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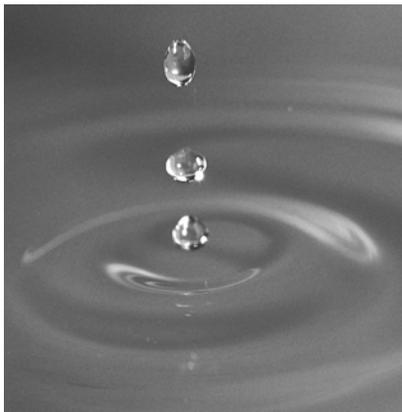
Snake River Fall Chinook – A Model Analysis:

Risks of Extinction or Recovery under Current Harvest Practices

Submitted to:

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Executive Summary

We constructed a Population Variability Analysis life-cycle model to simulate likelihood of future population trends of Snake River Fall Chinook (SRFC) as described by Paulsen *et al.* (2007). We initially modeled two simple options: continue with the *status quo* of harvesting about 50 percent of returns or eliminate harvest completely. Our population model assumes that the past 25 years, including periods of good and bad conditions would be the same in the future. Recruits show no density dependence; we assumed therefore not habitat limited.

Modeling the *status quo*, there is a 90 percent chance that populations will be at or below current levels near term (2020) and long term (2100). Eliminating harvest shows a median trajectory to exceed NMFS target of 3000 fish in two to four years.

The 2008 BiOp recommends a 30 percent reduction of the current ocean harvest. If implemented, our model predicts slow recovery such that the SRFC will reach 2000 spawners in 2020, 3000 by 2050 and 6000 spawners by 2100. Eliminating harvest could exceed these goals within five to ten years. This is because eliminating harvest doubles SRFC recruitment annually.

After circulation of the draft report, we were asked to model some additional harvest scenarios. C&S (ceremonial) harvest is small (ca. 1-2 percent of harvest) that we did not isolate it from any modeled outcomes except the zero-harvest benchmark.

Commercial ocean harvest takes the largest share of endangered Snake River Fall Chinook. We therefore added the ocean commercial harvest to the Zone 6 harvest but excluded all sport fishing. The results show recovery to be improbable similar to *status quo* projections.

Key conclusions of the model are as follows:

- Continuation of commercial harvest, especially in the ocean is the primary impediment to achieving recovery of SRFC in the foreseeable future.
- The 2008 BiOp scenario which reduces ocean harvest by 30 percent has a 50 percent probability of reaching 3000 fish in about a half century.
- Eliminating all harvest could allow recovery in less than five years.
- Analysis of harvest substructure shows that elimination of in-river or ocean component would allow recovery in about 20 years; reducing the combination of both to about half their combined total would have a similar outcome.

1.0 Background

The completion of seven large multipurpose dams on the lower and middle Snake River around 1970 eliminated significant spawning habitat for Snake River Fall chinook (SRFC) in the mainstem, blocked even more habitat upstream and added significant mortality to juveniles and adults where fish passage was provided. SRFC numbers were already low from the previous 30 years of dam operations in the lower Columbia and from excessive commercial harvest prior to the dams.

After 100 years of decline, SRFC were listed as needing a recovery plan under Endangered Species Act (NOAA, 1992). Columbia and Snake river dam owners and other river users were asked to help mitigate and contribute to recovery (NOAA, 2007a). Federal dam owners identified four areas of potential recovery focus: Hydro, Habitat, Hatcheries and Harvest. Known as the "Four H's" (NOAA, 1999), during the past 30 years, the majority of mitigation has been borne by the dam owners and rate payers. They have focused primarily on the hydro and secondarily the hatchery H's by building improved passage and many new hatcheries. Habitat mitigation began in the 1950's but probably represents a small percentage of the money thus far spent on the Hydro H (*Columbia Basin Bulletin,* 2008). Further, it has been difficult to demonstrate measurable salmon population benefits from habitat improvements, but this is a work in progress.

Harvest is a treaty right and involves multiple nations and legal jurisdictions. Recently, harvest levels of SRFC were modified from upwards of 60-70 percent of returning adults harvested to 42-48 percent including ocean and in-river, sport and commercial, Tribal and Non-Tribal fisheries (*cf.* Table 1, Mc Kern). From 2000-2006, the majority of salmon were harvested first in the ocean and then in the river by commercial operations. Sport harvest was between 2-6 percent of the total catch and about twice that for fish that enter the Columbia River (WDFW and ODFW data, *in* McKern, 2007). Columbia basin salmon harvest is also difficult to monitor and enforce but improvements are being made *(cf.* Harza, 1997).

Annually, about 300 million juvenile hatchery salmon are being released in the Columbia Basin. They represent the overwhelming majority of the recruitment source. The loss of natural spawning fish including SRFC has been largely replaced by hatchery fish. SRFC are now being supplemented by fish from the Lyons Ferry hatchery but also include other hatchery and wild strays. Hatchery-produced lower Columbia chinook as well as SRFC are outnumbering wild fish and according to the Hatchery Scientific Review Group are contributing to further decline of naturally produced fish (HRSC, 2007).

In sum, river users have spent billions in the past three decades, most visibly on Hydro, but also on Hatcheries and Habitat (CBB, 2008a). Although some study has focused on Harvest (*cf.* Norris, 1997; 2000) and NOAA began reducing fall chinook harvest levels after listing, our model suggests that more drastic reduction is needed to achieve recovery within 20 years.

Harvests of upriver bright (URB) chinook are near 50 percent down from historic levels in excess of 70 percent. The most recent BiOp driven recommendation is for a 30 percent reduction of ocean harvest but a flexible increase in river harvest will effectively produce an overall harvest rate of about 43 percent. (NOAA, 2008; CBB, 2008b). We will show, even if implemented, 2008 BiOp harvest criteria preclude SRFC recovery in the foreseeable future.

The Northwest Power Planning Council mandated a study of Columbia basin salmon harvest practices and science and this was completed by its Independent Science Assessment Board in 2005 (ISAB, 2005). The ISAB report identified many important issues including inadequate data collection, modeling, monitoring and enforcement of harvest regulations.

The reasons Harvest has not been leveraged more effectively are both complex and simple. In simple terms, treaties with Native American tribes and with other nations and states complicate regulation, monitoring and management. These problems are further complicated because salmon migrate thousands of miles of ocean coastline; and they mix with stronger stocks that are harvested (mostly hatchery fish but in the case of SFRC, Hanford-reach fish). Additionally our fishing industries both Native American and secular have been unable or unwilling to change fishing methods, such as the use of fish wheels and tangle nets, so as to protect weak stocks like SRFC (*cf*. HRSC, 2007). The goal to segregate wild and hatchery fish biologically or functionally has been elusive. So wild fish, including listed species, continue to be harvested.

This paper will show that unless harvest on SRFC is reduced significantly, there is a 90 percent chance that populations will be at or below current levels in both the near term (2020) and long term (2100). On the other hand, if we do cut harvest, there is a 75 percent chance the population will quadruple in the near term (2020) and possibly reach density dependent limiting size by 2040. This assumes no further changes in hydro or habitat but it does assume major hatchery reform. To repeat, unless harvest is cut significantly, in spite of the additional $900,000,000 BPA has committed to Habitat in the next 10 years (Columbia Basin Bulletin, 2008a), SRFC populations will most certainly (90 percent chance) be at current or diminished levels after the $900,000,000 is expended. But if we cut harvest, there is great likelihood that by 2020 (75 percent chance) these populations will have quadrupled in size, even if we do nothing further to improve habitat.

Examination of 1 percent and 5 percent probability percentiles of future populations reinforces the need to act. These outlier percentiles show near certainty that populations will increase continuously upward if harvest is cut; but with *status quo* harvest, there is near certainty that they will continue to decline toward extinction. The longer that population levels remain depressed, the greater the likelihood of extinction (NOAA, 2007b). Data and projections in this paper suggest harvest curtailment may represent the single most cost effective measure we have left to ensure the continued existence and recovery of un-aided reproducing fall chinook in the Snake River.

2.0 Methods

2.1 Description of the Data and Model

We constructed a Population Variability Analysis life-cycle model to simulate likelihood of future population trends of SRFC as described by Paulsen *et al.* (2007). The model code is provided in Appendix 7.0. The outputs from the model are shown in graphs but are available in original Excel spreadsheets. The PVA model output resembles NOAA's method of extinction risk but is intended to assess likely population trajectories in near-time (to 2020) and long-term (to 2100).

The data are population counts of adult SRFC passing Lower Granite Dam from 1975 to 2000, and estimates of marine and freshwater harvest from 1976-2005 Pacific Marine Fish Commission. The data are from agency sources cited in Appendix 6.0. These data enable estimates of annual variation in the numbers of recruits produced from previous year's spawners. Each year, contingent upon all mortality factors, there is a spawner count and a subsequent recruitment of the next generation. The amount of variation is partly driven by environmental factors, human factors and by random events that cannot be seen or easily measured (usually called error variance). In extremely good years, spawners can produce as many as 20 recruits each (very rare) or a very small fraction near zero (also rare). Any level above one recruit per spawner, the population is growing; any less that one recruit, it is declining. A ratio of one means the population is replacing itself, neither growing nor declining.

Note that the analysis is not entirely appropriate if one were interested mainly in extinction risk, as opposed to the distribution of future spawners and recruits for the population. Extinction analyses often consider autocorrelation, quasi-extinction thresholds, and other technical matters that we ignore in this simple simulation, because we do not think these complications will materially affect the results.

2.2 Model Assumption

In simulating the future, we assumed the characteristics of the past variation will be reflective of the future, i.e. the same spawner recruitment variation, same dams and ocean conditions of 1975-2000 to represent the future. As in games involving chance, future outcomes are based on past experience if we don't change the rules or our playing behavior. If we can win at cards on average more often than we lose, we will never go broke; however that assumes an infinite pile of chips to sustain us through rare periods of extended bad luck (losing streaks). If we have a small pile of chips, a short run of bad luck could mean we are broke (extinct). This fact is important because if the population declines to very low numbers, the risk of extinction increases.

The model enables us to simulate both future population extinction and recovery probabilities, where the latter is usually defined as the expected average number of returning spawners over multiple years (e.g., 2000 spawners on average over 10 years). And the former is the frequency of multiple tries that we run out of spawners (go broke) before the year 2020 or the year 2100.

As in simulating future trends, our population model assumes that the past 25 years, including periods of good and bad conditions would be the same in the future…no better, no worse. That is, the number of adult progeny measured as adults passing upstream of Lower Granite Dam in future will be similar to historical population fluctuations over the past 25 years including the high variability experienced. Simulating averages alone will not enable us to predict probability of growth or decline or extinction because these partly depend on population size and annual luck (survival variation).

2.3 Starting Point of Future Projections

Our starting point is the current state of the population in the year 2006 (the latest adult data available). We simulated three scenarios: (1) continuation of the *status quo* (2) elimination of all SRFC harvest and (3) 2008 recommended cuts to ocean harvest. Note that since each spawner may recruit for the following 5 years, our last recruit data are from 2005 and the last spawner counts from year 2000. We chose 1975 as the starting point as that is when reliable counts began at Lower Granite Dam, our control point of the population counts. The spike in population size beginning in 1995 is generally attributed to ocean conditions as other stocks of Columbia basin salmon have correlated shifts in abundance. However, the model does not rely on specific causal elements of variation; it only assumes that past variation will be reflected in the future. This includes the improved ocean conditions of the late 1990's as well as poor drought conditions experienced from 1975 to 2000.

2.4 Harvest Levels

We modeled two simple options: continue with the current plan of removal (about 50 percent) or eliminate this artificial take completely (zero harvest). Although we could set harvest at any number, we chose zero because we did not know what to expect, so we chose the maximum possible restraint. We recognize that eliminating harvest is politically unlikely and possibly unenforceable, but our goal here is to demonstrate to ourselves, our odds for the future. After initial model runs, NOAA recommended further ocean harvest reduction by 30 percent (i.e. approximately 7 percent total harvest reduction along with some flexibility to increase in-river harvest). We modeled this scenario but note that implementation may be many years away. Also, note that we model a zero harvest scenario starting in 2006; actual implementation could only start after 2009. If new harvest levels are implemented, it is possible to back-cast with the model to determine if it is reasonably calibrated to actual results. We did check 2006 results and they are within model error variance. Additional recruit data will be available soon to assess accuracy of near term model results.

2.5 Density Dependence

Standard population models assume there is an upward limit to population size limited by the environment. This is known as density dependence. The data demonstrate that there is no density dependence currently. For SRFC, statistical tests for Ricker-type density dependence (i.e., models of the form $\ln(R/S) = a - bS + e$, where R = recruits, S = spawners, e is estimated process error, and "a" and "b" are estimated parameters) did not reveal any density dependence in the 26 years brood years of data (1975-2000). Although habitat may constrain recruitment at some high levels sometime in the future, for now, we assumed this to be zero because there is no evidence in historic data for density dependence. We set an artificial limit of 100,000 spawners before the population starts limiting itself but this does not affect the model results. Our modeling showed that this artificial ceiling of 100,000 could be exceeded as soon as year 2040 with the median level for recruitment assuming harvest is eliminated immediately. The current SRFC population is around 2500 to 3000 spawners annually.

2.6 Hatchery Supplementation

The naturally spawning population of wild SRFC is currently supplemented by (1) allowing some hatchery produced adults to spawn upstream in the river and (2) outplanting Lyons Ferry juveniles upstream of Lower Granite Dam. This outplanting program began about 1995 and has led to more hatchery fish than wild fish in recent populations (Figure 1). These hatchery fish are usually tagged (adipose-clipped) so that the returning adults can be identified, counted at Lower Granite and then either allowed upstream to spawn or returned to Lyons Ferry to continue the "supplementation" program. Untagged hatchery-origin fish can be identified by reading scales, taken from a subsample of the run at Lower Granite Dam. Protocols are defined in the recovery program. Since hatchery production is not needed to sustain unlisted populations if harvest is controlled and since the Endangered Species Act is actually about continuation natural reproduction in the wild, it is by both definition and lack of necessity (as the model will show) that we discontinued the Lyons Ferry supplementation in the model. Thus the model data do not use hatchery origin fish for future projections.

2.7 Comparison with other H's

While it would be useful to investigate how changes in hydro operation and configuration might change juvenile downstream survival, that is not possible at present. This is because an unknown proportion of Snake fall chinook overwinters in the hydrosystem (Connor *et al.,* 2005). As a result, reach survival estimation (done routinely for spring/summer chinook and steelhead) is not possible. Nor can one say with any certainty what proportion of the fall run would be affected by changes in hydro operation, transport regimes, habitat improvements *etc*. Therefore, we chose not to simulate the effects of changes in the hydro or habitat changes on fall chinook abundance and persistence. In the future, comparisons to further hydro or habitat improvements might be possible. Arguments that other H's may be traded for harvest is irrelevant to this exercise since we have no data assess this question; hence we simply mathematically eliminate them and assume that things get no better, nor worse in the system and only assess SRFC harvest as a tool to further goals for recovery.

3.0 Results

3.1 Overview of Results

The following eight graphs provide synoptic pictures of population changes over the recent past and the near future for specific percentiles of probability. In order to estimate these, we use random generation of the scenario described in the model. Each run made 10,000 simulations (games played). The percentiles represent what percent of the 10,000 outcomes exceeded a specific result over time.

To recap, we assumed that future recruits per spawner (R/S) would be similar to the past, and that R/S would be log-normally distributed. Furthermore, we assumed an arbitrary upper limit of 100,000 spawners, above which additional spawners did not produce additional recruits. The resulting population viability analysis (PVA) model is therefore a simple lognormal projection, after doing the requisite bookkeeping to account for age-at-return, assumed to be an average of brood years with complete aging data. Future variation in R/S is assumed to be the same as in the past.

For the base-case harvest scenario, we simply assumed that adult recruits to Lower Granite would, on average, have the same R/S as in the 1975-2000 data. For the no-harvest case, we assumed that ocean harvest only affects fish in the year they return to the Columbia, and that upstream survival would be the same as in the past five years (*cf*. Section 6.0, Data Appendix for details). For both scenarios, following the 2000 and 2004 Biological Opinions, we assumed that all hatchery supplementation ceases in future.

3.2 Historic Recruitment of SRFC

Figure 1 shows the recruitment of spawners and natural spawners at LGR from 1975 to 2000. Note that natural spawning numbers have been declining in an irregular sawtooth pattern downward and now make up the minority of recruits. Fall chinook from other hatchery stocks including Umatilla have strayed upstream of Granite Dam since the 1980's. Beginning in 1995, Lyons Ferry hatchery began a supplementation program of juveniles out-planted upstream of Granite Dam. The hatchery component of returning adults is now primarily from the Lyons Ferry hatchery. These adults are either transported back to the hatchery from Granite Dam or allowed to migrate upstream and spawn naturally. Their in-river juvenile and adult recruits would be counted as "natural". However, our model discounts the hatchery origin adults as described in the Methods Section 2.0.
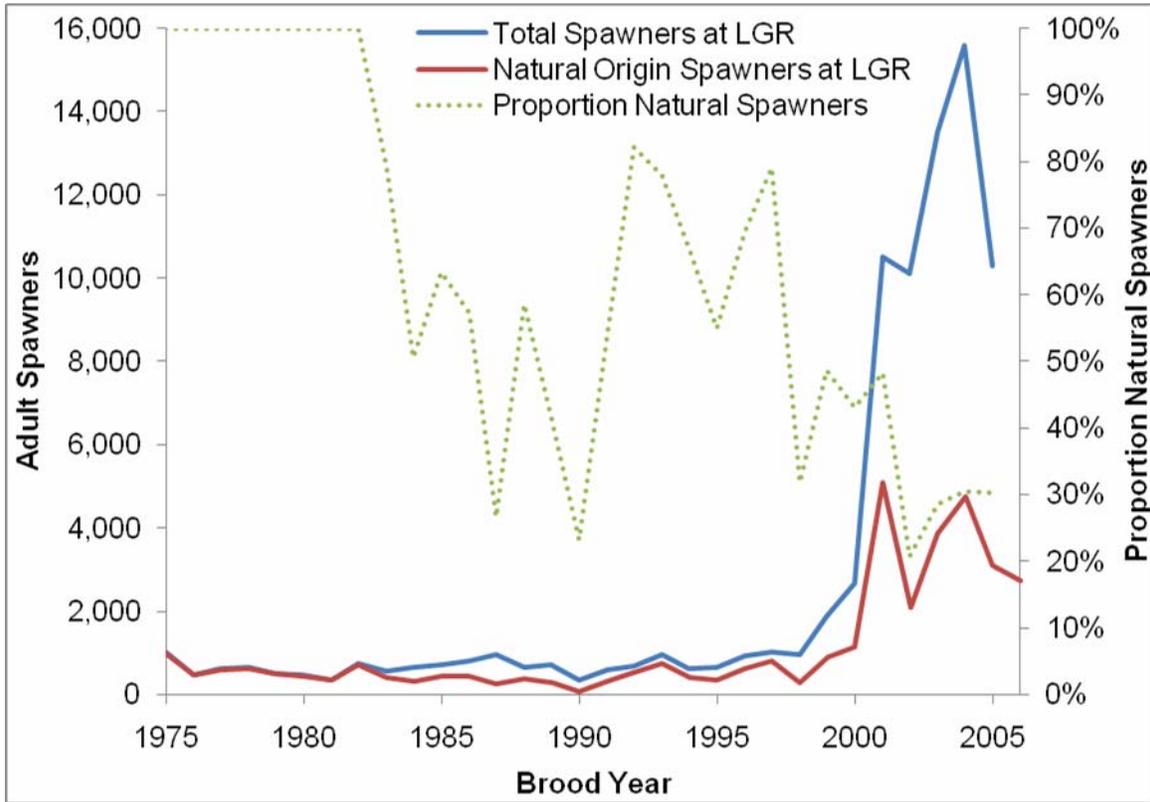
Figure 1. Spawners of hatchery and natural origin, Snake River fall chinook, 1975-2005

Figure 2 shows the book keeping of the historic levels of adult recruits to the mouth of the
Columbia, to Lower Granite Dam and the total recruitment including ocean harvest. Note
that from 1975 to about 1994, the population was bumping along at less than 2000 recruits.
The population expanded to about 8000 recruits of which about 4000 (50 percent) are
harvested in the ocean and in the Columbia River. This expansion is attributed primarily to
ocean conditions but the cause is irrelevant. The model simulates two alternatives: (1) either
continuation of harvest as in the past (about 50 percent) or (2) its complete elimination, *i.e.*
no harvest. Of course, the second alternative immediately doubles the number of spawning
fish (and recruits) leading to a rapid recovery of returning recruits in just a few years (see
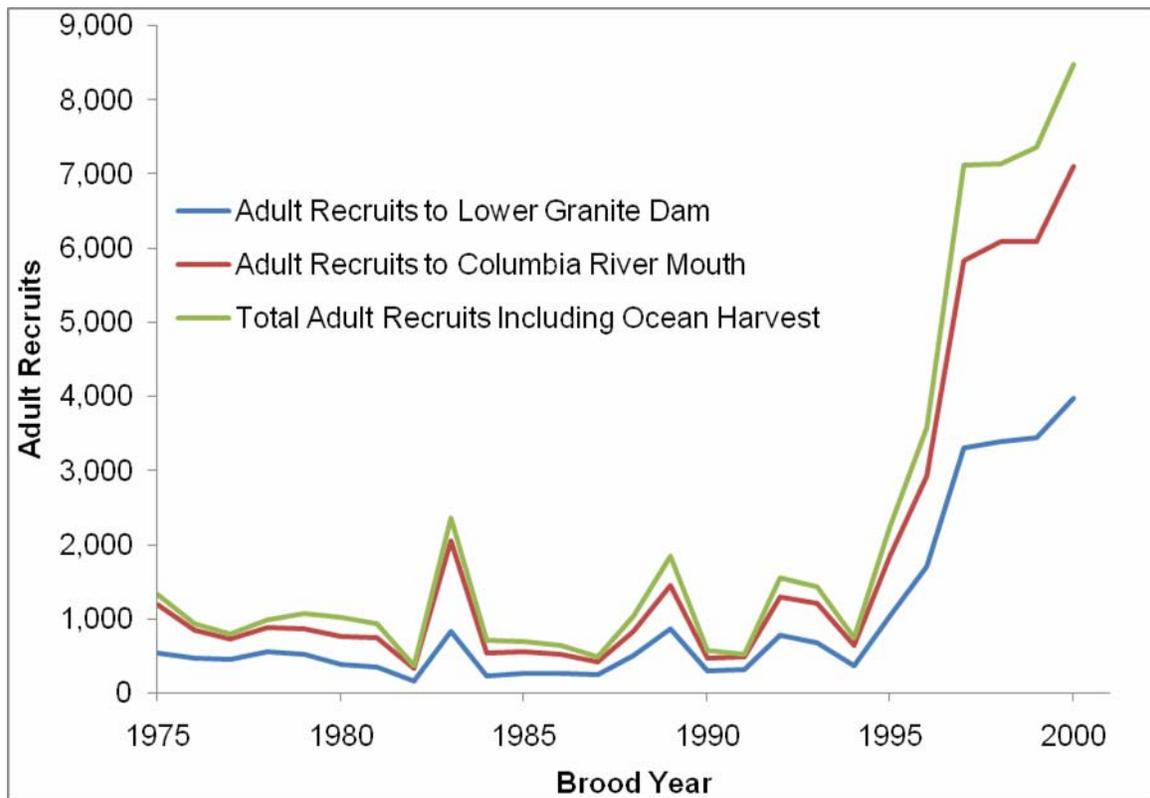Figure 6 below).

Figure 2. Adult recruits, brood years 1975-2000

Figure 3 shows the numbers of recruits per spawner historically. Note that when the data fall below the line of one recruit per spawner, the population declines in size. With harvest, about half the historic period has led to recruitment levels less than the replacement rate, i.e. in declining numbers. If we were to remove harvest, every year for the past 26 years would show a recruitment level greater than one in most every year (green line). This suggests that in the future, without harvest, the population will almost certainly be growing. The model will bear this out.
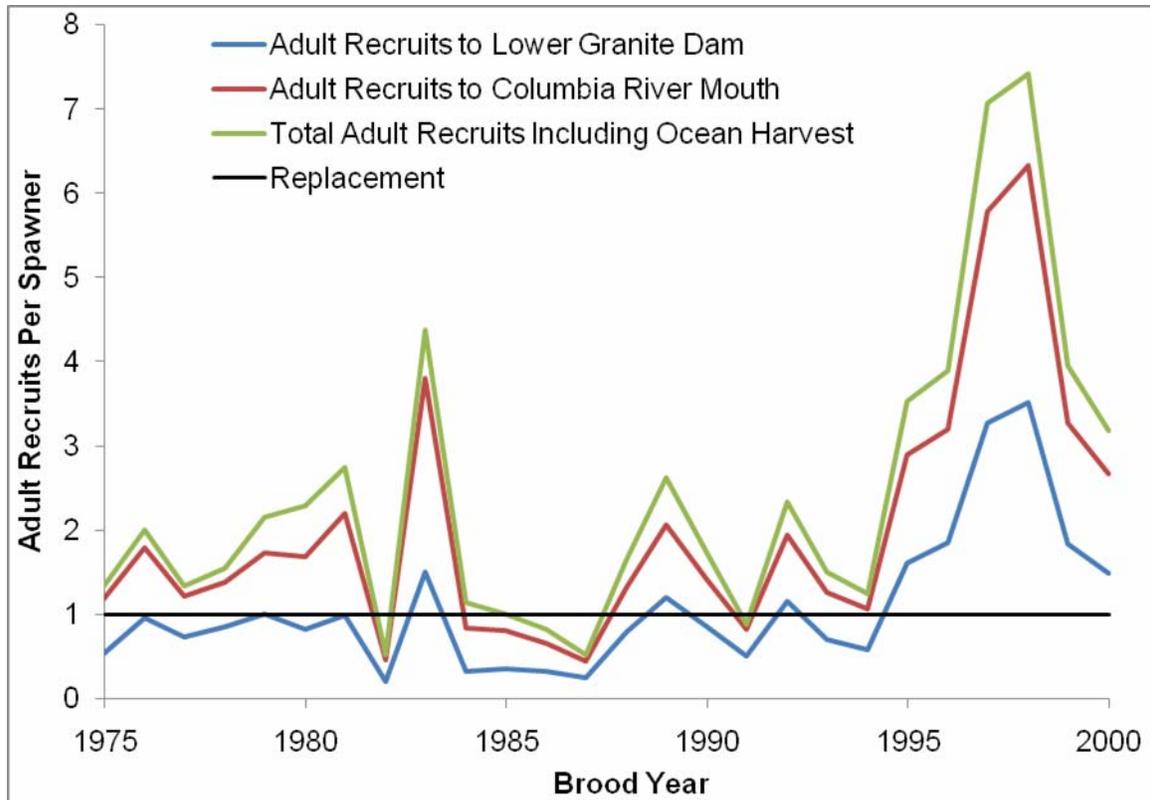
Figure 3. Adult recruits per spawner (R/S), 1975-2000. R/S greater than one implies that the stock replacing itself, R/S less than one that it was declining. Note that recruits per spawner are always higher if one applies in-river and ocean harvest to the spawner population (green line)

Figure 4 shows the historic number of recruits per spawner versus the number of spawners. There is no correlation, positive or negative between spawner population and subsequent recruitment level. If recruitment were being limited by population size (density dependence) we would expect to see a declining slope with fewer recruits per spawner at higher population sizes. This is the basis of eliminating density dependence from our population model.
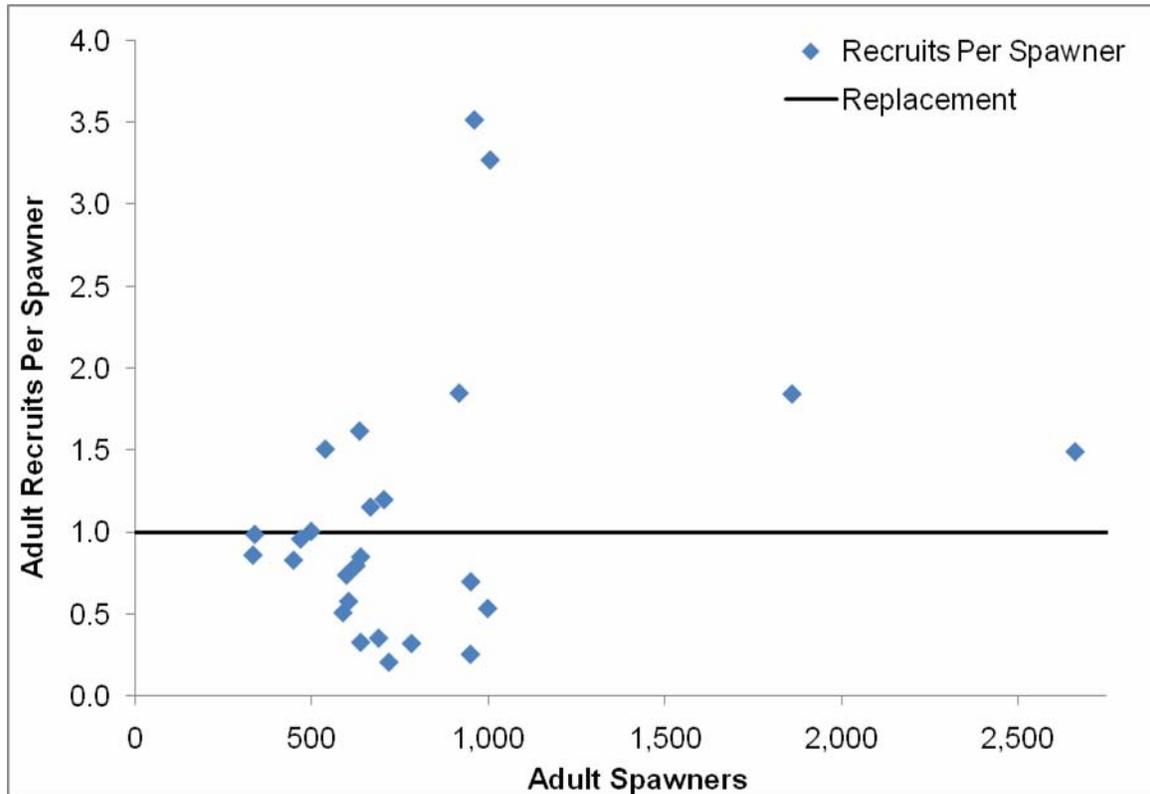
Figure 4. Adult recruits per spawner at Lower Granite Dam. No density-dependence is apparent in the graph, i.e. there is no slope (no correlation between variables)

3.3 Future Population Trends

Figure 5 shows PVA model projections from 2000-2020 if harvest levels are maintained at today's levels of 50 percent (both ocean and river combined). Note: the Interior Columbia TRT (2007) set 3000 as a draft recovery level for this ESU. There is only a 1 percent chance that the population will show regular increasing levels in the future. Most scenarios (90 percent) show flat to declining populations not achieving the 3000 spawner level by 2020. Instead there is more than a 50 percent chance that numbers will decline closer to extinction levels by 2020.
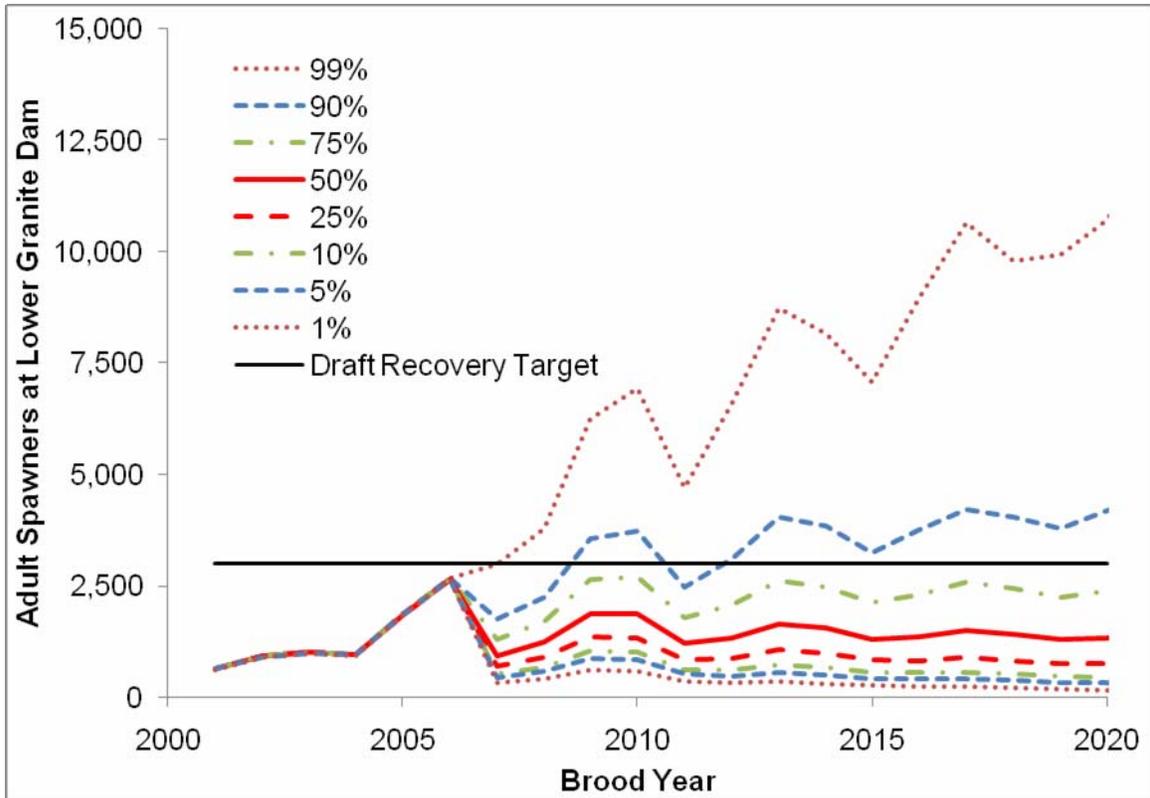
Figure 5. PVA projections, 2000-2020, base case marine and freshwater harvest rates. The Interior Columbia TRT (2007) set 3000 as a draft recovery level for this ESU (NOAA, 2007b)

Figure 6 shows that if harvest is eliminated, there is a 90 percent chance the population will be delisted by 2020 and only a 10 percent chance that the population will not have at least doubled in size.
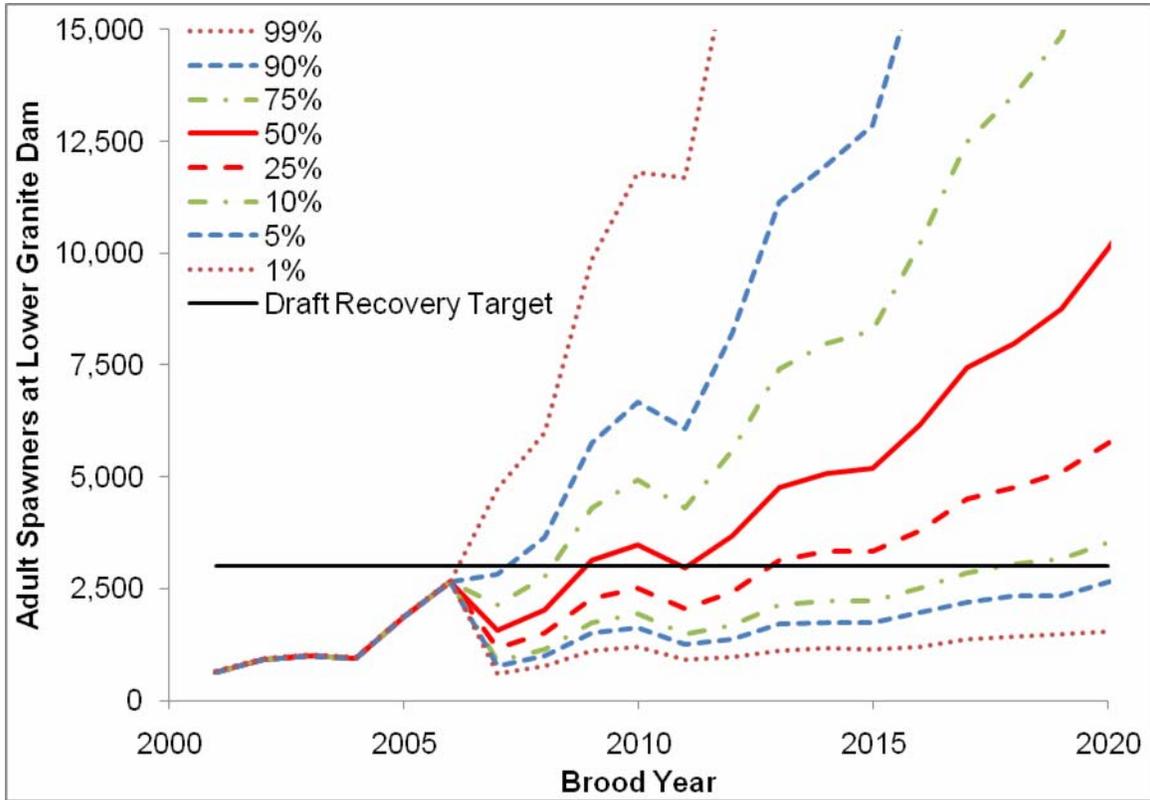

Figure 6. PVA projections, 2000-2020, no harvest scenario

The data in Figure 7 show the worst case for continuing harvest at current levels or most improbable scenarios eliminating harvest. Continuing harvest shows that populations could decline to near extinction i.e. drop to about 20 percent of current listed levels in less than 12 years. Without harvest, the populations, even in the poorest scenarios (runs of bad luck), will continue to expand and grow.
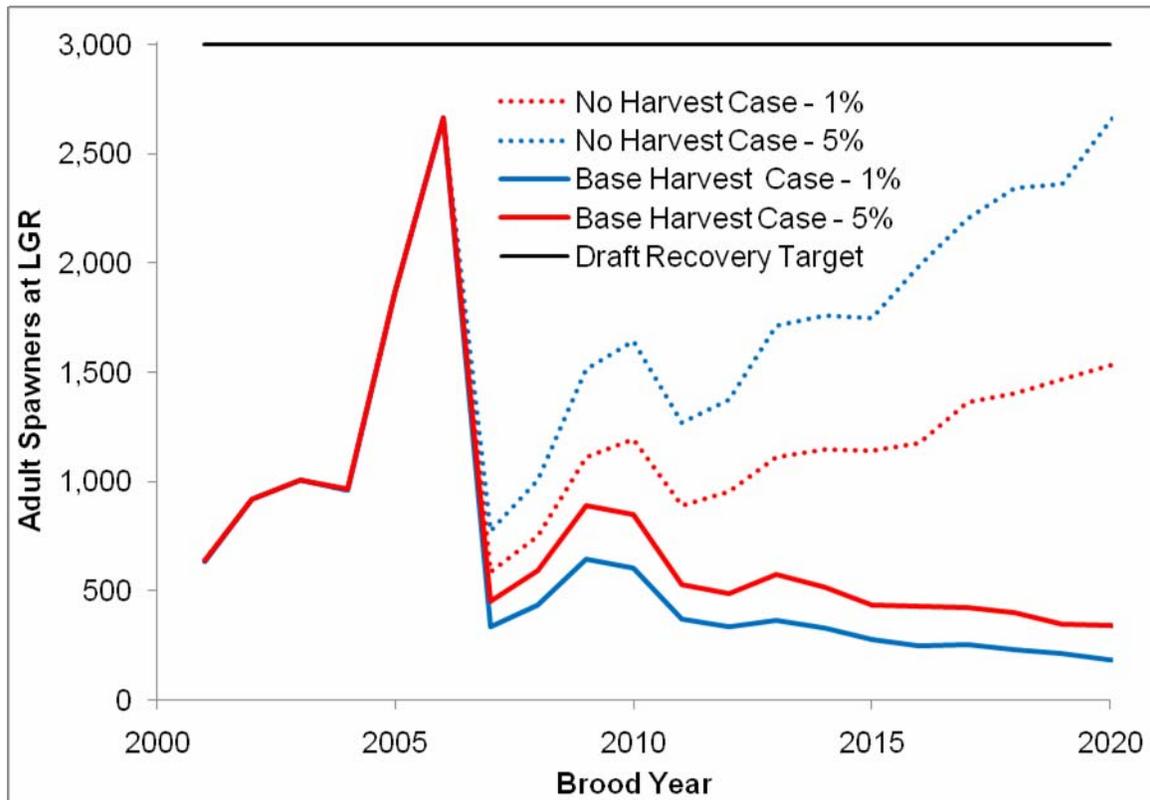
Figure 7. 1st and 5th percentiles for base-case and zero harvest scenarios, 2000-2020

Figure 8a shows median spawners at Lower Granite, base case (*status quo*) and no-harvest scenarios. Read the blue line on the left scale; the red line on the right scale. To show these on the same scale, Figure 8b places the differences between recovery and extinction probabilities more firmly in perspective. It shows that the median probability expectation with harvest suspended, the population would reach 100,000 spawners by 2040. The actual leveling out point would be controlled by carrying capacity which was artificially set at 100,000. Continuing with the Base Case (*status quo*) the expectation is a smaller population than the endangered population that currently exists.
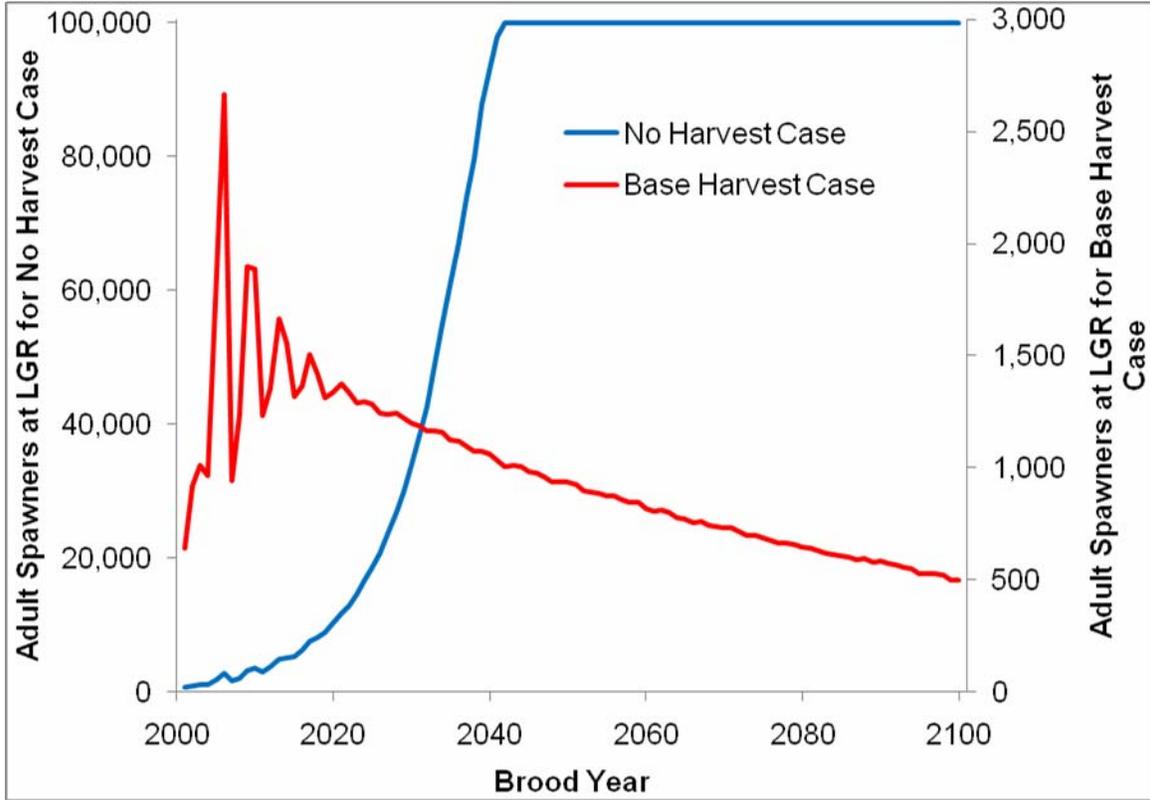
Figure 8a. Median spawners at Lower Granite, base case and no-harvest scenarios
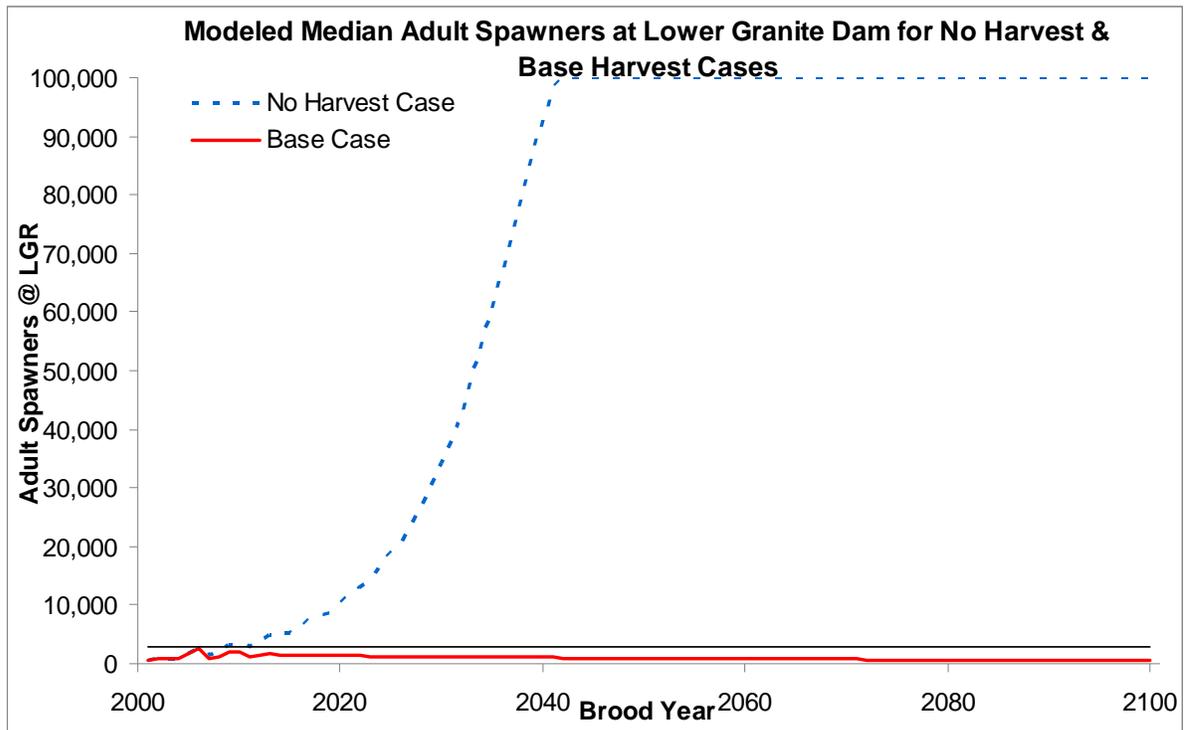
Figure 8b. Same data as Figure 8a but placed on the same scale (left side only)

During model preparation, agencies including the Pacific Salmon Commission (PSC) negotiated a 30 percent reduction of the current ocean harvest of SRFC with Canada (CBB, 2008b). The actual total harvest reduction would be equivalent to less than 8 percent. We modeled that outcome assuming implementation shown in Figure 9. This suggests that the population will on average be expected to increase to 2000 spawners in 2020, be delisted by 2050 and reach 6000 spawners by 2100. Since the 2008 agency recommendation also allowed an increased river harvest during years of large returns the graph may overestimate the recovery rate. The time frame is optimistic because implementation may not come until 2010 or later. With no harvest, the population would be delisted in about 2-4 years after implementation (*cf.* Figure 6 where the 50 percent line crosses 3000 fish) versus 45 years or more to delist with the new recommendation.
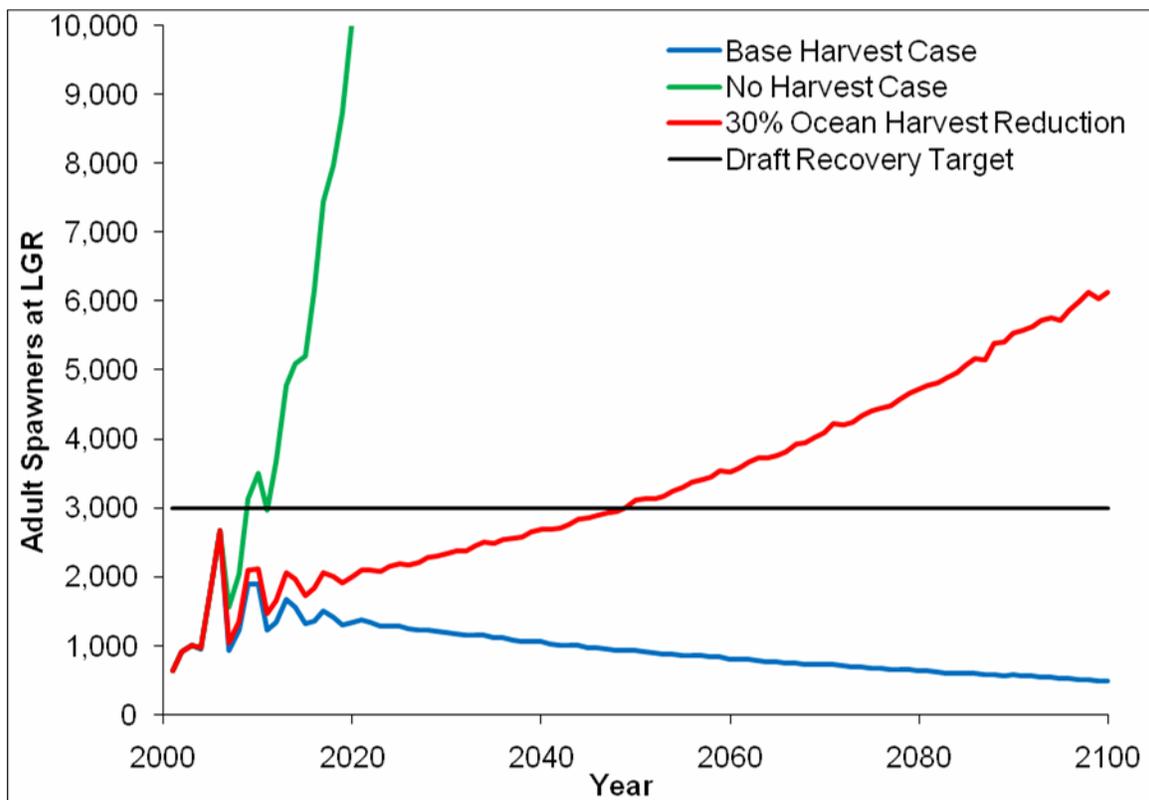
Figure 9. Comparison of three modeled population scenarios for Snake River fall chinook: Near Vertical Green Line = No Harvest after 2005; Declining Blue Line = Continuation of Past Harvest Levels; Gradual Increasing Red Line = NOAA 2008 BiOp.

Section 3.4 Harvest Substructure Analysis

Total harvest is the sum of ocean and in-river, sport, commercial and ceremonial and subsistence harvests. In order to better understand which components of harvest are affecting recovery the most, we analyzed the harvest data with the following sub-structural components:

- Sport harvest as distinct from all other commercial harvest
- Zone 6 Tribal commercial harvest upstream of Bonneville Dam
- Combined Zone 6 plus ocean commercial harvest

We ran the model assuming that future harvest would only be comprised of one of these three alternatives to see their separate affects on recovery. A more detailed analysis and rationale for this approach is provided in Section 9.0. The synoptic results are shown in Figure 10.
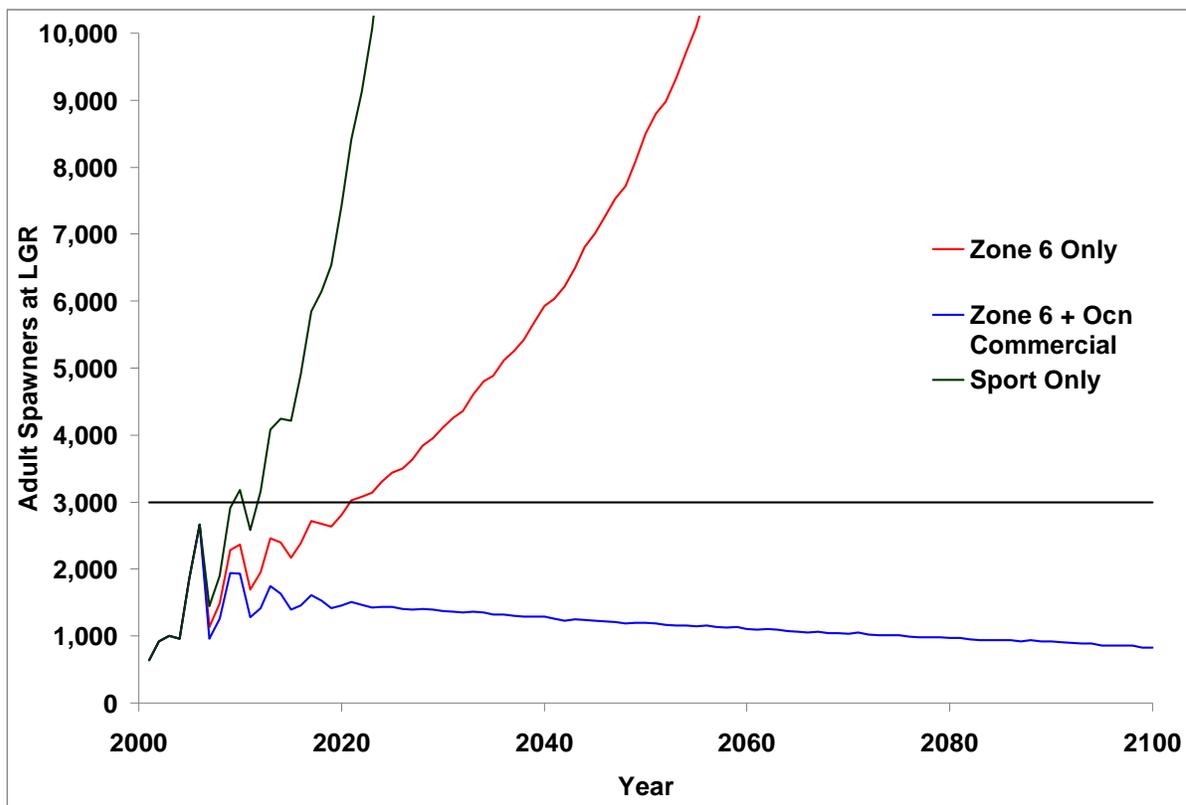
Figure 10. Median spawners through 2100 for three harvest reduction scenarios.

The results suggest that if we restrict future harvest to sport catch only, and maintain similar limits as the past, the outcome would be not very different from suspending harvest completely. Recovery is rapid. This is not surprising since sport catch comprises between 3-6 percent of the total harvest.

Restricting harvest to only Zone 6 tribal harvest leads to recovery in about 20 years but population growth is rapid and eventually reaches ten if not hundreds of thousands of fish limited only by carrying capacity.

If we continue to allow Zone 6 tribal harvest and commercial ocean harvest, recovery appears unattainable. Combined, the two harvests represent about co-equal segments of a 50 percent harvest level. This suggests that in order to obtain something similar to a Zone 6 recovery picture and continue to harvest in both Zone 6, the ocean, and have a sport fishery the total commercial harvest needs to be about 25 percent of the recruitment. We did not include other commercial harvests such as Zone 1-5 as the outcome would be the same.

Currently NMFS proposal to reduce only ocean harvest by 30 percent, and sometimes increase in-river harvest will reduce the total commercial harvest to about 43 percent. The outcome is a much more protracted recovery, one that is may only reach 6000 fish by the end of the century (Figure 8).

More details on the recovery probabilities are presented in Section 9.0 along with conclusion and caveats about the model.

4.0 Discussion

4.1 Lessons Learned

Models are not reality, but they provide a simplified structure and hence understanding of it. We have developed a relatively simple model of continuing or discontinuing harvest using a Monte Carlo simulation of population change similar to that employed in Paulsen *et al.* (2007). We recognize that we do not know what conditions will prevail in the Columbia Basin for salmon in 2020 or 2040. We have assumed in this model that they will basically mirror the past except for how we manage harvest. Whether other conditions improve or decline, the lessons learned from this harvest model will still apply. Whether they are sufficient or necessary will only be known after the fact. To do nothing about harvest and assume that other factors such as Habitat or more Hydro fixes will suffice is to risk losing all the chips in the game. In fact, most studies of other H's have indicated that without Harvest regulation, the other H's are unlikely to recover listed stocks. Hatchery solutions are at best, antithetical to the ESA according to NOAA's Biological Opinion (*op. cit.)* and may actually harm the population.

4.2 Comparisons with Hydro

For the past 15 years, there has been debate about whether habitat, hydro or hatcheries should be improved. Considerable money has been and will continue to be invested in hydro. Significant measurable progress has been made at the dams for enhancing adult and juvenile survival. It remains to be seen whether future investments there will have diminished return on investment. Much of the low hanging fruit appears to have been picked. Recent discoveries about juvenile survival (Conner *et al., op. cit*) suggest that survival may be higher than supposed since some percent of the late migrants overwinter in the hydro reservoirs and have high survivals as adult recruits. Norris (1997) provided a simple spreadsheet model to evaluate strategies and tradeoffs among dam improvements and harvest. Eventually, we can do a cost-benefit analysis of the hydro investment and returns and the harvest investment and returns. But in our view, we may have reached an asymptote, with hydro improvements unlikely to facilitate recovery without further harvest constraints.

4.3 Hatcheries

We are dependent on hatcheries to produce most salmon, including SRFC. The creation of artificial runs of fish has actually ecologically interfered with naturally produced fish (HRSC, 2007). Hatchery fish and the enormous investment in infrastructure and labor have politically interfered with recovery as they have become the drug of preference for the aliment and tend to be self preserving as they involve jobs. Continued production of hatchery fish, especially those that mix with wild fish, will likely lead to further the decline of naturally reproducing stocks. Hatchery production numbers overwhelm wild fish numbers, compete with them and preclude management for natural reproduction. SRFC could be the demonstration that shows

that recovery not only precludes the need for hatcheries, it more than replaces it and eliminates a large cost of production. But those lost facilities and jobs will be an issue that needs to be addressed as part of recovery, if wild fish are the real goal.

4.4 Weak Stocks and Strong Stocks

SRFC migrate in the same corridor at the same time as upriver bright fall chinook (URB) headed for the Hanford Reach of the mid-Columbia River. Both stocks are of similar size and biology except for spawning location. The Hanford stock represents the primary harvest fish of the Zone 6 Tribal fishery and the lower Columbia commercial fishery. It also is an important component of both upper and lower river sport harvests. A reasonable assumption is that whatever the harvest rate of the URB will also be the incidental harvest rate for SRFC. Thus to abandon harvest of the SRFC requires abandonment of the URB harvest with current harvest methods. The region has discussed alternative means for segregating strong and weak stocks via live catch methods enabling segregated harvest of strong stocks. The same applies to segregating hatchery fish by either location or fishing method.

Recovery of ESA listed stocks such as SRFC is in direct conflict with harvest management as currently practiced. At present, both harvesters and conservationists have legal mandates to do what they do. The PVA model suggests that compromises of limited harvest restrictions such as the 2008 BiOp that allows 43 percent total harvest are likely to lead neither to recovery, nor to converting weak stocks into sustainably harvestable populations in any realistic timeframe. If recovery is to be achieved with some degree of SRFC in a reasonable period of time, say less than 20 years, it will be important to reconcile these conflicts. It will also be important to reconcile the legal rights to harvest. Norris (2000) provides some technical approaches to allocating harvest restrictions among diverse and dispersed harvesting entities and to achieving escapement levels needed to reach and sustain specific population levels.

4.5 Habitat

No one would disagree that salmonids need freshwater habitat to complete their life cycle. Yet we know of no studies that show habitat is the limiting factor for current SRFC population levels. Although increasing habitat via fish passage into blocked areas is a noble idea, we simply do not know whether this will be an effective means to achieve recovery, much less a cost effective one (see comments of Jim Martin, in Columbia Basin Bulletin, 2008). Reintroductions of salmon upstream of Round Butte Dam in 2007 will be a telling experiment on the cost : benefit of such actions and should be watched carefully for results. As we attempt to repair damaged habitats and reopen blocked areas, we continue to degrade others just by human population expansion alone (*cf.* Lackey, 2008); so it is unclear whether the net benefit will tip in the positive direction for salmon habitat in the future. Habitat is a good goal but we are unaware of compelling evidence, models or experience to show it will be as effective as harvest restriction, to quickly rebuild stocks in the next 20 years.

4.6 Why Harvest is Important Now

The data show that wild populations are small and in a decline. We have the capacity to quickly change decline into growth using harvest because it assumes no improvement in any other factor including habitat or dams. The model shows we would double SRFC recruitment annually if we place a moratorium on harvest and do nothing else to Hydro, Hatcheries or Habitat. If this were an investment goal in financial terms, it would be equivalent of doubling annual income and investment capital every five years for at least 20 years.

4.7 Policy Issues

We have not tried to estimate what level of harvest might be a "compromise" between 50 percent and zero; that is for the political arena. We did model the newest "compromise" offered in the framework of the 2008 BiOp. And it is clear that it produces a very weak albeit, a positive population response. This reinforces that cutting harvest will be effective. We do know that even if a moratorium were to be employed and populations built up to some larger base than today's, it is not possible to return to the harvest levels of today without simply turning those curves upside down, at least with all other things being the same as today. Thus, the idea of going on a "crash diet" today, with the plan to return to our old eating habits after we lose weight is a fools' errand. We need to reduce harvest dramatically, at least until we can implement habitat expansion and improved harvest methods emerge.

As already mentioned, hatchery fish are an impediment to wild SRFC and likely many other listed stocks for reasons already cited. If hatchery stocks are not isolated from wild fish, they will swamp them by sheer numbers as the data demonstrate with Lyons Ferry fish and SRFC. The conflict with the "hatchery economy" and the questions of where those facilities and jobs go will need resolution.

4.8 Conclusion

This model shows that if we eliminate harvest of SRFC, we can expect recovery to occur surprisingly rapidly, possibly within 3-5 years and reach carrying capacity within 20-30 years. If we continue with the Base Case *status quo* harvest the populations will almost certainly decrease over time. After SRFC recruitment is sufficiently strong, then it would be appropriate to design harvest regulations and methods that would keep SRFC strong, sustainable and forever off the ESA species list. NOAA recognizes that current harvest levels are too high and they have mandated a 30 percent reduction ocean harvest. But even if that is implemented, recovery will not likely occur for 45 years after implementation. A complete hiatus on harvest suggests SRFC will "recover" to 3000 spawners in less than a decade. Analysis of the affects of various harvest components suggest that with only in-river, or, ocean harvest, recovery would occur within about 20 years. This suggest that overall harvest levels need to come down to about 25 percent instead of the 43 percent NMFS is suggesting if recovery is sought with any degree of certainty in the foreseeable future. Details of these separate harvest affects can be found in Section 9.0.

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6.0 Data Appendix

We used data specific to SRFC for the run reconstruction. Data used for the reconstruction is contained in the spreadsheet "Snake FAC BY Data 10-10-08.xls". The individual columns in Sheet "BY Data" (the run reconstruction) are described below.

Column A "Brood Year": The year in which the parent stock returned to freshwater and spawned.

Column B "Spawners @ LGR": All adult fall Chinook spawners of ages 3-6 (where age 0 = year of spawning of the parent stock), that passed Lower Granite Dam in each Brood Year. Jacks (age 2) are ignored in this run reconstruction. Values are from the "Adult Spawners" column in Sheet "BRT" of "Snake FAC BY Data 6-27-08.xls" (the spreadsheet filename will not be repeated further). This sheet is a SRFC run reconstruction from NOAA Fisheries' Biological Review Team's spreadsheet "Chinook datasets 11_14_07 for dist.xlsx" received from Tom Cooney of NOAA Fisheries. We assume that this is an update of the SRFC ESU analyses in NOAA Fisheries' 2005 Status Update of All Federally Listed ESUs (URL: http://www.nwfsc.noaa.gov/assets/25/6226_08302005_132955_brttechmemo66final2.pdf).

Column C "Natural Run Spawners @ LGR": Adult spawners (of all ages) of natural origin that passed Lower Granite Dam in each Brood Year. Values are from the " Broodstock=natural run" column in Sheet "BRT". We assumed that this column represents the brood (spawners) in each Brood Year that is composed of fish that were the progeny of natural spawning above Lower Granite (the parents could have been either hatchery or natural origin fish).

Column D "Prop. Natural Spawners": Proportion of adult spawners in each Brood Year that were of natural origin (Col. C Natural Run Spawners / Col. B Total Spawners).

Columns E-H "Adult Spawner Return (Wild Recruits from BY Spawners)": The proportion of adult recruits of natural origin of each age (ages 3-6), by age, from the parent stock (Col. B Spawners @ LGR) in each Brood Year. The proportions are arranged such that the proportion of recruits of each age class is placed in the Brood Year in which these fish returned (i.e., the Return Year). For example, in Brood Year 1975, the age 3 recruits (which returned to freshwater in 1978) represented 31.7 percent of the total recruits that returned in 1975. Additionally, recruits produced by each brood are placed in the year in which the fish returned to spawn; for example, the 1975 brood produced the age 3 recruits in the Brood Year 1978 row. These values are from Sheet "BRT" Columns K-N, "Unmarked adults only age composition". Note that these proportions differ substantially from the *Pacific Salmon Commission's Chinook Technical Committee* dataset (Table 8 in Sheet "Sn FAC Harv"; included for comparison with the BRT run reconstruction). We do not know the methods

used to calculate either of these datasets, so we used the BRT data for consistency. Also note that the BRT used average proportions for recruits produced from the 1975-1985 and 2000-2004 broods (yellow highlights).

Columns I-L "Ocean Exploitation Rate": The exploitation rate (see PATH 1998 for the methods used) from Columns I-L in Sheet "PATH", (source: PATH 1998; Table 3.1.2-2), that is applied to the fish of each age class (ages 3-6) in each brood year (we ignored exploitation rates for age 2 fish). These values are arranged by the calendar year in which they are applied. We assumed that PATH integrated natural mortality by age per PSC (1988) and catch mortality (PATH 1998; pp. 100-103). The exploitation rate is an estimate of the proportion of fish of each age class that were either harvested in the ocean fisheries (primarily fisheries from the northern Oregon coast northward to the fisheries of the west coast of Vancouver Island, BC, Canada) or died before reaching the next age (i.e., age-specific ocean mortality rates). This sheet is Table 3.1.2-2 in the aforementioned report.

Base case ocean exploitation rates (Sheet "HR – PATH & Ocn" Columns H through L) were changed for the Zone 6 and Ocean Commercial Harvest and Sport Harvest only Scenarios by changing the total exploitation rate by applying the relative proportion of sport and commercial catch in all ocean fisheries from the Coast Model (URL: http://www.cbr.washington.edu/harvest/coastmodel.html) in Sheet "Coast Model" Columns E and F.

Columns M-T "In-River Harvest Rates": The proportion of adult fish of each age class harvested in mainstem Columbia and Snake River fisheries, arranged in the same manner as the ocean exploitation rates. These rates are in Sheet "HR", columns B-E. We obtained these rates from the Pacific Salmon Commission Chinook Technical Committee (URL: http://www.psc.org/about_org_committees_technical.htm). spreadsheet "Snake FAC harvest 1975-2003 08-02-05.xlsm", PATH (PATH 1998; Columns F and G in Sheet "HR – PATH & Ocn"), and the US v. Oregon Columbia River Compact Fall Status Reports (URL: http://wdfw.wa.gov/fish/crc/crcindex.htm) for 2005-2007. See Sheet "HR" for a detailed explanation of the sources used for each return year. We used the total harvest rate (orange highlights) when separate in-river harvest rate estimates for Columbia River harvest zones 1-5 (below Bonneville Dam) and 6 (Bonneville Dam to McNary Dam) were not available.

> **Columns M-P "**CR Zones 1-5 Harvest Rate": The estimated in-river harvest rate by age class for fish harvested in CR Zones 1-5.
>
> **Column Q-T "**Total (highlighted) or CR Zone 6 Harvest Rate": The estimated in-river harvest rate by age class for fish harvested in CR Zone 6.

Note that the Zone 6 and Zones 1-5 in-river harvest rates in this spreadsheet were not used for the model; instead the rates from Sheet "HR – IR" Columns B through D were used.

In-river harvest rates were changed for the Zone 6 only, Zone 6 and Ocean Commercial Harvest, and Sport Harvest only Scenarios by applying the estimated change in harvest rate in Zone 6 and Zones 1-5 for each run year from Sheet "HR – IR".

Column U "BRT Brood Returns": For comparison with Column AB total brood returns to Lower Granite. The return of adult spawners to Lower Granite Dam from each brood. Values are from Sheet "BRT" Column V "Brood Returns". The BRT calculated the production of adult spawner recruits of each age from each brood as the product of the proportion of adult recruits for that age class and total natural recruits produced by each brood (Column U "Natural Run"). For example, the 1975 brood of 1,000 naturally produced spawners produced 32 percent of the 640 natural spawners from the 1978 brood (age 3 fish), 49 percent of the 500 spawners in 1979 (age 4), and 18 percent of the 450 spawners in 1980 (age 5), for a total of 529 adult recruits at Lower Granite.

Columns V-W "Adult Col. & Snake R. Survival": The estimated survival of adult SRFC from Bonneville Dam on the Columbia River to Lower Granite Dam on the Snake River. These estimates are from Sheet "Conv Rates" Columns J and K "Adjusted Conversion Rates" for adults (wild and hatchery) that were transported as juveniles. These survivals are estimates based on PIT tag detections of known origin adults (excluding one-ocean jacks) that as juveniles migrated in-river or were transported in barges.

> **Column V "BON-MCN":** 84.8 percent survival rate for adults from Bonneville Dam to McNary Dam.
> **Column W "MCN-LGR":** 87.8 percent survival rate for adults from McNary Dam to Lower Granite Dam.

Columns X-AD "Brood Returns to LGR @ Age": The calculated production of adult recruits to Lower Granite Dam (ages 3-6 and total) from natural spawners for each brood. We used the BRT methods described for Column U above. Also the calculated recruits per spawner (in natural and logarithmic units).

> **Columns X-AB:** Age 3-6 and total recruits at Lower Granite.
> **Columns AC and AD:** Calculated recruits at Lower Granite per spawner in natural and logarithmic units.

Columns AE-AK "Columbia Mouth Recruits at Age": The calculated production of adult recruits to the mouth of the Columbia River (ages 3-6 and total) from natural spawners for each brood. Back-calculated for each age class from brood returns to Lower Granite, adult upstream survival rates (Columns V and W), and In-river harvest rates (Columns M-T). Also the calculated recruits to the Columbia mouth per adult spawner (in natural and logarithmic units).

Columns AE-AI: Age 3-6 and total recruits to the Columbia River Mouth.

Columns AJ and AK: Calculated recruits to the Columbia River Mouth per spawner in natural and logarithmic units.

Columns AL-AR "Total Recruits Including Ocean Harvest": The calculated production of adult recruits to the Pacific Ocean before ocean harvest takes place (ages 3-6 and total) from natural spawners for each brood. Back-calculated for each age class from Columbia Mouth recruits (Columns AE-AH) and ocean exploitation rates (Columns I-L). Also the calculated recruits to the Pacific Ocean per adult spawner (in natural and logarithmic units).

Columns AL-AP: Age 3-6 and total recruits including ocean harvest.
Columns AC and AD: Calculated total recruits including ocean harvest per spawner in natural and logarithmic units.

Adjustments for Sport Harvest Estimates.

For estimating the effects of sport and commercial harvest reduction, we used the run reconstruction described in Methods Section 2.0 and in the Data Appendix Section 6.0, with sport-commercial harvest breakdowns as estimated by Norris et al., 2001 (http://www.cbr.washington.edu/harvest/coastmodel.pdf) from the COAST model. If, for example, marine harvest was 50 percent, and sport harvest was 20 percent of the total marine harvest, the harvest rate with no sport fishery would be 40 percent [(1-0.20)*0.50]. Note that because the COAST model estimates of harvest rates sometimes differed from those used in our extension of the PATH run reconstruction, we only used COAST for the sport and commercial proportions of total harvest in a given fishery, not for the absolute levels of harvest.

7.0 SAS Code Appendix

```
*** read_BY_data_2nd_simuls_NOHARVEST.sas;
title1 "D:\userfile\Pizzimenti 2008-06\
read_BY_data_2nd_simuls_NOHARVEST.sas";
options linesize=133 pagesize=60;
options sysprintfont = "SAS Monospace" regular 8;


data forregs;

   infile "D:\userfile\Pizzimenti 2008-06\Snake FAC BY Data 6-12-08 06-13
really.csv" dsd lrecl=200 pad;

   input brood_yr
     tot_spawners : 10.
     wild_spawners : 10.
     prop_age_3 : 10.
     prop_age_4 : 10.
     prop_age_5 : 10.
     prop_age_6 : 10.
     Brt_recs_to_LGR : 10.
     bon_mcn_surv : 10.
     mcn_lgr_surv : 10.
     tot_lgr_recs : 10.
     col_riv_recs : 10.
     tot_ocn_recs : 10. ;

   if brood_yr > 0 ;


   lgr_ln_r_s = log(tot_lgr_recs / tot_spawners );
   Recs_to_LGR_No_Harvest = tot_ocn_recs * bon_mcn_surv * mcn_lgr_surv ;
   Ln_Recs_to_LGR_No_Harvest = log(Recs_to_LGR_No_Harvest / tot_spawners) ;


   Prop_nat_spawners = wild_spawners / tot_spawners ;
   constant = 1;


run;
proc sort;
  by constant;
run;
proc summary nway data=forregs;
  class constant;
  var lgr_ln_r_s  Ln_Recs_to_LGR_No_Harvest ;
  output out = variances
  mean = lgr_ln_r_s_MU  Ln_Recs_to_LGR_No_Harvest_MU
  var = lgr_ln_r_s_Var  Ln_Recs_to_LGR_No_Harvest_Var  ;
run;
```

```
proc sort;
   by constant;
run;
proc print data = variances;
run;
data forsim1;
   merge forregs variances (keep = constant  lgr_ln_r_s_MU
Ln_Recs_to_LGR_No_Harvest_MU lgr_ln_r_s_Var  Ln_Recs_to_LGR_No_Harvest_Var
);
   by constant;
   if brood_yr > 1994;
   in_year = brood_yr;
run;

proc sort;
   by in_year;
run;
proc print;
run;

data forsim2;

   array sp(100) sp1-sp100;
   array totrec(100) totrec1-totrec100;
   array rec_3_(100) rec_3_1-rec_3_100;
   array rec_4_(100) rec_4_1-rec_4_100;
   array rec_5_(100) rec_5_1-rec_5_100;
   array rec_6_(100) rec_6_1-rec_6_100;

   retain   sp1-sp100

       rec_3_1-rec_3_100
       rec_4_1-rec_4_100
       rec_5_1-rec_5_100
       rec_6_1-rec_6_100

       totrec1-totrec100
       lgr_ln_r_s_MU  Ln_Recs_to_LGR_No_Harvest_MU
       lgr_ln_r_s_Var  Ln_Recs_to_LGR_No_Harvest_Var
           prop_age_3 prop_age_4 prop_age_5 prop_age_6 ;

   set forsim1;
   by in_year;

   do i = 1 to 100;
       sp(i) = . ;
       totrec(i) = . ;
       rec_3_(i) = . ;
       rec_4_(i) = . ;
       rec_5_(i) = . ;
       rec_6_(i) = . ;
   end;
```

```
   if first.in_year then do;
     year = in_year;
     i = year - 1994 ;
     sp(i) = tot_spawners ;
   end;


   output;
   keep year sp1-sp100
       lgr_ln_r_s_MU  Ln_Recs_to_LGR_No_Harvest_MU
       lgr_ln_r_s_Var  Ln_Recs_to_LGR_No_Harvest_Var
     prop_age_3 prop_age_4 prop_age_5 prop_age_6 ;
run;
proc print;
   var  year sp1-sp7
       lgr_ln_r_s_MU  Ln_Recs_to_LGR_No_Harvest_MU
       lgr_ln_r_s_Var  Ln_Recs_to_LGR_No_Harvest_Var
     prop_age_3 prop_age_4 prop_age_5 prop_age_6;
run;
data forsim3;

   array sp(100) sp1-sp100;
   array totrec(100) totrec1-totrec100;
   array rec_3_(100) rec_3_1-rec_3_100;
   array rec_4_(100) rec_4_1-rec_4_100;
   array rec_5_(100) rec_5_1-rec_5_100;
   array rec_6_(100) rec_6_1-rec_6_100;

   retain   sp1-sp100

       rec_3_1-rec_3_100
       rec_4_1-rec_4_100
       rec_5_1-rec_5_100
       rec_6_1-rec_6_100

       totrec1-totrec100
       Ln_Recs_to_LGR_No_Harvest_MU
       Ln_Recs_to_LGR_No_Harvest_Var
           prop_age_3 prop_age_4 prop_age_5 prop_age_6 ;
   ***** set forsim2;

do igame = 1 to 10000;
  do i = 1 to 6;
     set forsim2 point = i;
       year = i + 2000 ;
       r_s = exp ( Ln_Recs_to_LGR_No_Harvest_MU +
sqrt(Ln_Recs_to_LGR_No_Harvest_Var)*rannor(1234567)) ;
       totrec(i) = sp(i) * r_s ;
       ******totrec(i) = sp(i) *
           exp ( Ln_Recs_to_LGR_No_Harvest_MU /**+
sqrt(Ln_Recs_to_LGR_No_Harvest_Var)*rannor(1234567)**/ ) ;
       rec_3_(i) = totrec(i) * prop_age_3 ;
       rec_4_(i) = totrec(i) * prop_age_4 ;
```

```
          rec_5_(i) = totrec(i) * prop_age_5 ;
          rec_6_(i) = totrec(i) * prop_age_6 ;
          r3 = rec_3_(i) ;
          r4 = rec_4_(i) ;
          r5 = rec_5_(i) ;
          r6 = rec_6_(i) ;
          pred_sp = sp(i) ;
          recruits = totrec(i);
          output ;
     end;
        do i = 7 to 100;
          year = i + 2000 ;
          r_s = exp ( Ln_Recs_to_LGR_No_Harvest_MU +
   sqrt(Ln_Recs_to_LGR_No_Harvest_Var)*rannor(1234567)) ;
          sp(i) = rec_3_(i-3) + rec_4_(i-4) + rec_5_(i-5) + rec_6_(i-6) ;
          if sp(i) > 100000 then sp(i) = 100000;
          totrec(i) = sp(i) * r_s ;
          ****totrec(i) = sp(i) *
               exp ( Ln_Recs_to_LGR_No_Harvest_MU /**+
   sqrt(Ln_Recs_to_LGR_No_Harvest_Var)*rannor(1234567)**/ ) ;
          if sp(i) < 2 then totrec(i) = 0 ;
          rec_3_(i) = totrec(i) * prop_age_3 ;
          rec_4_(i) = totrec(i) * prop_age_4 ;
          rec_5_(i) = totrec(i) * prop_age_5 ;
          rec_6_(i) = totrec(i) * prop_age_6 ;
          r3 = rec_3_(i) ;
          r4 = rec_4_(i) ;
          r5 = rec_5_(i) ;
          r6 = rec_6_(i) ;
          pred_sp = sp(i) ;
          recruits = totrec(i);

          output;
          keep igame year pred_sp recruits r3 r4 r5 r6 r_s;
        end; ** i-loop;

   end; ** igame ;
      stop;
   run;
   /*********proc print;
      id igame year;
   run;
   **********/
   proc summary nway data = forsim3;
      class year;
      var pred_sp ;
      output out = sim_out_summary
      min = spwan_min
      p1 = spawn_sim_01st
      p5 = spawn_sim_05th
      p10 = spawn_sim_10th
      p25 = spawn_sim_25th
```

```
  median = spawn_sim_50th
  p75 = spawn_sim_75th
  p90 = spawn_sim_90th
  p99 = spawn_sim_99th
  max = spawn_max
  ;
run;
proc print data = sim_out_summary(drop = _type_ _freq_);
  id year;
run;
```

8.0 Data for SAS Code

Brood Year	Spawners @ LGR 5/	Wild Spawners at LGR	Wild Recruits from BY Spawners 1/ Age 3	Age 4	Age 5	Age 6	BRT Brood Returns 4/	Adult Col. & Snake R. Survival 6/ BON-MCN	MCN-LGR	Total	Columbia Mouth Recruits at Age Total	Total Recruits Including Ocean Harvest Total
1975	1000	1000	0.316585	0.494676	0.175036	0.013702	528.7189	0.848	0.878	533.3777	1182.82	1337.755
1976	470	470	0.316585	0.494676	0.175036	0.013702	440.4092	0.848	0.878	450.275	838.1724	939.9974
1977	600	600	0.316585	0.494676	0.175036	0.013702	436.6792	0.848	0.878	442.5439	725.9338	799.2913
1978	640	640	0.316585	0.494676	0.175036	0.013702	538.7213	0.848	0.878	543.1609	881.5781	983.1279
1979	500	500	0.316585	0.494676	0.175036	0.013702	496.3745	0.848	0.878	502.3762	859.989	1071.669
1980	450	450	0.316585	0.494676	0.175036	0.000883	372.4394	0.848	0.878	372.8359	756.277	1028.438
1981	340	340	0.316585	0.494676	0.035683	0.000622	335.2634	0.848	0.878	335.4207	744.2095	928.9785
1982	720	720	0.316585	0.019608	0	0	147.4683	0.848	0.878	147.4683	329.4724	369.9294
1983	540	428	0.943826	0.894118	0.429391	0.020045	808.0057	0.848	0.878	813.9191	2049.167	2357.614
1984	640	324	0.10526	0.411039	0.103327	0.008014	208.3748	0.848	0.878	208.9999	530.6206	721.1239
1985	691	438	0.15957	0.538334	0.221071	0.02711	234.7739	0.848	0.878	243.395	555.1157	689.5654
1986	784	449	0.338293	0.577991	0.307038	0.014063	242.5178	0.848	0.878	250.2381	511.6681	640.2112
1987	951	253	0.192924	0.412396	0.169922	0.002055	239.4772	0.848	0.878	241.0019	416.994	494.481
1988	627	368	0.253455	0.512305	0.168265	0.02774	486.7066	0.848	0.878	497.9692	822.4799	1031.564
1989	706	295	0.303711	0.735845	0.327964	0.001085	845.8876	0.848	0.878	846.2672	1453.288	1851.899

Brood Year	Spawners @ LGR 5/	Wild Spawners at LGR	Adult Spawner Return	0	0	0	BRT Brood Returns 4/	0	0	0	0	0
1990	335	78	0.093836	0.381655	0.124006	0.031227	267.9802	0.848	0.878	287.9343	471.0885	575.3014
1991	590	318	0.26264	0.421186	0.023009	0.038285	268.7499	0.848	0.878	299.2629	478.3124	517.7992
1992	668	549	0.453724	0.663623	0.234686	0.001868	769.9033	0.848	0.878	770.4748	1289.791	1550.79
1993	952	742	0.28214	0.507274	0.201534	0.018837	646.2544	0.848	0.878	663.3022	1198.17	1426.139
1994	606	406	0.219755	0.209103	0.104609	0.013702	333.8015	0.848	0.878	349.5319	644.9414	751.9679
1995	637	350	0.587495	0.640989	0.175036	0.013702	960.81	0.848	0.878	1030.46	1842.808	2240.377
1996	919	639	0.235564	0.494676	0.175036	0.013702	1670.782	0.848	0.878	1699.489	2930.083	3577.122
1997	1007	797	0.316585	0.494676	0.175036	0.013702	3244.58	0.848	0.878	3297.416	5817.612	7111.866
1998	962	306	0.316585	0.494676	0.175036	0.013702	3320.489	0.848	0.878	3385.657	6083.522	7127.551
1999	1862	905	0.316585	0.494676	0.175036	0.01	3403.189	0.848	0.878	3434.279	6081.592	7351.788
2000	2664	1148	0.316585	0.494676	0.12	0.01	3946.513	0.848	0.878	3973.973	7093.153	8474.562

9.0 New Alternatives for Harvest

After circulation of the draft report, a number of reviewers expressed concerns over the limited number of scenarios that were modeled. We selected *status quo* and no harvest the extremes, partly to understand how much benefit suspending harvest could provide. We also did not want to include policy judgment as to what intermediate harvest scenarios might be acceptable if reduced harvest would become a tool for recovery. We then added the NOAA proposal for 30 percent ocean harvest reduction (**Section 4**).

Reviewers pointed out that a zero-based harvest was not a productive place to move the discussion or conclude this report. We were asked then to model some additional alternatives to assess the affects of commercial, sport, ceremonial and subsistence (C&S), and tribal harvest. C&S harvest is so small compared to all other harvest as to be lost in error variance and is simply ignored in all modeling. Sport harvest is the smallest portion of harvest and as our model showed, when isolated has no significant effect on speed of recovery by itself. We took the following rationale for scenarios of reducing harvest as follows:

- **Zone-6**. Courts have adjudicated treaty rights of in-river tribal harvest although not within a framework of ESA. Harvest in-river has the potential of stricter enforcement compared to the high seas and international waters. Further, it is within the realm of gear technology to identify and release in-river captured fish. Use of selective gear is less easy to implement in the ocean environment. Thus, we modeled a case in which all harvest except Zone 6 Treaty harvest is eliminated. Results showed recovery to 8000 fish by 2050 (Table 1) and achieving the NOAA 3000 fish target shortly after 2020 (Figure 10). With enforcement and use of selective gear harvest of listed SRFC could be even lower than modeled yet still retain near current harvest levels and achieve relatively rapid recovery.
- **Ocean Harvest** by Canadian and Alaskan boats takes the largest share of endangered Snake River Fall Chinook. They also take the largest share of total chinook and thus have large economic stakes in harvest. We therefore added the ocean commercial harvest to the Zone 6 harvest as practiced excluding all sport fishing. The results (Figure 11) suggest recovery levels similar to *status quo*, i.e. no foreseeable recovery.
- **Sport Harvest** has lowest impact to endangered SRFC (<6 percent) compared to all other sources (45 percent) except Ceremonial and Subsistence harvest (< 1 percent). Additionally, the ability to release sport caught fish alive from a hook, plus capacity for strong enforcement of harvest enable more confidence in the data. The economic and social value of sport harvest permeates all geographic interests where it adds a much larger economic value per fish than commercial harvest. For these reasons, we

modeled the impact of sport harvest separately from all other commercial and tribal harvest. Results showed that continuing sport harvest without commercial elements provide recovery at a rate (Figure 12) similar to the No Harvest option (Figure 5).

- **Zone 1-5**. We added Zone 1-5 in river commercial harvest (downstream of Bonneville Dam) to the other commercial harvests (Zone 6 and ocean). As expected however there were very minor differences in the results and essentially with or without Zones 1-5, the recovery predictions are similar to *status quo* Base Case (Figure 5).
- **C&S Harvest.** Because of the small numbers of the C&S harvest, we did not extract these harvested fish from any of the above categories. Essentially, with only C&S harvest, recovery would occur in essentially the same time frames as the "no harvest" option and would not appreciably alter recovery path of other harvest scenarios.

9.1 Estimated SRFC Population in 2050 with Harvest

The model provides an annual estimate of population trajectories. We have selected year 2050 as a target to show whether various harvest restrictions enable recovery by that date. Table 1 shows the modal (50 percent) projections of population numbers in the year 2050 for each scenario. Two scenarios achieve recovery with harvest are (1) NOAA Fisheries Harvest level which will further restrict ocean harvest by 30 percent and (2) Zone 6 Harvest only. Other scenarios modeled show no significant improvement above *status quo*. C&S harvest has negligible affects on recovery and is assumed to occur in all scenarios.

STATUS QUO HARVEST	936
NO HARVEST	100,000+
NOAA 2008 - Reduce Ocean 30%	3,104
ZONE 6 ONLY	8,501
ZONE 6 + OCEAN COMMERCIAL	1,201
ALL COMMERCIAL	< 1,200
ALL COMMERCIAL + SPORT	<999
SPORT HARVEST ONLY	97,419
C&S HARVEST	SAME AS NO HARVEST

Table 1. Median estimated numbers of SRFC in 2050 with associated harvest practices.

9.2 Harvest Zone-6 Model

Assuming we restrict all harvests except Zone 6 and C&S, there is a 10 percent chance of reaching recovery targets in three to seven years (Figure 10). This eliminates all other commercial, sport and ocean harvests to achieve this. The modal result shows that recovery would be expected shortly after 2020. The population would reach 8000 by 2050 (Table 1).

9.3 Harvest Zone-6 + Ocean Model

If we permitted commercial ocean harvest and Zone 6 harvest with no sport harvest, we essentially achieve the equivalent of the *status quo*, i.e. we likely do not reach recovery. There is between a one and five percent chance the population would expand positively beyond 3000 fish. Conversely, there is greater than 90 percent chance the population would reach recovery this century (Figure 11).

9.4 Harvest Sport Catch Model

Allowing only sport harvest in ocean and rivers is nearly equivalent to completely eliminating harvest. There is almost no difference between results obtained from a No Harvest and a Sport + C&S. Recovery levels would be expected within about two years after implementation and be permanent after about five years.
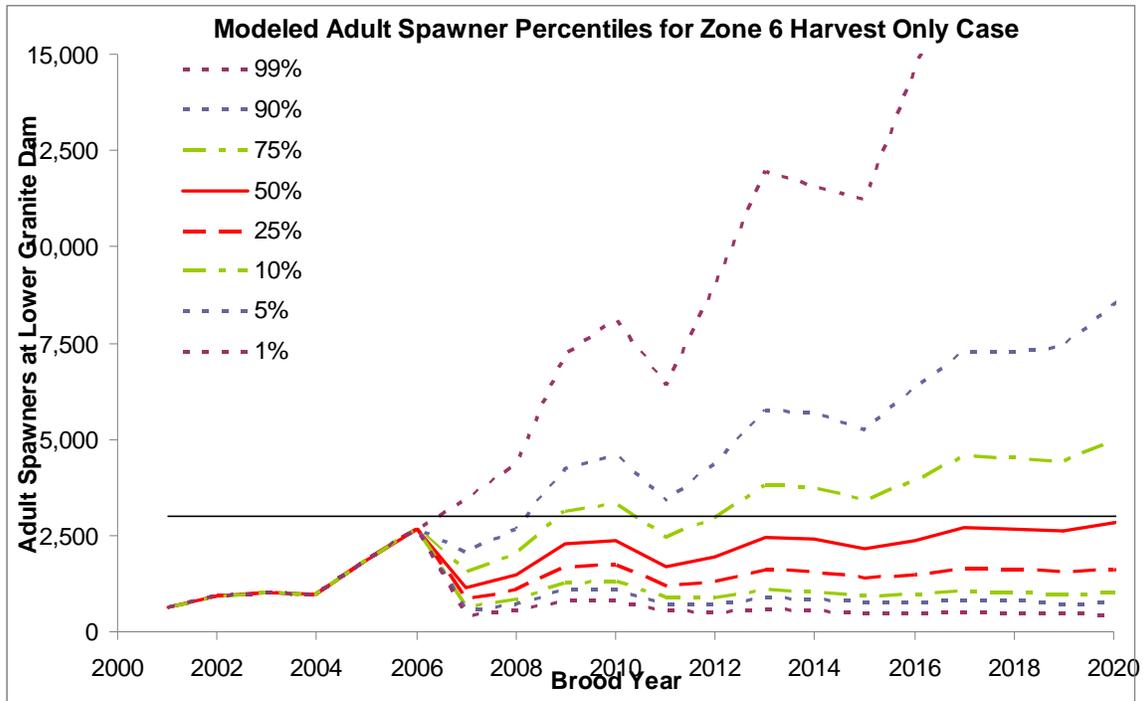

Figure 11. Model results of Zone 6 commercial harvest as practiced during the past 25 years. Without other harvests, SRFC would recover in about 15 years from implementation.
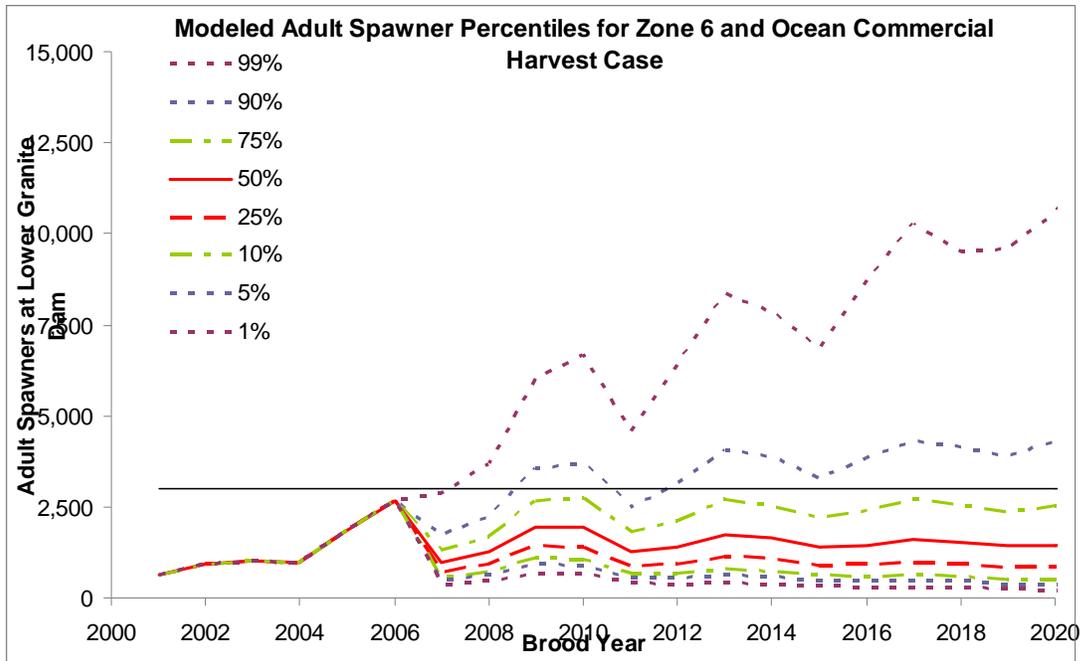
Figure 12. Combining commercial harvest of both ocean and Zone 6 is about equivalent to the *status quo* **(see Figure 5).**
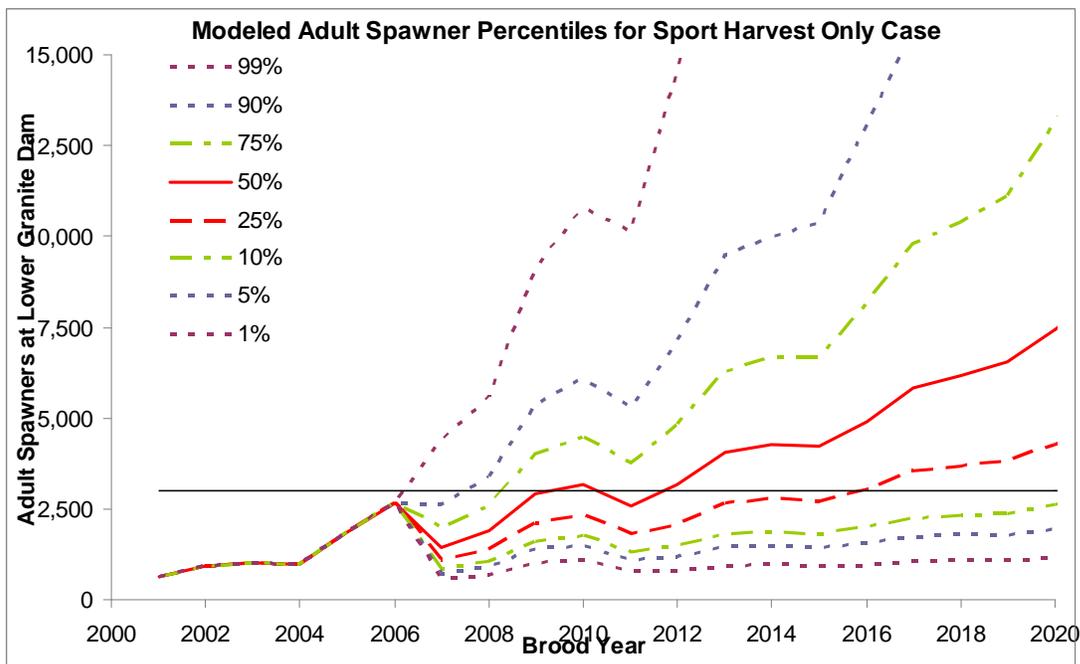

Figure 13. With only sport harvest and C&S there is less than a 25 percent chance that recovery would not occur within 10 years. Even the 5 percent trajectory shows increasing trends of population growth. There is a 95 percent chance of reaching recovery in 15 years.

9.5 Summary and Conclusions

We have re-examined some alternative scenarios other than just *Status Quo* or No Harvest scenarios. The model shows that eliminating ocean commercial harvest, the goals of the Endangered Species Act can be achieved in less than 15-20 years. With only sport harvest, recovery would be almost similar to suspending all harvest and result in recovery in less than 10 years.

Continuation of commercial harvest, especially in the ocean is the primary impediment to achieving recovery in the foreseeable future. The 2008 BiOp scenario which reduces ocean harvest by 30 percent has a 50 percent probability of reaching 3000 fish in about a half century.

The model used assumes no changes to factors other than harvest; no improvements or declines in habitat or hydropower affects. An additional bonus to a strategy of more disciplined harvest is that there will be sufficient fish to make hatchery supplementation unnecessary once sufficient recruits are available to spawn each year.

There may be opportunities for enhanced harvest once recovery is underway. Currently, recruitment levels continue to bump along at less than recovery levels because the majority of excess weak stock recruits are harvested. Allowing newly recruited salmon to spawn in increasing numbers during the early years of recovery will rapidly lead to increasingly available fish for harvest. Improvements in selective gear, catch enforcement, and data collection all would assure intended escapement goals. Any action that enhances escapement of weak stocks to spawn, would enable harvest levels to be gradually but judiciously increased and still maintain positive population trends for SRFC.

9.6 Caveats to Model Results

One should be careful not to over-interpret these results, as several caveats apply.

First, although the spawning stock has been heavily supplemented with hatchery juveniles in recent years, we have assumed that all supplementation ceases immediately, resulting in lower spawning escapement than would be the case with current practices.

Second, the harvest adjustments we have employed are simple, and probably far simpler than what would occur in practice were policy-makers to decide that harvest reduction should be pursued in earnest.

Finally, just because the data do not allow us to estimate a carrying capacity for Snake fall chinook does not mean that the stock will increase without limit – it only means that past

escapements do not allow an estimate of carrying capacity. If carrying capacity – whatever its true value – is reached in the future and is estimable in practice, this may affect the probability of meeting recovery goals, harvest rules, hatchery supplementation policies, and other important management decisions.