Canadian Journal of Fisheries and Aquatic Sciences
Journal canadien des sciences halieutiques et aquatiques

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Journal:	*Canadian Journal of Fisheries and Aquatic Sciences*
Manuscript ID	cjfas-2017-0127.R1
Manuscript Type:	Rapid Communication
Date Submitted by the Author:	27-Jun-2017
Complete List of Authors:	Price, Michael; Simon Fraser University, Biology; SkeenaWild Conservation Trust, English, Karl; LGL Limited Rosenberger, Andrew; Lake Babine Nation Fisheries; Raincoast Conservation Foundation MacDuffee, Misty; Raincoast Conservation Foundation Reynolds, John D.; Simon Fraser University, Department of Biological Sciences
Is the invited manuscript for consideration in a Special Issue? :	N/A
Keyword:	fisheries management, conservation status, overexploitation, STOCK ASSESSMENT < General, population recovery

Canada's Wild Salmon Policy: an assessment of conservation progress in British Columbia

Michael H.H. Price[1,2*], Karl K. English[3], Andrew G. Rosenberger[4,5], Misty MacDuffee[5], and John D. Reynolds[1]

[1] Earth to Ocean Research Group, Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, Canada, V5A 1S6

[2] SkeenaWild Conservation Trust, Terrace, British Columbia, Canada, V8G 1P2

[3] LGL Limited - Environmental Research Associates, Sidney, British Columbia, Canada, V8L 3Y8

[4] Lake Babine Nation Fisheries, Burns Lake, British Columbia, Canada, V0J 1E0

[5] Raincoast Conservation Foundation, Sidney, British Columbia, Canada, V8G 1P2

** Corresponding author: E-mail: mhprice@sfu.ca, Tel: 604-842-4409, Fax: 778-782-3496*

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Abstract

Canada's Policy for Conservation of Wild Pacific Salmon has been heralded as a transformative approach to the management of wild salmon whereby conservation is the highest priority. Given that changes to the Policy are under consideration, it is timely that we understand whether our state of knowledge and the status of wild salmon in Canada have indeed improved after its adoption in 2005. To answer these questions, we used two indices of improvement: 1) monitoring effort, and 2) abundance of spawning adults. Our results, based on data for all species from British Columbia's north and central coasts, show that monitoring effort has continued to erode, abundance of spawning adults has significantly declined for several species, the status of many salmon Conservation Units are in zones of concern, and 42% of the Conservation Units that we assessed as Red (threatened) would have improved in status had the Canadian fishery been reduced. We conclude with recommendations to help improve our knowledge of the status of salmon, and enable a robust and successfully implemented Wild Salmon Policy for the future.

Introduction

Canada's Policy for Conservation of Wild Pacific Salmon, referred to as the Wild Salmon Policy (WSP; DFO 2005), provides an integrated approach to the management of wild salmon (*Oncorhynchus* spp.) in British Columbia (BC) and Yukon Territory. In brief, the WSP outlines the specific steps by which Canada's commitment to the precautionary principle is to be applied to the conservation of wild Pacific salmon (Cohen 2012). Salmon diversity is to be managed and protected at the level of the Conservation Unit (CU); these are genetically and/or geographically distinct populations which, if extirpated, are unlikely to recolonize naturally within a human life-time (DFO 2005). When introduced to Canadian society in 2005, the WSP was considered transformative and timely: transformative by setting out a new conservation ethic that placed its highest priority on the conservation of salmon above all other uses (Cohen 2012), and timely in that it was a much-needed policy developed in response to repeated criticism from key stakeholders and Canada's Auditor General (e.g., Office of the Auditor General 1999, 2004) based (in part) on the eroding abundance of salmon, salmon habitat, and information required to assess population health (Irvine 2009).

Population metrics quantified by Fisheries and Oceans Canada's (DFO) salmon stock assessment program are the fundamental building block of the WSP. The purpose of the stock assessment program is to provide relevant information on biological status, trends, and productivity required to guide the decision-making process related to salmon populations, fisheries, and conservation (English 2016). The backbone of such a program is the annual estimates of fish returning to spawn ("escapement"); the time series of which extends for more than 60 years for many salmon populations in BC. Some of the most obvious and compelling reasons for obtaining spawning escapement estimates are to: i) monitor the health of salmon populations for conservation, ii) set and adjust fisheries management goals, iii) assess the impact of climate change, fisheries, and other human activities (e.g., logging, mining, etc.) on salmon, and iv) meet Canada's commitments to international treaties and First Nations. Despite such importance, monitoring effort for spawning streams had been in decline leading up to the adoption of the WSP in 2005, where 70% of all streams on BC's north and central coasts had not a single estimate of abundance (Price et al. 2008). While spawning streams are not the unit of conservation under the WSP, this dearth of information resulted in the inability to apply status evaluations to 41% of stream populations throughout BC (Slaney et al. 1996). The adoption of the WSP renewed optimism that monitoring effort for spawning streams would improve so as to provide relevant information on productivity (recruitments per spawner), trends in abundance, and biological status of wild salmon.

Wild salmon have been in a state of decline in BC for several decades. As of 1993, 600 of 9,204 salmon runs were considered at high risk of extirpation, 63 at moderate risk, and 57 were of special concern; 105 stream populations throughout BC were documented as extirpated (Slaney et al. 1996). Ninety-six percent of monitored streams on BC's north and central coasts consistently failed to meet management escapement targets during 1950 to 2005 (Price et al. 2008). In the Skeena watershed, Canada's second largest salmon producing system, roughly one third of the original biodiversity (as measured by the number of genetically distinct spawning units) is thought to have been lost before the 1950s due to habitat loss and heavy fisheries exploitation (Walters et al. 2008). Indeed, salmon in BC have been exploited for food for millennia, and by commercial industries since the late 19th century (Argue and Shepard 2005). A federal audit of DFO in 1999 reported that Pacific salmon fisheries were in trouble, stating that "The long-term sustainability of the fisheries was at risk because of overfishing, habitat loss, and other factors" (Office of the Auditor General 1999). While commercial fishery catches between 1995 and 2005 were at the time considered the lowest on record, catches since then (i.e., 2006 to 2014) have further declined by nearly one-half (DFO 2017). For many CUs, this decline is the result of reduced salmon abundance, and increased conservation actions to protect these depleted stocks. For a few CUs, fisheries have not been permitted due to the reductions in monitoring efforts required to assess the status of stocks that once supported these fisheries.

Strategy 6 of the WSP commits to periodic performance reviews to determine what is, and what is not, working with the policy (DFO 2005). The last independent performance review occurred in 2011, and reported on the progress of implementing each action step. Of 17 action steps outlined in the WSP, 4 were rated as having been completed, and 13 were rated either partially completed or wholly incomplete (Gardner Pinfold 2011). Importantly, 2 of 3 action steps in Strategy 1 – standardized monitoring of wild salmon status – deemed critical to the overall success of the WSP (Cohen 2012), were reported as only partially complete. Six years have elapsed since the last performance review, and it is important to examine whether further progress has been made. Furthermore, changes to the WSP are being considered (DFO 2016a); thus, it is timely that we understand whether the policy in its current form ultimately has improved the health of wild salmon, their habitats, and dependent ecosystems in Canada.

The primary goal of our paper is to assess whether the state of our knowledge, and the biological status of wild salmon in Canada, has improved over the decade since the adoption of the WSP. To achieve this goal, we used 2 indices to assess improvement: 1) monitoring effort; whether monitoring effort of spawning streams had improved and whether a strategic approach to monitoring has been applied, and 2) spawner abundance; whether abundance of spawners has increased in CUs that were previously depressed, resulting in positive shifts in biological status of CUs in BC. Three themes emerge from our provisional assessment: 1) the number of spawning streams assessed is at an all-time low, 2) there is inadequate information to determine the biological status of roughly one-half of all Conservation Units, and 3) implementation of the WSP needs to be given high priority. Given our results, we provide specific recommendations to improve our knowledge of salmon in BC, to ensure adequate protection is applied for diminished populations, and initiate a robust and successfully implemented WSP for the future.

Methods

We examined stream-specific escapement estimates between 1950 and 2014 (English 2016), and run-reconstructed escapement and exploitation estimates for CUs between 1954 and 2014 (English et al. 2016) for BC's north and central coasts (DFO Management Areas 1 through 10; Fig. 1); similar estimates were not publicly available for BC's south coast salmon CUs. A complete list and the location of all CUs is reported in Holtby and Ciruna (2007). Briefly, escapement estimates for each CU were derived by expanding the available estimates for indicator streams – spawning streams considered biologically representative of the productivity across a given CU - within each CU. The expansion accounted for any missing estimates for indicator streams, the portion that the indicator streams represent of the total average escapement for the CU, and the tendency for estimates to underestimate escapements based on visual surveys (English et al. 2016). Exploitation rate estimates were derived using several different approaches depending on the species and CU, and are thoroughly described in English et al. (2016) and our Supplementary material. Despite the many assumptions underlying the run-reconstruction data (see Appendix E, English et al. 2016; our Supplementary material), the resulting uncertainty is unlikely to lead to systematic bias that will alter our ultimate inference because such uncertainty applies across the time series comparison detailed below. However, we acknowledge the uncertainty associated with our assessment of how reduced fishing pressure could change the biological status of CUs between time periods. We assessed the five major salmon species in Canada: *O. tshawytscha* (Chinook), *O. keta* (chum), *O. kisutch* (coho), *O. gorbuscha* (pink), and *O. nerka* (sockeye). Given their distinct 2-year life cycle, we separated pink salmon into even- and odd-years for all analyses. There are 2,933 documented salmon spawning streams on BC's north and central coasts, many of which are small with less than a few hundred spawners of a given species, but may account for a disproportionate amount of the genetic diversity among populations (Hyatt et al. 2007).

Monitoring effort

Annual estimates of returns of each species to each management area and CU are derived from data collected during spawning escapement surveys, and stored in DFO's Salmon Escapement Database System (NuSEDS; DFO 2016b). While the accuracy of escapement estimates within this database system has been questioned (e.g., Irvine and Nelson 1995), there are few alternative data available. A sub-set of spawning streams consistently enumerated over time has further been classified as "indicator streams" based on historical time series, the reliability of escapement estimates, and the methods and costs of obtaining these data (English et al. 2006, 2016; Walters et al. 2008; Ogden et al. 2015). Our assessment of changes to monitoring efforts over time occurred at three scales: 1) total streams, 2) indicator streams, and 3) CUs. We used a linear regression to quantify the rate of change in monitoring effort of indicator streams for all species since the adoption of the WSP in 2005. For CUs, we examined the number of CUs with an assigned indicator stream, then examined monitoring effort by calculating the proportion of indicator streams surveyed for each of those CUs in all years during 2005-2014.

We also assessed whether fisheries managers used a strategic approach to the enumeration of salmon in spawning streams. The World Summit on Salmon (WSS 2003) identified various concerns regarding Canada's stock assessment programs for Pacific salmon. These concerns led to the development of the Core Stock Assessment Program (CSAP), a DFO commitment to strategic monitoring of spawning populations for each species returning to BC's north and central coast (English et al. 2006). The CSAP identified a set of indicator streams for each stock group, and three primary monitoring activities were recommended: escapement, fishery, and productive capacity. We compared CSAP recommendations with recent monitoring efforts to determine the extent to which the strategic monitoring program was implemented (see English 2016).

Population trends

We calculated the difference in arithmetic average (geometric mean also calculated for comparison; Holt et al. 2009; our Supplementary material) spawner escapement by species for each CU in the decade *before* (1995-2004) and *after* (2005-2014) the adoption of the WSP to determine the percent change in spawner abundance. We tested whether the percent difference was significant using a Wilcoxon Signed-Rank Test for non-normal data (set the "paired" argument = TRUE). While we excluded, from all comparisons, CUs with <50% of years with escapement data within a decadal period, the number of years in a given decade at times differed for some CUs (e.g., a CU with 10/10 data-years in one decade may have had 7/10 data-years in the following decade). This occurred for 25 CUs; 11 during pre-WSP years, and 14 for post-WSP years. A sensitivity analysis for all CUs with missing years showed that differences in spawning abundance were never large enough to change the biological status of a CU (our Supplementary material).

The first strategy of the WSP states that the conservation status of salmon CUs must be determined against specific biological benchmarks, such as spawner abundance, using a "stop-light" approach (i.e., 'Green', 'Amber', and 'Red' status zones; DFO 2005). While the WSP does not dictate any particular metric to assess the biological status of CUs, several examples are provided, and have subsequently been evaluated (e.g., Holt et al. 2009; Peacock and Holt 2010; Holt and Bradford 2011). However, to date, DFO has not published the biological status of CUs in BC. Our intention is not to perform this task for DFO, but rather to use a method that we consider reasonable for comparing the status of as many CUs and species across BC before and after the WSP was published. We have chosen to use the percentile approach for several reasons: i) they can be applied to a large number of data-limited CUs where reliable spawner escapement estimates are not available to derive stock-recruitment based benchmarks, ii) they have been applied to represent bounds (i.e., reference range) for management escapement goals (Pestal and Johnston 2015), and iii) an evaluation of percentile-based benchmarks in the context of other WSP abundance benchmarks currently is in progress (C. Holt pers. comm). We defined upper and lower benchmarks so as to delimit status zones by employing the 25th and 75th percentile of historic spawner abundance (1954-1994 for all species except Chinook, whose data spanned 1985-1994), for each salmon CU. If a CU's abundance in a given decade was below the 25th percentile, between the 25th and 75th percentiles, or above the 75th percentile, of the long-term abundance, the CU would be assigned "Red", "Amber", and "Green" status, respectively. The resulting status for each CU was compared between the decadal periods *before* (1995-2004) and *after* (2005-2014) the adoption of the WSP to determine a change in overall status.

We were interested to know whether or not resource managers have applied a more precautionary approach to fisheries management over the decade since the adoption of the WSP, and whether this approach resulted in changes to the status of CUs. We examined changes in arithmetic average exploitation from Canadian fisheries for the periods *before* (1995-2004) and *after* (2005-2014) the adoption of the WSP, and used a Wilcoxon Signed-Rank Test for non-normal data (set the "paired" argument = TRUE) for each species to determine statistical significance. While some BC salmon stocks are caught in Alaskan fisheries, we excluded this exploitation from our analyses because it is beyond the control of resource managers in Canada. To examine the influence of exploitation on biological status, we performed three assessments: 1) the change in Canadian fisheries exploitation between decadal periods for CUs assigned Red status in the decade post-WSP, 2) the number of CUs that would have declined in status had Canadian fisheries not been reduced post-WSP - we examined those CUs whose status did not change post-WSP, subtracted the average number of fish that would have been caught had exploitation not been reduced for a given CU, and compared the "revised" return to its benchmarks), and 3) the number of CUs that would have improved in status had Canadian fisheries been reduced from 0% to 100% on each CU - we assigned status for each CU post-WSP based on the total return to Canada estimates (Canadian catch plus escapement), compared the results with status derived from spawner abundance alone over the same period to determine whether status would have improved, and assessed the rate of exploitation that a given CU could sustain before its status declined. Two assumptions apply: 1) fish would not have experienced significant en-route mortality during upriver migration had they been allowed to escape fisheries capture, and 2) productivity is the same regardless of differences in numbers of spawning adults.

Finally, we performed a provisional status assessment for all CUs on BC's north and central coasts for the contemporary period using the percentile approach stated above, and the arithmetic mean (geometric mean also calculated for comparison; Holt et al. 2009; our Supplementary material) of the following "generational" (i.e., over the most recent generation) years: Chinook (2009-2014); chum (2011-2014; coho (2011-2014); even-year pink (2014); odd-year pink (2013); sockeye (2009-2014 depending on CU; English et al. 2016). Admittedly, there are uncertainties aligning percentile-based benchmarks with those defined under the WSP for data-rich CUs; the 25th and 75th percentile of abundance delineating Red and Green zones may be lower or higher than other metrics. We provide a cursory examination of differences in benchmark values (and associated status) between the percentile approach and a stock-recruitment approach in our Supplementary material. While we acknowledge that a status assessment integrated over numerous metrics is preferred, we believe that our provisional assessment based on a single metric serves to provide a rapid evaluation for resource managers of where conservation concerns may exist. All analyses and graphics were performed in R 3.3.2 (R Foundation for Statistical Computing, 2016) using the cowplot, dplyr, ggplot2, gridExtra, and lm packages.

Results

Monitoring effort

The number of spawning streams with escapement estimates on BC's north and central coasts has varied widely, peaking in the mid-1980s at 1,533 streams, declining to less than 1,000 by the mid-1990s, and reaching an all-time low of 476 streams in 2014 (Fig. 2a). Spawning locations referred to as "indicator streams" have been monitored more consistently over time. Escapement surveys averaged 490 (72%) indicator streams per year during 1950 to 2004, but has since declined at an average rate of 3.8% per year (for a total decline of 34% over the last 10 years; $R^2 = 0.614$, $df = 7$, $p = 0.013$) to an all-time low of 334 streams in 2014; thus, only 49% of the 679 indicator streams were surveyed in the most recent year (Fig. 2b). When monitoring effort was evaluated at the CU level, 58% (127 of 218) of CUs have at least one assigned indicator stream (Table S1). Of those CUs with an assigned indicator stream, the median proportion of CU-specific stream visits during 2005-2014 ranged from 60% for Chinook to 80% for sockeye, and averaged 68% across all CUs over the decade since the WSP (Fig. 3).

Of the 634 annual, and 134 periodic, spawning streams recommended for monitoring by CSAP, only 29% were monitored consistently during the 2007-2014 period (Table 1). Coho streams were monitored the least (20%), whereas streams with lake-type sockeye were monitored the most (42%). Twenty-four percent of CSAP recommended streams had zero effort over the time period for all species combined, including a low of 56% for river-type sockeye.

Population trends

The percentage of CUs with spawner averages that had changed since the adoption of the WSP varied by species. The relative change was highest and statistically significant (Wilcoxon rank score, $W = 146$, $p = 0.000$) for chum salmon where post-WSP spawners were 23% of the average that returned during the decade prior to the WSP (Table 2; Fig. 4). Even-year pink ($W = 28$, $p = 0.016$) and Chinook ($W = 74$, $p = 0.048$) also experienced large and statistically significant declines of 86% and 69%, respectively. Overall, there was a 14% decrease in average annual spawners in the decade after the WSP, driven largely by even-year pink salmon.

Of 218 CUs on BC's north and central coasts, 30 declined in biological status (e.g., Green to Amber, or Amber to Red), 15 improved, and 15 changed to Unknown status since the adoption of the WSP (Fig. 5; Table S2). There was variation among species: Chinook and chum salmon had the highest proportion of CUs that declined in status to Red (25% and 24%, respectively). Alternatively, coho salmon had the highest proportion of CUs that improved in status to Green (21%), followed by odd-year pink salmon (17%). The total number of CUs for all species with Unknown status – most of which were small coastal sockeye CUs - increased from

100 to 108; thus, roughly one-half of all CUs on BC's north and central coasts had insufficient data to determine status in the post-WSP period.

The relative change in exploitation before and after the adoption of the WSP was highest (-59%) and statistically significant (W = 26, p = 0.047) for even-year pink salmon, followed by chum (-56%; W = 136, p < 0.001), and sockeye (-50%; W = 630, p < 0.001); Chinook experienced the least (-12%) change in exploitation (Fig. 6). The change in Canadian fisheries exploitation between decadal periods for those CUs assessed as Red in the decade post-WSP ranged from -11% (chum) to +1% (coho), and averaged -7% across species (Table 2). Regarding biological status, 3 CUs would have declined in status from Amber to Red had fishing pressure not been reduced over the decade since the adoption of the WSP. However, 10 CUs would have improved in status either to Amber or Green had Canadian fisheries exploitation been further reduced by 50%. Ten of 24 CUs that we assessed as Red would have improved in status; 4 of 6 Chinook CUs would no longer be in the Red zone (Fig. 7).

Our contemporary period status assessment shows that only 5% of chum, 12% of Chinook, and 15% of sockeye CUs have Green status up to 2014; coho had the highest percentage of CUs with Green status (42%; Fig. 8; Table S2). Sixty-five percent of sockeye CUs are considered Unknown, and 50% of all CUs on BC's north and central coasts are of Unknown status in the contemporary period.

Discussion

Canada's Policy for Conservation of Wild Pacific Salmon has been articulated as the means by which the federal government will meet its obligation to protect and conserve wild salmon on the Pacific coast (Cohen 2012). We have asked whether the adoption of the WSP in 2005 has improved our state of knowledge and the status of these iconic fish. While considerable progress has been made in the 12 years since its adoption, implementation of the WSP is still far from complete. Three themes emerge from our assessment: 1) the number of spawning streams assessed is at an all-time low, 2) there is inadequate information to determine the biological status of roughly one-half of all Conservation Units, and 3) implementation of the WSP must be given high priority. To reverse these trends, and initiate a robust and successfully implemented WSP for the future, we conclude with specific recommendations.

Annual estimates of spawning salmon are the fundamental building block of fisheries management in Canada, essential for monitoring conservation status and estimating the total annual returns for each salmon Conservation Unit (CU; English et al. 2016). Such importance has long been acknowledged. For example, DFO's 1987 operational framework for Management Area 6 states that, "Escapement data are the basis of the whole fisheries management regime…neither pre-season planning nor computer modeling and run reconstruction or any other long-term strategic planning exercise is possible without this information." (DFO 1987). Despite its immense importance, visits to spawning streams on BC's north and central coasts have been trending downward since the mid-1980s; total stream visits in 2014 were 69% lower than those in 1986. Importantly, spawning locations referred to as indicator streams experienced a 34% reduction in effort since the adoption of the WSP in 2005. Indicator streams were selected by regional biologists because escapement estimates for these streams were more reliable and more consistently surveyed than those for other streams in a CU, and also because these streams were considered biologically representative of the productivity across a CU. Our state of knowledge regarding salmon populations is eroding rapidly. Without increased support for escapement surveys and the transfer of knowledge to the next generation, the rich legacy of population data available for BC's north and central coasts is at serious risk of becoming irrelevant for future assessments of management and conservation status.

How does such monitoring effort translate to the CU level of fisheries management? We are unable to assess the status of 40% of all north coast and central coast salmon CUs because these CUs do not have an assigned indicator stream; many of these are small isolated sockeye CUs without other nearby sockeye CUs with indicator streams. In addition to these unmonitored CUs, there are significant gaps in the escapement data for CUs with indicator streams. Escapement estimates are not available for 32% of the indicator stream-years in the post-WSP decade. These deficiencies in escapement monitoring efforts leave fisheries managers with inadequate information to assess population health, and opportunities for local fisheries.

While budget shortfalls have contributed to monitoring declines, there also has been a lack of strategic approach towards monitoring that otherwise could have improved our knowledge state for data-deficient CUs. There are three inter-related short-comings. First, the implementation of the Core Stock Assessment Program - a strategic approach to annual escapement surveys - has fallen far short of its goals (English 2016). Only 29% of all indicator streams recommended to be monitored were surveyed consistently during the period 2007-2014, and 24% of the indicator streams had zero survey effort. Second, enumeration monitoring at the CU-level is highly variable, with several CUs having received exhaustive effort, while other CUs for the same species have been ignored completely (see Table S1). Finally, visits to indicator streams declined to their lowest level ever in 2014. On average, 150 non-indicator streams were enumerated annually since the WSP, when, had a strategic approach been followed, they need not have been. Had managers chosen to annually enumerate 150 more indicator streams, rather than non-indicator streams, monitoring effort for indicator streams would have been reinstated to the peak period levels of the 1980s, and far fewer CUs would now be considered data-deficient.

Our assessment reveals that salmon abundance has declined over the decade since the WSP, driven largely by even-year pink salmon. Climate variability and poor marine survival have played a substantial role in the diminishment of populations. For example, sockeye salmon throughout southern portions of their range have exhibited downward trends in productivity in recent decades (Peterman and Dorner 2012), resulting in part from competition with increasingly abundant pink salmon across the North Pacific (Ruggerone and Connors 2015). There also have been widespread declines in chum salmon throughout BC, and pink salmon more recently in several areas on BC's central coast, likely due to large-scale climatic processes (Malick and Cox 2016). The overall decrease in average annual spawners that we report in the decade after the WSP was driven largely by the decline in even-year pink salmon, despite notable reductions in fisheries pressure. Similar to our results, recent increases in odd-year pink abundance in southern BC have been shown to be correlated with decreased fishery exploitation (Irvine et al. 2014), which begs the question as to what factor(s) may be influencing the differential dominance between odd- and even-year pink salmon. Evidence provided by Irvine et al. (2014) suggests that recent climate conditions may be challenging even-year pink salmon more than odd-year pink, due to their historical dispersal from divergent glacial refugia.

Resource managers have responded positively, at a broad scale, to diminished salmon returns over the last decade by reducing exploitation on all species in ocean fisheries, though not for some vulnerable CUs. If fishing pressure had not been reduced, 3 CUs (1 each of chum, even-year pink, and sockeye) would have declined in status from Amber to Red – assuming no significant change in productivity with these slightly higher numbers of spawning adults. More importantly, though, 10 of 24 CUs that we assessed as Red since the WSP would have improved in status to either Amber or Green had the Canadian fishery been further reduced, and all but 2

Chinook CUs would no longer be in the Red zone, assuming that all fish escaping the fishery were successful spawners; and these results are, of course, sensitive to assumptions in the run reconstruction data. A broad-scale reduction in Canadian fisheries exploitation from 40% to 30% would have improved the status of three CUs from Red to Amber or Green. However, fisheries exploitation would need to have been further reduced to <10% to improve the status of the majority of CUs in the Red zone, unless such exploitation were moved upriver to more terminal locations where vulnerable populations can be avoided. The degree to which exploitation rates in Canadian fisheries can be further reduced, or moved upriver, to improve the status for a few CUs is the subject of the type of trade-off discussion that the Skeena Independent Science Review Panel recommended nearly a decade ago (Walters et al. 2008).

Canada's Wild Salmon Policy provides the blueprint to safeguard the natural diversity of salmon, but slow progress towards defining the WSP benchmarks for salmon CUs has impeded the delivery of biological status assessments required to guide fisheries management. The classification of lower and upper benchmarks for exploited populations is an important action step for implementing the WSP, outlined in Strategy 1. While numerous candidate metrics have been proposed for data-rich CUs (e.g., Holt et al. 2009; Peacock and Holt 2010; Holt and Bradford 2011), benchmark development remains in the evaluation stage for some data-limited CUs (most of which occur along BC's north and central coasts). We understand that benchmark metrics will continue to evolve as new data are collected on CUs in BC, and that their evaluation is an ongoing objective of the WSP. However, Canada's management agency arguably has sufficient scientifically-defensible metrics to immediately assess the biological status of dozens of CUs throughout BC, especially those in the Skeena and Fraser watersheds. Furthermore, despite being a somewhat poor surrogate for stock-recruitment based benchmarks of data-rich

CUs (our Table S3), simple metrics such as the percentile approach can provide a rapid evaluation of conservation concerns for data-limited CUs, where stock-recruitment based benchmarks cannot be derived or are inappropriate. It is now 12 years since its publication and the WSP remains only partially implemented, with relatively few CUs having been formally assessed.

Can our contemporary period status assessment inform resource managers of conservation concerns? We believe so, in three ways. First, our results provide a “first cut” of where conservation concerns may exist. While such provisional assessments are not as rigorous as the recommended multi-metric approaches used for data-rich CUs (e.g., Fraser sockeye), assessments performed based on a single metric for dozens of CUs across a large region can identify where to prioritize more in-depth assessment efforts, including the need for a wider variety of data, metrics, and expertise. Second, patterns of diminished CUs are consistent across species. Our results show that, of those CUs with sufficient data to determine status, all species have 1 or more CUs assessed as Red and less than 50% assessed as Green. Third, and perhaps most important, one half of all CUs on BC’s north and central coasts have insufficient data to assign status using our proposed metric, and no alternative benchmark approach could markedly increase the number of CUs with assigned status. The take-home message to resource managers, is thus: conservation actions are required for each species, and more data need to be acquired to understand the true scale of the conservation concern for these iconic fishes. A logical next step would be to perform an analysis to determine which areas (or groups of CUs) host disproportionate declines in abundance or Red status, and whether exploitation has changed for those areas, so as to inform managers of where next to implement full integrated biological assessments.

To ensure adequate protection is applied for diminished populations, and to initiate a robust and successfully implemented WSP for the future, we make the following recommendations to the federal government of Canada and Canada's Department of Fisheries and Oceans:

1. Conduct a strategic planning review of Conservation Units to meet the requirements of the Wild Salmon Policy. Such a review should incorporate potential partners and collaborators to aid data acquisition and control financial cost, and restore key assessment programs as a priority for DFO annual programming. Implementation of the updated north and central coast core stock assessment program detailed in English (2016) would be an appropriate beginning to ensure that the most critical data for salmon management are collected each year, and provide the information necessary to adequately determine the biological status for most CUs on BC's north and central coasts. The total estimated annual cost for implementation is \$2.5 million, with an additional \$400,000 per year for 5 years recommended to build enumeration monitoring capacity - \$1.2 million more than funding allocated in recent years (English 2016). If funding is not improved for monitoring and status assessments of data-limited CUs, it is likely that a risk-based prioritization process will occur; in which case, we recommend that there be clear documentation of factors (e.g., conservation, First Nations and international obligations, habitat threats, etc.) considered in the prioritization.

2. Use a two-step approach to speed up the process for assessing biological status. Several candidate benchmark approaches have been identified for biological status assessments (Holt et al. 2009; Peacock and Holt 2010; Holt and Bradford 2011), and evaluated based on simulations that have quantified extinction and recovery probabilities (Holt and Folkes 2015). Stock-recruitment, recent trend in spawner abundance, exploitation rate, rearing habitat capacity, and the percentile approach have all been proposed. Each has its limitation, and the accuracy of assessed status is derived from the integration of the metrics collectively. We recommend a two-step process towards status assessments: 1) use the percentile approach as an efficient initial region-wide assessment of stock status, and 2) where possible and appropriate, immediately integrate (see Grant and Pestal 2013) the information from a larger suite of metrics to increase the confidence in the assessments for CUs initially classified as Red and Amber. We caution, however, that this approach should not supersede the need for integrated status assessments of CUs initially classified as Green, but locally identified as of concern.

3. Achieve a balance between mixed-stock ocean fisheries and in-river fisheries targeting specific stocks. This is a mitigation strategy that resource managers can use, and have used, in large watersheds like the Skeena and Fraser to address conservation concerns for specific CUs. A key requirement for implementing this strategy will be defining an initial set of management goals and benchmarks for the various CUs, and achieving some level of agreement between First Nations, recreational, and commercial fishing communities that catch fish returning to these watersheds. These management goals and benchmarks can be further refined over time with information from consistently applied escapement monitoring and other stock assessment programs.

4. Implement the existing WSP immediately. The development of an implementation plan was assured in the WSP (DFO 2005), but has yet to be developed. Without further delay, a detailed implementation plan should be developed that would stipulate the tasks required - how they will be performed, what collaborations and partnerships could assist in the tasks, and when they will be completed - and include a detailed breakdown of implementation costs, as Cohen (2012) recommended 5 years ago. While DFO recently has initiated a process to develop a plan, five years are proposed for implementation, together with changes to the WSP (DFO 2016a). We recommend that such a plan should immediately implement the WSP as written in 2005, thus retaining all Strategies and Action steps, as they are the blueprint for implementation that will ensure accountability. Indeed, "Further reviewing, reexamining, or reopening of the policy [WSP] would be a poor use of limited funds in the Pacific Region." (Think Tank of Scientists 2017).

5. Create a Wild Salmon Policy fund to ensure implementation. While the WSP is a federal policy, the Pacific Region of DFO has thus far been responsible to find the funds within its own annual allocation to implement it (Cohen 2012). With the current federal government's interest in First Nations and support for science, we recommend the creation of a WSP implementation fund to support the development of partnerships and the restoration of habitats where recovery of CUs is required. If DFO will not support annual needs for assessment and addressing CUs in the Red Zone as the WSP requires, the federal government could establish a fund managed collaboratively with DFO, yet directed via a trust fund.

Canada's Wild Salmon Policy sets out the specific steps by which Canada's commitment to the precautionary principle is to be applied to the conservation of Pacific wild salmon. Our results show that monitoring effort has continued to erode, there is inadequate information to determine the biological status of roughly one-half of all Conservation Units, and that an implementation plan for the Wild Salmon Policy is required now more than ever. Our five recommendations would help to ensure that Pacific salmon remain abundant in British Columbia for future generations.

Acknowledgements

We thank the many biologists who have gathered and processed salmon data on BC's coast over the past 60 plus years, the Pacific Salmon Foundation and LGL Limited for compiling and reconstructing CU-specific data used in this manuscript, Sean Godwin for analytical advice, and Brendan Connors, Eric Hertz, Carrie Holt, Brian Riddell, and two anonymous reviewers for helpful comments. Funding for this project was provided by a Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant, and the Tom Buell Endowment Fund supported by the Pacific Salmon Foundation and the BC Leading Edge Endowment Fund (J. Reynolds), and an NSERC Alexander Graham Bell Canada Graduate Scholarship (M. Price).

Literature cited

Argue, A.W., and Shepard, M.P. 2005. Historical commercial catch statistics for Pacific salmon (*Oncorhynchus* spp.) in British Columbia, 1828-1950. Canadian Technical report of Fisheries and Aquatic Sciences 2601. Vancouver, B.C. Available from: http://data. skeenasalmon.info/dataset/64ec64b1-0773-4ced-b4a5-21ba72c8a7de/resource/a0cf7e44-647a-4649-bd85-6139c8d3d6e8/download/argue--shepard-2005-historical-commercial-catch-statistics-for-pacific-salmon-in-bc-1828-to-1950.pdf [accessed 15 December 2016].

Cohen, B.I. 2012. Cohen Commission of inquiry into the decline of sockeye salmon in the Fraser

River - final report. The uncertain future of Fraser River sockeye, volume 3: recommendations, summary, process. Ottawa. Available from: http://publications.gc.ca/site/eng/432516/publication.html [accessed 15 March 2017]

DFO (Fisheries and Oceans Canada). 1987. Operational Framework – Area 6. Prepared by Department of Fisheries Oceans, Vancouver, BC.

DFO (Fisheries and Oceans Canada). 2005. Canada's policy for conservation of wild Pacific salmon. Vancouver, BC. 50p. Available from: http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especes/salmon-saumon/wsp-pss/docs/wsp-pss-eng.pdf [accessed 01 February 2017].

DFO (Fisheries and Oceans Canada). 2016a. Consultations on an updated Wild Salmon Policy implementation plan [online]. Available from: http://www.bucksuzuki.org/images/uploads/docs/WSP_Consult_Letter_to_Stakeholders_14Oct2016.pdf [accessed 20 January 2017].

DFO (Fisheries and Oceans Canada). 2016b. NuSEDS V2.0 Regional adult salmon escapement database system 1950-2014. Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C. Available from: http://open.canada.ca/en/suggested-datasets/new-salmon-escapement-database-nuseds [accessed 01 December 2016].

DFO (Fisheries and Oceans Canada). 2017. Preliminary summary commercial statistics 1996-2014. Available from http://www.pac.dfo-mpo.gc.ca/stats/comm/summ-somm/index-eng.html [accessed 05 February 2017].

English, K.K. 2016. Review of escapement indicator streams for the north and central coast salmon monitoring program. Available from http://skeenasalmonprogram.ca/library/lib_440/ [accessed 05 December 2016].

English, K.K., Peacock, D., and Spilsted, B. 2006. North and central coast core stock assessment program for salmon. Report prepared for Pacific Salmon Foundation and Fisheries and Oceans Canada, Sidney, B.C.

English, K.K., Peacock, D., Challenger, W., and Mochizuki, T. 2016. Review of north and central coast salmon escapement, catch, run size, and exploitation rate estimates for each salmon conservation unit for 1954-2014. Available from http://skeenasalmonprogram.ca/libraryfiles/lib_1.pdf [accessed 06 December 2016].

Gardner Pinfold. 2011. Performance review of the Wild Salmon Policy. Prepared for Fisheries and Oceans Canada. Sechelt, B.C.

Grant, S.C.H., and Pestal, G. 2013. Integrated biological status assessments under the Wild Salmon Policy using standardized metrics and expert judgement: Fraser River sockeye salmon (*Oncorhynchus nerka*) case studies. Canadian Science Advisory Secretariat Research Document 2012/106. Nanaimo, BC. Available from: http://waves-vagues.dfo-mpo.gc.ca/Library/349637.pdf [accessed 15 March 2017].

Holt, C.A., Cass, A., Holtby, B., and Riddell, B. 2009. Indicators of status and benchmarks for conservation units in Canada's Wild Salmon Policy. Canadian Science Advisory Secretariat Research Document 2009/058. Nanaimo, BC. Available from: http://waves-vagues.dfo-mpo.gc.ca/Library/339096.pdf [accessed 15 March 2017].

Holt, C.A., and Bradford, M.J. 2011. Evaluating benchmarks of population status for Pacific salmon. North American Journal of Fisheries Management 31: 363-378.

Holt, C.A., and Folkes, M.J.P. 2015. Cautions on using percentile-based benchmarks of status for data-limited populations of Pacific salmon under persistent trends in productivity and uncertain outcomes from harvest management. Fisheries Research 171: 188-200.

Holtby, L.B., and Ciruna, K.A. 2007. Conservation Units for Pacific salmon under the wild salmon policy. Canadian Science Advisory Secretariat Research Document 2007/070. Available from: http://waves-vagues.dfo-mpo.gc.ca/Library/334860.pdf [accessed 20 June 2017].

Hyatt, K., Johannes, M.S., and Stockwell, M. 2007. Ecosystem overview: Pacific north coast integrated management area (PNCIMA). Appendix 1: Pacific salmon. Canadian Technical Report of Fisheries and Aquatic Sciences 2667. Available from: http://salmonwatersheds.ca/libraryfiles/lib_260.pdf [accessed 01 January 2017].

Irvine, J.R., and Nelson, T.C. 1995. Proceedings of the 1994 Salmon Escapement Workshop and an annotated bibliography on escapement estimation techniques. Canadian Technical Report of Fisheries and Aquatic Sciences 2305, Nanaimo, B.C. Available from: http://publications.gc.ca/collections/collection_2014/mpo-dfo/Fs97-4-2305-eng.pdf [accessed 01 January 2017].

Irvine, J.R. 2009. The successful completion of scientific public policy: lessons learned while developing Canada's Wild Salmon Policy. Environmental Science & Policy 12: 140-148.

Irvine, J.R., Michielsens, C.J.G., O'Brien, M., White, B.A., and Folkes, M. 2014. Increasing Dominance of Odd-Year Returning Pink Salmon. Transactions of the American Fisheries Society 143: 939-956.

Malick, M.J., and Cox, S.P. 2016. Regional-scale declines in productivity of pink and chum salmon stocks in western North America. PLOS ONE 11: e0146009.

Office of the Auditor General of Canada. 1999. Pacific salmon: sustainability of the fisheries. Chapter 20. Available from http://publications.gc.ca/collections/collection_2016/bvg-oag/FA1-1999-3-20-eng.pdf [accessed 05 February 2017].

Office of the Auditor General of Canada. 2004. Fisheries and Oceans Canada – salmon stocks, habitat, and aquaculture. Chapter 5. Available from http://www.oag- bvg.gc.ca/internet/ docs/c20041005ce.pdf [accessed 05 February 2017].

Ogden, A.D., Irvine, J.R., English, K.K., Grant, S., Hyatt, K.D., Godbout, L., and Holt, C.A. 2015. Productivity (Recruits-per-Spawner) Data for Sockeye, Pink, and Chum Salmon from British Columbia. Canadian Technical Report of Fisheries and Aquatic Sciences 3130. 57 p. Available from: ftp://ftp.meds-sdmm.dfo-mpo.gc.ca/pub/openData/Recruits_Spawner/Canadian_Technical_Report_3130.pdf [accessed 01 January 2017].

Peacock, S.J., and Holt, C.A. 2010. A review of metrics of distribution with application to conservation units under Canada's Wild Salmon Policy. Canadian Technical Report of Fisheries and Aquatic Sciences 2888, Nanaimo, B.C. Available from: http://publications.gc.ca/collections/collection_2011/mpo-dfo/Fs97-6-2888-eng.pdf [accessed 15 March 2017].

Pestal, G., and Johnston, S. 2015. Estimates of a biologically-based spawning goal and biological benchmarks for the Canadian-origin Taku River coho stock aggregate. Canadian Science Advisory Secretariat Research Document 2015/048. Available from: http://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs70-5-2015-048-eng.pdf [accessed 01 May 2017].

Peterman, R.M., and Dorner, B. A widespread decrease in productivity of sockeye salmon

(*Oncorhynchus nerka*) populations in western North America. Canadian Journal of Fisheries and Aquatic Sciences 69: 1255–1260.

Price, M.H.H., Darimont, C.T., Temple, N.F., and MacDuffee, S.M. 2008. Ghost runs: management and status assessment of Pacific Salmon (*Oncorhynchus* spp.) returning to British Columbia's central and north coasts. Canadian Journal of Fisheries and Aquatic Sciences 65: 2712-2718.

Ruggerone, G.T., and Connors, B.M. 2015. Productivity and life history of sockeye salmon in relation to competition with pink and sockeye salmon in the North Pacific Ocean Canadian Journal of Fisheries and Aquatic Sciences 72: 1-16.

Slaney, T.L., Hyatt, K.D., Northcote, T.G., and Fielden, R.J. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21: 20-35.

Think Tank of Scientists. 2017. Speaking for the salmon. The protection of Pacific wild salmon: understanding potential risk factors and seeking solutions. Recommendation from a think tank of scientists. Vancouver, BC. Available from http://www.sfu.ca/content/dam/sfu/coastal/SfSJan2017Recommendations.pdf accessed [24 March 2017].

Walters, C.J., Lichatowich, J.A., Peterman, R.M., and Reynolds, J.D. 2008. Report of the Skeena Independent Science Review Panel. A report to the Canadian Department of Fisheries and Oceans and the British Columbia Ministry of the Environment. Available from: http://salmonwatersheds.ca/libraryfiles/lib_b_157.pdf [accessed 15 December 2016].

WSS (World Summit on Salmon). 2003. Proceedings. Available from http://www.sfu.ca/content/dam/sfu/coastal/Research%20&%20Series/Series/Speaking%20for%20the%20Salmon/WorldSummitonSalmon/Proceedings.pdf [accessed 21 January 2017].

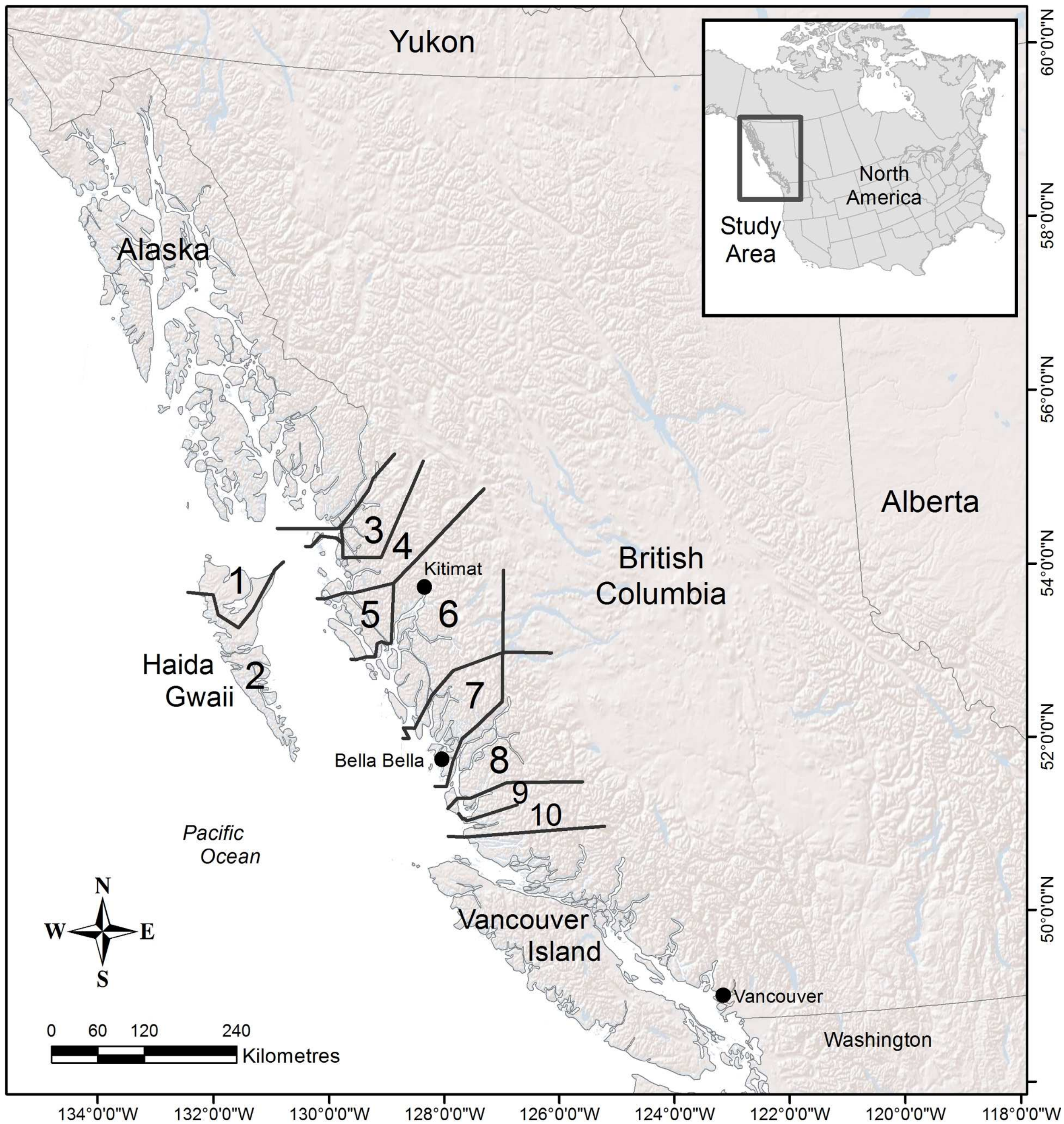

Figure 1. Region encompassed by the Wild Salmon Policy, including British Columbia (BC) and Yukon Territory, and DFO Fisheries Management Areas 1-10 for Pacific salmon (*Oncorhynchus* spp.) returning to BC's north and central coasts where much of the data used in our analyses originate. Copyright 2014 Esri.

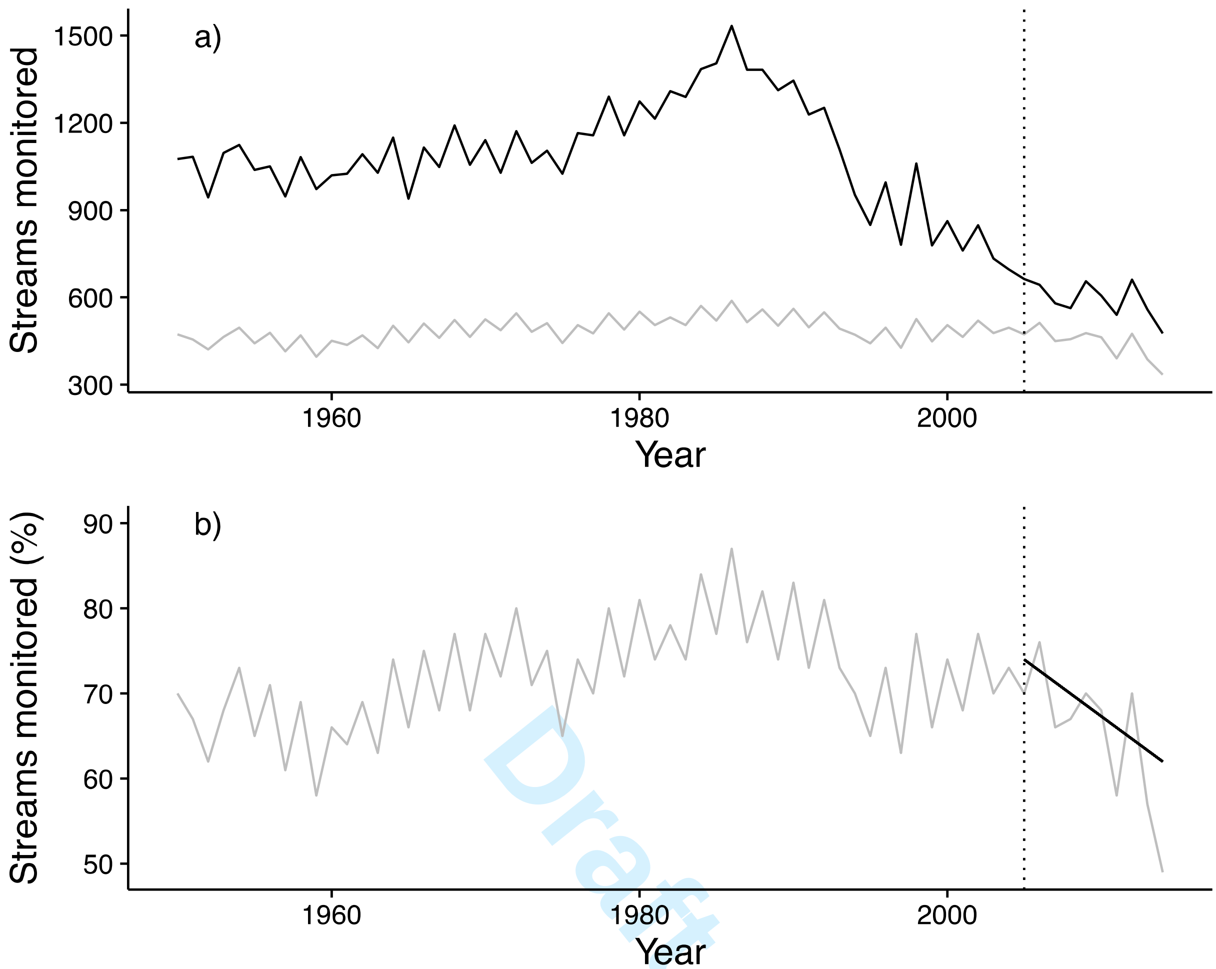

Figure 2. a) Comparison of the number of spawning streams monitored between *all streams combined* (black line) and *Indicator Streams* (grey line), and b) percentage of *Indicator Streams* routinely (i.e., ≥50% of the time) monitored, and the trend (black line) in monitoring since the adoption of the Wild Salmon Policy in Management Areas 1-10 of British Columbia's north and central coasts from 1950 to 2014. Vertical dashed lines demarcate the adoption of the Wild Salmon Policy in 2005.

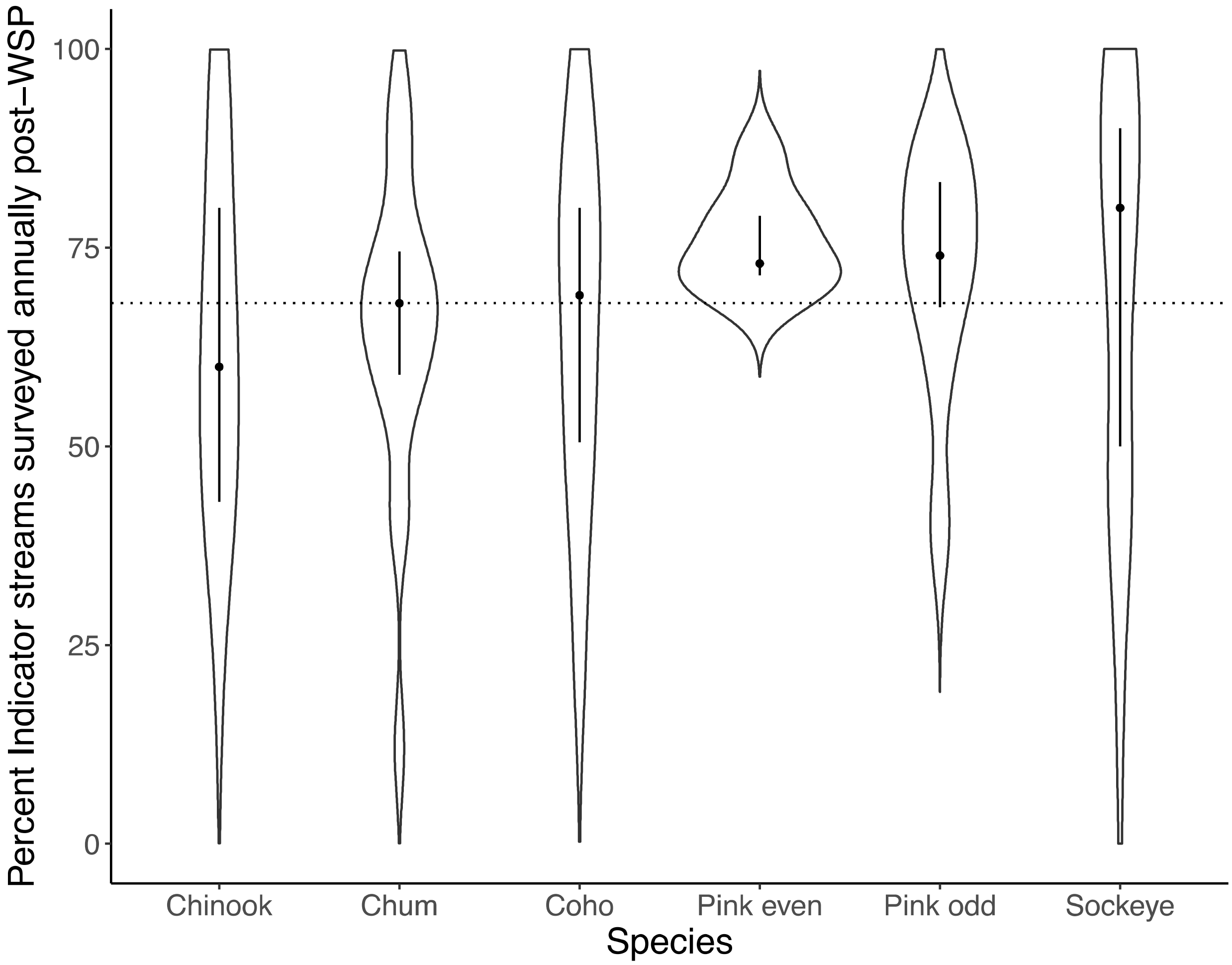

Figure 3. Violin plots of the percentages of Indicator spawning streams surveyed annually during 2005 to 2014, for each Conservation Unit (CU) with an assigned Indicator stream, for each species along British Columbia's north and central coasts. Dashed line is the overall mean monitoring effort across all CUs; black dots and lines are the medians and their 25th and 75th percentiles.

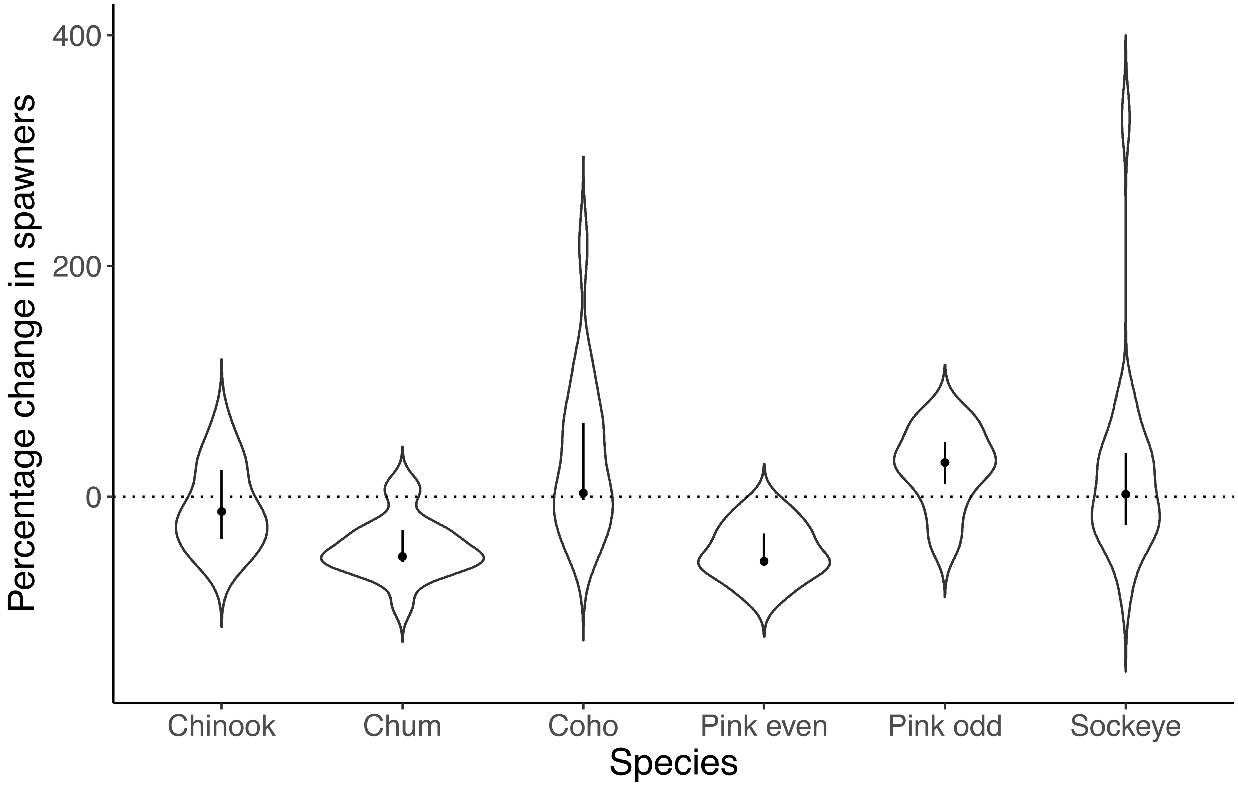

Figure 4. Violin plots of the relative change in average numbers of spawning adult salmon (escapement) for each Conservation Unit within each species between the decade *Before* (1995-2004) and *After* (2005-2014) the adoption of the Wild Salmon Policy. Dashed line demarcates zero change in escapement; black dots and lines are the medians and their 25th and 75th percentiles.

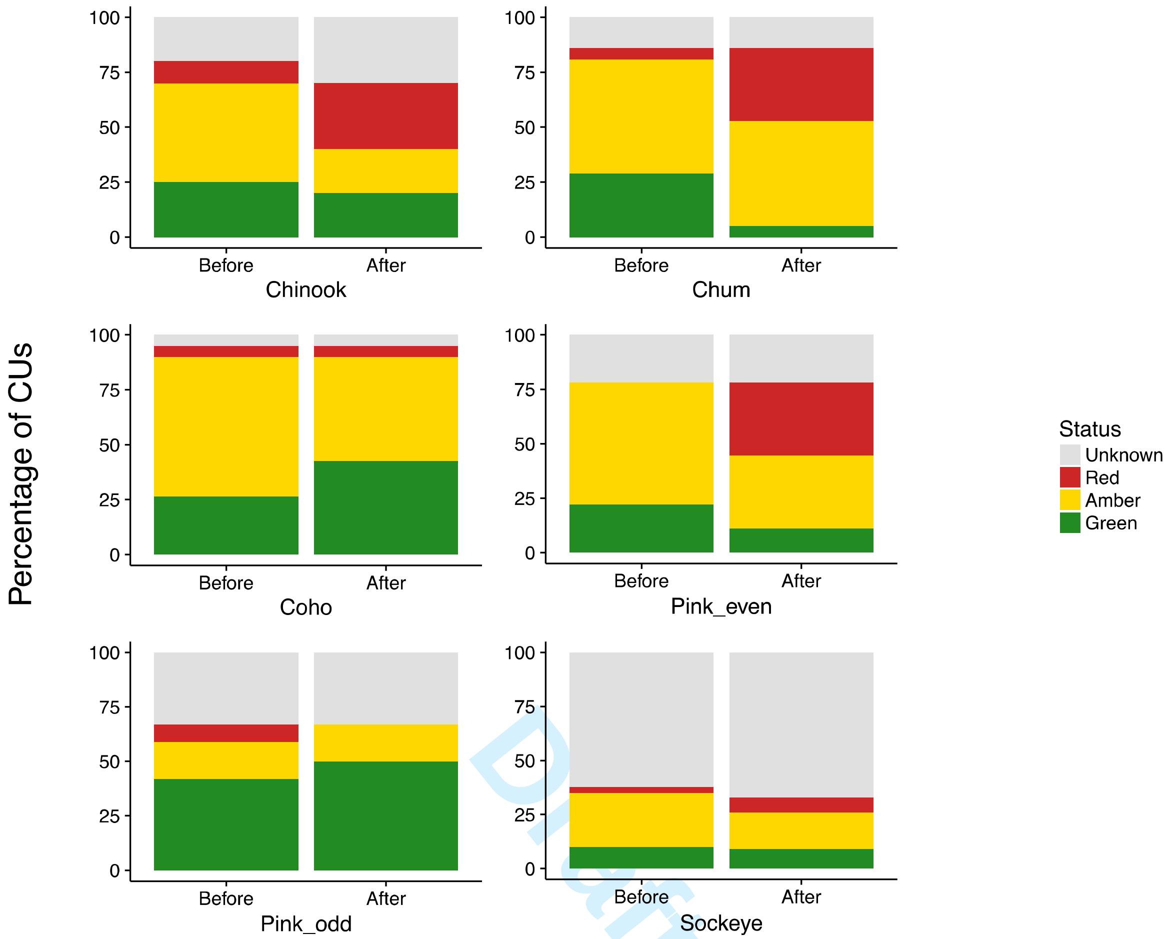

Figure 5. Status assignments for all Conservation Units (CU) and species based on average escapement *Before* (1995-2004) and *After* (2005-2014) the adoption of the Wild Salmon Policy, derived from benchmarks assigned using the 25th and 75th percentile approach of historical escapement for each CU.

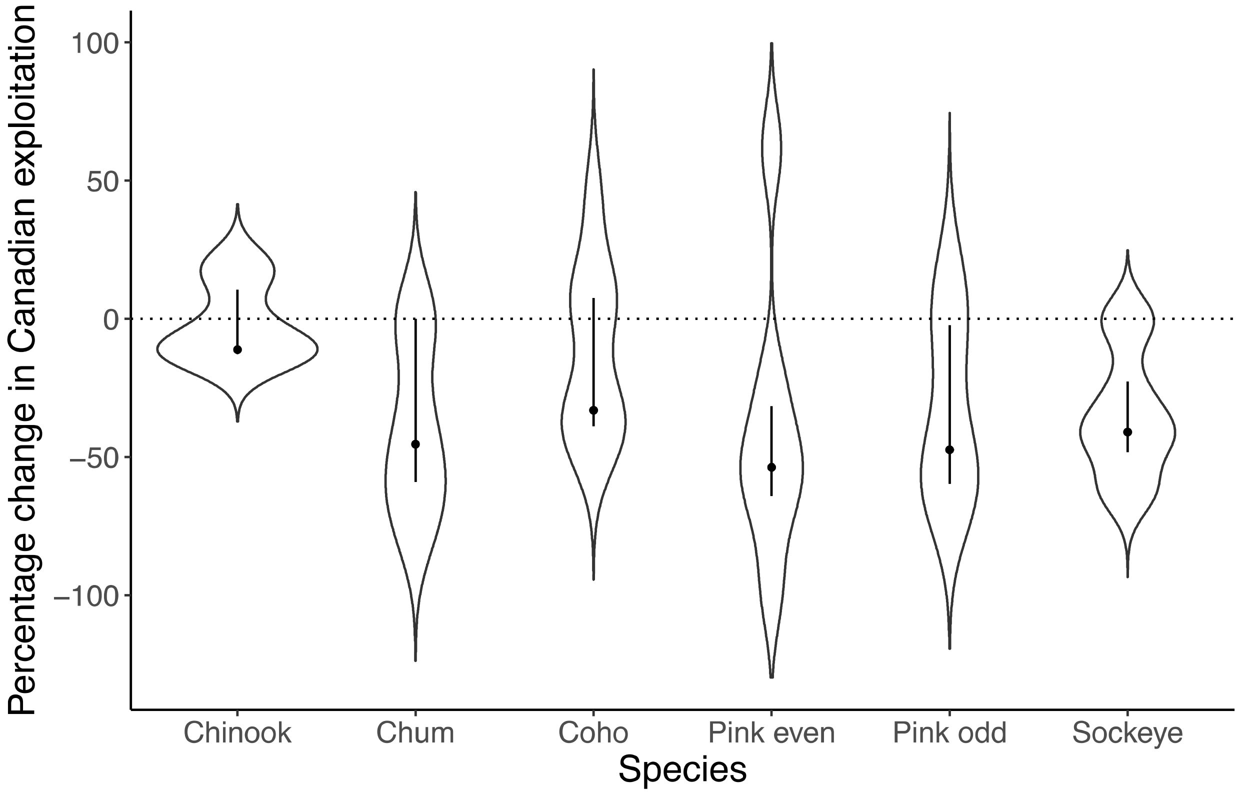

Figure 6. Violin plots of the percentage change in Canadian exploitation rates on each Conservation Unit within each species between the decade *Before* (1995-2004) and *After* (2005-2014) the adoption of the Wild Salmon Policy. Dashed line demarcates zero change in exploitation rates; black dots and lines are the medians and their 25th and 75^{th} percentiles.

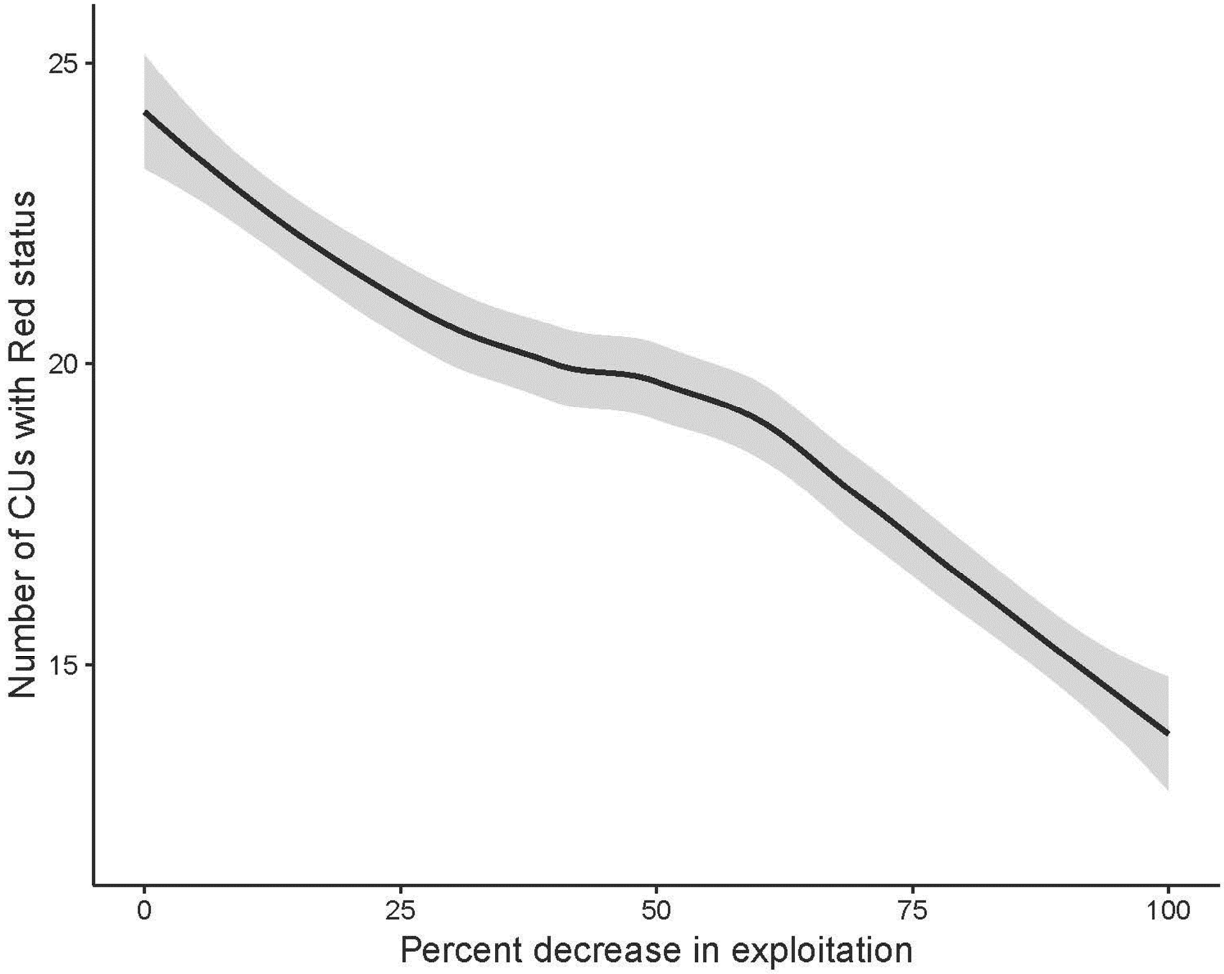

Figure 7. Relationship between the number of Conservation Units (CU) assessed with Red-zone status and percent reduction in Canadian fisheries exploitation of each CU across all species on BC's north and central coasts in the decade after the adoption of the Wild Salmon Policy in 2005. Black line is a fitted LOESS curve with standard error (grey shade).

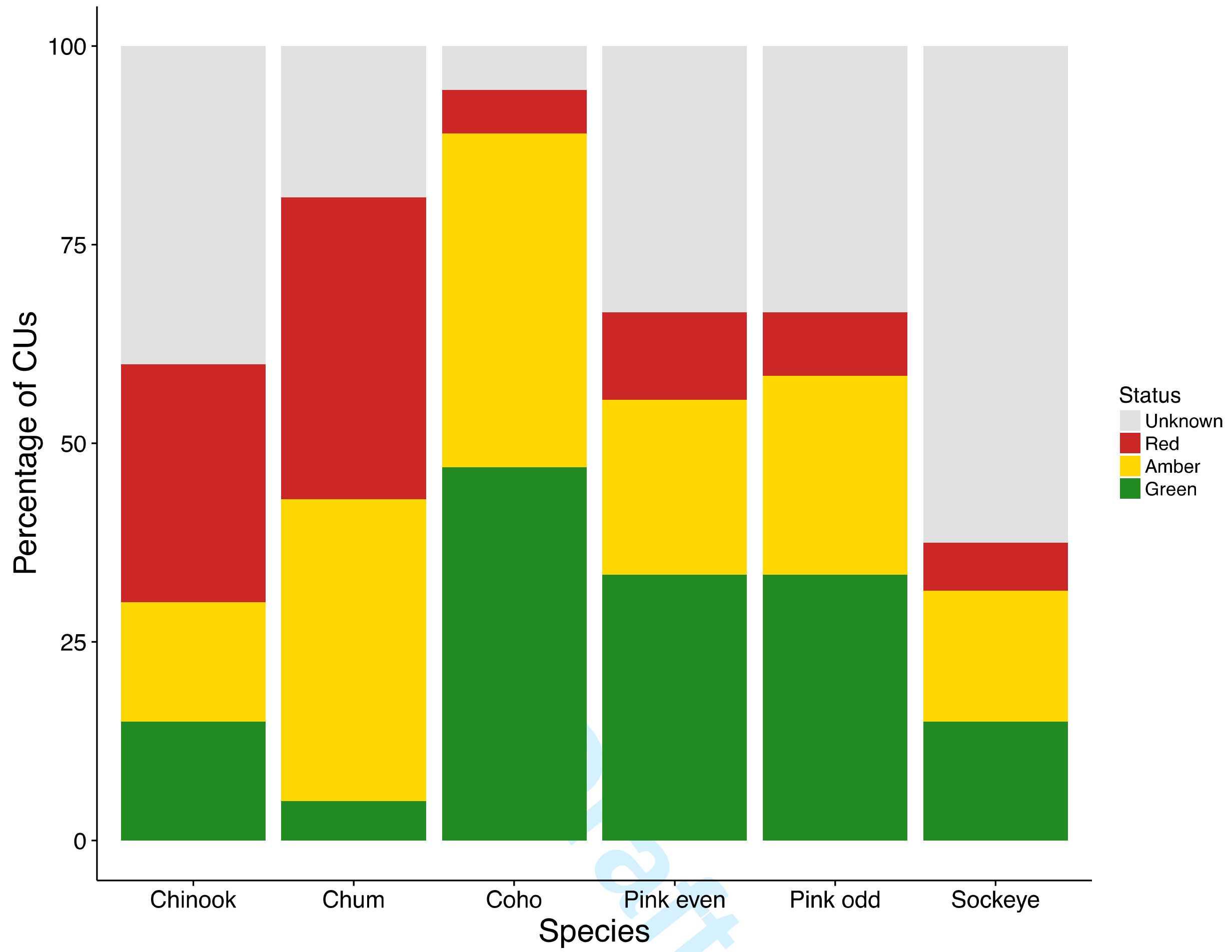

Figure 8. Contemporary period status assessment of Conservation Units (CU) for each species on BC's north and central coasts, based on the 25th and 75th percentile approach of spawner abundance, and the following "generational" (i.e., over the most recent generation) years: Chinook (2009-2014; 23 CUs); chum (2011-2014; 20 CUs); coho (2011-2014; 18 CUs); even-year pink (2014; 8 CUs); odd-year pink (2013; 11 CUs); sockeye (2009-2014 depending on CU; 138 CUs).

Table 1. Comparison of species-specific monitoring effort of spawning streams on BC's north and central coasts between those recommended in the Core Stock Assessment Program (English et al. 2006) and recent (2007-2014) efforts to determine the extent that a strategic approach has been implemented since the adoption of the Wild Salmon Policy in 2005.

Species	Streams with annual surveys recommended*	Streams with annual surveys met*	Streams with periodic surveys recommended**	Streams with periodic surveys met**	Streams with annual and periodic surveys met (%)	Recommended streams with zero effort (%)
Chinook	33	8	28	6	23	36
Chum	175	35	42	20	25	11
Coho	104	17	101	25	20	51
Pink - even	157	60	N/A	N/A	38	11
Pink - odd	132	53	N/A	N/A	40	11
Sockeye - lake	27	12	6	2	42	18
Sockeye - river	6	2	3	0	22	56
Combined total	634	187	180	53	29	24

* Includes annual fence counts and mark-recapture programs
** To be performed once every 2, 3, or 4 years, or 2 of 3 years

Table 2. Synopsis of the change in spawning abundance, percentage of Conservation Units (CU) that declined in spawning abundance, the number of CUs that declined to Red status, the influence of Canadian fisheries on CUs assessed as Red, and the change in Canadian fisheries exploitation on all salmon species returning to British Columbia's north and central coasts since the adoption of the Wild Salmon Policy in 2005.

Species	Average spawning abundance 2005-2014	Change in spawning abundance	Percentage of CUs that declined in spawning abundance	Number of CUs that declined to Red status	Number of CUs that would have declined in status**	Number of CUs that would have improved in status***	Percentage change in Canadian fisheries exploitation
Chinook	98,000	-25,000 *	69	5	0	5	-2
Chum	1,135,000	-999,000 *	89	5	1	2	-11
Coho	1,137,000	237,000	35	1	0	3	1
Pink - even	6,485,000	-4,421,000 *	86	2	1	1	-10
Pink - odd	11,255,000	1,998,000	25	0	0	1	-
Sockeye	874,000	-104,000	53	8	1	5	-9
Combined total	20,984,000	-3,314,000	58	21	3	17	-7

* Denotes statistical significance with Wilcoxon Signed-Rank Test for non-normal data.
** Had fisheries exploitation not been reduced in the decade since the adoption of the WSP.
*** Had fisheries exploitation been further reduced in the decade since the adoption of the WSP.