Improving Terminal Abundance Estimates of Spring- and Summer-run Age 5₂ Fraser River Chinook Salmon by Incorporating a Second CPUE Dataset from the Albion Test Fishery

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Fraser River Chinook salmon (*Oncorhynchus tshawytscha*) are currently managed as five stock aggregates that share similar ages and return timing (Fig. 1). An in-season Bayesian model has been used since 2012 to estimate the total abundance of two of these aggregates: spring- and summer-run age 5₂ Chinook. This model predicts the terminal aggregate abundance to the mouth of the Fraser River using cumulative weekly catch-per-unit-effort (CPUE) from the Albion test fishery and reconstructed annual run size. These predictions are used as an in-season tool to manage Fraser River fisheries in line with the expected abundance of the aggregated spring- and summer-run age 5₂ Chinook via a “zoned” approach (DFO 2018). The abundance of these aggregates has been declining in recent years, and it is critical to improve the precision of the in-season model for sustainable fishery management.

Fig. 1. Run timing of Fraser Chinook stock aggregates at the Albion Test Fishery, based on 2000–2001 data.

The current model uses cumulative catch-per-unit-effort (CPUE) data from the test fishery at Albion (near Fort Langley, B.C., Canada), which since 1981 has used a single panel (SP) net 200 fathoms long with 203 mm mesh. Catch and effort data are cumulated by week, starting the first full week in May (stat week 5_1), to provide the input to the model. Run size values used in the model are derived from a separate model that reconstructs the run size of Chinook salmon at the mouth of the Fraser River (terminal return) for individual populations and stock aggregates (English et al. 2007). The in-season abundance model fit to these data is a log-linear regression of cumulative CPUE against the terminal return, and a different regression is fit for each statistical week from 5_1 through 7_2 (first week of May until second week of July; see Chamberlain and Parken 2012). This regression is then used to predict the terminal return based on the cumulative CPUE for that stat week. The final in-season estimate typically occurs with stat week 6_2, when the cumulative CPUE is most often the best in-season predictor of the terminal return.

In 2004, the test fishery at Albion began fishing every other day with a variable mesh net (VMN) that consists of eight panels of four different mesh sizes (152 mm, 178 mm, 203 mm, and 229 mm; two 25-fathom panels each). The CPUE data from this VMN has not yet been used as an input for the run size model, as several years of data were required before its predictive abilities could be assessed. The objective of this study was to incorporate the VMN data into the in-season run size model to determine its effect on the precision of the weekly estimates. The predictive abilities of three different abundance index (CPUE) inputs to the Bayesian model were assessed: a model with only SP CPUE inputs, a second with only VMN CPUE inputs, and a third with both SP and VMN CPUE inputs (hereafter called a ‘combo model’).

The predictive Bayesian model is run using the statistical software R (v. 3.6.0); it also makes use of the modeling software OpenBUGS (v. 3.2.3 rev 1012). Predicted run sizes from three versions of the model that incorporated three datasets (SP only, VMN only, and a combination of these datasets) were compared across 10 statistical weeks (May through mid-July) over six years (2012–2017). CPUE for statistical weeks 5_2 through 7_3 in each year was calculated as the sum of weekly catch divided by the sum of weekly test fishing effort (thousand fathom minutes) as follows:

$$CPUE_{week} = \frac{\sum Catch}{\sum Effort}$$

Cumulative CPUE was the cumulative sum of weekly CPUE, starting with week 5_2 as the sum of CPUE in week 5_1 and 5_2; this value and the annual terminal abundance estimate were the abundance index inputs into the model. For predictions made in statistical weeks 5_2 and 5_3, SP data from 2014 and 2016 and VMN data from 2013 and 2016 were excluded from the model inputs due to a cumulative CPUE of 0, which prevented the model from completing calculations. Retrospective performance of the model was examined by comparing median run size estimates and 95% prediction intervals to the reconstructed annual run size estimate using mean average percent error (MAPE). MAPE is a measure of prediction accuracy of a forecasting method and expresses accuracy as a percentage where a low value suggests less error.

Table 1. MAPE summary for the run size prediction model with each of three datasets. Note that there is no MAPE calculated for the combo model in statistical week 5_2 and 5_3 as the model cannot support cumulative CPUE input of zero. Grey stat weeks are the weeks when the model estimate is used to inform fishery management.

Stat Week	combo	VMN	SP	Best model prediction
5_2	NA	50.0%	35.8%	SP
5_3	NA	33.5%	31.4%	SP
5_4	31.7%	46.7%	33.2%	combo
6_1	36.0%	41.7%	45.3%	combo
6_2	25.1%	35.4%	37.9%	combo
6_3	21.2%	24.2%	33.7%	combo
6_4	26.7%	23.7%	30.5%	VMN
7_1	24.2%	25.2%	24.5%	combo
7_2	21.0%	30.9%	28.0%	combo
7_3	22.4%	34.8%	27.2%	combo

Generally, the combo model had lower MAPE and smaller prediction intervals than the model that incorporated only either SP or VMN data (Table 1). However, model performance varied depending on the statistical week and year, which may be the result of a hyperstable relationship developing between CPUE and terminal abundance. All models performed worse in years of low terminal run abundance (e.g., 2017, Fig. 2). MAPE for the model incorporating only SP data increased since the model was developed in 2012. When examining model outputs from only the statistical weeks in which in-season management decisions are made (week 5_2, 5_4, and 6_2), the combo model typically had the lowest MAPE values, but not always. In most years, the combo model performs equally as well as the SP model at predicting the correct management zone (Table 2). There is a light improvement for 2015 where the combo model was able to predict the correct management zone earlier than the SP model. None of the models were able to detect the high abundance observed in 2014.

Fig. 2. Estimates of terminal run size in 2017 with 95% predictive intervals for each statistical week when incorporating each of the three datasets (SP = single panel data only; VMN = variable mesh data only; combo = both SP and VMN datasets). Solid line is the post-season terminal run size estimate.

Table 2. Comparison of the in-season model prediction with the post-season abundance estimate in terms of the zoned management approach. Green cells indicate the in-season prediction matches the post-season prediction.

Year	Stat Week	Fishery Zone (Post-season)	In-season model prediction		
			combo	SP	VMN
2012	5_2	zone 2	zone 1	zone 2	
	5_4		zone 2	zone 2	zone 2
	6_2		zone 2	zone 2	zone 2
2013	5_2	zone 1	zone 1	zone 1	zone 2
	5_4		zone 1	zone 1	zone 1
	6_2		zone 1	zone 1	zone 2
2014	5_2	zone 3		zone 1	zone 2
	5_4		zone 2	zone 1	zone 2
	6_2		zone 2	zone 2	zone 2
2015	5_2	zone 2	zone 2	zone 1	zone 2
	5_4		zone 2	zone 1	zone 2
	6_2		zone 2	zone 2	zone 2
2016	5_4	zone 1	zone 1	zone 1	zone 2
	6_2		zone 1	zone 1	zone 2
2017	5_2	zone 1	zone 1	zone 1	zone 2
	5_4		zone 1	zone 1	zone 1
	6_2		zone 1	zone 1	zone 1

Future model development would benefit from exploration of whether incorporating environmental variables may allow for more accurate estimation of terminal abundance of these aggregates, particularly given the potential impact of future climate change on Chinook abundance and return timing. Another future consideration could be an assessment of separating the VMN CPUE by mesh size.

In summary, incorporating both the SP and VMN net data improves the in-season median estimate of run size and modestly reduces uncertainty in some years. Incorporating VMN data could also make the overall dataset more representative of the stock aggregates since a greater range of sizes are caught. The model still does not detect very high and very low returns well in-season. While using the combo model results in no change to in-season management actions, there may be a desire to move to a management system of allocating catch numbers instead of using the zoned approach. To do this, more precise estimates of in-season run size are required to ensure confidence

in management actions. This model was originally developed in response to a very specific management strategy; there is a need to adapt the tool to match changes in management and conservation objectives.

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