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West Coast of Vancouver Island Chinook Terminal Return Forecast for 2022

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SUMMARY

- After deducting expected catch in ocean fisheries, the 2022 forecast return of Stamp River/Robertson Creek Hatchery (RCH) adult Chinook to the terminal area of Barkley Sound and Alberni Inlet is **135000** (range: **100000**–**170000**).
- The 2021 estimated terminal return of West Coast of Vancouver Island (WCVI) Chinook index stocks (*i.e*. excluding catch in pre-terminal fisheries) was 228100 adults, 3% lower than the pre-season forecast prediction. The terminal return of the Stamp River/RCH coded-wire tag (CWT) Indicator Stock was approximately 128000 adults and 10000 jacks (age-2 males), 4% lower than the pre-season prediction.
- In 2021, the total estimated pre-terminal exploitation rate on WCVI Chinook was 22%; estimates were 6%, 28% and 37% for ages 3, 4 and 5 fish, respectively.
- Terminal returns of other WCVI Chinook stocks are forecast to be moderate in 2022. The forecast of aggregate terminal abundance (sum of all hatchery and wild indicator stocks) is 240000 (range: 167000–313000), significantly higher than the long-term average of 159000 (1980–2021). The overall expected adult age composition of the WCVI aggregate terminal run is 30% age-3, 55% age-4, and 15% age-5, with an expected sex ratio of 41% female.
- After a period of modest increase of wild populations, escapements have been decreasing over the last four years for many wild stocks. Spawner levels in the South West Vancouver Island (SWVI) Conservation Unit (CU) remain below upper biological benchmarks with fewer than 100 spawners observed in some rivers in recent years. Wild WCVI Chinook therefore remains a stock of concern.

BACKGROUND

Chinook salmon spawn in over 100 medium and large rivers along the WCVI, with 60 systems having escapement records of at least 100 spawners. For implementation of Canada's Wild Salmon Policy, stock status is evaluated for a set of wild indicator populations within CUs, which are groups of biologically and genetically similar populations. There are three Chinook CUs defined within the WCVI; including SWVI (populations within DFO Statistical Areas 20–24, or from San Juan to Clayoquot Sound); Nootka-Kyuquot (populations within DFO Statistical Areas 25 and 26) and Northwest Vancouver Island (NWVI; populations within DFO Statistical Area 27, or Quatsino Sound).

The average aggregate terminal return (catch and escapement) of WCVI Chinook is approximately 159000; ranging from about 40000–300000 over the period from 1980–2021. However, a large portion of the terminal return and spawning escapement is hatchery-origin fish. About 20 WCVI populations receive some form of hatchery enhancement to supplement natural spawning. Annual releases of Chinook smolts from WCVI enhancement facilities total about 21 million. The majority (*c.* 17 million) are released directly from three major hatcheries located on the Stamp, Nitinat, and Conuma rivers, but there is also additional enhancement of Chinook populations in nearby systems either directly or through straying. About 4 million Chinook smolts are released annually from smaller facilities, including volunteer public involvement projects and community development projects.

The Stamp River/RCH Chinook salmon stock is the CWT "indicator stock" for survival, exploitation rate, and marine distribution patterns of WCVI Chinook populations. Detailed assessments and forecasts of the Stamp/RCH indicator stock are undertaken annually to support stock assessments for WCVI Chinook as a whole. Management actions taken to achieve goals for this stock in pre-terminal fisheries are assumed to have similar effects on other WCVI stocks. Forecasts developed for other WCVI Chinook stocks to determine the expected aggregate abundance of WCVI Chinook and to inform terminal fishery management are based on trends in marine survival and exploitation rate of the RCH indicator stock.

FORECAST METHODOLOGY

Stamp River / Robertson Creek Hatchery (RCH)

Riddell *et al*. (PSARC 96-01) outlined the analytical framework for forecasting returns of Stamp River/RCH Chinook. This forecast follows the same procedures.

Cohort analysis is conducted using "estimated" CWT recoveries (for select tag codes representing normal releases) to estimate production of RCH Chinook. The cohort model used is documented in Appendix 2 of Starr and Argue (1991) and was modified by the Pacific Salmon Commission's Chinook Technical Committee to account for the Chinook non-retention fisheries implemented in Canada (Pacific Salmon Commission, 1999). For each brood year, information generated from the cohort analyses and used in forecast models includes: i) survival to age 2 recruitment; ii) ocean exploitation rates by fishery and age; and iii) total estimated production. The cohort analysis produces estimates of CWT recoveries in all Canadian and USA fisheries, natal escapement, and stray escapement. Total production is then determined by expanding all estimated CWTs by the total release/CWT ratios for the selected tag codes and then correcting this using recent average observed total returns/CWT based estimates.

To forecast production of RCH Chinook, or "pre-fishery abundance," two sibling regression models are applied that use information from younger age classes to predict the production of older age classes:

- Model 1 uses total terminal return at a younger age class (independent variable) to predict total production (the surviving cohort in the ocean) of a subsequent age or ages from the same brood year. The dependent variable is the total (total ocean fishing mortality plus terminal run) production at a subsequent age or ages.
- Model 2 uses estimated total production (fishing mortality plus escapement) of particular age classes to predict total production of subsequent ages (*i.e.*, the surviving cohort from the same brood year).

Relationships between all possible age class combinations were examined using these two models. The actual models used for the forecast were based on the strongest correlations (highest R^2 values). In the case where more than one age class is used as a predictor (*e.g.* ages 2 & 3 fish) the total terminal runs at those ages were summed. Estimates of surviving cohort include natural mortality factors and are estimated as the pre-fishery abundance of the youngest age being predicted. Assuming recent average maturation rates, the remaining cohort was assigned either to the expected terminal run or to the surviving cohort remaining at sea. The terminal return to the Barkley Sound/Alberni Inlet is forecast after accounting for expected impacts in pre-terminal ocean fisheries. A forecast range is generated from the distribution of the deviations between the observed and forecast run size.

Beginning for the 2019 forecast and continuing through 2022, three adjustments were implemented based on recommendations from Peterman *et al*. (2016): i) all sibling regressions are based on log-transformed data; ii) only recent year average maturation rates are applied; and iii) age-specific pre-terminal exploitation rates are assumed similar to the recent 3-year average (Figure 2, Table 3, Table 4).

Other WCVI Populations

Overall, the data available for other WCVI populations are less precise than those for the Stamp/RCH stock. However, trends in brood year survival and ocean fishery impacts for other WCVI Chinook populations are assumed similar to the RCH Indicator Stock. Therefore, it is possible to use brood survival and age-specific exploitation rate information from the RCH cohort analysis to forecast returns for other WCVI terminal areas or populations.

In past years, the terminal return of the WCVI Chinook aggregate was forecast by expanding the expected return of the Stamp/RCH stock by the brood year average ratio of the return Stamp/RCH to the total of other WCVI index stocks. With increasingly detailed age data being collected from other stocks (*i.e.* sibling performance of earlier age classes that have already returned for the contributing brood years), specific forecasts have been developed for the Conuma and Nitinat hatchery returns, and the remaining index stocks as a whole (see list in Table 2). These models were initially developed to inform domestic management of Canadian fisheries, but have recently been applied to forecast the aggregate WCVI terminal abundance because the stock-specific forecasts are generally more accurate than the

simple ratio method described above. The contribution of Stamp/RCH stock to the aggregate WCVI abundance has been variable due to apparent differences in marine survival rate among WCVI hatchery stocks and from changes in hatchery release strategies (Figure 5).

2021 RETURN, COHORT ANALYSIS RESULTS, AND FORECAST PERFORMANCE

The estimated 2021 terminal adult return of WCVI index stocks (*i.e.* excluding catch in pre-terminal fisheries) was 228100, with estimated adult returns of 127600, 38500, 27000 and 34000 to Stamp/RCH, Conuma Hatchery, Nitinat Hatchery and other extensive indicator stocks, respectively (Table 1*Table 1*). The estimated age composition at return of the WCVI aggregate was 34%, 62% and 4% for 3-, 4- and 5-year-old Chinook, respectively.

The observed terminal returns of WCVI Chinook were higher than expected for Conuma and Nitinat stocks, but lower than expected for Stamp/RCH and the other WCVI index stocks (Table 2). Overall, the total observed WCVI return was 3% lower than forecast (Table 2). Trends in marine survival rate to age 2 estimated through cohort analysis using RCH CWT recoveries are plotted in Figure 3. The long-term average marine survival rate is about 4.7%. For the 2016, 2017, 2018 and 2019 brood years (returned as 5-, 4-, 3-, and 2-year-old fish in 2021), the estimated survival rates to age 2 were 5.2%, 6.8%, 6.4% and 4.9%, respectively (Figure 3). Estimates for the 2017–2019 brood years are based on incomplete brood returns and are therefore preliminary.

Age-specific *pre-terminal* exploitation rates estimated from the cohort analysis using RCH CWT recovery data are summarized in Table 3 and Figure 2. The total estimated pre-terminal exploitation rate was 22%. Estimated pre-terminal exploitation rates on 3-, 4- and 5-year-old fish in 2021 were 6%, 28% and 37%, respectively. In the last 3 years, the estimated pre-terminal exploitation rates of 4 and 5 year old WCVI Chinook have averaged about 38% and 46%, respectively. There has been a general trend of increasing pre-terminal exploitation of 4 and 5 year old fish since about the 1999 brood year, roughly coinciding with the start of AABM management (Figure 2). The management objective is to limit fishery exploitation in Canadian AABM fisheries to 10%, within which the Northern Troll fishery is limited to 3.2%. In 2021, the exploitation rate in Canadian AABM fisheries was estimated at 7.6% with the Northern Troll at 3.1%.

2022 FORECAST

Terminal return Stamp River / Robertson Creek Hatchery (RCH) Chinook

The forecast terminal return of adult Stamp/RCH Chinook to Barkley Sound and Alberni Inlet in 2022 is approximately 135000 (range: 100000–170000). This is an above average return and suggests a continuation to the trend of strong returns that began *c.* 2018 (Table 4, Table 2). The predicted adult age composition is 36%, 54% and 11% of 3, 4 and 5-year old fish, respectively. As the predicted return falls within the “abundant” category, directed Chinook fisheries are expected in the terminal Alberni Inlet area for all sectors.

The escapement target for the Somass River is adjusted annually based on a deposition goal of 39 million eggs; 9 million for RCH broodstock, and 30 million for natural spawning in the river. The 39 million egg deposition goal was set in 2014 on the following objectives: i) the goal for natural spawners in the river is triple the habitat-based lower biological benchmark of 5000 Chinook; ii) the broodstock target for RCH is 7 million eggs plus a 2 million egg buffer to ensure adequate representation of the escapement composition; iii) a precautionary buffer to allow for up to 20% prespawn mortality under poor environmental conditions. From 2014–2019, the escapement target was adjusted annually. However, the escapement target of 21000 spawners for 2019, which was based on the forecast age compositions (2%, 85%, and 13% for 3-, 4-, and 5-year-old Chinook, respectively), was carried forward into the management plans for 2020 and 2021. Additionally, escapement target calculations from 2014–2019 were based on historical fecundity biostandards that had not been updated since the 1980s (4000, 4400, and 4800 for 3-, 4-, and 5-year-old females, respectively). In recent decades, body size, age at maturity, and fecundity have been declining in Chinook salmon originating from the west coast of North America (Lewis et al., 2015; Ohlberger et al., 2018, 2020). A study carried out at Robertson Creek Hatchery in 2021 confirmed that fecundities have likewise declined in Stamp River Chinook from the historical biostandards, with

median fecundities of approximately 2900, 3500, and 4500 for 3-, 4-, and 5-year-old females, respectively (Figure 7). Using the age compositions forecasted for 2022 and these updated fecundity estimates, an escapement of 36000 Chinook is suggested to achieve the 39 million egg target. DFO stock assessment recommends returning to annual escapement target adjustments based on the forecast age compositions and the new fecundity estimates from the 2021 study.

Terminal return of other WCVI Chinook populations

While estimated marine survival rates for Nitinat, Conuma, and some other WCVI stocks from the 2009–2011 brood years exceeded estimates for the RCH Indicator Stock, the trend appears to have reversed in the most recent complete brood years (2013–2016). However, given the above-average returns observed for Nitinat, Conuma, and the other extensive indicators in 2021 (Table 2), general expectations are for roughly average returns of adult Chinook (Table 5). Similar to Area 23, directed fishery opportunities are expected in WCVI terminal areas dominated by hatchery stocks.

Conuma Hatchery: The predicted terminal return of Conuma Hatchery Chinook to Area 25 is 40000 (range 24000–56000) with an age composition of 32%, 58% and 10% for 3-, 4- and 5-year-old fish, respectively.

Nitinat Hatchery: The predicted terminal return of Nititat Hatchery Chinook to Area 22 is 27000 (range 18000–36000) with an age composition of 21%, 62% and 18% for 3-, 4- and 5-year-old fish, respectively.

Other WCVI Stocks: The predicted terminal return of other WCVI index stocks (see list in Table 2) is 38000 (25000–51000) with an age composition of 17%, 50% and 33% for 3-, 4- and 5-year-old fish, respectively. This forecast return results largely from index stocks that are enhanced. In most recent years, spawner abundances of wild indicator stocks within WCVI Conservation Units have been below provisional upper biological benchmarks and, in the case of the SWVI CU, below the lower biological benchmark in many recent years (Figure 7). Therefore, Canadian fisheries are managed to limit mortality on wild WCVI Chinook.

SOURCES OF UNCERTAINTY

In 2020, no CWTs were applied at RCH to Chinook from the 2019 brood year due to COVID-19 lockdown restrictions. Consequently, no recoveries were available to run the sibling model predicting total production of age 3 fish. The prediction for the age 3 return in 2022 is therefore much more uncertain than in previous years. The prediction is based on the total number of smolts released by the hatchery and an estimate for smolts produced by natural spawners, with estimated or biostandard survival rates applied to predict survival through the life stages to age 3. The number of 2-year-old Somass Chinook observed in the 2021 terminal return (≈10700) was the highest observed since 1991, which suggests production from the 2019 brood is likely to be strong.

The mean absolute percentage error (MAPE) for the forecast models used to predict terminal returns of Stamp/RCH Chinook is 26% for the years when the models have been applied (1988–2021, Figure 4). That is, on average, the observed return is about 26% higher or lower than the predicted return. In two of the last three years, the forecast has over-estimated the actual return (Figure 4). Factors that contribute to uncertainty in the forecast include, but are not limited to: model structure, uncertainty associated with cohort analysis CWT data and results that form the model inputs, changing dynamics in pre-terminal northern fisheries, and the changing ocean environment.

For other WCVI Chinook stock forecasts, there is higher uncertainty due to the general lower quality assessment data relative to the Stamp/RCH indicator stock. There are incomplete age data, relatively high uncertainty spawner abundance estimates (for extensive indicator stocks in particular), and also higher uncertainty in pre-terminal catch estimates. In addition, survival, exploitation, and maturation rates of other WCVI stocks could vary significantly from the Stamp/RCH indicator stock. The MAPE of forecasts for other WCVI stocks ranges from 32–39% when a retrospective analysis is applied for the 1996–2021 return years.

For all the WCVI terminal forecasts, two key sources of uncertainty are the maturation rate and pre-terminal exploitation rate assumptions applied to generate run size estimates. There has been a trend in recent decades toward increased maturation rates in WCVI Chinook; fish are generally maturing quicker and returning to the terminal area at younger ages. Declines in maturation rate will affect the expected return of older age classes relative to average rates (Lewis et al., 2015). The reliability of the terminal forecasts is also dependent on the accuracy of the prediction of the age-specific pre-terminal exploitation rates, which can vary considerably from year to year. Variability in fishery exploitation patterns are caused by a number of factors including regulatory changes to fisheries, relative stock abundances in mixed-stock fisheries, changes in the marine distribution of the WCVI stock, and changes in the maturation rate of the WCVI stock (such as described above).

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APPENDIX—FIGURES AND TABLES

Table 1. Estimated 2021 return of WCVI Chinook index stocks to the terminal WCVI area (*i.e.* after pre-terminal Canadian fisheries).

Stock	Age				Adult Total
	2	3	4	5	
Area 23	10800	49000	74400	4200	127600
Area 25	1500	10700	25900	1800	38500
Area 21/22	400	9500	18000	600	28000
Other WCVI	300	8400	23500	1800	34000
Total	13000	77600	141800	8400	**228100**

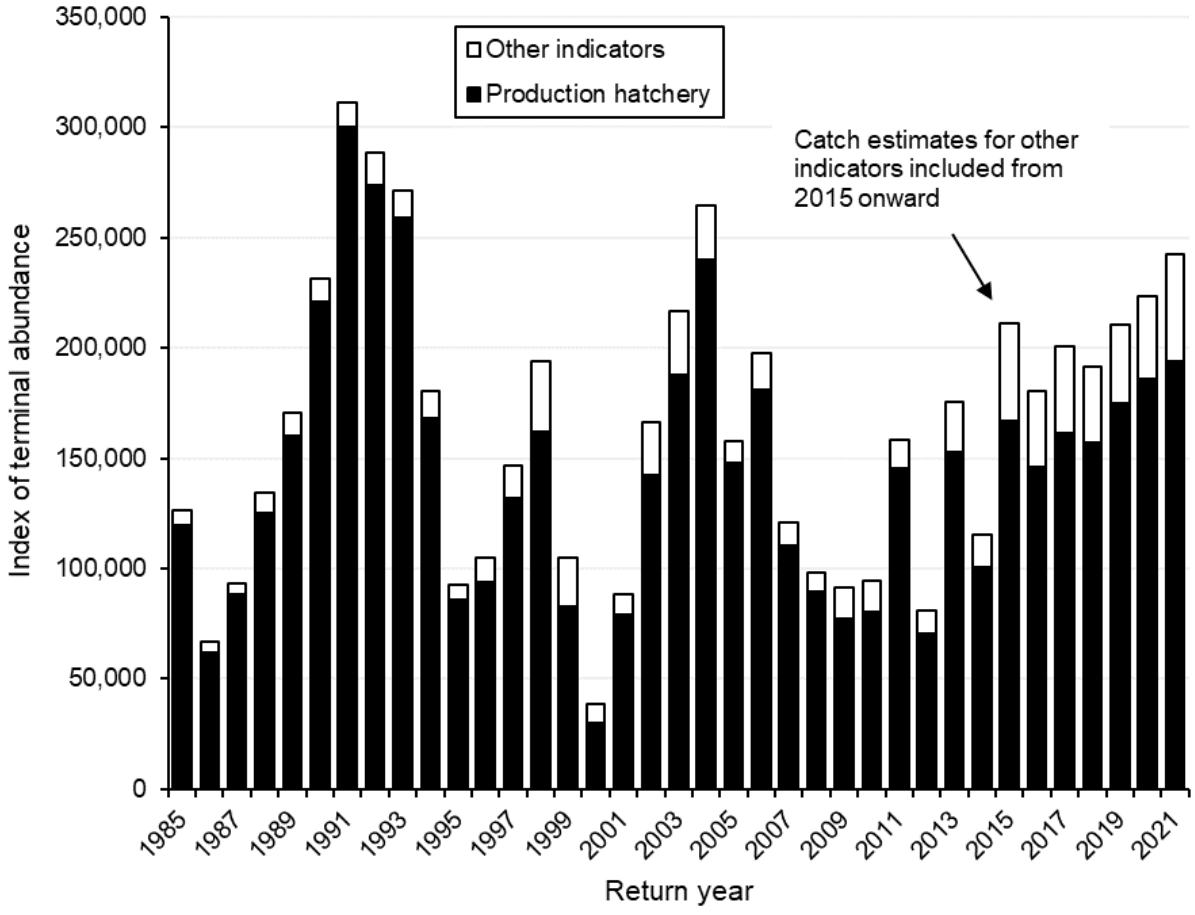

Figure 1. Aggregate terminal return of WCVI indicator stocks, including major hatchery facilities (Robertson, Conuma and Nitinat) and all other indicator stocks, many of which are also supplemented with hatchery production.

Table 2. The performance of 2021 WCVI Chinook adult (age ≥ 3 years) terminal return forecasts. "PE" is the percentage error of the forecast, *i.e.* the discrepancy between predicted and observed returns.

Stock(s)	Average (1996–2020)	2021 Observed	2021 Forecast Range	2021 Forecast Prediction	PE
*WCVI Index Stocks	†32 000	34 000	28 000–56 000	43 000	26%
Conuma	37 000	38 500	20 000–47 000	33 000	−14%
Nitinat	25 000	28 000	18 000–35 000	27 000	−4%
Somass/RCH	68 000	127 600	98 000–167 000	133 000	4%
Total	**168 000**	**228 100**	**142 000–257 000**	**236 000**	**3%**

*****An aggregate of the PSC indicators (Artlish, Burnam, Gold, Kaouk, Marble, Tahsis, & Tashish rivers) and "extensive" indicators (Bedwell, Colonial, Cypre, Leiner, Megin, Moyeha, Nahmint, San Juan, Sarita, Tranquil, & Zeballos rivers).
†Average from 2015–2020. Prior to 2015, catch was not included; only escapement estimates for the systems were available.

Table 3. Age-specific exploitation rates of WCVI Chinook in pre-terminal fisheries, 2021 (estimated by cohort analysis using RCH Indicator Stock CWT recoveries).

Age	Alaska			NBC Troll	CBC Troll	WCVI Troll	NBC Net	NCBC* Sport	WCVI Sport	OTHER Ocean	Total Pre-terminal
	Troll	Net	Sport								
3	0.9%	1.8%	0.1%	0.9%	0.0%	0.4%	0.0%	0.8%	1.3%	0.2%	6.3%
4	8.0%	3.4%	2.0%	2.8%	0.0%	0.6%	0.0%	3.1%	6.8%	1.5%	28.2%
5	12.9%	5.0%	0.5%	1.4%	0.0%	0.0%	0.0%	4.9%	11.5%	0.4%	36.6%

*Northern and Central BC

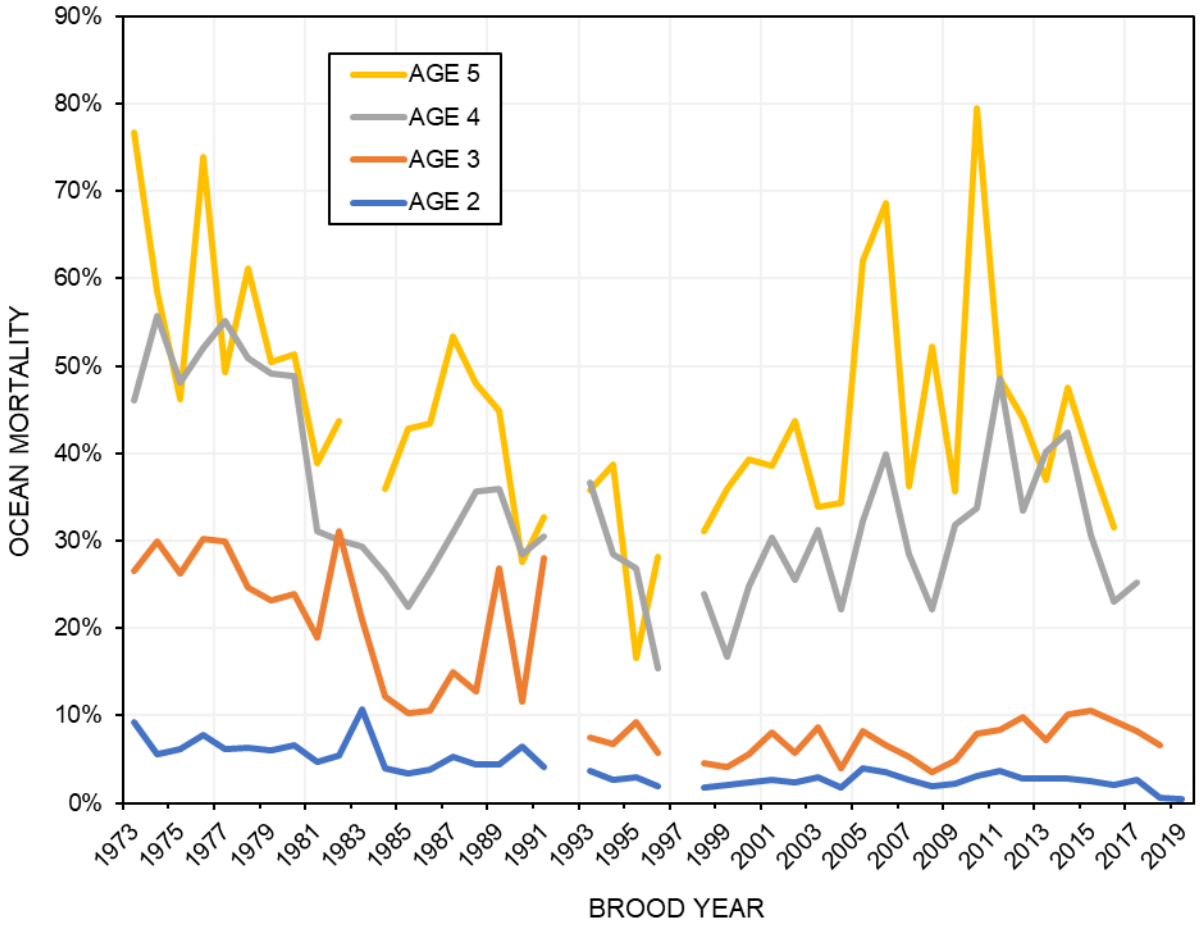

Figure 2. Age-specific exploitation rates of WCVI Chinook in pre-terminal fisheries, brood years 1973–2019. Exploitation rates are estimated by cohort analysis using RCH Indicator Stock CWT recoveries. Data from some years (*e.g*. 1992, 1997) were excluded because very low numbers of CWT recoveries were producing anomalous estimates.

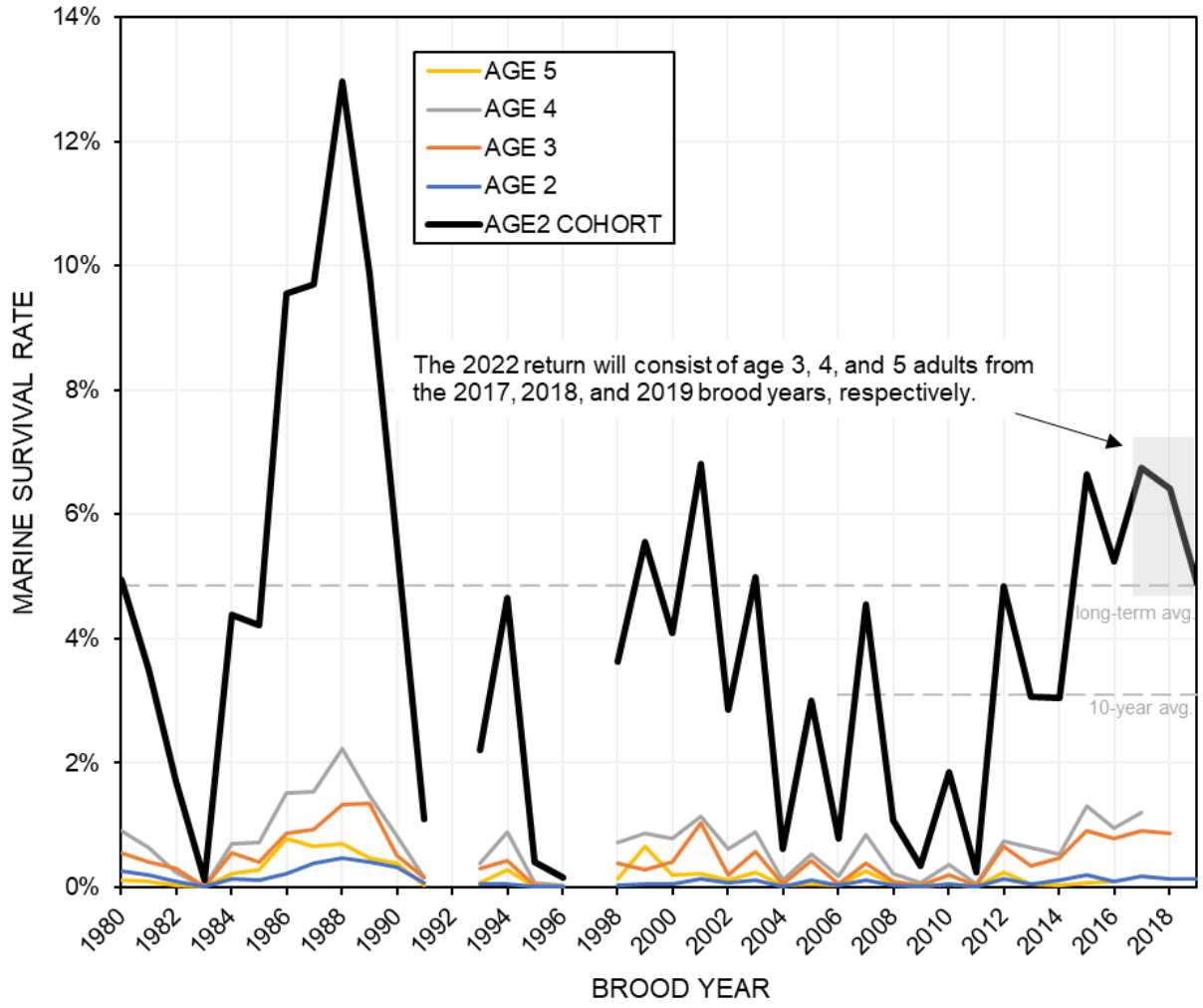

Figure 3. Estimated survival by age of WCVI Chinook (estimated by cohort analysis using RCH Indicator Stock CWT recoveries). The thick black line shows the survival rates from smolt to age 2, whereas the thin coloured lines show survival-at-age. *Note.*—estimates for the last 3 sea-entry years are based on incomplete brood years. Data from 1992 & 1997 were excluded because very low numbers of CWT recoveries were producing anomalous estimates. The grey dashed lines show the long-term average marine survival rate, and the 10-year recent average marine survival rate (which is based on the complete brood years 2006–2016, but extended for visual comparison to subsequent years).

Table 4. Summary of the 2022 Stamp River/Robertson Creek Hatchery forecast pre-fishery abundance and return of mature fish to Canada and the terminal run WCVI area.

Model	Pre-Fishery Abundance[1]	Return to Canada[2]	Terminal Return[3]	Terminal Age Comp
2. Terminal return versus Total Production				
2018 brood	222,847	52,141	48,084	37%
2017 brood	133,761	84,299	67,094	52%
2016 brood	31,525	21,800	14,980	12%
Total	388,132	158,240	130,158	
3. Total Production versus Total Production				
2018 brood	222,847	52,141	48,084	34%
2017 brood	154,912	97,629	77,703	56%
2016 brood	29,776	20,591	14,148	10%
Total	407,534	170,360	139,936	
Average of both models				
2018 brood	222,847	52,141	**48,084**	**36%**
2017 brood	144,336	90,964	**72,398**	**54%**
2016 brood	30,650	21,195	**14,564**	**11%**
Total	397,833	164,300	**135,047**	

1. Forecast total production from the respective brood years.
2. Forecast mature return to Canada prior to Canadian fisheries.
3. Forecast mature return to Barkley Sound/Alberni Inlet.

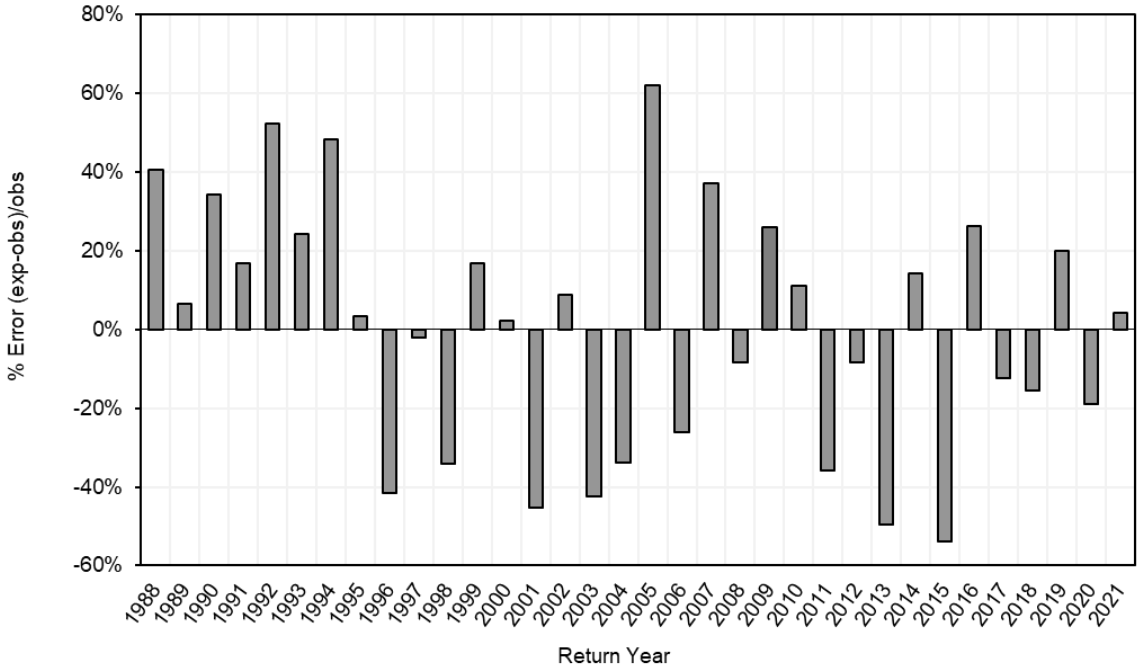

Figure 4. Average annual percentage error of the Somass/RCH terminal run forecast (both sibling models averaged), 1988–2021. The mean absolute percentage error (MAPE) in the forecast terminal run size versus observed is 26% since 1988.

Table 5. 2022 pre-season terminal run size expectations for indexed WCVI Chinook populations in addition to Stamp/Robertson Creek Hatchery. The total is the terminal run prediction for the WCVI aggregate (*i.e.* summed index stocks).

Stock	Age						Total	Range
	3	%	4	%	5	%		
RCH	48000	36%	72000	53%	15000	11%	135000	100000–170000
CON	13000	33%	23000	58%	4000	10%	40000	24000–56000
NIT	6000	21%	17000	61%	5000	18%	28000	18000–36000
OTHER	6000	16%	19000	51%	12000	32%	37000	25000–51000
Total	73000	32%	131000	53%	36000	16%	**240000**	**167000–313000**

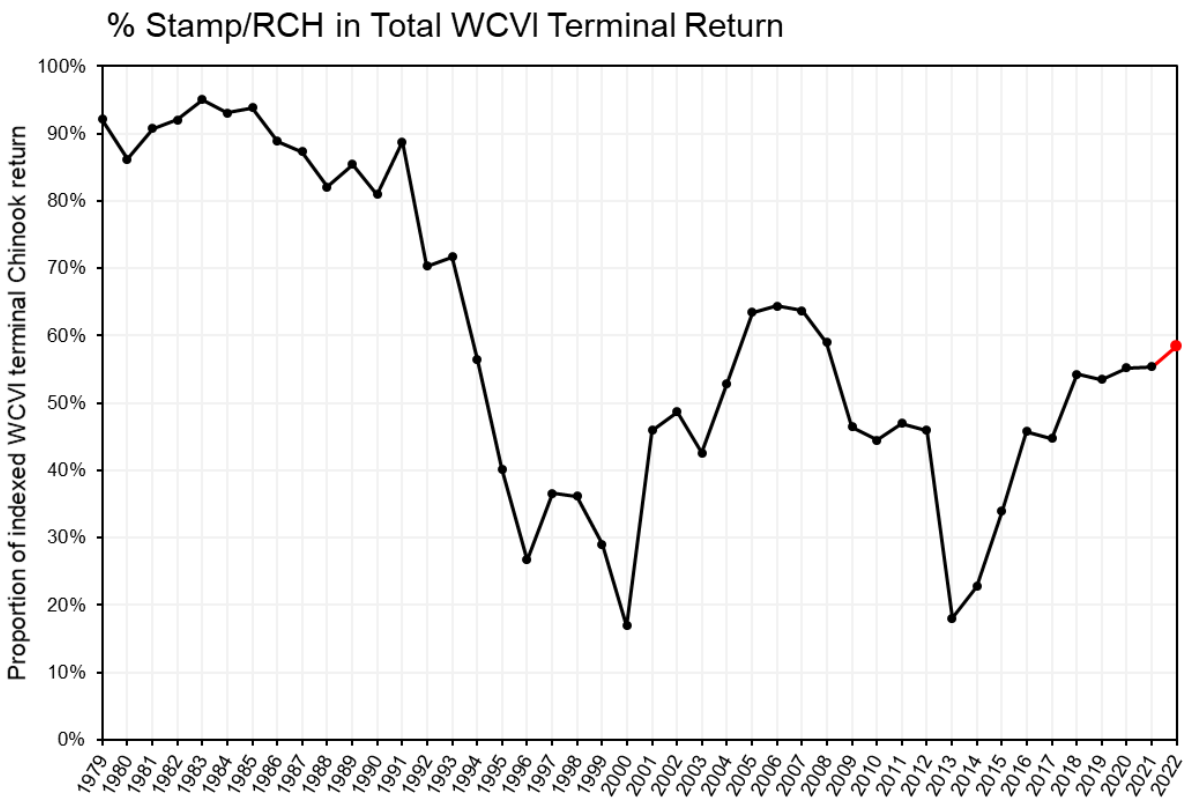

Figure 5. Estimated contribution of Stamp/RCH Chinook to the total return of WCVI indexed stocks, 1979–2021. The predicted contribution for 2022 (58%) is plotted in red.

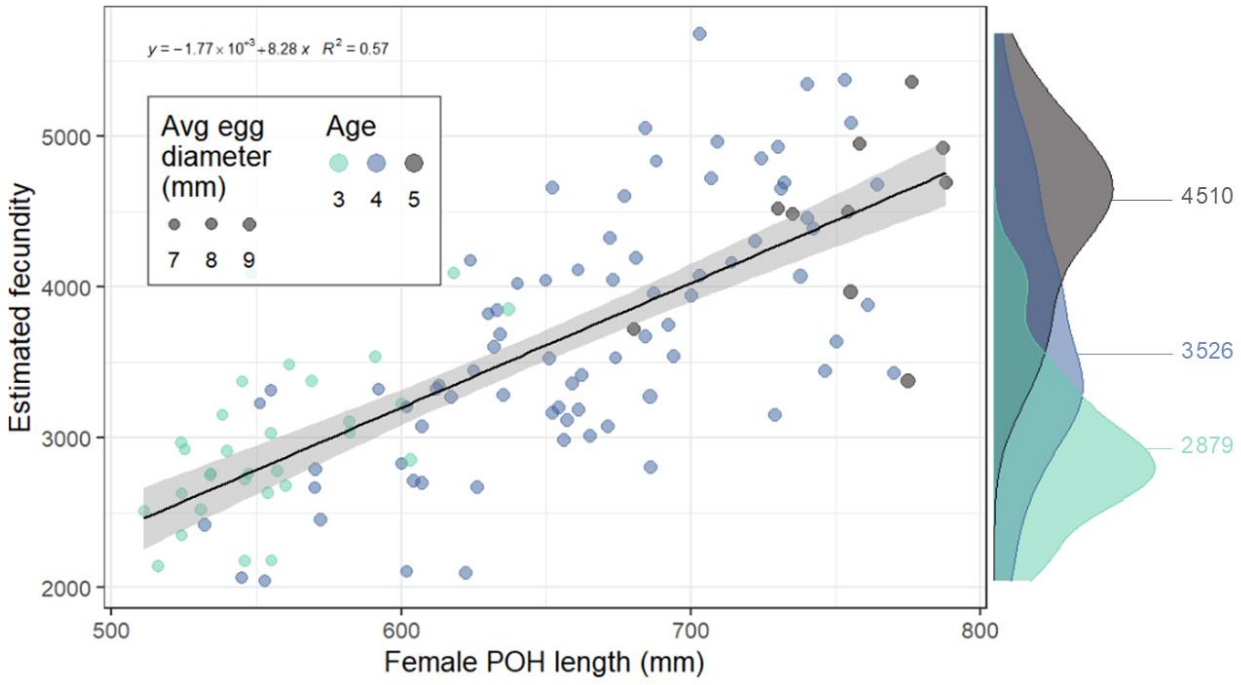

Figure 6. Estimated fecundities of Stamp River Chinook females as a function of body length (post-orbital to hypural) and age (3, 4, or 5 years). Density curves on the right side of the plot show the distributions of fecundities by age, with labels indicating the median values.

Table 6. Input data, assumptions, and calculated Somass River Chinook escapement target for 2022.

Age	Forecast return	Age comp.	Fecundity	% female	Pre-spawn mortality	Required spawners	Eggs
3	48084	36%	2900	7%	20%	10882	1767238
4	72398	54%	3500	50%	20%	24670	34537357
5+	14564	11%	4500	75%	20%	998	2695404
Total:	135047					**36550**	39000000

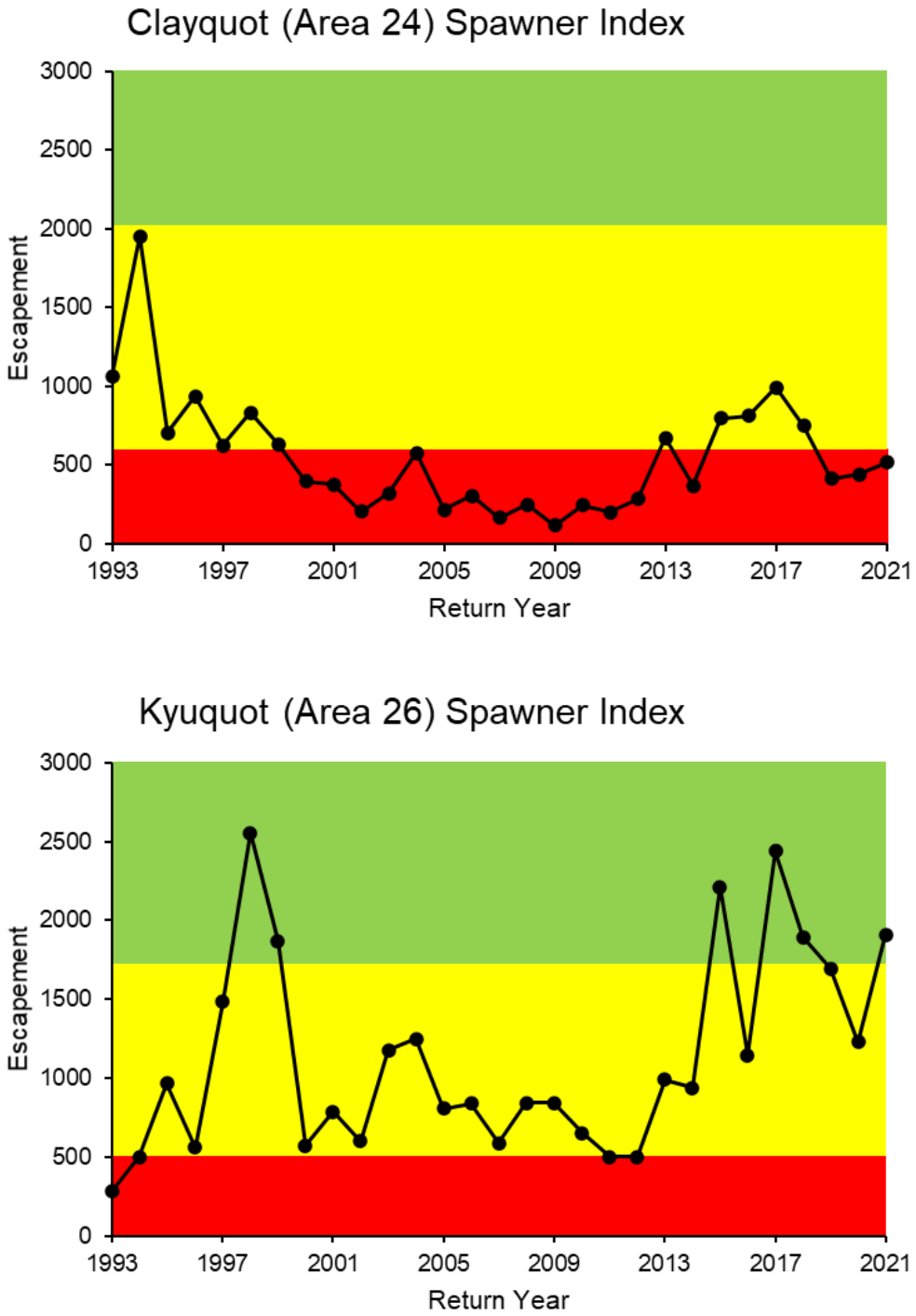

Figure 7. Spawner abundances of SWVI (top) and NWVI (bottom) CUs relative to provisional lower (red) and upper (green) biological benchmarks (0.40 and 0.85 $S_{MSY,}$ respectively; S_{MSY} for index stocks is estimated by the habitat model described in Parken et al. 2006). For each CU, spawner abundances are the summed estimates for wild index stocks that receive little or no enhancement. For each CU, the upper and lower biological benchmarks are summed across the same wild index stocks.