Independent Scientific Review Panel
for the Northwest Power & Conservation Council
851 SW 6th Avenue, Suite 1100
Portland, Oregon 97204
www.nwcouncil.org/fw/isrp

Memorandum (2020-9) September 24, 2020

To: Richard Devlin, Chair, Northwest Power and Conservation Council

From: Stan Gregory, ISRP Chair

Subject: Response Review: Yakama Nation's Revised Master Plan for Yakima Subbasin Summer- and Fall-run Chinook, Coho Salmon and Steelhead

Background

On August 7, 2020, the Northwest Power and Conservation Council requested that the Independent Scientific Review Panel (ISRP) review a response from the Yakama Nation regarding the ISRP's review of the *Revised Master Plan for Yakima Subbasin Summer- and Fall-run Chinook, Coho Salmon and Steelhead*, associated with Project #1988-115-25, *Yakima River Design and Construction-Yakima/Klickitat Fisheries Project (YKFP)*. The response is attached to a cover letter from the Yakama Nation and is titled *Responses to the "Independent Scientific Review Panel's Review of the Yakama Nation's Revised Master Plan for Yakima Subbasin Summer- and Fall-run Chinook, Coho Salmon and Steelhead (ISRP 2020-3)."* The response addresses thirteen primary questions the ISRP requested as part of our last review, which was the fourth review related to the Master Plan (ISRP 2020-3).[1] Our review below is organized around the thirteen questions.

Recommendation

Meets Scientific Review Criteria

The Yakama Nation (YN) Master Plan, along with the YN response to ISRP comments, largely meets scientific review criteria. The Master Plan represents an ambitious endeavor to reintroduce populations of summer/fall Chinook and coho salmon to the Yakima Basin while also providing harvest opportunities. Phases 1 and 2 of the effort have been underway for a number of years, and the current Master Plan primarily focuses on Phase 3 and Phase 4. Transition from

[1] The Yakama Nation's October 2019 cover letter to the Council includes a succinct summary of the sequence of Council and ISRP reviews since 2012 that led up to the 2019 Master Plan.

Phase 3 to Phase 4 will require significant improvement in capacity and productivity by restoring habitats in the Yakima Basin, plus adequate survival at sea and during migration through ocean and freshwater fisheries. The need for habitat restoration and amelioration of other factors affecting salmon survival is acknowledged in the Master Plan, but these efforts are beyond the scope of the Plan. Within the scope of the Master Plan, successful transition from Phase 3 to Phase 4 will likely require improved management of the natural reproductive capacity of salmon spawning in the watershed (e.g., management of pHOS) and expansion of habitats used by spawning salmon as a means to reduce density-dependent mortality.

The management plan for hatchery origin and natural origin salmon in the Yakima Basin meets most scientific expectations, except that it does not fully address the limitations of current or near-term future habitat conditions needed to sustain the expected number of natural spawning hatchery and natural origin fish. Observed coho spawner counts (hatchery- and natural-origin) greatly exceed the modelled (EDT and Beverton-Holt) recruitment capacity estimates for the Yakima Basin, and productivity (adult return per spawner) has been low and declining over time, possibly in response to many years of relatively high densities.

The ISRP comments below describe changes in the Plan that could be made to further promote adaptation of coho salmon to the local environment and facilitate development of a larger sustainable natural population. One suggested change involves implementing selective harvest of hatchery-origin coho salmon at Prosser and Roza dams in years when additional hatchery spawners would produce little or no additional progeny, based on empirical analysis of the spawner-recruit relationship (see discussion below). Removal of such hatchery salmon would reduce density effects on productivity in the short-term and improve fitness (intrinsic productivity) in the long-term. Furthermore, because the intrinsic productivity of the population determines the maximum harvest rate that can be sustained, higher intrinsic productivity is needed to help the natural population achieve sustainability (i.e., $R/S \geq 1$) given the existing and anticipated harvest rates in fisheries that are outside the proponents' control. Ongoing efforts to increase productivity and capacity of the population include habitat restoration, colonization of new habitats by spawning salmon and hatchery stocking, and management of natural-origin spawners in the hatchery broodstock. Productivity may also be boosted by reducing density through management of the number of hatchery salmon allowed to spawn in the watershed.

The ISRP respects the Yakama Nation's desire to allow as many salmon (hatchery and natural) as possible to spawn in the Yakima Basin given the significant changes that have occurred in the Columbia Basin over the past 200 years. Regarding the ISRP's encouragement to increase selective harvest of hatchery salmon during some years to reduce negative density dependence effects, the ISRP believes that this could be done with compatible methods that are sensitive to cultural approaches and compliant with legal frameworks. Creativity and adaptability of methods will be key to success. These ISRP suggestions focus on the science of re-establishing and maintaining sustainable natural-origin populations of Chinook and coho salmon that meet the Yakama Nation's goals of natural production and harvest in the Yakima River basin and Zone 6.

ISRP Comments on the Yakama Nation’s Responses

The text below identifies the topic that was addressed by the Yakama Nation's response to ISRP comments (bold or italic text) followed by the ISRP review of the YN response (normal font). Please see the YN response for more details.

> ISRP 2020-3: *Most ISRP concerns involve the use of the integrated hatcheries to re-establish natural populations of coho and summer/fall Chinook salmon above Prosser Dam, and the extent to which self-sustaining populations could be established, given current habitat conditions and exploitation rates in existing fisheries. This endeavor is complicated and challenging because coho and summer Chinook salmon were extirpated from this area, and fall Chinook runs currently are severely depressed. Ultimately, the success of re-establishing self-sustaining natural populations above Prosser Dam during the final stages of the program will depend on the success of planned habitat restoration activities, sustainable harvest rates on the less productive natural populations that co-mingle with more productive populations (mostly hatchery), and successful implementation of the integrated hatchery programs that enable fish to adapt to the local environment and increase survival.*

Thank you for your comments in the cover letter and to the ISRP statement shown above. The ISRP endorses the use of integrated hatchery programs to help rebuild natural self-sustaining populations that also support fishery harvests. Furthermore, we support the goal of increased harvests provided by integrated hatcheries and suggest that greater harvests of hatchery fish are beneficial especially if the total number of naturally spawning fish exceeds the estimated maximum equilibrium (i.e., replacement) value (see Comment 7).

The ISRP emphasizes the need to collect appropriate data so that biologically based spawner goals can be estimated and evaluated and harvests can increase while maximizing total production of progeny from the spawning population. Furthermore, harvest of hatchery fish that contribute few or no additional natural smolts (as quantified when appropriate data are collected) would increase PNI (Proportionate Natural Spawners) and help the natural spawning population maintain adaptations to the local environment thereby increasing intrinsic productivity, as needed to achieve replacement and sustain harvest (Walters and Hilborn 1992).

The ISRP recognizes the proponents’ desire to encourage as many coho and Chinook salmon to spawn naturally in the basin as possible. The ISRP acknowledges that this is a very important YN cultural goal. The ISRP provides these comments and previous review comments to identify scientific aspects of the planned management actions that could increase the likelihood of establishing productive, self-sustaining natural populations of coho and Chinook salmon.

Recommended Analyses to Inform Management

1. Describe how productivity and capacity of naturally spawning coho and summer/fall Chinook salmon will be evaluated and tracked over time.

The frequent update of spawner-recruit (SR) analyses with new data is highly worthwhile. In addition, the proposed 100% marking of summer/fall Chinook salmon will enable refinement to the Chinook recruitment analyses, which is currently compromised by the lack of hatchery- and natural-origin recruitment values. The empirically derived coho recruitment curve (brood years 2001-2015) suggests productivity was higher (2.07 adult returns per spawner [R/S]) and capacity was lower (1675 recruits) than the EDT model values both without the fitness adjustment (1.52 R/S, 3185 recruits) and with the hatchery fitness adjustment (0.76 R/S, 2389 recruits).

We note that the coho escapement objectives during Phase 3 (>4,400 NOR and HOR) and Phase 4 (>4,000 NOR and HOR) are considerably greater than the EDT-based capacity value with or without the reduced fitness factor and 2.6x greater than the empirical capacity estimate, suggesting that it may be difficult to reach the trigger to Phase 4 (i.e., 2,400 NOR over three consecutive years) without substantial increases in intrinsic productivity and capacity. From 2001-2018, the average return of natural-origin adult and jack coho salmon was 922 fish and the average count of coho spawning in the watershed above Prosser Dam (hatchery- and natural-origin) was approximately 4,800 fish. The high average spawner abundance, which is 2x greater than the Phase 3 EDT capacity estimate, raises the question of whether continuously high spawning densities have contributed to the decline in return per spawner since 2001 (see Larkin 1971, Martell et al. 2007).[2] The declining trend deserves further evaluation.

The ISRP understands that data are not available to develop separate spawner-recruit relationships for the Naches and Upper Yakima drainages, but we emphasize the value of collecting such data given that production from these two subbasins is likely very different.

No information was provided about the relationship between smolt production and spawner abundance. If reliable smolt counts become available, we encourage the proponents to develop these relationships because spawner-to-smolt production data provide the best indicator of fish response to Yakima Basin restoration activities, including habitat restoration efforts and fitness gains of natural-origin coho salmon.

2. Clarify how the fitness factors for hatchery salmon (0.5 and 0.8 depending on Phase or stock origin) were used to adjust EDT capacity estimates for determining "optimal" numbers of parr, smolts, and adults to be stocked into streams.

Thank you for the response, which clarifies that the EDT hatchery fitness factor reduced rather than increased the planned number of hatchery smolts released into the watershed. Thus, fewer

[2] The declining productivity trend over time is observed in both return per spawner and in the residual of the recruitment relationship.

smolts should be released during Phase 3 when PNI is low than during Phase 4 when PNI is higher. This is logical and what we expected.

Nevertheless, we remain confused by the data presented in Table 2-14 of the Master Plan. This table shows identical numbers of juvenile coho released from the hatchery during Phase 3 and Phase 4 (500, 000 parr, 200,000 smolts). Furthermore, Phase 3 includes 1,000 hatchery adult outplants (segregated program fish) that are not released during Phase 4. In other words, Table 2-14 is not consistent with the YN response suggesting that fewer hatchery fish would be stocked into the watershed during Phase 3 than during Phase 4. Also, the spawner escapement objective is higher for Phase 3 than Phase 4 (Table 2-19).

3. Justify the use of "effective pHOS" when calculating PNI or use actual pHOS, as recommended by the National Marine Fisheries Service (NMFS).

Although we agree that the results based on these data are somewhat similar when using effective and census pHOS values, the response seems to conflate the calculation of the PNI value with output from the EDT model. The number of natural-origin returns will increase proportionately if relative reproductive success (RRS) increases from 80% to 100%, so there is no reason to recalculate natural origin escapement assuming RRS = 100% when calculating the PNI for the current conditions. Instead, using data from Table 2 in the response, the PNI score should be calculated using data under the column RRS = 80% given that the EDT model is used to generate the data.

According to NMFS (see below), the census (observed) hatchery escapement (2,991) should be used, rather than the effective hatchery escapement (2,394), along with the natural origin escapement (1,038) and pNOB (0.3), leading to a PNI of 0.29. We raise this issue because there may be situations when the use of effective pHOS would have different implications for PNI.

In general, use of effective pHOS inflates the PNI score to some degree. In the Yakima Basin, coho and summer/fall Chinook salmon were extirpated, so the existing fish likely have similar genetic composition as the hatchery fish which were used to create the populations.

Below is a quote written by NMFS scientists in recent Biological Opinions involving hatcheries (text provided by Craig Busack, NOAA Fisheries):

> *NMFS feels that adjustment of census pHOS by RRS should be done very cautiously, not nearly as freely as the HSRG document would suggest. The basic reason is quite simple: the Ford (2002) model, the foundation of the HSRG gene flow guidelines, implicitly includes a genetic component of RRS. In that model, hatchery fish are expected to have RRS < 1 (compared to natural fish) due to selection in the hatchery. A component of reduced RRS of hatchery fish is therefore already incorporated in the model and by extension the calculation of PNI. Therefore reducing pHOS values by multiplying by RRS will result in underestimating the relevant pHOS and therefore overestimating PNI. Such adjustments would be particularly inappropriate for*

hatchery programs with low pNOB, as these programs may well have a substantial reduction in RRS due to genetic factors already incorporated in the model.

In some cases, adjusting pHOS downward may be appropriate, however, particularly if there is strong evidence of a non-genetic component to RRS. An example of a case in which an adjustment by RRS might be justified is that of Wenatchee spring Chinook salmon (Williamson et al. 2010) where, the spatial distribution of natural-origin and hatchery-origin spawners differs, and the hatchery-origin fish tend to spawn in poorer habitat. However, even in a situation like this it is unclear how much of an adjustment would be appropriate. By the same logic, it might also be appropriate to adjust pNOB in some circumstances. For example, if hatchery juveniles produced from natural-origin broodstock tend to mature early and residualize (due to non-genetic effects of rearing), as has been documented in some spring Chinook salmon and steelhead programs, the "effective" pNOB might be much lower than the census pNOB.

4. Revise PNI scores by explicitly accounting for natural spawning by segregated hatchery salmon (both outplanted and strays) which represent a third genetic component of the overall integrated population (segregated and integrated hatchery salmon plus natural origin salmon).

Thank you for clarifying this issue. The ISRP could not find in the Master Plan a statement that up to 1,000 segregated hatchery fish were incorporated into the PNI calculation during Phase 3. Inclusion of these segregated fish requires a more complicated calculation because the pNOB value is different for these fish (i.e., pNOB = 0).

The ISRP supports the planned removal of segregated hatchery fish at Roza Dam during Phase 4, as this may enhance local adaptation of coho salmon.

In Phase 3, the Master Plan calls for up to 1,000 segregated hatchery coho to be outplanted to the spawning grounds to increase spatial distribution and recolonize underutilized spawning habitat. The ISRP encourages the YN to prioritize the juvenile outplants (700,000 fish) and transplants of integrated hatchery salmon (~3,190 fish available) to achieve this goal as a means to promote local adaptation and increase productivity, and to only use segregated hatchery adults if NOR and integrated HOR coho salmon are too few to meet the sustainable escapement target (see Comment 7). The ISRP recognizes that segregated and integrated hatchery coho were recently derived from the same non-local populations, but minimal escapement of segregated hatchery coho is needed to facilitate adaptation of natural spawning coho salmon to the local habitat.

5. Justify why planned releases of juvenile summer and fall Chinook salmon (3.4 million per year) are so much higher than the reported capacity during the Transition Phase (1.34 million) and Long-term Phase (3 million).

Thank you for clarifying that juvenile hatchery Chinook salmon spend little time in the basin after release (as low as 7 days), and so the capacity estimates do not necessarily apply to them. The YN notes that the large releases of hatchery Chinook salmon were designed to meet harvest, broodstock, and spawning escapement needs. If the capacity estimates for summer and fall Chinook are not reflective of these fish, then these capacity values should be removed from the Master Plan. However, we encourage the YN to limit the number of juveniles and hatchery spawners to numbers that can be supported by the environment.

The ISRP supports the YN plans to monitor and evaluate juvenile hatchery Chinook salmon migration timing and survival in the Yakima Basin. The ISRP encourages the YN to consider the combined effects of their hatchery releases and releases in other watersheds on natural origin salmon growth and survival as they pass through the lower Yakima River, mainstem Columbia River and estuary (ISAB 2011-1, ISAB 2015-1).

6. **In the genetics monitoring and evaluation plan, describe how parentage-based tagging (PBT) will be used to monitor natural salmon, as noted in the response to ISRP (Appendix K).**

The ISRP supports the plan to use PBT to estimate the contribution of naturally spawning hatchery salmon to natural-origin returns in subsequent generations. The ISRP also supports differential marking and evaluation of juvenile coho produced from the Melvin R. Sampson (MRS) and Prosser facilities.

Recommended Management Considerations to Achieve Sustainability Goals

7. **Consider culling hatchery salmon from the segregated and integrated programs at Prosser and Rosa dams when the number of integrated hatchery and natural origin spawners exceeds the capacity of the system to support them and their progeny (e.g., the empirically derived spawner goal).**

Our recommendation for harvesting or culling "surplus" hatchery salmon in the terminal area is based on well-established fishery science principles dating back to Ricker (1954) and earlier. The ISRP encourages the YN to develop and update empirical spawner-recruit (SR) relationships so that productivity and capacity can be estimated and escapement goals can be revised from the data. Initial SR analyses were provided in Response No. 1 above.

The ISRP recognizes the YN desire to allow as many adult salmon to spawn in the watershed as possible. However, empirical data from the Yakima Basin and elsewhere demonstrate that adding more and more spawners to a watershed does not necessarily lead to more progeny. Instead, capacity is reached at some point leading to maximal or diminished production of juveniles or adults. Please see ISAB 2015-1, its supplement, and references for examples.

In the Yakima Basin, the ISRP recommends that the YN use empirical data to identify the maximum abundance of natural spawners that can replace itself (i.e., the maximum equilibrium point) while continuing to re-evaluate the relationship as variables change over time. For coho, the equilibrium point is approximately 870 coho based on recent empirical data and 1090 coho based on the unadjusted EDT model (i.e., fully adapted hatchery coho), but intrinsic productivity of coho in the adjusted EDT model is less than one, indicating that the coho population is not sustainable even at low densities. Considerable variability exists in spawner-recruit relationships, so the YN may wish to consider this variability and target the upper range in the equilibrium estimate. For example, for a limited pre-determined period of time, YN might allow higher spawner densities such as 1.5X the equilibrium point. However, high spawner abundance every year could constrain gains in intrinsic productivity, so monitoring is needed. We also strongly recommend identifying spawner-recruit relationships between smolts (growth and abundance) and parent spawners, as these relationships are most reflective of freshwater habitat conditions.

Relationships for Chinook salmon will take time to develop because hatchery Chinook are not yet marked as needed to estimate natural production. However, EDT modeling indicates a maximum replacement value of 8,600 spawners (no adjustment for hatchery salmon) and approximately 3,200 spawners when adjusting for the lower fitness of hatchery salmon.

The maximum equilibrium point or “replacement value” is a useful target for the number of natural plus hatchery-origin spawners. The reason for harvesting hatchery salmon that exceed the replacement value is to: 1) increase harvests and 2) reduce pHOS and increase PNI so that the population can adapt to local conditions and evolve higher intrinsic productivity. This approach seems to us to be a win-win strategy, although we recognize that the quality of fish harvested at Roza Dam is likely lower than in downstream areas. The ISRP also recognizes and respects that this approach conflicts with the YN goal of encouraging as many salmon to spawn in the watershed as possible.

8. **Given that hatcheries often produce more jacks than natural spawning salmon produce, and that age at maturation is in part heritable, consider managing (culling) hatchery jacks (coho and Chinook) at Prosser and Rosa dams so that their rate of interbreeding with older salmon on the spawning grounds remains at a natural level.**

The YN does not yet consider a natural population of summer Chinook to be established in the Yakima River from which to make a demographic comparison, but they will monitor the age structure of the re-introduced population and hatchery over time. The YN recognizes that some jacks are needed in the hatchery and the natural population as a means to maintain some inter-generational gene flow. Current YN data indicate a relatively low rate of coho jacks in the hatchery (6%) and natural (12%) adult returns.

9. **Clarify the strategy, criteria, and actions for transitioning between Phase 3 and Phase 4 of the integrated coho program.**

Thank you for the clarification. The program would transition from Phase 3 to Phase 4 when the three-year average return exceeds 2,400 NORs. This would allow the program to transition to the Phase 4 goal of using 100% pNOB while collecting <30% of the NOR run for broodstock. The program goal is to stay in Phase 4 once the phase is reached. However, if the NOR abundance falls below 810 fish (which has occurred in 8 of past 18 years), then the program would revert to Phase 3 protocols so as to avoid excessive mining of NORs for hatchery broodstock (i.e., >30%). The YN confirms that outplants of segregated program fish would not re-start if the program temporarily reverted back to Phase 3.

10. Reconsider development of separate coho and summer Chinook broodstocks and outplant strategies to promote adaptation in the Naches River and Yakima River, which are unique watersheds.

The YN notes that there are infrastructure limitations in the Naches River that would limit this strategy. Nevertheless, the YN will continue to evaluate and consider additional differential marking schemes that would allow collection and identification of Naches-origin fish at the Prosser Dam adult Denil trap and sampling facility to the extent that resources and logistics allow.

11. Develop (or clarify) an experimental or planned strategy for releasing parr, smolts, and adults into specific streams in the upper basin.

Artificial production strategies of the Yakima Basin coho reintroduction effort include adult coho outplants, summer parr outplants, and smolt outplants for selected tributaries within the Naches and upper Yakima watersheds. Justification for generating release numbers are based on natural production estimates from the EDT model using the reduced fitness assumption and reduced juvenile capacity. For tributaries utilizing hatchery coho adult outplants as a release strategy, the YN assumed that only 50% of adult outplants will spawn successfully and applied survival rates to generate estimates of smolts and returning adults. Other methods mentioned in the response were used to estimate numbers of juveniles released into select tributaries where colonization is most likely to be successful based on previous studies (tributaries are not randomly selected as implied in the Master Plan review).

The YN has not considered dusk and evening releases of juvenile hatchery salmon. However, they may adopt this strategy in the future. Fish releases are "scatter plants," meaning fish will be released at numerous sites throughout the tributary.

Evaluation of release strategies will be based on analysis of juvenile outmigration survival and adult return rates using fish tagged and released as smolts and parr and collected from returning adults. Parentage based tagging (PBT) will be used to evaluate the contribution of adult outplants to future adult returns. The YN will monitor whether production resumes in the tributaries receiving outplants of adults, parr, and/or smolts.

The proponents corrected the errors in the Table 2-24 and Table 2-15. Transplants of adult segregated HORs will be discontinued in Phase 4.

12. Clarify how harvest rates on unmarked NOR and hatchery origin (HOR) coho salmon will be reduced to 20% in Zone 6 if they are co-mingling with marked segregated hatchery coho that are being harvested at 35%.

Thank you for the detailed response and for correcting the analyses and tables. Although integrated coho will be CWT and unmarked (no adipose fin clip) in Phases 3 and 4, a mark-selective tribal fishery in Zone 6 is not feasible for both policy and management reasons. The YN therefore revised the Zone 6 (upper Columbia) harvest rate assumptions for coho during Phase 3. The harvest rate for unmarked integrated HORs and unmarked NORs is the same in both Phases 3 and 4.

According to the YN, coho are selectively harvested upstream to Hood River, but there is no mark-selective fishery from Hood River to the mouth of the Yakima. Therefore, unmarked integrated program fish and NOR coho should have a slightly lower harvest rate in Zone 6 than marked segregated program fish due to selective harvest in the sport fishery.

The YN revised the harvest rate assumption to account for previous double counting of mortality associated with dam passage. The Zone 6 harvest rate assumption was revised to 29%. Harvest plus the estimated 6% passage loss at the 3 dams upstream of Bonneville sums to 35% loss of adult coho between Bonneville and Prosser.

The revised (increased) upper Columbia (Zone 6) harvest rate assumption for NORs in Phase 3 (29% instead of 20%) and reduced Zone 6 harvest rate assumption for HORs in Phase 3 (29% instead of 35%) leads to slightly higher pHOS (70%) and lower PNI (0.30) in Phase 3, and it reduces the number of natural-origin spawners. The reduced Zone 6 harvest rate for both HORs and NORs in Phase 4 (29% instead of 35%) increases both NORs and HORs, and results in little change in pHOS and PNI.

The revised outcomes for the coho program were presented in updated versions of Tables 2-24 and 2-25 from the 2019 Master Plan. The ISRP encourages the YN to incorporate these revised tables, other revised information, and the ISRP review and YN responses in a 2020 updated version of the Master Plan.

13. Clarify whether or not coho hatchery facilities have the capacity to quickly shift from parr to smolt production, as proposed in a response to ISRP.

According to the YN, the initial program in the revised Master Plan for the MRS coho facility (200,000 smolts and 500,000 parr) was based on results to date demonstrating good survival to adult return for coho released as parr. However, the MRS facility was designed and built with sufficient infrastructure and water to accommodate a program of 700,000 smolts. Therefore, the

YN states that it can easily transition to a 700,000 smolt release program in the future if monitoring and evaluation results indicate this is desirable.

References

Hilborn, R., and C.J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty. Chapman and Hall, New York.

ISAB. 2011-1. Columbia River Food Webs: Developing a Broader Scientific Foundation for Fish and Wildlife Restoration. Northwest Power and Conservation Council, Portland, Oregon. www.nwcouncil.org/fw/isab/isab2011-1

ISAB. 2015-1. Density Dependence and its Implications for Fish Management and Restoration in the Columbia River Basin (and July 2016 addendum). Northwest Power and Conservation Council, Portland, Oregon. www.nwcouncil.org/fw/isab/isab2015-1

Larkin, P.A. 1971. Simulation studies of Adams river Sockeye salmon (*Oncorhynchus nerka*). Journal of the Fisheries Research Board of Canada 28:1493-1502.

Martell, S.J.D., C.J. Walters and R. Hilborn. 2008. Retrospective analysis of harvest management performance for Bristol Bay and Fraser River sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 65:409-424.

Ricker, W.E. 1954. Stock and recruitment. Journal of the Fisheries Research Board of Canada 11:559-623.