Skagit River Steelhead Fishery Resource Management Plan

Sauk-Suiattle Indian Tribe, Swinomish Indian Tribal Community, Upper Skagit Indian Tribe,
Skagit River System Cooperative,
and
Washington Department of Fish and Wildlife

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1.0 Scope of the Plan

The Sauk-Suiattle Tribe, Swinomish Tribe, Upper Skagit Tribe, Skagit River Cooperative, and Washington Department of Fish and Wildlife (co-managers) propose the Skagit River Fishery Resource Management Plan (Plan) for consideration by NOAA Fisheries under Limit 6 of the 4(d) rule (50 CFR Part 233). The Puget Sound Steelhead Distinct Population Segment (Puget Sound DPS) has been listed as threatened under the Endangered Species Act (ESA) since 2007 (72FR 26722).

This Plan describes the fishery management guidelines and objectives the co-managers propose to manage fisheries affecting steelhead in Marine Area 8 (Skagit Bay) and the Skagit River (collectively referred to as the Skagit Terminal Area). It does not govern management of other fisheries that may also incur mortality on Puget Sound steelhead (e.g., fisheries in the coastal marine waters of Washington, fisheries in freshwater areas in the Puget Sound region for trout or warmwater species, or marine fisheries in Puget Sound for halibut, rockfish, or other non-salmonid species).

Skagit River steelhead comprise about 38% of the total return of natural-origin winter steelhead to Puget Sound (NFSC 2015). After reaching a low point of abundance in 2009, the number of spawners in the Skagit River has increased by 350% and averaged 8,800 from 2013-2015 (Fig. 1). This exceeds the average escapement of 6,993 in the 25 years prior to consideration for listing (1980-2004). While we recognize that substantial improvements to enhance the productivity and protection of habitat are necessary to ensure the long-term viability of Skagit steelhead populations, the assessments presented in this Plan indicate that a low level of fishery mortality is consistent with the survival and recovery of the Puget Sound DPS.

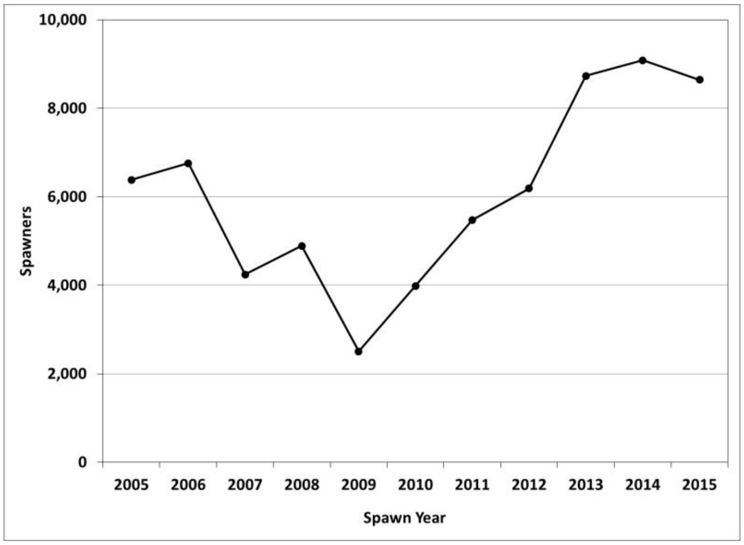

Figure 1. Steelhead spawners in the Skagit River.

This Plan describes fishery management and monitoring for a period of five years. Beginning in the fourth year of implementation the co-managers will begin reviewing the effectiveness of the

Plan from first three years of implementation, incorporating additional information as it becomes available. In the fifth year of implementation the co-managers will apply knowledge gleaned from the previous years to revise this Plan for implementation in Skagit steelhead management in subsequent years. The iterative nature of the Plan is intended to provide stability to management and data collection, while ensuring that assessment of the fisheries and monitoring activities is regularly evaluated using the most recent data and compared against the goals of this plan to inform and enable adaptive management of the resource.

The Plan draws upon the best available information for Skagit steelhead and has been carefully reviewed by the co-managers in support of this proposal. Should significant new information become available or substantial changes come to light, the co-managers will consult with NOAA Fisheries and determine an appropriate course of action.

2.0 Objectives and Principles

The Plan is based upon a multi-pronged assessment of the current status of Skagit wild steelhead. While we recognize that substantial improvements to enhance the productivity and protection of habitat are necessary to ensure the viability of Skagit steelhead populations, our assessments indicate that a low level of fishery mortality is consistent with the survival and recovery of the Puget Sound Distinct Population Segment (DPS). This conclusion is independent of the hatchery-target fishery take criteria established by NOAA under the 4(d) listing of the Puget Sound Steelhead DPS (NMFS 2010).

The objectives of this Plan are: 1) to designate Skagit-origin steelhead (*Oncorhynchus mykiss*) as an independently managed component of the Puget Sound DPS; and 2) to conduct Skagit Terminal Area fisheries in manner pursuant to *U.S. v Washington*[1]which will not appreciably reduce the likelihood of survival and recovery of ESA-listed Puget Sound steelhead.

In addition, the Plan assesses past population trends among the Skagit Terminal Area steelhead population and identifies data gaps to population and fisheries monitoring and evaluation that will be investigated by the co-managers and addressed as resources permit.

3.0 Management Unit & Population Structure

3.1 Population Structure

The Skagit Management Unit (SMU) is comprised of four DIPs (Myers et al. 2015) which have been identified as:

1) Skagit River Summer Run and Winter Run;
2) Nookachamps Creek Winter Run;
3) Sauk River Summer Run and Winter Run; and
4) Baker River Summer Run and Winter Run.

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[1] Pursuant to *U.S. v Washington*, this Plan recognizes the importance of the exercise of Indian treaty rights, within the usual and accustomed fishing areas legally defined for each tribe.

Myers et al. (2015) noted that many of the Puget Sound Technical Recovery Team (PSTRT) members and reviewers considered the Baker River Summer and Winter Run to have been extirpated. Currently, *O. mykiss* have been observed passing downstream through passage structures and this migration (production from resident *O. mykiss*) may contribute to steelhead [migratory *O. mykiss*] population productivity. However, genetic analysis suggests that the Baker River *O. mykiss* are similar to Skagit River steelhead.

Co-managers acknowledge while data exists for Skagit SMU population trends and productivity, there is limited information at the scale of the independent DIPs. Population-specific information has been used, where available, in the development of management objectives and guidelines (see Data Gap section). The Nookachamps Creek population, for example, is the DIP with the least known population size, structure and productivity. Recently, co-managers have sought to understand the Nookachamps DIP population size and potential production (Fowler and Turnbull 2016).

3.2 Management Unit

The Puget Sound Salmon Management Plan defines a management unit as "A stock or group of stocks which are aggregated for the purpose of achieving a desired spawning escapement objective." This Plan establishes a Skagit "Steelhead Management Unit (SMU)" consisting of all extant steelhead populations in the Skagit Terminal Area. The Skagit SMU represents about 40% of all returning steelhead to the Puget Sound DPS (Hard et al. 2015). Historically the Skagit SMU has been managed as a discreet stock aggregate with a variety of proposed escapement objectives.

Although part of the Puget Sound DPS, the Skagit SMU is independent from other Puget Sound steelhead populations. The co-managers established the Skagit SMU in recognition of both this composition of four DIPs and the historical management of these four DIPs as an aggregated stock. Therefore it is practical to consider management of the Skagit SMU independent of the other Puget Sound populations with confidence that independent management will "not appreciably reduce the likelihood of survival and recovery of ESA listed Puget Sound steelhead" (Limit 6 of the 4(d) Rule).

Management at the SMU level, rather than individual populations, is necessitated by the limited population-specific information available for steelhead in the Skagit River basin. Based upon the limited and often qualitative information available, the populations appear to share many characteristics. Perhaps the most comprehensive assessment was completed by Hard et al. (2015), who assessed the characteristics and viability of the populations within a Bayesian network using 13 attributes representing the abundance, productivity, diversity, and spatial structure of the populations. The three extant populations comprising the Skagit SMU were generally characterized similarly (Table 1), with the total nodal values for spatial structure, productivity, and diversity identical for all populations. The total nodal values for abundance varied from 36% to 42%, with the Nookachamps Creek population having a higher score for adults relative to spawner capacity, and the Sauk River population having a higher probability of extirpation over a 100-year time frame. Although by necessity the management controls described in this Plan are primarily directed at the SMU, fishery management actions that will have a conservation benefits to specific populations or diversity components of SMU are described in Section 8.4.

Table 1. Bayesian network characterization of steelhead populations comprising the Skagit SMU (see Table 10 of Hard et al. (2015) for a description of the attributes and figures F-5, F-6, and F-8 for source of attribute values).

Population	Spatial Structure		
	Spawning IP	Rear IP	Total
Skagit River Summer and Winter	40%	40%	33%
Sauk River Summer and Winter	40%	40%	33%
Nookachamps Creek Winter	40%	40%	33%

Population	Abundance			
	Adult	Juvenile	QET	Total
Skagit River Summer and Winter	20%	20%	90%	39%
Sauk River Summer and Winter	20%	20%	40%	42%
Nookachamps Creek Winter	40%	40%	90%	36%

Population	Productivity				
	Smolts/ Spawner	Adults/ Smolt	Lambda	Iteroparity	Total
Skagit River Summer and Winter	55%	55%	48%	30%	33%
Sauk River Summer and Winter	55%	55%	48%	30%	33%
Nookachamps Creek Winter	55%	55%	48%	30%	33%

Population	Diversity				
	Hatchery	Spawn Timing	Residents	Age	Total
Skagit River Summer and Winter	90%	95%	15%	45%	33%
Sauk River Summer and Winter	90%	95%	15%	45%	33%
Nookachamps Creek Winter	90%	60%	15%	45%	33%

4.0 Viable Salmonid Population Characteristics

The status of Skagit steelhead relative to viable salmonid population (VSP) characteristics (McElhany et al. 2000) is discussed in sections 4.1 through 4.3. As with many steelhead populations, more information is available on abundance and productivity than diversity and spatial structure, and for the SMU rather than the individual populations.

4.1 Abundance & Productivity

In the following sections and in the remainder of this plan, we discuss the abundance and productivity of natural-origin steelhead in the Skagit River. There is currently no hatchery program for steelhead in the Skagit River, although the co-managers are evaluating the risks and benefits of implementing a wild broodstock program.

The abundance of steelhead in many rivers in Puget Sound declined substantially over the last 40 years (Hard et al. 2007, Hard et al. 2015). Declines in Puget Sound steelhead DPS have been linked to degradation and fragmentation of freshwater habitat, with consequent effects on connectivity, as a primary limiting factor and threat facing the Puget Sound Steelhead DPS (NFSC 2015). Dams, major habitat modifications, and a multitude of minor impediments to passage have been implicated to reductions to Skagit SMU abundances. Further, observed declines in smolt-to-adult return rates estimated for hatchery-produced winter steelhead in the Skagit, Puyallup, and Elwha rivers declined from levels observed for the early 1980s, and have remained low since the mid-1990s (Scott and Gill 2008), suggesting that lower marine survival contributed to the observed decline.

Historically, the Skagit SMU has maintained the largest wild population and has been one of the most productive steelhead basins in the Puget Sound DPS (Busby et al. 1996, Hard et al. 2007). While many geographic regions were approaching functional extinction, the Skagit SMU was the only basin identified as containing large enough steelhead populations to resist adverse environmental or depensatory forces (Hard et al. 2007). Subsequent reviews of the Skagit SMU population abundance depict a reduction of mean spawners 6,993 (years: 1980-2004) to 5,418 (2000-2004) to 4,078 (2007-2011) (Hard et al. 2015). The number of mean spawners, however, has increased recently to 7,620 (2011-2015) suggesting that Skagit steelhead populations oscillate and it may be difficult to determine if populations are declining or increasing over years previously reported. Skagit River steelhead have maintained abundances well above the critical thresholds described within this Plan and by McElhany et al. (2006) population category of "very low risk" to extinction in 100 years (>1,000 number of spawners) (McElhany et al. 2007).

Over the period of record, the Skagit SMU has shown no clear evidence of an increasing or decreasing trend in population growth rate, specifically estimates of population growth rate (λ) do not significantly differ from zero ($p<0.05$). More recently estimates of λ are increasing yet becoming more variable (Table 2) that may reflect either variability in escapement estimates (fishery that was once managed to an escapement goal), or changes in productivity associated to environmental conditions. Population growth rate has thus been stable since 1970's. Estimates of λ do not include years 2013 and later with the imposed hatchery moratorium.

The Puget Sound Technical Recovery Team dentified steelhead spawning in Nookachamps Creek as a DIP (Myers et al 2015) although little information on the abundance of spawners was available. To address this shortcoming, the comanagers counted redds and estimated the abundance of spawners in 2015 and 2016 (Fowler and Turnbull 2016; WDFW unpublished data). In both years, there were approximately 250 spawners in Nookachamps Creek.

Table 2. Estimates of population growth rate λ (95% CI) for the Skagit River wild steelhead across different years.

Management Unit	Time Series	λ	95% CI	Source
Skagit River	1977-2011	0.997	0.921-1.079	Hard et al. 2015
Skagit River	1978-2013	0.987	0.913-1.053	Cram 2015
Skagit River	1985-2009	0.969	0.954-0.985	Ford et al. 2011
Skagit River	1995-2009	0.978	0.931-1.029	Ford et al. 2011
Skagit River	1995-2011	0.966	0.494-1.891	Hard et al. 2015
Skagit River	2004-2013	1.018	0.588-1.987	Cram et al. (in prep.)

4.2 Spatial Structure

The Skagit SMU is comprised of four DIPs (Myers et al. 2015) which have been identified as: Skagit River Summer Run and Winter Run; Nookachamps Creek Winter Run; Sauk River Summer Run and Winter Run; and Baker River Summer Run and Winter Run. The Baker River Summer Run and Winter Run are considered extirpated at this time. Hard et al. (2015) evaluated viability of each of the existing Skagit SMU DIPs using a Bayesian Network analysis. None of the DIPs were near QET. Each of the existing DIPs were deemed to have moderate or intermediate 40%-85% current viability.

Co-managers identified the limited information for each individual DIP's within the Skagit SMU, and are working to gather DIP level information into the future. Of particular interest, the Nookachamps Creek Winter Run represents the DIP occupying the smallest sub-basin within the Skagit SMU. As discussed above, spawner abundances have been estimated from spawn ground surveys in 2015 and 2016 and will continue into the foreseeable future.

The co-managers are also assessing *O. mykiss* habitat occupancy within the Skagit SMU. *O. mykiss* are found throughout the Skagit SMU anadromous zone and above some impassable barriers. In 2011-2012, *O. mykiss* were ubiquitous across the Skagit SMU and occupied 95% of the sites surveyed (Upper Skagit Indian Tribe (Shannahan), unpublished data). Larger O. mykiss tended to occupy large log jams and tributary streams. In the snow and rain hydro-regions larger O. mykiss occurred in greater densities and appear to trend towards a tributary specialist habit (Upper Skagit Indian Tribe (Shannahan), unpublished data).

4.3 Diversity

Steelhead are a component of a complex expression of migratory strategies exhibited by *O. mykiss*. *O. mykiss* exhibit a partial-migratory strategy from resident, fluvial, amphidromous and anadromous life histories (Kendall et al. 2014). Good et al. (2005) identified the anadromous component important to population viability. However, the contribution of resident *O. mykiss* to the migratory steelhead may be critical component to steelhead production (Wilzbach et al. 2012, Courter et al. 2013, Hodge et al. 2016). Current knowledge suggests that resident form contributes more than losses from steelhead residualization (Courter et al. 2013). Resident *O. mykiss* forms are likely buffering demographic and genetic changes (Wilzbach et al. 2012). Specifically, Courter et al. (2010) suggested that a reduction in steelhead below 50 spawners across four or more consecutive years would not lead to extinction when resident *O. mykiss* is in high abundance.

As described by the VSP (McElhany et al. 2000) resident component of the *O. mykiss* must be connected to the anadromous form and can be regenerated by residents. Within the Skagit SMU, resident *O. mykiss* are genetically indistinguishable from anadromous forms within the anadromous zone (Pflug et al. 2013). Also, it is common for resident *O. mykiss* above long standing barriers to be found within the anadromous zone. Juvenile *O. mykiss* are consistently collected at the downstream collection facility at Baker Lake, suggesting that these were smolts expressing anadromy from resident *O. mykiss*. Genetic work also identified genetic signature of isolated residents above impassible structures within the anadromous zone (Pflug et al. 2013).

Even though we do not consider resident *O. mykiss* directly within this Plan, resident *O. mykiss* are likely contributing to anadromous production. The presence of numerous rainbow trout populations reduces risk to steelhead population viability (Good et al. 2005, Courter et al. 2010). An *O. mykiss* population expressing a combination of migratory strategies and a heritable propensity to produce both types of progeny means residents can serve as a buffer when anadromous productivity is low and extinction risk is lower when residents are abundant (Hard et al. 2015). We are unable to directly assess resident contribution at this time, but view this as an important process and makes our estimate of risk higher than reality.

It is acknowledged that some hatchery programs and practices may pose ecological and genetic risks to natural populations and may represent a factor limiting the viability of the Puget Sound steelhead DPS into the foreseeable future (71 FRN 15666). Warheit (2014) estimated gene flow from returning hatchery-origin adult to natural-origin Skagit steelhead and found that rates ranged from 2% for the Skagit and Nookachamps populations to 4% for the Sauk population. Similarly, Hard et al. (2015) concluded that the hatchery program had only a nominal effect on the diversity of Skagit steelhead populations. However, the spawn-timing of the Nookachamps DIP may have been affected by fisheries directed at early returning hatchery-origin steelhead (Hard et al 2015). Management actions to maintain or increase the breadth of spawn timing are discussed in Section 8.4.

5.0 Critical and Viable Thresholds

The technical document “Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units” (McElhany et al. 2000) provides a framework for identifying the biological requirements of listed salmonids, assessing the effects of management and conservation actions, and ensuring that such actions provide for the survival and recovery of listed species. The framework includes population abundance thresholds (critical or viable) associated with the risk of extirpation. We have relied upon the concepts in that document to help frame the fishery management Plan for Skagit steelhead.

5.1 Critical Threshold

McElhany et al. (2000) defined a critical threshold as a population status that “implies a high risk of population extinction over a short time period” (e.g. 10 years) and provided the following guidance for establishing a critical threshold:

1) A population would be critically low if depensatory processes are likely to reduce it below replacement.
2) A population would be critically low if it is at risk from inbreeding depression or fixation of deleterious mutations.

3) A population would be critically low in abundance when productivity variation due to demographic stochasticity becomes a substantial source of risk.
4) Population status evaluations should take uncertainty regarding abundance into account.

The co-managers evaluated three methods for establishing a critical threshold for the Skagit SMU[2]: 1) the predicted number of spawners at the point of depensation; 2) the sum of the minimum effective size of each population; and 3) the sum of the quasi-extinction thresholds (QETs) of each population.

Method 1 – Depensation. Peterman (1977, 1987) provided a rationale for depensation and suggested relating the escapement level at which depensation occurs to the size of the population in the absence of fishing (equilibrium escapement level). Based on Peterman's work, we established the critical level equal to 5% of the equilibrium spawner size (8,949), or 447 spawners (see Appendix B).

Method 2 – Effective Population Size. The number of effective breeders per year, rather than annual spawner abundance, determines the genetic stability of a salmonid population over time. Waples (1990) estimated through modeling that 100 effective breeders per year would maintain genetic variation in salmon populations for 25 generations, for populations with a four year generation cycle. Annual effective breeder abundance less than 50 was estimated to expose the population to high risk of allele loss through genetic drift. The number of annual effective breeders multiplied by the average age at reproduction (approximately four years for steelhead) equals the generational effective population size (N_e), thus N_e lower than 200 is also associated with high risk.

Although the annual number of successful spawners is not easily determined, the relationship between census size and effective breeders (N_b) has been estimated for both Chinook and steelhead. Waples (2004) found that the ratio of effective population size to spawner census (N_e/N_c) for Chinook could be expected to range from 0.05 to 0.3. Estimates of N_e/N_c in three British Columbia steelhead populations ranged from 0.06 to 0.29 (Heath et al. 2002). In a study of the Snow Creek steelhead, Ardren and Kapuscinski (2003) estimated relatively higher ratios of the annual number of effective breeders to spawner census (N_b/N_c), ranging from 0.16 to 2.4, depending on methodology. Most importantly they found higher N_b/N_c ratios when census size was low, indicating higher reproductive success when fewer spawners were present in this relatively small watershed.

The combination of spawning escapement estimates and landed catch reports provide the only population size data to assess performance indicators for Puget Sound steelhead. We can refer to available information on the ratio of effective breeders to census size to estimate a minimum census size at which effective number of spawners may be expected to be large enough to maintain diversity and minimize inbreeding in a population, at least over the short-term

A critical threshold values for annual spawning escapement was chosen such that, for each potential population within an SMU, the annual effective size, or number of successful breeders, would not be lower than 50 if an N_b/N_c ratio of at least 0.40 was achieved. For the Skagit SMU,

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[2] Note: The contributions of resident *O. mykiss* is assumed to contribute to migratory *O.* mykiss production, but is not considered in any of the methods evaluated here.

with three extant populations, the critical threshold was set equal to three times the population specific value, for a total of 375 spawners.

Method 3 – Quasi Extinction Threshold. Hard et al. (2015) developed estimates of the QET for each Puget Sound steelhead population based on the intrinsic habitat potential (IP). Values for each population were interpolated from the relationship between the intrinsic habitat potential of a small basin (Snow Creek, QET = 24) and the largest basin (Skagit River Summer and Winter Run, QET = 157).

Predicted QET values for each DIP within the Skagit SMU were: 1) Nookachamps Creek Winter Run population, QET = 27; 2) Skagit River Summer and Winter run populations, QET = 157; and 3) Sauk River Summer and Winter Run populations, QET = 103 (Table 3). The total for populations within the Skagit steelhead MU was 287. Since these are QETs, the critical threshold for the Skagit SMU should be greater than 287.

After consideration of these methods, the co-managers selected a critical threshold of 500 spawners (higher than any value suggested by any of the methods) for this Plan. As discussed in Section 8.3, the projected frequency of spawners less than the critical threshold is an important consideration in the evaluation of the proposed management regime.

5.2 Viable Threshold

A viable population has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame. McElhany et al. (2000) provide the following guidance for establishing a viable population threshold:

1) A population should be large enough to have a high probability of surviving environmental variation of the patterns and magnitudes observed in the past and expected in the future.
2) A population should have sufficient abundance for compensatory processes to provide resilience to environmental and anthropogenic perturbation.
3) A population should be sufficiently large to maintain its genetic diversity over the long term.
4) A population should be sufficiently abundant to provide important ecological functions throughout its life-cycle.
5) Population status evaluations should take uncertainty regarding abundance into account.

Viability criteria are often established for salmon and steelhead populations during the development of a recovery plan. A recovery plan has not been completed for the Puget Sound steelhead DPS, but Hard et al. (2015) provided a number of analyses and preliminary recommendations.

Hard et al. (2015) used a stochastic population viability model to assess the current viability of the Skagit River Summer & Winter Run population. The joint probability of abundance (spawners) and recruits per spawner was plotted versus four viability curves representing different combinations of abundance and productivity and a 5% risk of reaching a quasi-extinction threshold (QET) of 1, 20, 50, or 157 spawners. Based on these analyses, Hard et al. (2015) concluded that Skagit River Summer & Winter population was at a low risk of quasi-extinction over the next 100 years (Figure 2).

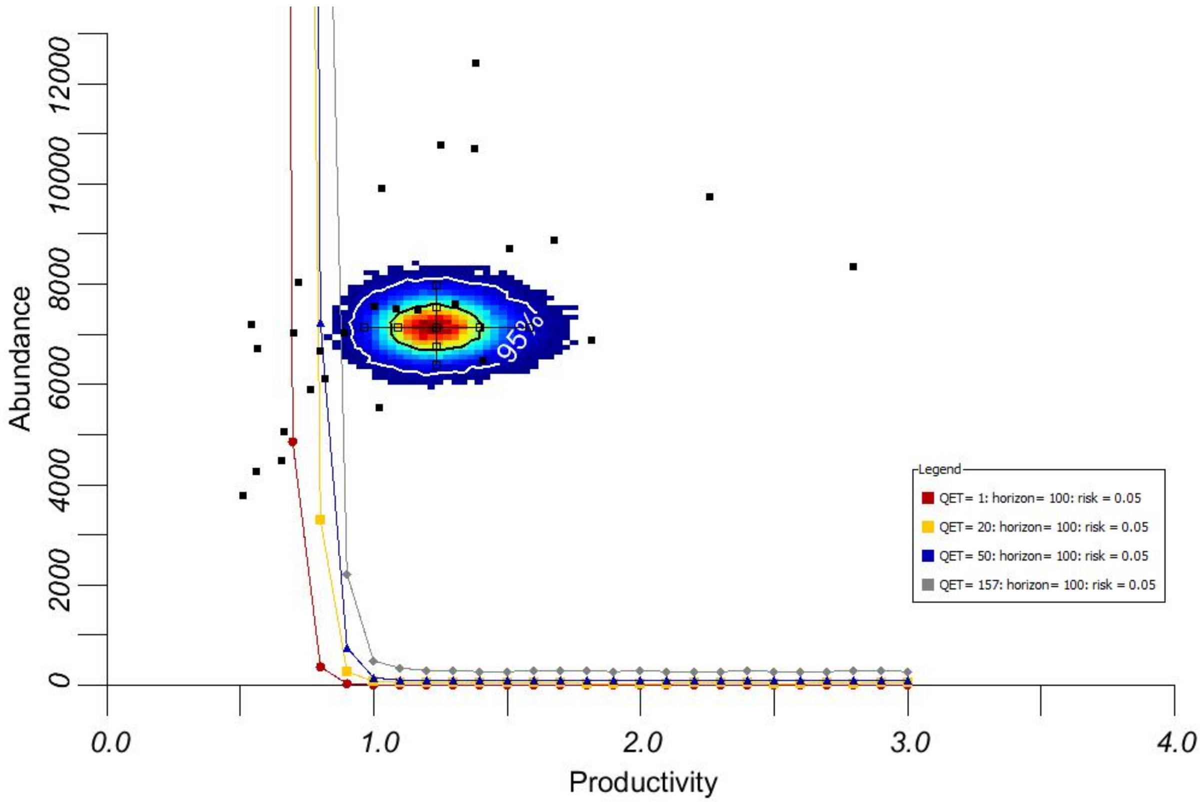


Figure 2. Population viability analysis for the Skagit River Summer and Winter Run population (from Hard et al. (2015)).

Hard et al. (2015) also provided preliminary recommendations for interim viability goals for use in recovery planning. Population specific viability thresholds were predicted by multiplying the intrinsic potential (IP), estimated from the estimated square meters of habitat, by a smolt to adult survival rate (SAS) of 5%. Values ranged from 616 for the Nookachamps Creek Winter population to 32,388 for the Skagit River Summer & Winter population and totaled 44,619 for the Skagit SMU (Table 3).

Table 3. Hard et al. (2015) QETs and preliminary recommendations for viable abundance thresholds for populations of steelhead in the Skagit River.

Population	QET	Viable
Nookachamps Creek Winter	27	616
Sauk River Summer & Winter	103	11,615
Skagit River Summer & Winter	157	32,388
Total	**287**	**44,619**

The use of the viable abundance threshold in evaluating the proposed management regime is discussed further in Section 8.3.

6.0 Fishery Impacts

Skagit steelhead are encountered in directed fisheries or as incidental catch in other non-steelhead directed fisheries throughout the Skagit Terminal Area (SMU) and marine pre-terminal areas. Impacts to Skagit steelhead for each fishery are assessed in preseason forecasts, in some cases monitored and assessed with inseason updates and accounted in post season run reconstructions that derive total population size. Fishery impacts to Skagit steelhead are described here including the type, duration and consideration of potential steelhead encounters in regular fisheries.

6.1 Directed Skagit Steelhead Fisheries

Treaty tribes directed Skagit SMU commercial, subsistence, and ceremonial fisheries for winter steelhead, which utilize net and hook and line gear, are operated by the Swinomish, Sauk-Suiattle and Upper Skagit tribes in Skagit Terminal Area. Under this Plan tribal net fisheries directed at the Skagit SMU will typically operate between December 1 and April 15, but time and area regulations will vary depending on the preseason estimate of wild steelhead run size as well as other species that may be potential affected by a fishery.

A directed Skagit SMU recreational fishery may be conducted during the period beginning no earlier than February and extending no later than April 30. Time and area restrictions that will vary depending on the forecasted return of wild winter steelhead and that of potential incidentally impacted species. Recreational steelhead fishing occurs primarily in freshwater, and the retention of marked hatchery steelhead may be allowed if an integrated hatchery program using Skagit steelhead broodstock has been initiated. Retention of unclipped wild Skagit steelhead may be allowed depending upon the preseason abundance projection and given the harvest rates proposed in this Plan. Since the retention of unclipped steelhead is currently prohibited, this would require a rule change approved by the Fish and Wildlife Commission.

Recreational summer-run steelhead fisheries are typically integrated with the general summer freshwater recreational fisheries that are open to the retention of trout, hatchery origin steelhead and salmon. Angling is restricted in some streams to protect migrating juvenile and adult salmonids.

6.2 Skagit Terminal Area Incidental Steelhead Impacts

Skagit steelhead are incidentally encountered during salmon and trout fisheries in the Skagit Terminal Area in both Treaty and non-treaty fisheries. These encounters may be retained in some of the treaty fisheries as by-catch, and currently the non-Treaty fishery is required to release all wild steelhead. Regulatory measures in both fisheries have been implemented to reduce or eliminate these incidental encounters which include such measures as; non-retention of wild steelhead, time and area closures, and gear restrictions.

Treaty Fisheries. Skagit Terminal Area treaty fisheries are directed at hatchery spring Chinook, Baker sockeye, summer fall Chinook, pink, coho, and chum salmon have the potential of encountering wild winter and summer steelhead. The hatchery spring Chinook fishery encounters both winter steelhead pre-spawn and kelts of wild origin. The Baker sockeye fishery in June through July encounters winter steelhead kelts and possibly summer wild steelhead. The summer fall Chinook fisheries (mid-June through end of spawning) would most likely encounter wild summer steelhead and straying hatchery-origin summer steelhead.

The Skagit pink fisheries (generally early August through mid-October in odd-numbered years only) may encounter both wild and hatchery-origin stray summer steelhead. The Skagit Terminal Area coho fisheries (generally August through December) may encounter both wild and hatchery-origin stray summer steelhead. A large component of steelhead encountered in all fisheries occurring from mid to late June and through July are kelts as opposed to pre-spawning fish. Fall chum fisheries (generally late October through December) will primarily encounter straying (out of basin) hatchery-origin steelhead and early-returning wild winter steelhead.

Recreational Fisheries. Recreational salmon fisheries in the Skagit Terminal Area encounter wild winter and summer steelhead.

The freshwater salmon fisheries are typically closed during the freshwater entry and upriver migration period (generally January through May) of winter-timed steelhead, and in stream reaches where summer-timed steelhead hold or spawn during the late winter. However, the hatchery spring Chinook fishery which occurs in May has the potential of encountering both winter pre-spawn and kelts of wild origin. The Baker sockeye fishery which occurs in June and July has the potential to encounter winter steelhead kelts and possibly summer wild steelhead. The coho fishery can be extended until the end of December in some years which will primarily encounter straying hatchery-origin winter steelhead, and early wild winter steelhead.

Recreational creel surveys have been conducted to estimate harvest and/or incidental mortality of steelhead during spring and summer Chinook, sockeye and some pink salmon fisheries (see Appendix A). Recent information indicates that few encounters with steelhead occur in these fisheries. Based on data collected during creel surveys of:

- The Cascade River spring Chinook fishery in 2005 - 2012, which operated from June 1st through the 15th of July, recorded 5 to 100 wild steelhead (mostly winter kelts) were caught and released.
- The pink salmon survey in the Skagit River in 2003 recorded eight steelhead encounters.
- A summer Chinook fishery from July 9 to August 9 in 2009 recorded three steelhead encounters.
- Sockeye fisheries in the mid-June to mid-July timeframe in 2012, 2014 and 2015 encountered 64, 37, and 5 steelhead respectively.

The recreational trout fisheries in the Skagit Terminal Area have the potential to encounter wild summer and winter Skagit steelhead, and both resident and pre-migratory juvenile *O. mykiss*. There are not currently estimates of the number of wild steelhead encountered during these fisheries. The trout fisheries are typically closed during the freshwater entry and upriver migration period (January-May) of adult winter-timed steelhead and in stream reaches where summer-timed steelhead hold or spawn during late winter.

Regulation based on a statewide stream strategy has also been implemented to protect juvenile wild steelhead through the closure of fishing in areas and times critical to juvenile steelhead, and the implementation of minimum size limits to limit fishery related mortality prior to smolts leaving freshwater. Retention of resident *O. mykiss* is currently allowed in some times and areas of the Skagit River basin. Recent literature has documented that resident *O. mykiss* can contribute to the life history diversity of steelhead (Weigel et al. 2014, Wilzbach et al. 2014).

6.3 Preterminal Fisheries Incidental Steelhead Impacts

Treaty subsistence and commercial fisheries and non-treaty commercial and recreational fisheries directed at Chinook, sockeye, pink, coho, and chum salmon that operate in marine waters outside Skagit Terminal Area also impact the Skagit SMU. Although not covered by this Plan, information on these fisheries is included to provide context for the evaluation of the proposed fishery management in the Skagit SMU.

For the purposes of this Plan, steelhead harvested in the following pre-terminal commercial catch reporting areas are assumed to be a mixture of Puget Sound and Canadian origin.:

- Strait of Juan de Fuca (Areas 4B, 5, 6, and 6C)
- San Juan Islands/Point Roberts (Areas 7, 7A, 7B, and 7C)
- Central Puget Sound (Areas 9, 10, 10E, and 11)
- South Puget Sound (Areas 13, 13A – 13I)

Annual total (November through October time period) Treaty harvest in Puget Sound pre-terminal areas averaged 116 fish for the management years 2003-04 through 2013-14 (Table 4). These regional harvest figures may not include some steelhead taken for subsistence purposes, nor do they include estimated mortalities from recreational and commercial non-retention of steelhead.

Table 4. Treaty commercial and take-home harvest of steelhead, in mixed-stock pre-terminal areas of Puget Sound from 2003-04 through 2013-14.

Year	Strait of Juan de Fuca	San Juan Is. Point Roberts	Central Sound	South Sound	Total
2003-04	58	1	0	5	64
2004-05	25	7	0	0	32
2005-06	128	2	28	0	158
2006-07	80	4	0	0	84
2007-08	69	21	0	0	90
2008-09	14	94	0	0	108
2009-10	136	450	0	0	586
2010-11	11	19	0	0	30
2011-12	22	20	0	0	42
2012-13	11	48	0	0	59
2013-14	11	10	0	0	21
Mean (St Error)	**51 (14.2)**	**62 (39.7)**	**3 (2.5)**	**<1 (0.5)**	**116 (48.6)**

We cannot estimate the stock composition, or hatchery and wild composition of catch in these pre-terminal fisheries. However, given the small volume of catch, and the likely presence of Canadian stocks, the collective impact of these fisheries on Skagit River steelhead populations is unlikely to exceed more than a small fraction of one percent of aggregate Skagit River and Puget Sound abundance.

Non-treaty commercial salmon fisheries directed at Chinook, coho, pink, sockeye, and chum salmon operate in some marine areas in Puget Sound. A low number of steelhead are encountered in these fisheries. Regulations for non-treaty commercial net fisheries prohibit retention and sale of steelhead and fishers must release all steelhead they encounter. From 1991 to 2014, observers monitoring non-treaty purse seine and gillnet fisheries recorded a total of 48 steelhead encounters while observing 6,850 purse seine sets and 689 gillnet sets (Kendall Henry pers. comm. WDFW). It is assumed that the 48 steelhead encounters include steelhead from the entire Puget Sound DPS and that Skagit steelhead represent only a portion of the 48 steelhead encounters over 23 years.

Recreational fisheries directed primarily at Chinook, coho, and pink salmon occur throughout the marine areas of Puget Sound. Retention of marked, hatchery steelhead is allowed in these fisheries, but the total average landed catch is low (Table 5). Encounters with, and incidental mortality of listed Puget Sound wild steelhead are currently not recorded, reported, or quantified.

Table 5. Landed catch of steelhead in Puget Sound recreational fisheries, 2003-04 through 2012–13 in Marine Areas 4-13.

Return Year	Hatchery
2003-04	160
2004-05	260
2005-06	102
2006-07	114
2007-08	163
2008-09	72
2009-10	110
2010-11	169
2011-12	231
2012-13	157
Mean (St Error)	**154 (18)**

The information currently available for preterminal fisheries indicates that these fisheries are not a significant factor affecting the viability of Skagit steelhead. However, the co-managers recognize the importance of understanding pre-terminal fishery impacts on Skagit steelhead, and will address the development and implementation of a strategy to better monitor and record the pre-terminal fishery impacts on Puget Sound steelhead after approval of the Plan.

7.0 Spawner-Recruit Analysis

Understanding population dynamics of Skagit Basin steelhead is a fundamental step in the development of a sustainable fisheries management regime. Cohort reconstruction forms the basis for evaluation and recent brood returns, terminal run reconstruction, and production are presented in Appendix A. Estimates of spawning escapement are the foundation for the cohort reconstruction, and are based on foot, floating, or aerial surveys conducted on a 10-14 day rotation throughout the known and accessible spawning areas in the Skagit basin. Surveys are typically conducted from late February/early March through June or early July (see section 9.3 for additional discussion of spawner estimates). The age composition of the return is also important for reconstructing the production from each brood year. Age composition is estimated from scales collected from commercial, recreational fisheries, and test fisheries, with sample sizes averaging approximately 100 fish for each the years analyzed.

The spawner-recruit dynamics of Skagit Basin steelhead were estimated using both Ricker and Beverton-Holt spawner recruit population dynamics models. Parameter and variance estimates are provided in Table 6 with details of the analysis provided in the Appendices.

Table 6. Transformed parameter and standard deviation estimates for the Skagit steelhead spawner-recruit analysis.

Parameter	Point Estimate	Standard Deviation
Ricker: $R = \alpha S e^{-\frac{S}{\beta}}$		
α	2.56	1.95
β	9,529	2,962
Error Variance	0.22	
Beverton-Holt: $R = \frac{S}{\alpha + \beta S}$		
α	7.23	14.12
β	10,321	3,574
Error Variance	0.27	

8.0 Conservation Management

This Plan provides a conservative harvest management strategy that incorporates the variability of steelhead populations within the Skagit SMU so that fishing mortality does not impede rebuilding and eventual recovery of the Puget Sound Steelhead DPS, while allowing harvest and ensuring that treaty rights are maintained. The Plan implements a stepped-abundance harvest regime to constrain harvest during periods of low abundance, providing additional protection for Skagit SMU compared to current management, while acknowledging that favorable conditions provide harvestable abundance.

The co-managers see constrained harvest at low abundances essential to providing adequate escapement and optimizing natural production under existing habitat and environmental conditions. Rebuilding and recovery of populations, however, depends on successful management of other factors affecting productivity, including the restoration of habitat function and, where applicable, hatchery actions or reforms (71 FR 15666). Within the Skagit River basin, co-managers are actively working on a recovery plan and evaluating the possible role of an integrated hatchery program for the Skagit SMU.

8.1 Limit 6 Requirements

Limit 6 of the 4(d) rule includes the following direction regarding allowable fishery impacts:

1) "Harvest actions impacting populations that are above the viable threshold must be designed to maintain the population or management unit at or above that level."
2) "For population shown with a high degree of confidence to be above critical level but not yet at viable levels, harvest management must not appreciably slow the population's achievement of viable function."
3) "Harvest management impacting populations that are functioning at or below critical threshold must not be allowed to appreciably increase genetic and demographic risks facing the population and must be designed to permit the population achievement of viable function, unless the plan demonstrates that that likelihood of survival and recovery of the entire ESU in the wild would not be appreciably reduced by greater risks to that individual population."

Some previous NMFS Limit 6 evaluations have assessed proposed fishery regimes relative to the following two criteria:

- The survival criterion: The percentage of escapements below the critical threshold (C) differs no more than 5% from under the baseline condition.
- The recovery criterion: "The viable threshold must be met 80% of the time, or the percentage of escapements less than the viable threshold (V) must differ no more than 10% from that under baseline conditions.

8.2 Proposed Fishing Regime

The co-managers proposed fishing regime provides for stepped impact rates ranging from 4% at low population abundance to 25% when the terminal run exceeds 8000 fish (Table 7). The 4% rate for low abundance is less than the rate currently allowed by NOAA Fisheries under the existing Section 7 permit. The proposed fishing regime meets or exceeds all requirements for Limit 6 as demonstrated in subsequent sections.

Table 7. Stepped fishing regime proposed for managing steelhead fisheries in the Skagit SMU.

Preseason Forecast for Natural-Origin Steelhead	Allowable Impact Rate
Terminal Run ≤ 4,000	4%
4,001 ≤ Terminal Run <6,000	10%
6,001 ≤ Terminal Run <8,000	20%
Terminal Run ≥ 8,001	25%

A preseason forecast of abundance and the stepped fishing regime will be used each year by the comanagers to develop a fishery plan consistent with the provisions of *U.S. v. Washington*. In developing the treaty and nontreaty steelhead fisheries, the comanagers will incorporate the anticipated directed and incidental impacts on steelhead from fisheries directed at salmon to ensure that the total impacts remain below the allowable impact limit.

8.3 Risk Analysis of Proposed Fishing Regime

The co-managers evaluated the stepped fishing regime described in Table 7 relative to the allowable fishery impacts within the Skagit SMU using risk assessment simulation models that incorporated the Ricker and Beverton-Holt spawner recruit population dynamics models..

The analysis used the following values for the risk analysis:

C	The critical threshold was set equal to 500 as discussed in Section 4.1.
V	The viable threshold was set equal to 44,619 as discussed in Section 4.2.

As discussed by Hard et al. (2015), “Under any potential scenario, it is likely that considerable time and effort will be required to reach the viability criteria”. In particular, the spawner-recruit analysis indicates that substantial improvements in habitat (taken in the broad sense) capacity and productivity will be needed before Skagit steelhead can approach this level of abundance. Until that time, the co-managers propose that harvest management objectives should be based on quantitative understanding of current population productivity, as defined by current habitat function. Escapement goals, for example, should refer to optimum seeding of existing habitat (e.g. a level associated with maximum sustainable yield), though adjusted higher to account for the uncertainties inherent to quantifying productivity, and recognizing the lesser risk associated with exceeding the spawners associated with the maximum sustainable yield, compared with the risks of underseeding spawning and rearing habitat.

Consistent with these concepts, the co-managers identified two additional reference points for use in the risk analysis:

R_{MSY}	Rebuilding threshold equal to the spawner level that will maximize the long-term yield under current habitat conditions. A similar reference point has been used in previous NMFS and comanager analyses.
R_{60}	Rebuilding threshold equal to 60% of the point on the spawner-recruit function where less than one recruit is produced per spawner (e.g., equilibrium point on spawner-recruit function). The intent of assessing the proposed management regime relative to this threshold is to ensure that the habitat productivity and

capacity are "probed" on a regular basis, and that sufficient spawners are provided to recolonize underutilized habitat.

The reference points used in the risk analysis are provided in Table 8.

Table 8. Critical, viable, and rebuilding reference points used in the risk analysis.

Reference Point	Spawner-Recruit Function	
	Ricker	Beverton-Holt
Critical (C)	500	
Viable (V)	44,619	
Rebuilding – MSY (R_{MSY})	3,912	2,127
Rebuilding – 60% Equilibrium (R_{60})	5,370	4,844

The simulations of the proposed fishery management regime were conducted using the following steps:

Step 1: Initiate the simulation with the number of spawners randomly drawn from a normal distribution with mean and standard deviation estimated from the observed spawners from 1978-2007.

Step 2: Apply the proposed harvest rate protocol (Table 7) and obtain a number of harvested fish.

Step 3: Subtract the number of harvest fish from the number of returning mature fish to obtain a number of spawners.

Step 4: Use the spawner recruit parameters to compute the next random number of recruits, and multiply this by a random variable in order to incorporate environmental and demographic stochasticity.

Step 5: Complete for 25 cycles.

Step 6: Repeat for N=1500 simulations.

It is important to note that the analysis provides a perspective on the short- and long-term (25 generation) effects of the proposed fishery regime on the abundance of Skagit steelhead. However, the co-managers recognize that the freshwater and marine environments are dynamic, with the potential for long-term degradation resulting in a reduction of the productivity of Skagit steelhead. The proposed fishery regimes address this uncertainty through a conservative, stepped harvest rate linked to abundance, monitoring and adaptively monitoring Skagit steelhead, and through the limited (5-year) length of this Plan.

Given these caveats, the results from the risk analysis are summarized in Table 9 and indicate that the proposed fishery regime has a very limited effect upon the Skagit SMU.

The risk analysis suggests that the probability of falling to either the critical threshold (500) was less constraining than either of the rebuilding thresholds. Among various simulations, the probabilities of steelhead abundance being below the critical threshold (500) were 0% for the proposed stepped harvest management regime. To increase the probability of falling below critical threshold (500) to between 1% and 2% the harvest rate of 40% or greater would need to be realized for either Ricker or Beverton-Holt models (appendices B and C). Skagit steelhead tended to be productive at low spawner abundances (intrinsic productivity). Intrinsic productivity is an important indicator of population viability for at least two reasons. First, it is a measure of a population's ability to rebound from short-term environmental or anthropogenic perturbations (resilience). Second, intrinsic growth rate partially determines the abundance at which demographic stochasticity begins to play an important role in determining the fate of the population (Lande 1998). The stepped harvest rates proposed in this Plan are unlikely to drive Skagit SMU below critical threshold levels.

Table 9. Summary of simulation results on risk expressed as the proportion of resulting escapements that meet the threshold criteria. Each criteria is provided and the metric is the probability for achieving that criterion in the 1,500 iteration model runs.

Spawner Reference Point	Ricker		Beverton-Holt	
	No Fisheries	Proposed Fishery Regime	No Fisheries	Proposed Fishery Regime
< Critical (C)	0%	0%	0%	0%
> Viable (V)	0%	0%	0%	0%
> Rebuilding (R_{MSY})	92%	88%	99%	99%
> Rebuilding (R_{60})	78%	68%	82%	75%

The risk analysis also suggests that implementation of the proposed fishery regime would have little effect upon the frequency with which the viable and rebuilding reference points would be achieved. Under the Ricker model, the spawner abundances are projected to exceed R_{MSY} 88% of the time, and R_{60} more than 68% of the time. Similarly, under the Beverton-Holt model, R_{MSY} would be exceeded 99% of the time, and R_{60} 75% of the time. Under neither model is there a more than 10% difference in achieving the reference points when comparing a no fishing regime with the proposed fishing regime.

Puget Sound steelhead have experienced periods of relatively good and relatively poor marine survival during the last 30 years. For example, in the Skagit River, the 1987 through 2006 brood years produced about 25% fewer recruits than would be predicted from a longer-term dataset (1978-2007 brood years). While recent brood years appear to have relatively good survival rates as evidenced by increased numbers of spawners, the fishery management regime must also be protective of Skagit River steelhead during periods of reduced productivity.

The resilience of the proposed management regime to reduced productivity was tested by simulating reductions in productivity of 15% to 35% for an entire 25-generation period. The number of spawners remained above the critical threshold in all simulations. Even at a 35% reduction in average survival over 25 generations, the percentage of years with spawners exceeding R_{MSY} was 75% for the Ricker model and 91% for the Beverton-Holt model as presented in Table 10. The management approach proposed in this Plan, with harvest rates stepping down to 4%, provide for protection of the SMU even over prolonged periods of poor survival.

Table 10. The effects of 15% to 35% reductions in survival over a 25-generation simulation on the performance of the management system.

Survival Reduction	Ricker		Beverton-Holt	
	% < Critical (C)	% > R_{MSY}	% < Critical (C)	% > R_{MSY}
0%	0%	88%	0%	99%
15%	0%	85%	0%	98%
20%	0%	83%	0%	97%
25%	0%	81%	0%	96%
30%	0%	79%	0%	94%
35%	0%	75%	0%	91%

8.4 Additional Conservation Actions for Populations and Diversity

In addition to the limits on the impact rate, the comanagers will implement fishery management actions that will have a conservation benefits to specific populations or diversity components of SMU. These include the following.

Protection of Kelts. In developing viability criteria for the Puget Sound steelhead, the PSTRT stated a “conviction that iteroparity is an important consideration in a comprehensive evaluation of viability for steelhead. Iteroparity is also arguably an important factor for diversity (and also for population persistence through temporal risk spreading)”, and “especially influential on viability in small populations during periods when marine mortality varies widely” (Hard et al. 2015).

This Plan provides protection for kelts by: 1) opening recreational fisheries for adult steelhead upstream of the Dalles Bridge in Concrete, well upstream of the relatively small Nookachamps Creek population; 2) closing recreational fisheries for adult steelhead no later than April 30 to limit mortalities on kelts; and 3) opening tribal fisheries during the weeks 18 – 30 targeting spring Chinook and sockeye will be conducted to limit kelt impacts.

Protection of Summer Run-Timing Population Component. Genetic, run-timing, and spawn-timing information suggest that steelhead return to the Skagit and Sauk rivers throughout the year, including the summer months. The PSTRT concluded that “there is likely to be some population substructure that should be considered in maintaining within-population diversity” (Myers et al. 2015).

This Plan provides protection for the summer-timed component of the populations by: 1) opening recreational fisheries directed at adult steelhead no earlier than February 1; and 2) not opening any tribal fisheries directed at the harvest of summer-timed steelhead.

Protection of Early-Timed Winter Steelhead. The PSTRT identified maintenance of the historical breadth of spawn-timing as a consideration in the viability of a population, and hypothesized that the spawn-timing of the Nookachamps Ceek population has been altered relative to historical conditions (Hard et al. 2015). More broadly, there are concerns that fisheries directed at the harvest of early-returning hatchery fish may have resulted in the loss of the early-run timed component of wild steelhead (NOAA 2016).

Early-timed hatchery steelhead are no longer released in the Skagit River, and this Plan provides protection for any early-timed component of the natural-origin return by not allowing any recreational fisheries directed at adult steelhead prior to February 1. Treaty fisheries will not concentrate on the early returns, but rather be designed to access steelhead across the entire return period.

Protection of Nookachamps Creek Population. The Nookachamps Creek population is the smallest extant population of steelhead in the Skagit River and, potentially, the smaller size could increase the risk of extirpation.

This Plan provides additional protection for the Nookachamps Creek population by opening recreational fisheries for adult steelhead upstream of the Dalles Bridge in Concrete, well upstream of the relatively small Nookachamps Creek population. Treaty fisheries will not concentrate on the early returns, but rather be designed to access steelhead across the entire return period.

9.0 Monitoring and Adaptive Management

For the duration of the Plan, annual accounting of recreational encounters, all landed catch, estimate of non-landed mortalities, and estimation of spawning escapement will provide the basic information needed to monitor population abundance trends and assess management performance against the harvest objectives (harvest rate ceilings and abundance thresholds) described in Section 8. Catch and escapement sampling to describe the age structure of populations are critical to developing analyses needed for improving the basis management, e.g. improving forecasting capability, quantifying recruitment, and developing escapement goals.

9.1 Performance Indicators

The performance indicators for evaluating this Plan will focus on the following questions:

1) Is the SMU as productive as estimated from the historical cohort reconstruction? The productivity of the population is an important factor in determining the allowable impact rate. The productivity (recruits per spawner) of each cohort will be compared with the distribution of productivity in the reconstruction of historical cohorts.

2) Is the preseason forecast accurately predicting the abundance of returning adults? The accuracy and precision of the forecast method will be evaluated each year and the error of the preseason forecast evaluated.

3) Are the fisheries managed consistent with the allowable impact rates? Postseason estimates of impact rates will be compared with the allowable rates for treaty and nontreaty fisheries identified during the preseason planning process,

4) Are the number of spawners consistent with expectations? The estimated number of spawners will be compared with the range as predicted in the risk assessment simulations and forecasts.

5) Is the range of spawn-timing maintained or increased? Spawn-timing information will be collected to assess long-term changes.

The Skagit terminal area co-managers have methods in place to monitor fisheries and observe spawning timing and frequency so to assess natural escapement of steelhead. These methods will be reviewed, evaluated, and where necessary modified, to enhance resulting data quantity and quality.

9.2 Fishery Monitoring

Tribal net fisheries are monitored to assess encounters and retention of steelhead in both directed and non-directed fisheries. Depending on forecasted returns of steelhead, fisheries will be implemented to retain or not to retain steelhead (see Section 8.2 for a discussion of the annual management process). Retained steelhead for Tribal commercial sales and fish taken for ceremonial and subsistence purposes are enumerated through normal catch accounting, i.e. fish tickets, which are corroborated by Tribal enforcement and/or Tribal biologists. The landings documented by fish tickets are compiled in near real time into a database managed by the co-managers. Retained steelhead are assessed for hatchery: wild composition via the presence or absence of adipose clip and scanned for a PIT tags. Scales are collected from wild steelhead sufficient to estimate age composition. The tribes will also assess sex and spawning condition (pre-spawn to kelt) of landed steelhead and tissue samples will be collected for future genetic analyses. In addition, otoliths from retained steelhead will be collected to assess isotopic chemistry, so to inform managers on the contribution of resident *O. mykiss* to steelhead populations (see Data Gaps Section, Zimmerman et al. 2000). Steelhead in non-retention fisheries are enumerated by fishers or by Tribal staff (i.e. Enforcement or Natural Resources), and when available information such as sex, length and markings of non-retained steelhead will be collected.

Over recent years, the number of landed wild steelhead in retention fisheries have decreased and has reduced the co-managers ability to monitor Skagit River steelhead populations and provide for in-season updates. The Upper Skagit Tribe has implemented a non-retention tangle net test fishery to ensure biological information are being collected to adequately characterize sex ratios, age structure, timing, detection of out-of-basin strays (hatchery or wild), and collection of DNA material useful to better assess abundance and to provide information essential to development of this RMP. Tangle net fisheries operate starting in management week 8 (Mid-February) until management week 18 (beginning May), when no other fisheries or monitoring of steelhead currently occurs. During tangle net fisheries, each steelhead encountered is measured for length, assessed for marks and PIT tag (and are PIT tagged if not present), sex, and a tissue sample is collected for future DNA analysis. These fish are sampled and released. Impacts in this fishery will count toward the allowable impact rate (see Table 7) and will be estimated at 18.5% of approximately 100-150 fish annually encountered in the fishery.

In addition to tangle net efforts, hook-and-line sampling is being conducted as part of genetic monitoring in the Skagit Basin to provide information on steelhead recovery efforts. Hook-and-line sampling has supplemented scale collection and will be assessed for length, sex, applied marks, and PIT tags. The very limited impacts in this fishery will continue to be covered under a annual research permits authorized by NOAA Fisheries (see 2017 4(d) permit 20929).

For sport catch WDFW regulations require each license holder to record retained marked hatchery steelhead on Catch Record Cards (CRC) in both pre-terminal and terminal (e.g. Skagit basin) areas. Landed catch of hatchery Skagit Basin steelhead in freshwater and marine catch is estimated for each management year (April thru March) from a subsample of CRCs. Estimates of landed catch are adjusted down to account for non-response bias, because successful anglers are more likely to return their CRCs (Alexandersdottir et al. 1994). The bias adjustment for 2012-13 large freshwater streams (stream with 20 or more fish reported on CCs) is 1.2 (Eric Kraig, pers. Comm., WDFW). There is no bias adjustment for catch estimates for small freshwater streams (stream less than 20 fish reported in CRCs). Co-managers will review and implement reporting requirements on the Skagit River, as needed, to address steelhead encounters, retention, and release mortality appropriate to this Plan. The comanagers will explore trout fishery monitoring strategies with the intent of better understanding the potential impact of those fisheries on resident and pre-migratory *O. mykiss*.

Recreational steelhead fisheries will initially be monitored through inseason creel surveys to ensure that impact limits are not exceeded. Details of the creel survey will be developed after the resource management plan has been approved, but the general approach anticipated by WDFW is described in WDFW Methods Manual-Creel Information from Sport Fisheries (Hahn et al. 1993) and summarized below.

To assess angler effort, catch, total harvest and impacts to other stocks and species WDFW will conduct a ground based creel survey conducted by trained personnel during the steelhead fishery. During the creel interview information collected will include angler effort and catch data. Information collected from angler interviews will include number in party, angler type (i.e., boat or shore), gear types used (conventional gear, fly), whether or not anglers have completed their trip, start and stop time, number of trailers and cars associated with the party, and the number of fish by species encountered and released or kept and any marks or tags. DNA samples and scale samples will be taken from wild steelhead by samplers if they encounter an angler in the process of playing a fish. These samples will be coordinated and taken as part of the long term age monitoring of steelhead in the basin, and as part of the Effectiveness Monitoring Program (EMP). Because the fishery will be actively monitored and creel data entered and calculated as collected, the fishery will be managed on a daily or weekly basis. If encounter rates and thus potential mortality is greater than expected, the fishery impacts can be projected forward and the fishery will be closed with a minimum 48 hour notice to the public prior to the time the impact limit would be achieved.

Data collected by the tribes and WDFW in these fisheries and with escapement estimates provide the basis for catch composition, return age structure and overall run reconstruction that are used for population trend monitoring. The tribes and WDFW also communicate regularly and share data on run size, timing and catch to ensure appropriate management of steelhead.

9.3 Spawning Escapement

Winter steelhead escapement surveys have been conducted on the Skagit River system since the mid-1970s. In general, surveys to enumerate redds are conducted using multiple methods; by foot, by floating stream sections, and by fixed-wing or helicopter aerial surveys, depending stream size and visibility. Surveys are conducted on index reaches on tributary streams on a 10-14 day rotation typically from late February/early March depending on where in the basin the stream is located through June or early July (Table 11). Typically lowland streams with warmer water temperatures see the earlier spawning activity with higher elevation streams with lower water temperatures spawning activity starts and ends later. The surveys are a census of total redds built in each index reach. The estimation of redds in unsurveyed tributaries is made using a regression of redds counted per km^2 of available spawning habitat in surveyed tributaries and km^2 of available spawning habitat in tributaries not surveyed.

On mainstem indexes four to six flights are typically conducted. All visible redds are counted during aerial surveys regardless to ability to identify unique previously constructed redds. Total estimated mainstem steelhead redds are calculated using a modified area under the curve methodology. Some reaches may also be surveyed by jet sled with a cumulative redd count conducted. Mainstem reaches not surveyed are expanded by using redd/mile in surveyed reaches that have similar spawning habitat/gradient. High flow and turbidity typical of the spawning season often preclude following the regular survey schedule, or may confound interpretation of the data.

Table 11. Skagit River spawning escapement survey reaches for wild steelhead.

Management Unit	**Estimate Type**	**Surveyed Index Reaches**
Skagit	System	Mainstem RM 22.0 – 94.0 Alder, Diobsud, Rocky, O'Toole, Cumberland, Day, Sorenson, Hansen and Jones Creeks Mainstem Sauk to RM 41.0, South Fork Sauk to RM 2.0 White, Dan, Murphy, and Falls Creeks

9.4 Annual Performance Assessment

The comanagers currently submit to NOAA Fisheries an annual report ("Puget Sound Steelhead Harvest Management Report") for compliance with ESA reporting requirements. The comanagers anticipate maintaining this report, but supplementing it with the Skagit specific report described below.

The effectiveness of management in achieving the objectives and guidelines stated in this Plan will be evaluated annually by the co-managers and linked to the performance indicators identified in Section 9.1. The Skagit SMU annual report will provide pre-season management agreements describing fisheries consistent with this RMP, the observed landed catch and estimated mortality in tribal and recreational fisheries, the estimated number and age composition of natural spawners, terminal harvest rates, any information on illegal harvests, results from any genetic analysis, and other data collected that would be useful in the evaluation of this plan. Significant deviations from the pre-season agreement will be described and evaluated. To facilitate a cumulative and comprehensive review, each year's report will include all information collected from the first year to the most recent year of fisheries authorized under this Plan by NOAA Fisheries.

The Skagit SMU annual report may be included in the annual postseason "Puget Sound Steelhead Harvest Management Report" currently submitted by WDFW and the Puget Sound Indian tribes. The Annual Skagit SMU Assessment report will be completed by November 30th of each year.

10.0 Enforcement

The WDFW Law Enforcement Program enforces regulations enacted by the Fish and Wildlife Commission for non-treaty commercial and recreational fishing regulations. These officers may assist city, county, other state, and tribal law enforcement agencies, and cooperate with the U.S. Fish and Wildlife Service, NMFS Enforcement branch, and the U.S. Coast Guard in fisheries enforcement.

Certain recreational fisheries may be assigned high priority for enforcement, and more intensively monitored. Officers are assigned to work during open fishing days and restricted periods, and conduct additional checks during closed periods. Officers carry out bank and boat patrols to check and assist anglers. Covert surveillance may also be conducted where reports of violations have been received.

The Program will consist of vehicle, boat, foot, and launch monitoring and;

- assures compliance with established seasons, catch limits, gear restrictions, boat restrictions and compliance with creel surveyors,
- focuses protection on federally listed species,
- provides presence to reduce user group conflict (tribal-non tribal),
- provides boating safety enforcement, and
- provides assistance to tribal enforcement or other law enforcement entities on an as need basis.

Individual tribal governments monitor and enforce their own commercial, subsistence, and ceremonial regulations for its on- and off-reservation fisheries. Tribal enforcement officers can be cross-deputized, and may cooperate with other tribal, state and federal fisheries enforcement agencies. Violations of tribal regulations involve fines or prosecution by tribal justice agencies. Officers are assigned to monitor all tribal U&A fishing areas, fisheries compliance for gear, area, and retention specifics, and other tribally imposed regulations and requirements. Officers patrol these fisheries from shore and boat, where they can also assist tribal fishers. Officers also patrol closed water for fishing out of season or in closed waters. The Skagit tribes have also provided leadership on the removal of derelict and phantom gear in the Skagit. A mandatory system of reporting lost gear (Swinomish, Sauk-Suiattle, Upper Skagit Indian Tribe) has proven effective at limiting incidental mortality. Tribal regulations state that any gear fishing outside of legally-opened fishery periods is fishing illegally. Therefore, fishers are required to report any lost or derelict gear immediately on loss or closure of the fishery. Tribal enforcement attempts to locate and remove any derelict gear in a timely manner.

11.0 Data Gaps

Steelhead harvest management objectives are and will be based on the abundance and productivity of steelhead populations within the Skagit SMU. Quantifying the productivity of populations, and thus trends of these populations, have and will enable management for sustainable steelhead populations within the Skagit SMU. It has been and will be the goal of the tribes and WDFW to identify gaps in knowledge and address these gaps to enable improvement in the understanding of steelhead populations and in turn the management of the Skagit SMU. The Upper Skagit Tribe and WDFW are developing a formal Gap Analysis (McGuire et al, in draft), which will be used in development of the strategy to improve escapement estimates for the Skagit SMU.

Conventionally, a spawner-recruit pair from each brood year may be fit to a recruitment function, from which estimates of maximum sustainable yield and equilibrium escapement, and capacity can be directly calculated. Cohort reconstructions are critical to spawner-recruit pairs and are based on natural spawning escapement, estimates of total fisheries-related mortality and maturation rates (i.e. age composition of adult spawners). Estimates of escapements that are used in cohort reconstructions are often derived from non-probabilistic sampling designs that may not associate to abundances (Isaak et al. 2007). In the case of the Skagit SMU, escapement estimates use a proven (but 40 year old) study design (Phillips et al. 1980). At the time of the design, there was no knowledge that the Skagit SMU is comprised of four distinct populations as identified in later genetic analysis (Meyers et al. 2015). The tribes and WDFW have identified that the study design, including: sampling methodology and analytical methods require updating and are seeking support to assess and validate these methods. In addition, the incidence of repeat-spawning must be factored in and the tribes are working on a long-term sampling plan that includes a network of Passive Integrated Transponder tags to potentially assess, among other things, repeat-spawning.

Research has identified that in some systems resident and migratory *O. mykiss* represent the same population (Zimmerman et al. 2000). Resident *O. mykiss* has propensity for anadromy even being landlocked for decades (Hecht et al. 2013). Contributions of resident *O. mykiss* to the migratory form have also been identified as important to the recovery of steelhead (Holecek and Scarnecchia 2013). Resident and migratory *O. mykiss* are components of the partial life history strategy that is identified as critical to the persistence of *O. mykiss* across its range (Kendall et al. 2014). It is thus important, as we consider populations and productivity, to understand the contribution of resident *O. mykiss* to migratory form of *O. mykiss* and an entire population. The tribes and WDFW will collect otoliths of adult returning steelhead to begin to assess the contribution of resident *O. mykiss* to the migratory form.

The tribes and WDFW are actively assessing other approaches to quantify productivity and population trends, including the use of habitat-based modeling of production potential and quantifying smolt production in management, e.g. improving forecasting capability, quantifying recruitment and developing escapement goals. In addition, the co-managers are discussing methods for assessing non-landed mortality in the Skagit Terminal Area

Further, the tribes and WDFW see the need for future work to develop a robust and timely catch and effort accounting system that improves our understanding of Skagit SMU fisheries and the impacts of pre-terminal fisheries impacts on Skagit steelhead.

12.0 Outreach and Education

WDFW consults recreational angler organizations, such as their Steelhead and Cutthroat Policy Advisory Group, and other interested citizens through Fish and Wildlife Commission hearings. In these forums, WDFW considers proposals for changes in recreational angling regulations, and discusses their rationale for annual regulations decisions. This process builds credibility for conservative fishing regulations and is intended to demonstrate the conservative effect of steelhead fishing regulations, and improve compliance. Prior to any recreational fishery opening for steelhead fishing in the Skagit River, the WDFW anticipates hosting one or more public meetings, providing a news release, webpage, and other outreach measures to ensure that information on the fishery rules are readily accessible to recreational fishers.

Tribal fisheries management agencies develop fisheries regimes under the oversight of their tribal Councils or fisheries committees. For many tribes harvest opportunity is currently limited to harvest of a relatively small number of steelhead that are used for subsistence or ceremonial purposes. Tribal fishers or their representatives participate in tribal decision-making, and are briefed by tribal management staff on the conservation measures, such as those incorporated in this Plan. Interactions among tribal fishers and management staff ensure that tribal fishing regulations are practicable and enforceable.

13.0 Climate Change

Climate change is projected to have the following effects on the Pacific Northwest environment (from Ford 2011 as summarized in NOAA 2016):

- Increased air temperature (high certainty)
- Increased winter precipitation (low certainty)
- Decreased summer precipitation (low certainty)
- Reduced winter and spring snowpack (high certainty)
- Reduced summer stream flow (high certainty)
- Earlier spring peak flow (high certainty)
- Increased flood frequency and intensity (moderate certainty)
- Higher summer stream temperatures (moderate certainty)
- Higher sea level (high certainty)
- Higher ocean temperatures (high certainty)
- Intensified upwelling (moderate certainty)
- Delayed spring transition (moderate certainty)
- Increased ocean acidity (high certainty)

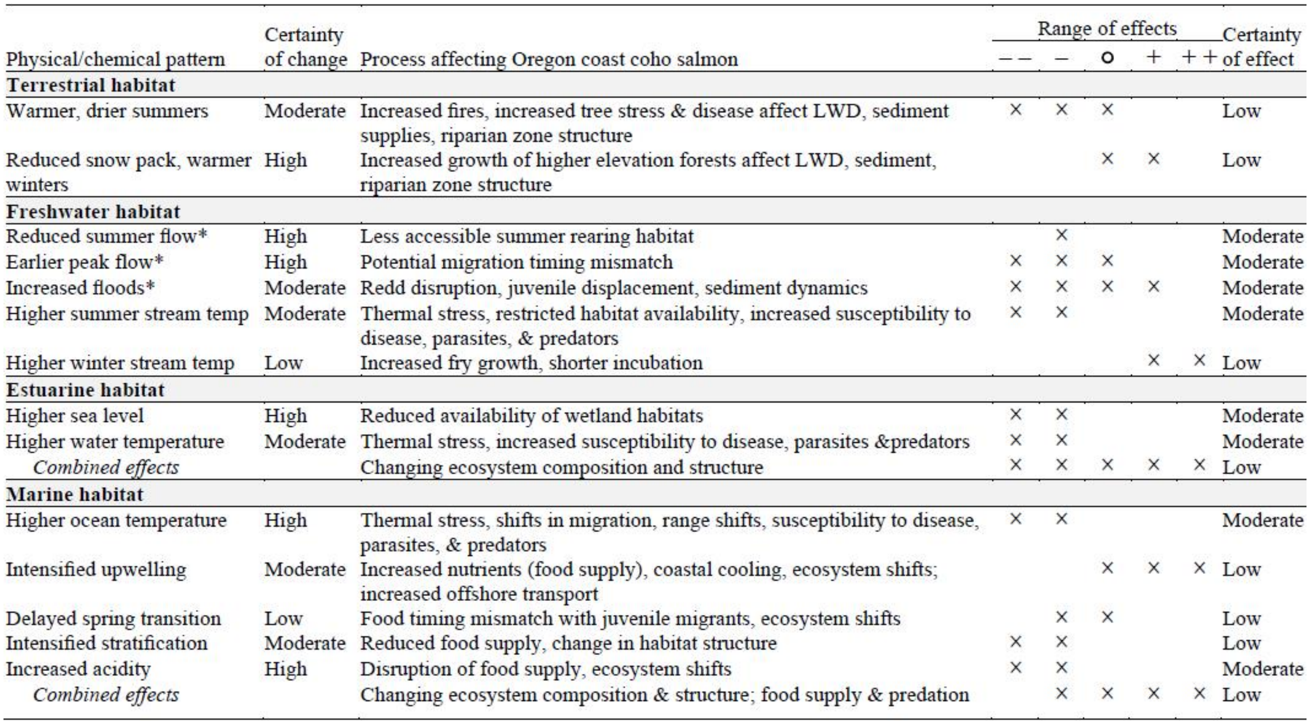
Lee et al. (2016) assessed the combined effects of climate change and dam operations on the hydrology and sediment loading of the Skagit River. The analysis projected: 1) a shift from dual peak flows in winter and spring to a single dominant peak in December; 2) a 23% increase in the 100-year flood by the 2040s; 3) a 23% reduction in the lowest consecutive 7-day flow with a 10-year return interval; and 4) a 376% increase in sediment load from December-February by the 2080s.

The effects of these environmental changes upon Skagit River steelhead are difficult to predict due to the complex interactions of biotic and abiotic factors, the plasticity of the steelhead life history, and uncertainties in our understanding of the rate at which adaptation will occur.

Wainwright and Weitkamp (2013) provided a summary table for Oregon coastal coho that illustrates the complexity of environmentally induced changes that salmon and steelhead will face during the next 60 years (Table 12).

This RMP addresses the uncertainty in future conditions by: 1) protecting the diversity of steelhead in the Skagit River basin; 2) reducing harvest rates to 4% when the forecasted abundance is less than 4000 fish; 3) annually monitoring the performance of the plan through the indicators identified in Section 9.4; and 4) limiting the initial duration of this plan to 5 years.

Table 12. Projected climate changes affecting Oregon coho (from Weitkamp and Wainwright (2013)).



Physical/chemical pattern	Certainty of change	Process affecting Oregon coast coho salmon	Range of effects					Certainty of effect
			– –	–	o	+	+ +	
Terrestrial habitat								
Warmer, drier summers	Moderate	Increased fires, increased tree stress & disease affect LWD, sediment supplies, riparian zone structure	×	×	×			Low
Reduced snow pack, warmer winters	High	Increased growth of higher elevation forests affect LWD, sediment, riparian zone structure			×	×		Low
Freshwater habitat								
Reduced summer flow*	High	Less accessible summer rearing habitat		×				Moderate
Earlier peak flow*	High	Potential migration timing mismatch	×	×	×			Moderate
Increased floods*	Moderate	Redd disruption, juvenile displacement, sediment dynamics	×	×	×	×		Moderate
Higher summer stream temp	Moderate	Thermal stress, restricted habitat availability, increased susceptibility to disease, parasites, & predators	×	×				Moderate
Higher winter stream temp	Low	Increased fry growth, shorter incubation				×	×	Low
Estuarine habitat								
Higher sea level	High	Reduced availability of wetland habitats	×	×				Moderate
Higher water temperature	Moderate	Thermal stress, increased susceptibility to disease, parasites &predators	×	×				Moderate
Combined effects		Changing ecosystem composition and structure	×	×	×	×	×	Low
Marine habitat								
Higher ocean temperature	High	Thermal stress, shifts in migration, range shifts, susceptibility to disease, parasites, & predators	×	×				Moderate
Intensified upwelling	Moderate	Increased nutrients (food supply), coastal cooling, ecosystem shifts; increased offshore transport			×	×	×	Low
Delayed spring transition	Low	Food timing mismatch with juvenile migrants, ecosystem shifts		×	×			Low
Intensified stratification	Moderate	Reduced food supply, change in habitat structure	×	×				Low
Increased acidity	High	Disruption of food supply, ecosystem shifts	×	×				Moderate
Combined effects		Changing ecosystem composition & structure; food supply & predation		×	×	×	×	Low

14.0 References

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Appendix A. Skagit River Steelhead DPS Runsize Reconstruction

Appendix Table A-1. Spawner recruit data set used in risk analysis.

BroodYear	Spawners	Recruits	ln(R/S)
1978	5,757	11,311	0.68
1979	2,982	8,485	1.05
1980	5,288	10,185	0.66
1981	4,308	12,114	1.03
1982	9,609	11,819	0.21
1983	7,732	11,500	0.40
1984	8,963	18,716	0.74
1985	8,603	11,486	0.29
1986	11,098	11,261	0.01
1987	8,305	6,845	-0.19
1988	13,194	7,570	-0.56
1989	11,854	7,410	-0.47
1994	6,412	7,466	0.15
1995	7,656	6,124	-0.22
1998	7,448	6,476	-0.14
1999	7,870	7,987	0.01
2000	3,780	6,743	0.58
2001	4,584	6,074	0.28
2002	5,394	5,959	0.10
2003	6,818	2,655	-0.94
2004	7,332	3,953	-0.62
2005	6,382	3,225	-0.68
2006	6,757	6,635	-0.02
2007	4,242	8,034	0.64

Appendix Table A-2. Skagit Management Unit (includes Baker, Cascade, Sauk, Skagit, and Suiattle rivers).

Return Year (N)	Sport Harvest[a]				Tribal & Test Fishery Harvest			Escapement		Baker River Trap		Estimated Terminal Runsize[f]		WSH Smolt ~May Release Return N+2
	Hatchery (1 Nov-30 Apr)[a]	Wild[b] One Stock	Wild[b] One Stock C&R mortality[e]	H&W Total	Hatchery (1 Nov-30 Apr)	Wild[b]	H&W Total	Hatchery	Wild[b]	Hatchery	Wild[b]	Hatchery	Wild	
1984/85	4,793	1,435[c]	NA	6,228	4,720	379	5,099	3,702	8,603	NA	35	13,215	10,452	336,417
1985/86	2,525	1,916[c]	NA	4,441	4,518	547	5,065	1,339	11,098	NA	35	8,382	13,596	298,357
1986/87	1,690	2,033	NA	3,723	3,482	683	4,165	964	8,305	47	29	6,183	11,050	136,096
1987/88	2,206	2,159	NA	4,365	3,987	872	4,859	1,195	13,194	NA	NA	7,388	16,225	264,376
1988/89	1,230	2,031	NA	3,261	2,903	819	3,721	779	11,854	NA	NA	4,912	14,704	286,833
1989/90	1,283	1,474	NA	2,757	3,076	380	3,456	840	10,017	626	NA	5,825	11,871	226,771
1990/91	141	767	NA	908	1,591	574	2,165	339	5,818	54	NA	2,125	7,159	212,814
1991/92	976	111	NA	1,087	2,246	126	2,372	611	7,514	NA	NA	3,833	7,751	157,842
1992/93	1,721	1,340	NA	3,061	698	82	781	460	6,900	52	26	2,931	8,348	409,017
1993/94	600	1,084	NA	1,684	173	76	249	143	6,412	212	38	1,128	7,610	447,336
1994/95	987	588	NA	1,575	917	317	1,234	496	7,656	81	5	2,481	8,566	415,706
1995/96	1,025	484	NA	1,509	980	51	1,031	392	NA	34	11	2,431	NA	367,747
1996/97	1,839	1,632	NA	3,471	99	68	166	347	NA	117	35	2,402	NA	349,510
1997/98	347	71	NA	418	32	53	85	449	7,448	NA	NA	828	7,572	592,471
1998/99	561	1,044	NA	1,605	186	105	292	262	7,870	377	74	1,386	9,093	446,734
1999/00	497	376	NA	873	177	51	228	96	3,780	58	30	828	4,237	463,027
2000/01	1,572	62	13	1,647	69	52	121	290	4,584	75	7	2,006	4,718	463,460
2001/02	2,860	132	16	3,008	186	111	297	427	5,394	283	37	3,756	5,690	473,712
2002/03	467	0	20	487	25	40	65	113	6,818	18	0	623	6,878	513,330
2003/04	936	0	22	958	126	209	335	392	7,332	113	0	1,567	7,563	529,821
2004/05	740	0	20	760	483	206	689	358	6,382	75	0	1,656	6,608	466,100
2005/06	782	0	23	805	95	287	382	283	6,757	237	0	1,397	7,067	517,000
2006/07	1,233	0	17	1,250	868	457	1,325	307	4,113	104	0	2,512	4,587	511,560
2007/08	1,373	0	17	1,390	347	300	647	159	4,887	86	0	1,965	5,204	235,010
2008/09	352	0	10	362	194	125	319	122	2,502	28	0	696	2,637	174,000
2009/10	280	0	22	302	295	123	418	293	3,981	14	0	882	4,126	231,500

2010/11	675	0	27	702	188	182	370	266	5,462	15	0	1,144	5,671	240,000
2011/12	1,156	0	30	1,186	189	161	349	264	6,185	54	0	1,663	6,376	226,050
2012/13	466	0	38	504	165	171	336	197	8,727	6	0	834	8,936	235,000
2013/14	260	0[d]	41	301[d]	43	215	259	74	9,084	15	0	392	9,340	5,100

[a] Winter Steelhead Time Period Creel Survey Estimates 1984/85, 1985/86, 1986/87; Catch Record Card data 1987/88 – 2013/14; all numbers final

[b] Wild Steelhead *One Stock*, July 1 – June 30

[c] Summer-run estimates not included; no creel or marked fish

[d] Preliminary CRC estimate, September 2015.

[e] Catch & Release incidental wild steelhead mortality during the steelhead and salmon recreational seasons.

Appendix B. Ricker Spawner-Recruit Analysis

This appendix provides supplementary information on the spawner-recruit analysis that is the foundation for the risk analysis of the proposed management regime.

Random Sets of Ricker Curves

To show the range of possible spawner/recruit curves, random sets of Ricker curves were created from pairs of parameters (*a*, *b*) generated from the asymptotic bivariate normal distribution of the intercept and slope regression parameter estimates respectively, preserving the covariance structure between the parameter estimates. Using the following parameterization of the Ricker spawner-recruit equation:

$$R = \alpha Sexp^{-\frac{S}{\beta}} => \qquad \text{Equation 1}$$

the natural log linearized form used in the simple linear regression, $Y = a + b\,X + \varepsilon$, is

$$ln(R/S) = ln(\alpha) - \frac{S}{\beta} + \varepsilon, \varepsilon \sim N(0, \sigma^2) \qquad \text{Equation 2}$$

with parameters *a* and *b*, where *a* = ln(α) and $\beta = -\frac{1}{b}$.

Step 1: Generate random values for *a* and *b* using the asymptotic normal distribution of the estimated parameters and the associated covariance structure.

A. Generate a random value for a ~ Normal$\left(\hat{a}, \hat{\sigma}_{\hat{a}}^2\right)$, where $\hat{a}$ is the intercept estimate and $\hat{\sigma}_a^2$ is the estimated variance of $\hat{a}$. Calculate $\alpha = e^a$.

B. Generate a random value for *b* from the conditional distribution given *a*

$$b|a \sim Normal\left(\hat{b} + \hat{\rho}\frac{\hat{\sigma}_{\hat{b}}}{\hat{\sigma}_{\hat{a}}}(a - \hat{a}), \hat{\sigma}_{\hat{b}}^2(1 - \hat{\rho}^2)\right)$$

where $\hat{\rho}$ is the estimated regression correlation between parameter estimates $\hat{a}$ and $\hat{b}$

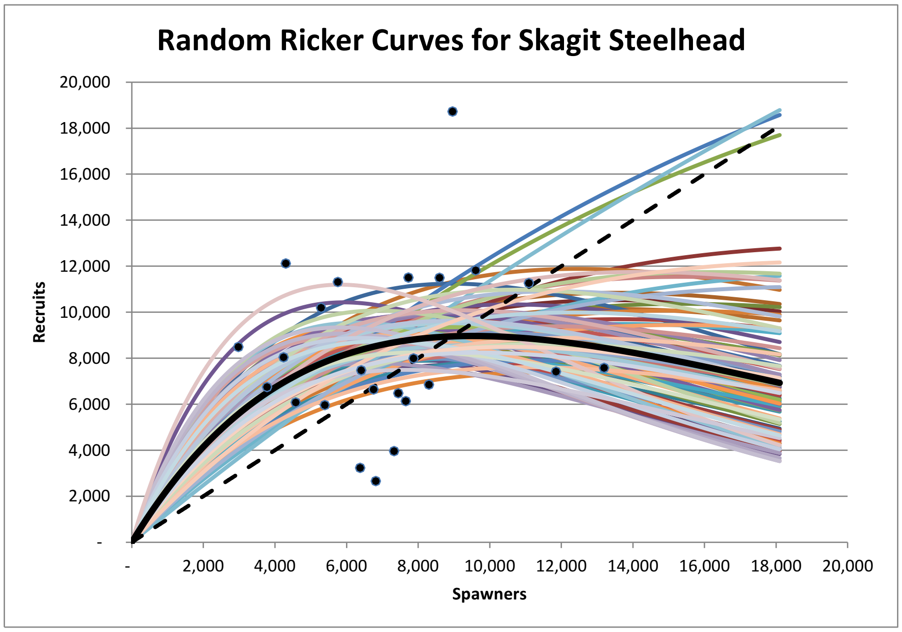
$$\hat{\rho} = \frac{Cov(\hat{a},\hat{b})}{\sqrt{\hat{\sigma}_{\hat{a}}^2 * \hat{\sigma}_{\hat{b}}^2}}.$$

Calculate $\beta = -\frac{1}{b}$.

Step 2: Calculate $\beta_{EIV} = \beta\left(1 + \frac{ME(S)}{V(S)}\right) = -\frac{1}{b}\left(1 + \frac{ME(S)}{V(S)}\right)$.

Step 3: For a range of spawners, create a spawner/recruit curve with the generated parameters (α, β).

Step 4: Repeat Steps 1-3.



Appendix Figure B-1. Random Ricker curves generated from estimated joint distribution of the regression parameter estimates. The dark line is the actual estimated Ricker curve and the dots are the actual data points.

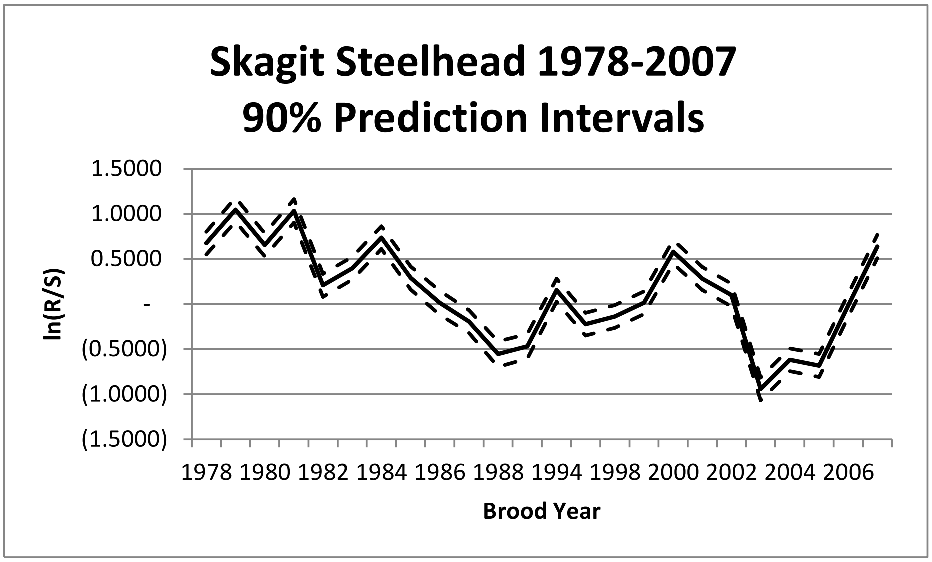
Prediction Intervals for the Estimated ln(R/S) from 1978-2007

Uncertainty in the measure of productivity (ln(R/S)) for each brood year was demonstrated using prediction intervals for calculated estimates. Using the linearized Ricker regression relationship along with 95% prediction intervals:

$$\hat{V}\left(\hat{Y}|x_i\right) = \hat{\sigma}^2\left(\frac{1}{n} + \frac{(x_i-\bar{x})^2}{(n-1)\sum_{i=1}^{n}(x_i-\bar{x})^2}\right) => \qquad \text{Equation 3}$$

$$\hat{V}\left(ln(R/S_i)|S_i\right) = \hat{\sigma}^2\left(\frac{1}{n} + \frac{(S_i-\bar{S})^2}{(n-1)\sum_{i=1}^{n}(S_i-\bar{S})^2}\right) \qquad \text{Equation 4}$$

Prediction intervals were calculated using the t-statistic with n-1 degrees of freedom (due to the asymptotic normal distribution of the parameter estimates).



Appendix Figure B-3. Prediction intervals for productivity measured as the natural log of recruitments over spawners.

Prediction Intervals for the Estimated Recruits from 1978-2007

To show the uncertainty in the parameter estimates, for each year recruits were predicted from the linearized Ricker regression relationship along with 95% prediction intervals. The tighter the prediction intervals, the greater the certainty with the estimates. In standard linear regression prediction intervals for $\hat{Y}|X = \hat{a} + \hat{b}\,X$, are based on the variance of the predictor $\hat{Y}$. The estimated variance is:

$$\hat{V}\left(\hat{Y}|x_i\right) = \hat{\sigma}^2\left(\frac{1}{n} + \frac{(x_i-\bar{x})^2}{(n-1)\sum_{i=1}^{n}(x_i-\bar{x})^2}\right) \Rightarrow$$

$$\hat{V}\left(ln(R/S_i)|S_i\right) = \hat{\sigma}^2\left(\frac{1}{n} + \frac{(S_i-\bar{S})^2}{(n-1)\sum_{i=1}^{n}(S_i-\bar{S})^2}\right) \ .$$

Under the model,

$$\hat{R}|\hat{\alpha},\hat{\beta},S = \alpha S e^{-\frac{S}{\beta}} e^{\varepsilon}, \epsilon \sim N(0,\sigma^2). \qquad \text{Equation 5}$$

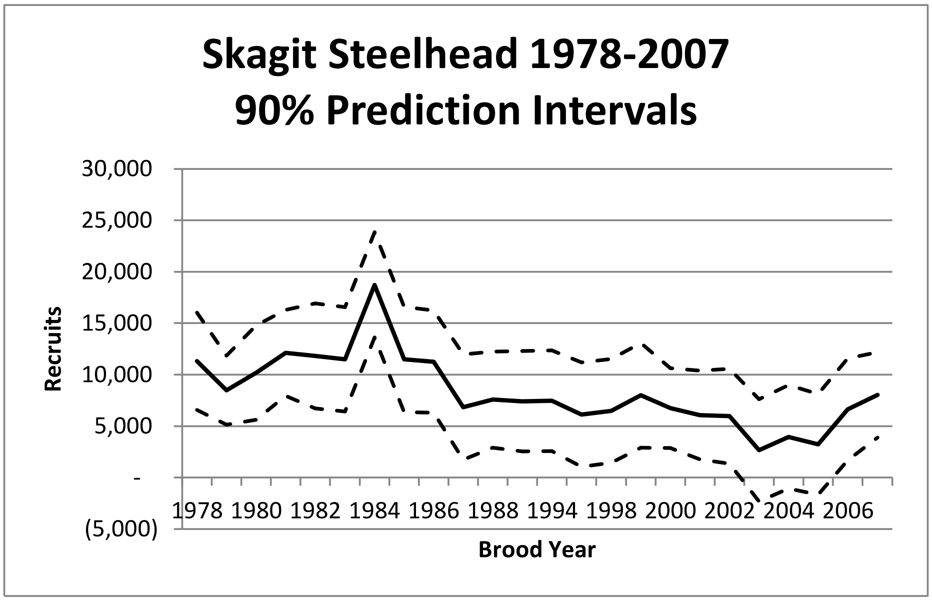
So that

$$\begin{aligned} V\left(\hat{R}|\hat{\alpha},\hat{\beta},S\right) &= V\left(\alpha S e^{-\frac{S}{\beta}} e^{\varepsilon}|\hat{\alpha},\hat{\beta},S\right) \\ &= \left(\alpha S e^{-\frac{S}{\beta}}\right)^2 V\left(e^{\varepsilon}|\hat{\alpha},\hat{\beta},S\right) \\ &= \left(\alpha S e^{-\frac{S}{\beta}}\right)^2 \left(e^{\epsilon}|_{E(\epsilon)}\right)^2 V(\epsilon) \\ &= \alpha^2 S^2 e^{-2S/\beta} \sigma^2 \end{aligned}$$

and

$$\hat{V}\left(\hat{R}|\hat{\alpha},\hat{\beta},S\right) = \hat{\alpha}^2 S^2 e^{-2S/\hat{\beta}} \hat{\sigma}^2 \qquad \text{Equation 6}$$

With these two equations, the prediction intervals for past recruitment is calculated using the t-statistic with n-1 degrees of freedom (due to the asymptotic normal distribution of the parameter estimates).



Appendix Figure B-4. Prediction intervals for recruitments created from linearized Ricker regression.

Probability of Exceeding 95% of R_{MSY}

The probability of meeting a percentage of R_{MSY} escapement can be calculated for specific escapement goals (S_{goal}) and a harvest rates. With

$$S = R(1 - HR)$$

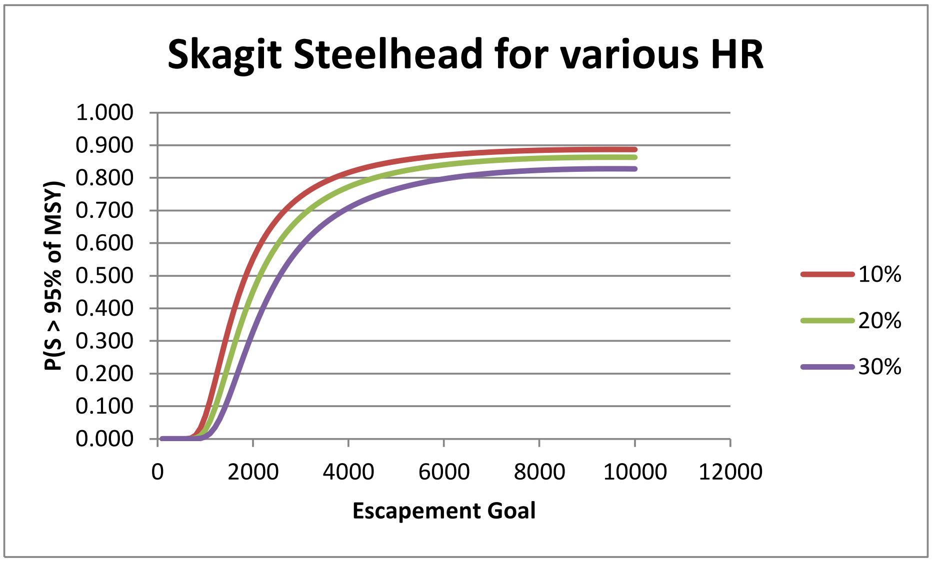
we have

$$P(S|S_{goal}, HR > 0.95R_{MSY})$$

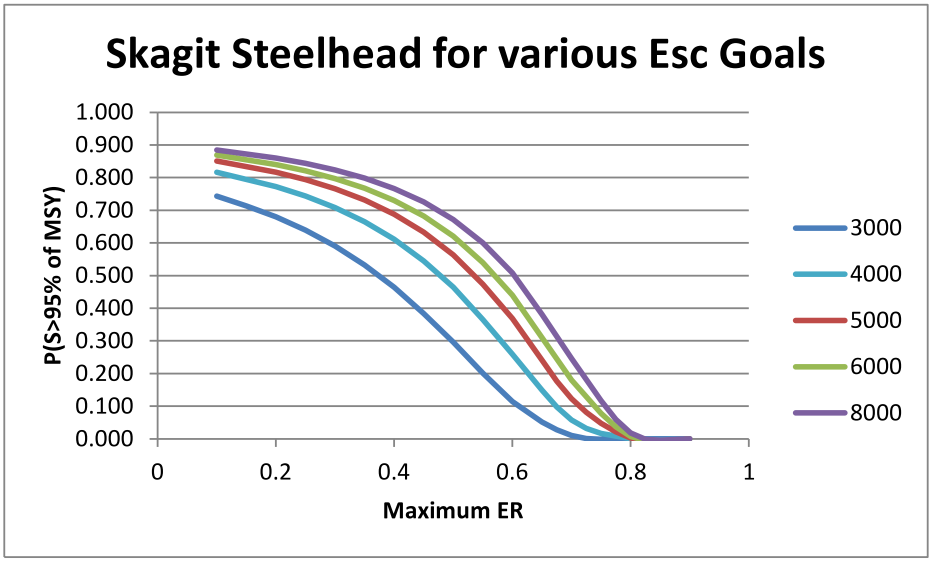
$$= P(R(1 - HR)|S_{goal}, HR > 0.95R_{MSY})$$

$$= P\left(R|S_{goal}, HR > \frac{0.95R_{MSY}}{(1-HR)}\right).$$

The desired probabilities can be derived from the asymptotic normal distribution of the resulting recruitment using Equations 5 and 6.



Appendix Figure B-5. The probability of spawners meeting at least 95% of R_{MSY} given random recruitment from a starting point of spawners equal to various escapement goals and harvest rates.



Appendix Figure B-6. The probability of spawners meeting at least 95% of R_{MSY} given random recruitment from a starting point of spawners equal to various escapement goals and harvest rates.

Appendix C. Beverton-Holt Spawner-Recruit Analysis

The Beverton-Holt analysis was used to corroborate the Ricker spawn-recruit analysis and to assess if the proposed management regime is robust to different density dependent relationships. The same data were used in the both spawn-recruit models, however, methods for deriving estimates of intrinsic productivity and carrying capacity differed.

Beverton-Holt Curves

We employed a Beverton-Holt spawn-recruit model without depensation using the following parameterization of the Beverton-Holt spawner-recruit equation:

$$R = \frac{S}{a + b * S}$$

Equation 1

Under this parameterization *a* is related to the density-independence portion of the equation often associated with intrinsic potential and *b* is related to the density-dependent portion of the equation associated with carrying capacity.

The model is assumed to have a multiplicative lognormal error structure with a lag of one year. A natural log was then applied to the equation:

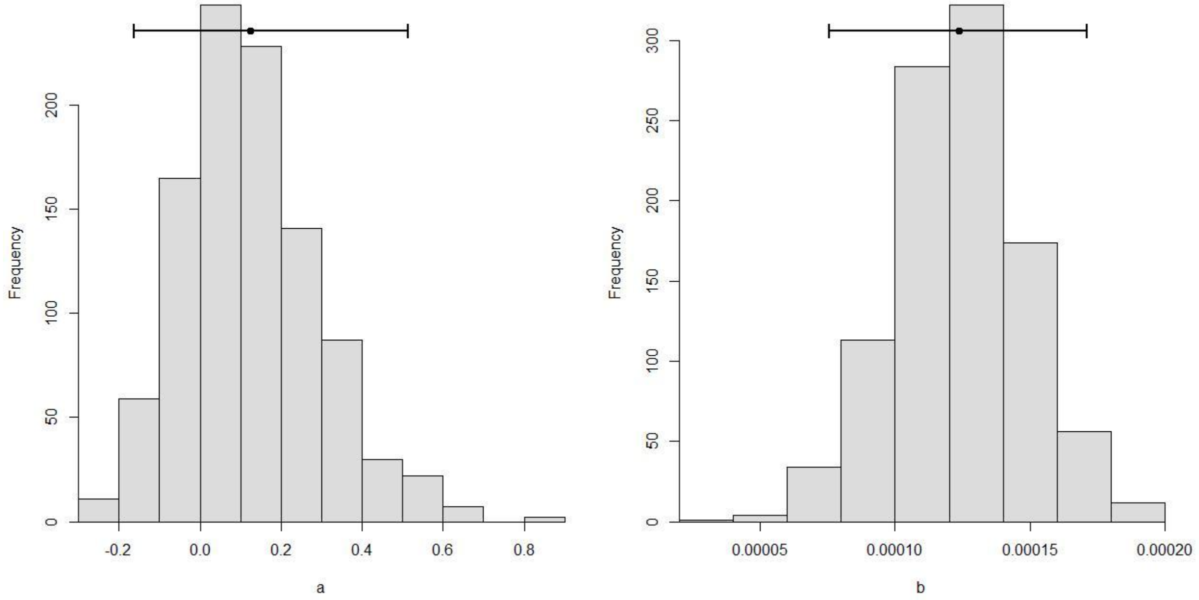
$$\ln(R|S) = \ln\left(\frac{S}{a + b * S}\right) + \varepsilon$$

Equation 2

Parameter estimates (*a* and *b*) were computed using maximum likelihood estimation using the nonleast squares and conditioned on the stock-recruitment model (see, Brodziak et al. 2001). The non-least squares (nls) function was implemented in R.

Bootstrapped Parameter Estimates

To show the range of possible uncertainty Beverton-Holt stock-recruitment parameters, the Beverton-Holt stock-recruitment parameters (*a*, *b*) were derived through nonparametric boot strapping (n=1,000) (Huet et al. 2003). Both parameters have normally distributed variances suggesting little bias in parameters estimates (Fig. C-1). The Beverton-Holt parameter *a* is variable likely associated to the few observations at low abundance.



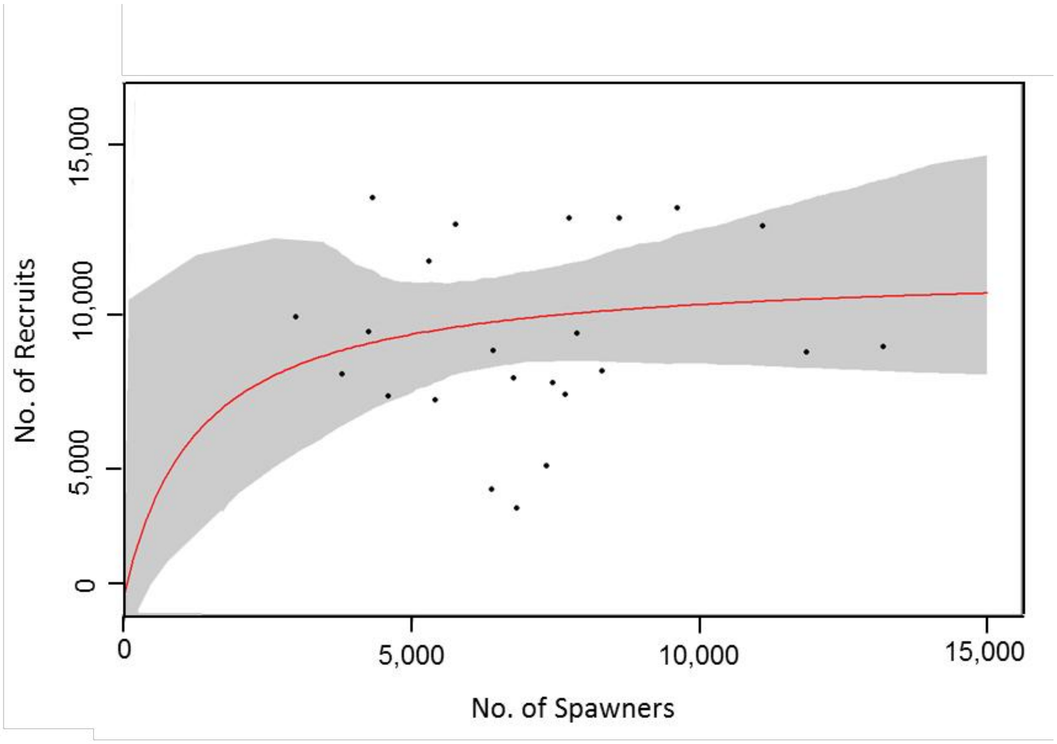
Appendix Figure C-1. Histogram of the bootstrap results (n=1000) for the Beverton-Holt stock-recruit model for the Skagit Steelhead data. Black horizontal line represents the 95% bootstrap confidence intervals.

<u>Deriving Intrinsic Productivity and Carrying Capacity</u>

We then generated Beverton-Holt curves from the bootstrapped Beverton-Holt parameters (*a* and *b*) for the range of spawners. There were a few extreme outliers among with the bootstrapped samples, so we restricted *a* and *b* parameters within the 95% confidence interval as shown (Fig. C-1). We also removed any negative *a* values within the 95% confidence interval. The restriction resulted in 642 Beverton-Holt curves (Fig. C-2). We did this to restrict some of the variation around the data, especially at lower spawner abundances that have not been observed within the Skagit SMU.

From these spawn-recruit curves intrinsic productivity and carrying capacity were estimated for comparison with Ricker estimates. Given this Beverton-Holt parameterization 1/b is directly estimable for carrying capacity β. Intrinsic productivity (α) was estimated by constraining the number of spawners to one (1) and estimating the maximum recruits per spawner (Table C-1). Variances for α and β were then estimated from the variance from the projected curves above, which were used to produce standard deviation and 95% confidence intervals around the estimates. Carrying capacity was adjusted for sample error (as also done in the Ricker spawn-recruit section), by adjusting:

$$\beta_{EIV} = \frac{1}{b}(1 + \frac{ME(S)}{V(S)})$$



Appendix Figure C-2. Median Beverton-Holt spawn-recruit curve (red line) and range of all bootstrapped Beverton-Holt curves (greyed area) (n=642). Back transformed Median *a* = 0.128 (95% CI 0.001 to 0.57) and Median *b* = 1.08e-4 (95% CI 6.82e-5 to 1.5e-4).

Appendix Table C-1. Stock recruitment parameter estimates from MLE Beverton-Holt spawn-recruit.

Parameter	Estimate	St. Dev.	95% CI
α	7.23	14.12	1.23-22.32
β	10,321	3,574	6,518-14,378
σ^2	0.27	0.23	0.17-0.69
Correlation(*a*,*b*)	0.99		

Fishery Management Regime Assessment

Estimates of *a* and *b* were then used to estimate the probability of attaining critical and viable thresholds (see Table 8 of this report). This was done in the same manner as described in the Ricker model (Appendix B). Both models were projected out 25 generations.

Appendix D. Estimation of Measurement Error Using Population Viability Analysis (PVA) for Winter Steelhead stocks

We used the analytical techniques based on a population viability analysis (PVA) presented in Dennis et al (1991) and Staples et al. (2004) for estimating measurement error on escapement estimates.

The simplest expression for the rate of population change is the deterministic equation written as follows,

$$N_{t+1} = N_t e^{\mu} \qquad \textbf{Eq. 2}$$

where,

N_t = the population at time *t* and;

μ = the instantaneous rate of population change.

For the purposes of this analysis time will be measured in years, and we will assume that estimates of escapement and harvest are obtained at the same time in the annual cycle. The growth rate parameter, μ, is greater than 0 for increasing populations, less than 0 ($\mu < 0$) for decreasing populations and for stationary populations $\mu = 0$. In Eq. 2 the number of years between the initial and ending population size is one year. Under the assumption of a constant rate of change μ, the population size at time *t* may be expressed in terms of the population size at time 0, N_0 and μ as follows,

$$N_t = N_0 e^{\mu t}, \qquad \textbf{Eq. 3.}$$

or between *t* and $t + \Delta t$ as $N_{t+\Delta t} = N_t e^{\mu \Delta t}$. The important concept is that the parameter μ is constant.

Staples et al (2004) refined the Dennis et al. (1991) method using a restricted maximum likelihood (REML) to separate natural and measurement error.

Variance estimates of μ obtained from a series of abundance indices or population estimates will include measurement errors not associated with natural demographic and environmental processes. Separating out measurement (sampling) and process (natural or non-measurement) error is often impossible in the absence of information on sampling error.

Incorporating process error into Eq. 3, is written in terms of *t* and $t+1$ as follows,

$$N_{t+1} = N_t e^{\mu + X_t} \qquad \textbf{Eq. 4}$$

where X_t = process error, and $X_t \sim N\left(0, \tau^2\right)$. Estimates of population size include measurement error, Y_t, and is expressed in terms of the true population size as,

$$\hat{N}_{t+1} = N_{t+1} e^{Y_{t+1}} \qquad \textbf{Eq. 5}$$

where N_{t+1} = the true population size at time t+1;

$\hat{N}_{t+1}$ = estimated population size at time t+1;

Y_t = measurement error for population estimates at time t;

$Y_t \sim N\left(0, \sigma^2\right)$.

Incorporating Eq. 4 into Eq 5, the estimate of abundance at time $t+1$ written as follows,

$$\hat{N}_{t+1} = N_t e^{\mu + X_t + Y_{t+1}} \qquad \textbf{Eq. 6}$$

Noting that abundance estimates at time t is also measured with error and is expressed as, $\hat{N}_t = Ne^{Y_t}$, and further dividing both sides of Eq. 6 by $\hat{N}_t$, abundance at time $t+1$ is as follows,

$$\frac{\hat{N}_{t+1}}{\hat{N}_t} = \frac{N_t e^{X_t + Y_{t+1}}}{N_t e^{Y_t}} \quad \text{or,}$$

$$\frac{\hat{N}_{t+1}}{\hat{N}_t} = e^{\mu + \left(X_t + Y_{t+1} - Y_t\right)} \quad . \qquad \textbf{Eq. 7}$$

Taking the natural logarithm of both sides of Eq. 7,

$$\ln\left(\frac{\hat{N}_{t+1}}{\hat{N}_t}\right) = \mu + \left(X_t + Y_{t+1} - Y_t\right).$$

Based on the use of the Central Limit Theorem, Tuljaparkur and Orzack (1980) and Heyde and Cohen (1985) showed that the distribution of $\ln\left(\frac{N_{t+1}}{N_t}\right)$ has an asymptotic normal distribution. Subsequently the use of normal errors is supported for the log ratio of abundance estimates. Using the distributions of process and measurement error, the expected value, or mean, of $\ln\left(\frac{N_{t+1}}{N_t}\right)$ is with variance

$$Var\left(\ln\left(\frac{\hat{N}_{t+1}}{\hat{N}_t}\right)\right)=Var\left(\mu+X_t+Y_{t+1}-Y_t\right),$$

or, noting that because μ is a constant, $Var\left(\mu\right)=0$,

$$Var\left(\ln\left(\frac{\hat{N}_{t+1}}{\hat{N}_t}\right)\right)=\tau^2+2\sigma^2$$

Eq. 8

Hence, the log-ratio of abundance estimates, $\ln\left(\frac{\hat{N}_{t+1}}{\hat{N}_t}\right)$ is normally distributed with mean μ and variance $\tau^2+2\sigma^2$, i.e., $N\left(\mu,\tau^2+2\sigma^2\right)$.

Extending the derivation to include several years, from time *t* to $t+\Delta t$ where Δt is the number of intervening years, gives as similar derivation for the variance (Eq. 8) as follows,

$$\frac{\hat{N}_{t+\Delta t}}{\hat{N}_t}=\frac{N_t e^{\left(\sum_{i=t}^{t+\Delta t-1}\mu+X_i\right)+Y_{t+\Delta t}}}{N_t e^{Y_t}},$$

and taking the natural logarithm of both sides for constant μ across all years,

$$\ln\left(\frac{\hat{N}_{t+\Delta t}}{\hat{N}_t}\right)=\mu\cdot\Delta t+\left(\sum_{i=t}^{t+\Delta t-1}X_i\right)+Y_{t+\Delta t}-Y_t.$$

Noting from above that the mean of X_t and Y_t are both zero, the expected value of the log ratio is as follows,

$$E\left(\ln\left(\frac{\hat{N}_{t+\Delta t}}{\hat{N}_t}\right)\right)=\mu\cdot\Delta t_t$$

with associated variance

$$Var\left(\ln\left(\frac{\hat{N}_{t+\Delta t}}{\hat{N}_t}\right)\right)=Var\left(\sum_{i=t}^{t+\Delta t-1}X_i+Y_{t+\Delta t}-Y_t\right)=\Delta t\tau^2+2\sigma^2.$$

Hence the log-ratios for any $\Delta t>1$ are distributed normal with mean $\mu\Delta t$ and variance $\Delta t\tau^2+2\sigma^2$, i.e., $\ln\left(\frac{\hat{N}_{t+\Delta t}}{\hat{N}_t}\right)\sim N\left(\Delta t\mu,\ \Delta t\tau^2+2\sigma^2\right)$.

The joint log-likelihood of successive ratios is written as follows,

$$\ln\left(L\right) = -\frac{n\ln\left(2\pi\right)}{2} - \ln\left(\left|\mathbf{U}'\mathbf{\Sigma}\mathbf{U}\right|\right) - \frac{1}{2}\left(\mathbf{U}'\mathbf{W}\right)'\left(\mathbf{U}'\mathbf{\Sigma}\mathbf{U}\right)^{-1}\left(\mathbf{U}'\mathbf{W}\right) \qquad \textbf{Eq. 9}$$

where, n = the number of log-ratios, or observations, for a particular stock;

$\mathbf{W}' = \left(\ln\left(\frac{\hat{N}_1}{\hat{N}_0}\right), \ln\left(\frac{\hat{N}_2}{\hat{N}_1}\right), \ldots, \ln\left(\frac{\hat{N}_T}{\hat{N}_{T-1}}\right)\right)$, the vector of log-ratios of length n;

$\mathbf{U}$ = a $\left(n\right)\times\left(n-1\right)$ matrix with $-\Delta t_n$ on the main diagonal and Δt_1 on the sub-diagonal, i.e.,

$$\mathbf{U} = \begin{matrix} -\Delta t_1 & 0 & & \cdots & \cdots & & 0 \\ \Delta t_2 & -\Delta t_2 & 0 & & & & \\ 0 & \Delta t_3 & -\Delta t_3 & 0 & & & \vdots \\ & 0 & \Delta t_4 & -\Delta t_4 & \ddots & & \vdots \\ \vdots & & \ddots & \ddots & \ddots & \ddots & \\ \vdots & \vdots & & \ddots & \ddots & \ddots & 0 \\ & & & & \ddots & \Delta t_{n-1} & -\Delta t_{n-1} \\ 0 & & \cdots & \cdots & & 0 & \Delta t_n \end{matrix}$$

$\Delta_i t$ = the difference in time between the observed abundance estimates for the i^{th} element in **W**.

$\mathbf{\Sigma}$ = the $n\times n$ variance-covariance matrix for the log-ratios of escapement observations,, i.e.,

$$\mathbf{\Sigma} = \begin{matrix} \sigma_1 & \sigma_2 & 0 & \cdots & 0 \\ \sigma_2 & \sigma_1 & \sigma_2 & \cdots & 0 \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & \sigma_2 & \sigma_1 & \sigma_2 \\ 0 & \cdots & 0 & \sigma_2 & \sigma_1 \end{matrix};$$

and where $\sigma_1 = \Delta t\tau^2 + 2\sigma^2$, the variance of each ratio, i.e., $Var\left[\ln\left(\frac{\hat{N}_{t+\Delta t}}{\hat{N}_t}\right)\right]$;

$\sigma_2 = -\sigma^2$, the measurement error and covariance between 2 adjacent log-ratios.

Although Eq. 9 is a restricted maximum likelihood (REML), estimators of the continuous growth rate, μ and the variance, σ^2 are still obtained using maximum likelihood methods. More about REML methods is found in Diggle et al. (1996). Expressing the matrix **U** in terms of the time lag between successive observations makes the model flexible enough to accommodate unequally spaced observations.

Appendix Table D-1. PVA parameter estimates for Skagit steelhead data using years 1980-1995 and 1998-2013.

Parameter	Estimate
Instantaneous rate of increase (μ)	0.012
Standard error of estimated μ	0.040
Process error variance estimate	0.053
Measurement error variance estimate	0.029