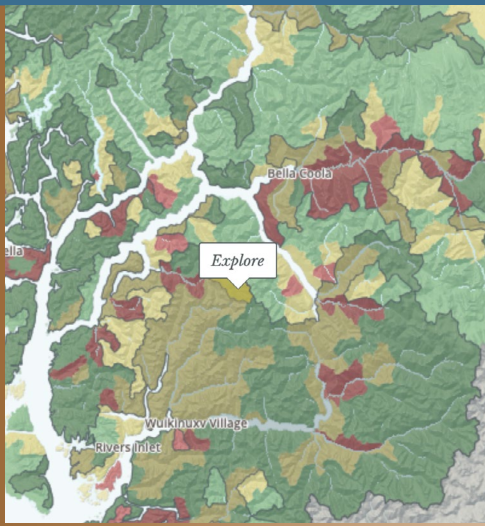
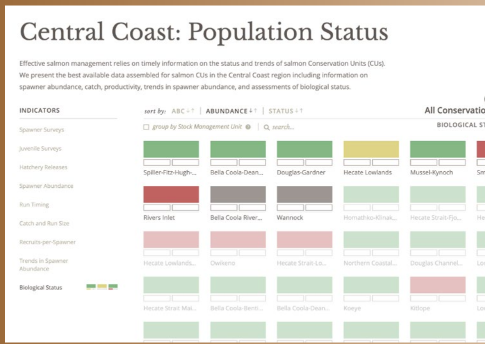
How does incomplete information for Pacific salmon affect estimates of biological status shown on the Pacific Salmon Explorer?

Canada's national policy for the conservation of wild Pacific salmon, known as the Wild Salmon Policy or WSP, identifies standardized monitoring of the biological status of Conservation Units (CUs) as a critical element of implementing strategies aimed at conserving wild salmon. This information on biological status is essential for designing, implementing, and evaluating management strategies and recovery plans for threatened salmon CUs.

Over the past decade, the the Pacific Salmon Foundation's (PSF) Salmon Watersheds Program has been working to advance the implementation of the WSP by taking a data-driven approach to assessing the biological status of Pacific salmon CUs throughout British Columbia following the approaches outlined in the WSP. These assessments of biological status, along with other information on salmon CUs, are made freely available to the public through an online data visualization platform called the ***Pacific Salmon Explorer***.

The Pacific Salmon Explorer
www.salmonexplorer.ca





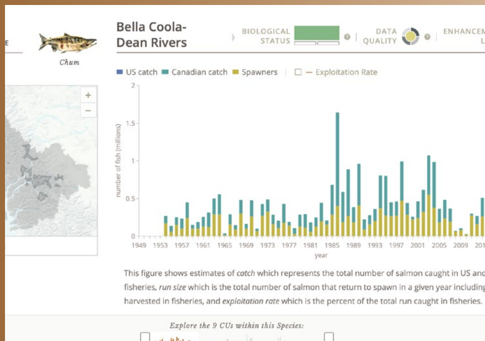


FIGURE 1

Illustration of the status assessment framework outlined in the WSP. The PSF's assessments of biological status are based on comparing a metric of spawner abundance against two sets of benchmarks (percentile and spawner-recruitment), yielding a status outcome of red, amber, or green. Adapted from Holt et al. (2009).

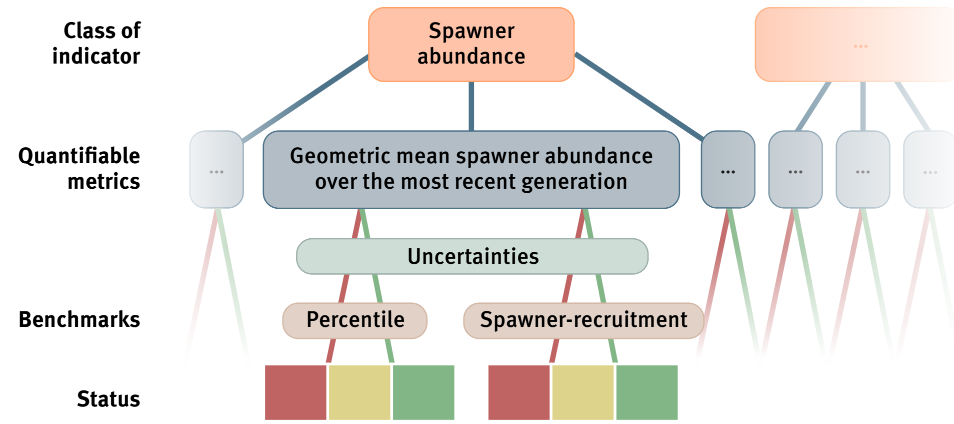
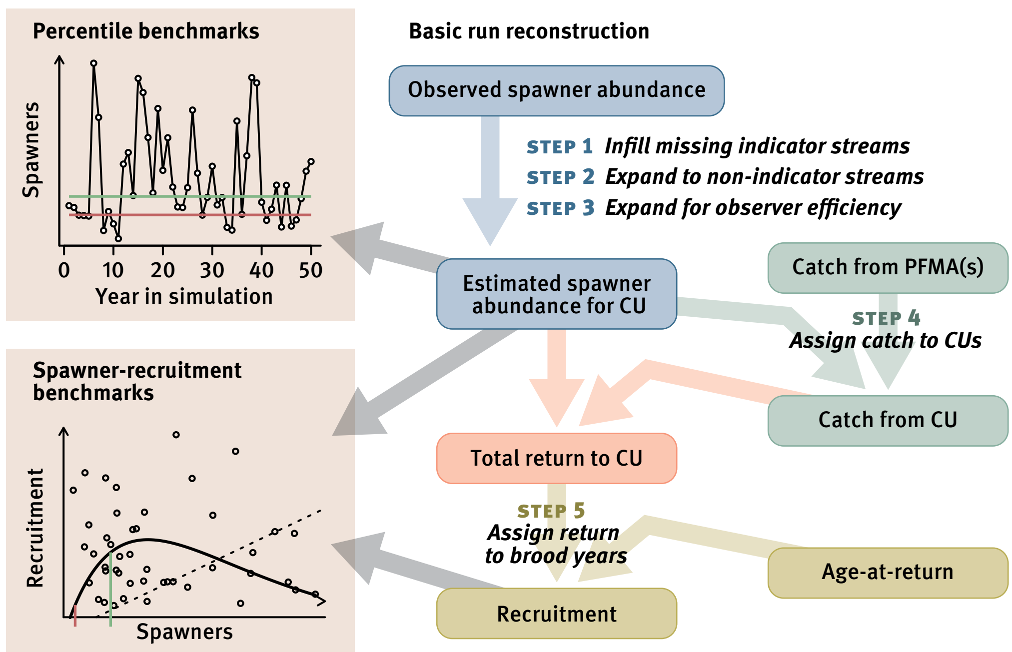


FIGURE 2

A basic run reconstruction involves expanding spawner abundances from observed streams to the entire CU (steps 1–3, blue), assigning catch to CUs (step 4, green), and assigning return to brood years (step 5, tan). The black arrows indicate the data required to assess status via percentile and spawner-recruitment benchmarks.



The estimates of biological status shown on the Pacific Salmon Explorer often involve "run reconstructions" that infill missing spawner data, expand observed spawner abundance to account for unmonitored streams, assign catch to individual populations, and quantify age-at-return. The PSF's methods for assessing biological status involve comparing the current spawner abundance of each CU against two types of benchmarks: (1) those based on percentiles of historical spawner abundance (referred to as "percentile" benchmarks) and (2) those based on the shape of the spawner-recruitment relationship for the CU (referred to as "spawner-recruitment" benchmarks; Figure 1).

Estimating percentile benchmarks requires a time series of reconstructed spawner abundance for the CU. Time series of observed spawner abundances are infilled and expanded to account for streams that may not have been monitored

FIGURE 3
An example of the proportion of simulations with different estimated and true statuses under high productivity and a harvest control rule — conditions representing Central Coast chum CUs. Black indicates the cases where estimated status was better than true status (i.e., biologically optimistic), which may be risky from a conservation perspective as management actions to prevent extirpation may not be taken. On the other hand, cases where estimated status was poorer than true status (i.e., pessimistic misclassifications, grey) — which were more common in our simulations — are less risky from a conservation and management standpoint, but may result in lost opportunity for fisheries as management may be overly conservative.

in a given year. Spawner-recruitment benchmarks require reconstructing the total return (catch plus spawners) for each CU to calculate recruitment for each spawner year. For species other than pink salmon, run reconstructions also require the distribution of age-at-return each year (Figure 2).

Due to missing data and different scales of data reporting, a number of assumptions are made in run reconstructions. In the most basic case, run reconstructions assume that the relative contribution of each monitored system to total abundance is constant over time, observer efficiency does not change, salmon are caught in the Pacific Fisheries Management Area (PFMA) where they will spawn and caught in proportion to the escapement to each CU that overlaps with that PFMA, and the age-at-return is constant throughout a CU and through time. The combined influence of these assumptions on the accuracy of status assessments is unknown, but of increasing concern as monitoring efforts decline, making these assumptions all the more necessary for deriving estimates of biological status.

We evaluated how common assumptions surrounding the expansion of spawner abundance, assignment of catch to CUs, and age-at-return may bias the kinds of assessments of biological status undertaken by the PSF and visualized in the Pacific Salmon Explorer. Using a stochastic simulation model tailored for chum salmon, we simulated the spawner-recruitment dynamics, including harvest, for multiple spawning populations within a hypothetical CU. The true status of the simulated CUs was known from the underlying demographic parameters. We then subsampled from the true spawner abundance and catch, incorporating observation error, and estimated status by applying the reconstruction techniques used in PSF's biological status assessments to these "observed" data. By repeating this simulation many times, we were able to quantify the probability of misclassifying status (Figure 3) under different scenarios. We investigated how the accuracy of estimated status and benchmarks was affected by monitoring coverage, bias in the observation of spawners and catch, and variability in biological parameters (including age-at-maturity and the carrying capacity of subpopulations).

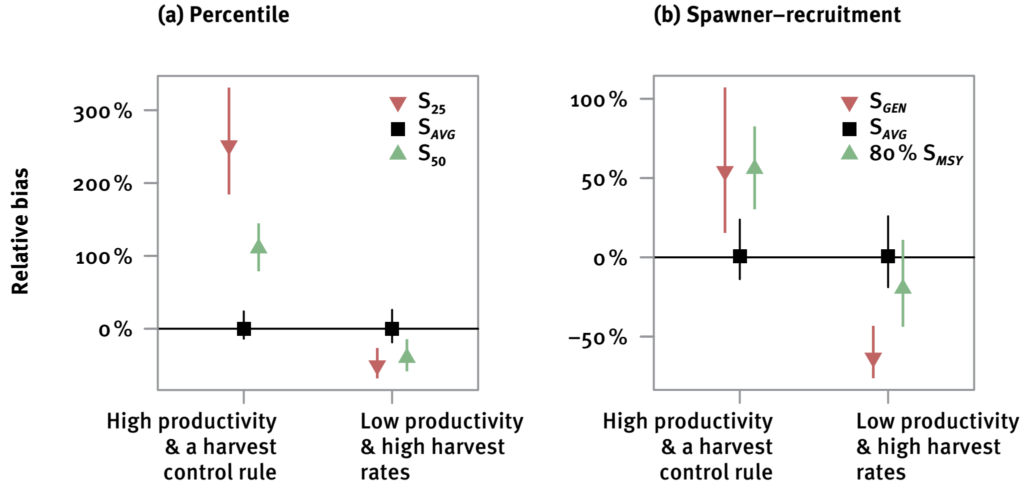


FIGURE 4
The relative bias as a percentage of the true value (y-axis; median ± interquartile range over 4,000 Monte Carlo simulations) for (a) percentile benchmarks (S_{25}, S_{50}) and (b) spawner-recruitment benchmarks (S_{GEN}, 80% S_{MSY}) and the average spawner abundance (S_{AVG}). Two scenarios with different productivity and harvest rates are shown (x-axis).

Common assumptions in run reconstructions had relatively little impact on status outcomes.

The probability of misclassifying biological status of CUs was not affected by: (1) reduced monitoring coverage (which affects the magnitude of expansion for spawner abundance), or (2) declines in the carrying capacity of some spawning populations (which was expected to affect the accuracy of expansions). Underestimating spawner abundance did tend to result in more misclassifications under the spawner-recruitment benchmarks, but the effect was relatively small. Overestimating catch (if salmon returning to other areas are incorrectly counted towards the catch for the CU being assessed) tended to result in more misclassifications than underestimating catch under the spawner-recruitment benchmarks; overestimating catch by 50% led to a 10% increase in misclassifications, which is potentially significant given the uncertainty in assigning catch to CUs.

The bias in benchmarks and associated misclassifications were sensitive to the underlying status of the CU (Figure 4). Underestimating status was common for populations with high productivity when harvest was adjusted based on the total return (i.e., a harvest control rule; Figure 3) due to positive bias in benchmarks. Under low productivity and high target harvest rates, however, the bias in benchmarks was negative, leading to status being overestimated — a potentially risky management scenario. As such, appropriate benchmarks for assessing current spawner abundance may depend on the productivity and fishing pressure for each CU. In extreme cases, alternative benchmarks such as a constant spawner threshold may be more appropriate. Criteria that clearly define the data requirements and biological and management parameters under which different benchmarks can be applied would help avoid substantial biases in assessments due to inappropriate application of benchmarks.

Future Research

The simulation model that we adapted and applied is flexible enough that it can accommodate different species and life-history traits of Pacific salmon, opening the door to future work investigating the impact of different assumptions and the impact of the assumptions that we focused on under additional scenarios. For example, temporal shifts in age-at-return associated with environmental change and selective fisheries may introduce more of a directional bias than the interannual variability in age-at-return than we investigated. The potential bias in assigning catch to CUs should be further investigated by exploring more complex run-reconstruction models that include spatial and temporal variability in returns.

Conclusions & Recommendations

Assessments of biological status are critical for devising management strategies that protect salmon biodiversity and manage for species resilience. Having complete information on the thousands of populations of Pacific salmon that spawn along our coast is not possible. Therefore, data-driven approaches to assessing biological status require assumptions to be made to estimate time series of the total number of spawners returning to CUs and corresponding recruitment (i.e., run reconstructions).

This project has shown that biological status assessments are robust to the common assumptions associated with run reconstructions, even in the face of declining monitoring coverage that has been observed in salmon-bearing regions throughout BC. However, misclassifications increased when catch was overestimated, highlighting the need to improve catch allocation to CUs (for example, through genetic stock identification). The collection of such data has been challenging, in part because the goals of the WSP — to preserve the incredible diversity within salmon species — are not reflected by the coarse scale at which salmon fisheries are managed (Management Areas often span multiple CUs).

Further research is required in order to understand how inherent biases in metrics and benchmarks depend on underlying status, and recommend criteria under which different benchmarks are reliable. However, despite the many unknowns, this project has demonstrated that efforts to assess biological status using imperfect and incomplete data are worthwhile.

The findings of this research have been published in the *Canadian Journal of Fisheries and Aquatic Sciences*.

For access to the journal article please visit: *https://cdnsciencepub.com/doi/abs/10.1139/cjfas-2019-0432*

Pacific Salmon Foundation
300 – 1682 West 7th Avenue
Vancouver, BC V6J 4S6
www.psf.ca *www.salmonwatersheds.ca*

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