2022 MARINE SURVIVAL FORECAST OF SOUTHERN BRITISH COLUMBIA COHO

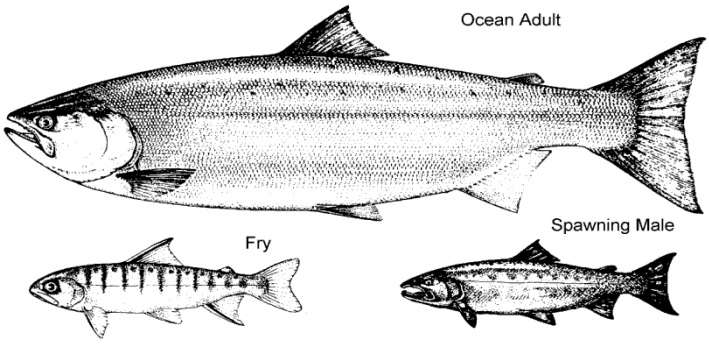

Figure 1: Coho salmon at three life stages: freshwater rearing fry; ocean rearing adult; and returning male. This image has been used on previous Coho Stock Status reports, origin unknown.

Figure 2: The Province of British Columbia, showing the major rivers in the South Coast, Lower Fraser and Interior BC areas.

SUMMARY

The observed indicator marine survivals and aggregate abundances from 2021 were generally higher (+15% to +52%) than the previous year. Carnation Creek wild indicator was much higher (+1092%), however, the 2020 observed marine survival was unusually low and Coded-Wire Tag (CWT) issues was suspected. The Black Creek wild indicator and Inch Creek had marine survivals were lower in 2021, with decreases of 38% and 44%, respectively. Almost all observed indicator survivals were higher than the forecasted levels (+26% to +718%), with Carnation Creek wild indicator as an exception with an 8% decrease from the 2021 forecast.

The 2022 forecasts for Coho indicator marine survivals are generally showing decreases from 2021 observed values (minus 10% - 45%), with the exception of Carnation Creek and Area 12 Aggreagate (+24% and +1%, respectively).The best performing models that were used for the indicators are the Three Year Average (Big Qualicum, Area 12 Aggregate and Area 13 Aggregate), the Sea Surface Temperature at Amphitrite Point Lighthouse (Carnation), the North Pacific Gyre Oscillation (Black (Wild), Inch and Robertson) and the ARIMA with Box-Cox transformation (Interior Fraser Aggregate).

The Chrome Island salinity Distribution Index indicates an outside distribution for Coho suggesting a late summer return of Coho adults to the Strait of Georgia.

INTRODUCTION

Coho marine survival and aggregate abundances for Indicator stocks in southern British Columbia and the Fraser River have been forecast annually since 1996. The estimates from

these Indicators are used in International stock management processes and domestically for informing fishery management, while the forecasts are used for shaping future fisheries.

Starting with the 2015 forecast, the Ocean Climate Indices was incorporated into the suite of models examined for the two WCVI indicators. In the following year, these indices were included as possible forecast models for the rest of the marine survival indicators. These models were not considered for the Aggregate Indicators.

Previously, marine survival or aggregate abundance forecasts for southern BC Coho stock groups have been published as Science Advisory Reports. Starting in 2012, this information is set out in an unpublished document for use in domestic and international Coho stock management processes.

Descriptions of the assessment methods, data sets, forecast models and sources of uncertainty have been documented in previous papers and will not be described herein. For more information see Simpson *et al.* (2004), DFO (2006), DFO (2008), DFO (2009) and DFO (2012). Baillie *et al.* (2005), DFO (2010), DFO (2011), DFO (2013), DFO (2014), DFO (2015), DFO (2016), DFO (2017), DFO (2018), DFO (2019), DFO (2020) and DFO (2021) are similar reports that are published on the Fisheries and Oceans Canada Library.

Data Sources

The data set used for the Area 12/13 aggregates is based on a subset of Coho populations from each Area. The forecast is based on the expected total return to the average stream in the area (derived via the P_{max} methodology to standardize escapements in the aggregate area). For the Interior Fraser aggregate, the data represents the estimated total abundance for that aggregate. Each datum includes Natural Spawners, Broodstock removals and Fishery catches, both recreational and commercial. All other indicators in this forecast use the survival rate between release of smolts and the resulting return of adult Coho, which includes Coho caught in commercial, sport and First Nation fisheries, and entering freshwater to spawn. There are four hatchery stocks used, Robertson Creek Hatchery, Quinsam Hatchery, Big Qualicum Hatchery and Inch Creek Hatchery. Additionally, there are two wild stocks used, at Black Creek and Carnation Creek.

Exploitation Rate

A change in the methodology used to estimate the exploitation rate for adipose fin clipped Coho indicators was incorporated into the 2015 forecast exercise and has been continued with the current forecast. The Black Creek wild indicator is the exception to this due to the lack of an adipose clip marker. Please see the 2015 forecast for further information.

Directed commercial and recreational fisheries on Coho were severely restricted in the late 1990s in response to decreasing stock abundances. Until recently most exploitation of Coho was incidental catch in commercial fisheries that targeted other species. Generally, non-retention of unmarked Coho is in effect in most areas except for Food, Social and Ceremonial fisheries for First Nations in specific areas where local abundances allow for retention of unmarked Coho (PSC 2013).

Marine Survival

Marine survival is defined as the portion of the coded-wire tagged smolt release that has survived to be either caught in marine fisheries or returned to freshwater as adult Coho , i.e. (Catch + Escapement) / Release. The 2016 brood year progeny from Big Qualicum hatchery were unfortunately lost due to a pump failure, leaving a missing datum from this indicator. In order to include the time series models as part of the forecast, the missing datum was infilled by using a regression of known Big Qualicum marine survivals against the Quinsam River Hatchery marine survivals ($R^2 = 0.46$), and using the corresponding Quinsam survival for the 2016 brood year to estimate a value for Big Qualicum.

The brood year 2017 escapement of coded-wire tagged adult Coho to the wild indicator, Carnation Creek, was unusually low. 2 of 33 adults were found to have a tag, which resulted in a marine survival of 0.1% from a release group of 2106 smolts, a decrease of 94% from the previous year. Marine survivals over the previous 10 years averaged 1.3% (range 0.3% - 2.2%). Also, observed marine survivals from all other indicators increased an average of 69% from the previous year (range -2% to +243%: see Appendix 2). In addition, nearly all smolts had a coded-wire tag applied and although a similar ratio is not expected, the observed very low return suggests an issue with either smolt tag application or adult tag detection. Therefore, for the purposes of the forecast models, a marine survival was estimated using a regression of known marine survivals with the results from Robertson Creek Hatchery Coho.

Similar to the BY 2016 Big Qualicum infill, a regression with Robertson Creek Hatchery marine survival ($R^2 = 0.52$) was used to estimate the BY 2017 Carnation Creek marine survival for the purposes of running the forecast models.

Forecast Models

The forecast is chosen from a variety of both time-series and biologically based methods which are evaluated and selected based on performance criteria. See Simpson *et al.* (2004) for a description of the times series models.

The 2022 Interior Fraser Aggregate forecast is based on using an ARIMA (0,1,1) with Box-Cox transformation model which the retrospective analysis showed had the best predictive capability relative to the other time series models.

Climate Indicators

Large scale climate indicators have been shown to be correlated to biological processes, including marine survival of Pacific salmon (Trudel *et al*., 2015). In addition, the odd\even year has been shown be a co-variable in association with the climate indicators. This was used in developing the forecast model regressions.

The marine survival forecast models in this report use direct data input from the specific populations and a marine survival forecast is generated in a naïve manner with respect to climate trends. Specifically, marine climate indicators such as the Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation (NPGO), El Nino Southern Oscillation (ENSO), and Sea Surface Temperature (SST) will be included. In this year's annual report the marine climate indices will be included in the forecast model comparison for all the marine survival indicators.

The data for the climate indicators was obtained from: PDO, NPGO, ENSO and Amphitrite SST

Passive Integrated Transponder (PIT) Tags
PIT tags are small (9-12 mm) inert devices that are inserted into the abdominal cavity of juvenile salmonids. These tags utilize Radio Frequency Identification (RFID) technology that is read when a tag passes over an antenna at short distances. The antenna records the date, time and unique ID from each tag. When the unique ID is linked to a tagging database the origin, time of tagging and age can be determined.

This method is currently being used to estimate survival at different life stages. The ability to link the unique ID back to the tagging database allows for calculations of survival through various life stages. Marine survival can be calculated by comparing the detections from adult returns to the number of smolts that were initially tagged. PIT systems can also be used to estimate escapement through expansion factors determined from the proportion of PIT tags in a population that passes through a counting fence. After a fence has been removed, the expansion factor can then be applied to the PIT detections from permanent antennas to calculate the total escapement.

For the 2022 forecast, PIT data was used to calculate the 2021 marine survival for Black Creek. This was because no smolts were tagged with CWTs in 2020 due to the COVID-19 pandemic. The same methods were used to calculate PIT marine survival as typically are used for CWT marine survival.

Appendix 3 shows Coho marine survival estimates using Passive Integrated Transponder (PIT) from the Cowichan, Black, Quinsam, Big Qualicum, Englishman, Puntledge, Nanaimo and Sakinaw systems.

RESULTS

Graphical depictions of the observed marine survival or aggregate abundance for all Coho indicators used in this forecast are shown in Appendix 1, while Appendix 2 is a table that shows the observed 2020 and 2021 values, and the forecast for 2022 returns.

Johnstone Strait/Mainland Inlets
In 2021 the observed return to the average stream in Area 12 was 696, 24% higher than forecast, and the Area 13 return was 303, 50% higher than forecast. Compared to the brood year (2018), returns to Area 12 were 1.63 times greater, while escapement to Area 13 were similarly improved at 1.64 times greater. Our indicators at the Keogh River and Black Creek provide smolt abundance information; in 2020, we saw higher than average smolt production at both Keogh River (86,770) and Black Creek (83,000). Based on the observed returns in 2021, marine survival is improving but continues to be low for both Area 12 and Area 13 Coho stocks.
The Area 12 forecast for 2022 is 702, which is 1% higher than the returns in 2021. The Area 13 forecast is 217, which is 28% lower than the 2021 observed indices. Coho abundance in this region can be characterized as 'well below average' for both Area 12 stocks and for Area 13 stocks. See Simpson et al., 2004 for description of characterizations. Smolt production in 2021 was above average for both Black Creek (86,119 smolts) and the highest observed (129,000) since the Keogh River project began in 1977. Keep in mind that these more recent year returns

do not have the high levels of exploitation as in the past and these forecasts are highly uncertain. These forecasts should be viewed with caution due to the continued decline of contributing index streams, further exacerbating the uncertainty in the expectations.

Georgia Basin – West

The observed 2021 marine survival rates of Quinsam and Big Qualicum Hatcheries were 2.0% and 3.3%, respectively, and the marine survival at the wild indicator at Black Creek was 2.3%. For Quinsam Hatchery, this marine survival is 20% higher than the previous year and 85% higher than the 2021 forecast. For Big Qualicum the marine survival is higher than the previous year by 30% and substantially higher than the forecast by 718%. The wild indicator at Black Creek was lower than the previous year (-38%) but higher than the forecast (+130%).

After a retrospective analysis with the addition of the 2021 return, the best performing forecast model for the Quinsam River Hatchery Indicator changed to the PDO index. The best performing model for Big Qualicum was the 3 year average. The best performing model for the Black Creek Indicator was still the NPGO.

The 2022 forecast for the three indicators is for a continuation of the low marine survival levels seen in recent years although the figure in Appendix 1 suggests a slow increase since the low levels in the early 2000s. The model forecasts a marine survival of 1.1%, 2.1% and 1.2% for Quinsam Hatchery, Big Qualicum Hatchery and Black Creek (changes of -43%, -36% and -45% from 2021 observed levels), respectively. Smolt production in 2021 (86,119) was above average for Black Creek.

Lower Fraser

The observed 2021 marine survival from the Inch Creek Hatchery indicator was 4.4% which was lower than the previous year (-44%), but was higher than the forecast level (+92%). The retrospective analysis showed that the best performing model has remained the NPGO climate index. The 2022 forecast for marine survival for this indicator is 2.7%, a decrease (-39%) from the observed level in 2021.

Interior Fraser

The preliminary estimate of the 2021 pre-fishery abundance for the Interior Fraser Aggregate was 93,308, 113% higher than the 2021 forecast and 15% higher than the 2020 pre-fishery abundance of 81,100 (2020).

The forecast model selected for the 2022 return is an ARIMA (0,1,1) with Box-Cox transformation, which is different from the 2021 forecast that used a linearized Ricker stock-recruit relationship. The 2022 forecast of pre-fishery abundance for the Interior Fraser Aggregate is 83,613 Coho with an 80% forecast range of 25,542-173,248. Note that the confidence interval has changed from 50% to 80% to highlight the uncertainty in these forecasts. This forecast is 10% less than the preliminary estimate of recruitment in 2021.

Southwest Vancouver Island

The two indicators in this Management Unit are Robertson Creek Hatchery and Carnation Creek, both located in Barkley Sound. For the Robertson indicator the estimate of Coho escapement is based on the estimated abundance from the Stamp Falls fishway project.

The observed 2021 marine survival of 6.9% for Robertson (Stamp) Indicator was higher than the previous year (+52%) and the forecast (+26%). The marine survival of the wild indicator at Carnation Creek was 1.2% which was slightly lower than the forecast (-8%), but significantly higher than 2020 (+1092%). However, the marine survival for 2020 was unusually low due to a small number of returning CWTs.

For the 2022 forecast, two models (NPGO and PDO) that provided similar performance have been identified in the forecast table below for the Robertson (Stamp) Indicator. In evaluating those two models the NPGO model forecast of 4.5% is a 34% decrease in marine survival relative to what was observed in 2021 and the PDO based forecast of 7.5% is a 9% increase relative to 2021. WCVI Stock assessment is recommending the PDO based forecast as it aligns with other marine indicators. Improvements observed in the 2021 returns were likely attributed to shifts in marine conditions that favour salmon survival (Coho returns in 2021 tended to be above forecast in many jurisdictions). Marine conditions had continued to improve for the 2021 ocean residency of the 2022 return. For instance, generally cooler marine sea surface temperatures in 2021 into 2022 as well as a shift to a more dominant fat-rich Northern Copepod biomass (Ocean Indicators Summary for 2021 | NOAA Fisheries) in 2021 should result in continued improvements in WCVI Coho survival (demonstrated by the PDO based forecast) and not a decline as observed in the NPGO based forecast.

The best performing model for the Carnation Wild Indicator has changed to the Sea Surface Temperature index. The marine survival for the wild indicator at Carnation Creek is forecast to be 1.5%, a 24% increase from the 2021.

Distribution

The distribution Index is a metric that uses salinity in the Strait of Georgia to forecast whether Coho will be present in the Strait during their final summer ("inside") or wait until fall to re-enter the Strait ("outside"). In Figure 3, the central red line indicates the base period average distribution of Coho catches between Strait of Georgia and WCVI fisheries. Deviations from this line suggest a greater 'Inside' or 'Outside' catches of Coho, if the same fisheries regimes were in place.

This model is based on the relationship between salinity and the relative quantity of Coho that were harvested, using data from a base period (1975-1997). As fisheries have been restricted since the late 1990's the relationship is fixed and cannot be updated or have a retrospective analysis.

The average salinity as measured at Chrome Island lighthouse for February and March 2022 was 27.35 ppt, which results in a $P_{in\ side}$ statistic of 0.190, suggesting an outside distribution of Coho.

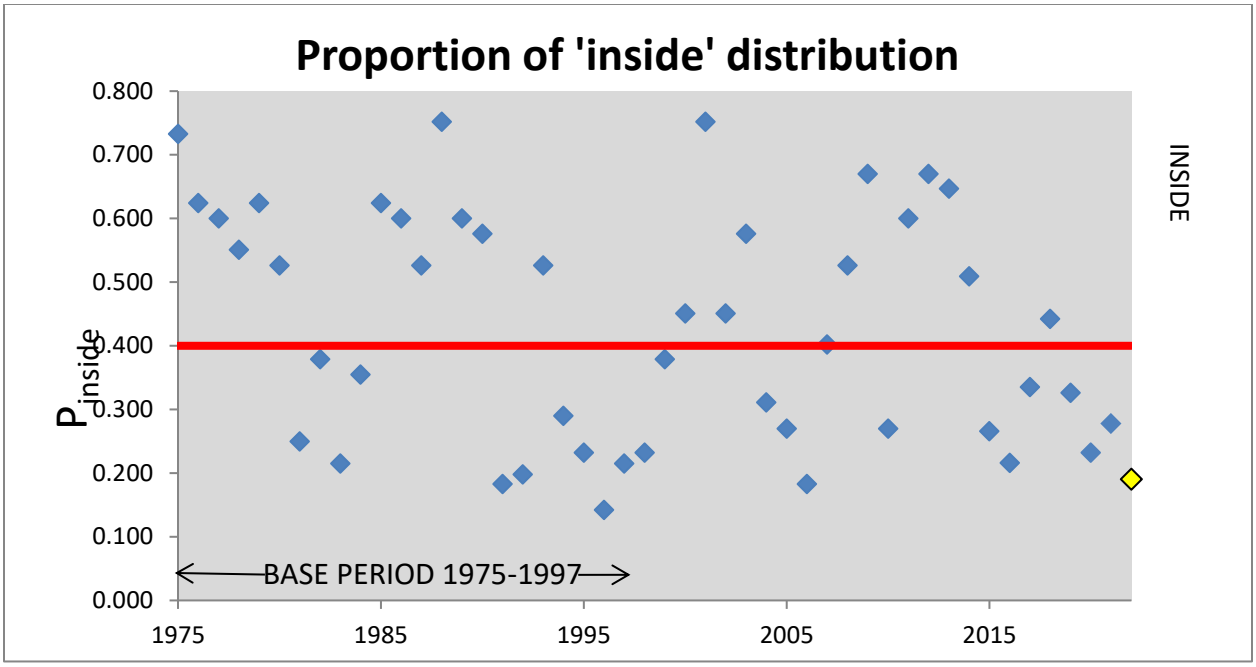

Figure 3. Distributional index for Strait of Georgia Coho, with observed data from 1975-1997, and results from the salinity-based model for 1998-2022. The red line indicates the division between an 'inside' year and an 'outside' year. The yellow datum represents the current year.

ACKNOWLEDGEMENTS

The Coho forecast for southern British Columbia requires data from many sources and is very much a collaborative document. All sources are DFO staff except where noted. Data analysis of the Interior Fraser Management Unit was completed by Michael Arbeider, and the Johnstone Strait Aggregates by Pieter Van Will and Matt Clarke. Karalea Cantera (author) completed analysis of WCVI and Strait of Georgia indicators.

Freshwater creel survey data were provided by Joan Bennett (Strait of Georgia) and Michael Arbeider (Lower Fraser). Coho data from the WCVI indicators was collated by Diana McHugh and Pieter Van Will. Cheryl Lynch provided escapement data from the hatcheries. Wild Coho data were provided by Andrew Pereboom (Black Creek) and, Dr. Peter Tschaplinski and Steve Voller (BC Ministry of Environment - Carnation Creek). Commercial catch data was provided by Lee Keary. Chrome Island salinities were collected by the lighthouse keeper and provided by Peter Chandler, Institute of Ocean Sciences. PIT tag data and support was provided by Kevin Pellett. Steve Baillie graciously offered assistance and answered many questions.

Ocean Climate indices were obtained from various internet sources noted in the text.

REFERENCES AND PREVIOUS FORECAST DOCUMENTS

Ocean Climate index sources were accessed in February 2021.

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FOR MORE INFORMATION

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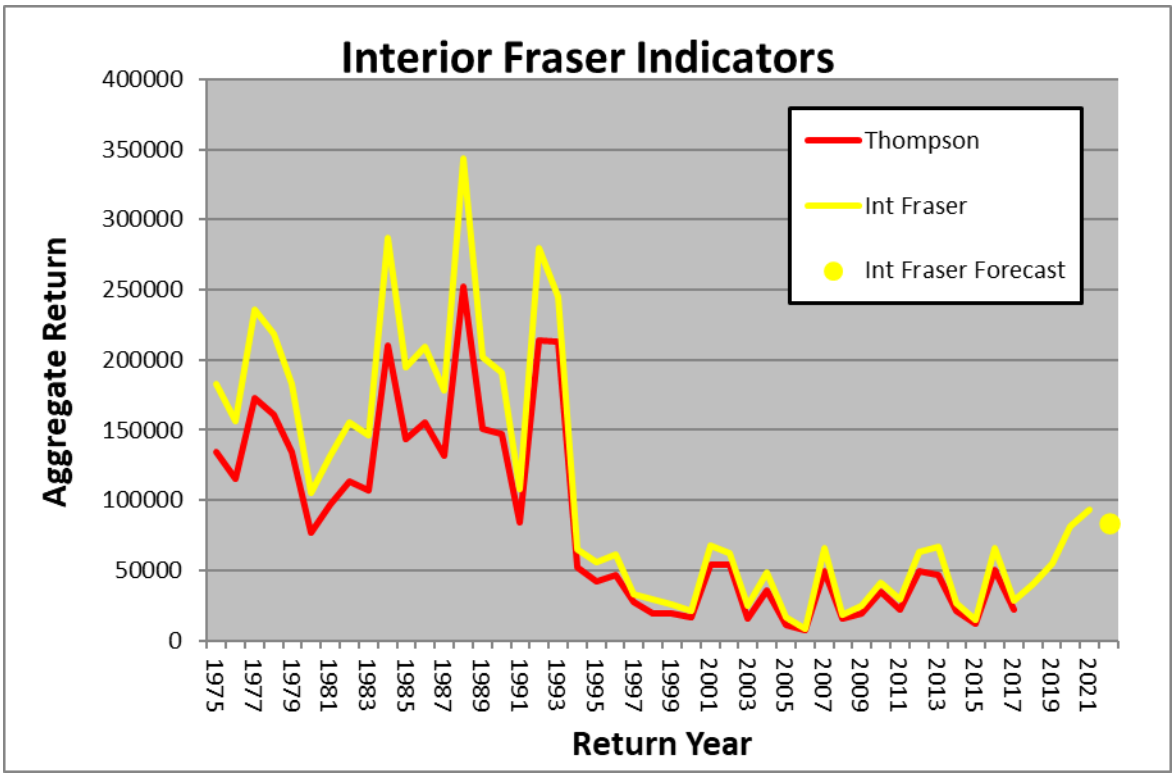
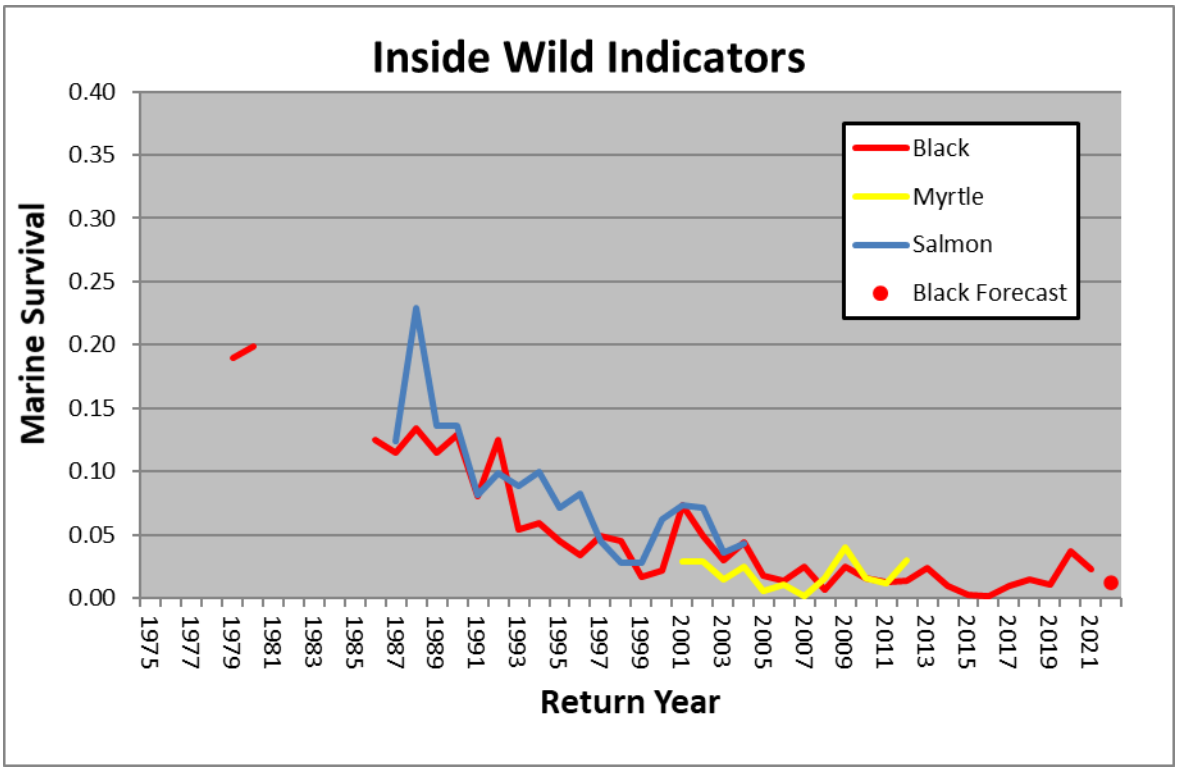
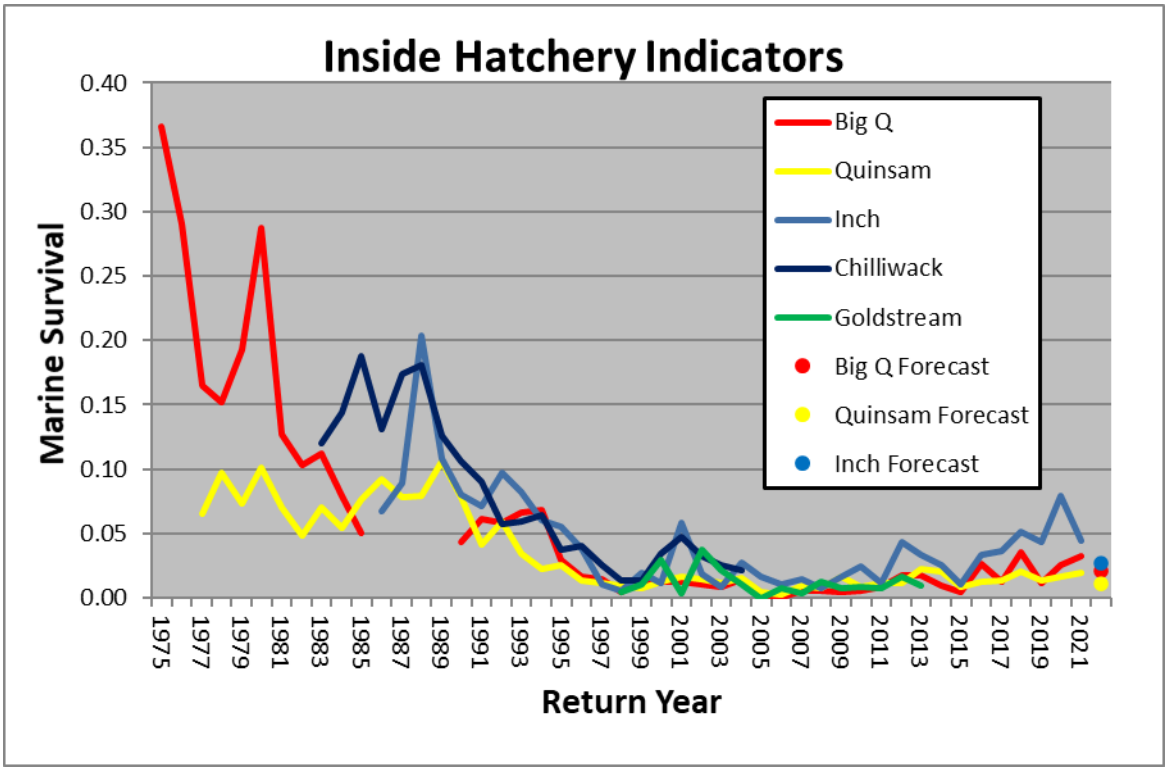
Appendix 1. Marine survival or aggregate abundances for southern BC Coho indicators, including the 2022 forecast.






Inside Hatchery Indicators
Marine Survival
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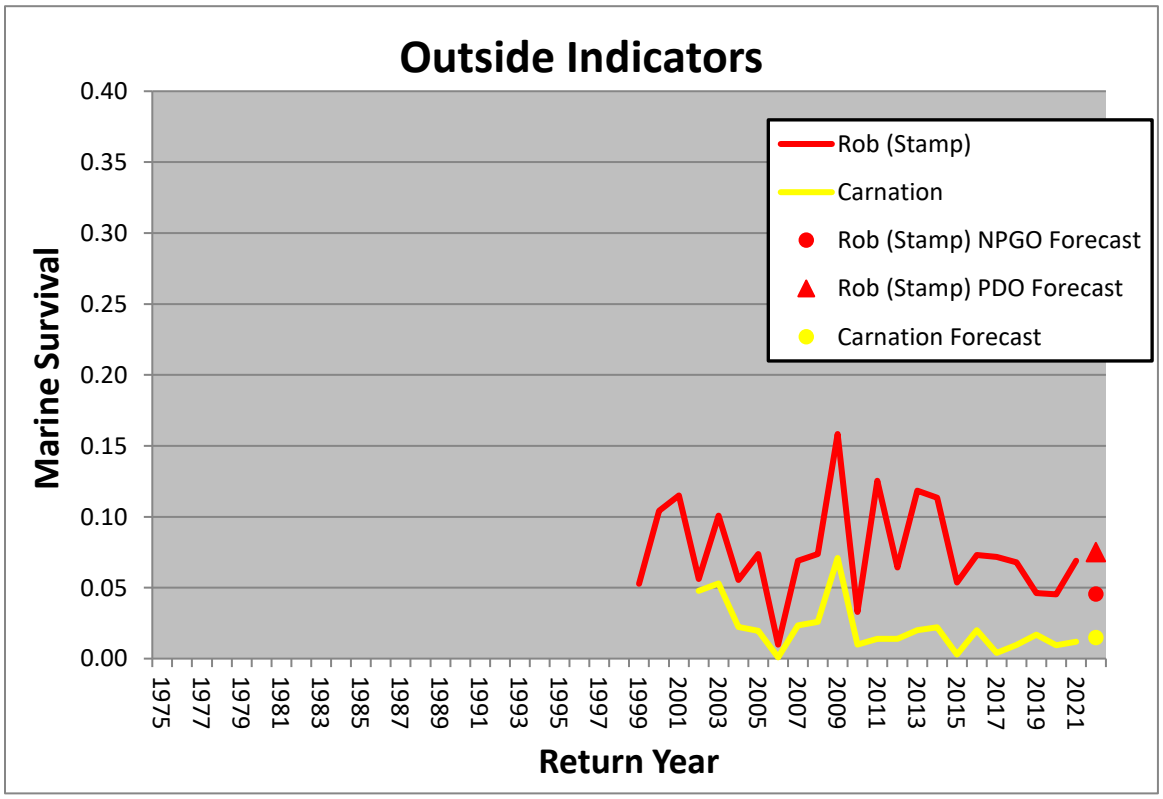
Inch
Chilliwack
Goldstream
Big Q Forecast
Quinsam Forecast
Inch Forecast


Outside Indicators
Marine Survival
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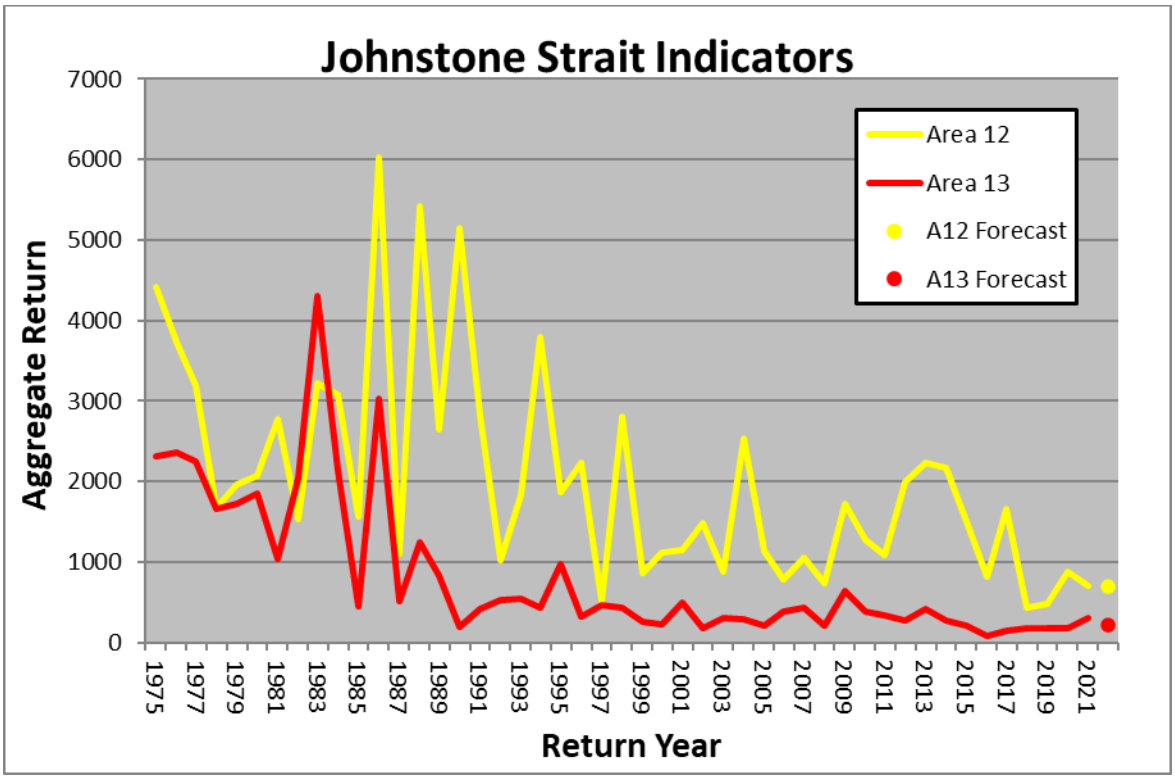
Rob (Stamp)
Carnation
Rob (Stamp) NPGO Forecast
Rob (Stamp) PDO Forecast
Carnation Forecast


Johnstone Strait Indicators
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Return Year
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Area 13
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Appendix 2. Observed and forecast marine survival and aggregate abundance indicators from southern BC Coho indicator stocks.

Column Headings

Stock: The name of the Management Unit in **Bold**, followed by the individual indicator or stock grouping within that Management Unit.

2020 Observed: The values in this column represent either the aggregate value (whole numbers) or the estimated marine survival (decimal numbers), from the 2019 return year.

2021 Forecast, 50% CI, and Model refer to the forecast for the 2020 return year. The actual forecasted value is given first, followed by the 50% confidence interval, then the forecasting model used.

2021 Observed, Change from forecast and Change from 2019 refer to the estimated values for each indicator, then the % change from the forecasted value and from the observed value in the previous year. The % change is in relation to the base value so a marine survival of 1.5% in year one increasing to 2.0% in the next year is expressed as a plus 33% change and is highlighted in green. A decrease of 2.0% to 1.5% is expressed as a minus 25% change and is highlighted in pink.

2022 Forecast, 50% CI and Model refer to the forecast for the current year.

Change from 2021 is the change in value from the observed 2020 value to the 2021 forecast. Each change is highlighted in green or pink, depending on whether the change is up, or down.

Distribution Index (*P_{inside}*) does not have an annual inside/outside measure so there are no Observed data to report or compare to.

Stock	2020	2021			2021	Change from forecast	Change from 2020	2022			Change from 2021
	Observed	Forecast	50% CI	Model	Observed			Forecast	50% CI	Model	
Johnstone Strait/Mainland Inlets											
Area 12 Aggregate	874	561	390 - 808	3YRA	696	**24%**	**-20%**	702	488-1,009	3YRA	**1%**
Area 13 Aggregate	180	202	139 - 294	3YRA	303	**50%**	**68%**	217	150-315	3YRA	**-28%**
Georgia Basin - West											
Quinsam Hatchery	0.017	0.011	0.008 - 0.015	SST	0.020	**85%**	**20%**	0.011	0.008 - 0.016	PDO	**-43%**
Big Qualicum Hatchery	0.025	0.004	0.002 - 0.006	ENSO	0.033	**718%**	**30%**	0.021	0.011 - 0.038	3YRA	**-36%**
Black Creek (wild)	0.037	0.010	0.006 - 0.017	NPGO	0.023	**130%**	**-38%**	0.012	0.007 - 0.022	NPGO	**-45%**
Lower Fraser											
Inch Hatchery	0.079	0.023	0.015 - 0.036	NPGO	0.044	**92%**	**-44%**	0.027	0.017 - 0.043	NPGO	**-39%**
Interior Fraser											
Interior Fraser Aggregate*	81,100	43,882	36,969 - 52,087	Ricker	93,308	**113%**	**15%**	83,613	25,542-173,248	ARIMA with Box-Cox	**-10%**
South-west Vancouver Island											
Robertson (Stamp Falls) Hatchery**	0.045	0.055	0.040 - 0.075	NPGO	0.069	**26%**	**52%**	0.045	0.033- 0.062	NPGO	**-34%**
								0.075	0.054 - 0.103	PDO	**9%**
Carnation Creek (wild)	0.001	0.013	0.006 - 0.028	ENSO	0.012	**-8%**	**1092%**	0.015	0.009 - 0.025	SST	**24%**
Distribution Index (P_{inside})		0.278	0.204 - 0.366	Salinity				0.190	0.134-0.263	Salinity	

* Interior Fraser Aggregate uses an 80% CI for forecast uncertainty

** WCVI Stock Assessment has chosen to use the PDO model, which ranked closely to the NPGO. See text for rationale.

Appendix 3. PIT tag application on wild Coho smolts, and the associated jack and adult escapement. Survival estimates in this table do not include any exploitation data.

Watershed	Brood Year	Release Year	# Tags used	Jack Return	Adult Return	Smolt to Jack Survival	Smolt to Adult Survival
Cowichan	2016	2018	534	0	15	0.00%	3.16%
Cowichan	2017	2019	4821	19	219	0.44%	4.82%
Cowichan	2018	2020	1642	1	100	0.06%	6.73%
Cowichan	2019	2021	5416	5		0.09%	
Black Creek	2016	2018	4000	92	26	2.42%	0.65%
Black Creek	2017	2019	4300	183	78	4.26%	1.81%
Black Creek	2018	2020	8326	121	167	1.45%	2.01%
Black Creek	2019	2021	8647	217		2.51%	
Quinsam	2019	2021	5000	30		0.06%	
Big Qualicum	2019	2021	5000	18		0.36%	
Englishman	2019	2021	3647	10		0.38%	
Puntledge	2019	2021	5000	90		1.80%	
Nanaimo	2019	2021	5000	14		0.42%	
Sakinaw	2018	2020	1094	16	9	1.46%	1.29%
Sakinaw	2019	2021	3154	22		1.10%	

The only comparison that can be made at this time is the Black Creek indicator, Brood years 2016 & 2017. Using the estimated CWT and ER-Effort model estimate for exploitation rate of 19.6% and 4.3%, respectively, to the PIT-based adult escapement results in a marine survival of 0.8% and 1.9%, respectively. For 2018, marine survival was calculated only from PIT tags due to issues with CWT tagging during the COVID-19 pandemic in 2020. To clarify:

Watershed, Brood Year	CWT Marine Survival	PIT Marine Survival
Black, BY 2016	0.011	0.008
Black, BY 2017	0.037	0.019
Black, BY 2018		0.023

CWT Marine Survival uses CWT for escapement, CWT and ER-Effort Model for exploitation. PIT Marine Survival uses PIT tags for escapement, CWT and ER-Effort Model for exploitation.

On a sample size of two, both data suggest that a PIT based marine survival is lower than the corresponding CWT based marine survival. Over the ensuing years additional observations will increase the size of this dataset to allow for a more significant comparison.