# ADDENDUM 8. Biological Evaluation of Alternative Strategies using the SHIRAZ model.

As mentioned in the general EASC document, the task in Step 8 of the EASC is to use models linking habitat conditions to fish population status to evaluate the biological consequences of alternative habitat protection and restoration strategies in the Snohomish River Basin. This Addendum presents results from the SHIRAZ model that were presented to the Snohomish Forum during the Spring of 2004 to help in their choosing among alternative suites of habitat actions for inclusion in the draft salmon recovery plan. The technical group conducting the SHIRAZ modeling worked closely with the Snohomish Technical Committee to translate several habitat protection and restoration alternatives into inputs for the SHIRAZ model. The fish population status and habitat condition results from this modeling are reported in this document in two parts: (1) a description of the SHIRAZ model and how it links habitat conditions to predictions of fish population dynamics, and (2) a discussion of how alternative landscape features (produced as part of Step 7 in the EASC) were translated into habitat conditions and fish capacity inputs for the SHIRAZ modeling.

# Addendum 8.1. SHIRAZ model results for the Snohomish River Basin EASC

Mark D. Scheuerell, Mary H. Ruckelshaus, Krista L. Bartz, Kerry Lagueux
*NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Blvd E, Seattle, WA 98112*

## INTRODUCTION

Developing a salmon recovery plan involves making estimates of the effects of habitat condition and functioning, hatchery and harvest management, interactions with other species, and other environmental factors on salmon population status. The proximal effects of habitat condition on fish populations also can be indirectly influenced by land use and its effects on landscape-forming processes (Beechie et al. 2004). Understanding all of these "H" factors in a salmon life cycle context can help to identify those factors whose improvements are likely to have the greatest effect on salmon recovery (Fig. 1). Population models are a useful way of integrating the effects of the so-called "H's" on salmon populations, especially those models that incorporate effects of the H's on stage-specific survival or capacity. In this section, we describe how we used the SHIRAZ model to link habitat effects to fish population dynamics to inform selection of alternative landscapes that in the future are estimated to lead to salmon recovery.

## METHODS

**Fish stocks and life-history**. The SHIRAZ model framework begins by assigning fish to various "stocks" which can be used to represent 1) different life history strategies (e.g., ocean-type vs. stream-type chinook), 2) wild vs. hatchery fish, and 3) different species. Coincident with assigning fish to their respective stocks, the user must specify each life-history trajectory. This could take the very simple case of only considering spawners and their subsequent offspring that recruit back to freshwater, or it might assume a much more detailed form. For our purposes, we use the following life history stages: adults maturing and returning to rivers, spawners surviving the harvest, eggs, fry, smolts, and fish in the ocean for 1-5 years. For the present analyses, we consider only ocean-type chinook salmon that go to sea after only a few months of rearing in freshwater habitat.

**Spatial resolution**. As the model is spatially explicit, the user must decide what level of spatial resolution to consider. This could be as broad as an entire watershed or as fine as individual stream reaches. We track fish during their freshwater residency within each of these areas, with subsequent spawners returning to their natal location to spawn (unless they stray). We treat the estuary and ocean as one location each, but there is no reason why another application could not split either habitat into a greater variety of spatial units. For the case study presented here, we use the 62 subbasins within the Snohomish River watershed (including the estuary) as our level of spatial resolution (Figure 2). These subbasins range in size from 12.2 to 246 km$^2$ and the length of stream within each subbasin ranges from 0.34 to 98 km.

**Temporal resolution**. The model generally operates on an annual time scale, but several life-stage transitions may occur within a given year (e.g., spawning of eggs and the emergence of the fry from the gravel). By defining a beginning and an end year, the model allows for forward projections of population size by stock, life stage, and location. All of the analyses presented here used a 50 year time horizon beginning in 2001. In general, the model reached its equilibrium spawner abundance in approximately 30 years.

**Fish movement**. SHIRAZ permits fish to move between areas, and once movement takes place, SHIRAZ tracks the number of fish by stage, stock, year, area of birth, and current area of residence. Therefore, the fish know where their natal area is and can return there when spawning takes place. The model allows for movement at any number of life history stages, and can be specified either by a fixed preference (i.e. the proportion of fish moving from area *i* to area *j*) or by letting the fish migrate to an area based on their expected survival in that area according to an ideal free distribution (IFD, sensu Fretwell 1972). Furthermore, we provide a parameter for a "mixed" solution, so that the spatial allocation might be weighted evenly by intrinsic probabilities and by trying to maximize survival. For each life stage where movement occurs, the user must specify a matrix of intrinsic probabilities of movement, which at the very least should represent the physical structure of the watershed, such that fish will move downstream, and not upstream (unless they really do). In our example, we chose to let fish move downstream according to a specified movement matrix without any specific knowledge of the quality of the habitat (i.e. no IFD movement). For the analyses presented here, we did not include any straying due to a lack of data for parameterizing the model.

**Habitat indicators.** We use the underlying physical environment as the primary driver of fish population dynamics. Therefore, the user must specify a set of habitat indicators for each area of interest. These can be detailed physical factors such as stream gradient or width, percentage of pools, riparian vegetation cover, or quantities such as juvenile rearing area, spawning area, etc. The condition of habitat indicators we modeled can change over time gradually by exponential or logistic growth (or decay), but do not change from year to year in a stochastic way. For the Snohomish case study, we relied primarily on physical habitat indicators and literature sources to estimate the capacity of habitat to support juvenile and adult salmon (see EASC Step 4 and Addendum 8.2). In addition, we used a few habitat attributes (i.e., peak flows, fine sediment and water temperature) to predict the survival of eggs to fry under different habitat conditions (see Addendum 8.2). Other life-stage-specific survivals were not modeled to vary with habitat conditions due to limitations in data and the availability of functional relationships linking habitat conditions to survivals at particular life stages.

We modeled 5 alternative landscapes in the Snohomish River Basin, using estimates of the quality and amount of habitat under each alternative as described in Step 7 of the EASC and in Addendum 8.2. Each landscape alternative resulted in different habitat conditions and accessibility, and we asked how fish population dynamics varied under each set of habitat conditions (see Results.)

**Initial conditions**. SHIRAZ requires the user to set up initial starting conditions including where fish occur and how the total population is distributed among sites in the watershed. The user must also input how many individuals of each life stage are alive at the beginning of a model run, such that one could start with only spawners, or specify an entire age distribution across all life stages. Lastly, one must specify the beginning and end years of the model run. In all of the scenarios presented here, we used 1000 spawners each of age-3, age-4, and age-5 chinook salmon as our initial population size. We seeded fish spatially in the "current path" scenario in proportion to the current observed spawner abundance (EASC Step 1). For the "historical" scenario, we seeded adult fish in proportion to the estimated historical spawner capacity (see EASC Step 4, Sanderson et al., unpublished manuscript). For the various "test case" scenarios, we allocated fish to subbasins in proportion to the estimated current adult capacity (see EASC Step 4, Sanderson et al., unpublished manuscript**).**

**Model formulation**. Our model development begins with a multi-stage Beverton-Holt model (Moussalli and Hilborn 1986)

$$N_{s+1} = \frac{N_s}{\dfrac{1}{p_s} + \dfrac{1}{c_{s+1}} N_s}, \tag{1}$$

where the number of fish surviving to their next life-history stage ($N_{s+1}$) is a function of the number alive at the current life stage ($N_s$), their survival or productivity ($p_s$), and the capacity of the environment to support them ($c_{s+1}$). The parameters $p$ and $c$ can assume fixed values or be functions of the environment, such that

$$p_s = \prod_i p_{s,i}\ , \tag{2}$$

$$c_s = \prod_i c_{s,i}\ , \tag{3}$$

and $i$ represents the number of functional relationships for a given life stage. The basic habitat model consists of specifying how habitat indicators and stochastic variables relate to productivity and survival, and a range of functional forms are available to develop these relationships, ranging from simple linear, to exponential, to line segments.

**Functional relationships**. For the Snohomish River case study, we used a combination of fixed parameter values and habitat-based functions to relate various attributes of the physical environment to the survival and capacity of several life stages (Table 1). For survival, these include the transitions from spawners to eggs and from eggs to fry. For capacity, these include spawners, fry, and smolts. First, we model the prespawning survival of adults in the river ($p_1$) as a nonlinear function of temperature ($T$) based on the analyses of Cramer (2001), such that

$$p_1 = \begin{cases} 1 & \text{if } T < 16 \\ 1 - 0.15(T - 16) & \text{if } T \geq 16 \end{cases}. \tag{4}$$

We use three separate functions for estimating the effects of the physical environment on egg-fry survival. The first, a nonlinear relationship with temperature ($p_{1\text{a}}$), is a series of line segments fit from data in Olson et al. (1970), where

$$p_{2,1} = \begin{cases} 0.190T + 0.001 & \text{if } T < 5 \\ 0.95 & \text{if } 5 \le T < 15 \\ -0.237T + 4.51 & \text{if } 15 \le T < 19 \\ 0.001 & \text{if } T \ge 19 \end{cases}. \tag{5}$$

Secondly, we model egg-fry survival as a nonlinear function ($p_{2b}$) of the flood recurrence interval (*FRI*), defined as the average number of years between consecutive incidents of annual peak flow equal to or greater than a certain magnitude (Sumioka et al. 1998). Following Beamer and Pess (1999),

$$p_{2,2} = 0.129 * \exp(-0.0446FRI). \tag{6}$$

Lastly, egg-fry survival is also a nonlinear function of the percent fine sediment (<6.3 mm) in the spawning gravel. Based on data from Tappel and Bjornn (1983), we developed the following relationship between egg-fry survival and the proportion of fine sediment (*f*)

$$p_{2,3} = \begin{cases} 0.95 & \text{if } f < 0.268 \\ -3.32f + 1.81 & \text{if } 0.268 \le f < 0.544 \\ 0.06 & \text{if } f \ge 0.544 \end{cases}. \tag{7}$$

**Harvest management.** We did not include any harvest management in the analyses here per se, but we did adjust the number of spawners in the "current path" scenario to match the observed escapement for both Skykomish River and Snoqualmie River stocks. We include the description of harvest here for those interested in how the model works. If the model application is to include fishery catch, those fish maturing and returning to spawn are then subject to harvest. We can adopt two possible harvest management policies: a constant escapement goal or a constant harvest rate. When managing for constant escapement, the model allows a set number of adult fish to "escape" the fishery and return to freshwater before harvesting the remaining spawners. Under a constant harvest rate policy, the model treats harvest as another source of mortality by taking a set proportion of the returning adult fish ($z_c$). The harvest rates on wild and hatchery fish are potentially stochastic variables, and computed directly from a uniform distribution. Therefore, the harvest rate for a given year ($z_t$) becomes

$$z_t = \begin{cases} 1 - \dfrac{escapement}{\sum adults} & \text{if escapement policy} \\ \mathrm{z_c} & \text{if constant harvest policy} \end{cases}. \tag{8}$$

**Hatchery operations**. As for harvest, we did not include any hatchery effects in the analyses here, but we did adjust the number of spawners in the "current path" scenario to match the observed escapement for both Skykomish River and Snoqualmie River stocks. We include the description of how SHIRAZ addresses hatchery operations for those interested in how the model works. We can simulate hatchery operations from two perspectives: the number of eggs taken from returning spawners and the number of juveniles released back into the river. The user specifies the number of eggs to take each year and the stock of fish from which they are to be taken. After accounting for hatchery mortality due to egg takes, any remaining fish are allowed to spawn in the wild. For hatchery releases, the user must specify the life stage(s) of fish (e.g., fingerlings or yearlings), the number of fish of each stage to release, and the location within the watershed where the fish should be released. After release, the hatchery fish follow survival and capacity rules, whether similar or different to those applied to the wild fish. Any returning adults are also subject to harvest as described above.

## RESULTS AND DISCUSSION

Model simulations suggest that the total number of spawners under the current path scenario are only 35% and 49% of the historical scenario for the Snoqualmie River and Skykomish River populations, respectively (Figure 3). As implemented in SHIRAZ, the original recovery alternative (i.e. the 100% test case) developed by King and Snohomish County (EASC Step 7 Table) predicted spawner abundances that were 55% and 76% of the historical abundance for the Snoqualmie River and Skykomish River populations, respectively (Figure 3). Based on these results, the Snohomish Basin policy staff revisited their suite of possible policy decisions and developed two additional test cases that resulted in 50% and 75% of the original targeted actions. For the 50% of original test case alternative, the predicted spawner abundances were 52% and 73% of the predicted historical abundance for the Snoqualmie River and Skykomish River populations, respectively (Figure 3). For the 75% of original test case alternative, the predicted spawner abundances were 53% and 75% of the predicted historical abundance for the Snoqualmie River and Skykomish River populations, respectively (Figure 3).

To assess the degree of potential spatial structure under each recovery alternative, we mapped the total number of spawners predicted by SHIRAZ to occur in each sub-basin under each of the alternatives. As one might predict, the historical scenario had the greatest range of spawners spread throughout the Snohomish River basin (Figure 4, top). The current path alternative showed the least number of subbasins that supported spawning adults, but it did include some additional occupied subbasins upstream of Sunset Falls on the Skykomish River, resulting from active transport of spawners above the falls by truck (Figure 4, middle). All three of the test cases resulted in the same spatial distribution of spawners as predicted by SHIRAZ (but see Conclusions, below). In all 3 alternative test cases, several additional subbasins supported spawning adults that were not observed under the current path alternative, including those above Sunset Falls (Figure 4, bottom).

In an attempt to describe the potential diversity of life history strategies that chinook salmon might exhibit under each recovery alternative, we examined the proportion of the total spawning that occurred within the various EPA Level-IV Ecoregions. These ecoregions were identified through an analysis of the patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Omernik 1995). These phenomena include geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. For the Snoqualmie River population, the diversity of spawners appeared quite even among the various alternatives, with most spawning habitat occurring within the East Puget Uplands Ecoregion (Figure 5, top). For the Skykomish River population, we found much more variability among the five alternatives, but the test cases appeared closer to the historical case than did the current path alternative (Figure 5, bottom).

## CONCLUSIONS

The SHIRAZ model results predict differences in chinook population dynamics under current and alternative future landscapes in the Snohomish River Basin. This basic result suggests that there is room for improvement in Chinook population status, and that significant improvement is achievable through changes in land use and habitat functioning in the Basin. The predicted

Chinook population status for the Snoqualmie and Skykomish populations under the current path alternative is well below the planning targets provided by the Shared Salmon Strategy (http://www.sharedsalmonstrategy.org/goals.htm), which are broad salmon recovery goals the Snohomish Forum has been using to guide its planning process. The planning targets describe for each population the co-managers' estimation of what productivity and abundance is required for healthy, self-sustaining and harvestable Chinook populations. Those target numbers are approximately 75-80% of estimated historical spawner numbers in populations throughout Puget Sound. The magnitude of the predicted Chinook population response we modeled with SHIRAZ suggests that the Skykomish population spawner numbers are likely to achieve the planning targets under the alternative future landscapes. The Snoqualmie population numbers predicted by SHIRAZ are slightly lower under the alternatives, but they are estimated to improve to over 50% of historical abundances (Fig. 3).

Two important caveats follow from our results. First, it is important to note that we consider the SHIRAZ results to be a likely **under-estimate** of the potential differences in Chinook population response to the changes in habitat quantity and quality modeled under the alternatives. We were not able to represent all of the changes in habitat factors we expect to change due to the land use changes described in the Step 7 table. As depicted in Figure 8.2.6, data limitations did not allow us to fully capture the likely biological effects of changes in land use on habitat conditions in the Basin. We conclude that because we did not fully represent the habitat consequences of land-use changes under the different alternatives, the fish population responses modeled in the SHIRAZ alternatives show less distinction than they would in reality. Another factor contributing to very slight differences among modeled alternatives is that we did not vary potential adult capacity among the 3 test case alternatives. In reality, we expect that the different landscape recovery alternatives would result in differences in potential capacity of habitats to support adults. Nevertheless, because we were lacking data to describe how those capacities would vary with land use differences, we again did not capture those likely differences in the modeling.

The second important caveat to keep in mind is that in this exercise, we only modeled the effects of one "H"—habitat quality and quantity—on Chinook population status. In order for a full exploration of the consequences of recovery alternatives, the cumulative effects of hatchery and harvest management and habitat condition on salmon population status must be considered. Such analyses are ongoing in the Snohomish River Basin, and we expect that results from such integrated work will help to further crystallize what suites of recovery actions are consistent with healthy salmon populations for all of the anadromous species in the Basin.

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## TABLES

**Table 1**. The parameter values and functional relationships affecting the productivity (survival) and capacity of each life stage for the SHIRAZ application to the Snohomish River Basin. Unless otherwise noted, parameter values come from Greene and Beechie (2004). See Methods section for details regarding the forms of the functional relationships.

| Life stage | Productivity ($p$) | Life stage | Capacity ($c$) |
|---|---|---|---|
| Spawners-eggs | $f_1$(temperature)[1] | Eggs | $2500 \cdot c_1$(habitat)[2] |
| Eggs-fry | $f_2$(temperature, flow, sediment)[3] | Fry | $c_2$(habitat)[4] |
| Fry-smolt | 0.306 | Smolts | $c_3$(habitat)[5] |
| Smolts to 1-ocean | 0.024 | 1-ocean | $\infty$ |
| 1-ocean to 2-ocean | 0.6 | 2-ocean | $\infty$ |
| 2-ocean to 3-ocean | 0.7 | 3-ocean | $\infty$ |
| 3-ocean to 4-ocean | 0.8 | 4-ocean | $\infty$ |
| 4-ocean to 5-ocean | 0.9 | 5-ocean | $\infty$ |

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[1] Prespawning mortality is a nonlinear function of temperature (Cramer 2001).

[2] The egg capacity equals an index of spawner fecundity (5000 eggs per female), divided by 2 to account for females only, times the estimated spawner capacity from B. Sanderson, K. Lagueux, and J. Davies (unpublished manuscript; see EASC Step 4).

[3] Egg-fry survival is a nonlinear function of temperature (Olson et al. 1970), river flows (Beamer and Pess 1999), and fine sediment (Tappel and Bjornn 1983).

[4] Fry capacity is derived from the detailed habitat analyses described in Addendum 8.2

[5] Smolt capacity is derived from the detailed habitat analyses described in Addendum 8.2

## FIGURE LEGENDS

Figure 1. Conceptual diagram for 4H's integrating with a life-cycle model.

Figure 2. Map of the Snohomish River Basin and its 61 subbasins. The estuary is treated as a additional subbasin.

Figure 3. Model predictions for the number of spawning chinook relative to the estimated historical level for the various scenarios.

Figure 4. Spatial structure of the spawning population of chinook salmon for historical (top), current (middle), and three test case (bottom) scenarios. The color scheme indicates a range in the number of spawners such that gray = zero, light blue = 1-500, medium blue = 501-1000, and dark blue >1000.

Figure 5. The proportion of spawners across a diversity of spawning habitats represented by EPA Level-IV Ecoregions (Omernik 1995) under the three scenarios.

Figure 1

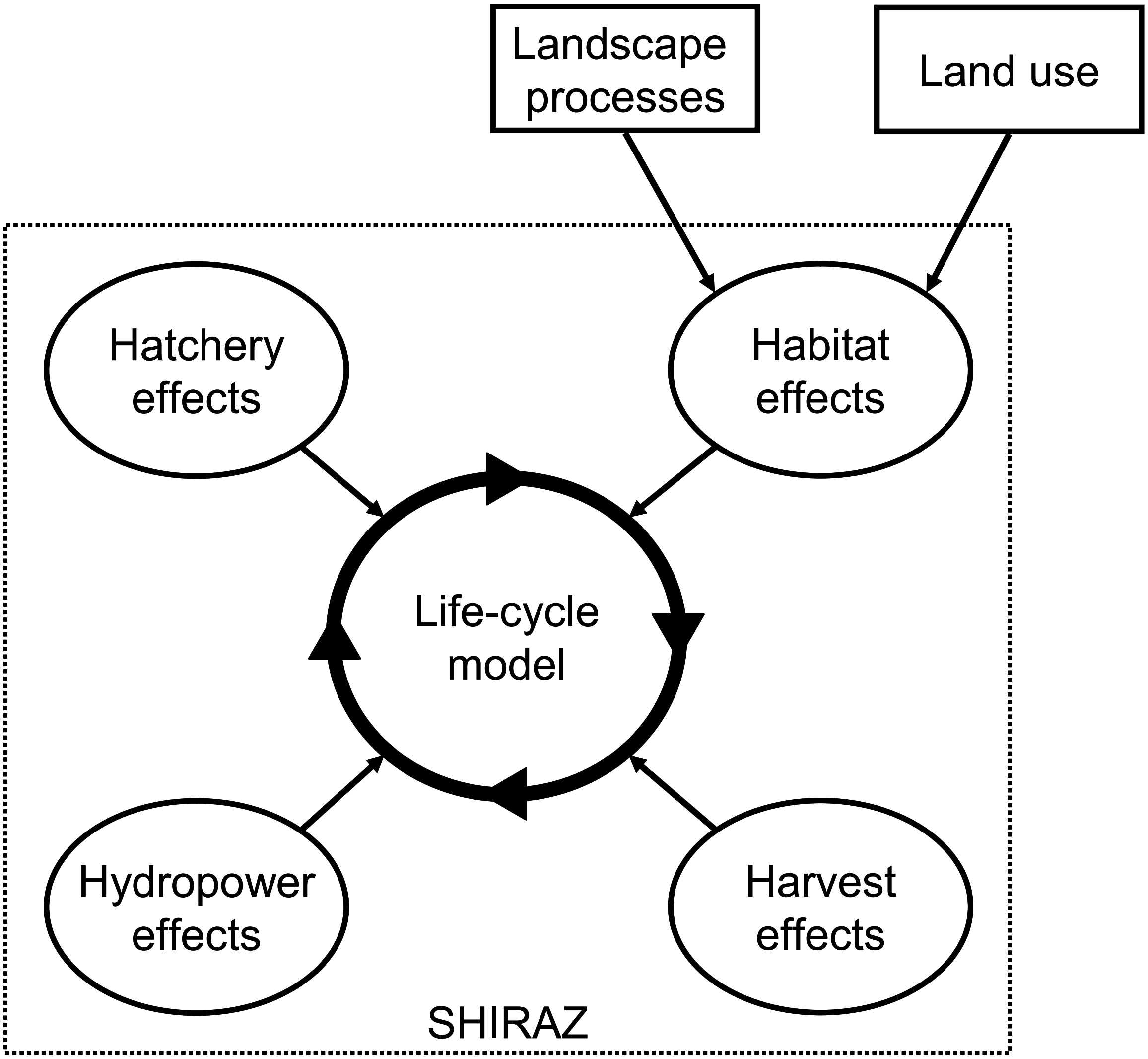
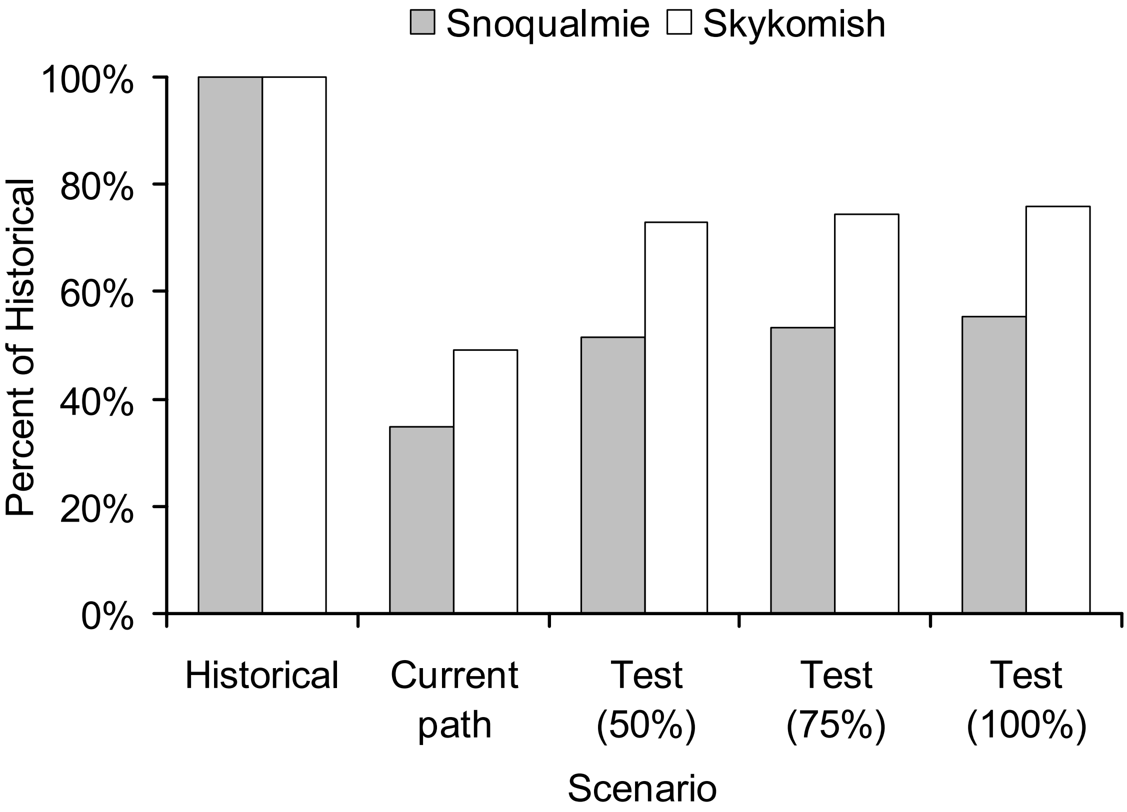

Landscape processes
Land use
Hatchery effects
Habitat effects
Life-cycle model
Hydropower effects
Harvest effects
SHIRAZ

Figure 2

Figure 3



▨ Snoqualmie ☐ Skykomish
100%
80%
60%
40%
20%
0%
Percent of Historical
Historical
Current path
Test (50%)
Test (75%)
Test (100%)
Scenario

Figure 4

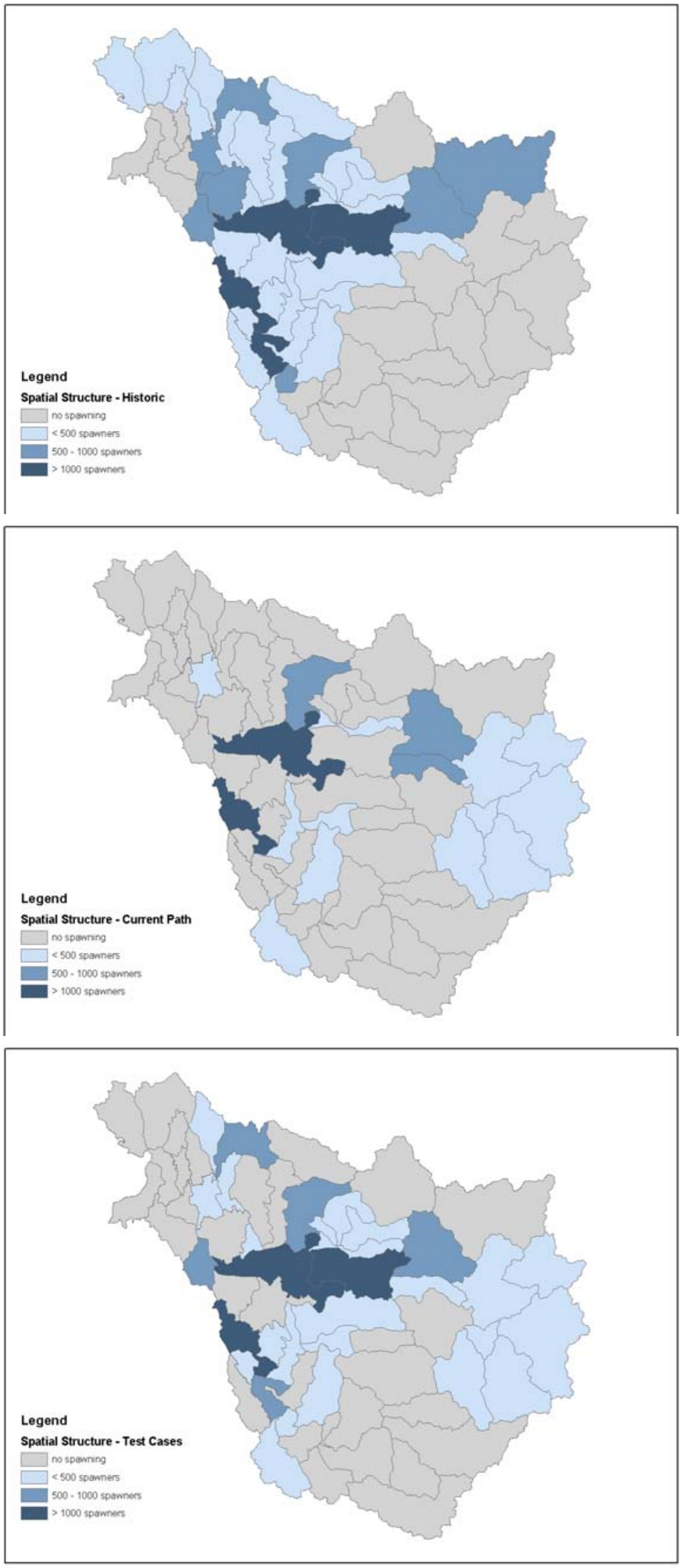
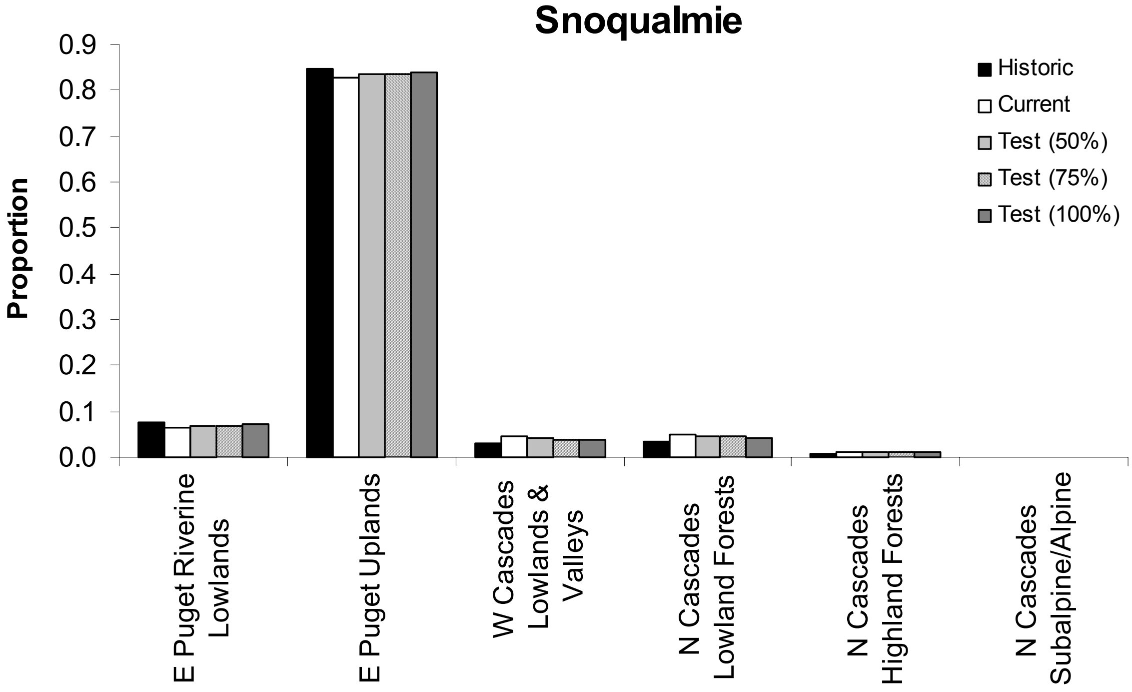
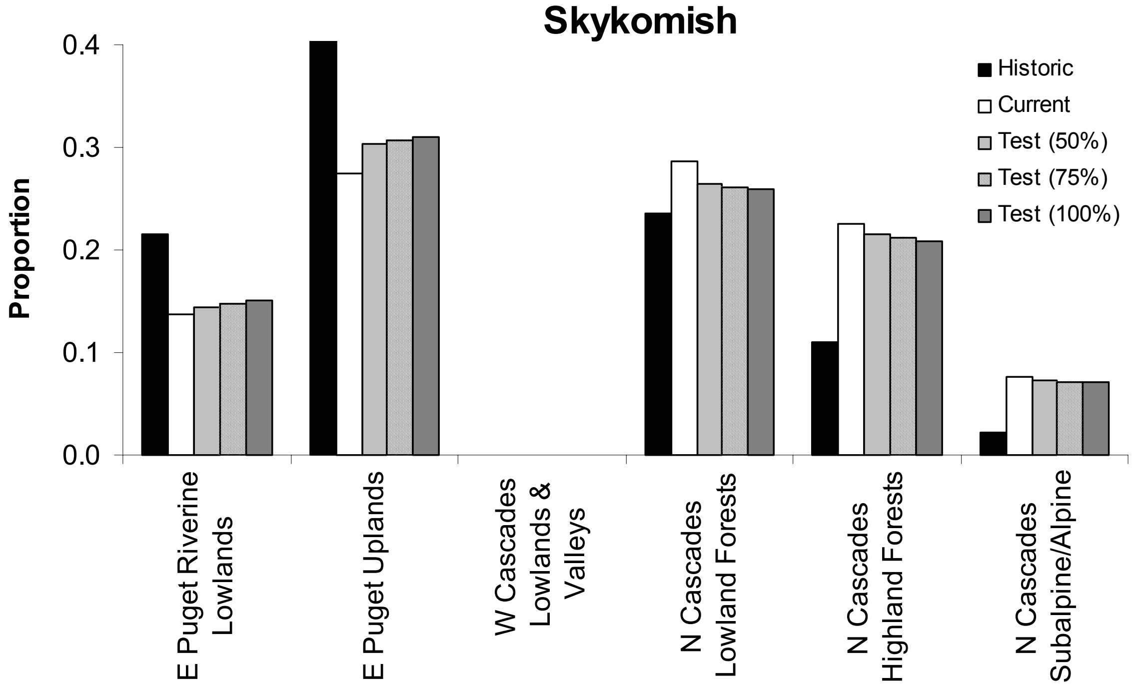

Legend
Spatial Structure - Historic
no spawning
< 500 spawners
500 - 1000 spawners
> 1000 spawners
Legend
Spatial Structure - Current Path
no spawning
< 500 spawners
500 - 1000 spawners
> 1000 spawners
Legend
Spatial Structure - Test Cases
no spawning
< 500 spawners
500 - 1000 spawners
> 1000 spawners

Figure 5



Snoqualmie
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Proportion
■ Historic
□ Current
▨ Test (50%)
▨ Test (75%)
▨ Test (100%)
E Puget Riverine Lowlands
E Puget Uplands
W Cascades Lowlands & Valleys
N Cascades Lowland Forests
N Cascades Highland Forests
N Cascades Subalpine/Alpine



Skykomish
0.4
0.3
0.2
0.1
0.0
Proportion
■ Historic
□ Current
▨ Test (50%)
▨ Test (75%)
▨ Test (100%)
E Puget Riverine Lowlands
E Puget Uplands
W Cascades Lowlands & Valleys
N Cascades Lowland Forests
N Cascades Highland Forests
N Cascades Subalpine/Alpine

# Addendum 8.2. Derivation of Inputs to the SHIRAZ Model

Krista Bartz, Kerry Lagueux, Mark Scheuerell, Mary Ruckelshaus and Tim Beechie
*NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Blvd E, Seattle, WA 98112*

## DESCRIPTION

The SHIRAZ model has three main components: 1) a description of habitat conditions; 2) a set of relationships linking habitat conditions to productivity or capacity at particular life stages; and 3) a population dynamic model that moves individuals through the landscape, accounting for their survival over time. This addendum focuses on the first two components, and is intended to supplement the information contained in Step 8. For a description of the third component (i.e., the population dynamic model), see Addendum 8.1.

We used SHIRAZ to model chinook population responses to the alternative scenarios described in EASC Step 7: current path, test case, two intermediate alternatives, and an historical baseline. In order to estimate the effects of these alternatives on chinook viability, we needed to translate the Step 7 Table targets into productivity and capacity values. In this section, we describe the means by which we made those translations.

## METHODS

The population dynamic model at the core of SHIRAZ defined the number of chinook at a given life stage as:

$$N_{s+1} = \frac{N_s}{\dfrac{1}{p_s} + \dfrac{1}{c_{s+1}} N_s}$$

where $p$ was productivity, $c$ was capacity, and $N_s$ was the number of chinook at the previous life stage. For freshwater life stages, the model was parameterized to accept inputs at the scale of the 62 Snohomish River subbasins. However, since neither productivity nor capacity had been directly quantified at that scale, both types of inputs needed to be computed. Below is a detailed description of the derivation of the productivity and juvenile capacity inputs. The derivation of the adult capacity inputs is summarized here only briefly, because a detailed description is provided in Step 4 of the EASC document.

### Productivity

SHIRAZ used four habitat conditions to predict stage-specific chinook productivities in the Snohomish River Basin. The conditions were: 1) water temperature during the pre-spawning period; 2) water temperature during the egg incubation period; 3) percentage of fine sediment in the streambed; and 4) peak flood recurrence interval. Equations linking these habitat conditions to productivities were drawn from the literature (Olson et al. 1970, Tappel and Bjornn 1983, Beamer and Pess 1999, Cramer 2001; Appendix 8.2.1). Here we describe the derivation of the habitat condition inputs. The derivation involved estimating in each subbasin current habitat conditions, historical habitat conditions, and habitat conditions under four alternative scenarios provided by the Snohomish Basin planning staff.

### Current habitat conditions

We first amassed as much empirical data as we could find for the four habitat conditions in each subbasin. These data were patchy in their availability over space and time— only about ¼ of the subbasins were represented (Table 8.2.1). To fill in the data gaps in the remaining subbasins, we developed four regression models, one for each habitat condition. The models relied on two types of independent variables. One type, hereafter referred to as "land use variables," consisted of factors primarily driven by humans, while the other type, hereafter referred to as "fixed variables," consisted of factors primarily driven by natural processes and other non-human phenomena. Data for independent variables of both types were derived through GIS analyses (Table 8.2.1, Appendix 8.2.2). Data for dependent variables were derived through gage measurements and field samples collected from 1990 onward (Table 8.2.1, Appendix 8.2.3).

As a preliminary step in developing the regression models, all variables were transformed, and correlation analyses were conducted to assess the bivariate relationships between the transformed and untransformed versions of the dependent and independent variables. The correlation results were then used to select variables to enter into stepwise multiple regression analyses. We performed the analyses with SYSTAT 10 software using the backward elimination option (p to remove variables = 0.15; SPSS Inc. 2000). We accepted the resulting models if residuals met the assumptions of normality and homogeneity of variance, and if the signs of the land use variable coefficients aligned with expectations based on empirical results in the literature. If these criteria were not met, we altered the list of variables entered into the regressions and repeated the analyses.

### Historical habitat conditions

To quantify historical habitat conditions in each subbasin, we estimated historical values for the land use variables, then entered these values into the regression models. Road density $_{\text{historical}}$ and total impervious area $_{\text{historical}}$ were estimated as 0 km/km$^2$ and 0%, respectively, for all subbasins. Total forest cover $_{\text{historic}}$ was estimated as 100% - (% alpine rock + % open water + % unknown land cover), and riparian forest cover $_{\text{historical}}$ was estimated as riparian forest cover $_{\text{current}}$ • total forest cover $_{\text{historical}}$ / total forest cover $_{\text{current}}$.

### Habitat conditions under alternative scenarios

To quantify habitat conditions under alternative scenarios in each subbasin, we needed to express the Step 7 Table, which specified the scenarios, at the subbasin scale. This was accomplished by calculating the percent change from "current" to "target" values for each land use variable, then by multiplying these percentages by the appropriate land use variable at the subbasin scale (Appendix 8.2.4). Essentially, these calculations produced new land use variables for each scenario (e.g., road density $_{\text{current path}}$, road density $_{\text{alternative 2}}$, road density $_{\text{alternative 3}}$, road density $_{\text{test case}}$), which we then entered into the regression models.

## Juvenile capacity

We took a two-step approach to estimate the potential of habitats to support juvenile rearing in the Snohomish River Basin. First, we quantified rearing areas by habitat type, then we multiplied the areas by habitat type-specific juvenile densities (Table 8.2.2). Habitat types, at the broadest level, were defined as being either freshwater or estuarine. Freshwater habitat was further divided into channel, off-channel, and lake types. Estuarine habitat was further divided into riverine tidal, estuarine scrub-shrub, and estuarine emergent marsh types. These divisions were guided by the availability of juvenile density data in the literature. As with productivity, current, historic and alternative capacity values were computed.

<u>Current freshwater rearing area</u>

*Channel area.* In order to quantify the current channel rearing area, we limited our analysis at the outset to accessible reaches with gradients < 4%. Gradient was determined using a digital elevation model of the Snohomish River Basin (Davies et al. *in prep.*). Accessibility was determined using GIS data layers of natural and anthropogenic barriers (WDFW 2003, NWIFC 2003, Snohomish County *unpublished data*). We estimated bankfull widths (bfw) for these accessible, low gradient reaches using an equation developed by Davies et al. (*in prep*). We then divided the reaches into three habitat subtypes based on bfw: large mainstems (> 50 m bfw), small mainstems (10-50 m bfw), and tributaries (< 10 m bfw). For all three subtypes, the total rearing area of a reach was determined by multiplying the reach length by the estimated wetted width (Davies et al. *in prep*). For large mainstem and tributary reaches, the total area was summed by subbasin then partitioned into additional habitat subtypes using data compiled from the Skagit River in Washington (Beechie et al. 1994, Holsinger, *unpublished data*; Table 8.2.3). Additional habitat subtypes included pools, riffles, and glides, as well as banks, bars, and backwaters for large mainstem reaches. For small mainstem reaches, the total area was not partitioned because data like those in Table 8.2.3 did not exist.

*Off-channel area.* In order to quantify the current off-channel rearing area, we relied on an analysis performed by the Snohomish County Public Works Department (Snohomish County *unpublished data*). The analysis identified all currently accessible water bodies within the 100-year floodplain, and all side channels connecting the water bodies to the main channels. Side channel lengths were multiplied by an estimated width of 5 m to calculate area, then side channel and water body areas were summed by subbasin.

*Lake area.* In order to quantify the current lake rearing area, we limited our analysis to lakes connected to accessible, low gradient channel reaches. Piaskowski and Tabor (2001) found that chinook rearing in lakes favored the shallow areas near lake edges. They reported that chinook occupied varying widths of this edge habitat depending on lake shore gradient— if the gradient was ≤ 20%, chinook occupied a mean width (i.e., distance from shore) of 3.7 m, otherwise they occupied a mean width of 1.6 m. Since we did not have bathymetric data, we multiplied the mean of these two widths by the perimeter of each lake to calculate lake rearing area. We then summed the lake rearing areas by subbasin and lake size class (< 500 $m^2$, 500–50,000 $m^2$, > 50,000 $m^2$).

<u>Current estuarine rearing area</u>

In order to quantify current estuarine rearing area, we partitioned the estuary into riverine tidal, estuarine scrub-shrub, and estuarine emergent marsh habitat types using National Wetland Inventory maps (USFWS 2002). We then estimated the area of main, distributary, and blind-tidal channels in each habitat type. For main and distributary channels, we calculated the area within 10 meters from the bank, since juveniles preferentially use the margins of these channels (Haas and Collins 2001). For blind-tidal channels, we estimated the area based on data in Haas and Collins 2001 (Table 8.2.4). As with freshwater areas, estuarine areas were summed by subbasin.

Historical freshwater and estuarine rearing area

The methods for quantifying historical rearing area differed from those outlined above in three respects. First, anthropogenic barriers were omitted from the assessment of channel accessibility. Second, the habitat subtype compositions in Table 8.2.3 were altered. Finally, off-channel and estuarine rearing areas were estimated from GIS data layers by Collins and Sheikh (2003).

Alternative freshwater and estuarine rearing area

Freshwater and estuarine rearing areas were adjusted based on target levels specified in the alternative scenarios developed by the Snohomish Basin planning staff (see the Step 7 Table). The target levels pertained to channel, off-channel, and estuarine areas. Lake areas did not change.

*Channel area.* To quantify channel rearing area under the alternative scenarios, we applied the natural bank target levels in the Step 7 Table. Specifically, we multiplied the current bank area in a subbasin by the target percentage of natural bank area under each scenario. The remaining current bank area for that subbasin was assumed to be hydromodified. Since natural banks had higher juvenile densities than hydromodified banks, changes in natural bank area were expected to alter juvenile capacity. Additionally, Snohomish County identified culverts in the Snohomish River Basin that blocked potential rearing area (Snohomish County *unpublished data*). Using this information, we selected upstream reaches with < 4% gradient and subjected them to the same methods described for the "current" channel areas (above). The resulting channel areas were then multiplied by the target reconnection levels to compute additional channel areas under each scenario.

*Off-channel area.* To quantify off-channel rearing area under the alternative scenarios, we multiplied the historic off-channel area in a subbasin by the target percentage of reconnected off-channel area under each scenario.

*Estuarine area.* To quantify estuarine rearing area, we assumed that 80% of the historic area was currently inaccessible, based on calculations by Haas and Collins (2001). We multiplied this inaccessible area by the target percentage for reconnected off-channel area under each scenario, then added the product to the 20% of the historic area that was currently accessible.

### Adult capacity

We quantified adult capacity by estimating the potential of various types of habitat to support chinook during spawning (Sanderson et al. *in prep.*). As with productivity and juvenile capacity, adult capacity was estimated for current and historic conditions at the subbasin scale. However, adult capacity was not estimated under alternative scenarios due to difficulties in linking the Step 7 Table targets with the variables used to calculate adult capacity.

Current adult capacity

To estimate current adult capacity, we 1) determined the width, gradient and accessibility of each stream reach, 2) quantified by subbasin the total amount of accessible habitat in several width and gradient classes, and 3) applied chinook density data to the totals. Channel width and gradient were determined at the reach scale using a digital elevation model of the Snohomish River Basin (Davies et al. *in prep.*). Accessibility was determined using GIS data layers of natural and anthropogenic migration barriers (WDFW 2003, NWIFC 2003). Once width, gradient and accessibility were determined, the amount of accessible spawning habitat was summed in three width/gradient classes by subbasin. For reaches with > 25 m bfw and ≤ 4% gradient, the amount of habitat was summed by area (A, Table 8.2.5). For reaches 5 − 25 m bfw and ≤ 4% gradient, the amount of habitat was summed by length (B and C, Table 8.2.5). In general, capacity was estimated by multiplying the amounts of habitat in each width/gradient class by the density of spawners in each class, as reported in the literature (Table 8.2.6).

Historic adult capacity

The methods for estimating historic adult capacity differed from those outlined above in two ways. Anthropogenic migration barriers were omitted from the assessment of reach accessibility, and the equations in Table 8.2.6 were altered to reflect historic geomorphic conditions. Specifically, the percentage of spawnable area for reaches > 25 m in bfw increased from 6.2% to 10.0%. Also, the percentages of forced pool riffle and plane bed habitats changed to 92.2% and 7.8%, respectively, for reaches with 5 − 25 m bfw and 1% − 4% gradient.

## RESULTS

### Productivity

The multiple regression analyses produced four models— one to predict each habitat condition. These models varied in explanatory power and in the number of independent variables retained at the end of the stepwise selection procedure (Table 8.2.7). Specifically, the model predicting pre-spawning temperature retained five independent variables (road density, drainage area, stream gradient, and two variables pertaining to surficial geology: Qmw/Qvrl/Qvro, and Qal; $p = 0.001$; adjusted $R^2 = 0.749$), while the model predicting incubation temperature retained three (total forest cover, drainage area, and Qal; $p = 0.014$; adjusted $R^2 = 0.496$). The model predicting fine sediment retained four independent variables (total impervious area, riparian forest cover, drainage area, and Qal; $p < 0.001$; adjusted $R^2 = 0.742$), as did the model predicting flood recurrence interval (riparian forest cover, drainage area, elevation, and Qal; $p = 0.002$; adjusted $R^2 = 0.672$).

### Juvenile capacity

Fewer subbasins were used by juveniles historically (44 subbasins) than are used currently (51 subbasins) due to the transport of chinook above Sunset Falls. However, historical estimates of juvenile salmonid habitat (54,316,589 $m^2$) were more than double the current estimates (20,464,325 $m^2$). The average current habitat per accessible subbasin was 405,616 $m^2$ of habitat, which is significantly less than the average historical habitat of 1,210,815 $m^2$. The current habitat ranged from 6,752 $m^2$ to 2,292,166 $m^2$ per subbasin, while historical habitats ranged from 8,389 $m^2$ to 19,976,199 $m^2$ per subbasin.

The distribution of current and historical juvenile habitat differs spatially within the basin as a whole. The historical estimates of juvenile habitat show the majority of the habitat in the lower portion of the basin, specifically the lower mainstem subbasins and the Marshland subbasin that is directly adjacent to the estuary subbasin (Figure 8.2.1). These lower subbasins are where most of the historical off-channel habitat was distributed. The current distribution of juvenile habitat changes dramatically with the passage above Sunset Falls. Still most of the total habitat still resides in the lower mainstem reaches, but the current distribution is closer to the confluence between the Skykomish and the Snoqualmie mainstems (Figure 8.2.2).

In the Test Case scenario, we made changes to the bank, off-channel, and estuary habitat based upon predicted restoration. Additionally, we reconnected juvenile habitats currently blocked by culverts. These habitat changes resulted in a total usable habitat of 41,375,290 $m^2$, which was more than double the current estimates. The average habitat area per subbasin was 811,260 $m^2$, with a minimum and maximum of 6,252 $m^2$ and 14,171,872 $m^2$, respectively.

The geographic distribution of habitat changed as well, though the majority of habitat remained in the lower mainstem reaches (Figure 8.2.3). The reconnection of off-channel habitat increased the total usable area in the subbasins below the confluence of the Skykomish and Snoqualmie Rivers. Similar to historical conditions, the Marshland subbasin contained the most habitats of any subbasin.

**Adult capacity**
Estimated current capacity throughout the Snohomish River Basin is 18% less than estimated historic capacity (98,275 vs. 119,220 spawners). Likewise, mean current capacity at the subbasin scale (1,585 spawners/subbasin) is lower than mean historic capacity (1,923 spawners/subbasin). However, more subbasins are accessible to spawners currently than were historically (45 vs. 38 subbasins; Figs. 8.2.4 and 8.2.5) due to the transport above Sunset Falls.

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**Table 8.2.1.** Dependent and independent variables used in the multiple regression analyses.

| Variable type | Variable name | Units | N (subbasins) | Source(s) [a] |
|---|---|---|---|---|
| Dependent habitat conditions | Pre-spawning temperature | C | 17 | 1, 2 |
| | Incubation temperature | C | 15 | 1 |
| | Fine sediment | % < 6.3 mm | 17 | 3, 4, 5 |
| | Flood recurrence interval | Years | 16 | 6, 7 |
| Independent land use variables | Road density | $km/km^2$ | 62 | 8 |
| | Total impervious area | % | 62 | 9 |
| | Total forest cover | % | 62 | 9 |
| | Riparian forest cover | % | 62 | 9 |
| Independent fixed variables | Drainage area | $km^2$ | 62 | 10 |
| | Mean channel gradient | % | 62 | 11 |
| | Mean elevation | m | 62 | 11 |
| | Mean annual precipitation | cm | 62 | 11 |
| | Stream power per channel width | $kg/s^3$ | 62 | 10 |
| | Qal surficial geology [b] | % | 62 | 12 |
| | Qmw/Qvrl/Qvro surficial geology [c] | % | 62 | 12 |

[a] 1 = Washington Department of Ecology 2004; 2 = Solomon and Boles 2002; 3 = Booth et al. 1991; 4 = DeVries et al. 2001; 5 = Snohomish County Public Works Department 2002; 6 = United States Geological Survey 2004; 7 = Sumioka et al. 1998; 8 = Washington Department of Natural Resources 2003; 9 = Purser et al. 2003; 10 = K. Bartz, unpublished data 2004; 11 = K. Lagueux, unpublished data 2004; 12 = M. Purser, personal communication 2003.

[b] Qal = the geological symbol for alluvium.

[c] Qmw , Qvro, and Qvrl = the geological symbols for mass wasting deposits, Vashon recessional outwash deposits, and Vashon recessional lacustrine deposits, respectively.

**Table 8.2.2.** Summary of mean juvenile densities (chinook/$m^2$) by habitat type.

| Habitat type | Habitat unit or size | Density | Variance | Source(s) [a] |
|---|---|---|---|---|
| Freshwater − large mainstems | Bar | 0.330 | — | 1 |
| Freshwater − large mainstems | Bank − natural | 0.884 | — | 1 |
| Freshwater − large mainstems | Bank − hydromodified | 0.388 | — | 1 |
| Freshwater − large mainstems | Backwater | 0.529 | 0.595 | 1, 2, 3 |
| Freshwater − large mainstems | Pool | 0.026 | 0.003 | 3, 4, 5 |
| Freshwater − large mainstems | Glide | 0.042 | 0.004 | 3, 4, 5 |
| Freshwater − large mainstems | Riffle | 0.001 | 0.000 | 3, 4, 5 |
| Freshwater − small mainstems | (all) | 0.225 | 0.118 | 4, 5, 6, 7 |
| Freshwater − tributaries | Pool | 0.702 | 0.974 | 8 |
| Freshwater − tributaries | Riffle | 0.181 | 0.040 | 8 |
| Freshwater − lake | < 500 $m^2$ | 0.009 | — | 2 |
| Freshwater − lake | 500 $m^2$ - 5 ha | 0.059 | 0.005 | 9 |
| Freshwater − lake | > 5 ha | 0.092 | — | 10 |
| Freshwater − off-channel | — | 0.032 | 0.001 | 1, 2 |
| Estuary | Riverine tidal | 0.108 | 0.014 | 1, 11 |
| Estuary | Estuarine scrub-shrub | 0.628 | 0.729 | 12, 13 |
| Estuary | Estuarine emergent marsh | 0.215 | 0.059 | 1, 12-16 |

[a] 1 = Hayman et al. 1996; 2 = Murphy et al. 1989; 3 = G. Pess, unpublished data; 4 = Jonasson et al. 1997; 5 = Keefe et al. 1995; 6 = Johnson et al. 1992; 7 = Lister and Genoe 1970; 8 = Sekulich 1980; 9 = Swales and Levings 1989; 10 = Tabor and Piaskowski 2002; 11 = Levy et al. 1979; 12 = Beamer and LaRock 1998; 13 = Korman et al. 1997; 14 = Congleton and Smith 1976; 15 = Congleton et al. 1982; 16 = Dunford 1972.

**Table 8.2.3.** Percentage of reach area comprised by each habitat type. Data were derived from the Skagit River Basin, then applied to the Snohomish River Basin according to discharge class and time frame.

| **Habitat types** | **Large mainstems** | | | | **Tributaries** | |
|---|---|---|---|---|---|---|
| | Discharge class | | Time frame | | Time frame | |
| | < 10,000 cfs | > 10,000 cfs | Current | Historical | Current | Historical |
| Total edge | 37.45 % [a] | 15.35 % [a] | | | | |
| Bars | 69.60 % [a] | 60.50 % [a] | | | | |
| Backwaters | 4.85 % [a] | 4.80 % [a] | | | | |
| Banks | 25.55 % [a] | 34.70 % [a] | | | | |
| Pools | | | 8.70 % [a] | 47.00 % [a] | 52.40 % [b] | 67.80 % [b] |
| Riffles | | | 15.30 % [a] | 26.00 % [a] | 47.60 % [b] | 32.20 % [b] |
| Glides | | | 12.40 % [a] | 26.00 % [a] | | |

[a] Data from Holsinger 2002.
[b] Data from Beechie et al. 1994.

**Table 8.2.4.** Percentage of estuarine area composed of blind tidal channels according to habitat type.

| Habitat type | Percent area in blind tidal channels |
|---|---|
| Riverine tidal | 3.0 % [a] |
| Estuarine scrub shrub | 5.6 % [a] |
| Estuarine emergent marsh | 10.5 % [a] |

[a] Data from Haas and Collins 2001.

**Table 8.2.5.** Gradient and bankfull width classes used to estimate adult potential capacity for mainstem streams (A), small, low-gradient streams (B), and small, high gradient streams (C).

| **Bankfull width** | **Channel gradient** | | |
|---|---|---|---|
| | < 1% | 1-4% | >4% |
| > 25 m | A | A | 0 |
| 5 − 25 m | B | C | 0 |
| < 5 m | 0 | 0 | 0 |

**Table 8.2.6.** Equations used to calculate capacity for each of the width and gradient classes.

| **Spawning Category (Table 8.2.5)** | **Equation** |
|---|---|
| A | # spawners = [(stream area) • (% spawnable) • (# fish/redd)] / redd area |
| B | # spawners = (stream length) • (# spawners/redd) • (# redds/km) |
| C (forested riparian) | # spawners = $(\text{length}_i)$ • $\%\text{FPR}_i$ • # $\text{redds/km}_{\text{FPR/PR}}$ • # spawners/redd |
| C (non-forested riparian) | # spawners = $(\text{length}_i)$ • $\%\text{PB}_i$ • # $\text{redds/km}_{\text{PB}}$ • # spawners/redd |

**Table 8.2.7.** Four statistical models resulting from the multiple regression analyses we used in predicting changes in habitat conditions (dependent variables) in response to changes in land-use and physical habitat features (main effects).

| Dependent variable | Main effect | Coefficient | SE | Standard. Coefficient | t | P (2-tail) |
|---|---|---|---|---|---|---|
| Pre-spawning temperature | Constant | 8.180 | 1.709 | 0.000 | 4.785 | 0.001 |
| | Road density [a] | 4.526 | 1.354 | 0.49 | 3.343 | 0.007 |
| | Drainage area | 0.001 | 0.000 | 0.571 | 2.918 | 0.014 |
| | Gradient [b] | 5.943 | 2.732 | 0.454 | 2.176 | 0.052 |
| | Qmw/Qvrl/Qvro | -0.086 | 0.025 | -0.572 | -3.473 | 0.005 |
| | Qal | -0.054 | 0.028 | -0.487 | -1.945 | 0.078 |
| Incubation temperature | Constant | 15.696 | 3.919 | 0.000 | 4.005 | 0.002 |
| | Forest cover [a] | -2.056 | 0.845 | -0.743 | -2.434 | 0.033 |
| | Drainage area [b] | 101.905 | 62.117 | 0.388 | 1.641 | 0.129 |
| | Qal | -0.063 | 0.038 | -0.563 | -1.672 | 0.123 |
| Fine sediment [a] | Constant | 2.192 | 1.039 | 0.000 | 2.11 | 0.057 |
| | Riparian forest cover | -0.024 | 0.014 | -0.395 | -1.689 | 0.117 |
| | Total impervious area [a] | 0.602 | 0.276 | 0.576 | 2.183 | 0.05 |
| | Drainage area | 0.001 | 0.000 | 0.753 | 4.303 | 0.001 |
| | Qal [b] | 3.574 | 1.054 | 0.581 | 3.392 | 0.005 |
| Flood recurrence interval [a] | Constant | 2.140 | 0.251 | 0.000 | 8.518 | 0.000 |
| | Riparian forest cover | -0.013 | 0.004 | -1.182 | -3.403 | 0.006 |
| | Drainage area [b] | -16.283 | 6.273 | -0.493 | -2.596 | 0.025 |
| | Elevation [b] | -49.075 | 13.846 | -1.115 | -3.544 | 0.005 |
| | Qal [b] | 0.488 | 0.128 | 0.653 | 3.826 | 0.003 |

[a] Variable was natural log transformed (i.e., ln(x + 1)).

[b] Variable was inverse transformed (i.e., 1/(x + 1)).

**Figure 8.2.1**. The percent of total habitat available to juvenile chinook historically in each subbasin.

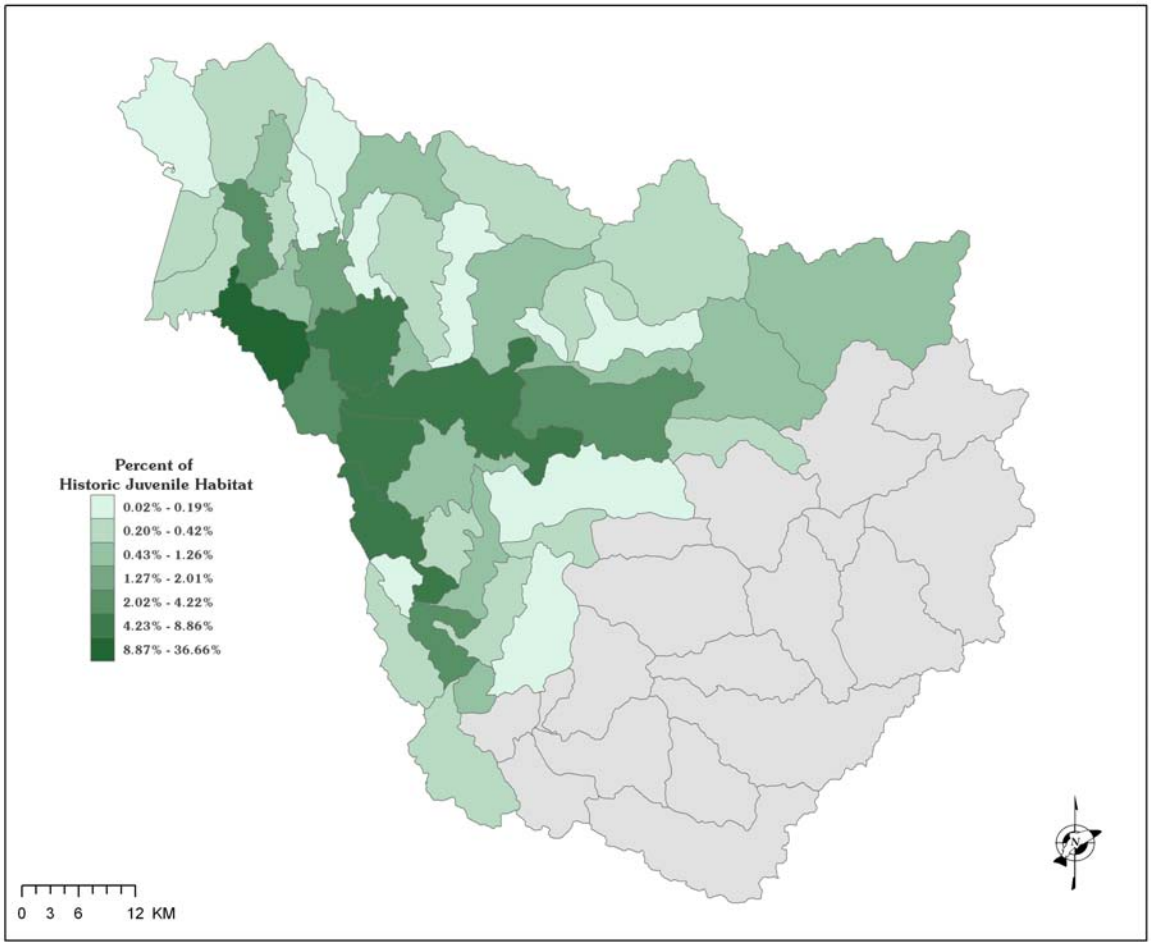


**Figure 8.2.2.** The percent of total habitat available to juvenile chinook currently in each subbasin.

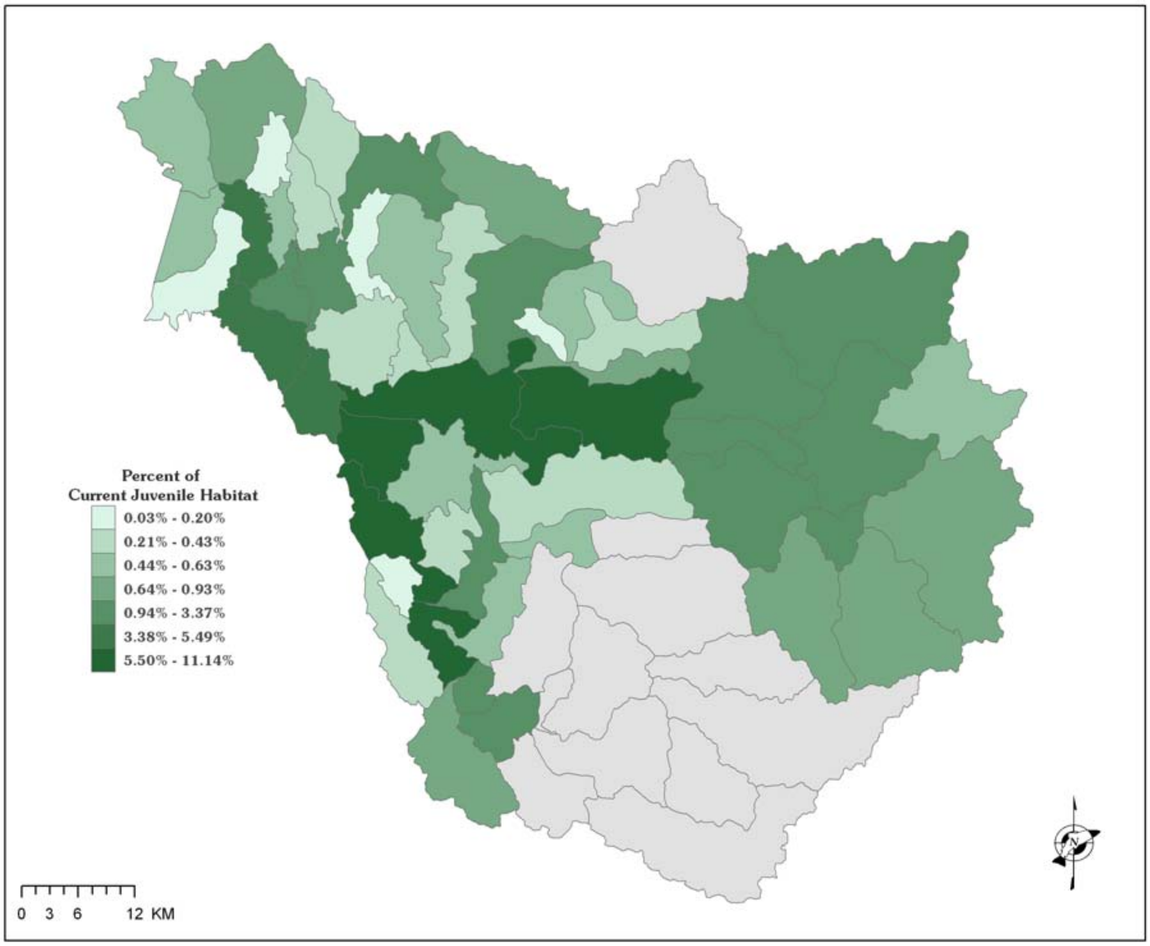


**Figure 8.2.3.** The percent of total habitat available to juvenile chinook under the “Test Case” alternative in each subbasin.

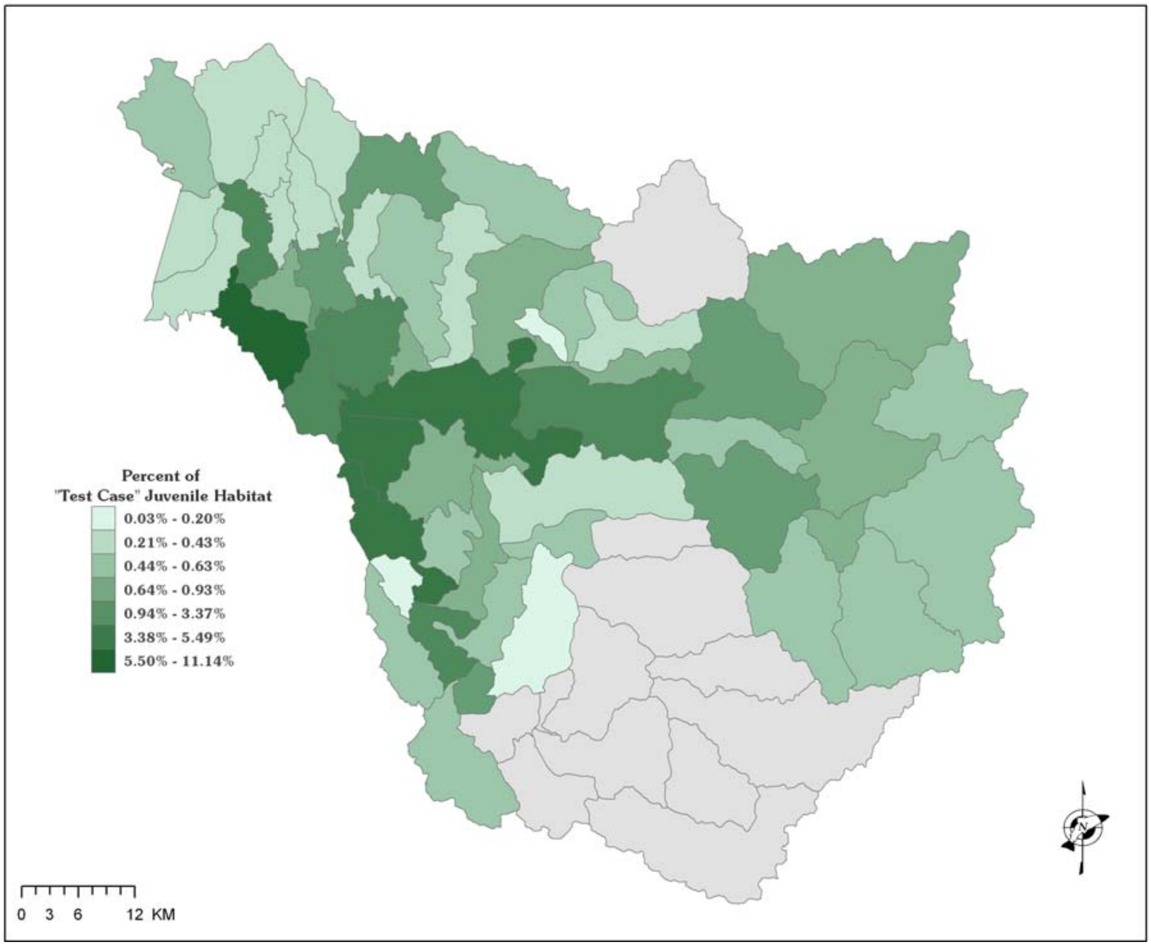


**Figure 8.2.4.** The historic potential chinook spawning per subbasin in the Snohomish River Basin.

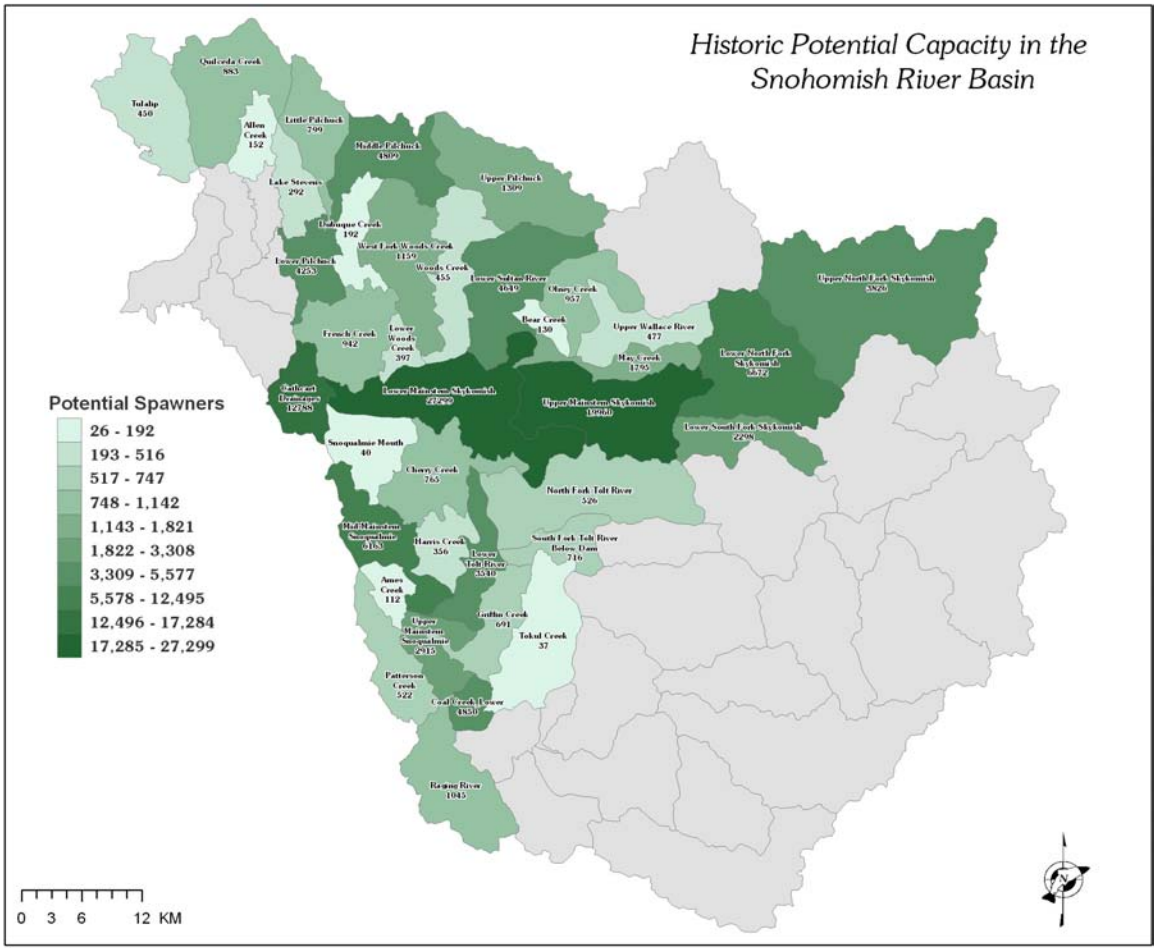
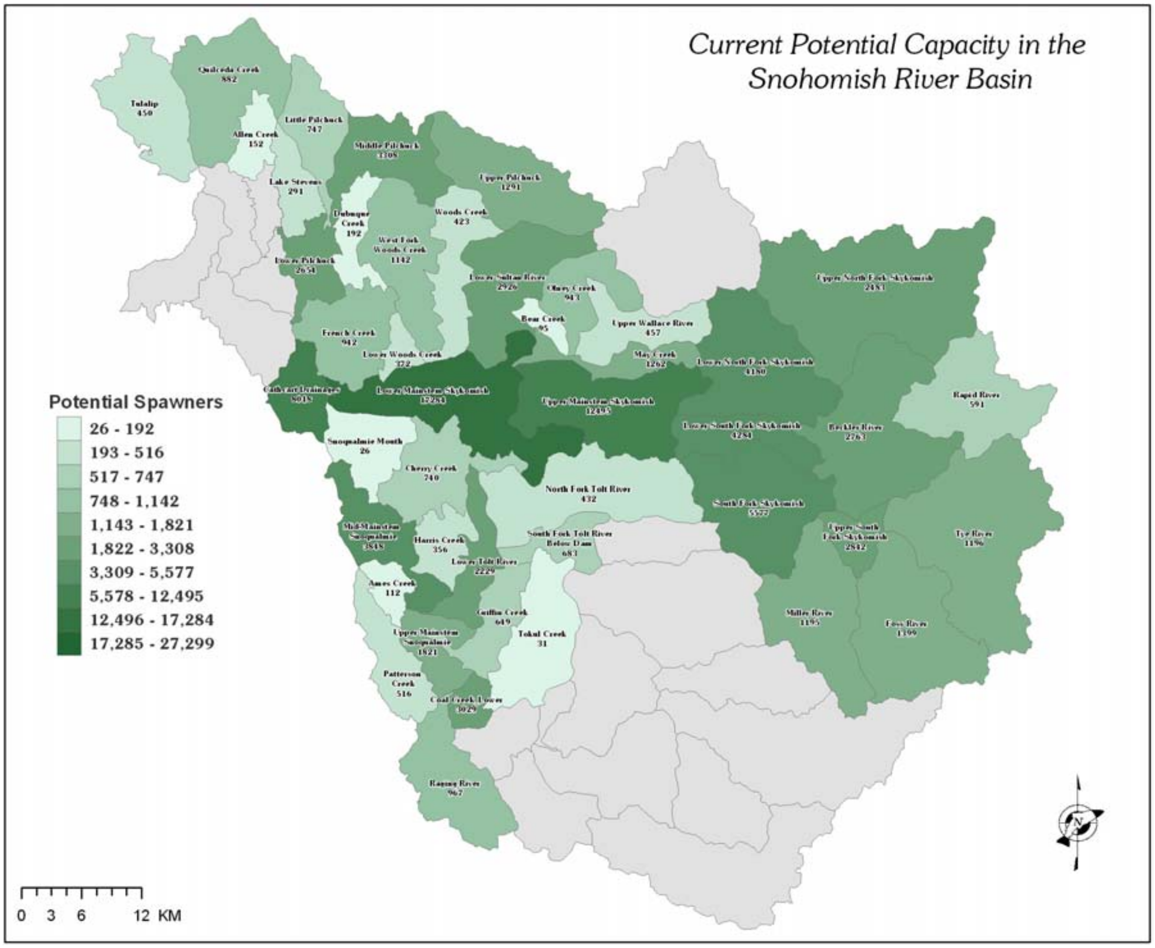


**Figure 8.2.5.** The current potential chinook spawning per subbasin in the Snohomish River Basin.



**Appendix 8.2.1.** Relationships linking habitat conditions to stage-specific productivities of chinook.

### Pre-spawning temperature → spawner-to-egg survival

Warm freshwater temperatures pose a thermal challenge to adult salmonids. This challenge may have various sublethal effects including delayed migration, depleted energy reserves, reduced swimming capability, and increased susceptibility to disease (McCullough et al. 2001). It also may induce direct mortality. Cramer et al. (1985) reported that pre-spawning mortality of wild spring chinook increased from 5% to 35% as the mean maximum water temperature increased from 16.2°C to 18.5°C, while the mortality of hatchery chinook increased from 15% to 80%. Cramer (2001) developed the following relationship based on those data:

- if mean maximum temperature (T) is < 16 °C, pre-spawning survival = 1
- if mean maximum temperature (T) is > 16 °C, pre-spawning survival = 1 – [(T-16) • 0.15].

### Incubation temperature → egg-to-fry survival

Though optimal water temperatures during incubation are likely to vary between stocks, chinook eggs generally require temperatures between 5.0 and 14.4ºC for survival (Bjornn and Reiser 1991). SHIRAZ uses a series of line segments based on data from Olson et al. (1970) to link incubation temperature and egg-to-fry survival. These line segments connect the points (0, 0.0001), (5, 0.95), (15, 0.95), (19, 0.0001) and (>19, 0.0001), where the x-coordinate = temperature (°C) and the y-coordinate = egg-to-fry survival.

### Fine sediment → egg-to-fry survival

Interstitial spaces within salmonid redds enable the influx of dissolved oxygen, the efflux of metabolic wastes and, eventually, the emergence of alevins. Excessive levels of fine sediment can obstruct interstitial spaces, reducing the rate of egg-to-fry survival (Meehan and Swantson 1977, Beschta and Jackson 1979). SHIRAZ uses a relationship based on data reported by Tappel and Bjornn (1983) to link fine sediment (< ~6.3 mm in diameter) and egg-to-fry survival:

- if fine sediment (F) is < 26.8%, egg-to-fry survival = 0.95
- if fine sediment (F) is ≥ 26.8% but < 54.4%, egg-to-fry survival = 1.81 – (3.32 • F)
- if fine sediment (F) is ≥ 54.4%, egg-to-fry survival = 0.06.

### Flood recurrence interval → egg-to-migrant survival

Severe peak flows can reduce egg-to-fry survival by silting over or scouring out redds (Sidle 1988, Vronskii and Leman 1991). However, because relationships between peak flows and egg-to-fry survival are location-dependent (e.g. Seiler et al. 2002), flood recurrence interval is a more useful predictor when considering multiple subbasins. Recurrence interval is defined as the average number of years between consecutive incidents of annual peak flow equal to or greater than a certain magnitude (Sumioka et al. 1998). Beamer and Pess (1999) developed a general model relating recurrence interval to chinook egg-to-migrant fry survival in the Skagit River Basin:

$$\text{egg-to-migrant survival} = (0.1285 * e^{-0.0446 * \text{recurrence interval (yrs)}})\ (r^2 = 0.97).$$

**Appendix 8.2.2.** Subbasin-scale data for independent variables used in the multiple regression analyses.

| Subbasin | Road density (km/km$^2$) | Total imperv. area (%) | Total forest cover (%) | Riparian forest cover (%) | Drainage area (km$^2$) | Mean channel gradient (%) | Mean elevation (m) | Mean annual precip. (cm) | Stream power per width (kg/s$^3$) | Qal (%) | Qmw + Qvro + Qvrl (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Allen Crk. | 4.2 | 24.3 | 10.2 | 7.0 | 27.0 | 1.3 | 47.2 | 95.7 | 483.3 | 11.1 | 33.5 |
| Ames Crk. | 2.6 | 1.8 | 40.4 | 29.0 | 20.0 | 2.6 | 93.0 | 116.0 | 928.2 | 19.7 | 11.2 |
| Bear Crk. | 3.9 | 0.0 | 49.5 | 46.5 | 12.5 | 2.3 | 212.4 | 160.0 | 25.8 | 0.9 | 47.2 |
| Beckler R. | 1.6 | 0.0 | 74.7 | 62.6 | 261.4 | 14.3 | 990.3 | 257.9 | 5597.1 | 9.0 | 2.2 |
| Cathcart Drainages | 3.3 | 5.9 | 24.5 | 21.2 | 3770.9 | 2.0 | 80.5 | 127.4 | 35.8 | 19.6 | 2.4 |
| Cherry Crk. | 3.0 | 1.4 | 51.5 | 51.0 | 79.0 | 4.4 | 220.1 | 158.1 | 276.4 | 4.6 | 13.1 |
| Coal Crk. - Lower | 3.4 | 5.9 | 43.4 | 40.4 | 1079.6 | 5.3 | 145.1 | 154.5 | 1088.0 | 23.0 | 53.7 |
| Coal Crk. - Upper | 3.7 | 5.9 | 44.4 | 42.0 | 973.5 | 3.0 | 219.5 | 161.9 | 425.1 | 27.9 | 25.3 |
| Dubuque Crk. | 2.2 | 1.4 | 41.2 | 40.4 | 33.0 | 1.6 | 141.1 | 133.0 | 776.4 | 0.5 | 0.6 |
| Everett Coastal Drainages | 2.9 | 48.6 | 8.3 | 16.0 | 53.7 | 2.6 | 86.0 | 93.5 | 4612.6 | 4.8 | 0.7 |
| Fobes Hill | 2.4 | 13.5 | 9.4 | 11.2 | 27.4 | 1.1 | 42.4 | 101.5 | 6.0 | 18.7 | 11.8 |
| Foss R. | 0.6 | 0.0 | 74.0 | 62.8 | 143.5 | 18.5 | 1255.2 | 309.1 | 5849.0 | 6.2 | 1.7 |
| French Crk. | 2.5 | 7.7 | 20.0 | 25.0 | 72.4 | 1.4 | 67.7 | 122.3 | 22.6 | 35.4 | 8.3 |
| Griffin Crk. | 2.9 | 0.0 | 54.0 | 57.0 | 45.5 | 3.5 | 240.5 | 161.2 | 460.8 | 1.8 | 17.7 |
| Harris Crk. | 2.8 | 2.3 | 45.5 | 48.0 | 34.9 | 2.9 | 134.7 | 140.7 | 1051.7 | 5.3 | 26.5 |
| Lake Stevens Drainages | 2.9 | 13.1 | 23.0 | 18.2 | 34.4 | 0.7 | 92.1 | 110.7 | 606.4 | 8.7 | 4.1 |
| Little Pilchuck Crk. | 3.5 | 2.3 | 30.0 | 28.0 | 54.7 | 0.9 | 112.2 | 117.9 | 101.1 | 4.0 | 15.0 |
| Marshland Drainages | 2.1 | 18.0 | 10.0 | 7.0 | 4253.4 | 1.7 | 56.7 | 108.3 | 8.7 | 44.4 | 0.1 |
| May Crk./ Wallace R. - Lower | 2.8 | 4.1 | 56.4 | 43.9 | 153.9 | 7.9 | 506.9 | 212.1 | 548.2 | 36.5 | 3.2 |
| Miller R. | 0.4 | 0.0 | 68.3 | 66.3 | 118.7 | 17.7 | 1085.1 | 310.7 | 4683.1 | 6.4 | 0.7 |
| Nearshore |  |  |  |  |  | 0.0 | 0.0 | 89.0 |  |  |  |
| Olney Crk. | 1.9 | 0.0 | 82.8 | 69.7 | 51.9 | 6.2 | 552.9 | 240.4 | 1083.7 | 0.2 | 25.9 |
| Patterson Crk. | 2.2 | 3.2 | 38.0 | 41.0 | 53.5 | 2.8 | 128.9 | 137.8 | 1.0 | 9.4 | 22.5 |
| Pilchuck R. - Lower | 2.9 | 8.1 | 24.0 | 26.0 | 339.1 | 1.7 | 70.1 | 112.9 | 179.6 | 17.6 | 7.3 |
| Pilchuck R. - Middle | 3.6 | 2.7 | 43.4 | 44.4 | 176.8 | 1.9 | 160.0 | 144.6 | 278.2 | 11.4 | 25.1 |
| Pilchuck R. - Upper | 1.8 | 0.0 | 81.8 | 77.8 | 105.8 | 8.5 | 556.6 | 250.8 | 1026.1 | 0.3 | 21.5 |
| Pratt R. | 0.4 | 0.0 | 79.1 | 77.4 | 73.2 | 16.3 | 1053.4 | 268.4 | 2771.2 | 3.0 | 2.6 |
| Quilceda Crk. | 3.5 | 16.7 | 15.0 | 20.0 | 103.9 | 1.0 | 55.5 | 108.4 | 33.0 | 2.8 | 56.4 |
| Raging R. | 2.9 | 1.4 | 57.6 | 52.0 | 84.9 | 7.6 | 445.3 | 224.5 | 1255.1 | 1.3 | 12.5 |
| Rapid R. | 0.5 | 0.0 | 78.7 |  | 107.0 | 15.2 | 1207.6 | 232.0 | 2264.5 | 3.0 | 1.6 |

| Subbasin | Road density (km/km$^2$) | Total imperv. area (%) | Total forest cover (%) | Riparian forest cover (%) | Drainage area (km$^2$) | Mean channel gradient (%) | Mean elevation (m) | Mean annual precip. (cm) | Stream power per width (kg/s$^3$) | Qal (%) | Qmw + Qvro + Qvrl (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Skykomish R. - Lower MS | 3.1 | 2.7 | 43.4 | 37.4 | 2180.3 | 4.1 | 250.5 | 163.1 | 1651.0 | 22.4 | 21.5 |
| Skykomish R. - Lower NF | 0.6 | 0.9 | 70.3 | 61.2 | 379.7 | 16.1 | 901.9 | 275.2 | 3899.6 | 10.8 | 0.2 |
| Skykomish R. - Lower SF | 1.3 | 0.0 | 71.1 | 61.5 | 936.2 | 9.0 | 726.3 | 267.8 | 5726.1 | 11.5 | 16.0 |
| Skykomish R. - SF | 1.1 | 0.0 | 71.1 | 53.1 | 884.4 | 14.4 | 845.8 | 281.4 | 5708.2 | 10.3 | 1.4 |
| Skykomish R. - Upper MS | 2.5 | 2.3 | 64.2 | 50.5 | 1443.7 | 9.0 | 509.3 | 225.8 | 2356.3 | 20.5 | 20.4 |
| Skykomish R. - Upper NF | 0.6 | 0.0 | 73.0 | 62.5 | 245.8 | 14.3 | 1154.9 | 303.6 | 6912.6 | 7.0 | 1.1 |
| Skykomish R. - Upper SF | 2.5 | 1.4 | 78.6 | 58.6 | 643.1 | 11.5 | 657.8 | 259.4 | 1606.0 | 12.6 | 11.0 |
| Snohomish Estuary | 1.4 | 8.6 | 10.6 | 11.2 | 4524.5 | 0.0 | 0.6 | 94.9 | 1.3 | 80.4 | 0.0 |
| Snoqualmie R. - Lower MF | 2.2 | 1.4 | 60.0 | 58.2 | 442.9 | 10.7 | 617.8 | 236.6 | 986.6 | 18.0 | 17.6 |
| Snoqualmie R. - Lower NF | 2.1 | 0.0 | 73.9 | 72.6 | 254.7 | 13.4 | 824.5 | 266.4 | 4037.7 | 2.9 | 17.4 |
| Snoqualmie R. - Lower SF | 3.8 | 5.4 | 51.5 | 40.4 | 224.3 | 4.0 | 322.8 | 196.3 | 401.2 | 31.3 | 36.1 |
| Snoqualmie R. - Mid-MS | 2.4 | 4.5 | 30.3 | 26.3 | 1418.6 | 1.7 | 77.7 | 119.4 | 183.9 | 31.3 | 3.0 |
| Snoqualmie R. - Mouth | 2.9 | 1.8 | 26.3 | 22.2 | 1549.5 | 2.1 | 96.9 | 132.8 | 112.7 | 36.5 | 7.5 |
| Snoqualmie R. - Upper MS | 2.6 | 3.2 | 33.3 | 24.2 | 1301.1 | 1.6 | 75.6 | 144.5 | 6551.6 | 41.1 | 32.7 |
| Snoqualmie R. - Upper MF | 0.5 | 0.0 | 69.2 | 71.0 | 272.5 | 15.4 | 1128.1 | 298.3 | 218.0 | 6.4 | 0.6 |
| Snoqualmie R. - Upper NF | 1.2 | 0.0 | 73.6 | 68.0 | 160.4 | 11.5 | 941.5 | 260.6 | 2442.8 | 2.9 | 3.0 |
| Snoqualmie R. - Upper SF | 2.3 | 0.9 | 67.4 | 67.3 | 163.2 | 13.5 | 975.1 | 277.1 | 2816.4 | 7.4 | 6.9 |
| Sultan R. - Lower | 2.3 | 1.4 | 70.1 | 68.0 | 271.7 | 4.5 | 301.8 | 200.0 | 1313.2 | 5.6 | 24.1 |
| Sultan R. - Upper | 0.8 | 0.0 | 69.4 | 64.6 | 176.3 | 12.5 | 939.1 | 273.1 | 2686.3 | 1.7 | 7.4 |
| Sunnyside Drainages | 2.0 | 12.6 | 14.3 | 20.4 | 19.3 | 1.4 | 59.4 | 103.3 | 412.1 | 19.1 | 1.3 |
| Tate Crk. | 3.1 | 0.5 | 55.6 | 49.0 | 12.3 | 4.4 | 279.5 | 184.7 | 11.3 | 9.7 | 61.0 |
| Taylor R. | 0.5 | 0.0 | 73.3 | 72.9 | 79.1 | 14.7 | 1004.3 | 281.0 | 2577.0 | 3.0 | 0.0 |
| Tokul Crk. | 3.0 | 0.5 | 50.5 | 52.0 | 87.8 | 2.5 | 324.3 | 187.7 | 692.6 | 1.2 | 36.7 |
| Tolt R. - Lower | 2.4 | 1.4 | 60.0 | 57.6 | 256.1 | 3.2 | 170.4 | 159.2 | 323.3 | 9.9 | 15.0 |
| Tolt R. - NF | 2.1 | 0.9 | 68.0 | 72.7 | 131.9 | 10.4 | 706.8 | 238.9 | 1917.6 | 0.0 | 28.6 |
| Tolt R. - SF Above Dam | 1.9 | 0.0 | 74.4 | 70.4 | 48.1 | 10.4 | 883.6 | 230.5 | 432.0 | 3.2 | 0.0 |
| Tolt R. - SF Below Dam | 2.0 | 1.4 | 55.0 | 57.0 | 81.3 | 6.1 | 489.2 | 201.6 | 1588.2 | 0.4 | 48.4 |
| Tulalip and Battle Crks. | 1.9 | 3.6 | 27.5 | 26.3 | 81.2 | 1.9 | 91.4 | 99.7 | 959.4 | 2.2 | 9.1 |
| Tye R. | 1.3 | 0.0 | 78.0 | 72.7 | 209.5 | 13.4 | 1211.0 | 240.1 | 4956.8 | 3.2 | 1.6 |
| Wallace R. - Upper | 1.1 | 0.0 | 70.8 | 76.8 | 54.7 | 10.4 | 744.9 | 258.6 | 2184.9 | 5.1 | 7.3 |
| Woods Crk. | 3.0 | 1.4 | 53.0 | 52.0 | 63.5 | 3.9 | 241.1 | 174.5 | 247.9 | 2.9 | 27.5 |
| Woods Crk. - Lower | 4.2 | 8.6 | 19.2 | 28.0 | 167.0 | 2.2 | 83.8 | 135.3 | 164.5 | 23.4 | 19.2 |
| Woods Crk. - WF | 3.3 | 0.5 | 38.8 | 41.0 | 88.7 | 2.6 | 161.5 | 148.9 | 175.7 | 1.2 | 15.0 |

**Appendix 8.2.3.** Derivation of dependent variables used in the multiple regression analyses.

**Pre-spawning temperature**

The pre-spawning period in the Snohomish River Basin extends from mid-July to mid-November (A. Haas, personal communication). Water temperature data during this period were derived from Washington Department of Ecology water quality gages (Washington Department of Ecology 2004). For each month during the pre-spawning period, we found the maximum recorded temperature at each gage, then took the average of the monthly maximums, such that mean maximum pre-spawning temperature =

$$\frac{\max_{Jul.} + \max_{Aug.} + \max_{Sep.} + \max_{Oct.} + \max_{Nov.}}{5}$$

| **Subbasin** | **Gage** | **Mean maximum pre-spawning temp. (C)** | **SE** |
|---|---|---|---|
| Coal Creek - Upper | 07D130 | 13.0 | 1.7 |
| French Creek | 07R050 | 14.0 | 1.4 |
| Marshland Drainages-Lower Snohomish | 07A090 | 15.7 | 2.3 |
| Patterson Creek | 07P070 | 12.2 | 0.9 |
| Pilchuck River - Lower | 07B055 | 15.9 | 2.6 |
| Raging River | 07Q070 | 14.0 | 1.8 |
| Skykomish River - Lower Mainstem | 07C070 | 14.8 | 2.2 |
| Skykomish River - Upper Mainstem | 07C120 | 13.7 | 2.2 |
| Snoqualmie River - Lower Middle Fork | 07D150 | 11.2 | 2.7 |
| Snoqualmie River - Lower North Fork | 07N070 | 11.9 | 1.6 |
| Snoqualmie River - Lower South Fork | 07M070 | 11.7 | 1.4 |
| Snoqualmie River - Mid-Mainstem | 07D070 | 14.6 | 2.3 |
| Snoqualmie River - Mouth | 07D050 | 15.9 | 2.5 |
| Snoqualmie River - Upper Mainstem | 07D100 | 12.4 | 3.0 |
| Sultan River - Lower | 07E055 | 13.3 | 1.4 |
| Tolt River - Lower | 07G070 | 12.9 | 1.7 |
| Woods Creek - Lower | 07F055 | 14.2 | 1.8 |

**Incubation temperature**

The egg incubation period in the Snohomish River Basin extends from October through December (SASSI). Water temperature data during this period were derived from Washington Department of Ecology water quality gages (Washington Department of Ecology 2004). For each gage, we found the mean temperature for months during the incubation period, then took the average of those monthly means, such that mean incubation temperature =

$$\frac{\overline{x}_{Oct.} + \overline{x}_{Nov.} + \overline{x}_{Dec.}}{3}$$

| Subbasin | Gage | Mean incubation temperature (C) | SE |
|---|---|---|---|
| Coal Creek - Upper | 07D130 | 5.9 | 0.8 |
| French Creek | 07R050 | 9.7 | 1.7 |
| Marshland Drainages-Lower Snohomish | 07A090 | 6.9 | 1.2 |
| Patterson Creek | 07P070 | 8.9 | 1.0 |
| Pilchuck River - Lower | 07B055 | 8.2 | 1.0 |
| Raging River | 07Q070 | 7.3 | 1.2 |
| Skykomish River - Lower Mainstem | 07C070 | 6.6 | 1.2 |
| Skykomish River - Upper Mainstem | 07C120 | 6.1 | 1.2 |
| Snoqualmie River - Lower Middle Fork | 07D150 | 4.5 | 1.8 |
| Snoqualmie River - Mid-Mainstem | 07D070 | 7.9 | 1.0 |
| Snoqualmie River - Mouth | 07D050 | 6.9 | 1.1 |
| Snoqualmie River - Upper Mainstem | 07D100 | 5.3 | 1.9 |
| Sultan River - Lower | 07E055 | 7.6 | 2.0 |
| Tolt River - Lower | 07G070 | 8.5 | 1.2 |
| Woods Creek - Lower | 07F055 | 9.1 | 1.1 |

**Fine sediment**

Fines were defined as the fraction of streambed sediments with diameters < ~6.3 mm. Data were derived from Booth et al. 1991, DeVries et al. 2001, and Snohomish County Public Works Department 2002. Together, these sources contained fine sediment measurements for 17 of the 62 subbasins. For subbasins with more than one measurement, we used the average percent fines value.

| Subbasin | Mean % fines (< ~6.3 mm) | SE | n |
|---|---|---|---|
| Allen Creek | 68.2 | 15.0 | 6 [3] |
| Coal Creek - Lower | 51.0 | 24.9 | 3 [1] |
| Coal Creek - Upper | 50.8 | — | 1 [1] |
| French Creek | 25.6 | 5.4 | 40 [3] |
| Lake Stevens Drainages | 78.8 | 10.1 | 13 [3] |
| May Creek/Lower Wallace River | 5.1 | — | 1 [3] |
| Pilchuck River - Lower | 12.4 | 1.7 | 9 [3] |
| Quilceda Creek | 75.7 | 7.8 | 15 [3] |
| Raging River | 26.5 | 2.5 | 2 [2] |
| Skykomish River - Upper North Fork | 3.5 | 1.2 | 11 [3] |
| Snoqualmie River - Lower South Fork | 25.7 | 7.0 | 4 [1] |
| Snoqualmie River - Mid-Mainstem | 62.2 | 7.2 | 21 [1,2] |
| Snoqualmie River - Mouth | 100.0 | 0.0 | 4 [1] |
| Snoqualmie River - Upper Mainstem | 49.4 | 9.5 | 13 [1] |
| Sunnyside Drainages | 29.3 | 15.6 | 6 [3] |
| Tokul Creek | 12.5 | 5.6 | 2 [2] |
| Tulalip and Battle Creeks | 48.6 | — | 1 [3] |

[1] = Booth et al.1991; [2] = DeVries et al. 2001; [3] = Snohomish County Public Works Department 2002

**Flood recurrence interval**

Flood recurrence interval was defined as the average number of years between consecutive incidents of annual peak flow equal to or greater than a certain magnitude (Sumioka et al. 1998). We derived flood recurrence intervals by downloading annual instantaneous peak flow data from the USGS National Water Information System website (United States Geological Survey 2004), then converting each peak flow value to a ln-transformed recurrence interval (Sumioka et al. 1998). After conversion, the transformed recurrence intervals were averaged by gage and back-transformed, such that the dependent variable in the multiple regression was a mean recurrence interval.

| **Subbasin** | **Gage** | **Mean recurrence interval (yrs.)** |
|---|---|---|
| Cathcart Drainages - Upper Snohomish | 12150800 | 2.2 |
| Coal Creek - Lower | 12144500 | 1.9 |
| Pilchuck River - Lower | 12155300 | 2.0 |
| Raging River | 12145500 | 3.5 |
| Skykomish River - Upper Mainstem | 12134500 | 2.9 |
| Snoqualmie River - Lower Middle Fork | 12141300 | 2.3 |
| Snoqualmie River - Lower North Fork | 12142000 | 2.4 |
| Snoqualmie River - Lower South Fork | 12144000 | 3.1 |
| Snoqualmie River - Mid-Mainstem | 12149000 | 2.7 |
| Snoqualmie River - Upper South Fork | 12143400 | 2.3 |
| Sultan River - Upper | 12137290 | 3.1 |
| Tolt River - Lower | 12148500 | 2.1 |
| Tolt River - North Fork | 12147500 | 3.1 |
| Tolt River - South Fork Above Dam | 12147600 | 1.6 |
| Tolt River - South Fork Below Dam | 12148300 | 2.7 |
| Wallace River - Upper | 12135000 | 1.0 |

**Appendix 8.2.4.** Percent changes from “current” to “target” values in the Step 7 Table for the four land use variables used in the multiple regression analyses.

| Alternate Scenarios | Subbasin Strategy Groups | % Δ in Rd. Den. | % Δ in TIA | % Δ in For. Cov. | % Δ in Rip. For. Cov. |
|---|---|---|---|---|---|
| **Current Path:** Current level of protection and restoration projected out 25 years into the future. Continued degradation from road expansion and rates of land cover change. | Nearshore restoration | [a] | [a] | [a] | 0.0 |
| | Estuary restoration | [a] | 4.2 | [a] | -0.9 |
| | Mainstem - primary restoration | [a] | 105.7 | -17.4 | -0.2 |
| | Mainstem-secondary restoration | [a] | 152.1 | -7.7 | -0.1 |
| | Rural streams - primary restoration | [a] | 121.3 | -21.0 | -0.8 |
| | Rural streams - secondary restoration | [a] | 163.1 | -42.7 | -0.7 |
| | Urban streams restoration | [a] | 116.1 | -62.9 | -0.5 |
| | Headwaters - primary protection | 0.0 | 0.0 | 3.4 | -0.2 |
| | Headwaters - secondary restoration | -2.9 | 0.0 | 2.3 | 0.1 |
| | Headwaters - secondary protection | 0.0 | 0.0 | 5.3 | -0.2 |
| | Headwaters - protection above barriers | 0.0 | 0.0 | 3.0 | [a] |
| | Headwaters - restoration above barriers | 0.0 | 67.8 | 19.9 | [a] |
| **Alternative 2:** Moderate improvement over current path. Current path plus ~50% of the difference between current path and test case target habitat conditions. | Nearshore restoration | [a] | [a] | [a] | 62.9 |
| | Estuary restoration | [a] | 4.2 | [a] | 174.8 |
| | Mainstem - primary restoration | [a] | 109.2 | 6.9 | 21.2 |
| | Mainstem-secondary restoration | [a] | 157.0 | 1.1 | 0.5 |
| | Rural streams - primary restoration | [a] | 411.0 | 12.0 | 5.6 |
| | Rural streams - secondary restoration | [a] | 133.6 | 20.0 | -0.7 |
| | Urban streams restoration | [a] | 62.9 | 104.1 | 99.0 |
| | Headwaters - primary protection | 0.0 | [b] | 3.4 | -0.2 |
| | Headwaters - secondary restoration | -20.6 | 114.7 | 5.4 | 0.7 |
| | Headwaters - secondary protection | 0.0 | [b] | 5.3 | -0.2 |
| | Headwaters - protection above barriers | 0.0 | [b] | 3.0 | [a] |
| | Headwaters - restoration above barriers | -16.1 | 24.6 | 19.9 | [a] |
| **Alternative 3:** Moderate-high improvement over current path. Current path plus ~75% of the difference between current path and test case target habitat conditions. | Nearshore restoration | [a] | [a] | [a] | 94.4 |
| | Estuary restoration | [a] | 4.2 | [a] | 262.6 |
| | Mainstem - primary restoration | [a] | 110.9 | 19.1 | 31.8 |
| | Mainstem-secondary restoration | [a] | 159.4 | 5.5 | 0.9 |
| | Rural streams - primary restoration | [a] | 555.9 | 28.5 | 8.8 |
| | Rural streams - secondary restoration | [a] | 118.9 | 51.4 | -0.7 |
| | Urban streams restoration | [a] | 36.3 | 187.6 | 148.8 |
| | Headwaters - primary protection | 0.0 | [b] | 3.4 | -0.2 |
| | Headwaters - secondary restoration | -32.4 | 172.2 | 7.0 | 1.0 |
| | Headwaters - secondary protection | 0.0 | [b] | 5.3 | -0.2 |
| | Headwaters - protection above barriers | 0.0 | [b] | 3.0 | [a] |
| | Headwaters - restoration above barriers | -25.8 | 3.1 | 19.9 | [a] |

| Alternate Scenarios | Subbasin Strategy Groups | % Δ in Rd. Den. | % Δ in TIA | % Δ in For. Cov. | % Δ in Rip. For. Cov. |
|---|---|---|---|---|---|
| **Test Case:** Hypothesized distribution of effort needed to achieve a result at the high end of the Shared Strategy planning range. | Nearshore restoration | [a] | [a] | [a] | 125.8 |
| | Estuary restoration | [a] | -18.9 | [a] | 350.5 |
| | Mainstem - primary restoration | [a] | 112.7 | 31.2 | 42.5 |
| | Mainstem-secondary restoration | [a] | 161.8 | 9.9 | 1.2 |
| | Rural streams - primary restoration | [a] | 700.8 | 45.1 | 12.0 |
| | Rural streams - secondary restoration | [a] | 104.2 | 82.8 | -0.7 |
| | Urban streams restoration | [a] | 9.7 | 271.1 | 198.5 |
| | Headwaters - primary protection | 0.0 | [b] | 3.4 | -0.2 |
| | Headwaters - secondary restoration | -41.2 | 229.7 | 8.5 | 1.3 |
| | Headwaters - secondary protection | 0.0 | [b] | 5.3 | -0.2 |
| | Headwaters - protection above barriers | 0.0 | [b] | 3.0 | [a] |
| | Headwaters - restoration above barriers | -35.5 | -18.5 | 19.9 | [a] |

[a] No target was set as part of the alternative, hence no percent change was calculated.

[b] Increases from 0% to 0.5% (in Alt. 2), 0% to 0.75% (in Alt. 3), and 0% to 1.0% (in Test Case) were given in the Step 7 Table. The zeros did not allow for calculations of percent change, therefore the target values were used (i.e., 0.5%, 0.75