables explored to predict coho survival. Appendix B describes methods associated with the methods WDFW uses to reconstruct Willapa Bay coho runsizes.

As we use the Chehalis Basin within the Grays Harbor management unit as a surrogate for Willapa Bay, the methods described are mainly for the Chehalis Basin. The natural coho forecasting methods can be divided into methods related to (1): smolt abundance, (2): marine survival rate, and (3): model performance. We first describe methods used to scale measurements of smolt density in the Chehalis Basin to Willapa Bay. Second, we describe the method used to back-calculate "observed" smolt abundance in the Chehalis Basin using mark-recapture, with the understanding that there is a one-year delay between back-calculating "observed" abundance and developing an "estimate" of smolt abundance needed for forecasting. Third we describe relationships between "observed" smolt abundance and freshwater flow regimes during spawning, incubation, and rearing. Fourth we describe model selection based on multiple regressions of river flows on smolt abundance to develop an "estimate" of smolt abundance for ocean entry year 2019 needed for the 2020 forecast. We then switch to describe the

methods of model development and model selection to estimate marine survival using ocean indicators. Finally, we describe model evaluation based on cross-validation hindcasting and present results comparing three candidate forecasts.

Background

Run size forecasts of coho salmon returns are an important part of the pre-season planning process for Washington State salmon fisheries. A coho salmon run (harvest + escapement) typically refers to the total number of mature fish returning in a given year from ocean-rearing areas to spawn, this is the case, tributaries of Willapa Bay. Forecasts of a run are often based on information such as parent-year escapements, subsequent juvenile (smolt) abundance, and spring seawater temperatures. Accurate forecasts are needed at the scale of management units to ensure adequate spawning escapements, realize harvest benefits, and achieve harvest allocation goals. The WDFW Fish Program, Science Division has developed forecasts of natural-origin (NOR; hereafter referred to as "wild") coho run size since 1996 when a wild coho forecast was developed for all primary and most secondary management units in Puget Sound and the Washington coast (Seiler 1996). In 2020, the WDFW Science Division forecast of wild coho from the Willapa Bay management unit is defined as the product of juvenile (smolt) abundance at freshwater emigration and a marine survival rate (smolt-to-adult ratio; Litz 2020).

Smolt abundance, or freshwater production, is measured as the number of coho smolts leaving freshwater at the conclusion of the juvenile freshwater life stage. Over the last four decades, biologists from WDFW have made substantial investments to monitor smolt abundance in order to assess watershed capacity and escapement goals and to improve run size forecasts. In addition, long-term studies on wild coho populations have been used to identify environmental variables contributing to freshwater production (e.g., influence of freshwater flow on quality and availability of suitable habitat). For stocks where smolt abundance is not measured, like Willapa Bay, smolt abundance is estimated by using the identified correlates and extrapolating information from neighboring or comparable watersheds. For the Willapa Bay management unit, information comes from the neighboring Grays Harbor coho population to the north.

Marine survival rate is defined as proportion of smolts that survive after passing the smolt trap through the ocean rearing phase to the point that harvest begins. Marine survival rate of a given cohort is measured by summing adult coho harvest and spawner escapement then dividing by smolt production. Harvest of wild coho is measured by releasing a known number of coded-wire tagged wild coho smolts and compiling their recoveries in coastwide fisheries. Coastwide recoveries are compiled from the Regional Mark Processing Center database (www.rpmc.org). Tags detected in returning adults (spawners) are enumerated at upstream trapping structures. Results from these monitoring stations are correlated with ecological variables from the marine environment to describe patterns in survival among years and watersheds. The identified correlations are used to predict or forecast marine survival of wild coho cohort for a given year.

Forecasting Methods

Converting Chehalis Smolt Density to Willapa Smolt Density

Unknown wild coho smolt production estimates for Willapa Bay (drainage area = 850 mi^2) are derived from smolt counts in the Chehalis River (drainage area = 2,114 mi^2), a neighboring system which enters the Pacific through Grays Harbor. The Willapa Bay and Grays Harbor systems (Figure 1) are both characterized by low-gradient rivers with rain-driven hydrology. Grays Harbor tends to produce higher
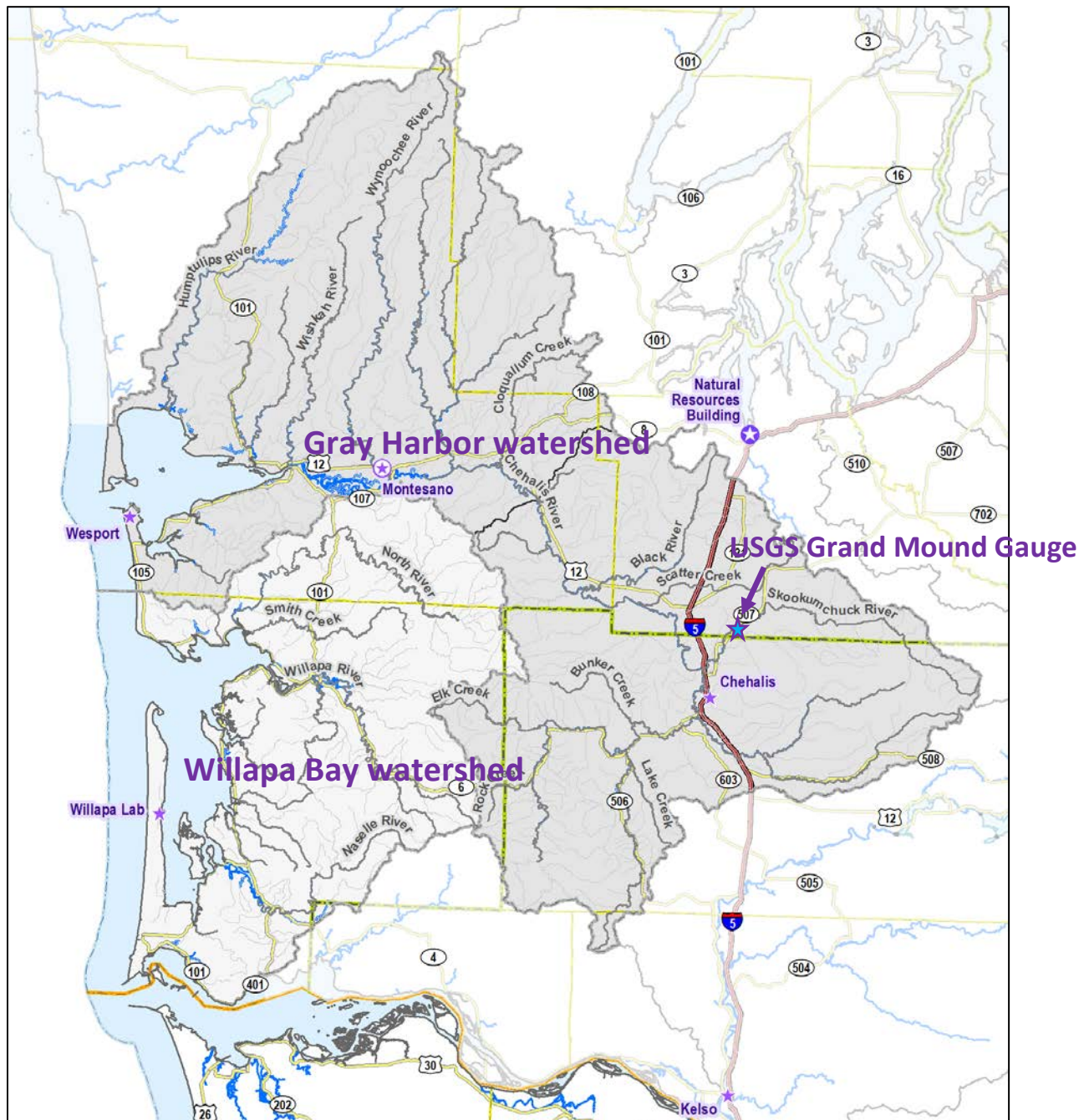

Figure 1. Watersheds of Willapa Bay and Grays Harbor in Southwest Washington State.

densities of smolts (fish/mi^2) than other higher-gradient coastal systems where smolt production is measured, such as the Quillayute (Zimmerman et al. 2015). However, Willapa Bay has more degraded habitat than the Chehalis, thus it is assumed that smolt production is lower in Willapa Bay than the Chehalis Basin, even though smolt production estimates for that system are not available. In previous WDFW forecasts, Willapa Bay smolt density was determined qualitatively in each year based on an assessment of freshwater habitat quality, harvest rates, and escapement in comparison to the Chehalis Basin. For smolt ocean entry years 1998 to 2018, estimated Willapa Bay smolt production averaged 69% of the production in the Chehalis Basin (Table 1). A summary of smolt density scalars used to determine smolt density in Willapa Bay relative to the Chehalis Basin (ocean entry years 2003 to 2019; Table 2) will be applied to the Willapa Bay wild coho forecast in 2020. By comparison, the average wild adult coho runsize in Willapa Bay from 1999-2018 has also been 72% that of the Chehalis Basin wild adult coho return (Table 3).

Table 1. Estimated smolt density calculated for the Chehalis River based on relationships between freshwater rearing flows, and estimated smolt density applied to the Willapa Bay population for ocean entry year (OEY) 1998-2019 (source = WDFW Science Division Wild Coho Forecasts for Puget Sound, Washington Coast, and Lower Columbia 1999-2020).

OEY	Chehalis Estimate	Chehalis smolts/mi^2	Willapa smolts/mi^2	Willapa Estimate
1998	2,857,000	1,351	500	425,000
1999	500,000	237	200	170,000
2000	2,000,000	946	400	340,000
2001	1,817,000	860	500	425,000
2002	1,696,000	802	700	595,000
2003	1,978,000	936	700	595,000
2004	1,411,000	667	500	425,000
2005	1,978,000	936	700	595,000
2006	1,945,813	920	700	595,000
2007	1,638,863	775	600	510,000
2008	1,523,860	721	600	510,000
2009	1,693,985	801	600	510,000
2010	1,880,626	890	600	510,000
2011	2,639,487	1,249	800	680,000
2012	2,414,885	1,142	800	680,000
2013	2,134,405	1,010	700	595,000
2014	2,756,604	1,304	850	722,500
2015	2,875,301	1,360	850	722,500
2016	2,445,340	1,157	800	680,000
2017	2,986,880	1,413	900	765,000
2018	2,453,370	1,161	800	680,000
2019	2,053,869	972	700	595,000

Observed Smolt Abundance: Back-Calculation

Natural-origin, or wild smolts emigrating from the Chehalis River have been monitored by WDFW since the late 1970s at two trapping locations located on the main stem Chehalis River (river mile RM 52) and Bingham Creek, right bank tributary to the East Fork Satsop River at RM 17.4 (Figure 2). Wild coho smolt abundance in the Chehalis Basin is estimated when juveniles tagged as smolts are re-captured as adults as they recruit to the fishery. Trapping methodology for the Chehalis mainstem is described in detail in Winkowski and Zimmerman (2019). Wild origin smolts are coded-wire tagged and released from the juvenile traps. In each year, the total number of tagged fish at each location is recorded. The number of tagged fish is scaled down to account for tagging mortality (mortality rate = 16%) and tag retention (tag retention rate = 96%; Blankenship and Hanratty 1990). To back-calculate smolt abundance, tag groups are expanded to a basin-wide smolt abundance based on the recaptures of tagged and untagged wild coho in the Grays Harbor terminal net fishery when adult coho recruit to the fishery. Tagged jacks (male coho returning to freshwater after spending just a few months at sea) are intercepted in the same year as ocean entry whereas tagged adults are intercepted the following year. Coded-wire tag recoveries in this fishery are processed and reported by the Quinault Tribe (Jim Jorgenson, Quinault Division of Natural Resources, personal communication).
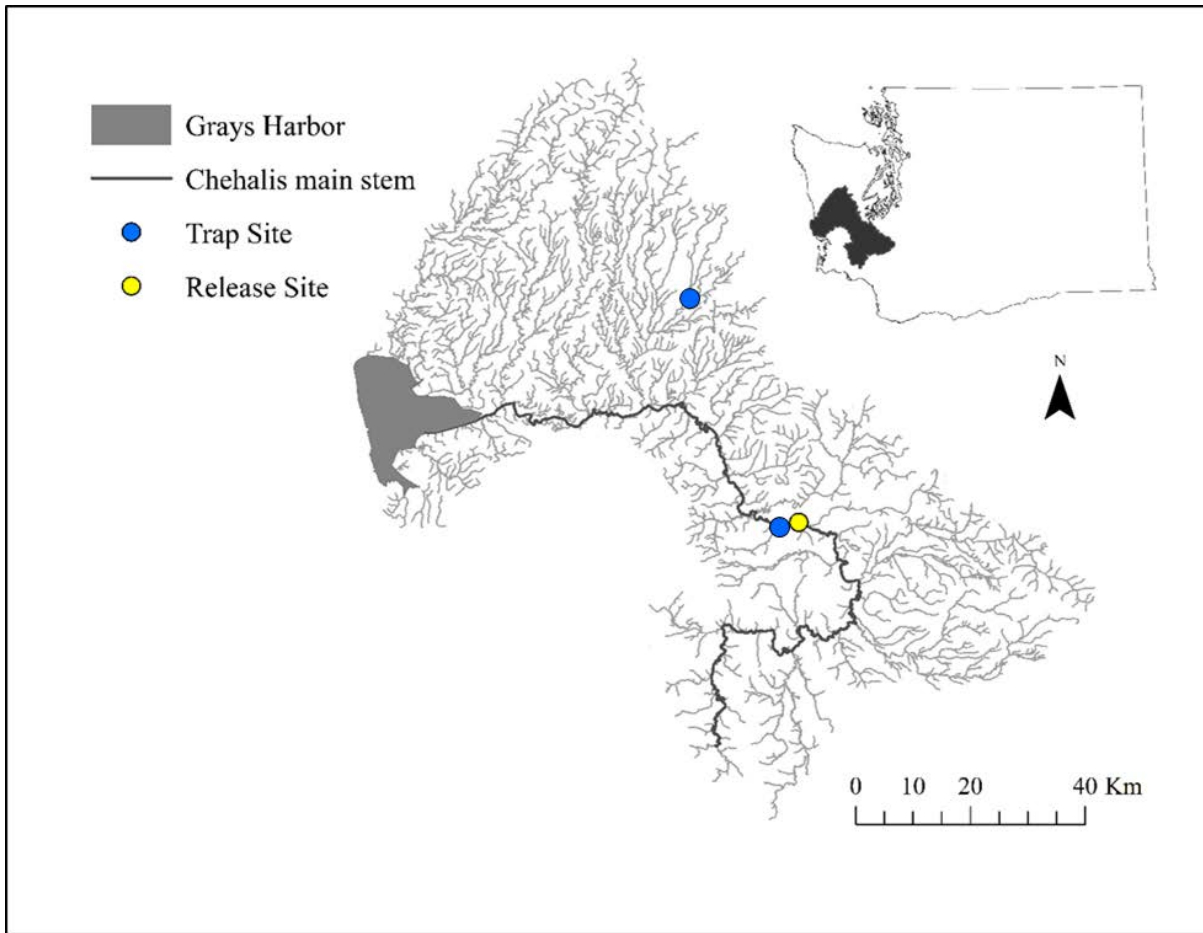
Figure 2. Location of the Bingham Creek and Chehalis River smolt traps (blue dots) and release site (yellow dot) for marked fish tagged at the mainstem trapping location in the Chehalis River, Washington (map generated by J. Winkowski).

Table 2. Bins used to scale smolt density estimated in the Chehalis River to Willapa Bay for WDFW Science Division forecasts (ocean entry year 2003-2019). Note that in previous forecasts, years 1998 and 2000-2002 did not adhere to the scalars shown below.

Chehalis Smolt Estimate	Willapa Smolt Estimate
<200	100
200<300	200
300<400	300
400<500	400
500<700	500
700<900	600
900<1,100	700
1,100<1,300	800
1,300<1,400	850
≥1,400	900

Table 3. Comparison, the average wild adult coho runsize in Willapa Bay to that of the Chehalis Basin from 1999-2018.

Return Year	Willapa Bay NORs	Grays Harbor NORs	WB NOR/GH NOR
1999	11,593	33,816	34%
2000	28,037	37,737	74%
2001	65,679	60,797	108%
2002	83,598	89,535	93%
2003	75,557	81,903	92%
2004	48,385	61,087	79%
2005	41,754	42,751	98%
2006	23,637	20,263	117%
2007	19,247	26,341	73%
2008	25,592	40,056	64%
2009	89,413	77,045	116%
2010	76,321	105,771	72%
2011	48,355	72,587	67%
2012	34,686	97,434	36%
2013	32,023	73,293	44%
2014	71,939	135,774	53%
2015	14,480	28,716	50%
2016	32,920	31,106	106%
2017	13,601	32,490	42%
2018	16,209	52,358	31%
		Average ratio WB/GH	72%

Total smolts produced from the Chehalis River Basin between ocean entry years 1998 – 2018 averaged 2,337,483 (range from 555,538 and 3,769,789; Table 4). This abundance is derived via back-calculation using the proportion of tagged to untagged wild coho caught in the Grays Harbor terminal fishery and reported by the Quinault Tribe.

Observed Smolt Abundance = Total Juvenile Tags / (Tagged Catch/Total Catch)

In each year, the Quinault Tribe reports the total number of harvested wild adult coho and total number of wild tags recovered from the fishery. Assuming a sampling rate of 30% (J. Jorgenson, Quinault Tribe, personal communication), the number of observed wild tags is expanded to the entire catch of wild coho and a proportion of tagged adults is determined by dividing the number of wild tagged adults by the total catch of wild coho. Next, the proportion of tagged adults is used to back-calculate total smolt abundance for each ocean entry year by dividing the total number of tagged smolts in each ocean entry year by the proportion of tags recovered in the fishery in the following year. This value is used as the observed smolt abundance and reported with associated 95% confidence intervals calculated based on mark-recapture variance. For ocean entry years 1998 – 2018, the coefficient of variation for smolt abundance ranged from 2% to 24%.

Table 4. Back-calculated smolt abundance originating from the Chehalis Basin for each ocean entry year (OEY). Wild catch refers to the total number of wild coho captured by Quinault in the Grays Harbor terminal fishery. Wild tags refers to the number of wild coho caught in the Quinault fishery containing a tag from the smolt trapping operations in the Chehalis Basin. The proportion of tagged adults is the ratio of tagged to total wild coho catch. Total smolt abundance in the Chehalis Basin for each OEY is calculated by multiplying the proportion of tagged adults by the number of tagged smolts.

OEY	Wild Catch	Wild Tags	Proportion of Tagged Adults	Number of Tagged Smolts	Total Smolts	CV
1998	4,806	181	3.8%	82,791	2,198,298	7%
1999	4,594	292	6.4%	35,311	555,538	5%
2000	3,359	214	6.4%	89,763	1,408,940	6%
2001	4,847	131	2.7%	55,558	2,055,636	8%
2002	5,334	101	1.9%	64,174	3,389,156	9%
2003	9,019	377	4.2%	87,002	2,081,367	5%
2004	8,395	441	5.3%	72,882	1,387,410	4%
2005	3,627	55	1.5%	45,852	3,023,725	12%
2006	3,245	116	3.6%	40,390	1,129,880	9%
2007	3,733	117	3.1%	51,489	1,642,821	9%
2008	10,499	96	0.9%	19,049	2,083,262	7%
2009	12,978	170	1.3%	35,739	2,723,180	6%
2010	15,465	178	1.2%	31,467	2,733,876	5%
2011	22,581	361	1.6%	60,242	3,769,789	4%
2012	13,819	235	1.7%	50,564	2,973,361	5%
2013	35,445	653	1.8%	47,913	2,600,733	2%
2014	6,938	74	1.1%	27,506	2,578,902	10%
2015	612	12	2.0%	29,859	1,522,828	24%
2016	3,688	18	0.5%	15,771	3,231,254	18%
2017	4,390	22	0.5%	13,577	2,709,300	16%
2018	4,828	60	1.2%	40,860	3,287,891	12%

Estimated Smolt Abundance: Relationship Between Observed Abundance and River Flow

Grays Harbor

Smolt abundance estimates from the mark-recapture method are not available in the year that coho recruit into the fishery; therefore, the run size forecasts are based on a modeled smolt estimate. In previous forecasts, predictive models explored flow metrics associated with spawning, incubation, and rearing flows as measured at USGS gage #12027500, Grand Mound (Seiler 2005; Zimmerman 2015) (Figure 1). These relationships are biologically relevant, but the strength of their predictability has depended on the time period used for analysis. For ocean entry year 2019, the current predictive model includes metrics of maximum summer rearing flows in August and average overwinter rearing flows December to February (Figure 3).
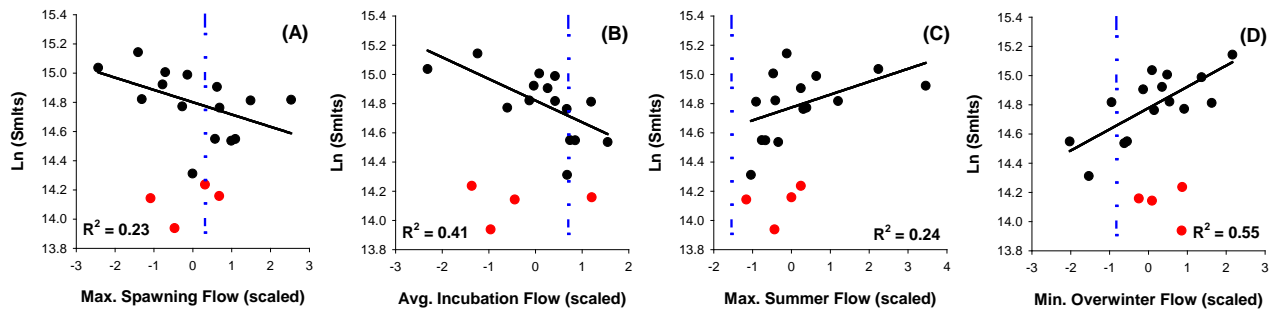
Figure 3. Chehalis River wild coho smolt production as a function of spawning flows (a), incubation flows (b), summer flows (c), and overwinter rearing flows (d) for ocean entry year 2000-2019 as measured at USGS gage #12027500 in Grand Mound. Spawning flows are maximum flows measured October 1 to December 31. Incubation flows are the cumulative daily mean flows between December 1 and March 1. Summer rearing flows are maximum daily flows in the month of August. Overwinter rearing flows are minimum daily flows between November 1 and February 28. Four data points were removed (OEY 2000, 2004, 2006, and 2015) because of high leverage on the flow regressions (shown in red). Vertical blue dashed line indicates the conditions associated with the 2019 ocean entry year.

The relationship between smolt abundance and flow was evaluated using multiple regression. Flow metrics were generated for the relevant time periods (spawning, incubation, summer rearing, and overwinter) and scaled to a mean of zero and standard deviation of one. Individual linear regression models were used to examine relationships between scaled flow regimes and natural log-transformed smolt abundances. The current analysis was limited to ocean entry years 2000 through 2019 and four years were identified as outliers during this time period (2000, 2004, 2006, and 2015) due to high leverage across the flow metrics. The outlier years were identified by observing residual plots and evaluating Cook's distances. Individual variables that were determined to be significant predictors of survival ($\alpha = 0.10$) were combined into a multiple regression model to forecast smolts for the 2019 ocean entry year. When correlations among variables were high ($R > 0.7$), only one of the correlated variables was used in the multiple regression.

Est. Smolt Abundance = exp(intercept + [slope*scaled Max. Sum. Flow] + [slope*scaled Min. OW Flow])

Multiple regression models predicting natural log-transformed smolt abundance based on flow regimes were ranked using corrected Akaike's Information Criterion (AIC_c) to account for low sample size. A backwards stepwise regression process compared nested multiple regression models (one model compared to the same model with one variable missing) using a likelihood ratio test until the inclusion of all variables significantly ($\alpha = 0.10$) improved the prediction of smolt abundance. Predicted smolt abundance for the 2019 ocean entry year was provided as a median and 95% confidence intervals from the selected multiple regression model. All analyses were completed in the R platform (R Core Team 2019).

In the 2019 ocean entry year, coho smolts were associated with average spawning and incubation flows, and lower than average summer rearing and overwinter flows as measured at USGS gage #12027500, Grand Mound (Figure 3). Chehalis 2019 smolt production was predicted to be 2,053,869 (1,807,605 – 2,333,683, 95% C.I.) based on the multiple regression model including summer and overwinter flows (Table 5). This prediction is 12% lower than the time series average of 2,337,483 wild coho smolts from 1998 to 2018. Spawning and incubation flows are also correlated with smolt production,

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however including these variables does not improve model fit and therefore they were not used in the predictive model. For the 2018 ocean entry year (2019 return), this model predicted a smolt abundance of 2,453,370 (2,148,445 – 2,801,573, 95% C.I.) which was lower than the mark-recapture estimate of 3,287,691 (2,536,564 – 4,039,218, 95% C.I.). Based on the estimated size of the Chehalis Basin (2,.114 mi^2), the smolt density in 2019 was predicted to be 972 (2,053,869 smolts/2,114 mi^2).

Table 5. Model ranks for flow-based predictions of smolt abundance in the Chehalis Basin in 2019 based on cumulative daily mean incubation flows between December 1 and March 1, maximum daily flows during the summer rearing period in August, and minimum daily overwinter rearing flows between November 1 and February 28 for ocean entry years 2000-2019 as measured at USGS gage #12027500 in Grand Mound. Years 2000, 2004, 2006, and 2015 were identified as outliers and removed from the analysis due to high leverage across individual regressions.

Model	K	AIC$_c$	ΔAIC$_c$	AIC Wt.	Cum. Wt.	LL
Max. Summer Flow + Min. Overwinter Flow	4	-9.66	0.00	0.38	0.38	10.83
Avg. Incubation Flow + Min. Overwinter Flow	4	-9.48	0.18	0.35	0.72	10.74
Avg. Incubation Flow + Max. Summer Flow + Min. Overwinter Flow	5	-7.97	1.70	0.16	0.89	12.32
Min. Overwinter Flow	3	-6.93	2.74	0.10	0.98	7.55

Converting 2019 Smolt Production Estimates in Chehalis Basin to Willapa Bay

A total of 595,000 coho smolts are estimated to have emigrated from the Willapa Bay basin in 2019. As smolt abundance was not directly measured, this estimate is based on smolt densities in the Chehalis Basin (972 smolts/mi^2 in 2019). The Willapa Basin consists of four main river systems and several smaller tributaries. Like Grays Harbor, rivers in the Willapa Bay management unit are low gradient with rain-dominant hydrology. But in comparison to Grays Harbor, Willapa Bay has a high harvest rate (limiting escapement) and degraded freshwater habitat which may result in lower wild coho smolt densities than observed in the Chehalis Basin. Wild coho production in 2019 (595,000 smolts) was calculated by applying a scaled down production rate of 700 smolts/mi^2 (72% of the smolt estimate in Chehalis Basin) to the total basin area (850 mi^2).

*Willapa Bay Smolt Abundance = 700 smolts/mi^2 * 850 mi^2*

Modeling Marine Survival

Marine survival of Willapa Bay coho was estimated in coastal Washington using Bingham Creek in Grays Harbor as a surrogate. Bingham Creek is a right bank tributary to the East Fork Satsop River at RM 17.4 where WDFW has a long-term wild coho monitoring program that began in the late 1970s. A full weir captures and passes all juvenile and adult wild coho, assuming a full census of the population. Marine survival is estimated based on the release and recovery of coded-wire tagged coho marked at Bingham Creek. All wild coho smolts are coded-wire tagged during the outmigration period and recaptured as jack (age-2) and adult (age-3) coho during fishery sampling and in upstream weir traps. The smolt tag group is adjusted downward by 16% for tag-related mortality and 4% for tag loss (Blankenship and Hanratty 1990).

Jack marine survival rate is the harvest (minimal to none) and escapement of tagged jacks divided by the adjusted number of tagged smolts. Adult marine survival is the sum of all tag recoveries (harvest + escapement) divided by the adjusted number of tagged smolts. Coast-wide tag recovery data were accessed through the Regional Mark Information System database (RMIS, www.rmpc.org/).

Marine Survival Rate = Total Return of Tagged Adults / Total Tagged Smolts

Variables Selected as Potential Indicators

Indices of North Pacific atmospheric conditions are broadly predictive of salmon marine survival (Beamish et al. 1999; Burke et al. 2013; Mantua et al. 1997) and multiple studies have demonstrated predictive correlations between physical conditions in the ocean (e.g., sea surface temperature, upwelling, spring transition timing) and coho marine survival (Logerwell et al. 2003; Nickelson 1986; Ryding and Skalski 1999). The WDFW Science Division estimates marine survival rate each year for coho management units through a process of model selection to forecast wild coho abundance. For coastal Washington stocks, salmon marine survival is positively correlated with salinity (high salinity = high survival) and negatively correlated with temperature (low temperature = high survival). Environmental variables that are predictive of marine survival represent physical and biological oceanographic processes that are captured at three spatial scales: ocean, regional, and local. Additional detail and data sources for marine variables explored in this forecast are provided in Appendix A.

At the "Ocean Scale," we applied indices provided by the NOAA NWFSC ocean monitoring research program (Peterson et al. 2014), including broad scale indices such as the Pacific Decadal Oscillation (PDO) and the Oceanic Nino Index (ONI). The PDO is based on patterns of variation in sea surface temperature in the North Pacific Ocean, demonstrated to vary on the order of decades (Mantua et al. 1997). The ONI is based on conditions in equatorial waters that result from the El Niño Southern Oscillation. El Nino conditions result in the transport of warm water northward along the coast of North America and have variable effects on Washington coastal waters. The North Pacific Gyre Oscillation (NPGO) is an indicator of salinity and nutrients in the areas of the North Pacific Ocean (DiLorenzo et al. 2008) and is correlated with marine survival of coho salmon in Oregon coastal rivers (Rupp et al. 2012). The PDO and NPGO index were represented by prior winter (January to March) and ocean entry (May to September) time periods. The ONI was represented by a single time period (January to June) representing the ocean entry year.

At the "Region Scale," we applied a set of pre-developed indicators to the Washington coast. Regional indicators for the Washington coast include temperature and salinity data as well as zooplankton and juvenile fish indices compiled and derived by the NWFSC ocean monitoring research program. The biological indicators assess prey availability and prey quality for outmigrating smolts during early ocean residence. The basis for these indicators and their relationship to (primarily) Columbia River salmon is updated annually by NWFSC scientists (Peterson et al. 2014). We also include indicators that describe the physical Spring transition date from predominantly downwelling to upwelling conditions along the coast of Oregon and Washington, as well as indicators describing the length of the upwelling season and the monthly upwelling anomaly value. Upwelling timing and strength has been identified as a reliable predictor of coho marine survival (Logerwell et al. 2003).

At the "Local Scale", we applied indices of flow from the Chehalis River during the outmigration period (April to June). We also included an index of jack marine survival. Previous models found high

correlation between the marine survival of jacks and adults originating from the same brood year, however, those relationships have become unreliable in recent years (Rupp et al. 2012; Zimmerman et al. 2015).

Statistical Analyses

Linear regression models were used to examine the relationships between marine survival and marine environmental variables for the Grays Harbor management unit. Marine survival estimates for the 2018 ocean entry year (2019 return) are preliminary, however all other marine survival estimates are considered final (1998 to 2018). Final estimates of tagged catch for Chehalis coho are typically reported in RMIS one year after the conclusion of the fishery. Marine survival estimates for return years 2014-2018 (ocean entry years 2013 to 2017) were updated prior to completing the 2020 forecast. Linear models were fit with a beta distribution appropriate for modeling survival data (ratio with range between 0 and 1). For 2020, the analysis was limited to ocean entry years 1998-2019 to align survival estimates with available time series for indicator datasets. This date range also corresponds to the ecosystem conditions following the described regime shift for the northeast Pacific ecosystem in 1998 (Overland et al. 2008; Peterson and Schwing 2003). Predictor variables were scaled to a mean of zero and standard deviation of one prior to conducting the multiple regression. Individual linear regressions were used to identify variables that were significant predictors of survival (α = 0.10), which were combined into a multiple regression model to forecast survival of smolts for the 2020 return (2019 ocean entry year). When correlations among variables were high ($R > 0.7$), only one of the correlated variables was used in the multiple regression.

A backwards stepwise regression process compared nested multiple regression models (one model compared to the same model with one variable missing) using a likelihood ratio test until the inclusion of all variables significantly (α= 0.10) improved the prediction of marine survival. Fit of the multiple regression model was evaluated with a leave-one-out cross validation. A plot of the observed versus predicted (estimated) values from the cross-validation was visually inspected. Model evaluation statistics including mean raw error (MRE), mean absolute error (MAE), raw mean square error (RMSE), mean percent error (MPE), and mean absolute percent error (MAPE) were derived for each multiple regression model (Haeseker et al. 2008) and were used to evaluate competing models (when predictor variables were highly correlated and could not be combined into a single predictive model). These statistics may also be useful as common metrics to compare the predicted marine survivals in this forecast with alternate models derived by other scientists or managers during the finalization of forecasts for the 2020 return. Predicted marine survival for the 2020 return year (2019 ocean entry year) was provided as a median and 90% confidence intervals from the selected multiple regression model. Predictions were compared for regression model with and without outlier years to determine the sensitivity of the analysis to any outlier survival years.

2020 Natural Coho Forecast

Marine survival of wild coho in the coastal Washington region is measured at Bingham Creek, a tributary to the East Fork Satsop River (a right bank tributary to the Chehalis River). Marine survival of Bingham Creek wild coho has averaged 4.6% (range 1.5% to 10.2%) between ocean entry years 1998 and 2018 with no apparent trend over this time period (Table 6 and Figure 4). It should be noted that the estimate of marine survival for 2019 (2018 ocean entry year) is preliminary and dependent upon updated tagged catch estimates input into the RMIS database. For this forecast, updated RMIS values were used

to adjust the marine survival estimate for smolts outmigrating in 2013-2017. These values are not anticipated to change.

Table 6. Marine survival of Bingham Creek wild coho by ocean entry year 1998 – 2018. Trapping operations assume full census of wild coho production above the trapping site. Estimates of tagged returns are reported in the Regional Mark Information System. The total run is a sum of harvest and return. Marine survival is calculated by dividing the total tagged run by the total number of tagged juveniles.

OEY	Tagged Juveniles	Estimated Tagged Catch			Tagged Return	Total Tagged Run	Marine Survival
		Ocean	Harbor	Sport			
1998	36,154	50	97	0	903	1,050	2.9%
1999	11,608	13	189	11	908	1,120	9.7%
2000	42,871	33	82	54	2,165	2,334	5.4%
2001	33,175	28	99	10	1,698	1,835	5.5%
2002	21,060	3	40	10	862	915	4.3%
2003	25,394	6	70	10	450	536	2.1%
2004	18,450	11	88	4	581	684	3.7%
2005	26,697	11	28	5	360	404	1.5%
2006	17,938	14	27	5	452	498	2.8%
2007	20,172	7	25	5	429	466	2.3%
2008	16,165	12	86	29	1,528	1,655	10.2%
2009	27,350	6	128	61	1,905	2,100	7.7%
2010	22,771	39	168	32	1,324	1,563	6.9%
2011	44,596	155	343	52	1,730	2,280	5.1%
2012	34,172	70	116	27	631	844	2.5%
2013	31,114	80	530	108	1,728	2,446	7.9%
2014	19,124	5	53	0	281	339	1.8%
2015	21,624	22	15	0	724	761	3.5%
2016	15,771	46	22	0	525	593	3.8%
2017	7,591	1	22	0	301	324	4.3%
2018	23,409	5	60	0	650	715	3.1%

The final model selected for forecasting included two variables – PDO index between May and September of ocean entry, and timing of the hydrographic physical Spring transition from predominantly downwelling to upwelling conditions (Table 7). Higher survival was associated with lower PDO values (i.e., cooler ocean temperatures) and an earlier physical Spring transition date. Winter ichthyoplankton biomass was also predictive of marine survival but was highly correlated with the PDO index between May and September. An alternative model including winter ichthyoplankton and physical Spring transition date was included in the set of models but performed more poorly by all model evaluation criteria. Another model was fit using axis 1 scores from a Principle Component Analysis of salmon ocean indicators generated by the NWFSC (PC1). This index reduces a set of correlated indicators into one value representative of the ecosystem.

The selected multiple regression model predicted a 3.0% (1.2% to 6.0%, 90% C.I.) marine survival for the 2020 return year (2019 ocean entry year). Based on these results, a marine survival of 3.0% was applied to the Willapa Bay management unit (Table 7). The total return of ocean age-3 (OA3) wild coho in 2020 is 17,850 (595,000 smolts * 3.0% marine survival). To adjust for January age-3 recruits to provide

appropriate inputs for the coho Fishery Regulation Assessment Model (FRAM) used bilaterally for fisheries planning, an expansion factor of 1.23 was applied to the forecast to account for natural mortality. The forecasted abundance of January age-3 coho originating from Willapa Bay is therefore 21,986 (17,850 * 1.23).

*Table 7. Model evaluation statistics for multiple regression models used to predict marine survival (MS) of wild coho salmon from Bingham Creek. Model was developed and evaluated for 1998-2019 ocean entry years (OEY). Variables include PDO.MS (PDO index May to September of ocean entry), Phys.Trans (day of the year representing the hydrographic physical Spring transition from predominantly downwelling to upwelling conditions during ocean entry), NPGO.JM (NPGO index January to March prior to ocean entry), and the Principle Components Axis 1 (PC1), an annual value summarizing all of the ocean indicators developed by the NWFSC. Model evaluation statistics are shown for each model. **Model selected for 2020 forecast is in blue text**.*

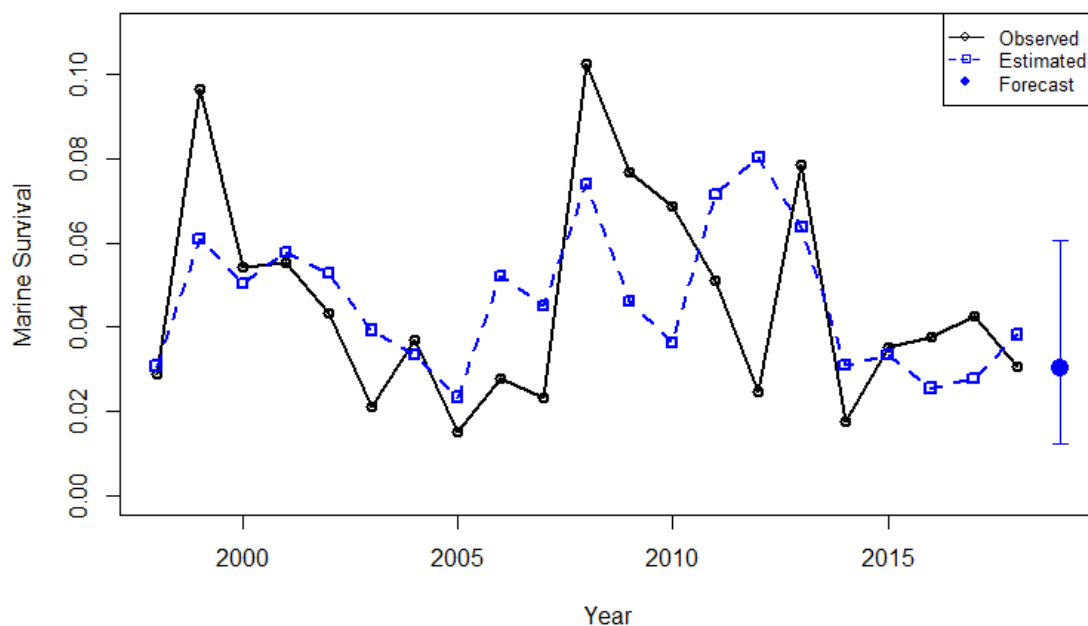| Model	MRE	MAE	RMSE	MPE	MAPE	Forecasted Marine Survival (2019 OEY)
MS ~ PDO.MS + Phys.Trans	-0.0002	0.0172	0.0218	-22.0%	46.7%	0.0304
MS ~ PDO.MS + Phys.Trans + NPGO.JM	-0.0004	0.0177	0.0218	-20.8%	46.5%	0.0250
MS ~ Wint.Ichthyo + Phys.Trans	0.0002	0.0190	0.0227	-21.6%	49.3%	0.0311
MS ~ PC1	0.0004	0.0186	0.0223	-24.7%	52.8%	0.0337

Bingham Creek (Grays Harbor)

Figure 4. Marine survival of wild coho from Bingham Creek, Washington, ocean entry year 1998 to 2019. Black solid line shows observed marine survival. Blue dashed line shows marine survival estimated by leave-one-out (jackknife) cross validation. Solid blue point is the forecasted marine survival (±90% C.I) for the 2019 ocean entry year (2020 return year).

Model Evaluation

Willapa Bay Hindcasted Smolt Abundance

We used cross validation to hindcast smolt abundance and marine survival for the Willapa Bay wild coho management unit (ocean entry years 2000 to 2018) using the forecasting methodology proposed for 2020 (Table 8). This exercise was completed in two steps, generating a hindcast of Willapa Bay wild coho abundance through time. For the first step, smolt abundance in the Chehalis Basin was estimated using a leave-one-out cross validation (jackknife) based on the multiple regression model that took the form:

Log smolts ~ Maximum Summer Rearing Flow + Minimum Overwinter Flow;

where log smolts is the natural-log transformation of smolts determined from mark-recapture in the Chehalis Basin, maximum summer rearing flows are maximum daily flows measured for the Chehalis River (USGS gage #12027500 in Grand Mound) for the month of August (scaled to a mean of 0 and standard deviation of one), and overwinter rearing flows are minimum daily flows for the Chehalis River between November 1 and February 28 (scaled to a mean of 0 and standard deviation of one) for ocean entry years 2000 to 2018. For the hindcasting exercise, flow values from outlier years (2000, 2004, 2006, and 2015) were not included in the predictive model. Log-transformed smolt abundance was back-

transformed and estimated smolt abundance converted to smolt density in the Chehalis basin by dividing by the area of the Chehalis basin (2,114 mi^2). Next, to determine smolt density in Willapa Bay, the Chehalis smolt densities were scaled downwards using criteria defined in Table 2. Finally, smolt abundance in Willapa Bay was estimated by multiplying estimated smolt density in Willapa Bay by the area of the basin (850 mi^2). Over the time series (2000 to 2018 ocean entry years), estimated Willapa Bay smolt density averaged 811 smolts/mi^2 (range 600 to 900 smolts/mi^2). Notably, estimated Willapa smolt densities varied little from smolt densities estimated in previous forecasts, despite the use of different methodologies through time.

Willapa Bay Hindcasted Marine Survival

The second step in hindcasting Willapa Bay wild coho abundance (ocean entry years 2000 to 2018) estimated marine survival through time. For this, we used the Chehalis Basin wild coho population as a surrogate for Willapa Bay. Marine survival of wild coho smolts originating from the Chehalis was estimated using leave-one-out cross validation (jackknife) based on the multiple regression model that took the form:

Marine Survival ~ PDO + Physical Spring Transition Date;

where marine survival is the smolt to adult ratio of wild coho returning to Bingham Creek in Grays Harbor, PDO represents the Pacific Decadal Oscillation index May to September of ocean entry (scaled to a mean of zero and standard deviation of one), and physical Spring transition date represents day of the year when the hydrography transitions from predominantly downwelling to upwelling conditions along the coast of Oregon and Washington (scaled to a mean of zero and standard deviation of one). The hindcast values for marine survival of wild coho from the Grays Harbor management unit averaged 4.6% (range 2.3% to 8.30%) over the time series. Throughout the time series, we assumed that marine survival rates were the same in Willapa Bay as they were in Grays Harbor.

Willapa Bay Hindcasted Abundance

The hindcast of Willapa Bay wild coho using the proposed forecasting methodology in 2020 produced an average estimate of abundance of 31,770 (range 17,595 to 55,080) for ocean entry years 2000 to 2018 (return years 2001 to 2019; Table 8). By comparison, actual run sizes averaged 44,314 (range 13,616 to 89,413) over this time period. Complete details on run reconstruction methodology for the Willapa Bay wild coho population for the determination of actual abundance can be found in Appendix B.

Table 8. Hindcast smolt production and marine survival for Willapa Bay wild coho ocean entry year (OEY) 2000 to 2018 and prediction for OEY 2019. Smolts in the Chehalis were hindcast using a jackknifed predictive multiple regression model with summer and overwinter rearing flows in the Chehalis River as covariates. Next, Chehalis smolt densities were determined by dividing the smolt estimate by 2,114 mi2. Then, Chehalis smolt densities were scaled to Willapa Bay smolt densities using scalars defined in Table 2. Willapa smolt abundance was determined by multiplying the Willapa smolt density by 850mi2. Hindcast marine survival was estimated for the Chehalis wild coho population from a jackknifed predictive multiple regression model with PDO (Pacific Decadal Oscillation index values May to September) and physical Spring transition dates as covariates, then applied directly to the Willapa Bay wild coho management unit.

OEY	Hindcast Smolt Production Chehalis	Hindcast Smolt Density Chehalis	Estimated Smolt Density Willapa	Estimated Smolts Willapa	Hindcast Marine Survival
2000	2,487,392	1,177	800	680,000	5.0%
2001	2,305,652	1,091	700	595,000	5.8%
2002	3,066,935	1,451	900	765,000	5.3%
2003	1,859,915	880	600	510,000	3.9%
2004	2,392,756	1,132	800	680,000	3.3%
2005	3,471,424	1,642	900	765,000	2.3%
2006	2,798,775	1,324	850	722,500	5.2%
2007	1,935,402	916	700	595,000	4.5%
2008	2,258,083	1,068	700	595,000	7.4%
2009	2,467,311	1,167	800	680,000	4.6%
2010	2,685,706	1,270	800	680,000	3.6%
2011	3,420,094	1,618	900	765,000	7.2%
2012	2,569,913	1,216	800	680,000	8.0%
2013	2,997,984	1,418	900	765,000	6.4%
2014	2,682,500	1,269	800	680,000	3.1%
2015	2,946,308	1,394	850	722,500	3.3%
2016	3,245,321	1,535	900	765,000	2.6%
2017	3,002,901	1,420	900	765,000	2.8%
2018	2,654,254	1,256	800	680,000	3.8%
2019	2,053,869	972	700	595,000	3.0%

Model Comparison

Three models forecasting Willapa Bay wild coho run sizes were compared for return years 2011 to 2019 (ocean entry years 2010 to 2018). The models were **(1)** the proposed methodology for the 2020 forecasted return based on smolt production and marine survival, **(2)** recent (average 3-year) returns, and **(3)** long-term (average 10-year) returns (Table 9). For each forecasting approach, we evaluated differences between observed and predicted run sizes and used forecasting error to generate five statistics (MRE, MAE, RMSE, MPE, and MAPE) to rank model performance among the three candidate models (Haeseker et. al. 2008).

Table 9. Comparison of actual run size of ocean age-3 wild coho from the Willapa Bay management unit for run years 2001 to 2019 (ocean entry years OEY 2000 to 2018) and predictions for 2020 run size based on the proposed methodology (marine survival estimate), recent-year returns (3-year average), and longer term returns (10-year average).

OEY	Return Year	Actual Return	Marine Survival Estimate	Recent (3-yr) Average Estimate	Long-Term (10-yr) Average Estimate
2000	2001	28,037	34,000	--	--
2001	2002	65,679	34,510	--	--
2002	2003	83,598	40,545	--	--
2003	2004	75,557	19,890	59,105	--
2004	2005	48,385	22,440	74,945	--
2005	2006	41,754	17,595	69,180	--
2006	2007	23,637	37,570	55,232	--
2007	2008	19,247	26,775	37,925	--
2008	2009	25,592	44,030	28,213	--
2009	2010	89,413	31,280	22,826	--
2010	2011	76,321	24,480	44,751	50,090
2011	2012	48,355	55,080	63,776	54,918
2012	2013	34,686	54,400	71,363	53,186
2013	2014	32,023	48,960	53,121	48,295
2014	2015	71,939	21,080	38,355	43,941
2015	2016	14,481	23,843	46,216	46,297
2016	2017	32,951	19,890	39,481	43,570
2017	2018	13,616	21,420	39,790	44,501
2018	2019	16,703	25,840	20,349	43,938
2019	**2020**	**--**	**17,850**	**21,090**	**43,049**

The proposed model (smolt abundance * marine survival) for the 2020 Willapa Bay forecast had the least error over the 2010-2018 ocean entry years (2011 to 2019 return years) and ranked more highly than alternative models based on recent or long-term averages. Overall, the selected model overpredicted run size by 13.6% during this time period, which was better than the recent-year model, that overpredicted Willapa wild coho by 63.2%, or the long-term model that overpredicted run size by 76.3% (Table 10). The marine survival model was more sensitive to interannual variability in run size, presumably because it captured some of the variation related to marine survival (Figure 4.). In decreasing order of model performance, it was determined that the proposed marine survival model ranked first, despite being based on empirical observations in neighboring Grays Harbor, the recent-year model ranked second, and the longer-term model ranked last. Based on this assessment, the marine survival forecast is recommended for the Willapa Bay wild coho forecast in 2020.

Table 10. Model evaluation statistics (mean raw error, MRE, mean absolute error, MAE, raw mean square error, RMSE, mean percent error, MPE, and mean absolute error, MAPE) and mean ranks based on comparison of model evaluation statistics across models for run years 2011 to 2019. Each model evaluation statistic was ranked in increasing order from lowest to highest value and the mean rank represents average rank from the five model evaluation statistics.

Model Evaluation 2011-2018	Marine Survival	Recent Average	Long-Term Average
MRE	5,120	-8,459	-9,740
MAE	20,605	22,937	21,791
RMSE	26,662	25,606	23,435
MPE	-13.6%	-63.2%	-76.3%
MAPE	53.2%	82.7%	92.5%
Mean Rank	1.4	2.2	2.4
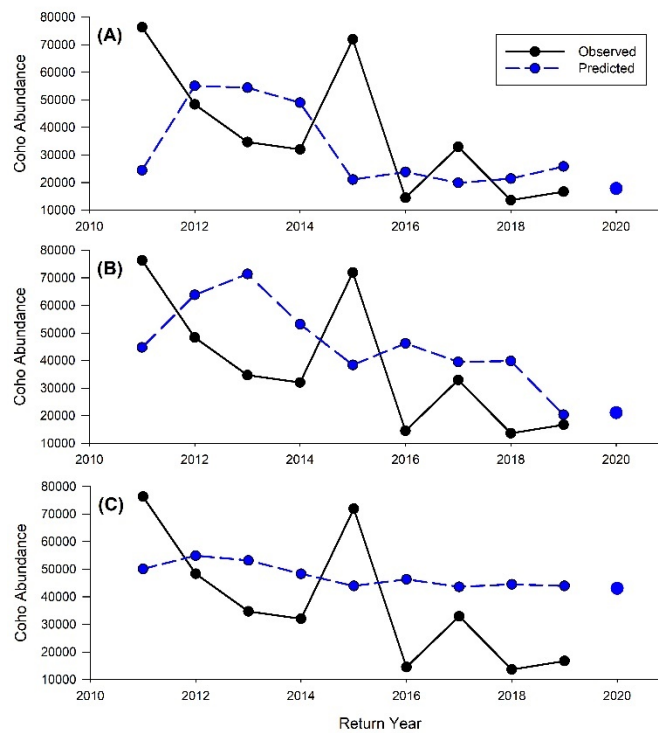
Figure 5. Actual and predicted abundance of wild Willapa Bay coho, return year 2011 to 2020 (ocean entry year 2010 to 2019). Black solid line shows observed abundance of Willapa Bay wild coho. Blue dashed line shows abundance estimated by leave-one-out cross validation based on a marine survival model (A), or average 3-year (B), or average 10-year (C) returns. Solid blue point is the forecasted marine survival for the 2019 ocean entry year (2020 return year).

2020 Hatchery Coho Forecast

Similar to the natural (wild) coho forecast, the hatchery coho forecast is the product of marine survival rate estimated for wild coho and number of smolt released. Hatcheries in Willapa Bay use

"automatic electronic smolt counters" to enumerate smolts as they are released from the hatchery. There are three basic types of automatic counters, these are: resistive counters, optical counters, and hydroacoustic counters. Management biologists obtain the number of hatchery smolts released from Willapa Bay hatcheries from the RMIS database and verify that with hatchery staff.

Discussion

An accurate forecast of abundance is critical for the effective management of Willapa Bay wild coho. The proposed forecasting methodology for 2020 represents an approach that uses the best available science and has the least amount of error among candidate models. The proposed model produces an estimate of smolt abundance based on identified relationships between smolt abundance and rearing flows in the Chehalis Basin, a neighboring system to Willapa Bay. Scalars are used to convert estimated smolt density in the Chehalis Basin to Willapa Bay and smolt abundance in Willapa Bay is estimated by multiplying the smolt density to the watershed area. Next, marine survival of the smolts is estimated using a model parameterized with environmental covariates that are indicators of marine survival, again borrowed from Chehalis Basin. It is likely that wild coho from the Chehalis Basin (Grays Harbor management unit) and Willapa Bay management unit co-vary in terms of smolt production and marine survival, however these relationships have not been peripherally evaluated. There are opportunities for more research that could more fully explore these relationships, or to make empirical measurements of wild coho production from the Willapa Bay management unit that may improve forecast performance.

Smolt production of wild coho in the Willapa Bay management unit is not directly measured but could be estimated using a smolt trap. Smolt traps use mark-recapture of tagged smolts, with efficiency trials, to expand generate estimates of abundance (see Winkowski and Zimmerman 2019). Additional information, including run-timing, size, and age structure, can also be measured using smolt traps. Preliminary studies identified North River in Willapa Bay as a potential site for a smolt trap. Currently, there are no dedicated funds to support a smolt trap in Willapa Bay.

Marine survival of hatchery-origin (HOR) coho in Willapa Bay is reported for each ocean entry year based on mark-recapture of tagged hatchery smolts. Those values are processed and available through the Regional Mark Processing Center database and WDFW catch record card database (G. Marsden, WDFW Hatchery Evaluation Unit, personal communication). For ocean entry years 2003 to 2017, marine survival of coho smolts marked with a coded wire tag (CWT only) originating from the Forks Creek hatchery in Willapa Bay averaged 2.6% (range 0% to 10%). Over the same time period, marine survival for wild coho originating from Bingham Creek (Chehalis Basin) averaged 4.4% (1.5% to 10.2%). The correlation coefficient between the two populations was lower ($r = 0.34$) than the correlation coefficient between Forks Creek hatchery coho mark groups (adipose clip and CWT vs. CWT only; $r = 0.99$). Marine survival of wild coho in Willapa Bay may be more closely related to hatchery smolts in that management unit than wild smolts in Grays Harbor, but currently there is no information to evaluate this issue. In Grays Harbor, the correlation coefficient in marine survival for ocean entry years 2003 to 2017 between wild coho originating from Bingham Creek and hatchery smolts marked with a CWT only from Bingham hatchery is high ($r = 0.65$). Future forecasts in Willapa Bay may consider using hatchery marine survival rates, rather than Chehalis marine survival rates, to estimate marine survival.

In 2019, the Pacific Salmon Commission accepted a proposal for Southern Endowment Funds to build upon previous work forecasting wild coho in Washington (M. Zimmerman, Salmon Coast Partnership, D. Schindler and M. Scheurell, University of Washington). The proposed work is developing a new class of forecast models for Southern U.S. naturally spawning coho salmon management units that accounts for possible environmental and demographic effects on the proportion of jacks within cohorts. The approach uses spatially structured correlations in marine survival and population dynamics among stocks to share information extracted from the dynamic relationship between jack and adult marine survival (sibling relationship) with surrounding populations that lack information on jacks. Incorporating multiple sources of information, including sibling relationships (and environmental influences therein), spatial correlations in population dynamics, smolt outmigration estimates, and marine environmental indicators, has been shown to better capture uncertainty and lead to more reliable parameter estimates in fisheries assessment models (Maunder and Punt 2013).

The forecasting method presented for wild coho from the Willapa Bay management unit performs better than naïve models when evaluated over the last nine years. Forecasting approaches continue to be refined and improved as more information becomes available. Multiple regression models estimating marine survival are developed each year using environmental covariates, and then evaluated using cross validation to ensure that the best performing model is selected. The proposed forecast predicts a return of 17,850 OA3 wild coho to Willapa Bay in 2020, which is 4,760 above the natural spawning escapement goal of 13,090. If fisheries are approved for 2020, in-season update models based on catch-per-unit-effort (CPUE) replace pre-season forecasts for harvest management so that fishery managers can be responsive to changes between pre-season estimates and actual run size.

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Appendix A. Environmental indicators explored as predictors of coho salmon marine survival in populations of coastal Washington. Scale type is ocean (O), regional (R), or local (L), and physical (P) or biological (B). Expectations reflect *a priori* hypotheses about whether coho marine survival will be positively or negatively related to the indicator.

Type	Indicator	Expectation	Data Source
O/P	PDO (Dec-Mar)	-	NWFSC[1]
O/P	PDO (May-Sept)	-	NWFSC[1]
O/P	ONI (Jan-Jun)	-	NWFSC[1]
O/P	NPGO (Jan-Mar)	+	E. Di Lorenzo[2]
O/P	NPGO (May-Sept)	+	E. Di Lorenzo[2]
R/P	Physical Spring Transition Date	-	NWFSC[1]
R/P	Upwelling Anomaly (Apr-May) 45°N	+	NWFSC[1], PFEL[3]
R/P	Upwelling Length 45°N	+	NWFSC[1]
R/P	Sea Surface Temperature 46°N (May-Sept)	-	NWFSC[1]
R/P	NH05 20 m Temperature (Nov-Mar)	-	NWFSC[1]
R/P	NH05 20 m Temperature (May-Sept)	-	NWFSC[1]
R/P	NH05 Deep Temperature (May-Sept)	-	NWFSC[1]
R/P	NH05 Deep Salinity (May-Sept)	+	NWFSC[1]
R/B	Biological Spring Transition Date	-	NWFSC[1]
R/B	Copepod Richness Anomaly (May-Sept)	+	NWFSC[1]
R/B	N. Copepod Biomass Anomaly (May-Sept)	+	NWFSC[1]
R/B	S. Copepod Biomass Anomaly (May-Sept)	-	NWFSC[1]
R/B	Copepod Community (May-Sept)	-	NWFSC[1]
R/B	Winter Ichthyoplankton Biomass (Jan-Mar)	+	NWFSC[1]
R/B	Winter Ichthyoplankton Community (Jan-Mar)	+	NWFSC[1]
R/B	Juvenile Chinook Density (Jun)	+	NWFSC[1]
R/B	Juvenile Coho Density (Jun)	+	NWFSC[1]
L/P	River Flow (Apr-Jun)	+	USGS[4]
L/B	Jack Marine Survival	+	WDFW Science

[1]Ocean indicator data for the Pacific coast continental shelf were from ocean monitoring program

developed at the NOAA Northwest Fisheries Science Center, Newport, OR. Data available at:

https://www.nwfsc.noaa.gov/research/hottopics/salmon_forecasts.cfm
[2]Monthly NPGO indices are available at:
http://www.o3d.org/npgo/npgo.php

[3]Upwelling indices available at: https://oceanview.pfeg.noaa.gov/projects

[4]River flow data available at: https://waterdata.usgs.gov/nwis/uv?site_no=12027500

Appendix B. Run reconstruction methodology for Willapa Bay natural-origin coho.

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Overview of elements contributing to Runsize Reconstruction for Willapa Bay Coho

Willapa Bay coho salmon runsize reconstruction combines direct measures and estimates of abundance from a variety of sources to estimate the total number of coho salmon returning to Willapa Bay in a given run year. This accounting includes measures of harvest and estimates of harvest related incidental mortality as well as estimates of escapement (fish which have survived sources of mortality to both spawn naturally or return to hatcheries). The systems associated with calculating each of these is described below.

Willapa Bay coho are harvested in recreational and commercial fisheries from Alaska to California. The vast majority of harvest occurs in the terminal areas within the inland marine waters of Willapa Bay and its freshwater tributaries. These terminal area commercial and recreational fisheries are not mark-selective for hatchery-origin coho. Commercial and recreational fisheries in Pacific Fishery Management Council area waters are a combination of mark-selective and non-selective fisheries, as are those in northern water (collectively these are referred to as pre-terminal fisheries). Harvest of Willapa Bay origin coho in pre-terminal fisheries is estimated through recovery of micro-sized code-wire-tags (CWTs) which were implanted into the nasal cartilage of a portion of Willapa Bay hatchery-origin as juveniles. Sampling program in these pre-terminal fisheries are implemented by a number of international, state, federal, and tribal fisheries organizations and vary widely. All aspects of CWT marking, recovery and harvest estimation across these fisheries are coordinated and reported through the Regional Mark Processing Center (RMPC, https://www.rmpc.org/home.html). Nandor, 2010, provides a detailed "Overview of the Coded Wire Tag Program in the Greater Pacific Region of North America."

Non-Landed harvest related mortalities, commonly referred to as drop-out or drop-off, are accounted for by applying an associated mortality rate to the total encounters in commercial and recreational fisheries. The mortality rates used are those adopted by the Council's Salmon Technical Team

for use related to FRAM/TAMM models for coho salmon harvest management in Southern U.S. fisheries. The rates associated with these mortalities are applied to the catch in each fishery sector: PFMC commercial ocean troll, 5%; commercial marine net, 2%; PFMC, coastal marine, and freshwater recreational 5%.

Escapement is accounted for both in natural spawning areas and at fish hatcheries. The origin, hatchery or natural, is determined by the presence of externally identifiable or internal marks applied to hatchery origin coho. These are described in more detail later in the *Estimating Spawner Escapement*. Briefly, however, Willapa Bay hatchery-origin coho are "mass marked" by the removal of the adipose fin, a portion are also coded-wire tagged (referred to as a single index tag group); estimates of bad or missed clips is done at the hatchery prior to release. Another portion are CWT'ed and retain their adipose fin (referred to as a double index tag group or DIT); DIT groups are used by managers to represent wild or natural-origin coho in calculating harvest of wild coho occurring in non-selective fisheries.

Fishery Sampling

The Washington Department of Fish and Wildlife's Ocean Sampling Program (OSP) conducts dockside sampling of ocean recreational catch and samples commercial troll catch at commercial dealer locations from Neah Bay to Ilwaco Washington. Regional WDFW staff sample commercial net catch occurring in Willapa Bay at commercial dealer locations around Willapa Bay. Biological samples are collected from the various species of salmon landed and fish are assessed to determine origin (natural or hatchery; this process is described in greater detail later).

Catch Accounting

Recreational harvest - estimation of salmon catch in Washington ocean fisheries

Harvest of coho salmon occurs in both recreational hook and line and commercial fisheries. The WDFW Ocean Sampling Program (OSP) estimates total ocean recreational effort and catch by boat type (charter and private), port, catch area, and trip type (primary target species). Boat trip sampling is conducted randomly to generate estimates of catch for most ocean-caught species: salmon, rockfish and other groundfish, halibut, albacore, sharks, and cods. Estimates of released fish are also generated using angler interviews. Creel data are used exclusively in the ocean areas to estimate Washington recreational catch and effort. The ocean fisheries have been sampled by the WDFW since the early 1960's.

Sampling Methods

Field samplers are stationed in all major coastal access sites: Ilwaco, Chinook, Cape Disappointment State Park, Westport, La Push, and Neah Bay. All ports are monitored from May through September, with some sampling occurring during March, April, and October in some areas.

The OSP mainly uses a two-stage design for each port, with days constituting the primary sampling units (PSU) and boats within each sampled day as the secondary sampling units (SSU). Selection of days follows simple random procedures. Although sampling of boats is approximately systematic (e.g., every kth boat), the selection procedure is not exact and this stage is treated as simple random for estimation purposes. Each port is sampled a minimum of 4 to 5 days per week and days are stratified by weekend and weekday. Typically, all weekend days and holidays are sampled and the remaining available sampling

effort within a port is randomly assigned to the weekdays. Daily estimates are expanded over days within strata to produce weekly, monthly and annual estimates. Variations on this theme are employed when sampling the land-based fishery at the Columbia River North jetty; here, weekdays and weekend days are not distinguished.

Effort is measured in units of boat-trips and angler-trips, and on sampled days, is measured throughout the entire period of boat activity, i.e., from the time when the first boat leaves a port until the last boat returns. On a given sampling day, the total number of boats leaving or entering a port is counted. During periods of high effort, effort is measured through an exit count, where all boats exiting a port are counted throughout daylight hours. In Westport, this method includes boats exiting from Ocean Shores and all Grays Harbor launching sites. In Neah Bay, this method includes boats launching from the Snow Creek resort.

During periods of low effort, effort is measured through an entrance count: a count of all boats entering that marina. During an entrance count, boats that exited from Ocean Shores and other Grays Harbor launching sites are excluded from the Westport effort count; in Neah Bay, entrance counts include boats exiting from the Snow Creek resort.

The catch per boat is sampled through intercept surveys. Returning boats are systematically sampled at a minimum target rate of 20% within each boat type (charter and private). Every kth boat to enter the harbor is included in the sample regardless of size, mooring location, trip type, etc. The size of the sample (leading to the calculation of m) depends on the projected effort and the number of available samplers. Overall, the sampling rate in each port in a year averages over 50% for charter boats and over 40% for private boats.

Through year 2000, data collected from each sampled boat trip include target species, area fished, number of anglers, landed catch by species, released salmon by species, and other biological data. Beginning in 2001, data collected include released yelloweye and canary rockfish and beginning in 2002, releases of all marine fish by species were enumerated in the samples. Beginning in 2003, depth at which the majority of rockfish in the catch were hooked was added. Beginning in 2013, data were recorded on the use of descending devices by anglers targeting bottomfish; recorded data evolved such that by 2014, numbers of yelloweye and canary rockfish released using a descending device was added. In 2016, the Ocean Sampling Program transformed its data collection method from paper-based to electronic using Apple iPads and the iForms form-building platform.

Catch and Effort Estimation

The OSP generates preliminary estimates of catch and effort in-season to meet the demands of ocean fishery management. Catch estimates for quota fisheries (currently salmon and halibut) are generated weekly; catch estimates for all other species are generated monthly and provided to the RecFin database by the end of the following month. Final post-season catch and effort estimates for all species are generated by February 1 each year; these post-season estimates replace any existing in-season estimates.

OSP Estimated Stratum Totals (Primary Stage)

Combined (total) catch estimates are typically stratified by weekend/holiday and weekday. In some strata, every day is sampled. In those strata the combined estimates are simply sums of the daily catches. In other strata, where some days are not sampled, the average catch per day over all sampled days is multiplied by the number of days in the stratum to estimate the total catch.

Where:

a	=	the marine catch area,
i	=	trip type,
h	=	Weekend/holiday or Weekday stratum,
N_h	=	the number of days in stratum h,
T_h	=	collection of all days in stratum h,
N_h	=	the number of days sampled in stratum h, (rather than the number of boats sampled as above),
S_h	=	collection of sampled days in stratum h (when $S=T$, $n=N$),
Y_{haik}	=	estimated catch (or effort) on day k for stratum h in area a from trip type i,
C_{hai}	=	catch for stratum h in area a from trip type i,

then,

$$\hat{C}_{hai} = Nh \frac{\sum\limits_{k \in Sh} \hat{Y}_{haik}}{n_h}$$

with estimated variance (Thompson 1992, p. 129):

$$\hat{V}\left(\hat{C}_{hai}\right) = \frac{N_h(N_h - n_h)}{n_h} \frac{\sum\limits_{k \in S_h}\left(\hat{Y}_{haik} - \hat{\bar{Y}}_{hai}\right)^2}{n_h - 1} + \frac{N_h}{n_h} \sum\limits_{k \in S_h} \hat{V}\left(\hat{Y}_{haik}\right)$$

where

$$\hat{\bar{Y}}_{hai} = \frac{\sum\limits_{k \in S_h} \hat{Y}_{haik}}{n_h} \; .$$

For strata with all days sampled, $n_h = N_h$, and the catch and variance estimators reduce to:

$$\hat{C}_{hai} = \sum\limits_{k \in T_h} \hat{Y}_{haik}$$

and

$$\hat{V}\left(\hat{C}_{hai}\right) = \sum_{k \in T_h} \hat{V}\left(\hat{Y}_{haik}\right).$$

OSP Daily Catch and Effort Estimation (Secondary Stage)

Both catch and effort are grouped by trip-type and area fished. Effort in terms of boat-trips is simply the sample number of boats for each trip-type and area expanded by the appropriate boat-type (charter or private) exit/entrance count. Effort in terms of angler-trips is calculated as the mean number of anglers per boat (indexed by trip-type and area) expanded by the counted total population of boats.

The total catch for a given species on a sampled day is the product of the population of boats and the estimated catch per boat, grouped by trip-type and area fished. Key assumptions in the current estimation procedures are that:

1) All boats exiting/entering a port are included in the exit/entrance count

2) Exit/entrance counts are made without error

3) The approximate systematic sample of boats can be treated as a simple random sample

4) Anglers answer questions accurately and do not conceal fish

In the following discussion, subscripts referring to port and boat-type are suppressed. Let:

M_t = total exit or entrance count for a given port on day t (assumed known without error),

m_t = total boats sampled on day t,

m_{tai} = number of boats sampled of trip type i fishing in area a on day t,

a_{taij} = number of anglers on the jth boat from trip type i fishing in area a on day t,

y_{taij} = number of species specific fish caught on the jth boat from trip type i in area a on day t, and

Y_{tai} = total catch of specific species caught from trip type i in area a on day t.

The estimate of the number of boat-trips of trip-type i and area a follows the procedure outlined in Lai et. al. (1991) where the proportion of boats in each category is estimated by:

$$\hat{p}_{tai} = \frac{m_{tai}}{m_t}$$

with estimated variance (Cochran 1977, p. 52):

$$V(\hat{p}_{tai}) = \frac{\hat{p}_{tai} \cdot (1 - \hat{p}_{tai})}{(m_t - 1)} \cdot \left(\frac{M_t - m_t}{M_t}\right)$$

The estimated total boat-trips is then obtained by:

$$\hat{M}_{tai} = M_t \cdot \hat{p}_{tai}$$

with estimated variance:

$$\hat{V}(\hat{M}_{tai}) = M^2_t \cdot \hat{V}(\hat{p}_{tai})$$

Effort expressed in terms of angler-trips is the product of the average anglers per boat-trip times the total number of boat-trips. The mean number of anglers per boat-trip (for trip-type i and fishing area a) is estimated as:

$$\hat{\bar{a}}_{tai} = \frac{\sum_j a_{taij}}{m_t}$$

with variance:

$$\hat{V}(\hat{\bar{a}}_{tai}) = \frac{\sum_j (a_{taij} - \hat{\bar{a}}_{tai})^2}{m_t(m_t - 1)} \cdot \left(\frac{M_t - m_t}{M_t}\right)$$

Thus the estimated total number of angler-trips is:

$$\hat{a}_{tai} = M_t \cdot \hat{\bar{a}}_{tai}$$

with variance:

$$\hat{V}(\hat{a}_{tai}) = M^2_t \cdot \hat{V}(\hat{\bar{a}}_{tai})$$

The catch (or number released) for a specific species on sampled day t in area a from trip type i is similarly estimated by:

$$\hat{Y}_{tai} = \frac{\sum_j y_{taij}}{m_t} M_t$$

with estimated variance:

$$\hat{V}(\hat{Y}_{tai}) = \frac{\sum_j (y_{taij} - \hat{\bar{y}}_{tai})^2}{m_t(m_t - 1)} M_t(M_t - m_t)$$

This estimate and it's variance differs somewhat from that described in Lai et al. (1991) since the total count, Mt (assumed to be a known quantity), is used to expand the estimated CPUE (calculated over all sampled boats) rather than the estimated boat-trips by trip-type and area fished.

Staff and Training

Approximately 24 field samplers are employed each season to collect catch and effort data. Two full time biologists coordinate sampling activities, one full time biologist generates in-season groundfish

catch estimates, and one full time technician provides data quality control. In addition, 2 onboard observers collect encounter, mark status, and other information from salmon fishing vessels participating in mark-selective fisheries.

Each season, new samplers are provided a general sampling manual and a sampling supplement specific to the port to which they are assigned. One or more days of office training is provided, followed by two or more days of intense field training. Field training and performance feedback continue throughout the season.

Recreational harvest - estimation of salmon catch in Washington waters excluding ocean fisheries

In addition to creel estimates for areas like the recreational ocean salmon fishery, WDFW estimates recreational harvest of salmon through angler self-reporting on catch record cards (CRCs); this is the method used to account for recreational coho harvest in Willapa Bay and its freshwater tributaries. Commercial salmon harvest in WDFW managed fisheries is documented through the state's commercial fish receiving ticket requirement (WAC 220-354-020) and WDFW's fish ticket database (WA Fish Tickets-WAFT). The data collected represent a full census of all fish landed within commercial ocean troll and in net fisheries in Willapa Bay.

Card Issuance

Catch cards are issued to anglers who purchase a fishing license and indicate their intent to fish for salmon or the other catch card species (steelhead, sturgeon, and halibut). It is illegal to fish for any of these species without possessing a valid CRC. This applies to everyone, including anglers under the age of fifteen who are not required to purchase an actual fishing license.

Each card issued includes the angler's name, city of residence, and a unique identifier (the WILD ID) which is assigned to each angler in the licensing database. A fourteen-digit document number (DocID) is printed on each CRC. This number is specific to the individual card; a different DocID is generated for each document produced by the licensing system. Pre-printed catch cards are provided to charter boat operators and fishing guides to be issued along with one-day charter licenses. These operators may not have computers available for access to the WILD system. The charter cards have unique seven-digit numbers printed on them. Anglers write their name/address information on the charter card "stub" which is retained by the operator and sent back to the agency. The same pre-printed cards may also be issued to anglers that purchase "Hot Key" licenses; temporary licenses sold through the WILD system, but without the requirement for an angler entry in the database. The angler name and address is entered on the stub, just as with charter licenses. Charter and hot key cards make up about three to five percent of the total card issuance annually.

Card Returns

The CRCs are due back on April 30, one month after the end of the license year, which runs from April 1 through March 31. For fish cards, there is no penalty associated with late return of cards, or failure to return cards, so many are mailed in well after the deadline. A processing cutoff date is set in August. Cards received by the cutoff date are processed as described below; those arriving after are treated as being out-of-sample and are not used for estimation.

Cards can be mailed in or dropped off at WDFW offices. In past years, some license dealers accepted cards from anglers and returned them to the agency. This practice is no longer officially sanctioned but continues to a limited extent. If anglers lose their cards, they are allowed to contact the CRC unit and report their catch from memory.

The CRC unit randomly selects twenty-five percent of the cards issued each year for use in generating catch estimates. These cards are referred to as the "in-sample" group. Cards are selected based on the last two digits of the document numbers printed on the cards. Prior to the license year a range of twenty-five sequential numbers is randomly selected: 1-25, 26-50, 51-75, or 76-00. Cards ending in the selected range are in-sample. Cards falling out of that range are referred to as "out-sample" and are not used for salmon estimation. (Out-sample cards are used for steelhead estimation, however.) For cards issued from the WILD system, the document numbers are assigned sequentially to all license documents. Since a single license transaction typically results in four or five documents, and transactions are occurring at hundreds of locations statewide, DocID assignment is essentially random. This is not true for charter cards, where operators are issued books of sequentially numbered cards. It is common for all members of a family, for instance, to be in the in-sample group if they went on a charter trip together.

Reminders are sent out to anglers with cards in the in-sample range, in an effort to increase return rates. The first reminder is a postcard mailed out in March, with instructions on how to mail in the cards. The second reminder is a letter sent out in May, after the reporting deadline. The letter mailing includes a form that anglers can fill in with their catch data in case they have lost or misplaced their card. It also includes a postage-paid business reply envelope for returning either the card or the form.

Card Processing

Cards coming into the CRC unit are sorted into in-sample and out-sample groups. The in-sample cards are grouped into batches, and the document numbers are entered into an MS Access database, along with information about the batch – catch or no-catch, response type (voluntary, after first reminder, after second reminder) and document type (actual card, reminder letter form, etc.).

In-sample cards with catch are inspected for missing, illegible or questionable entries. Edits are made directly on the cards. To resolve issues with missing or questionable data prior to sending the cards to data entry, staff contacts anglers by phone.

The cards with catch are sent to the data entry unit, where document numbers and catch data are entered and verified. For salmon, the catch data elements are:

Catch area code: a numeric code entered by the angler. Marine areas are 1-2 digits; freshwater areas are 3 digits. Missing data is entered as area 192.

Month: numeric 1-12, 99 for missing

Day: numeric, 99 for missing

Species: Anglers check a column indicating the salmon species. The data is keyed as a single letter code. Missing entries are entered as "U".

Clip type: "H" for hatchery fish with a clipped adipose fin; "W" for wild fish with an intact adipose. Missing values are left blank.

After data entry, the cards with catch are scanned and the images saved for future reference. The actual cards are bundled by batch and stored in boxes which are ultimately sent to the state archives.

Estimation Method

The data input by the data entry group is run through an error-checking program. All of the CRC programs are written in SAS. Entries with missing data have the appropriate missing value code filled in. Checks are made for invalid dates and areas. (The data entry validation program includes a list of valid catch area codes; therefore, few invalid areas make it through to this step.) Duplicate entries show up for various reasons – an angler may return both an actual card and a letter, or a card may inadvertently be batched twice; these issues are resolved here.

Next, the expansion factor is calculated. This is the ratio of total cards issued to cards returned. For cards issued through the WILD system, calculating the total sold is straightforward; canceled or voided cards are subtracted from the total issuance number to arrive at the number of valid cards that were available for use. For charter cards, the total issued is estimated. Some, but not all, of the name/address stubs are returned by the charter operators, and some, but not all, of the cards are returned by anglers. Thus, total issuance for charter cards is estimated as follows:

N_T = total charter/hot key cards issued
N_r = in-sample name/address stubs returned
n_v = total in-sample cards voluntarily returned (returned prior to reminder mailings)
n_m = voluntary returns that match returned stubs

It is assumed that: $$\frac{n_m}{n_v} = \frac{N_r}{N_T}$$

Therefore: $$N_T = \frac{N_r n_v}{n_m}$$

Charter and hotkey cards make up less than five percent of the total card issuance; thus, we assume that the uncertainty in the numbers does not have a large impact in the overall estimation process.

Catch from the returned in-sample cards is expanded out across all issued cards. The expansion factor is one over the in-sample return rate multiplied by the twenty-five percent sample rate. In-sample return rates in recent years have been in the 50 to 60 percent range. For example, in 2009 the return rate was about 56%, so the expansion factor was:

$$\frac{1}{0.56(0.25)} = 7.1$$

Estimates are generated for each catch area, species and statistical week ("statweek" - starts on Monday and ends the following Sunday). The salmon species is recorded on the catch card and entered by data entry. However, species identification can be problematic for anglers, particularly in saltwater. Therefore, species composition proportions from Puget Sound creel sampling are substituted for those from the cards themselves. The salmon species proportions from the cards are used only for those locations and times where the creel data is not available.

The following estimation method was implemented after a five-year intensive study conducted in the late 1980's (Conrad, Alexandersdottir, 1993). Variance is calculated using a random group method (Wolter, 1985) in which the in-sample returned cards are randomly assigned to four subgroups. Estimates are then calculated separately for each subgroup as well as for the entire group, and the variance is calculated using the deviations of the sample estimates from the over-all estimate.

Generally, cards that are not returned have a lower mean catch per card than those that are returned. To adjust for this non-response bias, a correction factor is applied. For Marine Area 5, the correction factor is 1.0, indicating no difference in catch rate between responders and non-responders; for the other Puget Sound areas, the correction factor used is 0.68. (Conrad and Alexandersdottir, 1993)

The in-sample cards are randomly subdivided into four groups, and estimates for each area/statweek are calculated using each of those groups as follows:

N_i = number of cards in subsample i
N_T = total number of cards issued
h_i = number of fish for subsample i
H_i = estimated harvest based on subsample i
B = non-response bias correction factor

$$H_i = h_i \left(\frac{N_T}{N_i}\right) B$$

Then the total estimate of salmon harvest is generated as follows:

$$H_T = \frac{\sum_{i=1}^{4} h_i}{4}$$

$$V_{H_T} = \frac{\sum_{i=1}^{4}(H_i - H_T)^2}{4(4-1)}$$

where; H_T = total estimate
V_{H_T} = variance of total estimate

The above process generates estimates for total salmon harvest for each area/statweek combination.

Time periods are variable based on fishing seasons and availability of creel data. Time periods are either statistical weeks, statistical months, or some combination. For instance, if the salmon season opens midway through a month, the first two statweeks of the month might be treated as a single time period, and the last two weeks might each be treated as a separate period. The time periods by area for each year are determined by salmon biologists and provided to the CRC unit. Estimates for a given time period are simply the sum of the estimates for each stat week within the period.

Next, the species proportions from the creel sampling data are applied to the total salmon estimates for each time period. If no creel data is available, the proportions used are those from the reported catch. Catch estimates by species and the variances are calculated as follows:

$$H_s = H_T \, \widehat{p}_s$$

$$V_{H_s} = \left(V_{\widehat{p}_s} H_T^2\right) + \left(V_{H_T} \, \widehat{p}_s^2\right) - \left(V_{H_T} V_{\widehat{p}_s}\right)$$

where;

$\widehat{p}_s$ = sample proportion of species s from creel survey

$V_{\widehat{p}_s}$ = variance of proportion of species s

H_T = total salmon estimate

V_{H_T} = variance of total salmon estimate

H_s = estimate for species s

V_{H_s} = variance of estimate for species s

For those cases where creel data is not available, the variances of the species estimates are not calculated.

Estimation Review Process

The CRC catch estimates for each area/time period/species are routed to biologists (both state and tribal) for review. The biologists are asked to list those entries that are questionable, either because the area was closed to fishing during that time period or because the likelihood of encountering that species at that time/place was low. The review comments are compiled and used to draw up a list of those anglers reporting the questionable catch. CRC staff attempt to contact these anglers by phone in order to resolve the issues. If the anglers cannot be reached, the biologists make the decisions on how to handle the reports; generally, if the catch is biologically feasible the report is left as is, otherwise it is changed to "unknown".

Once the calls are completed to resolve possible errors, and the individual catch records are corrected accordingly, we rerun the estimation process. For recent years, this review cycle has been repeated at least twice for each year.

Commercial harvest – WDFW managed commercial salmon fisheries in Washington

Commercial salmon harvest in WDFW managed fisheries is documented through the state's commercial fish receiving ticket requirements (WAC 220-352-060). A paper copy of these tickets are

required to be submitted to WDFW where the data are entered into WDFW fish ticket database (WA Fish Tickets-WAFT). These tickets are completed by the commercial dealer and include a variety of required information which is, in part, comprised of the dealer's and fisher's names, buying location, the number by species of fish harvested, the date, and catch location. The data collected represent a full census of all fish landed within Willapa Bay.

WDFW also samples the commercial landed coho catch for coded wire tags and mark status (adipose clipped (marked/hatchery) or unmarked/natural). The sampling data is a stratified sample over time and space; targeting a 20% sample rate in each strata. All commercial fishing areas are sampled on a weekly basis throughout the duration of the fishery. The proportion of those marked and unmarked coho sampled in the commercial fishery is then used to break down the total number coho landed within Willapa Bay from the fish receiving tickets into an estimated number of natural- and hatchery-origin fish.

Estimating Spawner Escapement

Natural Escapement

A variety of techniques have been used to estimate spawning escapements of Pacific salmon (Cousens et al., 1982). These methods range from mark recapture to fish or redd index counts. The method used throughout western Washington evolved out of the experience of both Washington Department of Fish (WDFW) and tribal biologists. It reflects some of the unique circumstances found in this area, foremost of which are the highly dynamic streamflow patterns caused by extreme rainfall. These high flows result in significant variation in migration patterns of spawners, reduce visibility of pooled fish in spawning areas, and flush carcasses downstream.

The following describes the method employed by WDFW to estimate stock abundance for wild spawning coho in the Willapa Bay watershed; and more generally in anadromous waters of western Washington.

Field Data Collection

The estimate of coho escapement in Willapa Bay is based on counts of coho salmon spawning nests or "redd". Counts of redds rather than fish is done because redds are observed with greater reliability than individual fish. They are easier to detect under most conditions since they are stationary, and usually are readily observed. This is particularly important in coastal streams of the Willapa watershed because of the very dynamic flow regime. Frequent freshets and associated turbid water conditions make detection of spawners extremely difficult. Although redds are may be obscured during high flow event; they are usually visible long enough for detection between events. They can be associated with a particular location and can be individually identified, allowing for accounting of total abundance. This is important since it allows for direct estimates of actual abundance rather than estimates that act as an index of relative abundance from year to year. Individual redds are identified and marked using surveyor's flagging (high visibility, colored, non-adhesive plastic tape) and a specific numbering system that uniquely identifies each individual site. Detailed records are kept on the date first observed, subsequent survey dates when each redd remains visible, and the cumulative redds constructed in each survey area. For the purposes of this work a redd is assumed to represent the spawning activity of a single female. In the rare

case where spawning activity by a female does not appear as a discrete redd, some judgement must be used to determine a single female's activity. However, most redds are separated spatially or temporarily as a result of the territorial interaction between the spawning females. This is particularly true for chinook and coho as compared to other species such as pinks or churns. With the exception of a few areas there is little overlap with other species so identification of redds as coho redds is a minor problem. In areas of higher spawning activity, a map may be drawn that shows the location of each redd.

Surveys conducted to count coho redds consist of walking or floating established, fixed sampling sites (or reaches). The survey plan developed for Willapa Bay tributaries is divided into roughly 60 of these sampling sites categorized as "index" surveys and more than 150 "supplemental" surveys. These sites are located in all six major river basins (North, Willapa, Palix, Nemah, Naselle, and Bear rivers). Survey activity is conducted in a manner so as to maximize the amount of useful information collected.

Index reaches represent the primary extend of spawning activities while supplemental reaches are areas with low density spawning. Index reaches are surveyed weekly throughout the spawning season from before the first redds are constructed until spawning activity has ceased. At the point when peak spawning is occurring in index reaches (generally in mid-October into November for normal times coho and late-January to February for late-times coho), surveys in supplemental reaches are conducted at seven to ten-day intervals.

A variety of information is gathered on each survey. This includes information on the river section surveyed, viewing conditions such as flow and visibility, counts of live and dead fish by sex including a separate estimate of any jacks, and the numbers of new and visible spawning redds. In addition, surveyors collect biological information including the presence and absence of external marks and coded-wire-tags (CWTs).

Data Analysis and Estimation

The index area, and any associated supplemental and unsurveyed areas form the three basic units for estimating escapements. The first step estimates the season cumulative redd count in the index areas:

$$CRI_i = \sum NR_{it}$$

where:

CRI_i = season cumulative redds in the 'I' th index area

NR_{ij} = new redds constructed in the 'j' th time period in the 'I' th index area

The second step is to estimate the total number of redds constructed in each of the supplemental survey areas. This is done by expanding the visible redds seen during the supplemental survey by the ratio of the total redds constructed in the index for a given season over the visible redds in the index area at the time of the supplemental survey. For example, if 50% of the total redds constructed for a season in the index area were visible at the time of the supplemental survey, the redd count in the supplemental survey would be doubled to estimate the total number of redds constructed in the supplemental area during the entire season. The viewing conditions and the redd detectability must be similar during the index and supplemental surveys to generate accurate expansions, which is why it is important for the supplemental surveys to be done at the same time the index area is surveyed. Also doing the supplemental

surveys near the peak of spawning reduces the magnitude of the expansion which helps to reduce error levels. The estimate described above is represented as follows:

$$CRS_{ik} - VRS_{ijk}/(VRI_{ij}/CRI_i)$$

where:

CRS_{ik} = estimated season total number of redds constructed in the 'k' th supplemental area associated with the 'I'th index

VRS_{jk} = visible redds in the kth supplement during the 'j' th survey period

VRI_j = visible redds in the 'I' th index during the 'j' th survey period

The third step is to apply these estimated levels of spawning activity for the index and supplemental areas to the unsurveyed areas of the watershed that are used by spawning fish. As noted above, the index and supplemental areas are chosen to be representative of the watershed. This requires a determination regarding which unsurveyed areas are to be associated with which surveyed areas. For example, the number of redds in unsurveyed reaches of a stream that are upstream or downstream of a survey area can be estimated using redd data from that survey area, or survey information on a particular tributary may be used for a number of other tributaries in a surrounding area in the simplest example, while is described here, each unsurveyed area is associated with a single index or supplemental area. In practice, unsurveyed areas may be represented by average or composite indexes depending on the location and suitability of the various areas. This stage of the estimation process is very dependent on the skill and knowledge of the person making the estimate. It requires that the person making the estimate have sufficient knowledge of the drainage and spawning patterns.

The estimate for the unsurveyed areas is based on the number of redds constructed per mile of index or supplement (redd density) and the miles of unsurveyed area associated with a given survey area. This calculation can be represented relative to redd density in an index area as:

$$USI_i = UMI_i \: X \: (CRI_i/MI_i)$$
where:

USI_i = estimate of redds in unsurveyed areas associated with the 'I' th index area

UMI_i = miles of unsurveyed area associated with the 'I' th index

MI_i = length (in miles) of the 'I' th index

or relative to the density in a supplemental survey reach as:

$$USS_{ik} = UMS_{ik} \: X \: (CRS_{ik}/MS_{ik})$$
where;

USS_{ik} = estimate of redds in unsurveyed areas associated with the 'k' th supplemental area

UMS_{ik} = miles of unsurveyed area associated with the ' k' th supplemental area

MS_{ik} = length (in miles) of the ' k' th supplement

The total number of redds associated with a particular index area is then calculated by the sum of these various components:

$$TR_i = CRI_i + \sum CRS_{ik} + \sum USS_{ik}$$

The number of coho redds must then be converted to fish, Gallagher and Wright (2008) describe this relationship to be 2.23 fish per redd; however, WDFW conservatively uses 2.0 fish per redd. We acknowledge that using a value of two fish per redd means that the estimate may not accurately account for multiple males, including jacks, spawning with a single female yet this method of expanding redds to fish has been used consistently through the dataset. The resulting overall estimate of spawner escapement to an entire watershed is then given by:

$$TF = \sum TR_i \ X \ 2.0 \ \text{(1:1 sex ratio)}$$

Typically, WDFW makes independent estimates of the escapements for each watershed because of variability in spawning density. Estimating escapement at the watershed level is also done to account for differing rates or hatchery origin coho which may stray from the hatchery and spawn naturally with natural origin coho. To address straying of hatchery fish into wild spawning areas survey staff use visual and electronic methods to determine the origin of carcasses that are sampled. Hatchery coho are visually identified by the absence of their adipose fin, the small fleshy fin found between the dorsal fin and the caudal fin which is removed at the hatchery. A portion of hatchery origin coho are also marked by inserting a coded-wire-tag (CWT, a small piece of magnetized stainless-steel wire) into the snout of juvenile fish prior to being released from the hatchery. Surveyor utilize a sensitive metal detector to determine if the fish has a CWT.

The resulting differences in the escapement estimates often require a process of reconciliation between the observers to generate a final escapement estimate for a given watershed. This reconciliation requires a series of discussions about how the various estimates for a given system were made. This process has the added advantage of providing a check on the large number of calculations that go into making these estimates. Where differences continue to exist, the mean value between the different approaches is typically chosen as the final estimate.

Appendix B References

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