April 11, 2008

Using the All-H Analyzer (AHA) Model to Advance H-Integration in the Snohomish Basin

Janne Kaje[1], Kit Rawson[2], Andy Haas[3] and Mike Crewson[2]

[1]King County, Department of Natural Resources & Parks, Water and Land Resources Division
201 South Jackson Street, Suite 600
Seattle, Washington 98104
e-mail: Janne.Kaje@kingcounty.gov
Tel. (206) 205-8309

[2]Tulalip Tribes, Natural Resources Department
7515 Totem Beach Road
Tulalip, Washington 98271
e-mail: krawson@tulaliptribes-nsn.gov
Tel. (360) 716-4621
e-mail: mcrewson@tulaliptribes-nsn.gov
Tel. (360) 716-4626

[3]Snohomish County, Surface Water Management
3000 Rockefeller Avenue, M/S 607
Everett, Washington 98201-4046
e-mail: andy.haas@co.snohomish.wa.us
Tel. (425) 388-3464

Cite as:

Kaje, J., K. Rawson, A. Haas and M. Crewson. 2008. Using the All-H Analyzer (AHA) Model to Advance H-Integration in the Snohomish Basin. 59 p.

Report of the Snohomish Basin Salmonid Recovery Technical Committee

Acknowledgements

The Committee would like to thank Andy Appleby (Washington Department of Fish and Wildlife) for lending his time and expertise to the preparation of this report. Andy's expertise in using the All-H Analyzer model made our analysis possible. We also thank Adrian Spidle (Northwest Indian Fisheries Commission) for his contributions to the report. Adrian's assistance with the interpretation and discussion of genetics in the context of interbreeding hatchery-origin and natural-origin salmon greatly enhanced the quality of our work. Finally, Maria Calvi of the Tulalip Tribes provided a very through review and several suggestions that markedly improved the final product.

Table of Contents

List of Tables

List of Figures

1 INTRODUCTION AND BACKGROUND

The Snohomish River Basin Salmon Conservation Plan (Plan, Snohomish Basin Salmon Recovery Forum 2005) was completed in June 2005 as part of a broader recovery plan for the Puget Sound Chinook Evolutionarily Significant Unit, listed as threatened under the Endangered Species Act (ESA). The Snohomish River Basin supports two distinct Chinook populations (Ruckelshaus et al., 2006). The Snoqualmie Chinook population includes fish that spawn in the Snoqualmie River and its tributaries. The Skykomish Chinook population includes fish that spawn in Skykomish River, Snohomish River and their tributaries. The Tulalip Tribes and the Washington Department of Fish and Wildlife (WDFW) provide harvest opportunities by operating two Chinook hatcheries in the basin. Operations at the Wallace River Hatchery (located on a tributary to the Skykomish River) and Tulalip Hatchery (located on the Tulalip Reservation) are closely-coordinated as part of a hatchery program that is genetically integrated with the Skykomish Chinook population.

The Snohomish Basin Salmon Recovery Forum (Forum) developed the Plan to, "protect, restore, and enhance the productivity of all natural salmon stocks in the Snohomish River basin to a level that will sustain fisheries and non-consumptive salmon-related cultural values." The Plan describes actions under habitat, harvest, and hatchery management that are collectively intended to achieve this goal. The Snohomish Basin Salmonid Recovery Technical Committee (Committee), a group of scientists representing governmental and non-governmental organizations in the basin, provided the scientific foundation for the recovery strategy and technical assistance to the Forum in development of Plan recommendations.

The purpose of this report is to document the Committee's application of the All-H Analyzer (AHA; Mobrand - Jones & Stokes, 2007) model to explore the implications of alternative assumptions and strategies related to the management of habitat, harvest and hatcheries in the Snohomish Basin. The modeling exercise is one element of the broader "H-Integration" process, as described further below. The Committee will use the results of this effort to inform the development of a monitoring plan and the identification of research priorities in the basin.

Following a brief description of H-Integration and the salient features of the AHA model, we report the methods and results for two sets of model scenarios pertaining to the Snoqualmie and Skykomish Chinook populations and the Skykomish hatchery program.

1.1 Snohomish Basin Planning and H-integration

While the Plan includes harvest, hatchery and habitat management actions and a chapter on "H-integration", further coordination and analysis is needed to provide greater certainty that the actions among the "H's" work synergistically to move Chinook and other salmonid populations toward recovery. With the goal of improving understanding and coordination among the H's, the Committee embarked on the six-step "H-integration" process that is being applied in numerous Puget Sound watersheds. Using existing "H-integration" efforts in the basin as a foundation and adaptive management as the context, the Committee is following the six-step process as a framework for identifying and addressing remaining gaps in the strategy.

Six-steps of H-integration:

1. Identify the people that need to participate and how to involve them.
2. Gain a common understanding of how the system works—habitat conditions and fish populations.
3. Agree upon common goals that reflect salmon recovery needs and community values and a set of outcomes across the H-sectors that describe what will be achieved related to those goals in measurable terms.
4. Examine, evaluate and select a suite of complementary actions to achieve the outcomes.
5. Document rationale, implementation steps (specific complementary actions in hatcheries, harvest, and habitat), expected outcomes (including effects on Viable Salmonid Population parameters), and benchmarks.
6. Monitor results, prepare annual performance reports and adjust over time using a verification and accountability system.

To date the Technical Committee has completed steps 1 through 4 of "H-integration". The process began in the mid-1990s by bringing together a group of scientists working on harvest, hatchery and habitat management in the basin. Prior to the listing of Puget Sound Chinook salmon under the Endangered Species Act, in 1999, the Committee produced a precursor of a recovery plan for Chinook salmon in the basin. Subsequent to the listing, the committee began to work with the Forum to produce a basin recovery plan intended to be part of the overall recovery plan for the Puget Sound Chinook Evolutionarily Significant Unit. This chapter and the overall plan were completed in 2005, and the plan was formally adopted by the National Oceanic and Atmospheric Administration in 2007.

Although the Snohomish recovery chapter includes elements of habitat, harvest, and hatchery management, the Committee and the Forum have not fully analyzed the degree to which these individual plans are compatible or conflicting. To begin this work, and because there has been almost complete turnover in committee membership since 1999, in late 2006, committee members provided presentations on plans for harvest management, hatchery management, habitat restoration and habitat protection to build a common understanding of the system. Goals and outcomes across the H-sectors were discussed in the context of agreements reached in the recovery plan, setting the stage for the evaluation of additional "H-integration" scenarios that build on the recovery plan. The All-H Analyzer (AHA) model was used as a tool to improve our understanding regarding interactions among the "H's" and potential areas of risk or uncertainty. Assumptions, methods and results of the AHA modeling effort are documented in this report as part of Step 5 and will be used, along with other inputs, to identify research and monitoring priorities to be highlighted in the revised monitoring and adaptive management strategy, the final step of "H-integration".

1.2 Summary of Integrated and Segregated Hatchery Programs

The concepts of integrated and segregated hatchery programs and their associated guidelines were developed by the co-managers (i.e., Treaty Tribes and WDFW), during earlier Hatchery

Reform efforts (WDFW and Puget Sound Treaty Tribes 1998a, 1998b). The term Integrated Hatchery Program describes the intended reproductive relationship of a hatchery population and an associated naturally spawning population, where gene flow takes place in both directions. The principal goal of an Integrated Hatchery Program is to manage the broodstock as an artificially propagated component of a naturally spawning population wherein the natural environment drives adaptation and fitness of a composite population of fish that spawns both in a hatchery and in the natural environment (HSRG 2004a). In practice, this entails the incorporation of natural fish into the hatchery brood stock at a rate that is higher than the rate at which hatchery-origin fish are estimated to contribute to the natural spawning population.

The term Segregated Hatchery Program describes a hatchery population that is intended to be reproductively isolated from a naturally spawning population. The principal intent of a Segregated Hatchery Program is to propagate a genetically segregated hatchery stock to meet goals for harvest or other purposes (research, education, etc). Segregated Hatchery Programs are intended to be managed in a way that maximizes productivity or efficiency, irrespective of the ability of returning adults to reproduce naturally or confer any benefits to naturally spawning populations (HSRG 2004b). The HSRG notes that:

> *"Natural spawning of fish from segregated programs may pose genetic and ecological risks to natural-spawning populations. The risks that segregated hatchery programs pose to natural populations depend on the status and goals for the natural populations, the extent to which hatchery-origin fish interact genetically and ecologically with natural-origin fish, and on the amount of genetic and phenotypic divergence between the hatchery and natural populations."* (HSRG 2004b).

The concepts of integrated and segregated programs are accompanied by terminology that describes the level of genetic interchange between hatchery populations and naturally spawning populations. These terms are key to understanding the operation of the AHA model:

pHOS: Proportion of hatchery origin spawners contributing to the natural spawning population (HRSG, 2004a).

pNOS: Proportion of natural origin spawners contributing to the natural spawning population (HRSG, 2004a).

pHOB: Proportion of hatchery origin broodstock contributing to a hatchery broodstock (HRSG, 2004a).

pNOB: Proportion of natural origin broodstock contributing to a hatchery broodstock (HRSG, 2004a).

PNI: Proportion of natural influence. PNI = pNOB/(pHOS + pNOB).

For integrated hatchery programs, the principal goal is to manage both the hatchery and natural populations as one composite population that spawns both in a hatchery and in the natural environment, but where gene flow drives adaptation and fitness toward the natural population from the hatchery population. This is accomplished by first marking hatchery fish as juveniles and then estimating the contribution rates or proportions of natural and hatchery origin spawners (pNOS and pHOS), while regulating the relative proportion of natural and hatchery origin broodstock (pNOB and pHOB).

Specifically, the HSRG guidelines for genetic broodstock management assume that as long as the proportion of natural-origin fish in the broodstock exceeds the proportion of hatchery-origin fish on the spawning grounds (PNI > 0.50), then the natural environment will drive adaptation and fitness of a composite hatchery and natural population. This condition is achieved by ensuring that pNOB is greater than pHOS through genetic broodstock integration and mating protocols. Once pHOS is determined, hatchery managers can integrate a higher proportion of NOB to ensure that PNI exceeds 0.5 (above that where gene flow is neutral). For certain populations of high biological significance, including Skykomish Chinook, the HSRG suggests that PNI should exceed 0.67 (i.e., pNOB is at least twice as high as pHOS).

Segregated hatchery populations are intended to be managed so that interbreeding between the natural and hatchery populations is minimized to avoid outbreeding depression. In model terminology, the HSRG has recommended that for segregated populations pHOS should remain at levels less than 5%, i.e., the effective genetic contribution of hatchery fish to the naturally-spawning population should be less than 5% per generation (HSRG 2005).

If the reader is interested in further detail about these concepts and practices, the objectives and characteristics of integrated versus segregated production are described in a set of discussion papers prepared by the HSRG in collaboration with the Northwest Indian Fisheries Commission (NWIFC) and WDFW, as well as the associated Hatchery Reform Technical Discussion Group (HSRG et al. 2004a and 2004b; Hatchery Reform Technical Discussion Group 2005). The documents together provide a brief primer for the AHA model, and describe the appropriate context for and some of the strengths and weaknesses of both integrated and segregated models of hatchery production – the central components around which the model is constructed. Also, the HSRG's (2004) principles and recommendations for hatchery reform in Puget Sound and Coastal Washington hatcheries is an additional, valuable resource.

1.3 AHA Model Description and Limitations

AHA was developed jointly by the co-managers to investigate potential risks and to develop a set of genetic and ecological management guidelines for integrated and segregated hatchery programs. The HSRG (2004) furthered the model's development for use in a series of technical hatchery workshops held during the summer of 2004 for watersheds in Puget Sound and coastal Washington State.

The model has primarily been used to investigate management implications for hatchery populations or hatchery-natural composite populations. Our use of the model in the Snoqualmie case to evaluate risks solely to a natural population, i.e., where no portion of the population spends any time in a hatchery situation, is a novel application of the model which has not been done elsewhere to our knowledge.

As part of the Snohomish basin H-Integration process, the WDFW demonstrated the use of the AHA model to the Committee. Specifically, the demonstration illustrated how the model had been applied by co-managers to the management of the Skykomish Chinook population to help inform broodstock integration efforts. The Technical Committee then elected to use the AHA model for exploring in a heuristic way the interdependencies of assumptions about all three H's for the Snoqualmie and Skykomish Chinook salmon populations.

Like any model, AHA is a simplification of reality and thus the results and their implications should be evaluated in light of other lines of investigation. As stated by the Columbia River basin's Independent Scientific Review Panel (ISRP) and Independent Scientific Advisory Board (ISAB), the appropriate use of AHA is to generate hypotheses that should be tested, rather than accepted at face value. The model's utilization for the generation of hypotheses assumes that the model itself is adequately documented, and that inputs are adequately documented as part of reporting outputs (ISRP/ISAB 2005), but according to the review, neither of these conditions has been adequately met to date. The same review cautioned against using the model to "generate specific objectives, numerical or otherwise, or to propose recovery goals for anadromous fish", due in part to incomplete model documentation, the deterministic nature of the model, lack of robust sensitivity analysis, and the inherent risk in application of an "expert system" model by *non*-expert user groups.

The model has also been evaluated by the Puget Sound Technical Recovery Team[1] (TRT) (with input from the Willamette/Lower Columbia TRT and the Interior Columbia TRT), a group of experts from a variety of organizations in the region that provides technical guidance to the region's salmon recovery efforts. The TRT review shared many of the concerns raised by the ISRP/ISAB and also noted that the model "does not include genetic drift or ecological interactions of hatchery and natural fish, such as intra- or inter-specific competition and predation, disease transfer and amplification, or nutrient flow, which also affect productivity" (Puget Sound TRT 2005). Moreover, from a salmon recovery perspective, the model does not incorporate consideration of all four parameters associated with viability: abundance, productivity, spatial distribution and diversity (McElhany et al., 2000), but rather addresses abundance and productivity only.

Consistent with the recommendations of both reviews, we applied the model in an heuristic manner to explore the many "what-if" scenarios posed by different combinations of assumptions related to the management of harvest, hatcheries and habitat. In this report, we do not attempt to fully document the model itself; rather, we document how the Committee used the model, the selection of model inputs based on data and expert opinion, and the resulting outputs, with an emphasis on the identification of hypotheses and priorities for research and monitoring.

1.3.1 Model architecture - summary

The model applies a set of equations that describe the implications of interbreeding between one natural and one 'captive' (i.e., hatchery) population (Ford, 2002). It is used in combination with estimates of productivity based on habitat condition to approximate the effects of gene flow between one hatchery stock and one natural stock, although estimates of

---

[1] The Puget Sound TRT is no longer active and has been replaced by the Puget Sound Recovery Implementation Technical Team (RITT).

‘strays’ from outside populations can also be included. The model produces a variety of outputs based on a 100-year simulation, including ranges and means for the numbers of returning natural fish and hatchery fish; numbers of natural and hatchery fish harvested in one or more ‘fisheries’; hatchery releases of juvenile fish; and the number of hatchery fish spawning in the river. The model also calculates specific values (such as pHOS, described above) that attempt to describe the level of genetic interaction between the hatchery and wild stock.

In our analysis, harvest rates and hatchery production scenarios are tested across ranges to describe (as nearly as possible) current or potential management scenarios for the stocks of interest, including broodstock management for the integrated Skykomish population. The condition of habitat is reflected in the model as a function of two values – the intrinsic productivity and capacity of the naturally spawning population. Thus, the model’s construct of ‘habitat’ assumes that productivity and capacity are strictly functions of habitat quality and quantity. These values are discussed in greater detail in the Methods section(s).

In the model, the fitness of both populations (hatchery and natural) changes over time as a result of interbreeding. In brief, the model assumes that both the natural stock and the hatchery stock are preferentially adapted to their respective environments, that fitness for each can be represented as a single, normally-distributed ‘trait’, and that the respective selective forces acting on each population have produced a gap between the ‘optimum’ trait values of the two populations – i.e., in a phenotypic sense, the peaks of the two normally distributed curves are at different values (see Ford 2002 for details). Thus, as the populations interbreed, the fitness of the combined population shifts to sub-optimal values somewhere between the respective optima. This, in turn, reduces subsequent productivity and population abundance. The ISRP/ISAB review notes that there should be additional explanation of how the fitness equation is employed throughout the population model in AHA, but also commends as laudable and important the inclusion of the explicit consideration of fitness impacts of hatchery fish on natural fish (ISRP/ISAB, 2005).

Ford’s (2002) approximation of fitness as a single trait with discrete optima for the hatchery and natural environments and constant strength of selection across environments toward each environment’s optimum is useful heuristically to generate ‘what if’ scenarios. But because true ‘fitness’ results from multiple traits with varying (and unknown) degrees of interactions, heritability, strength of selection and, most importantly, phenotypic plasticity (variation in expression of a fixed trait with respect to the environment), it may not be prudent to draw specific management conclusions from a qualitative summary of the model’s quantitative output. The model allows the user to adjust several variables related to these factors (such as the strength of selection), but we have not done so to date.

AHA provides an option to introduce ‘out of basin strays’ – hatchery fish that originate outside the basin of interest – in order to simulate genetic exchange between hatchery fish and wild fish. We elected to use this option for the Snoqualmie analysis. It allowed us to use available data more easily (e.g., otolith and coded-wire-tag recoveries from carcass surveys) to estimate the mean annual number of hatchery strays in the basin. The use of available data sources to generate estimates of strays is described in the Methods section, below.

A key factor in determining the genetic influence of hatchery strays is their spawning effectiveness. The model provides a way to adjust the spawning effectiveness of hatchery fish relative to their natural counterparts. In the model, this is a scalar adjustment to the number of hatchery fish on the spawning grounds. For example, for purposes of computing the respective contributions of natural and hatchery-origin fish to the subsequent generation, 350 hatchery-origin spawners with a spawning effectiveness of 0.5 translates to the equivalent of 175 hatchery-origin spawners. The spawning effectiveness variable can be used to model a spatial, temporal or behavioral separation that renders hatchery spawners less effective at passing their genes to the next generation. For instance, this rate can be used to reflect different assumptions about overlap in the timing of spawning. This is relevant to the Snoqualmie case in that the Skykomish-origin hatchery stocks tend to enter fresh water in the mid- to late-summer months, while Snoqualmie Chinook tend to arrive later in the fall, though overlap in spawn-timing may still occur. Return timing is thought to affect the original contribution rate, whereas temporal and spatial differences in spawn timing might be more apt to affect spawning effectiveness. Also, like the natural Snoqualmie stock, many strays from outside of the Snohomish basin are from hatchery stocks that tend to feature a fall return and spawn timing, which have implications for both contribution rate and spawning effectiveness. In our analysis, we varied the spawning effectiveness value from 0 to 1 in increments of 0.1.

2 THE SNOQUALMIE ANALYSIS

The Committee explored different assumptions and different key questions for the Snoqualmie and Skykomish Chinook populations because the populations of interest and areas of concern are different in the two cases. This section describes the assumptions, research questions and results for the Snoqualmie population.

The Snoqualmie stock Chinook population is managed for natural production, and there are no releases of Chinook salmon into the watershed. Still, hatchery-origin Chinook spawners from a variety of hatcheries have been documented in the watershed. From 1993-2002, the annual hatchery-origin contribution to the wild spawning population average 25%, with an annual low of 5% and a high of 72% (Snohomish Basin Salmon Recovery Forum, 2005 – Appendix G) Thus, we adapted the AHA model to the Snoqualmie case in order to simulate the potential effects of hatchery fish on the naturally spawning population.

The following are the principal assumptions that informed our analysis of the Snoqualmie case.

- Snoqualmie and Skykomish Chinook are distinct populations.
- Tulalip and Wallace Hatcheries are the source(s) of some, but not all, hatchery strays into the Snoqualmie.
- The level of temporal, spatial and behavioral overlap between hatchery strays and natural fish – and thus the spawning effectiveness of hatchery fish - is unknown.

- For modeling purposes, hatchery fish, regardless of their origin, are regarded as genetically distinct from the naturally spawning Snoqualmie stock, and thus functionally equivalent to out-of-basin strays.

The Committee selected the following model outputs as most important for the Snoqualmie analysis. For each output category, the naming convention corresponding with the output sheets (Appendix 1) is provided in parentheses.

- *pHOS:* the proportion of natural spawners that are of hatchery origin (adjusted for spawning effectiveness) - 100-yr average.

- *Long-term fitness (Fitness – Gen. 100): Fitness of naturally spawning population in generation 100 (Scale 0-1).* Based on the fitness equations in the model (Ford 2002), as natural fish and hatchery fish interbreed, the fitness of the natural stock erodes over time (unless the rate of hatchery→natural gene flow is very low). Fitness values range from a value of 0 to 1, with 1 as the maximum fitness value. We imposed a 0.5 "floor" level on fitness, the default value in the model. The selection of 0.5 is arbitrary, and its use merits further discussion.

- *Percentage of natural fish on spawning grounds (NOS% Gen. 90-100): Mean percentage in generations 90-100.* This value is the proportion of natural-origin fish on the spawning grounds during the final ten years of the model run. It is fairly analogous to pHOS, except that the value has not been adjusted for spawning effectiveness, and the scale is reversed relative to pHOS, so that high values are 'good' from a natural stock perspective.

- *Abundance of natural-origin fish on spawning grounds (NOS Mean): 100-year mean and 100-year time series.* In addition to the long-term mean, we also computed the average number of natural fish over time and retained a time-series of all model runs for potential analysis at a later date.

- *Natural-origin Harvest (NOR Harvest): 100-yr mean.* The harvest output in the Snoqualmie scenario is limited to wild natural fish only,. This is because the Snoqualmie scenario does not include a hatchery stock that is harvested. The stray estimates generated for the model (see Section 2.2) are based on fish reaching the spawning grounds (i.e., post-harvest).

2.1 Study questions and output categories for the Snoqualmie case

The following questions framed our analysis of the Snoqualmie case. The first question represents the overarching objective of the analysis and frames our discussion of model results.

- Analysis 1: How do assumptions about each "H" – individually and in combination - affect the Snoqualmie population's performance in terms of abundance, harvest, fitness and composition of the spawning population?

- Analysis 2: How sensitive is the performance of the Snoqualmie population to the mean abundance of hatchery strays?

Results and discussions for each of these questions are provided in Section 2.3.

2.2 Methods

Figure 1 shows a simplified representation of the key elements of the Snoqualmie model in AHA.

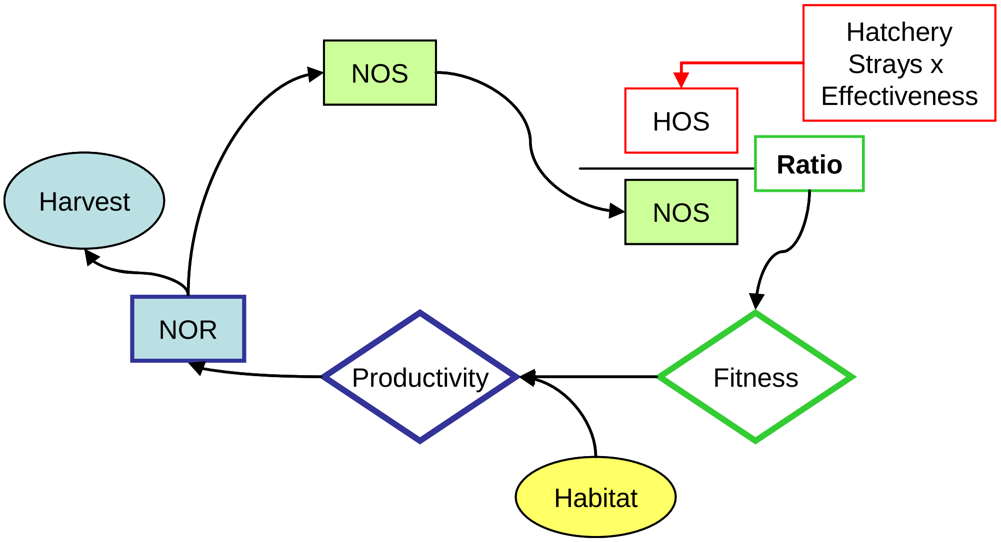


Figure 1. Simplified model schematic of one generation in the Snoqualmie scenario.

In order to analyze each of the study questions across a range of assumptions, we generated a suite of scenarios describing habitat, harvest, and straying by hatchery fish.

2.2.1 Habitat Scenarios

We simulated four scenarios of habitat conditions derived from analyses completed during development of the Plan. These used the Ecosystem Diagnosis and Treatment (EDT) model (Lestelle, Mobrand, Lichatowich and Vogel 1996; Mobrand et al. 1997) to simulate population performance under different sets of freshwater habitat conditions. The EDT model consists of three major elements: 1) a characterization of the environment using a standardized set of physical and biological descriptors, 2) a rating of the quality and quantity of the habitat with regard to the biological needs of the focal species, and 3) an analysis of species/population performance along life history pathways (also called life history trajectories) through space and time.

The plan includes separate recovery targets for the Snoqualmie and Skykomish populations. These were originally developed by the co-managers and represent 75-80% of the estimated historical Chinook population abundance in the Skykomish and Snoqualmie rivers. The target condition is expressed as a range along a population trajectory, with high-end population targets of 39,000 Chinook for the Skykomish and 25,000 for the Snoqualmie. The Forum adopted the target ranges as its long term recovery goal.

Here, the long-term population target is referred to as the Recovery Goal. In a collaborative effort with the Northwest Fisheries Science Center, the Committee modeled historic habitat conditions and four habitat scenarios during the development of the Plan. Both the EDT and the SHIRAZ model were used. Importantly, the scenarios were constructed to achieve the results after 50 years based on 10 years of restoration actions. As a starting point, the Committee developed the Recovery Test Case scenario, which captures the hypothesized habitat conditions necessary to achieve population levels well within the Forum's recovery planning range, though lower in terms of productivity and capacity than the long-term Recovery Goal (Snohomish Basin Salmon Recovery Forum 2005 - EDT Appendix). Next, the Committee modeled a Current Path scenario, reflecting the current level (1999-2004) of restoration project implementation focused in key areas, mostly status quo for policies and regulations that affect habitat condition, as well as anticipated habitat-degrading actions. The Recovery Goal and Current Path Scenarios established the "bookends" for the modeling of two additional alternatives, Current Path plus 50% of the difference between the habitat condition targets established in the Current Path scenario and the Test Case scenario (CP+50), and Current Path plus 75% of that difference in habitat condition (CP+75). The Snohomish Forum selected the CP+75 to establish habitat recovery benchmarks for the next ten years on the path to recovery. The AHA-modeling exercise evaluated the alternative selected by the Forum, as well as the Current Path, Recovery Goal and Historic scenarios (Table 1).

Habitat scenarios developed by the Committee in 2004 for Snohomish Basin recovery planning include values for 45 habitat attributes in each of 24 reaches in the Snoqualmie and Snohomish Rivers and their tributaries (excluding the Skykomish River and its tributaries for the Snoqualmie population). The actual values used in each scenario are documented in the 2005 Snohomish basin registered dataset, stored on the Mobrand, Jones, and Stokes computer and available through the Snohomish Basin Technical Committee. Scenarios we used encompass a range from a projection of current trends to an historical template condition (Table 1).

Table 1. Description of habitat scenarios modeled for the Snoqualmie Chinook population.

Population	Habitat Scenario	General description
Snoqualmie	Current Path	Projection of habitat conditions given current trends in land use and the 1999-2004 level of effort for habitat restoration projects.
Snoqualmie	CP+75	Current Path plus 75% of the difference between the habitat condition targets established in the Current Path scenario and the Recovery Test Case scenario. This is the strategy selected by the Forum for the first ten years.
Snoqualmie	Recovery Goal	Hypothesized habitat conditions necessary to achieve population levels at the high end of recovery planning range established by the co-managers.
Snoqualmie	Historic	Historic, or template, habitat conditions (see EDT references for further definition).

These habitat scenarios were originally modeled using the 2004 registered Snohomish Basin baseline dataset. The scenarios were updated in December of 2006 to reference the 2005 registered baseline dataset.

We used EDT output expressed as productivity (P) and maximum abundance (capacity - C) parameters of Beverton-Holt spawner-recruit curves for the entire Snoqualmie population. Equilibrium abundance (N_{eq}) is computed as:

$$N_{eq} = C \times (1 - {}^{1}\!/_{P})$$

and maximum sustainable yield (MSY_{rate}) exploitation rate is:

$$MSY_{rate} = 1 - \frac{1}{\sqrt{P}}$$

(Ricker 1975).

Values of these parameters for the four habitat scenarios for the Snoqualmie population are in Table 2.

Table 2. Productivity and capacity results for habitat scenarios for the Snoqualmie Chinook population. Equilibrium abundance, Maximum Sustainable Harvest (MSH) escapement level, and MSY Exploitation rate are computed from productivity and capacity (see Ricker 1975).

Population	Habitat Scenario	Productivity	Capacity	Equilibrium Abundance	MSY Exp Rate
Snoqualmie	Current Path	3.21	7,526	5,181	0.442
Snoqualmie	CP+75	4.65	10,691	8,394	0.54
Snoqualmie	Recovery Goal	12.89	23,430	21,611	0.721
Snoqualmie	Historic	17.33	37,393	35,235	0.760

2.2.2 Hatchery Scenarios

We used available information from spawner surveys to estimate the contribution of hatchery fish to areas where fish spawn naturally in the Snoqualmie system. Because the summer Chinook hatchery programs are relatively new to the region, prior contribution rate data used in this modeling exercise for fall Chinook hatchery programs did not include hatchery contribution rates for the existing summer Chinook hatchery programs.

Because there are no releases of Chinook salmon into the Snoqualmie system, we modeled all hatchery fish in the system as "strays", meaning that they were hatchery fish from a population outside the system. It is important to note that hatchery-origin Chinook salmon from a geographic range extending from the Skagit River to Hood Canal and the Puyallup Rivers have been documented to contribute strays to the Snoqualmie system (Table 3). Coded-wire tag (CWT) data provide an idea of the geographic range that provides hatchery strays to the Snoqualmie system.

Due to spotty and non-random carcass sampling methods employed in past years, and the fact that not all hatchery programs were represented by CWT groups, these past contribution rate data are not useful for a quantitative assessment of the number of fish from these out-of-basin hatchery programs that may have entered the system.

Table 3. Numbers of coded-wire tags (CWT) recovered from Chinook salmon carcasses in the Snoqualmie basin 1997-2005 by source and recovery location.

CWT release locations		**CWT by recovery location**					
Release Site	**Basin**	**Raging**	**Snoq**	**Tokul**	**Tokul H**	**Tolt**	**TOTAL**
Big Soos Creek	Green	2		3	4	2	**11**
Cascade River	Skagit			1			**1**
Diru Creek	Puyallup			2			**2**
Grovers creek	Kitsap	1		2		1	**4**
Purdy Creek	Hood Canal	1					**1**
Stillaguamish River – NF	Stillaguamish		5	2		1	**8**
Tulalip Creek	Snohomish	2	2	3	4	2	**13**
Voight Creek	Puyallup				1		**1**
Whitehorse Springs	Stillaguamish	2	4				**6**
Unknown[1/]		1	1	2	3		**7**
Grand Total		**9**	**12**	**15**	**12**	**6**	**54**
Known out-of-basin		**6**	**9**	**10**	**5**	**4**	**34**

[1/] Where the release location is identified as "unknown" the head sent to the laboratory did not contain a tag, the tag was not sent to the laboratory or lost by the laboratory, or the tag was unreadable for some other reason. These were not included in out of basin totals

Because of thermal mass-marking of Chinook released at the Tulalip Hatchery since brood year 1993 and of Chinook released at Wallace River hatchery from brood years 1993-1997, it is possible to generate quantitative estimates of the contribution of Chinook from these in-basin facilities to natural spawning areas in the Snohomish system, but only for the fall Chinook programs that have since been discontinued. Since 1997, regular sampling of Chinook in natural spawning areas throughout the Snohomish basin has included collection of otoliths from spawned out carcasses found along the river bank or at the bottom of pools. These otoliths are examined in a laboratory for the presence of a thermal mark. Estimates of the number of fish from each hatchery are made by multiplying the fraction of the sampled fish that are found to have a hatchery mark times the estimated total spawning escapement. These estimates are made separately for sections of the basin and summed to obtain the overall contribution estimate for a population or for the whole basin. Overall, we are able to sample approximately 10% of the estimated spawning escapement each year throughout the basin (Rawson, Kraemer, and Volk 2001).

Using the above approach, it was possible to estimate the contribution of Wallace River hatchery-origin Chinook to the Snoqualmie system for 1997-2000 and the contribution of

Tulalip Hatchery fish for 1997-2005 (Table 4). While this sampling continues with the new hatchery summer stocks, these data still consist almost exclusively of fall Chinook contribution rates from the old programs.

Table 4. Estimated number of Wallace and Tulalip hatchery origin Chinook salmon reaching natural spawning grounds in the Snoqualmie system, 1997-2005, expanded from recoveries of thermally-marked otoliths from spawned-out carcasses (Rawson, Kraemer, and Volk 2001 and K. Rawson, Tulalip Tribes, unpublished data). Because thermal mass-marking of Wallace River Hatchery Chinook ceased with the 1997 brood year due to funding constraints, estimates are not available after 2000.

	Wallace releases - Tag recovery sub-basin			**Tulalip releases - Tag recovery sub-basin**		
Year	**Tokul**	**Other**	**Total**	**Tokul**	**Other**	**Total**
1997	0	0	0	12	105	117
1998	8	111	119	31	318	349
1999	34	17	51	98	146	244
2000	2	24	26	64	75	139
2001				49	256	305
2002				42	380	422
2003				50	331	381
2004				105	105	209
2005				22	35	57
Avg	11	38	49	53	194	247
SD	16	50	51	32	128	127
Min	0	0	0	12	35	57
Max	34	111	119	105	380	422

Based on these data, we modeled 400 hatchery strays on average per year: 250 from Tulalip hatchery, 50 from Wallace River Hatchery, and 100 from miscellaneous other hatcheries. We acknowledge that the estimate of 100 is particularly difficult to calibrate due to the paucity of data. This is one reason for our assessment of model sensitivity to the average number of strays (Analysis 3).

Importantly, while AHA models nearly all other inputs as fixed values, the marine survival life stage simulates a cyclic, ten-year pattern of variability that affects the natural- and hatchery-origin fish in equal measure. Thus, the 400 strays represents an average value, with more strays in some model-years and less in others. But, the model applies an identical pattern of variability in marine survival rates for natural fish and hatchery fish; thus, their relative proportion is not affected on an annual basis by this model attribute.

As described further, below, we also performed a separate set of model runs (Analysis 2) to evaluate the sensitivity of the results to the average annual number of strays (estimated above as 400) for values between 100 and 700. The details of these scenarios are described in Section 2.2.4.

2.2.3 Harvest Scenarios

We modeled four harvest management scenarios, ranging from zero harvest to harvest at the MSY rate. The current harvest plan, one of the scenarios, is between these two endpoints, and we expect that harvest impacts will be within this range during and after the period of population recovery. Each scenario is described briefly below.

Zero harvest

This is a hypothetical situation unless all fisheries for salmon and other fisheries - such as the trawl fishery for Pacific whiting, which also has incidental impacts on Chinook salmon - are closed from Southeast Alaska to southern Oregon. However, it is a useful endpoint, and it is straightforward to model. For all levels of the habitat and hatchery scenarios, if the zero harvest scenario is being modeled, then it is assumed that no fish from the population are removed or otherwise killed due to fishing activities, incidental or otherwise (Table 5).

Current harvest management plan

Chinook salmon fisheries are currently controlled according to a resource management plan developed by the state and tribal co-managers (Puget Sound Indian Tribes and Washington Department of Fish and Wildlife 2004) and adopted by NOAA (70 FR 12194, March 4, 2005) under a 4(d) rule as provided for in the Endangered Species Act. The harvest management plan is incorporated into the Snohomish Plan as adopted by the Forum (2005), and is therefore also included in the Puget Sound Salmon Recovery Plan.

The plan includes a recovery exploitation rate for the Snohomish Chinook management unit, which is the combination of the Skykomish and Snoqualmie populations. The recovery exploitation rate (RER) was derived using simulation modeling such that if the realized exploitation rate is equal to or less than the RER, then the management unit natural escapement (fish returning to the river to spawn) will exceed an escapement reference point 80% or more of the time. The escapement reference point is set at the level of escapement where the first derivative (i.e., slope) of the spawner-recruit curve equals one. This level is also known as the maximum sustainable harvest (MSH) escapement level (Ricker 1975). (See Puget Sound Indian Tribes and Washington Department of Fish and Wildlife, 2005, Appendix A, for details of the derivation. See also Snohomish Basin Salmon Recovery Forum, 2005, Appendix G).

The way that the RER is derived means that the RER will change if the underlying parameters of the spawner-recruit curve change. The habitat scenarios entail different spawner-recruit parameters (i.e., productivity and capacity), which in turn implies different MSH escapement levels (Table 2). Therefore, the RER, the exploitation rate that results the spawning escapement exceeding the MSH level 80% of the time, depends upon the population productivity and capacity. For modeling the current harvest plan scenario, we assumed that the realized exploitation rate would equal the RER. Thus, the exploitation rate modeled for the current harvest plan scenario depended upon the habitat scenario it was paired with.

In lieu of completing lengthy Monte Carlo computer simulations for every habitat scenario, we made the simplifying assumption that the ratio of the RER to the MSY exploitation rate would remain the same over all habitat scenarios. Under the current harvest management plan, the RER for the Snohomish system, applying to both the Skykomish and Snoqualmie populations is .24. This is .24/.44, or 54.5% of the MSY exploitation rate under the current habitat condition (Table 2). So, we applied the 54.5% factor to the MSY exploitation rates for each habitat scenario to derive the modeled RER for the "current plan" harvest scenario to go with each habitat scenario (Table 5).

Table 5. Exploitation rates for harvest management scenarios corresponding with habitat scenarios, Snoqualmie population. The rate used for a particular harvest scenario depends on the habitat scenario modeled. See text for further explanation.

Population	**Habitat Scenario**	**Zero Harvest**	**Current Plan**	**Current Plan w/ northern**	**MSY**
Snoqualmie	Current Path	0.000	0.240	0.380	0.442
Snoqualmie	CP+75	0.000	0.292	0.380	0.536
Snoqualmie	Recovery Goal	0.000	0.392	0.392	0.721
Snoqualmie	Historic	0.000	0.413	0.413	0.760

Current plan with northern fisheries

The Current Plan + Northern harvest scenario acknowledges the fact that due to interceptions of Chinook in fisheries north of the border, harvest rates likely exceed the calculated rates that co-managers would prefer to apply. Under the co-managers' harvest management plan, the exploitation rate may exceed the RER when fisheries north of the U.S./Canadian border intercept so many fish from a population that management of fisheries south of the border cannot reduce the overall rate below the RER. In this situation, for the Snohomish populations, the maximum exploitation rate south of the U.S./Canadian border is .15. In practice, the co-managers have reduced the southern rate below this level when impacts to the Snohomish stock in minimal incidental fisheries could accommodate a lower rate. However, for modeling purposes, we assumed a .15 exploitation rate south of the U.S./Canadian border and the 2007 preseason estimated northern rate of .23, for a total rate of .38. This is on the high end of recent overall exploitation rates for Snohomish Chinook, but it best reflects the most recent situation of increasing northern interceptions.

For matching this harvest scenario with habitat scenarios, we used the .38 rate in the Current Path and CP+75 habitat scenarios to reflect the realities of cross-border management as they exist today. The Recovery Goal and Historic condition rates are unaffected because the calculated rates for these more productive scenarios exceeds .38 in any case.

Maximum Sustainable Yield rate

Finally, we modeled a harvest scenario with the overall exploitation rate at the MSY level based on the particular habitat scenario being modeled (Table 3).

2.2.4 Snoqualmie scenario definitions

As described above, we tested the sensitivity of model outputs to changes in four different variables:

1. harvest rate (4 options, rates are conditional based on habitat condition)
2. habitat condition (4 options),
3. spawning effectiveness (10 options), and
4. the number of hatchery strays (7 options).

In other words, these are the four 'dials' that we turned to evaluate changes in the outputs of interest.

The first set of model runs focused on the first three variables. For these model runs, the average number of hatchery strays was held constant at 400 (as described above in Section 2.2.2).

The second set of Snoqualmie model runs focused on the fourth variable – the average number of hatchery strays. If we had run each of the stray number scenarios together with every other combination of variables, the total number of model runs would have made the presentation of results unwieldy. Thus, for purposes of displaying results in the case of Analysis 2, we held the harvest scenario constant as "Current Plan + Northern", which is thought to be the most realistic estimate of current harvest rates, including interceptions in fisheries north of the U.S./Canadian border.

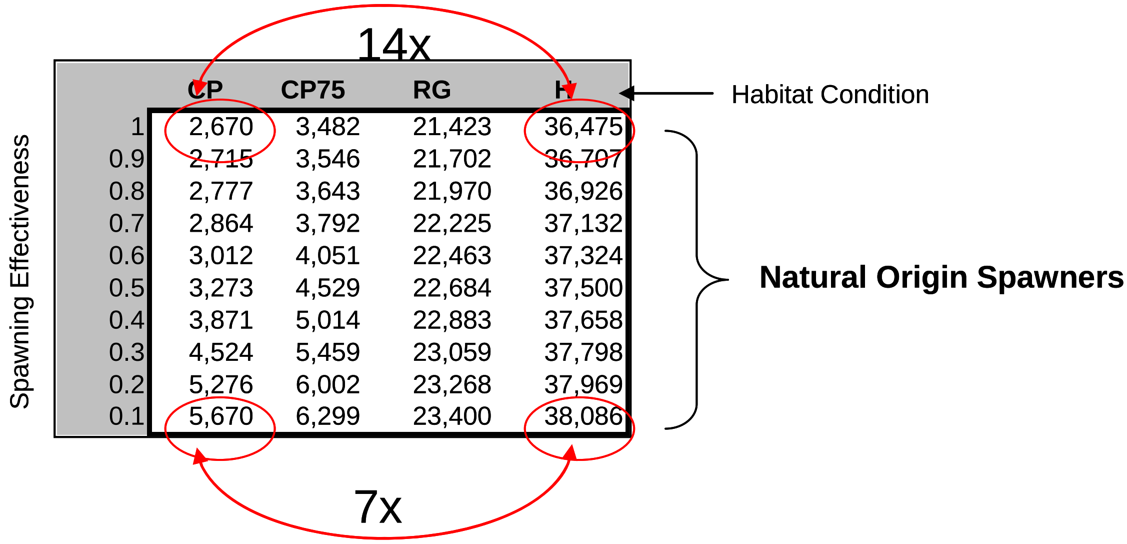
2.3 Snoqualmie Results

For the first set of model runs, outputs are shown in Output Sheets 1-4 in Appendix 1. In addition, selected tables are reproduced in the body of the report for ease of reference. Each of the four sheets corresponds to one of the four harvest scenarios. Each table on a sheet shows the output result for 40 combinations of habitat condition and spawning effectiveness. Color coding was applied to the values in the pHOS, fitness and percentage of natural-origin spawners (NOS) tables to visually capture patterns in quantitative output values. The numerical thresholds for the color-codes are shown at the top of each output sheet. In general, white values are 'good' while red values are 'poor', but some of the values selected as thresholds are arbitrary. For example, in the case of pHOS, the HSRG has identified 5% as a critical threshold, corresponding to our white category. However, the intermediate (pink) threshold of 10% is set arbitrarily at twice the 5% threshold.

For the second set of model runs, the outputs (pHOS and long-term fitness, only) are shown in Output Sheets 5 and 6, also in Appendix 1.

2.3.1 Analysis 1: How do assumptions about each "H" – individually and in combination - affect the Snoqualmie population's performance in terms of abundance, harvest, fitness and composition of the spawning population?

The effects of improved habitat (i.e., higher intrinsic productivity and capacity) on model outputs are substantial. The results shown for the Zero Harvest case (Output sheet 1) are informative in that they reflect the combined effects of two H's (habitat and the spawning effectiveness of hatchery strays), in the absence of the third (harvest). According to the model, if habitat condition were to be improved to historical conditions, the average number of natural-origin spawners would increase from seven to fourteen-fold over the Current Path condition, depending on the spawning effectiveness of hatchery strays (Figure 2).

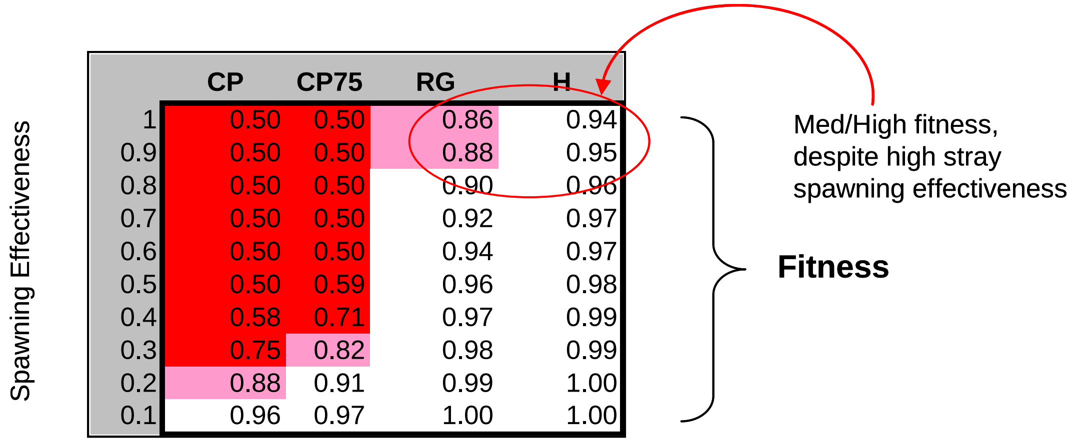


	CP	CP75	RG	H
1	2,670	3,482	21,423	36,475
0.9	2,715	3,546	21,702	36,707
0.8	2,777	3,643	21,970	36,926
0.7	2,864	3,792	22,225	37,132
0.6	3,012	4,051	22,463	37,324
0.5	3,273	4,529	22,684	37,500
0.4	3,871	5,014	22,883	37,658
0.3	4,524	5,459	23,059	37,798
0.2	5,276	6,002	23,268	37,969
0.1	5,670	6,299	23,400	38,086

Figure 2. Average annual number of natural origin spawners with Zero Harvest.

A comparison of the Current Path and the Current Path + 75 scenarios shows that the latter case results in 11-30% more natural-origin spawners.

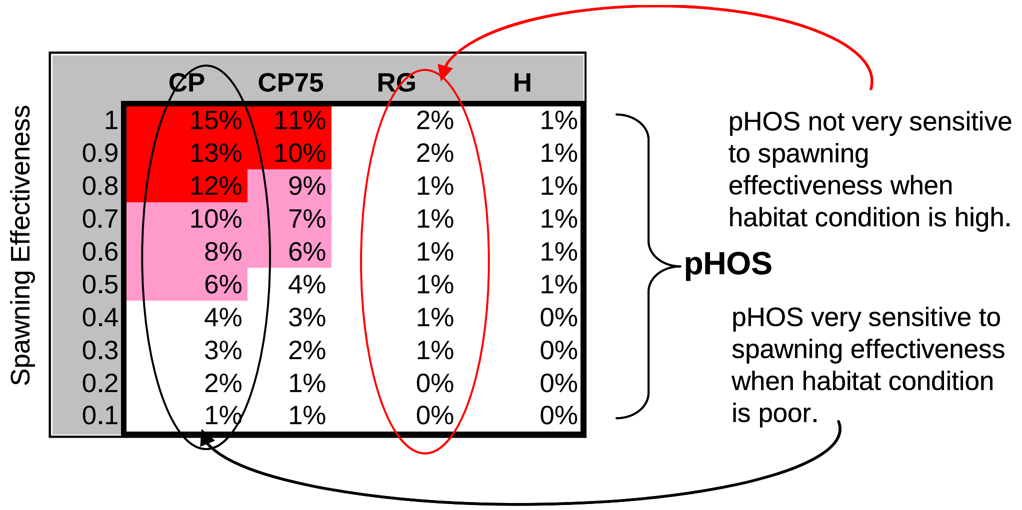
The same basic pattern is seen in the results for fitness. The long-term fitness can reach a high level even when hatchery strays are effective spawners, but only if habitat condition provides for productivity and capacity at levels that are much higher than the Current Path or the Current Path + 75 scenario (Figure 3).



	CP	CP75	RG	H
1	0.50	0.50	0.86	0.94
0.9	0.50	0.50	0.88	0.95
0.8	0.50	0.50	0.90	0.96
0.7	0.50	0.50	0.92	0.97
0.6	0.50	0.50	0.94	0.97
0.5	0.50	0.59	0.96	0.98
0.4	0.58	0.71	0.97	0.99
0.3	0.75	0.82	0.98	0.99
0.2	0.88	0.91	0.99	1.00
0.1	0.96	0.97	1.00	1.00

Figure 3. Fitness of the composite naturally-spawning population (i.e., natural fish and strays), with Zero Harvest.

For pHOS, again using the Zero Harvest output tables as a reference, the results have a range of 1% to 15% under the Current Path habitat assumption, depending on the effectiveness of strays. In contrast, if habitat condition is at the Recovery Goal level, pHOS is fairly insensitive to spawner effectiveness for the presumed average number of strays (Figure 4).



Spawning Effectiveness	CP	CP75	RG	H
1	15%	11%	2%	1%
0.9	13%	10%	2%	1%
0.8	12%	9%	1%	1%
0.7	10%	7%	1%	1%
0.6	8%	6%	1%	1%
0.5	6%	4%	1%	1%
0.4	4%	3%	1%	0%
0.3	3%	2%	1%	0%
0.2	2%	1%	0%	0%
0.1	1%	1%	0%	0%

pHOS not very sensitive to spawning effectiveness when habitat condition is high.

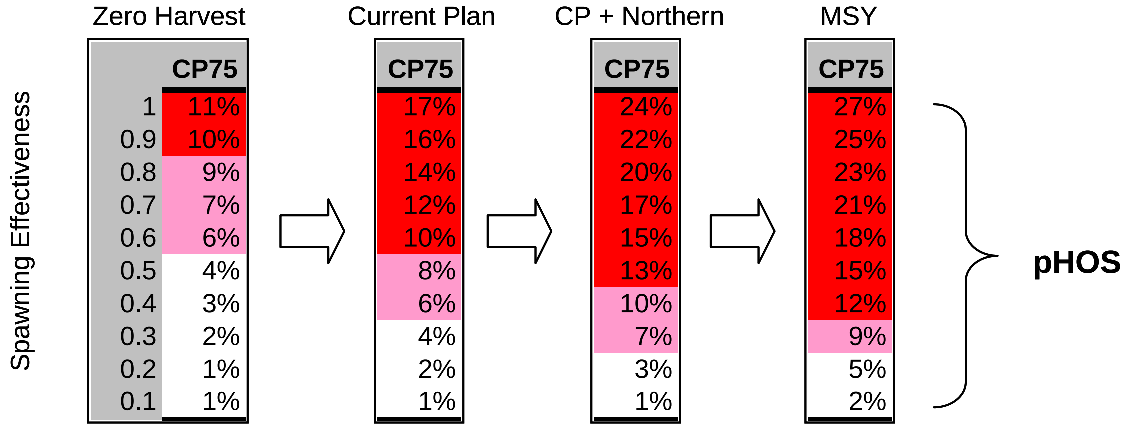
pHOS

pHOS very sensitive to spawning effectiveness when habitat condition is poor.

Figure 4. pHOS results in the Zero Harvest scenario.

Output sheets 2-4 reflect harvest as an additional component to the patterns observed in Output sheet 1. This allows us to examine the effect of each modeled harvest plan on each of the outputs, and to ask how harvest is affected by changes in habitat and in the spawning effectiveness of stray hatchery fish.

Figure 5 contains a single column from the pHOS output tables for each harvest scenario. The figure shows the pHOS outputs when habitat condition is Current Path + 75 and the harvest plan changes from Zero Harvest progressively to the Maximum Sustainable Yield scenario. Harvest has the effect in the model of decreasing the number of returning natural-origin spawners, while the hatchery fish in the Snoqualmie case are strays with an average annual abundance of 400. Thus, with a higher harvest rate, the ratio of NOS to strays decreases which translates to a higher pHOS.



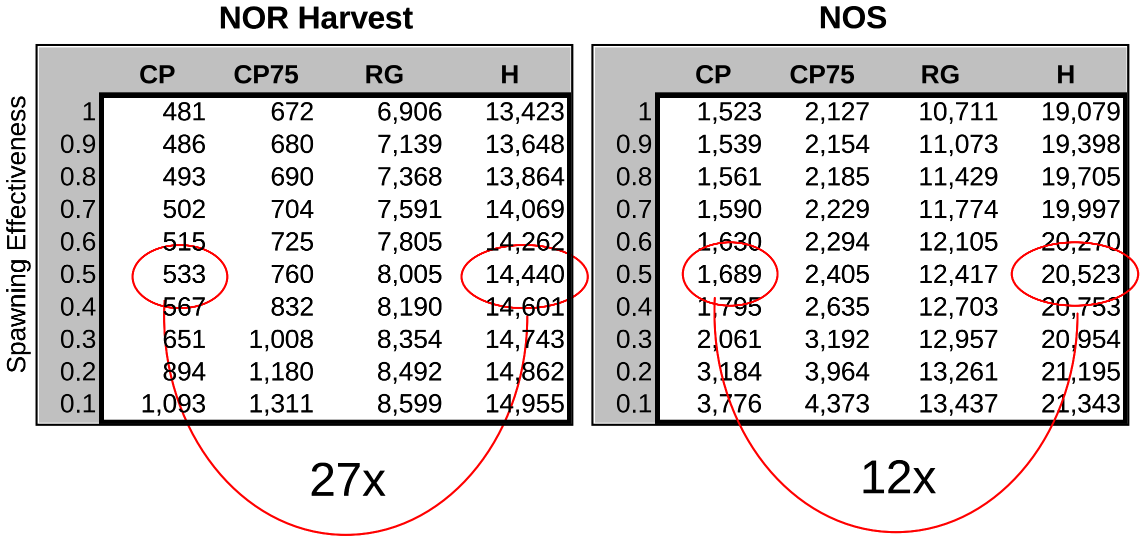
Spawning Effectiveness	Zero Harvest CP75	Current Plan CP75	CP + Northern CP75	MSY CP75
1	11%	17%	24%	27%
0.9	10%	16%	22%	25%
0.8	9%	14%	20%	23%
0.7	7%	12%	17%	21%
0.6	6%	10%	15%	18%
0.5	4%	8%	13%	15%
0.4	3%	6%	10%	12%
0.3	2%	4%	7%	9%
0.2	1%	2%	3%	5%
0.1	1%	1%	1%	2%

pHOS

Figure 5. Effect of progressively higher harvest rates on pHOS, with habitat condition of

Current Plan + 75.

Harvest results are very sensitive to habitat condition, i.e., improvements in habitat condition produce a large increase in harvest. This is because the harvest rate is linked to stock productivity (Table 5), so that a highly productive population can be harvested at a higher rate. For example, on Output Sheet 2 - Current Harvest Plan – assume that spawner effectiveness is 0.5. As habitat improves from Current Path to Historical condition, harvest increases 27-fold (Figure 6). Habitat improvement also has a strong influence on the mean abundance of NOS, though the response is not as dramatic as is the case for harvest (Figure 5).



NOR Harvest

Spawning Effectiveness	CP	CP75	RG	H
1	481	672	6,906	13,423
0.9	486	680	7,139	13,648
0.8	493	690	7,368	13,864
0.7	502	704	7,591	14,069
0.6	515	725	7,805	14,262
0.5	533	760	8,005	14,440
0.4	567	832	8,190	14,601
0.3	651	1,008	8,354	14,743
0.2	894	1,180	8,492	14,862
0.1	1,093	1,311	8,599	14,955

NOS

Spawning Effectiveness	CP	CP75	RG	H
1	1,523	2,127	10,711	19,079
0.9	1,539	2,154	11,073	19,398
0.8	1,561	2,185	11,429	19,705
0.7	1,590	2,229	11,774	19,997
0.6	1,630	2,294	12,105	20,270
0.5	1,689	2,405	12,417	20,523
0.4	1,795	2,635	12,703	20,753
0.3	2,061	3,192	12,957	20,954
0.2	3,184	3,964	13,261	21,195
0.1	3,776	4,373	13,437	21,343

Figure 6. Results for NOR Harvest and NOS in the Current Plan harvest scenario.

This pattern holds true in both the Current Plan and MSY scenarios, but is not as pronounced in the Current Plan + Northern scenario because the harvest rates do not increase as much with improved productivity. This makes sense in that the Current Plan + Northern scenario is essentially constructed to reflect the assumption that fisheries north of the U.S./Canadian border are not managed to be responsive to current conditions of productivity and capacity, which causes the target exploitation rate to be exceeded in some cases (Table 5).

In general, the MSY harvest scenario produces the highest catch, but the difference between that and the Current Plan + Northern scenario is much smaller than the difference in the harvest rates themselves. Also, the percentage gain in harvest is strongly influenced by spawning effectiveness. Figures 7 and 8 show the effect of spawning effectiveness on harvest and total recruitment (computed simply as natural-origin harvest plus spawners) under Historical and Current Path + 75 habitat conditions, respectively.

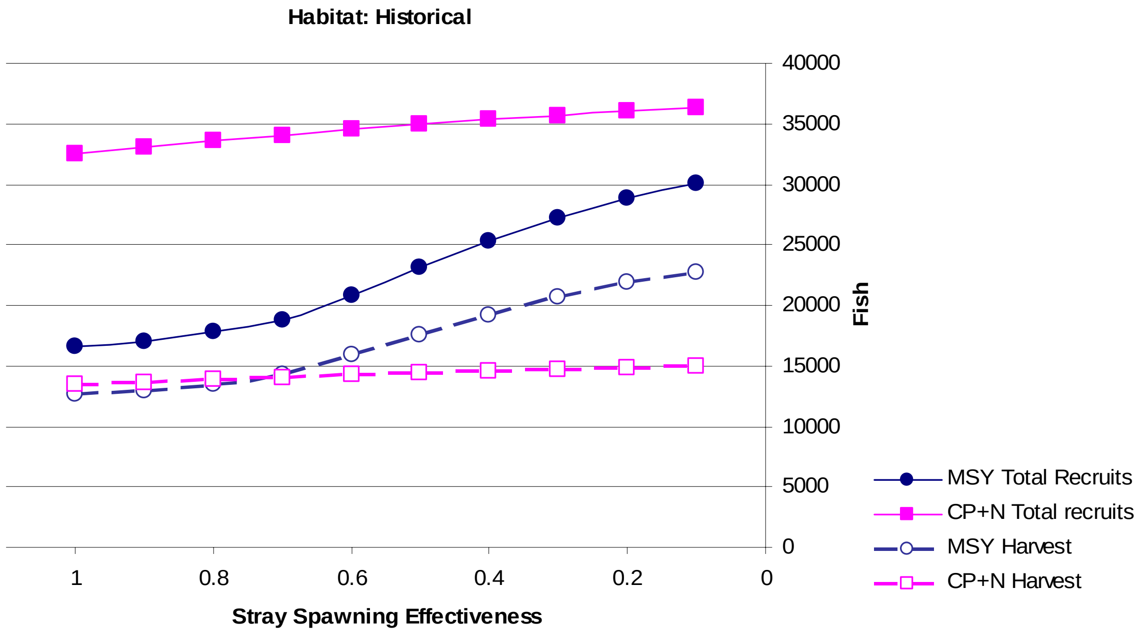


Figure 7. Total recruits and harvest as a function of spawning effectiveness for MSY and Current Plan + Northern harvest scenarios, assuming Historical habitat.

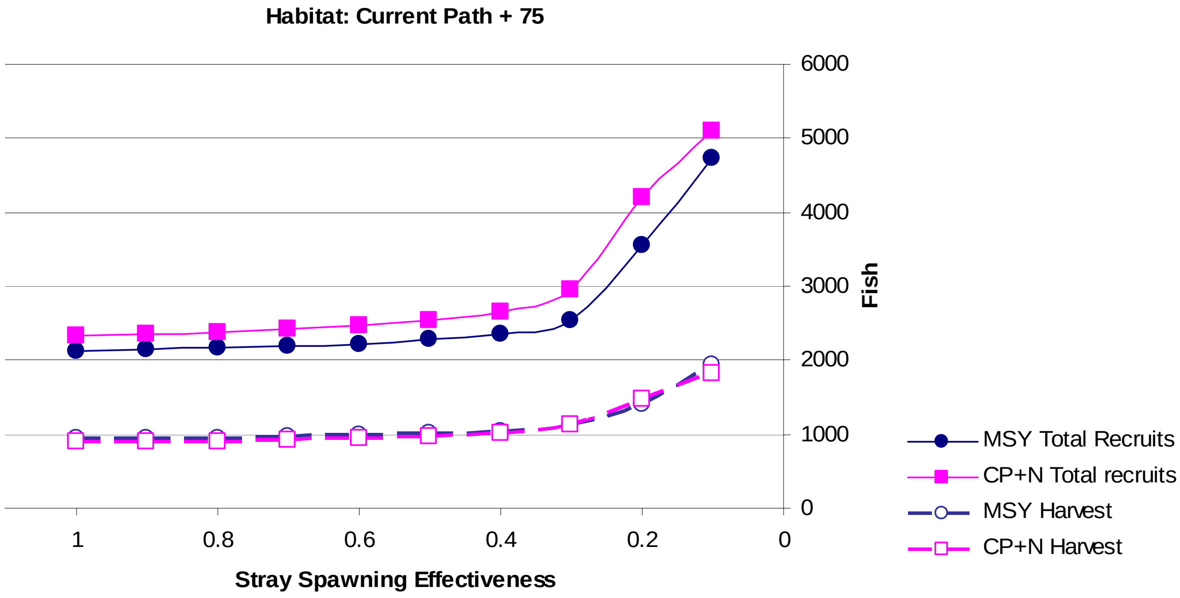


Figure 8. Total recruits and harvest as a function of spawning effectiveness for MSY and Current Plan + Northern harvest scenarios, assuming CP+75 habitat.

In Figure 7 (Historical habitat), while total recruitment is significantly higher for all values of spawning effectiveness for the Current Plan + Northern harvest scenario than for MSY, harvest numbers are nearly indistinguishable while spawning effectiveness of strays is high. In fact, harvest is higher for the Current Plan + Northern scenario when spawning effectiveness is very high. As spawning effectiveness decreases below a value of approximately 0.7, harvest under the MSY rate yields more fish.

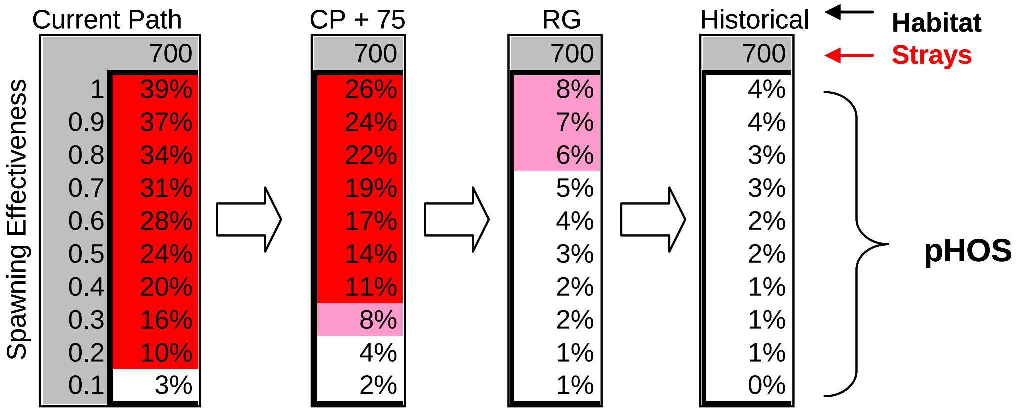
In Figure 8 (Current Path + 75 habitat), the harvest curves are indistinguishable between the two scenarios, though total recruitment is consistently higher for the lower rate of harvest under the Current Plan + Northern scenario. Under both harvest scenarios, as spawning effectiveness decreases to values below approximately 0.3, both total recruitment and harvest increase sharply.

2.3.2 Analysis 2: How sensitive is the performance of the Snoqualmie population to the mean abundance of hatchery strays?

For the second portion of the Snoqualmie analysis, we held the harvest plan constant in the Current Plan + Northern scenario, since this is the best estimate of current harvest rates. Output sheets 5 and 6 show the results for pHOS and Fitness, respectively.

The effect of increasing the mean number of strays is computationally equivalent to increasing the spawning effectiveness of a smaller number of strays. As strays increase from 400 to 700, pHOS increases by 30-100%, depending on the presumed habitat condition. Similarly, with habitat at presumed historical conditions, the spawning effectiveness of 700 strays must be less than 0.5 to keep the fitness value above 0.9. The other output categories follow similar patterns. So, a mean number of strays that is higher than the 400 used in Analysis 1 amplifies the patterns described above, whereas a lower number mutes them.

Figure 9 shows the effect of habitat condition on pHOS when the average number of strays is 700. Consistent with other results, improved habitat increases the productivity of the naturally spawning population and consequently increases the ratio of NOS to strays.



	Current Path	CP + 75	RG	Historical
	700	700	700	700
1	39%	26%	8%	4%
0.9	37%	24%	7%	4%
0.8	34%	22%	6%	3%
0.7	31%	19%	5%	3%
0.6	28%	17%	4%	2%
0.5	24%	14%	3%	2%
0.4	20%	11%	2%	1%
0.3	16%	8%	2%	1%
0.2	10%	4%	1%	1%
0.1	3%	2%	1%	0%

Figure 9. pHOS results for Analysis 2 with the mean number of strays set to 700. Harvest plan is Current Plan + Northern, the best estimate of actual current harvest.

In sum, Analysis 1 for the Snoqualmie case shows that all three H's strongly influence the results for the abundance of natural-origin spawners, and hence the number of fish available for harvest, as well as the ratio of NOS to hatchery strays (HOS). This ratio drives the results for pHOS and for Fitness.

Analysis 2 suggests that mean number of strays also has a strong influence on results, if those strays are effective spawners.

3 SKYKOMISH ANALYSIS

Since the Skykomish stock hatchery program is managed under an Integrated production strategy, the analysis focused on a different set of questions than the Snoqualmie exercise. In an integrated scenario, natural fish are integrated into the hatchery broodstock at rates based on the number of hatchery fish that spawn in the natural environment. The proportion of hatchery spawners must be controlled to prevent excess hatchery influence on the naturally spawning component of the stock.

The number of hatchery fish that spawn in the natural environment can be regulated in a number of ways within the AHA model. In the Snoqualmie case, all hatchery fish were deemed to be out-of-basin strays; but, in the Skykomish scenario, the focus is on the management of in-basin hatchery broodstock and natural spawning to meet specific genetic benchmarks. It should be noted that out-of-basin strays also occur in the Skykomish (as described below, Section 3.2.2, Table 7), but we did not include such an assumption in our analysis. The omission of out-of-basin strays allowed us to focus our analysis on the attributes of the current management approach in isolation, though future analyses could incorporate this feature.

Two ways to adjust the number of hatchery fish spawning in the natural environment were incorporated into our analysis:

- Selective harvest. The model allows the user to define different harvest rates for hatchery fish and natural fish in ocean and/or terminal fisheries.

- Hatchery surplus trapping efficiency rate. This rate is defined in the model as the proportion of hatchery-origin fish, after harvest, that are successfully trapped and thus removed from the naturally spawning population for use as broodstock and other purposes. The remaining proportion of hatchery fish (i.e., *1-trapping rate*) are presumed to be on natural spawning grounds.

The hatchery trapping efficiency rate analysis reflects a key component of broodstock management in the Skykomish. Currently, fish are trapped at two locations: the hatchery rack in the Wallace River, and the trap at the base of Sunset Falls that is used to transport fish above the falls. These traps are used to capture both hatchery and natural fish for use as broodstock in the integrated program.

3.1 Study questions and output categories for the Skykomish case

The Skykomish analysis investigated the following questions. As in the Snoqualmie case, the first question represents the overarching objective of the analysis and frames our discussion of model results:

- Analysis 1: How do assumptions about each "H" affect the Skykomish population's performance?
- Analysis 2: What effect would selective fisheries – such as mark-selective fisheries that only allow retention of hatchery fish in some areas – have on model results?
- Analysis 3: How sensitive are model results to the hatchery surplus trapping efficiency rate?

The outputs of interest in the Skykomish case are largely the same as in the Snoqualmie case, with two exceptions. While harvest in the Snoqualmie case focused only on the natural-origin stock, in the Skykomish analysis we also recorded results for harvest of the hatchery stock. Also, in place of pHOS as the primary measure of genetic interchange, it is more appropriate to use the Proportion of Natural Influence, or PNI, in its place.

  - *PNI: Proportion of natural influence.* As described above, in the integrated case, the key factor is the balance between the amount of hatchery influence on the naturally-spawning stock (pHOS) and the proportion of natural-origin fish integrated into the hatchery broodstock (pNOB). PNI describes the relative proportion of these two measures.

$$PNI = \frac{pNOB}{\left(pNOB + pHOS\right)}$$

In order to meet the goal of having the natural stock 'drive' the composite fitness of the integrated population, pNOB must be greater than pHOS (i.e., PNI > 0.5). For core populations of moderate to high biological significance, the HSRG recommends that pNOB should be at least twice as high as pHOS. Thus, PNI should exceed 0.67.

3.2 Methods

Figure 10 is a simplified representation of the key elements of the Skykomish model in AHA.

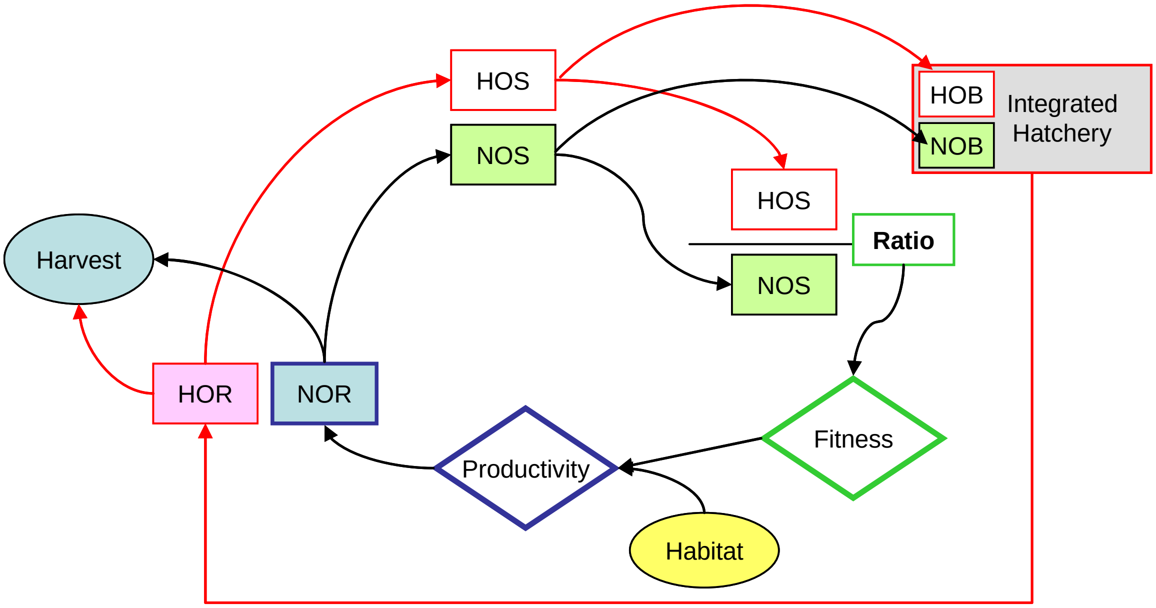


Figure 10. Simplified schematic of the Skykomish analytical framework.

As in the Snoqualmie case, we generated a suite of scenarios describing habitat conditions and harvest. In addition, we modeled a set of selective harvest scenarios and rates of trapping efficiency for surplus hatchery fish, as described, below.

3.2.1 Habitat Scenarios

Habitat scenarios simulated for the Skykomish population were the same as for the Snoqualmie and also derived using EDT. The parameter values for these were different, however (Table 6), because the model used reaches in the Skykomish River and its tributaries and excluded reaches in the Snoqualmie River and its tributaries.

Table 6. Productivity and capacity results for various habitat scenarios for the Skykomish Chinook population. Equilibrium abundance, MSH escapement level, and MSY Exploitation rate are computed from productivity and capacity (see Ricker 1975).

Population	Habitat Scenario	Productivity	Capacity	Equilibrium Abundance	MSY Exp Rate
Skykomish	Current Path	4.26	13,786	10,552	0.52
Skykomish	CP+75	5.23	16,430	13,286	0.56
Skykomish	Recovery Goal	11.07	32,286	29,370	0.70
Skykomish	Historic	15.85	52,878	49,542	0.75

3.2.2 Hatchery Scenarios

Hatchery fish in the Skykomish were modeled differently from the Snoqualmie because of the presence of an in-system hatchery, whose intent is to be integrated with the natural population. Hatchery-origin, native, Skykomish summer Chinook found on the spawning grounds in the Skykomish basin are not “strays”. Out-of-basin hatchery Chinook have been documented in the Skykomish and tributaries from the Skagit, Stillaguamish, and net pen facilities (Table 7), a geographic range apparently much smaller than that which contributes to the Snoqualmie (Table 3). This information is useful for illustrating the geographic range of hatcheries contributing to the Skykomish basin, but, because of uneven or spotty sampling effort throughout the basin and the inability to distinguish intended hatchery integrated fish from out-of-basin strays, the data are not useful for a quantitative assessment of the contribution of out-of-basin hatchery Chinook to the Skykomish system. Since our analysis for the Skykomish did not incorporate an element of out-of-basin 'strays', these data are presented for informational purposes only.

Table 7. Coded-wire tags (CWT) recovered from Chinook salmon carcasses in the Skykomish basin 1997-2005 by source and recovery location. This simply represents an accumulation of tags recovered over a 9 year period.

Release Site	Basin	Bridal Veil	Snohomish & Pilchk.	Skyk. & tribs	Wallace Riv	Total
Battle Creek	Snohomish	1				1
Grovers Creek	Kitsap		1			1
Mukilteo Net Pen				1		1
Red Creek	Skagit			1		1
Skagit River	Skagit			4		4
Stillaguamish River – NF	Stillaguamish			1		1
Wallace River	Snohomish	5	17	3	131	156
Whitehorse Springs	Stillaguamish				1	1
Unknown[1/]		13	1	3	75	92
Grand Total		19	19	14	207	258
Known Out-of-basin		0	1	8	1	9

[1/] Where the release location is identified as "unknown" the head sent to the laboratory did not contain a tag, the tag was not sent to the laboratory or lost by the laboratory, or the tag was unreadable for some other reason. These are not included in out-of-basin totals.

The contribution of in-system hatchery Chinook that is available to date (primarily from prior Tulalip and Wallace River Hatchery fall Chinook programs with minor summer Chinook data) has been assessed through thermal mass-marking. Assessments of the new summer Chinook programs are underway, but are still awaiting the adult returns necessary for them to be completed. Estimates of the contribution of Wallace River Hatchery fall Chinook for 1997-2000 and Tulalip Hatchery fall (and some summer) Chinook for 1997-2005, expanded from sampling of carcasses and analysis of otolith for thermally- marked otoliths (see 2.2.2 for more detail on methods), are shown in Table 8. Since these hatchery programs are currently integrated (i.e., gametes for the Tulalip Hatchery summer Chinook program are provided from the Wallace Hatchery annually), these data on the relative contribution of

Wallace versus Tulalip fall Chinook salmon to the spawning population are not explicitly incorporated into our analysis.

Table 8. Estimated number of Wallace and Tulalip Hatchery origin Chinook salmon reaching natural spawning grounds in the Skykomish system, 1997-2005, based on recoveries of thermally-marked otoliths from spawned out carcasses (Rawson, Kraemer, and Volk 2001 and K. Rawson, Tulalip Tribes, unpublished data). Because thermal mass-marking of Wallace River hatchery Chinook ceased with the 1997 brood year due to funding constraints, estimates are not available after 2000.

	Wallace releases - Tag recovery locations				Tulalip releases - tag recovery locations			
Year	**Skyk./Sno.**	**Wallace**	**Bridal Veil**	**Total**	**Skyk./Sno.**	**Wallace**	**Bridal Veil**	**Total**
1997	18	285	188	491	0	91	13	104
1998	1081	1320	431	2832	46	15	26	87
1999	597	1165	278	2041	5	0	0	5
2000	205	1607	275	2088	34	35	0	69
2001					110	0	0	110
2002					64	57	60	181
2003					41	0	175	216
2004					49	0	37	87
2005					31	0	0	31
Avg	475	1094	293	1863	42	22	35	99
SD	470	570	101	984	33	33	57	66
Min	18	285	188	491	0	0	0	5
Max	1081	1607	431	2832	110	91	175	216

Trapping efficiency

We modeled a range of values between 0.4 and 1.0 for the trapping efficiency rate for surplus hatchery fish. The default value entered into the model by WDFW is 0.85; this implies that 85% of surplus hatchery fish are successfully trapped while the remainder are allowed to spawn in the natural environment. The default rate was inferred from an examination of fish-count data from the two trap locations, coupled with estimates of total spawning escapement for hatchery fish (Andy Appleby, WDFW, personal communication).

3.2.3 Harvest Scenarios

Harvest management scenarios for the Skykomish population were derived in the same way as for the Snoqualmie population, but the numbers are different because the population parameters are different for the Skykomish population (Table 9).

Table 9. Exploitation rates for harvest management scenarios corresponding with habitat scenarios, Skykomish population. The rate used for a particular harvest scenario depends on the habitat scenario modeled. See text for further explanation.

Population	**Habitat Scenario**	**Zero Harvest**	**Current Plan**	**Current Plan w/ northern**	**MSY**
Skykomish	Current Path	0.000	0.242	0.380	0.516
Skykomish	CP+75	0.000	0.264	0.380	0.563
Skykomish	Recovery Goal	0.000	0.328	0.380	0.699
Skykomish	Historic	0.000	0.351	0.380	0.749

Finally, AHA allows for input on the differential between the exploitation rate on marked hatchery fish and on unmarked fish to take into account mark-selective fisheries. In mark-selective fisheries, anglers (currently selective regulations have been applied only to hook-and-line recreational fisheries) are allowed to keep hooked fish that have been marked by removal of the adipose fin while they are required to release hooked fish that do not bear this mark. Currently some portion of Puget Sound recreational fisheries for Chinook salmon operate under mark-selective regulations. There have been proposals to increase this fraction in the future, and there have been discussions regarding proposing that some portion of Canadian fisheries intercepting Puget Sound Chinook also operate under mark-selective regulations.

We ran three scenarios for selective fisheries that affect the harvest of Wallace River and Tulalip hatchery Chinook: no selective fishery, 2007 level of selective fisheries, and 2007 level plus northern selective fisheries.

No selective fishery

Under this scenario, the exploitation rates for Wallace River and Tulalip hatchery-origin Chinook salmon equal the rates for natural-origin Chinook.

2007 Level of Selective Fisheries

Because the pattern and amount of selective fisheries are not currently consistent from year to year, and because basic parameters of these fisheries are still being estimated through intensive monitoring, it is difficult to construct a current conditions scenario for selective fisheries at this time. Instead, we looked at the difference between the exploitation rate on natural-origin Snohomish Chinook and Wallace River Hatchery Chinook in the preseason planning model for 2007, which was .08. So, for this scenario, we obtained the exploitation rate on marked hatchery fish by adding .08 to the exploitation rate for natural-origin fish in all scenarios, except for the zero harvest scenario, which assumed no fisheries of any kind would be opened.

2007 Level of Selective Fisheries plus Northern Add-on

For this scenario, we added an additional .10 to the marked hatchery fish Chinook exploitation rate. This number is somewhat arbitrary, pending more analysis of possible levels of additional exploitation in selective fisheries north of the U.S./Canadian border.

3.2.4 Skykomish scenario definitions

As in the Snoqualmie case, the model scenarios can be divided into two groups. In the first set we held the trapping efficiency rate constant at 0.85 and analyzed the effect of changes in:

1. habitat condition (4 options),
2. harvest rate (4 options, rates are conditional based on habitat condition)
3. selective harvest rate (3 options)

The second set of model runs focused on the trapping efficiency rate.

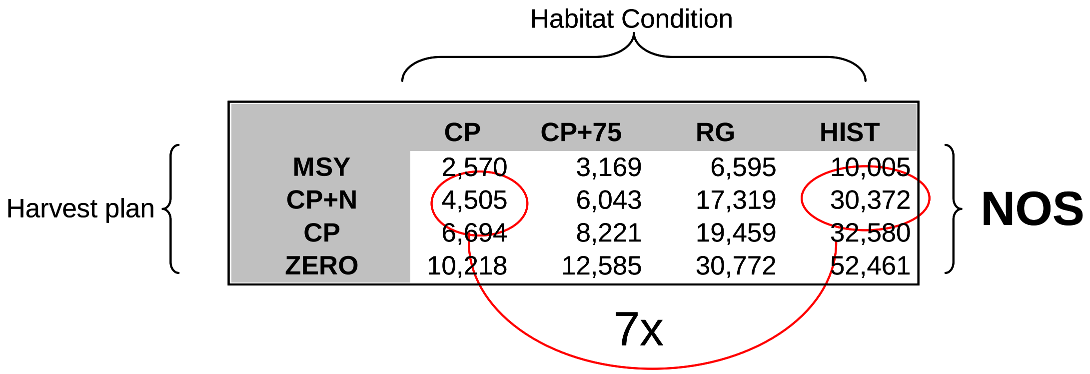
3.3 Skykomish results

The tabular results for the Skykomish are presented in Appendix 2. The PNI thresholds described above are reflected in the color-coding for the PNI tables. The results for the first study question can be found in the left-hand column of Output sheet 1. The results for the second study question regarding selective fisheries are in the middle and right-hand columns of the same sheet. The results for the third study question regarding trapping efficiency are located on Output sheets 2-4.

As in section 2.3, some of the output tables are reproduced in the text of the document for added clarity.

3.3.1 Analysis 1: How do assumptions about each "H" affect the Skykomish population's performance?

Habitat improvement, as reflected in higher productivity and capacity, has a significant effect on the natural population size and thus on results for all of the outputs of interest (Appendix 2, Output Sheet 1). For example, NOS increases seven-fold as habitat condition improves from Current Path to Historical, with Current Plan + Northern as the harvest scenario (Figure 11).



	CP	CP+75	RG	HIST
MSY	2,570	3,169	6,595	10,005
CP+N	4,505	6,043	17,319	30,372
CP	6,694	8,221	19,459	32,580
ZERO	10,218	12,585	30,772	52,461

Figure 11. Skykomish NOS results in the absence of selective fisheries.

For similar reasons as those described in the Snoqualmie case, the magnitude of the positive effects of improved habitat on metrics like PNI and fitness are reduced when harvest rates are lower, i.e., the ratio of natural-origin fish to hatchery-origin fish on the spawning grounds gets higher.

As in the Snoqualmie case, increases in harvest as a result of improved habitat are larger than the NOS improvements by comparison, in part due to the fact that the harvest rates themselves are tied to the productivity of the population. Under the MSY harvest scenario (without selective harvest), NOR harvest increases ten-fold from about 3,000 fish under the Current Path habitat condition to 31,000 under the Historic habitat scenario.

The harvest plan of course has a strong influence on the number of natural-origin spawners. Under the Current Path habitat condition, NOS abundance with MSY harvest is roughly one-fourth of the abundance in the Zero Harvest scenario.

When habitat conditions are at the Current Path level, the mean annual harvest of natural-origin fish is slightly higher in the Current Plan + Northern fishery than under MSY harvest, despite the higher nominal harvest rate in the MSY case. This is because the total recruitment is significantly higher under the Current Plan + Northern scenario.

3.3.2 Analysis 2: What effect would selective fisheries – such as mark-selective fisheries that only allow retention of hatchery fish in some areas – have on model results?

The effect of selective harvest can be seen by comparing results in adjacent columns of Output Sheet 1. The left column is the base case without selective harvest. The middle column harvests hatchery fish at a rate that is 8% higher than the base case. Finally, the right column shows the results for the “2007 + Northern Selective” case which has an 18% higher harvest rate on hatchery fish.

In this analysis (i.e., with trapping efficiency fixed at 0.85), the effect of selective harvest is fairly subtle. As one would expect, the benefits to natural fish are greatest when harvest rates are highest (i.e., the MSY case). For example, fitness in the MSY scenario under Current Path habitat conditions, improves from 0.81 without selective harvest to 0.87 at the 18% selectivity level (Figure 12). The improvement in fitness is less for the more conservative harvest scenarios.

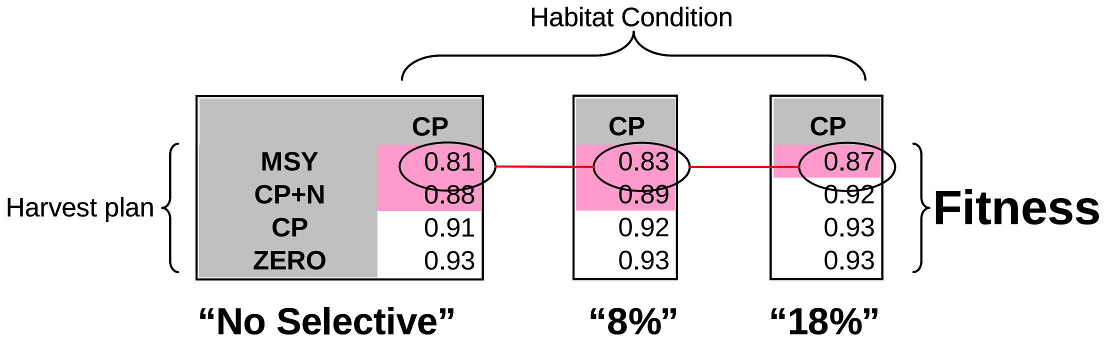


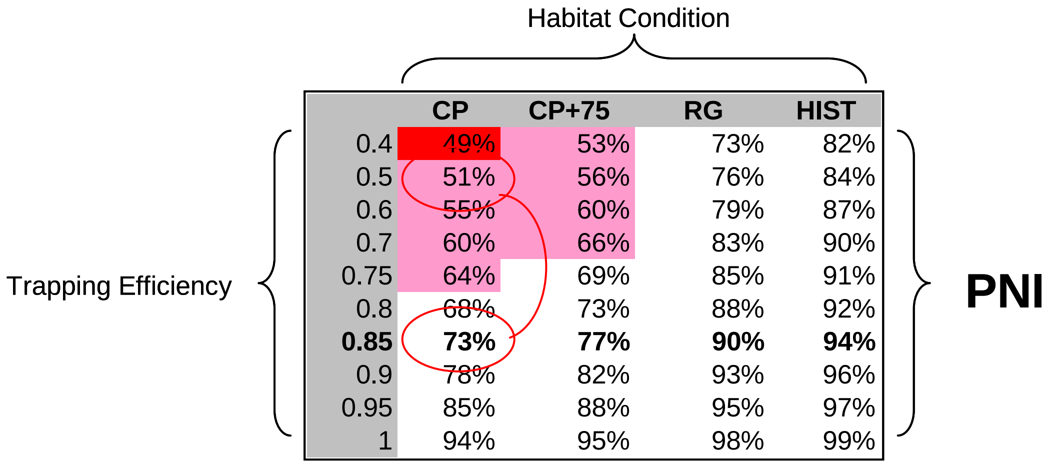
Figure 12. Fitness results for different levels of selective fisheries. Hatchery fish trapping efficiency rate is the default rate of 0.85.

Importantly, since selective harvest has a positive impact in the model on the fitness of the composite, naturally spawning population thus on productivity, even the total harvest of natural-origin fish is slightly higher on average due to higher abundance when fishing is selective, even though the harvest rate itself is unchanged.

3.3.3 Analysis 3: How sensitive are model results to the hatchery surplus trapping efficiency rate?

The results for the trapping rate analysis are shown in Output Sheets 2-5, with a range of rates from 0.4 to 1.0, shown as row headings on the result tables. Recall that the default rate used for the first analysis was 0.85.

For purposes of this discussion, we will focus on the No Selective Fishery case. The results show that if habitat condition reaches the Historical or Recovery Goal level, then all of the output categories are insensitive to trapping efficiency. However, with habitat condition at the Current Path or Current Path + 75 level, the rate has a strong influence on results. For example, if the trapping rate were 0.5 instead of 0.85 with the Current Path habitat condition and the Current Plan + Northern harvest scenario, PNI would decrease to 51% from 73% (Figure 13).



	CP	CP+75	RG	HIST
0.4	49%	53%	73%	82%
0.5	51%	56%	76%	84%
0.6	55%	60%	79%	87%
0.7	60%	66%	83%	90%
0.75	64%	69%	85%	91%
0.8	68%	73%	88%	92%
0.85	**73%**	**77%**	**90%**	**94%**
0.9	78%	82%	93%	96%
0.95	85%	88%	95%	97%
1	94%	95%	98%	99%

Figure 13. PNI results for Analysis 3. Bold values for an efficiency of 0.85 correspond with the default rate assumption.

In general, under one of the two lower-productivity habitat scenarios, NOS abundance increases by 13 to 25% as trapping efficiency increases from 0.4 to 1.0, depending on the harvest plan. A similar change is seen in the results for NOR harvest.

Note that the harvest of hatchery fish does not change with trapping efficiency. This is because trapping is applied as a post-harvest action, with fish used for broodstock or other non-harvest purposes.

As expected, the influence of the trapping efficiency rate is greatest when productivity is low and harvest is high and non-selective. Changes in any of these variables changes NOS abundance, as well as PNI and fitness values.

4 DISCUSSION

Successful recovery of Snohomish Basin Chinook salmon will require concerted efforts from harvest and hatchery program managers, and from the entities charged with protecting and restoring habitat. Proactive steps for recovery have already been taken across all three H's as described in the recovery Plan. Hatchery broodstock selection and management have been substantially modified from historic practices in the Skykomish system in order to meld natural and hatchery Chinook into a single, integrated stock. The shift to summer return timing from prior fall-run production may also help to reduce the spawning overlap of hatchery fish that stray into the Snoqualmie river where the natural stock is genetically distinct.

The Chinook harvest management plan is similarly intended to aid recovery of natural stocks by focusing directed fisheries on hatchery fish and by striving to limit total exploitation rates of natural stocks to a level that promotes population recovery.

Habitat restoration is under way on a number of fronts, with ambitious projects completed or underway in the mainstem Snoqualmie River and major tributaries, Skykomish River, the marine nearshore and in the estuary. Smaller-scale projects, such as riparian plantings on tributaries, have been completed along many miles of stream, though the rewards from these efforts will accrue over the long-term as vegetation matures. However, the funding for habitat restoration has not been adequate to date at federal, state and local levels and may bring into question the ability to meet the milestones identified in the Plan. Additional, creative avenues for funding must be identified. A new State agency – the Puget Sound Partnership – holds promise for gaining momentum on the State and Federal levels to support recovery efforts.

Habitat protection is applied unevenly, depending upon several factors, including the types of activities in question, land-use practices, jurisdiction, enforcement, and funding. Land acquisitions have taken place in several key areas and many environmental regulations have improved in the level of protection afforded to wetlands and waterways. Still, much remains to be done on this fragmented front while the pressure for development remains substantial.

As part of the ongoing H-integration process, the Committee elected to use the AHA model in a heuristic way to explore the interdependencies among assumptions and strategies across all three H's. The results of our analysis suggest that both Chinook populations in the basin are sensitive to the management of hatcheries, harvest, and to the condition of habitat. The relative influence of each "H" on population performance varies across a range of scenarios. The main findings for each population are summarized below, followed by a discussion of the limitations inherent to the AHA model and how they affect the interpretation of results. We then provide a brief summary of some of the key factors that were not included in this analysis and suggest priorities for future work in these areas. Finally, we discuss the implications of this effort for monitoring and plan implementation in the Snohomish Basin.

4.1 Summary of key results

In both the Snoqualmie and Skykomish analyses, a change in habitat was simply modeled as a change in the productivity and capacity of the population. With regard to harvest, the analyses differed in that only harvest of natural-origin recruits was computed in the Snoqualmie case, since the only hatchery fish in the model were those that had survived fisheries and strayed into the basin to spawn. In the Skykomish case, we computed harvest for both natural and hatchery-origin fish, and added an element of selective fishing to our assessment.

The hatchery element in the two analyses was substantially different. In the Snoqualmie analysis, we focused only on the role of stray hatchery fish and their potential to adversely affect the natural population via interbreeding. We analyzed the role of spawning effectiveness of stray fish, and the sensitivity of results to the average number of strays that reach the spawning grounds on an annual basis.

In the Skykomish analysis, we focused on a different element of the hatchery component of the model. We tested the sensitivity of the model to the hatchery trapping efficiency assumption, i.e., the rate at which hatchery fish are trapped in the river, prior to an opportunity to spawn naturally.

4.1.1 Snoqualmie findings

Our results show a stark difference in the population's performance depending on the condition of habitat. Most importantly, the results are markedly different between the Current Path + 75 habitat scenario and the Recovery Goal. This is not surprising in that the productivity rate and population capacity for the latter are much higher, but it has important implications for recovery planning and management in the basin. The CP+75 habitat scenario is the habitat condition that the Plan aims to achieve, based on work completed in the first ten years. Attainment of productivity and capacity commensurate with the Recovery Goal scenario will depend on future plans and commitments that have not been achieved yet. Thus, we must concern ourselves with the short- to medium-term implications associated with the Current Path and CP+75 scenarios, and also with the long-term interplay of the H's under hypothetical, significantly improved habitat conditions.

The Snoqualmie results illustrate an important pattern: when productivity is low (i.e., habitat is poor or only slightly improved), natural fish abundance is limited significantly by the spawning effectiveness of stray hatchery fish. In contrast, when productivity is high, abundance is limited by capacity, as the effect of strays is diluted by the high ratio of natural-origin fish to hatchery fish. Harvest directly regulates the ratio of natural fish to hatchery strays. Thus, the higher the harvest rate (which is only applied to natural fish in the Snoqualmie case), the lower the proportion of natural origin fish on the spawning ground. Thus, the fitness of the composite population is reduced, which translates in the model to lower productivity and subsequent recruitment.

According to the model, while habitat conditions are within the lower two categories, the pHOS and Fitness are very sensitive to spawning effectiveness, even in the absence of harvest. For example, in order to meet the HSRG guideline that pHOS should be less than 5%, the spawning effectiveness of stray hatchery fish at their current estimated abundance (i.e., 400 per year) should be no higher than 0.4 under the Current Path habitat case and no more than 0.5 in the CP+75 case. It is possible that due to spatial and/or temporal differences in spawning that we are meeting that guideline, but it is an important area for monitoring and research. The Fitness results show a serious long-term degradation with even lower rates of effectiveness by strays. If the foundation for the model's fitness calculation is sound, then this suggests that reliance on pHOS as a descriptor of risk related to interbreeding is inadequate.

As explained above, the addition of harvest further impacts the proportion of hatchery strays to natural fish on the spawning grounds in the Snoqualmie. If the Current Plan + Northern harvest scenario is indeed the best estimate of current harvest rates (despite the absence of directed fishing on the natural stocks in U.S. fisheries), then the thresholds of spawning effectiveness are even lower for maintaining both low pHOS and high Fitness (see Appendix 1, Output Sheet 3).

Even with much improved habitat and resulting improvements in productivity and capacity, the model suggests that pHOS and Fitness are sensitive to the harvest rate if spawning effectiveness of strays is high. This of course ignores the fact that harvest and hatchery management might well change substantially if natural stock recruitment were to increase by 10 to 20-fold, but it does suggest that even at high rates of natural production, hatchery strays that are effective as spawners can retard fitness, leading to lower recruitment and harvest.

4.1.2 Skykomish findings

The Skykomish analysis addressed a different set of questions in a very different context. The population itself is managed as an integrated one and thus has a different set of management objectives and potential concerns. Specifically, through the active management of hatchery broodstock, the naturally spawning stock is intended to drive selection in the composite population. An important assumption, however, is that the ratio of hatchery origin and natural origin spawners on the spawning grounds is known so that hatchery broodstock composition can be adjusted accordingly. This assumption was the focus of our second analysis regarding the trapping efficiency rate.

Our first analysis focused on the effects of changes in harvest management to emphasize selective harvest so that hatchery Chinook are harvested at a higher rate than naturally spawning Chinook. Selective harvest decreases the proportion of hatchery origin fish to natural fish on the spawning grounds and thus influences PNI and Fitness. As our results show (Appendix 2, Sheet 1), a progressively more selective harvest regime results in higher PNI and Fitness values. However, even in the non-selective fishery and with the hatchery broodstock collection protocol populated in the model according to current practice (as modeled by Andy Appleby, WDFW), there are no 'red flags' regarding PNI or Fitness. Only slightly reduced Fitness and elevated pHOS are evident when habitat is in the Current Path state and only if harvest rates are relatively high. So, if the model is populated correctly and if the default hatchery trapping efficiency rate of 0.85 is accurate, then the model suggests that management is currently meeting the objectives associated with an integrated program.

Our second analysis focused on the trapping rate assumption. This is an important model element since it has direct bearing on the ratio of HOS to NOS on the spawning grounds, coupled with the fact that the Skykomish does not have a mainstem weir that is low in the system where spawning composition could be directly controlled. The Sunset Falls trap provides that opportunity for the South Fork Skykomish, and the Wallace hatchery rack provides a collection point for the upper Wallace River, but returning Chinook have access to many spawning areas without ever encountering one of the traps.

As shown in Output Sheets 2-5 in Appendix 2, the results are in fact very sensitive to the trapping rate, especially as harvest rates increase. Even in the absence of harvest, if trapping efficiency is 0.7 or lower, the PNI values drop below the 0.67 threshold for biologically significant populations when habitat is in one of the two lower quality categories, which is likely to be the case for some time to come. As is the case in the Snoqualmie, the effects on fitness are even greater when harvest is added to the mix. For example, under the best-estimate Current Plan + Northern harvest scenario, fitness falls below 0.8 at trapping efficiency rates that are only modestly lower than the default assumption. Again, the validity of the fitness model is key to understanding the importance of these results, but even the PNI results suggest an important area for validation monitoring.

Of course one element of an integrated program is the ability to change the broodstock mix in order to meet genetic goals in response to data. The current broodstock management plan has contingency features associated with the availability of sufficient numbers of hatchery and naturally spawning Chinook that are collected at the traps (Appendix H, Snohomish Basin Salmon Recovery Forum 2005). The ability to monitor the composition of the spawning population and to change the broodstock mix in real time should be a key part of the management system.

Finally, recall that our modeling of the Skykomish system did not include the addition of out-of-basin hatchery strays, though we know that these fish are found in the Skykomish. The choice to omit them was simply based on our interest in focusing on the elements of the Skykomish system that are part of the current integrated management approach. Based on our Snoqualmie results and our understanding of the model, out-of-basin strays present an additional challenge for meeting genetic objectives, whether measured in terms of PNI or as reflected in fitness. In fact, we expect that if there were an equivalent proportion of out-of-basin strays in the Skykomish, they would have a greater negative effect on model results in that basin than in the Snoqualmie. This is because the fitness of an integrated population is lower than that of a purely natural population to begin with. Thus, the effects of outside hatchery fish – if they are effective as spawners – would be felt more strongly. Available data suggest that the proportion of strays is not currently as high in the Skykomish, but monitoring of spawner composition will remain an important priority.

It may be that large differences in genetic and life history diversity among different hatchery strays can have profoundly different effects on spawning effectiveness of the target natural population, resultant genetic exchange and adaptive management decisions, which may account for how different certain target populations and the corresponding hatchery stocks are from each other. For example, different genetic assumptions and management implications might be derived where the hatchery stock is locally-derived from a genetically similar, integrated stock, compared to an out-of-basin stock hatchery stock that is genetically very different and not integrated with a natural stock. It remains to be seen how the recent changes in broodstock at the Wallace hatchery from an out-of-basin, fall-timed, non-integrated stock with a relatively high contribution rate to an in-basin, summer-timed, genetically integrated stock, might affect contribution rates, resultant spawning effectiveness and genetic exchange, and ultimately, risk assessment and implications for management.

4.2 Limitations of the underlying model

As is the case with any model, an understanding of the assumptions and simplifications that are inherent in model design are just as important as the results. Our discussion in this section is focused on just two of these elements – the underlying model of fitness as it relates to interbreeding between natural and hatchery populations (adapted from Ford 2002), and the lack of stochasticity in the model.

4.2.1 Fitness

The Ford model reduces fitness to a single trait with hatchery and wild optima rather than combination of multiple traits with variable levels of phenotypic plasticity. In reality, fitness is a product of multiple genetic traits with varying degrees of heritability and variable degrees of expression. A single trait (or suite of traits) can be expressed differently in the hatchery and wild environments without any heritable change. The variation in expression of a trait across environments is called its ‘norm of reaction’ (Lynch and Walsh 1998). Finally, in reality, selection is not necessarily directional toward either hatchery or wild optima (and away from the other). Traits that are directionally selected in one environment can have selective forces simply relaxed/absent in the other environment so that the trait drifts randomly (to the extent of the population’s genetically effective size) rather than being pushed away from one optimum toward the other.

As the Ford model is applied within the AHA model, the default inputs for the ‘distance’ between hatchery and wild fitness optima appear arbitrary, as is strength of selection in each environment on the single fitness trait. These variables can be adjusted, but we have not done so for this analysis as the model and associated documentation lack guidance on the use of these model variables (Mobrand – Jones & Stokes 2007).

While fitness loss inputs are somewhat arbitrary and may be overly reductive, model outputs of projected rates of fitness can still be compared to observed rates of fitness loss in both inbred hatchery populations (e.g., Quilcene National Fish Hatchery coho), and wild populations with extensive evidence of long-term hatchery contributions (e.g., Cedar River Chinook) to estimate the realism of worst-case scenario outputs from the model. In the case of Quilcene NFH coho, heterozygosity has been measured to decrease, as would be expected from a population maintained in a hatchery for 20 or more generations (Smith et al. 2007), but performance in the hatchery has not declined over that time, and the population has not been shown to contribute its unique genetic structure into populations that do not immediately neighbor it (Adrian Spidle, Northwest Indian Fisheries Commission, personal communication).

There is evidence from Atlantic salmon in Maine, Nooksack River coho, and Sol Duc system Chinook that despite the apparent ubiquity of hatchery fish, that aboriginal/native genotypes can persist despite apparent swamping with out-of-basin gene flow, suggesting that fitness loss from introgression is not a linear process, that while natural population fitness (numbers) may decrease with (effective) gene flow, there may be a floor below which effective gene flow stops occurring, or below which natural population fitness cannot be reduced. The model does include a fitness ‘floor’ variable, but this too is fairly arbitrary absent data to support a specific value. Also, the presence of fish of native ancestry where they have been looked for suggests that they may also be found in other locations where they are thought to be extinct, but simply have not been sought out (e.g. Atlantic salmon in Maine, NRC 2002, Spidle et al. 2003, Nooksack River coho salmon, Small et al. 2004). The Ford model does not consider this possibility.

Finally, AHA also allows the user to set the initial fitness values of each population. For example, the default values in the model provided by WDFW are 93.1 and 92.0 (out of 100) for the natural and hatchery stocks, respectively. Importantly, the values are not relative to each other, but to the potential maximum of each in its respective environment.

This poses an interesting question about the current or ‘initial’ fitness of the stocks. In particular, given decades of influence by hatcheries and by habitat and harvest management, how fit should we presume the natural stock to be? In terms of how the model works, a different initial value mainly influences the rate (during a model run of 100 generations) at which fitness either degenerates or improves over time.

It all amounts to an important ‘next step’, a sensitivity analysis of every permutation of the Ford model parameters and see if any of those outputs appear realistic compared to known situations such as Nooksack coho (Small et al. 2004). (such as Sol Duc Chinook, Quilcene coho, Adrian Spidle, Northwest Indian Fisheries Commission, personal communication).

4.2.2 Stochasticity

The AHA model is deterministic - it does not incorporate stochasticity for any variables. The marine survival component incorporates a 10-year repeating pattern of low, medium and high productivity years, but the sequence itself is not up to chance. Moreover, the natural and hatchery stocks experience the variable productivity regime in lockstep, so that a particular year is good, or bad, for both stocks. What if this is not the case? For example, suppose that the natural stock for a particular year experiences extremely poor egg-to-smolt survival, the life-stage that hatcheries are able to bypass with artificially high survival rates. If we then assume that marine survival patterns are the same, then the ratio of strays-to-spawners would likely be higher than average for that particular year, with a consequently higher rate of genetic influence (i.e., higher pHOS). The opposite case is of course also possible.

Similar issues may arise relative to other variables of interest, such as the number of strays that enter the Snoqualmie annually, and the rate of hatchery trapping efficiency in the Skykomish. Without integrating stochasticity into the analysis, we fail to appreciate the implications of natural and management-related variability, and we may generally understate or overstate the results associated with a particular set of assumptions.

4.3 Important features of the system not addressed by the model

A model is not intended to capture all aspects of the system that it is designed to represent. Below we describe just a few of the most important elements of habitat, harvest and hatchery management that bear on the issues explored in this assessment.

4.3.1 Hatchery management

The AHA model does not explicitly allow for the consideration of spatial separation of hatchery Chinook and natural Chinook on the spawning grounds. The spawning effectiveness variable provides a somewhat blunt way to reflect assumptions about overlap, but it is likely that hatchery fish are more prevalent in certain spawning locations than in others. Capturing a more explicit spatial component in the model would allow for a more realistic assessment of local spawning distribution and resulting effects on spawning effectiveness.

Importantly, the model does not include any ecological interactions between hatchery fish and wild fish, such as competition, predation or disease transmission. Even in the absence of actual interbreeding, competition among adult spawners may affect the spawning success and resulting productivity of the natural population. Similarly, competition and predation among juveniles may affect juvenile survival directly or through effects on feeding efficiency, energy expenditure and resulting growth. Consideration of the spatial distribution and timing of hatchery juvenile release locations should be incorporated in such as assessment, coupled with data about the rearing distribution of natural-origin juveniles.

The model incorporates a simplistic model of life-history diversity for both juveniles and adults that may exaggerate some interactions and dynamics between hatchery and natural fish while muting others. Natural Chinook in the basin express a diverse suite of juvenile life histories with both yearling and fry-migrant population components and variable periods of rearing in the river, estuary and nearshore areas. Similarly, the model assumes that hatchery juveniles are exclusively released as smolts rather than as fry.

Adult life-history is also far from uniform, with differences in the age-of-return over time and between hatchery and natural populations. The current version of the model assumes discrete rather than overlapping generations. Modifying the model to account for age and life-history structure would allow for a more realistic depiction of the local populations.

4.3.2 Harvest management

Recruitment and harvest are modeled in AHA as if all fish from a population enter fisheries at the same age and all fish escaping fisheries return to spawn. In fact, neither assumption is valid for Chinook salmon. AHA uses so-called “adult equivalent” rates of fishing mortality to compensate for these limitations to some degree, but the lack of accounting for age distributions and fisheries that harvest a combination of mature and immature fish means that the model is not able to distinguish the effect of fish caught as mature fish (reduces escapement in the current year) from the effect of fish caught as immature (reduces escapement in a future year).

Because AHA is a deterministic model it does not consider risk due to various sources of management error, such as deviation of forecasted abundance form actual abundances, differences between projected and actual harvest or encounter numbers, and uncertainly about the mortality rate of fish hooked and released in mark-selective fisheries, to name a few. In general, stochastic simulation models show an increased risk with increased variance in these kinds of parameters, so, this aspect of AHA modeling would tend to portray less risk than is actually the case.

4.3.3 Habitat Management

The model's depiction of habitat is the most simplistic of the three H's, with habitat reduced to a static adult capacity and productivity rate. The values selected for this analysis were developed through the use of the EDT model. Thus, it is fairly unwieldy to explore alternative habitat restoration scenarios without re-running the EDT analysis to generate comparable values, a very substantial effort.

Habitat condition is also expected to change through time. Thus, the productivity and capacity of the populations will change during the 100-generation period of the model. The addition of a temporal element to allow either continuous or stepwise improvements in habitat would add important realism to model output.

Our modeling exercise utilized paired productivity and capacity values developed via EDT. However, we did not explore the possibility that the two values may change somewhat independently. For example, one of the priority restoration actions in mainstem areas is the reconnection of floodplain habitats, primarily to increase rearing habitat and resulting productivity. The adult capacity may remain unchanged in this scenario. Similarly, if new spawning areas are made available thorough barrier removal, the adult capacity would increase, though the productivity rate may remain the same. Further exploration of the relative sensitivity of model results to changes in productivity versus capacity may be informative, especially if coupled with stochastic processes and a temporal component to the habitat trajectory.

Finally, the model assumes that habitat is solely responsible for productivity and capacity, while it is plausible that harvest and hatchery practices also affect these variables. For example, changes in the age distribution of adult Chinook as a result of fishing may reduce the mean productivity of spawners over time. Similarly, if ecological interactions between hatchery fish and natural fish reduce juvenile survival or adult spawning success, productivity would be reduced for the natural stock.

4.4 Next steps for the technical committee

The results of our modeling effort have implications for areas of further research, monitoring and for adaptive management.

4.4.1 Monitoring priorities

One of the primary purposes of the modeling exercise was to develop guidance for prioritizing monitoring efforts. Specifically, we are referring here to the need for 'validation monitoring' - efforts that will help to calibrate model inputs and to assess the validity of assumptions made during the modeling process. The following list highlights some of the key data gaps that the Committee should attempt to address through monitoring efforts in the coming years.

Are stock productivity and capacity improving over time?

Habitat condition is expected to improve over time if the Plan is fully implemented. Monitoring and updating habitat conditions as they are defined in the EDT model would allow the Committee to assess whether sufficient progress is being made to meet Plan milestones. In addition, monitoring of escapement and harvest data should be used to better characterize the population trajectories over time and to recognize changes in the population that result from efforts in all three H's and other factors.

How many hatchery fish stray into the Snoqualmie and what is their origin?

Prior to the fairly recent changes in hatchery production (i.e., changing from imported fall-run fish to native summer-run broodstock in the Wallace and Tulalip hatcheries), hatchery fish comprised 20-30% of the spawners in the Snoqualmie. Following the initiation of thermal otolith marking, it has been possible to distinguish in-basin hatchery fish from their out-of-basin counterparts. In order to better quantify the average number of strays as well as the interannual variability in stray numbers, spawner sampling and identification efforts should be expanded temporally and spatially. For example, a recently proposed project by the Tulalip Tribes (in collaboration with WDFW and both Counties) would involve just such an effort. The project would expand escapement monitoring beyond currently sampled reaches, including tributaries and mainstem areas. Enhanced collection and accelerated processing of otolith samples are also included in the proposal. The results of the study would allow the Committee to revisit and refine the assumptions in the AHA model, and, more generally, to better assess the likely influence of hatchery fish on the natural stock.

Do the spawn timing and distribution of summer returning strays overlap with those of natural fall returning Chinook?

A key step in defining the spawning effectiveness of hatchery strays is to quantify the opportunity for interbreeding in temporal and spatial terms. For example, although summer-run fish enter rivers at an earlier date, they also may hold in rivers for extended periods prior to spawning. The extent of temporal overlap in spawning activity is a key data gap. Similarly, existing data suggests that strays may not be uniformly distributed throughout the spawning areas utilized by the natural stock. A better characterization of the spatial overlap of natural and hatchery fish is critical to developing estimates of spawning effectiveness.

Will summer returning fish exhibit different patterns of straying than fall returning fish?

As described above, both hatcheries in the basin have converted to native, summer-run stock from the Skykomish basin. Thus, estimates of straying rates that are based on the prior production regime may not be valid in the future. It is possible that - by virtue of their genetic make-up and altered return timing - the 'new' hatchery regime will produce a lower number of strays to the Snoqualmie.

Are certain hatchery practices more prone to produce strays?

This issue is by no means limited to the two hatcheries in the Snohomish Basin, but more generally to hatcheries around the Sound. Given the potential impact of strays and existing evidence of fairly widespread straying by hatchery Chinook, a region-wide analysis of hatchery practices, release strategies, broodstock and other factors should be undertaken in an effort to better understand factors that promote or dissuade straying. While the Snohomish Basin stakeholders are unlikely to take on this task independently, the Technical Committee and the Forum should support such an effort at the regional scale. The results could help to improve practices at our own facilities, and to reduce the adverse effects of out-of-basin hatcheries on Snoqualmie and Skykomish Chinook.

What is the trapping efficiency rate for hatchery fish in the Skykomish? How much does it vary year-to-year?

Quantification of the composition of naturally spawning Chinook in the Skykomish is imperative for successful management of the integrated program. The model suggests that the ability to meet integrated stock objectives (e.g., PNI) is highly dependent on this assumption. If variability can be quantified, the broodstock integration protocol could be adapted to allow for a safety margin that recognizes the potential risk. Alternatively, it may be desirable to adjust broodstock composition in real time in response to in-season spawning data.

4.4.2 Recommendations for adaptive management.

In addition to the monitoring priorities identified above, the Committee, Forum and co-managers will need to identify potential management responses to monitoring data and other new information over time. Example scenarios that require potential responses may include the following:

- If monitoring of spawner distribution in the Snoqualmie indicates that hatchery spawners from Wallace and Tulalip hatcheries tend to be found in some locations more than others, what actions are available for in-river management? What if they are equally distributed in all areas where natural fish spawn?
- Alternatively, if it is evident that out-of-basin stray numbers are higher than estimated for this report, what options are available for addressing the issue in relevant regional policy forums? Are there selective removal strategies that could be pursued in near-terminal areas to reduce this effect?
- If habitat plan implementation does not produce anticipated responses in productivity, what steps can be taken to accelerate effectiveness of habitat restoration efforts and assure that habitat protection measures are effective?
- If the habitat plan is not implemented as planned due to lack of funding or other factors, how would the management of the other H's need to change to make up for that failure? Is it possible to make up for insufficient habitat protection and restoration through management of harvest and hatcheries?

These are but a few examples of the difficult decisions that may confront the Forum, co-managers and other responsible parties as we work toward salmon recovery in the coming years. The AHA model is one tool – with its many shortcomings and limitations, and hopefully with future improvements – that can be used to revisit the questions addressed in this report as we collect more and better information through monitoring of all three H's.

5 REFERENCES

Ford, M. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology 16(3), P.815–825.

Hatchery Reform Technical Discussion Group. 2005. The All-H Hatchery Analyzer (AHA). Hatchery Reform Technical Discussion Paper, August 2005.

Hatchery Scientific Review Group (HSRG)–Lars Mobrand (chair), John Barr, Lee Blankenship, Don Campton, Trevor Evelyn, Tom Flagg, Conrad Mahnken, Robert Piper, Paul Seidel, Lisa Seeb and Bill Smoker. April 2004. Hatchery Reform: Principles and Recommendations of the HSRG. Long Live the Kings, 1305 Fourth Avenue, Suite 810, Seattle, WA 98101 (available from http://www.hatcheryreform.org)

HSRG. 2005. Hatchery reform in Washington State: principles and emerging issues. Fisheries 30(6):11-23.

HSRG/NWIFC/WDFW. 2004a. Technical Discussion Paper #1: Integrated Hatchery Programs. Hatchery Scientific Review Group (HSRG). 2004a. HSRG/WDFW/NWIFC technical discussion paper #1: Integrated hatchery programs. Long Live the Kings, Seattle, WA (available from http://www.lltk.org/)

Hatchery Scientific Review Group (HSRG). 2004b. HSRG/WDFW/NWIFC Technical discussion paper #2: Segregated hatchery programs. Long Live the Kings, Seattle, WA (available from http://www.lltk.org/)

Hatchery Reform Technical Discussion Group. 2005. The All-H Hatchery Analyzer (AHA). Hatchery Reform Technical Discussion Paper, August 2005.

ISRP/ISAB 2005. Review of the All-H Analyzer (AHA). Document ISRP/ISAB 2005-5.

Lestelle, L. C., L. E. Mobrand, J. A. Lichatowich, and T. S. Vogel. 1996. Ecosystem diagnosis and treatment: applied ecosystem analysis -- A primer. US Department of Energy, Bonneville Power Administration, Portland, OR. May 1996. 95 +.

Lynch, M. and B. Walsh. 1998. Genetics and Analysis of Quantitative Traits. 980 pp. Sinauer Press, Sunderland MA.

McElhany, P., M.H. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42,156 p.

Mobrand, L. E., J. A. Lichatowich, L. C. Lestelle, and T. S. Vogel. 1997. An approach to describing ecosystem performance "through the eyes of salmon". Canadian Journal of Fisheries and Aquatic Sciences 54:2964-2973

Mobrand – Jones & Stokes. 2007. All H Analyzer (AHA) User Guide – DRAFT. Updated November 2007. Version 7.3

National Research Council 2002. Genetic status of Atlantic salmon in Maine. 62 pp. National Academy Press Washington DC.

Puget Sound Indian Tribes and The Washington Department of Fish and Wildlife. 2004. Comprehensive Management Plan for Puget Sound Chinook – Harvest Component. (Available at: http://wdfw.wa.gov/fish/papers/ps_chinook_management/harvest/ps_chinook_harvest.pdf)

Puget Sound Indian Tribes, and Washington Department of Fish and Wildlife. 2004. Comprehensive management plan for Puget Sound Chinook: Harvest management component. Northwest Indian Fisheries Commission, Olympia, Washington, USA, 1-247 pages.

Rawson, K., C. Kraemer, and E. Volk. 2001. Estimating the abundance and distribution of locally hatchery-produced Chinook salmon throughout a large river system using thermal mass-marking of otoliths. North Pacific Anadromous Fisheries Commission Technical Report 3:31-34.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries and Marine Service, Ottawa.

Ruckelshaus, M., K.P. Currens, R. Fuerstenberg, W. Graeber, K. Rawson, N.J. Sands, and J.B. Scott. 2006. Independent Populations of Chinook Salmon in Puget Sound. U.S. Department of Commerce, NOAA, Northwest Fisheries Science Center, Seattle, WA, Tech. memo No. NMFS-NWFSC-78, 125 p..

Shared Strategy Development Committee. 2005. Puget Sound Salmon Recovery Plan. http://www.sharedsalmonstrategy.org/plan

Small, M.P., A.E. Pichahchy, J.F. Von Bargen, and S.F. Young. 2004. Have native coho salmon (*Oncorhynchus kisutch*) persisted in the Nooksack and Samish rivers despite continuous hatchery production throughout the past century? Conservation Genetics 5: 367–379.

Smith, C., J. Baumsteiger, M. Diggs, S. Walden, and W. Ardren. 2007. Genetic analysis of coho salmon populations in Hood Canal: How similar genetically are hatchery and natural populations? Abernathy Fish Technology Center, Conservation Genetics Program USFWS 1440 Abernathy Creek Rd Longview WA 98632.

Snohomish Basin Salmon Recovery Forum. 2005. Snohomish River Basin Salmon Conservation Plan. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.

Spidle, A.P., S.T. Kalinowski, B.A. Lubinski, D.L. Perkins, K.F. Beland, J.F. Kocik, and T.L. King. 2003. Population structure of Atlantic salmon in Maine with reference to populations from Atlantic Canada. Trans. Am. Fish. Soc. 132: 196-209.

Tulalip Tribes and Washington Department of Fish and Wildlife. 2005. Memorandum of Understanding. October 24, 2005, 16 pages.

WDFW and Puget Sound Treaty Tribes 1998a. Comprehensive Coho Artificial Production Plan. Washington Department of Fish and Wildlife & Puget Sound Treaty Tribes. A component of the Comprehensive Coho Salmon Management Plan. May 5, 1998.

WDFW and Puget Sound Treaty Tribes 1998b. Comprehensive Coho Salmon Management Plan. Washington Department of Fish and Wildlife & Puget Sound Treaty Tribes. May 5, 1998. Chapter 7 (Categories of Artificial Production); pp. 1-3.

WDFW and Puget Sound Treaty Tribes 2004. Research Management Plan for Puget Sound Chinook Salmon Hatcheries. Washington Department of Fish and Wildlife & Puget Sound Treaty Tribes. A component of the Comprehensive Chinook Salmon Management Plan. March 31, 2004. 148pp. Appendix A (Artificial Production Guidelines; pp 119-130 (Tables A1-A4; Guidelines for integrated and segregated hatchery programs).

APPENDIX 1: SNOQUALMIE MODEL OUTPUT SHEETS

1. Zero Harvest - output tables

Color Formatting Legend

		🟪	🟥
pHOS	5%	10%	> 10%
100g Fitness	0.9	0.8	< 0.8
NOS-esc%	0.9	0.8	< 0.8

CP: Current Path
CP75: Current Path + 75
RG: Recovery Goal
H: Historic

pHOS

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	15%	11%	2%	1%
	0.9	13%	10%	2%	1%
	0.8	12%	9%	1%	1%
	0.7	10%	7%	1%	1%
	0.6	8%	6%	1%	1%
	0.5	6%	4%	1%	1%
	0.4	4%	3%	1%	0%
	0.3	3%	2%	1%	0%
	0.2	2%	1%	0%	0%
	0.1	1%	1%	0%	0%

NOS Mean

	CP	CP75	RG	H
1	2,670	3,482	21,423	36,475
0.9	2,715	3,546	21,702	36,707
0.8	2,777	3,643	21,970	36,926
0.7	2,864	3,792	22,225	37,132
0.6	3,012	4,051	22,463	37,324
0.5	3,273	4,529	22,684	37,500
0.4	3,871	5,014	22,883	37,658
0.3	4,524	5,459	23,059	37,798
0.2	5,276	6,002	23,268	37,969
0.1	5,670	6,299	23,400	38,086

Fitness - Gen.100

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	0.50	0.50	0.86	0.94
	0.9	0.50	0.50	0.88	0.95
	0.8	0.50	0.50	0.90	0.96
	0.7	0.50	0.50	0.92	0.97
	0.6	0.50	0.50	0.94	0.97
	0.5	0.50	0.59	0.96	0.98
	0.4	0.58	0.71	0.97	0.99
	0.3	0.75	0.82	0.98	0.99
	0.2	0.88	0.91	0.99	1.00
	0.1	0.96	0.97	1.00	1.00

NOR Harvest mean

	CP	CP75	RG	H
1	0	0	0	0
0.9	0	0	0	0
0.8	0	0	0	0
0.7	0	0	0	0
0.6	0	0	0	0
0.5	0	0	0	0
0.4	0	0	0	0
0.3	0	0	0	0
0.2	0	0	0	0
0.1	0	0	0	0

NOS% (Gen 90-100)

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	82%	86%	98%	99%
	0.9	83%	87%	98%	99%
	0.8	85%	89%	98%	99%
	0.7	86%	90%	99%	99%
	0.6	88%	91%	99%	99%
	0.5	90%	94%	99%	99%
	0.4	94%	96%	99%	100%
	0.3	97%	97%	99%	100%
	0.2	98%	98%	100%	100%
	0.1	99%	99%	100%	100%

2. Current Harvest Plan - output tables

Color Formatting Legend

	⬜	▨	🟥
pHOS	5%	10%	> 10%
100g Fitness	0.9	0.8	< 0.8
NOS-esc%	0.9	0.8	< 0.8

CP: Current Path
CP75: Current Path + 75
RG: Recovery Goal
H: Historic

pHOS

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	23%	17%	4%	2%
	0.9	21%	16%	3%	2%
	0.8	19%	14%	3%	2%
	0.7	17%	12%	2%	1%
	0.6	15%	10%	2%	1%
	0.5	12%	8%	2%	1%
	0.4	9%	6%	1%	1%
	0.3	6%	4%	1%	1%
	0.2	3%	2%	1%	0%
	0.1	1%	1%	0%	0%

NOS Mean

	CP	CP75	RG	H
1	1,523	2,127	10,711	19,079
0.9	1,539	2,154	11,073	19,398
0.8	1,561	2,185	11,429	19,705
0.7	1,590	2,229	11,774	19,997
0.6	1,630	2,294	12,105	20,270
0.5	1,689	2,405	12,417	20,523
0.4	1,795	2,635	12,703	20,753
0.3	2,061	3,192	12,957	20,954
0.2	3,184	3,964	13,261	21,195
0.1	3,776	4,373	13,437	21,343

Fitness - Gen.100

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	0.50	0.50	0.68	0.84
	0.9	0.50	0.50	0.72	0.86
	0.8	0.50	0.50	0.76	0.88
	0.7	0.50	0.50	0.81	0.91
	0.6	0.50	0.50	0.85	0.93
	0.5	0.50	0.50	0.89	0.95
	0.4	0.50	0.50	0.92	0.96
	0.3	0.50	0.63	0.95	0.98
	0.2	0.72	0.82	0.98	0.99
	0.1	0.92	0.94	0.99	1.00

NOR Harvest mean

	CP	CP75	RG	H
1	481	672	6,906	13,423
0.9	486	680	7,139	13,648
0.8	493	690	7,368	13,864
0.7	502	704	7,591	14,069
0.6	515	725	7,805	14,262
0.5	533	760	8,005	14,440
0.4	567	832	8,190	14,601
0.3	651	1,008	8,354	14,743
0.2	894	1,180	8,492	14,862
0.1	1,093	1,311	8,599	14,955

NOS% (Gen 90-100)

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	72%	79%	96%	98%
	0.9	74%	81%	96%	98%
	0.8	76%	83%	97%	98%
	0.7	79%	84%	97%	99%
	0.6	81%	86%	98%	99%
	0.5	83%	88%	98%	99%
	0.4	86%	90%	99%	99%
	0.3	89%	95%	99%	99%
	0.2	96%	97%	99%	100%
	0.1	99%	99%	100%	100%

3. Current Plan plus Northern Fishery - output tables

Color Formatting Legend

		▨	🟥
pHOS	5%	10%	> 10%
100g Fitness	0.9	0.8	< 0.8
NOS-esc%	0.9	0.8	< 0.8

CP: Current Path
CP75: Current Path + 75
RG: Recovery Goal
H: Historic

pHOS

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	31%	24%	4%	2%
	0.9	29%	22%	3%	2%
	0.8	27%	20%	3%	2%
	0.7	24%	17%	2%	1%
	0.6	21%	15%	2%	1%
	0.5	18%	13%	2%	1%
	0.4	14%	10%	1%	1%
	0.3	11%	7%	1%	1%
	0.2	6%	3%	1%	0%
	0.1	2%	1%	0%	0%

NOS Mean

	CP	CP75	RG	H
1	1,003	1,451	10,711	19,079
0.9	1,010	1,463	11,073	19,398
0.8	1,019	1,479	11,429	19,705
0.7	1,031	1,500	11,774	19,997
0.6	1,047	1,531	12,105	20,270
0.5	1,071	1,574	12,417	20,523
0.4	1,111	1,649	12,703	20,753
0.3	1,184	1,830	12,957	20,954
0.2	1,840	2,725	13,261	21,195
0.1	2,712	3,271	13,437	21,343

Fitness - Gen.100

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	0.50	0.50	0.68	0.84
	0.9	0.50	0.50	0.72	0.86
	0.8	0.50	0.50	0.76	0.88
	0.7	0.50	0.50	0.81	0.91
	0.6	0.50	0.50	0.85	0.93
	0.5	0.50	0.50	0.89	0.95
	0.4	0.50	0.50	0.92	0.96
	0.3	0.50	0.50	0.95	0.98
	0.2	0.50	0.67	0.98	0.99
	0.1	0.85	0.90	0.99	1.00

NOR Harvest mean

	CP	CP75	RG	H
1	615	889	6,906	13,423
0.9	619	897	7,139	13,648
0.8	625	907	7,368	13,864
0.7	632	920	7,591	14,069
0.6	642	939	7,805	14,262
0.5	657	965	8,005	14,440
0.4	681	1,010	8,190	14,601
0.3	726	1,122	8,354	14,743
0.2	870	1,479	8,492	14,862
0.1	1,390	1,826	8,599	14,955

NOS% (Gen 90-100)

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	64%	72%	96%	98%
	0.9	66%	74%	96%	98%
	0.8	69%	76%	97%	98%
	0.7	71%	79%	97%	99%
	0.6	74%	81%	98%	99%
	0.5	77%	84%	98%	99%
	0.4	81%	86%	99%	99%
	0.3	85%	89%	99%	99%
	0.2	89%	95%	99%	100%
	0.1	98%	98%	100%	100%

4. MSY Harvest - output tables

Color Formatting Legend

		▨	🟥
pHOS	5%	10%	> 10%
100g Fitness	0.9	0.8	< 0.8
NOS-esc%	0.9	0.8	< 0.8

CP: Current Path
CP75: Current Path + 75
RG: Recovery Goal
H: Historic

pHOS

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	36%	27%	14%	10%
	0.9	34%	25%	13%	9%
	0.8	31%	23%	12%	7%
	0.7	28%	21%	10%	6%
	0.6	25%	18%	8%	5%
	0.5	22%	15%	6%	3%
	0.4	18%	12%	4%	3%
	0.3	13%	9%	3%	2%
	0.2	8%	5%	2%	1%
	0.1	2%	2%	1%	1%

NOS Mean

	CP	CP75	RG	H
1	812	1,188	2,600	3,986
0.9	817	1,196	2,636	4,098
0.8	823	1,206	2,686	4,261
0.7	831	1,221	2,756	4,518
0.6	841	1,241	2,874	5,010
0.5	855	1,271	3,083	5,554
0.4	880	1,317	3,564	6,061
0.3	922	1,413	4,115	6,514
0.2	1,227	2,147	4,784	7,057
0.1	2,261	2,792	5,145	7,354

Fitness - Gen.100

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	0.50	0.50	0.50	0.50
	0.9	0.50	0.50	0.50	0.50
	0.8	0.50	0.50	0.50	0.50
	0.7	0.50	0.50	0.50	0.50
	0.6	0.50	0.50	0.50	0.55
	0.5	0.50	0.50	0.50	0.67
	0.4	0.50	0.50	0.57	0.77
	0.3	0.50	0.50	0.73	0.86
	0.2	0.50	0.52	0.86	0.93
	0.1	0.76	0.87	0.96	0.98

NOR Harvest mean

	CP	CP75	RG	H
1	643	941	6,719	12,622
0.9	647	947	6,812	12,976
0.8	652	956	6,942	13,494
0.7	658	967	7,123	14,307
0.6	666	983	7,427	15,865
0.5	678	1,007	7,968	17,588
0.4	697	1,043	9,210	19,194
0.3	731	1,120	10,635	20,629
0.2	820	1,404	11,855	21,843
0.1	1,361	1,942	12,788	22,768

NOS% (Gen 90-100)

Habitat Scenario -----		CP	CP75	RG	H
Spawning Effectiveness	1	59%	68%	82%	87%
	0.9	62%	71%	84%	88%
	0.8	64%	73%	85%	90%
	0.7	67%	75%	87%	91%
	0.6	70%	78%	89%	93%
	0.5	73%	81%	90%	95%
	0.4	77%	84%	94%	97%
	0.3	82%	87%	96%	98%
	0.2	87%	92%	98%	99%
	0.1	97%	98%	99%	99%

5. pHOS - Stray number analysis output tables

Color Formatting Legend

	⬜	🟪	🟥
pHOS	5%	10%	> 10%

Habitat: Current Path

Stray Number ------		700	600	500	400	300	200	100
Spawning Effectiveness	1	39%	37%	34%	31%	28%	23%	14%
	0.9	37%	35%	32%	29%	26%	21%	12%
	0.8	34%	32%	30%	27%	23%	18%	10%
	0.7	31%	29%	27%	24%	21%	16%	8%
	0.6	28%	26%	24%	21%	18%	14%	5%
	0.5	24%	22%	20%	18%	15%	11%	3%
	0.4	20%	19%	17%	14%	12%	8%	2%
	0.3	16%	14%	13%	11%	8%	4%	1%
	0.2	10%	9%	8%	6%	4%	2%	1%
	0.1	3%	3%	2%	2%	1%	1%	0%

Habitat: Current Path + 75

Stray Number ------		700	600	500	400	300	200	100
Spawning Effectiveness	1	26%	24%	21%	18%	14%	9%	3%
	0.9	24%	22%	19%	16%	13%	8%	2%
	0.8	22%	20%	17%	14%	11%	7%	2%
	0.7	19%	17%	15%	13%	9%	5%	2%
	0.6	17%	15%	13%	11%	8%	4%	1%
	0.5	14%	13%	11%	8%	6%	3%	1%
	0.4	11%	10%	8%	6%	4%	2%	1%
	0.3	8%	7%	5%	3%	2%	1%	1%
	0.2	4%	3%	3%	2%	1%	1%	0%
	0.1	2%	1%	1%	1%	1%	0%	0%

Habitat: Recovery Goal

Stray Number ------		700	600	500	400	300	200	100
Spawning Effectiveness	1	8%	6%	5%	4%	3%	2%	1%
	0.9	7%	6%	4%	3%	2%	1%	1%
	0.8	6%	5%	4%	3%	2%	1%	1%
	0.7	5%	4%	3%	2%	2%	1%	1%
	0.6	4%	3%	2%	2%	1%	1%	0%
	0.5	3%	2%	2%	2%	1%	1%	0%
	0.4	2%	2%	2%	1%	1%	1%	0%
	0.3	2%	1%	1%	1%	1%	0%	0%
	0.2	1%	1%	1%	1%	0%	0%	0%
	0.1	1%	0%	0%	0%	0%	0%	0%

Habitat: Historic

Stray Number ------		700	600	500	400	300	200	100
Spawning Effectiveness	1	4%	3%	3%	2%	1%	1%	0%
	0.9	4%	3%	2%	2%	1%	1%	0%
	0.8	3%	3%	2%	2%	1%	1%	0%
	0.7	3%	2%	2%	1%	1%	1%	0%
	0.6	2%	2%	1%	1%	1%	1%	0%
	0.5	2%	1%	1%	1%	1%	0%	0%
	0.4	1%	1%	1%	1%	1%	0%	0%
	0.3	1%	1%	1%	1%	0%	0%	0%
	0.2	1%	1%	0%	0%	0%	0%	0%
	0.1	0%	0%	0%	0%	0%	0%	0%

6. Fitness Gen. 100 - Stray number analysis output tables

Color Formatting Legend

	⬜	🟪	🟥
100g Fitness	0.9	0.8	< 0.8

Habitat: Current Path

	Stray Number ------	700	600	500	400	300	200	100
Spawning Effectiveness	1	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	0.9	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	0.8	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	0.7	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	0.6	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.54
	0.4	0.50	0.50	0.50	0.50	0.50	0.50	0.79
	0.3	0.50	0.50	0.50	0.50	0.50	0.50	0.89
	0.2	0.50	0.50	0.50	0.50	0.57	0.82	0.95
	0.1	0.63	0.70	0.78	0.85	0.90	0.95	0.99

Habitat: Current Path + 75

	Stray Number ------	700	600	500	400	300	200	100
Spawning Effectiveness	1	0.50	0.50	0.50	0.50	0.50	0.50	0.71
	0.9	0.50	0.50	0.50	0.50	0.50	0.50	0.77
	0.8	0.50	0.50	0.50	0.50	0.50	0.50	0.82
	0.7	0.50	0.50	0.50	0.50	0.50	0.50	0.86
	0.6	0.50	0.50	0.50	0.50	0.50	0.60	0.89
	0.5	0.50	0.50	0.50	0.50	0.50	0.73	0.92
	0.4	0.50	0.50	0.50	0.50	0.62	0.82	0.95
	0.3	0.50	0.50	0.50	0.64	0.79	0.89	0.97
	0.2	0.58	0.67	0.76	0.83	0.90	0.95	0.98
	0.1	0.88	0.90	0.93	0.95	0.97	0.99	1.00

Habitat: Recovery Goal

	Stray Number ------	700	600	500	400	300	200	100
Spawning Effectiveness	1	0.50	0.50	0.57	0.68	0.78	0.88	0.96
	0.9	0.50	0.53	0.62	0.72	0.82	0.90	0.97
	0.8	0.52	0.59	0.68	0.76	0.85	0.92	0.98
	0.7	0.58	0.66	0.73	0.81	0.88	0.94	0.98
	0.6	0.66	0.72	0.79	0.85	0.90	0.95	0.99
	0.5	0.73	0.79	0.84	0.89	0.93	0.96	0.99
	0.4	0.81	0.85	0.89	0.92	0.95	0.98	0.99
	0.3	0.88	0.90	0.93	0.95	0.97	0.99	1.00
	0.2	0.94	0.95	0.96	0.98	0.99	0.99	1.00
	0.1	0.98	0.99	0.99	0.99	1.00	1.00	1.00

Habitat: Historic

	Stray Number ------	700	600	500	400	300	200	100
Spawning Effectiveness	1	0.64	0.70	0.77	0.84	0.90	0.95	0.98
	0.9	0.68	0.74	0.80	0.86	0.91	0.96	0.99
	0.8	0.73	0.79	0.84	0.88	0.93	0.96	0.99
	0.7	0.78	0.82	0.87	0.91	0.94	0.97	0.99
	0.6	0.82	0.86	0.90	0.93	0.96	0.98	0.99
	0.5	0.87	0.90	0.92	0.95	0.97	0.98	1.00
	0.4	0.91	0.93	0.95	0.96	0.98	0.99	1.00
	0.3	0.94	0.96	0.97	0.98	0.99	0.99	1.00
	0.2	0.97	0.98	0.98	0.99	0.99	1.00	1.00
	0.1	0.99	0.99	1.00	1.00	1.00	1.00	1.00

APPENDIX 2: SKYKOMISH MODEL OUTPUT SHEETS

1. Trap Efficiency: Default Value 0.85

Color Formatting Legend

	⬜	▨	🟥
PNI	67%	50%	< 50%
100g Fitness	0.9	0.8	< 0.8
NOR-esc%	0.8	0.7	< 0.7

Harvest Scenario Key

MSY: Maximum Sustainable Yield
CP+N: Current Plan + Northern
CP: Current Plan
Zero: Zero Harvest

Habitat Scenario Key

CP: Current Path
CP75: Current Path + 75
RG: Recovery Goal
H: Historic

No Selective Fishery

PNI

	CP	CP+75	RG	HIST
MSY	66%	71%	86%	91%
CP+N	73%	77%	90%	94%
CP	76%	80%	90%	94%
ZERO	79%	82%	91%	95%

Fitness - Gen.100

	CP	CP+75	RG	HIST
MSY	0.81	0.86	0.97	0.99
CP+N	0.88	0.92	0.98	0.99
CP	0.91	0.93	0.98	0.99
ZERO	0.93	0.95	0.99	1.00

NOS% (Gen 90-100)

	CP	CP+75	RG	HIST
MSY	76%	81%	93%	96%
CP+N	83%	88%	95%	97%
CP	87%	89%	96%	97%
ZERO	89%	91%	96%	98%

NOS Mean

	CP	CP+75	RG	HIST
MSY	2,570	3,169	6,595	10,005
CP+N	4,505	6,043	17,319	30,372
CP	6,694	8,221	19,459	32,580
ZERO	10,218	12,585	30,772	52,461

NOR Harvest mean

	CP	CP+75	RG	HIST
MSY	3,073	4,342	16,040	30,786
CP+N	3,080	4,063	11,273	19,618
CP	2,237	3,014	9,650	17,789
ZERO	0	0	0	0

HOR Harvest mean

	CP	CP+75	RG	HIST
MSY	3,800	4,087	5,147	5,515
CP+N	2,872	2,872	2,872	2,872
CP	1,782	1,922	2,415	2,585
ZERO	0	0	0	0

"8%" Model

PNI

	CP	CP+75	RG	HIST
MSY	69%	74%	88%	93%
CP+N	75%	79%	91%	95%
CP	78%	81%	91%	95%
ZERO	79%	82%	91%	95%

Fitness - Gen.100

	CP	CP+75	RG	HIST
MSY	0.83	0.88	0.98	0.99
CP+N	0.89	0.93	0.99	0.99
CP	0.92	0.94	0.99	1.00
ZERO	0.93	0.95	0.99	1.00

NOS% (Gen 90-100)

	CP	CP+75	RG	HIST
MSY	79%	84%	94%	97%
CP+N	85%	89%	96%	98%
CP	88%	90%	96%	98%
ZERO	89%	91%	96%	98%

NOS Mean

	CP	CP+75	RG	HIST
MSY	2,597	3,213	6,639	10,045
CP+N	4,556	6,098	17,361	30,408
CP	6,751	8,277	19,500	32,616
ZERO	10,218	12,585	30,772	52,461

NOR Harvest mean

	CP	CP+75	RG	HIST
MSY	3,101	4,396	16,143	30,905
CP+N	3,113	4,098	11,299	19,641
CP	2,255	3,033	9,670	17,809
ZERO	0	0	0	0

HOR Harvest mean

	CP	CP+75	RG	HIST
MSY	4,389	4,676	5,736	6,071
CP+N	3,461	3,461	3,461	3,461
CP	2,371	2,511	3,004	3,174
ZERO	0	0	0	0

"18%" Model

PNI

	CP	CP+75	RG	HIST
MSY	73%	78%	95%	98%
CP+N	78%	82%	92%	95%
CP	80%	83%	92%	95%
ZERO	79%	82%	91%	95%

Fitness - Gen.100

	CP	CP+75	RG	HIST
MSY	0.87	0.91	1.00	1.00
CP+N	0.92	0.95	0.99	1.00
CP	0.93	0.95	0.99	1.00
ZERO	0.93	0.95	0.99	1.00

NOS% (Gen 90-100)

	CP	CP+75	RG	HIST
MSY	82%	87%	97%	98%
CP+N	87%	90%	97%	98%
CP	89%	91%	97%	98%
ZERO	89%	91%	96%	98%

NOS Mean

	CP	CP+75	RG	HIST
MSY	2,638	3,271	6,777	10,151
CP+N	4,623	6,166	17,410	30,450
CP	6,821	8,344	19,549	32,659
ZERO	10,218	12,585	30,772	52,461

NOR Harvest mean

	CP	CP+75	RG	HIST
MSY	3,145	4,469	16,462	31,223
CP+N	3,155	4,142	11,330	19,668
CP	2,277	3,057	9,694	17,832
ZERO	0	0	0	0

HOR Harvest mean

	CP	CP+75	RG	HIST
MSY	5,125	5,412	4,165	3,105
CP+N	4,197	4,197	4,197	4,197
CP	3,108	3,247	3,741	3,910
ZERO	0	0	0	0

2. Harvest: ZERO

Color Formatting Legend

	⬜	🟪	🟥
PNI	67%	50%	< 50%
100g Fitness	0.9	0.8	< 0.8
NOR-esc%	0.8	0.7	< 0.7

CP: Current Path
CP75: Current Path + 75%
RG: Recovery Goal
H: Historic

No Selective Fishery

PNI

		CP	CP+75	RG	HIST
Trapping Efficiency	0.4	53%	57%	75%	83%
	0.5	57%	61%	78%	85%
	0.6	61%	65%	81%	88%
	0.7	67%	71%	85%	90%
	0.75	70%	74%	87%	92%
	0.8	74%	78%	89%	93%
	0.85	**79%**	**82%**	**91%**	**95%**
	0.9	84%	86%	94%	96%
	0.95	90%	92%	96%	98%
	1	97%	98%	99%	99%

Fitness - Gen.100

		CP	CP+75	RG	HIST
Trapping Efficiency	0.4	0.69	0.74	0.90	0.96
	0.5	0.73	0.78	0.92	0.97
	0.6	0.78	0.82	0.95	0.98
	0.7	0.84	0.87	0.96	0.99
	0.75	0.87	0.90	0.97	0.99
	0.8	0.90	0.92	0.98	0.99
	0.85	**0.93**	**0.95**	**0.99**	**1.00**
	0.9	0.96	0.97	0.99	1.00
	0.95	0.98	0.99	1.00	1.00
	1	1.00	1.00	1.00	1.00

NOS% (Gen 90-100)

		CP	CP+75	RG	HIST
Trapping Efficiency	0.4	63%	69%	86%	92%
	0.5	68%	73%	88%	93%
	0.6	73%	78%	91%	94%
	0.7	79%	83%	93%	96%
	0.75	82%	86%	94%	96%
	0.8	86%	88%	95%	97%
	0.85	**89%**	**91%**	**96%**	**98%**
	0.9	92%	93%	97%	98%
	0.95	95%	96%	98%	99%
	1	99%	99%	100%	100%

NOS-esc Mean

		CP	CP+75	RG	HIST
Trapping Efficiency	0.4	8,603	10,757	28,786	50,604
	0.5	8,838	11,068	29,259	51,075
	0.6	9,141	11,441	29,728	51,522
	0.7	9,522	11,875	30,178	51,934
	0.75	9,742	12,109	30,390	52,123
	0.8	9,977	12,348	30,589	52,300
	0.85	**10,218**	**12,585**	**30,772**	**52,461**
	0.9	10,452	12,807	30,934	52,604
	0.95	10,655	12,994	31,069	52,728
	1	10,788	13,118	31,171	52,830

NOR Harvest mean

		CP	CP+75	RG	HIST
Trapping Efficiency	0.4	0	0	0	0
	0.5	0	0	0	0
	0.6	0	0	0	0
	0.7	0	0	0	0
	0.75	0	0	0	0
	0.8	0	0	0	0
	0.85	**0**	**0**	**0**	**0**
	0.9	0	0	0	0
	0.95	0	0	0	0
	1	0	0	0	0

"8%" Model

PNI

	CP	CP+75	RG	HIST
0.4	53%	57%	75%	83%
0.5	57%	61%	78%	85%
0.6	61%	65%	81%	88%
0.7	67%	71%	85%	90%
0.75	70%	74%	87%	92%
0.8	74%	78%	89%	93%
0.85	**79%**	**82%**	**91%**	**95%**
0.9	84%	86%	94%	96%
0.95	90%	92%	96%	98%
1	97%	98%	99%	99%

Fitness - Gen.100

	CP	CP+75	RG	HIST
0.4	0.69	0.74	0.90	0.96
0.5	0.73	0.78	0.92	0.97
0.6	0.78	0.82	0.95	0.98
0.7	0.84	0.87	0.96	0.99
0.75	0.87	0.90	0.97	0.99
0.8	0.90	0.92	0.98	0.99
0.85	**0.93**	**0.95**	**0.99**	**1.00**
0.9	0.96	0.97	0.99	1.00
0.95	0.98	0.99	1.00	1.00
1	1.00	1.00	1.00	1.00

NOS% (Gen 90-100)

	CP	CP+75	RG	HIST
0.4	63%	69%	86%	92%
0.5	68%	73%	88%	93%
0.6	73%	78%	91%	94%
0.7	79%	83%	93%	96%
0.75	82%	86%	94%	96%
0.8	86%	88%	95%	97%
0.85	**89%**	**91%**	**96%**	**98%**
0.9	92%	93%	97%	98%
0.95	95%	96%	98%	99%
1	99%	99%	100%	100%

NOS-esc Mean

	CP	CP+75	RG	HIST
0.4	8,603	10,757	28,786	50,604
0.5	8,838	11,068	29,259	51,075
0.6	9,141	11,441	29,728	51,522
0.7	9,522	11,875	30,178	51,934
0.75	9,742	12,109	30,390	52,123
0.8	9,977	12,348	30,589	52,300
0.85	**10,218**	**12,585**	**30,772**	**52,461**
0.9	10,452	12,807	30,934	52,604
0.95	10,655	12,994	31,069	52,728
1	10,788	13,118	31,171	52,830

NOR Harvest mean

	CP	CP+75	RG	HIST
0.4	0	0	0	0
0.5	0	0	0	0
0.6	0	0	0	0
0.7	0	0	0	0
0.75	0	0	0	0
0.8	0	0	0	0
0.85	**0**	**0**	**0**	**0**
0.9	0	0	0	0
0.95	0	0	0	0
1	0	0	0	0

"18%" Model

PNI

	CP	CP+75	RG	HIST
0.4	53%	57%	75%	83%
0.5	57%	61%	78%	85%
0.6	61%	65%	81%	88%
0.7	67%	71%	85%	90%
0.75	70%	74%	87%	92%
0.8	74%	78%	89%	93%
0.85	**79%**	**82%**	**91%**	**95%**
0.9	84%	86%	94%	96%
0.95	90%	92%	96%	98%
1	97%	98%	99%	99%

Fitness - Gen.100

	CP	CP+75	RG	HIST
0.4	0.69	0.74	0.90	0.96
0.5	0.73	0.78	0.92	0.97
0.6	0.78	0.82	0.95	0.98
0.7	0.84	0.87	0.96	0.99
0.75	0.87	0.90	0.97	0.99
0.8	0.90	0.92	0.98	0.99
0.85	**0.93**	**0.95**	**0.99**	**1.00**
0.9	0.96	0.97	0.99	1.00
0.95	0.98	0.99	1.00	1.00
1	1.00	1.00	1.00	1.00

NOS% (Gen 90-100)

	CP	CP+75	RG	HIST
0.4	63%	69%	86%	92%
0.5	68%	73%	88%	93%
0.6	73%	78%	91%	94%
0.7	79%	83%	93%	96%
0.75	82%	86%	94%	96%
0.8	86%	88%	95%	97%
0.85	**89%**	**91%**	**96%**	**98%**
0.9	92%	93%	97%	98%
0.95	95%	96%	98%	99%
1	99%	99%	100%	100%

NOS-esc Mean

	CP	CP+75	RG	HIST
0.4	8,603	10,757	28,786	50,604
0.5	8,838	11,068	29,259	51,075
0.6	9,141	11,441	29,728	51,522
0.7	9,522	11,875	30,178	51,934
0.75	9,742	12,109	30,390	52,123
0.8	9,977	12,348	30,589	52,300
0.85	**10,218**	**12,585**	**30,772**	**52,461**
0.9	10,452	12,807	30,934	52,604
0.95	10,655	12,994	31,069	52,728
1	10,788	13,118	31,171	52,830

NOR Harvest mean

	CP	CP+75	RG	HIST
0.4	0	0	0	0
0.5	0	0	0	0
0.6	0	0	0	0
0.7	0	0	0	0
0.75	0	0	0	0
0.8	0	0	0	0
0.85	**0**	**0**	**0**	**0**
0.9	0	0	0	0
0.95	0	0	0	0
1	0	0	0	0

3. Harvest: Current Plan

Color Formatting Legend

	⬜	▨	🟥
PNI	67%	50%	< 50%
100g Fitness	0.9	0.8	< 0.8
NOR-esc%	0.8	0.7	< 0.7

CP: Current Path
CP75: Current Path + 75%
RG: Recovery Goal
H: Historic

No Selective Fishery

PNI

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	51%	55%	73%	82%
0.5	54%	58%	76%	84%
0.6	58%	63%	80%	87%
0.7	64%	68%	84%	90%
0.75	67%	72%	86%	91%
0.8	71%	75%	88%	93%
0.85	**76%**	**80%**	**90%**	**94%**
0.9	82%	84%	93%	96%
0.95	88%	90%	95%	97%
1	96%	96%	98%	99%

Fitness - Gen.100

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	0.66	0.71	0.89	0.95
0.5	0.70	0.75	0.92	0.96
0.6	0.74	0.79	0.94	0.97
0.7	0.80	0.85	0.96	0.98
0.75	0.84	0.88	0.97	0.99
0.8	0.87	0.90	0.98	0.99
0.85	**0.91**	**0.93**	**0.98**	**0.99**
0.9	0.94	0.96	0.99	1.00
0.95	0.97	0.98	1.00	1.00
1	1.00	1.00	1.00	1.00

NOS% (Gen 90-100)

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	58%	65%	85%	91%
0.5	63%	70%	87%	93%
0.6	69%	75%	90%	94%
0.7	76%	80%	92%	95%
0.75	79%	83%	93%	96%
0.8	83%	86%	94%	97%
0.85	**87%**	**89%**	**96%**	**97%**
0.9	90%	92%	97%	98%
0.95	94%	95%	98%	99%
1	98%	98%	99%	100%

NOS-esc Mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	5,712	7,031	18,121	31,366
0.5	5,827	7,208	18,435	31,674
0.6	5,990	7,435	18,749	31,966
0.7	6,218	7,717	19,053	32,236
0.75	6,360	7,878	19,198	32,360
0.8	6,520	8,048	19,334	32,475
0.85	**6,694**	**8,221**	**19,459**	**32,580**
0.9	6,871	8,388	19,569	32,674
0.95	7,031	8,532	19,661	32,754
1	7,136	8,627	19,729	32,818

NOR Harvest mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	1,923	2,593	8,997	17,133
0.5	1,960	2,656	9,150	17,299
0.6	2,012	2,736	9,304	17,457
0.7	2,085	2,836	9,452	17,603
0.75	2,130	2,892	9,523	17,670
0.8	2,181	2,952	9,589	17,732
0.85	**2,237**	**3,014**	**9,650**	**17,789**
0.9	2,293	3,073	9,704	17,840
0.95	2,344	3,124	9,749	17,883
1	2,378	3,157	9,782	17,918

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	1,801	1,942	2,441	2,612
0.5	1,801	1,942	2,441	2,612
0.6	1,801	1,942	2,441	2,612
0.7	1,801	1,942	2,441	2,612
0.75	1,801	1,942	2,441	2,612
0.8	1,801	1,942	2,441	2,612
0.85	**1,801**	**1,942**	**2,441**	**2,612**
0.9	1,801	1,942	2,441	2,612
0.95	1,801	1,942	2,441	2,612
1	1,801	1,942	2,441	2,612

"8%" Model

PNI

	CP	CP+75	RG	HIST
0.4	53%	57%	75%	84%
0.5	56%	60%	78%	86%
0.6	60%	65%	82%	88%
0.7	66%	70%	85%	91%
0.75	69%	74%	87%	92%
0.8	73%	77%	89%	93%
0.85	**78%**	**81%**	**91%**	**95%**
0.9	83%	86%	93%	96%
0.95	89%	91%	96%	97%
1	96%	96%	98%	99%

Fitness - Gen.100

	CP	CP+75	RG	HIST
0.4	0.68	0.73	0.91	0.96
0.5	0.72	0.77	0.93	0.97
0.6	0.77	0.81	0.95	0.98
0.7	0.82	0.86	0.97	0.99
0.75	0.85	0.89	0.97	0.99
0.8	0.89	0.92	0.98	0.99
0.85	**0.92**	**0.94**	**0.99**	**1.00**
0.9	0.95	0.97	0.99	1.00
0.95	0.98	0.98	1.00	1.00
1	1.00	1.00	1.00	1.00

NOS% (Gen 90-100)

	CP	CP+75	RG	HIST
0.4	62%	68%	87%	92%
0.5	66%	72%	89%	93%
0.6	72%	77%	91%	95%
0.7	78%	82%	93%	96%
0.75	81%	85%	94%	96%
0.8	85%	88%	95%	97%
0.85	**88%**	**90%**	**96%**	**98%**
0.9	91%	93%	97%	98%
0.95	94%	96%	98%	99%
1	98%	98%	99%	100%

NOS-esc Mean

	CP	CP+75	RG	HIST
0.4	5,780	7,141	18,345	31,595
0.5	5,906	7,324	18,622	31,856
0.6	6,077	7,550	18,896	32,102
0.7	6,305	7,820	19,157	32,328
0.75	6,442	7,969	19,280	32,432
0.8	6,592	8,123	19,395	32,528
0.85	**6,751**	**8,277**	**19,500**	**32,616**
0.9	6,907	8,422	19,593	32,695
0.95	7,046	8,545	19,671	32,762
1	7,136	8,627	19,729	32,818

NOR Harvest mean

	CP	CP+75	RG	HIST
0.4	1,945	2,632	9,106	17,256
0.5	1,985	2,697	9,242	17,398
0.6	2,040	2,777	9,375	17,531
0.7	2,113	2,872	9,503	17,653
0.75	2,156	2,925	9,563	17,709
0.8	2,204	2,979	9,619	17,761
0.85	**2,255**	**3,033**	**9,670**	**17,809**
0.9	2,305	3,085	9,716	17,851
0.95	2,349	3,128	9,753	17,888
1	2,378	3,157	9,782	17,918

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	2,396	2,537	3,036	3,207
0.5	2,396	2,537	3,036	3,207
0.6	2,396	2,537	3,036	3,207
0.7	2,396	2,537	3,036	3,207
0.75	2,396	2,537	3,036	3,207
0.8	2,396	2,537	3,036	3,207
0.85	**2,396**	**2,537**	**3,036**	**3,207**
0.9	2,396	2,537	3,036	3,207
0.95	2,396	2,537	3,036	3,207
1	2,396	2,537	3,036	3,207

"18%" Model

PNI

	CP	CP+75	RG	HIST
0.4	56%	60%	78%	86%
0.5	59%	64%	81%	88%
0.6	64%	68%	84%	90%
0.7	69%	73%	87%	92%
0.75	72%	76%	89%	93%
0.8	76%	79%	91%	94%
0.85	**80%**	**83%**	**92%**	**95%**
0.9	84%	87%	94%	97%
0.95	90%	91%	96%	98%
1	96%	96%	98%	99%

Fitness - Gen.100

	CP	CP+75	RG	HIST
0.4	0.72	0.77	0.93	0.97
0.5	0.75	0.80	0.95	0.98
0.6	0.80	0.84	0.96	0.98
0.7	0.85	0.89	0.97	0.99
0.75	0.88	0.91	0.98	0.99
0.8	0.91	0.93	0.99	0.99
0.85	**0.93**	**0.95**	**0.99**	**1.00**
0.9	0.96	0.97	0.99	1.00
0.95	0.98	0.99	1.00	1.00
1	1.00	1.00	1.00	1.00

NOS% (Gen 90-100)

	CP	CP+75	RG	HIST
0.4	66%	72%	89%	94%
0.5	70%	76%	91%	95%
0.6	75%	80%	92%	96%
0.7	81%	85%	94%	97%
0.75	84%	87%	95%	97%
0.8	86%	89%	96%	98%
0.85	**89%**	**91%**	**97%**	**98%**
0.9	92%	94%	97%	99%
0.95	95%	96%	98%	99%
1	98%	98%	99%	100%

NOS-esc Mean

	CP	CP+75	RG	HIST
0.4	5,889	7,306	18,626	31,870
0.5	6,027	7,492	18,854	32,073
0.6	6,205	7,709	19,074	32,264
0.7	6,426	7,955	19,281	32,437
0.75	6,552	8,085	19,378	32,517
0.8	6,685	8,217	19,467	32,591
0.85	**6,821**	**8,344**	**19,549**	**32,659**
0.9	6,951	8,462	19,621	32,720
0.95	7,063	8,561	19,682	32,773
1	7,136	8,627	19,729	32,818

NOR Harvest mean

	CP	CP+75	RG	HIST
0.4	1,980	2,691	9,244	17,405
0.5	2,024	2,756	9,355	17,515
0.6	2,080	2,833	9,462	17,618
0.7	2,151	2,920	9,563	17,712
0.75	2,191	2,966	9,610	17,755
0.8	2,234	3,012	9,654	17,795
0.85	**2,277**	**3,057**	**9,694**	**17,832**
0.9	2,319	3,099	9,729	17,865
0.95	2,355	3,134	9,759	17,893
1	2,378	3,157	9,782	17,918

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	3,140	3,282	3,780	3,951
0.5	3,140	3,282	3,780	3,951
0.6	3,140	3,282	3,780	3,951
0.7	3,140	3,282	3,780	3,951
0.75	3,140	3,282	3,780	3,951
0.8	3,140	3,282	3,780	3,951
0.85	**3,140**	**3,282**	**3,780**	**3,951**
0.9	3,140	3,282	3,780	3,951
0.95	3,140	3,282	3,780	3,951
1	3,140	3,282	3,780	3,951

4. Harvest: Current Plan + Northern

Color Formatting Legend

	⬜	▨	🟥
PNI	67%	50%	< 50%
100g Fitness	0.9	0.8	< 0.8
NOR-esc%	0.8	0.7	< 0.7

CP: Current Path
CP75: Current Path + 75%
RG: Recovery Goal
H: Historic

No Selective Fishery

PNI

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	49%	53%	73%	82%
0.5	51%	56%	76%	84%
0.6	55%	60%	79%	87%
0.7	60%	66%	83%	90%
0.75	64%	69%	85%	91%
0.8	68%	73%	88%	92%
0.85	**73%**	**77%**	**90%**	**94%**
0.9	78%	82%	93%	96%
0.95	85%	88%	95%	97%
1	94%	95%	98%	99%

Fitness - Gen.100

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	0.63	0.68	0.89	0.95
0.5	0.66	0.72	0.91	0.96
0.6	0.70	0.76	0.94	0.97
0.7	0.76	0.82	0.96	0.98
0.75	0.80	0.85	0.97	0.99
0.8	0.83	0.88	0.98	0.99
0.85	**0.88**	**0.92**	**0.98**	**0.99**
0.9	0.92	0.95	0.99	1.00
0.95	0.96	0.98	1.00	1.00
1	0.99	0.99	1.00	1.00

NOS% (Gen 90-100)

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	54%	61%	85%	91%
0.5	58%	66%	87%	93%
0.6	64%	72%	89%	94%
0.7	71%	78%	92%	95%
0.75	75%	81%	93%	96%
0.8	79%	84%	94%	97%
0.85	**83%**	**88%**	**95%**	**97%**
0.9	88%	91%	97%	98%
0.95	92%	94%	98%	99%
1	97%	98%	99%	100%

NOS-esc Mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	3,987	5,213	16,103	29,229
0.5	4,023	5,317	16,387	29,518
0.6	4,089	5,461	16,672	29,793
0.7	4,202	5,656	16,949	30,047
0.75	4,283	5,774	17,081	30,164
0.8	4,384	5,905	17,205	30,273
0.85	**4,505**	**6,043**	**17,319**	**30,372**
0.9	4,639	6,181	17,420	30,460
0.95	4,769	6,304	17,504	30,535
1	4,859	6,386	17,566	30,595

NOR Harvest mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	2,749	3,532	10,495	18,887
0.5	2,772	3,599	10,677	19,072
0.6	2,814	3,691	10,859	19,248
0.7	2,886	3,816	11,036	19,410
0.75	2,938	3,891	11,120	19,485
0.8	3,003	3,975	11,200	19,554
0.85	**3,080**	**4,063**	**11,273**	**19,618**
0.9	3,165	4,152	11,337	19,674
0.95	3,249	4,230	11,391	19,722
1	3,306	4,282	11,430	19,760

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	2,902	2,902	2,902	2,902
0.5	2,902	2,902	2,902	2,902
0.6	2,902	2,902	2,902	2,902
0.7	2,902	2,902	2,902	2,902
0.75	2,902	2,902	2,902	2,902
0.8	2,902	2,902	2,902	2,902
0.85	**2,902**	**2,902**	**2,902**	**2,902**
0.9	2,902	2,902	2,902	2,902
0.95	2,902	2,902	2,902	2,902
1	2,902	2,902	2,902	2,902

"8%" Model

PNI

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	51%	55%	75%	84%
0.5	54%	59%	78%	86%
0.6	58%	63%	81%	88%
0.7	63%	68%	85%	91%
0.75	66%	72%	87%	92%
0.8	70%	75%	89%	93%
0.85	**75%**	**79%**	**91%**	**95%**
0.9	80%	84%	93%	96%
0.95	86%	89%	96%	97%
1	94%	95%	98%	99%

Fitness - Gen.100

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	0.66	0.71	0.91	0.96
0.5	0.69	0.75	0.93	0.97
0.6	0.73	0.79	0.95	0.98
0.7	0.79	0.84	0.96	0.99
0.75	0.82	0.87	0.97	0.99
0.8	0.86	0.90	0.98	0.99
0.85	**0.89**	**0.93**	**0.99**	**0.99**
0.9	0.93	0.96	0.99	1.00
0.95	0.97	0.98	1.00	1.00
1	0.99	0.99	1.00	1.00

NOS% (Gen 90-100)

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	57%	65%	87%	92%
0.5	62%	70%	89%	93%
0.6	68%	75%	91%	95%
0.7	74%	80%	93%	96%
0.75	78%	83%	94%	96%
0.8	81%	86%	95%	97%
0.85	**85%**	**89%**	**96%**	**98%**
0.9	89%	92%	97%	98%
0.95	93%	95%	98%	99%
1	97%	98%	99%	100%

NOS-esc Mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	4,014	5,292	16,326	29,458
0.5	4,062	5,406	16,575	29,700
0.6	4,141	5,557	16,819	29,930
0.7	4,265	5,748	17,054	30,140
0.75	4,347	5,859	17,163	30,237
0.8	4,445	5,977	17,267	30,326
0.85	**4,556**	**6,098**	**17,361**	**30,408**
0.9	4,674	6,216	17,444	30,481
0.95	4,785	6,318	17,514	30,544
1	4,859	6,386	17,566	30,595

NOR Harvest mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	2,766	3,583	10,638	19,033
0.5	2,797	3,656	10,796	19,188
0.6	2,847	3,752	10,953	19,335
0.7	2,926	3,874	11,103	19,469
0.75	2,979	3,945	11,173	19,531
0.8	3,042	4,021	11,239	19,588
0.85	**3,113**	**4,098**	**11,299**	**19,641**
0.9	3,188	4,174	11,352	19,687
0.95	3,258	4,239	11,397	19,727
1	3,306	4,282	11,430	19,760

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	3,497	3,497	3,497	3,497
0.5	3,497	3,497	3,497	3,497
0.6	3,497	3,497	3,497	3,497
0.7	3,497	3,497	3,497	3,497
0.75	3,497	3,497	3,497	3,497
0.8	3,497	3,497	3,497	3,497
0.85	**3,497**	**3,497**	**3,497**	**3,497**
0.9	3,497	3,497	3,497	3,497
0.95	3,497	3,497	3,497	3,497
1	3,497	3,497	3,497	3,497

"18%" Model

PNI

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	54%	59%	79%	86%
0.5	57%	63%	81%	88%
0.6	61%	67%	84%	90%
0.7	67%	72%	87%	92%
0.75	70%	75%	89%	93%
0.8	74%	78%	90%	94%
0.85	**78%**	**82%**	**92%**	**95%**
0.9	82%	86%	94%	97%
0.95	88%	90%	96%	98%
1	94%	95%	98%	99%

Fitness - Gen.100

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	0.69	0.75	0.93	0.97
0.5	0.73	0.79	0.95	0.98
0.6	0.77	0.83	0.96	0.98
0.7	0.83	0.88	0.97	0.99
0.75	0.85	0.90	0.98	0.99
0.8	0.89	0.92	0.99	0.99
0.85	**0.92**	**0.95**	**0.99**	**1.00**
0.9	0.95	0.97	0.99	1.00
0.95	0.97	0.98	1.00	1.00
1	0.99	0.99	1.00	1.00

NOS% (Gen 90-100)

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	63%	70%	89%	94%
0.5	67%	74%	91%	95%
0.6	72%	79%	92%	96%
0.7	78%	83%	94%	97%
0.75	81%	86%	95%	97%
0.8	84%	88%	96%	98%
0.85	**87%**	**90%**	**97%**	**98%**
0.9	91%	93%	97%	99%
0.95	94%	95%	98%	99%
1	97%	98%	99%	100%

NOS-esc Mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	4,071	5,424	16,607	29,732
0.5	4,136	5,547	16,806	29,917
0.6	4,229	5,697	16,998	30,090
0.7	4,359	5,874	17,177	30,249
0.75	4,439	5,970	17,261	30,321
0.8	4,528	6,069	17,339	30,389
0.85	**4,623**	**6,166**	**17,410**	**30,450**
0.9	4,718	6,257	17,472	30,506
0.95	4,803	6,334	17,525	30,554
1	4,859	6,386	17,566	30,595

NOR Harvest mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	2,802	3,667	10,817	19,208
0.5	2,844	3,746	10,944	19,327
0.6	2,903	3,842	11,067	19,438
0.7	2,987	3,955	11,182	19,539
0.75	3,038	4,016	11,235	19,585
0.8	3,095	4,079	11,285	19,628
0.85	**3,155**	**4,142**	**11,330**	**19,668**
0.9	3,216	4,200	11,370	19,703
0.95	3,270	4,249	11,404	19,734
1	3,306	4,282	11,430	19,760

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	4,241	4,241	4,241	4,241
0.5	4,241	4,241	4,241	4,241
0.6	4,241	4,241	4,241	4,241
0.7	4,241	4,241	4,241	4,241
0.75	4,241	4,241	4,241	4,241
0.8	4,241	4,241	4,241	4,241
0.85	**4,241**	**4,241**	**4,241**	**4,241**
0.9	4,241	4,241	4,241	4,241
0.95	4,241	4,241	4,241	4,241
1	4,241	4,241	4,241	4,241

5. Harvest: MSY

Color Formatting Legend

	⬜	🩷	🟥
PNI	67%	50%	< 50%
100g Fitness	0.9	0.8	< 0.8
NOR-esc%	0.8	0.7	< 0.7

CP: Current Path
CP75: Current Path + 75%
RG: Recovery Goal
H: Historic

No Selective Fishery

PNI

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	45%	48%	67%	78%
0.5	48%	51%	70%	80%
0.6	51%	55%	74%	83%
0.7	55%	59%	78%	86%
0.75	58%	62%	81%	88%
0.8	61%	66%	83%	89%
0.85	**66%**	**71%**	**86%**	**91%**
0.9	72%	77%	89%	93%
0.95	80%	83%	92%	95%
1	90%	92%	95%	97%

Fitness - Gen.100

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	0.59	0.63	0.83	0.92
0.5	0.61	0.65	0.86	0.94
0.6	0.64	0.69	0.89	0.95
0.7	0.69	0.74	0.92	0.97
0.75	0.72	0.78	0.94	0.97
0.8	0.76	0.81	0.95	0.98
0.85	**0.81**	**0.86**	**0.97**	**0.99**
0.9	0.86	0.90	0.98	0.99
0.95	0.92	0.95	0.99	0.99
1	0.98	0.98	1.00	1.00

NOS% (Gen 90-100)

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	46%	52%	79%	88%
0.5	50%	57%	82%	90%
0.6	55%	62%	85%	92%
0.7	61%	69%	88%	93%
0.75	65%	73%	90%	94%
0.8	70%	77%	91%	95%
0.85	**76%**	**81%**	**93%**	**96%**
0.9	82%	86%	95%	97%
0.95	88%	91%	96%	98%
1	94%	95%	98%	99%

NOS-esc Mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	2,580	2,954	6,016	9,523
0.5	2,549	2,953	6,137	9,632
0.6	2,524	2,968	6,266	9,750
0.7	2,512	3,011	6,401	9,861
0.75	2,517	3,049	6,469	9,913
0.8	2,535	3,101	6,534	9,961
0.85	**2,570**	**3,169**	**6,595**	**10,005**
0.9	2,630	3,252	6,650	10,043
0.95	2,717	3,339	6,696	10,075
1	2,814	3,403	6,728	10,099

NOR Harvest mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	3,084	4,074	14,696	29,347
0.5	3,051	4,072	14,975	29,673
0.6	3,023	4,091	15,277	30,026
0.7	3,011	4,144	15,590	30,358
0.75	3,016	4,191	15,746	30,512
0.8	3,035	4,256	15,897	30,656
0.85	**3,073**	**4,342**	**16,040**	**30,786**
0.9	3,136	4,445	16,167	30,901
0.95	3,229	4,554	16,274	30,996
1	3,330	4,633	16,348	31,067

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	3,840	4,130	5,201	5,551
0.5	3,840	4,130	5,201	5,573
0.6	3,840	4,130	5,201	5,573
0.7	3,840	4,130	5,201	5,573
0.75	3,840	4,130	5,201	5,573
0.8	3,840	4,130	5,201	5,573
0.85	**3,840**	**4,130**	**5,201**	**5,573**
0.9	3,840	4,130	5,201	5,573
0.95	3,827	4,130	5,201	5,573
1	3,796	4,130	5,201	5,573

"8%" Model

PNI

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	48%	51%	74%	86%
0.5	50%	54%	76%	86%
0.6	53%	58%	79%	87%
0.7	58%	63%	82%	89%
0.75	61%	66%	84%	91%
0.8	64%	70%	86%	92%
0.85	**69%**	**74%**	**88%**	**93%**
0.9	74%	79%	91%	94%
0.95	81%	85%	93%	96%
1	90%	92%	95%	97%

Fitness - Gen.100

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	0.61	0.66	0.89	0.97
0.5	0.64	0.69	0.90	0.97
0.6	0.67	0.73	0.93	0.97
0.7	0.72	0.78	0.95	0.98
0.75	0.75	0.81	0.96	0.98
0.8	0.79	0.85	0.97	0.99
0.85	**0.83**	**0.88**	**0.98**	**0.99**
0.9	0.88	0.92	0.98	0.99
0.95	0.93	0.96	0.99	1.00
1	0.98	0.98	1.00	1.00

NOS% (Gen 90-100)

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	50%	57%	84%	93%
0.5	54%	61%	86%	93%
0.6	59%	67%	88%	94%
0.7	65%	73%	91%	95%
0.75	69%	76%	92%	96%
0.8	74%	80%	93%	96%
0.85	**79%**	**84%**	**94%**	**97%**
0.9	84%	88%	95%	97%
0.95	89%	92%	97%	98%
1	94%	95%	98%	99%

NOS-esc Mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	2,550	2,954	6,272	9,930
0.5	2,527	2,965	6,312	9,867
0.6	2,513	2,995	6,410	9,898
0.7	2,517	3,052	6,508	9,963
0.75	2,530	3,095	6,554	9,992
0.8	2,556	3,148	6,599	10,020
0.85	**2,597**	**3,213**	**6,639**	**10,045**
0.9	2,654	3,284	6,676	10,066
0.95	2,734	3,353	6,706	10,085
1	2,814	3,403	6,728	10,100

NOR Harvest mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	3,051	4,073	15,291	30,562
0.5	3,027	4,088	15,383	30,375
0.6	3,012	4,124	15,610	30,467
0.7	3,016	4,196	15,837	30,660
0.75	3,030	4,249	15,945	30,749
0.8	3,057	4,316	16,048	30,831
0.85	**3,101**	**4,396**	**16,143**	**30,905**
0.9	3,163	4,485	16,227	30,970
0.95	3,246	4,572	16,297	31,025
1	3,330	4,633	16,348	31,069

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	4,435	4,725	5,668	5,397
0.5	4,435	4,725	5,794	5,972
0.6	4,435	4,725	5,797	6,135
0.7	4,435	4,725	5,797	6,135
0.75	4,435	4,725	5,797	6,135
0.8	4,435	4,725	5,797	6,135
0.85	**4,435**	**4,725**	**5,797**	**6,135**
0.9	4,435	4,725	5,797	6,135
0.95	4,414	4,725	5,797	6,135
1	4,384	4,725	5,797	6,135

"18%" Model

PNI

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	51%	56%	92%	97%
0.5	54%	59%	92%	97%
0.6	58%	63%	93%	98%
0.7	62%	68%	94%	98%
0.75	65%	71%	94%	98%
0.8	69%	74%	95%	98%
0.85	**73%**	**78%**	**95%**	**98%**
0.9	78%	82%	96%	98%
0.95	83%	86%	96%	98%
1	90%	92%	97%	99%

Fitness - Gen.100

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	0.65	0.71	0.99	1.00
0.5	0.68	0.75	0.99	1.00
0.6	0.72	0.79	0.99	1.00
0.7	0.77	0.83	0.99	1.00
0.75	0.80	0.86	0.99	1.00
0.8	0.83	0.89	1.00	1.00
0.85	**0.87**	**0.91**	**1.00**	**1.00**
0.9	0.91	0.94	1.00	1.00
0.95	0.95	0.96	1.00	1.00
1	0.98	0.98	1.00	1.00

NOS% (Gen 90-100)

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	56%	65%	94%	97%
0.5	60%	69%	94%	97%
0.6	65%	74%	95%	98%
0.7	71%	79%	96%	98%
0.75	75%	81%	96%	98%
0.8	79%	84%	96%	98%
0.85	**82%**	**87%**	**97%**	**98%**
0.9	86%	90%	97%	98%
0.95	90%	93%	97%	98%
1	94%	95%	98%	99%

NOS-esc Mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	2,519	2,986	6,783	10,163
0.5	2,512	3,012	6,771	10,160
0.6	2,517	3,059	6,772	10,158
0.7	2,541	3,128	6,775	10,155
0.75	2,564	3,171	6,776	10,154
0.8	2,596	3,219	6,777	10,153
0.85	**2,638**	**3,271**	**6,777**	**10,151**
0.9	2,691	3,323	6,776	10,150
0.95	2,755	3,370	6,775	10,148
1	2,814	3,403	6,774	10,147

NOR Harvest mean

Trapping Efficiency	CP	CP+75	RG	HIST
0.4	3,018	4,113	16,476	31,259
0.5	3,011	4,146	16,449	31,250
0.6	3,016	4,205	16,450	31,243
0.7	3,042	4,290	16,458	31,235
0.75	3,066	4,344	16,460	31,231
0.8	3,101	4,404	16,462	31,227
0.85	**3,145**	**4,469**	**16,462**	**31,223**
0.9	3,201	4,534	16,461	31,219
0.95	3,269	4,592	16,459	31,214
1	3,330	4,633	16,456	31,210

HOR Harvest mean

	CP	CP+75	RG	HIST
0.4	5,179	5,462	3,964	3,088
0.5	5,179	5,469	4,136	3,129
0.6	5,179	5,469	4,192	3,134
0.7	5,179	5,469	4,192	3,134
0.75	5,179	5,469	4,192	3,134
0.8	5,179	5,469	4,192	3,134
0.85	**5,179**	**5,469**	**4,192**	**3,134**
0.9	5,172	5,469	4,192	3,134
0.95	5,146	5,469	4,192	3,134
1	5,120	5,469	4,192	3,134