**Retrospective Summary**

We examined temporal changes in Fraser River sockeye salmon productivity (log(R/S)) using three metrics of metapopulation variability: 1) the mean coefficient of variation of the components within in aggregate (CVC), 2) the synchrony index (), which reflects the degree of similarity in the dynamics of an aggregate’s components, and 3) aggregate variability (CVA) which represents the cumulative effects of CVc and on temporal variability. We used 10-year moving windows to calculate trends in each metric for two Fraser River datasets. The first contained 11 CUs with time series of productivity extending to 1948, the second contained 18 CUs with time series extending to 1973.

Mean Fraser River sockeye salmon productivity declined from the late 1980s through 2005, the brood year producing the majority of the fish that returned in low numbers in 2009. Subsequently the aggregate exhibited several years of higher productivity, but the trend has remained variable and productivity has recently declined again (Fig. 2a). Mean CVC (i.e. the temporal variability of the “average” CU’s productivity) was relatively stable for most of the time series before showing an increase in the 1990s that steepened over several years (Fig. 2b). Productivity was highly synchronized in the first decade of the time series, followed by a variable, but generally asynchronous period. In the early 2000s, approximately when CVC reached unusually high levels, synchrony increased again (Fig. 2c). Changes in CVA mirror these patterns, showing a dramatic increase in the early 2000s (Fig. 2d).

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Figure 1. Temporal variation in Fraser River sockeye salmon productivity, log(recruits/spawner). (a) Trends in observed productivity for 18 CUs with time series beginning between 1948 and 1973; heavy black line represents the unweighted mean. 10-year moving windows of (b) the mean component coefficient of variation, weighted by abundance, (c) the synchrony index, and (d) the coefficient of variation of the aggregate. Solid blacks lines represent trends for 11 CUs with time series extending back to 1948, light red lines represent trends for 18 CUs beginning in 1973.

**Forward-Simulation Summary**

*Model specification*

The closed-loop model forward simulates, with stochasticity, the dynamics of 19 Fraser River CUs. For CUs with evidence of cyclicity (based on the most recent WSP report), recruits are generated using a Larkin model; all other CUs use a Ricker model with autocorrelated process variance (correlation coefficient fixed at 0.2). To parameterize each CU’s stock-recruit relationship we used median estimates of , , and from an independent analysis.

Within the model yearly recruitment deviations are drawn from a multivariate normal distribution with mean 0 and standard deviation described by the variance-covariance matrix

where represents the variance parameters of *n* CUs and the correlation among variance parameters. We generated a suite of operating models (Table 1) that varied and/or to assess the relative effect of different component variance and synchrony regimes on sockeye salmon population trajectories. To manipulate component variance, we adjusted CU-specific estimates of upwards or downwards with a fixed multiplier, while we created synchrony treatments by setting to specific values (Table 1). A third set of treatments (‘Interaction’) represented scenarios where both parameters were adjusted simultaneously. These parameter specifications resulted in appropriate shifts in and CVC relative to observed trends (Fig. 2, 3).

Table 1. Operating models used to explore the relative effect of component variance and synchrony regimes on population trajectories.

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Low | Moderate | High |
|  |  |  |  |
| CVC |  |  |  |
| Interaction |  |  |  |

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Figure 2. Trends in synchrony of productivity simulated with low, reference or high values of . Black line represents observed trend and vertical dotted line the beginning of the simulation period. Colored lines represent median values across 1000 trials.

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Figure 3. Trends in mean component CV of productivity simulated with low, reference or high values of . Black line represents observed trend and vertical dotted line the beginning of the simulation period. Colored lines represent median values across 1000 trials.

To adequately represent the framework used to manage Fraser River sockeye salmon we modeled four sequential sources of mortality: American fisheries, Canadian mixed-stock fisheries, en route mortality during freshwater migration, and terminal Canadian single-stock fisheries. Total allowable catches in both American and Canadian fisheries were calculated using a harvest control rule (HCR) that replicates the Total Allowable Mortality framework currently in use. In reality, this HCR uses in-season estimates of recruitment derived from test fisheries to adjust target exploitation rates and meet escapement goals specific to each management unit (MU). If in-season recruitment estimates exceed escapement goals, the HCR switches to a fixed maximum target mortality rate. Escapement goals vary among years due to the cycles present in several CUs and are typically adjusted downwards to account for mortality during upstream migration. This process was replicated in the simulation by generating a forecasted estimate of abundance using true return abundance plus normally distributed error. We introduced additional interannual stochasticity into the model via variation in age at maturity, en route mortality, and outcome uncertainty.

*Performance measures*

We evaluated the relative impact of different operating models on population trajectories using a suite of aggregate performance measures (PMs; Table 2). The selected PMs reflect a mixture of potential long-term conservation and socio-economic targets using either abundance-based or biological benchmarks.

Table 2. Definition of focal performance measures.

|  |  |
| --- | --- |
| **PM** | **Definition** |
| Spawner abundance | Median number of spawners, across all CUs, per year over simulation period |
| Recruit abundance | Median number of recruits, across all CUs, per year over simulation period |
| Catch | Median total catch (i.e. summed across all fisheries), per year over simulation period |
| CUs above lower BM | Mean proportion of CUs above Sgen every year during last generation of simulation period |
| CUs above upper BM | Mean proportion of CUs above SMSY every year during last generation of simulation period |
| Years all fisheries open | Proportion of years all MUs are above their lower fishery reference point during the simulation period |
| CUs extant | Proportion of CUs above extinction threshold at the end of simulation period |

High levels of synchrony were associated with moderate declines in median spawner abundance and median catch, as well as more severe declines in median recruit abundance (Fig. 4). Conversely, CVC­ was positively correlated with all three abundance-based PMs. When and CVC were increased simultaneously median spawner and recruit abundance, as well as catches, declined; however status was more variable than when synchrony was increased in isolation (Fig. 4).



Figure 4. Status of the Fraser River aggregate relative to abundance-based performance metrics at the end of 60-year simulation period. Points represent the median value of the performance metric during the simulation, then the median among 1000 trials with whiskers representing 90% posterior intervals.

Unlike the abundance-based PMs, increases in synchrony had negligible effects on benchmark-based PMs. Even at high levels of synchrony the median proportion of CUs above Sgen­ or SMSY was stable, although variance among trials increased. While the proportion of years all four MU’s fisheries could be opened declined at higher levels of synchrony, these changes were minor (Fig. 5). Higher levels of CVC, however,had relatively severe negative impacts. The median proportion of CUs above their lower benchmark declined from ~50% to 30% and the probability of any CUs being above their upper benchmark was less than 5%. When CVC was at low levels all fisheries were open in over 80% of simulation years, but when variability increased this declined to less than 60%. As with the abundance-based PMs, variability among trials increased when CVC and synchrony were increased simultaneously, however median status was generally equivalent to simulations where CVC was changed in isolation. There was no observable effect of either CVC or synchrony on extinction risk, with the proportion of CUs going extinct was remaining low in all treatments (not shown).



Figure 5. Status of the Fraser River aggregate relative to benchmark-based performance metrics at the end of 60-year simulation period. CU proportions reflect status at the end of the 60 year simulation period. Points represent medians across 1000 trials and whiskers 90% posterior intervals.