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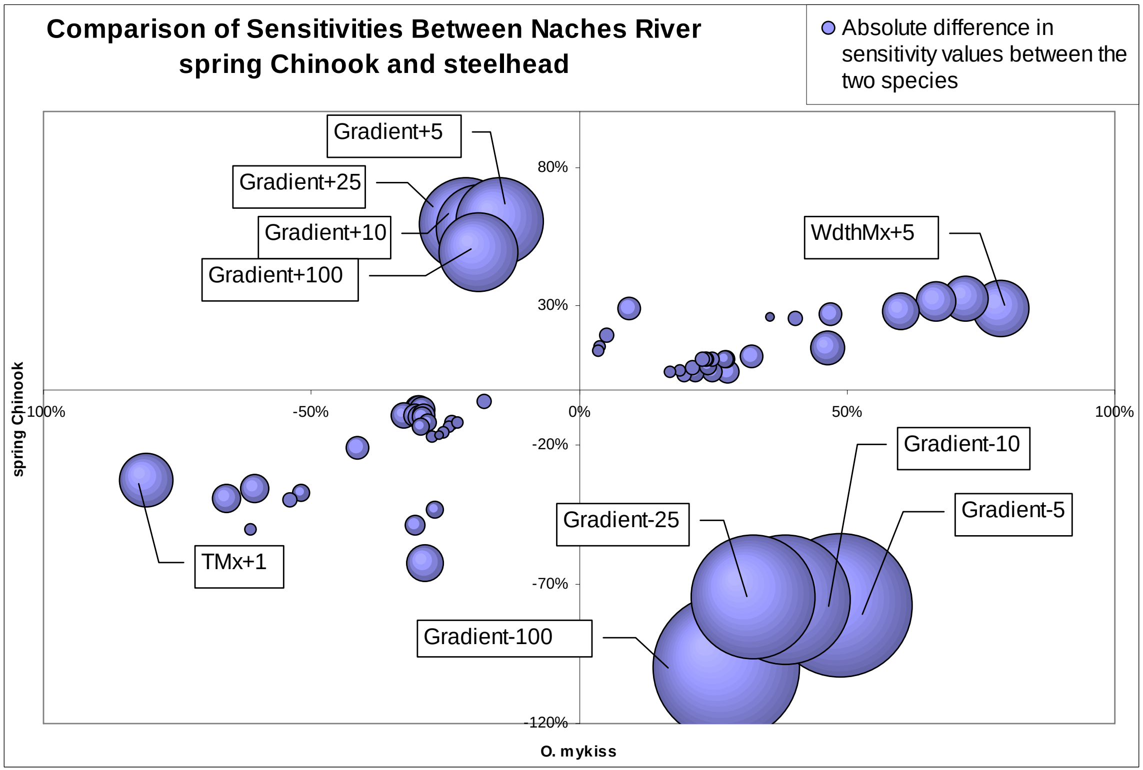
Technical Memorandum 86-68290-11

Systematic Sensitivity Analysis of the EDT Model Applied to Selected Fish Populations in the Yakima River Basin



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Technical Memorandum 86-68290-11

Systematic Sensitivity Analysis of the EDT Model Applied to Selected Fish Populations in the Yakima River Basin

by

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Introduction

The mission of the Bureau of Reclamation (Reclamation) is to manage, develop, and protect water and related resources in an environmentally and economically sound manner. Reclamation works to ensure that project operations do not jeopardize existing fish populations or their critical habitats by entering into partnerships with federal, state, and local agencies and tribes to study the needs of the populations and to cooperate in habitat restoration projects.

In the Yakima River basin of the upper Columbia River (Figure 1), Naches River steelhead (*Oncorhynchus mykiss)* are listed as threatened (National Oceanic and Atmospheric Administration 1999) (*Oncorhynchus mykiss* sea-going forms are referred to as steelhead while stream-resident forms are referred to as rainbow trout (Nelson et al. 2004)). American River spring Chinook and Naches River spring Chinook salmon (*Oncorhynchus tshawytscha*) are listed as depressed populations under National Oceanic and Atmospheric Administration listings (Haring 2001, Good et al. 2005). Because these fisheries resources are of concern, there has been an emphasis by Reclamation to conduct studies, alter operations, modify structures, provide supplemental water, and to participate in recovery activities of these migrating fish species. In the Yakima River basin, this process began with managers and scientists familiar with the watershed collaborating to form an action management plan for that watershed.

One approach that is being considered to evaluate plan alternatives is the application of the Ecosystem Diagnosis and Treatment (EDT) model to the Yakima River basin. EDT is a system for rating the quality, quantity, and diversity of habitat along a watershed relative to the needs of a focal species (Mobrand et al. 1997). EDT has been used extensively in the Pacific Northwest for a number of years as a method for assessing the impact on the performance of fish populations attributable to fresh water habitat conditions. EDT is a complex model and it would be prohibitive to explain the details of it in this paper. Please refer to http://www.mobrand.com/MBI/edt.html for complete documentation and description of the model.

In EDT, the habitat supporting the population being analyzed, or “focal population”, is described in terms of 45 environmental attributes for both the current and the undisturbed historical condition. The historical dataset, or “Template”, is compiled from existing historical data and from widely-accepted inferences concerning pre-development conditions in specific eco-regions and sub-basins. In EDT, the Template represents the environmental conditions under which endemic populations evolved, and therefore is considered to embody locally optimal conditions. Using a clinical metaphor, the dataset representing current disturbed environmental conditions is referred to as the “Patient” (Lichatowich et al. 1995). Both the Patient and Template can be updated as new information is gathered and old assumptions are revised. The fish populations within the watershed are defined biologically (in terms of seasonal movement patterns describing species-specific life history patterns) and geographically (in terms of spawning and rearing areas).

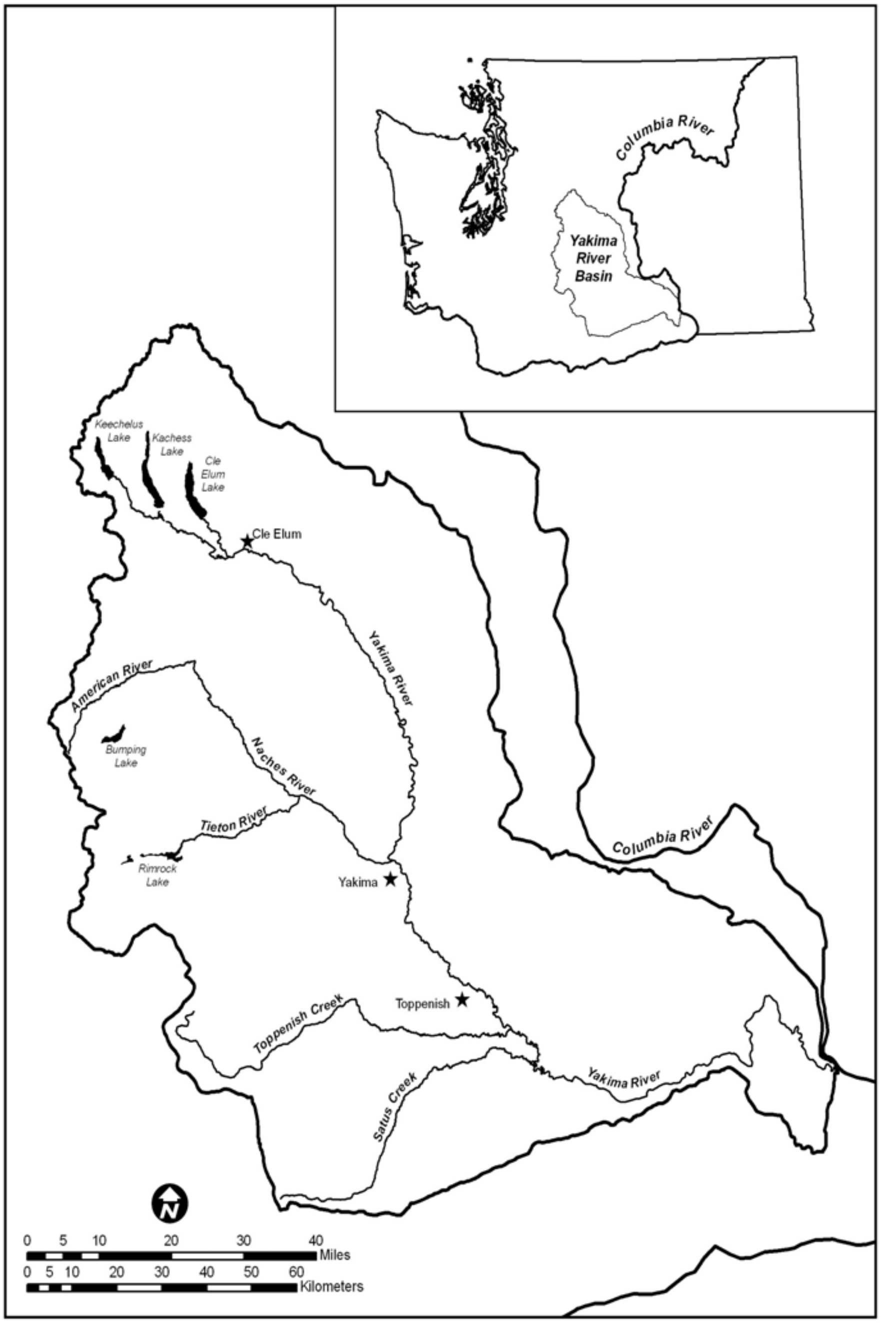

Figure 1: Study area used for EDT Sensitivity Analysis of Yakima Basin fish populations.

Watershed units are divided into sections called stream reaches within which environmental conditions are considered to be relatively homogenous. Environmental attributes are assigned by the user to each reach for both current and historical conditions and input into the model. Raw environmental variables are transformed into standardized EDT units called "Level 2 attributes" (Appendix A). Some environmental variables change seasonally, and therefore require values in EDT that differ by month. Other environmental variables, such as gradient or natural confinement, are not seasonally variable and can be entered into EDT as constants.

The EDT model uses combinations of Level 2 attributes to compute 16 survival factors (Lestelle et al. 2004). The product of all of the survival factors across the life stages representing a specific life history pattern is used to compute the productivity of that life history pattern. More complex calculations involving both survival factors and habitat area generate estimates of carrying capacity. The model then averages productivity and carrying capacity across all life history patterns to compute the productivity and carrying capacity for the population as a whole.

The outputs from EDT are the parameters of the Beverton-Holt stock-recruitment curve (Beverton and Holt 1957) (Figure 2). These outputs include a prediction of population productivity (the maximum number of return spawners produced per spawner), carrying capacity (the maximum number of fish the habitat can support), equilibrium abundance (Neq), and life history diversity (the proportion of life history pathways that have a productivity of 1.0 or more and therefore are theoretically self-sustaining), under current and historical conditions. The EDT model is typically used to complete a diagnosis of factors and geographic areas affecting population performance. Conditions within the watershed unit can then be examined systematically, allowing the identification of stream reaches and survival factors that have been most degraded relative to their historical potential and a prioritization of restoration potential. The result of this "Patient/Template analysis" is used in the design or evaluation of watershed-level fish enhancement projects.

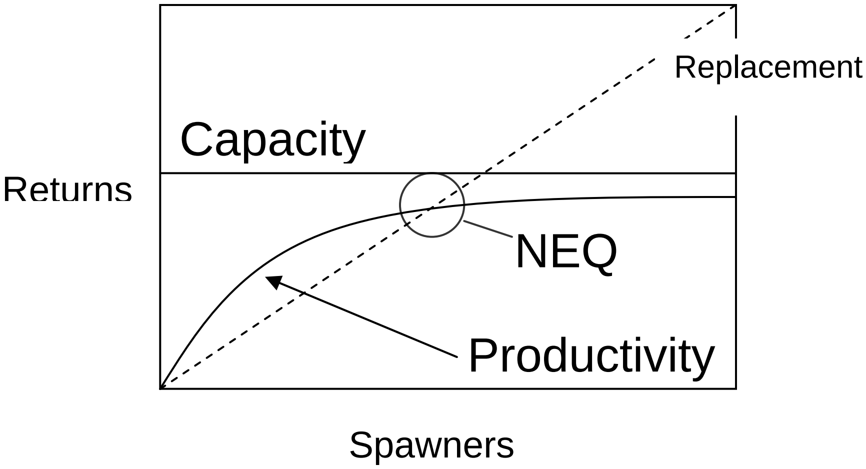

Figure 2: The Beverton-Holt stock-recruitment curve.

The EDT model was designed to allow the user to manipulate the input of the environmental quality attributes (Level 2 attributes) in order to compare effects of possible watershed management decisions on focal populations. Because of this, we were interested in determining how much model outputs are affected by a change in an input value of an environmental attribute. Specifically, we were interested in how EDT determines the relative effect on equilibrium abundance of a specified degree of change (positive or negative) in each environmental attribute. We applied a “systematic sensitivity analysis” to three Yakima River sub-basin EDT populations: American River and Naches River spring Chinook salmon, and Naches River steelhead.

Sensitivity analysis can be used when dealing with uncertain or competing model scenarios, contributing to the evaluation of model-based inference (Saltelli et al. 2000). Mobrand and Kareiva (1999) recommend performing sensitivity analysis to “guide refinement and modification of management strategies and/or objectives and development of monitoring and evaluation plans”. Therefore, we conducted a systematic sensitivity analysis (SSA) of the EDT model in order to determine how sensitive EDT input parameters are to changes in value. Such changes in value could occur due to real improvement or degradation of the habitat. The relative sensitivity of model output to changes in specific environmental attributes can be used to identify those attributes for which accurate information is most important. Furthermore, SSA can suggest where future research should be directed because a manager will want the best possible information regarding the most sensitive parameters.

Methods

EDT Model Inputs

The sensitivity analysis was conducted using the Yakima River sub-basin datasets and the Yakima River basin population definitions registered on the Mobrand Jones-Stoke website (http://www.mobrand.com/MBI/edt.html). As mentioned, the three populations used as our focal species were American River spring Chinook salmon, Naches River spring Chinook salmon, and Naches River steelhead. In order to preclude confounding the effect of revisions to the underlying dataset with systematic attribute changes, we created a static database using the registered Yakima River sub-basin data available on March 1, 2004. Baseline population abundance (Neq) used in the SSA analysis are shown in Table 1. This database partitions the Yakima River sub-basin into a total of 352 reaches (Appendix B).

	American spring chinook	**Naches spring chinook**	**Naches steelhead**
Baseline Population Abundance (N_{eq})	250	1,070	898

Table 1: Initial abundances for the focal species used for the EDT sensitivity analyses.

The Scenario Builder module in EDT is used to evaluate the impact on population performance of a “scenario” of environmental conditions that are assumed to have changed from current values. Using the Scenario Builder, we systematically altered Level 2 environmental attributes for each reach. New attributes were entered as either index ratings, actual values, or actual proportions (Appendix A) based on the Guidelines for Rating Level 2 (L2) Environmental Attributes in EDT (Lestelle 2005). Attributes measured by “index ratings” are assigned values between 0 and 4, in which a rating of “0” represents “zero imperfections”, or optimal conditions for the attribute, and a rating of “4” represents lethal or unusable conditions. Attributes measured by actual values are expressed in terms of numbers (e.g., miles of stream, or reach width in feet) or proportions (e.g., the proportion of the wetted area of a reach consisting of pools). Attributes expressed as proportions consisted of a set for which the sum of the values was 100% in any reach. All 45 attributes were altered systematically within each reach.

Systematic Alteration of the Attribute Input

Each attribute value was systematically changed to show either degradation or improvement in each reach. For attributes expressed in terms of 0-4 Index values, we changed the baseline (or Patient) value by adding plus or minus “4, 3, 2, or 1” to the current Index rating. This stepwise, integer-change process was repeated until Index ratings reached “4” or “0” in every reach. Thus, there were eight possible runs for every Index attribute. Depending on the starting point of the current ratings, some attributes had only four runs.

In practice, subtracting 1, 2, 3, or 4 from an L2 attribute generally “improves” the habitat, leading to higher predicted Neq. Conversely, adding 1, 2, 3, or 4 to an L2 attribute generally “degrades” habitat and reduces the predicted Neq. However, the inverse of these statements is true for the alkalinity attribute: when the value of an alkalinity rating is increased, carrying capacity and Neq increase, and vice versa.

In the interest of displaying information efficiently, we designate systematic changes to Index value attributes by abbreviating the attribute and following the abbreviation with a plus or minus sign and an integer indicating the number of index values added to or subtracted from the baseline values. Thus, “Alk –1” would indicate a scenario in which alkalinity values were decreased by 1 index value across all reaches utilized by a focal population. Alternatively, the attribute will simply be spelled out or abbreviated and followed by one or more numbers in parenthesis indicating the magnitude of changes for scenarios – e.g., “Alk (-1, -2, +3)” represents three scenarios in which alkalinity values are, respectively, decreased by one index value, decreased by two index values and increased by three index values. For actual proportional attributes, each attribute was changed by adding plus or minus 5%, 10%, 25% or 100% to the current proportion. For the attribute *Obstructions*, an obstruction action was created in the scenario builder that increased or decreased passage by 25%, 50%, or 100% for each species and life stage affected by the obstruction. Scenarios targeting proportional, non-proportional and obstruction attributes are designated in a manner similar to that used for Index value attributes. Thus, “ChnLength –10” represents a scenario entailing 10% reductions in reach length, “HabPool +25” represents a scenario providing 25% increases in the proportion of wetted area consisting of pools, and “Obstruct +50” represents a scenario in which passage at all obstructions was increased by 50% for all species and life stages affected. For the sake of economy of expression, systematic changes to proportional, non-proportional and obstruction attributes were described by spelling or abbreviating the attribute and adding one or more numbers in parenthesis indicating the magnitude of changes for one or more scenarios – e.g., “HabPool (-10, -25, -100)” represents three scenarios in which pool area is decreased by 10, 25 and 100%.

For all kinds of attributes, current and altered ratings were summed and averaged over all the reaches used by each of the focal populations for every Scenario Builder run.

In this document, we will refer to EDT parameters by their full attribute names in italics. Tables and graphs will contain abbreviated attribute names and followed by one or more numbers in parenthesis indicating the magnitude of changes for scenarios. We will refer to raw environmental variables and Level 3 attributes in biological terms. For example, the change in daily flow fluctuations is a raw environmental variable. The EDT attribute name for this environmental variable is *Flow-Diel.*

Sensitivity Analysis

Sensitivity Analysis was used to identify the attributes to which model output, in terms of Neq, was most sensitive. We defined sensitivity (S) as a ratio of the relative change in the predicted Neq to the absolute change of the mean input parameter (Level 2 environmental quality attribute) value (adapted from Haefner 2002). For index and proportional attributes, sensitivity was calculated as:

$$S = \frac{(A_0 - A_1)/A_0}{|P_{AVG0} - P_{AVG1}|}$$

Where:

- A_0 is the original spawner equilibrium abundance (Neq) predicted by EDT
- A_1 is the estimated spawner equilibrium abundance (Neq) predicted by EDT after a specified change in attribute value
- P_{AVG0} is the average initial attribute value over all reaches
- P_{AVG1} is the average changed attribute value over all reaches

For non-proportional actual value attributes, the sensitivity equation was adjusted to account for large values. An overly large value in the denominator of the sensitivity equation would lead to a proportionately smaller sensitivity value. Therefore, sensitivity was calculated as:

$$S = \frac{(A_0 - A_1)/A_0}{|(P_{sum0} - P_{sum1})/P_{sum0}|}$$

Where:

- A_0 is the original spawner equilibrium abundance (Neq) predicted by EDT
- A_1 is the estimated spawner equilibrium abundance (Neq) predicted by EDT after a specified change in the attribute value
- P_{sum0} is the sum of initial attribute values over all reaches
- P_{sum1} is the sum of the changed attribute values over all reaches

We also reported relative population change without factoring in some measure of parameter change, expressing sensitivity in terms of a simple change of equilibrium abundance. This procedure allowed the identification of parameters that require large changes in value to produce substantial changes in abundance (making the parameter technically insensitive)[1].

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[1] Because the denominator of the sensitivity equation consists of a number representing the change in attribute value, it is possible for an altered attribute to cause a large change in abundance without showing high sensitivity if the denominator contains a large number.

Statistical Analysis

We calculated the mean and standard deviation for each sensitivity and relative abundance change dataset. We compared sensitivities within attribute type (index, actual non-proportional, and actual proportional) for each of the three populations. We considered those environmental attributes that had sensitivity values greater than or equal to two standard deviations from the mean to be the most sensitive, and to be "significant" for the purposes of this analysis. We concentrate our discussion on these "significant" parameters. We interpret larger sensitivity values as indicating variables for which a given change in input results in relatively larger changes in predicted equilibrium abundance.

The three focal populations for the study allowed comparison of environmental and species differences in sensitivity. Specifically, we compared the sensitivity of the same species in different environments (American River vs. Naches River spring Chinook), as well as different species in the same environment (spring Chinook and steelhead in the Naches River).

For each population pair, we assumed that the similarity in sensitivity across all attributes would be reflected by the Pearson product moment correlation coefficient, r, between all sensitivity values for each population. The Pearson product moment correlation coefficient is a dimensionless index that ranges from -1.0 to 1.0 inclusive and reflects the extent of a linear relationship between two data sets.

$$r = \frac{n(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{\left[n\Sigma X^2 - (\Sigma X)^2\right]\left[n\Sigma Y^2 - (\Sigma Y)^2\right]}}$$

Where:

- X is a data point (or sensitivity) of population 1
- Y is a data point (or sensitivity) of population 2
- n is the number of data points

The correlation at issue is the degree to which sensitivities across all attributes varied in parallel between the populations. The closer r is to 1.0, the more likely the populations are to be positively correlated. Conversely, the closer r is to -1.0, the more likely the populations are to be negatively correlated (to react oppositely to the same attributes).

Graphical Representations

The results of the sensitivity analyses will be presented as XY scatter plots, with sensitivity values plotted against themselves for each population and for each type of attribute (index, actual non-proportional, and actual proportional). This allows for a spatial perspective of the spread of the sensitivity results. For comparing populations, we will use XY bubble plots. Each axis will represent the sensitivity values for each population, and the size of the bubble will represent the *difference* in sensitivities between the two populations for each attribute.

Results

Sensitivity results are presented by population for index, actual non-proportional, actual proportional attributes, and obstruction attributes. This is followed by a summary of attributes that showed the greatest sensitivity to a one-step increase or decrease in attribute rating. Finally, we present results comparing sensitivity results between populations of the same species and between species for the same geographic area. Results that show a “negative sensitivity” are those for which a relative decrease in predicted abundance when a parameter is changed. Conversely, “positive sensitivity” denotes a relative increase in abundance when a parameter changes value.

Index Attributes

American River Spring Chinook

The American River spring Chinook population showed the largest significant negative sensitivities to the *Temperature-daily maximum* and *Temperature-daily minimum* attributes (Figure 3 and Table 2). In this case, the predicted abundance of American River spring Chinook decreased most rapidly as *Temperature-daily maximum* and *Temperature-daily minimum* became more severe. American River spring Chinook were also strongly negatively sensitive to *Fine Sediment* , *Embeddedness* , *Miscellaneous toxins*, *Turbidity,* and *Alkalinity.* American River spring Chinook showed the largest positive sensitivity to alkalinity and maximum daily temperature, because predicted abundance increased most rapidly as ratings for these variables became systematically more suitable. Even these largest positive sensitivities were, however, less than two standard deviations from the mean sensitivity over all attributes, and thus were not “significant” in the sense used in this report. The attributes toward which the population was least sensitive included *Flow-diel*, *Flow-intraannual pattern, Waterwithdrawals, and Hydrologic regime-natural*.

Attribute	Sensitivity American River spring Chinook	Attribute	Sensitivity Naches River spring Chinook	Attribute	Sensitivity Naches River steelhead
TMn+2	-66%	**TMx+1**	-81%	**TMn+2**	-79%
TMx+1	-64%	**TMn+2**	-73%	**TMn+3**	-75%
TMn+3	-61%	**TMn+3**	-67%	**TMn+4**	-74%
TMn+4	-61%	**TMn+4**	-66%	**FnSed+2**	-63%
TMx+3	-59%	**TMx+2**	-61%	**TMx+3**	-59%
TMx+4	-58%	**TMx+3**	-59%	**TMx+4**	-58%
FnSed+3	-56%	**TMx+4**	-58%	**Emb+3**	-57%
Alk-1	-56%	**FnSed+3**	-55%	**FnSed+3**	-56%
Emb+3	-54%	**Emb+3**	-55%	**Turb+1**	-52%
Emb+4	-52%	**Emb+2**	-52%	**Emb+4**	-52%
TMx+2	-51%	**Emb+4**	-52%	**Turb+2**	-51%
Alk-2	-48%	**Alk-2**	-51%	**TMx+2**	-50%
MscTox+2	-48%	**MscTox+2**	-47%	**MscTox+2**	-50%
Turb+2	-48%	**TMx-1**	46%	**Alk-2**	-50%
Turb+1	-44%			**TMn+1**	-49%
Emb+2	-44%			**FnSed+1**	-43%
Alk-3	-43%			**Alk-3**	-42%
Alk-4	-43%			**Alk-4**	-42%

Table 2: Sensitivity for the index attributes that were two standard deviations from the mean for the three Yakima Basin populations.

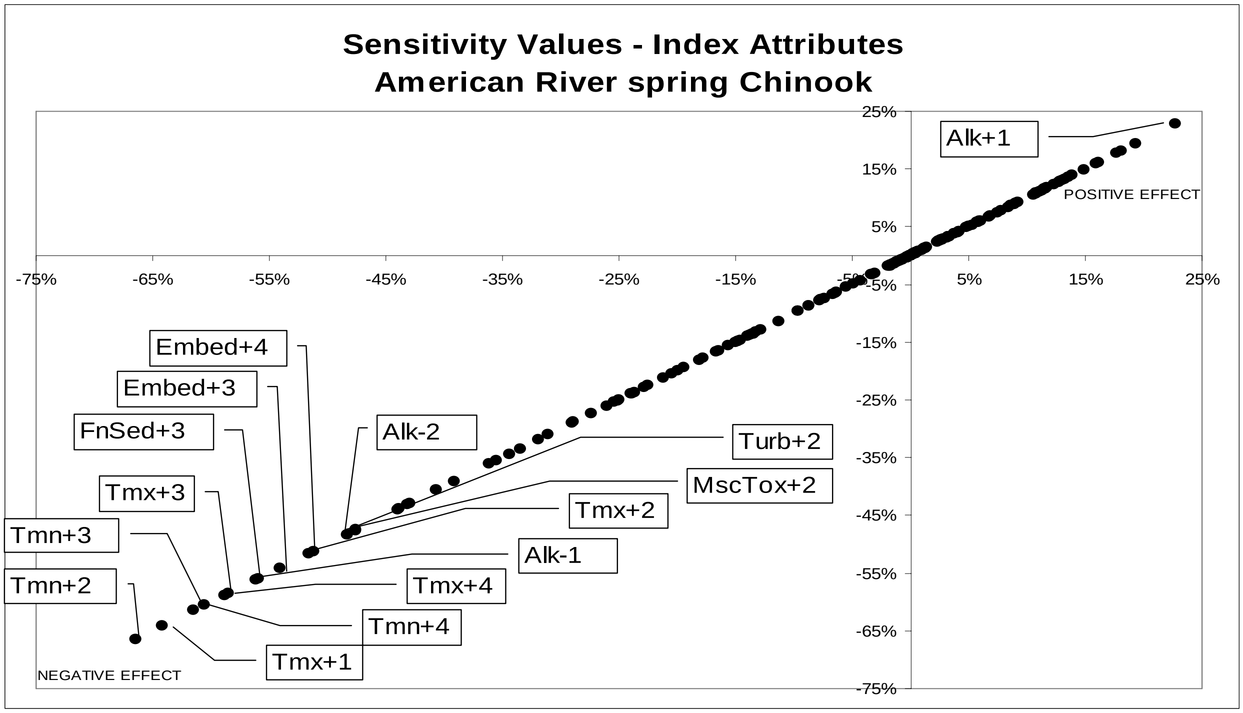

Figure 3: Sensitivity of the Index Attributes for American River spring Chinook.

The following attributes caused large decreases in predicted equilibrium abundance as ratings were systematically made more severe: *Dissolved oxygen, Embeddedness, Dissolved heavy metals, Miscellaneous toxins*, *Temperature-daily maximum, Temperature-daily minimum*, *Turbidity*, *Fine sediment*, and *Alkalinity*. Thus, with the exception of *Dissolved oxygen* and *Dissolved heavy metals*, there was no difference between attributes with the largest rate of impact per change in attribute value (viz., the most sensitive attributes) and the attributes capable of producing large abundance impacts.

Naches River Spring Chinook

The Naches River spring Chinook population showed the largest negative sensitivities to *Temperature - daily maximum* and *Temperature -daily minimum* ratings (Figure 4 and Table 2). The population was also significantly negatively sensitive to *Fine sediment*, *Embeddedness*, *Confinement-hydromodifications*, *Miscellaneous toxins*, *Turbidity* and *Alkalinity*. Naches spring Chinook showed the greatest positive sensitivity to *Temperature - daily maximum* and *Confinement-hydromodifications*, although positive sensitivity to *Confinement-hydromodifications* was not significant (more than two standard deviations from the mean). The attributes toward which the population was least sensitive included *Flow-diel*, *Flow intra-annual*, *Withdrawals,* and *Hydrologic regime natural.*

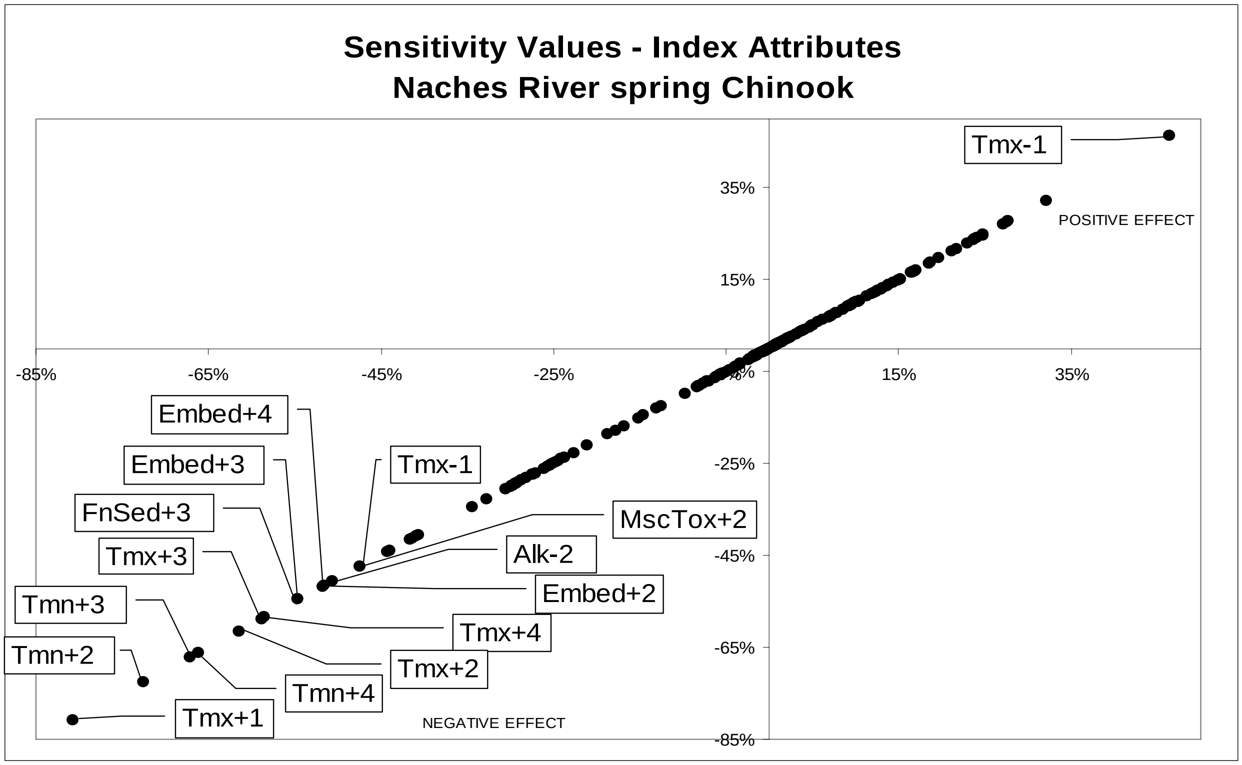

Figure 4: Sensitivity of the Index Attributes for Naches River spring Chinook.

The attributes with the largest impact on population abundance considered independently of parameter change were *Dissolved oxygen*, *Embeddedness, Dissolved heavy metals, Miscellaneous toxins, Temperature-daily maximum, Temperature-daily minimum, turbidity*, *Fine sediment,* and *Alkalinity*.

Naches River Steelhead

The Naches River steelhead population showed the largest negative sensitivities to *Temperature-daily minimum* and *Fine sediment* (Figure 5 and Table 2). The population was also significantly negatively sensitive to *Temperature-daily maximum*, E*mbeddedness*, *Turbidity*, *Miscellaneous toxins*, and *Alkalinity*. Naches steelhead were most positively sensitive to *Temperature-daily minimum* and *Fine sediment,* although these sensitivities were not significant at the two standard deviation level. The attributes to which the population was least sensitive included *Flow-diel, Flow intra-annual, Withdrawals*, and *Hydrologic regime natural*.

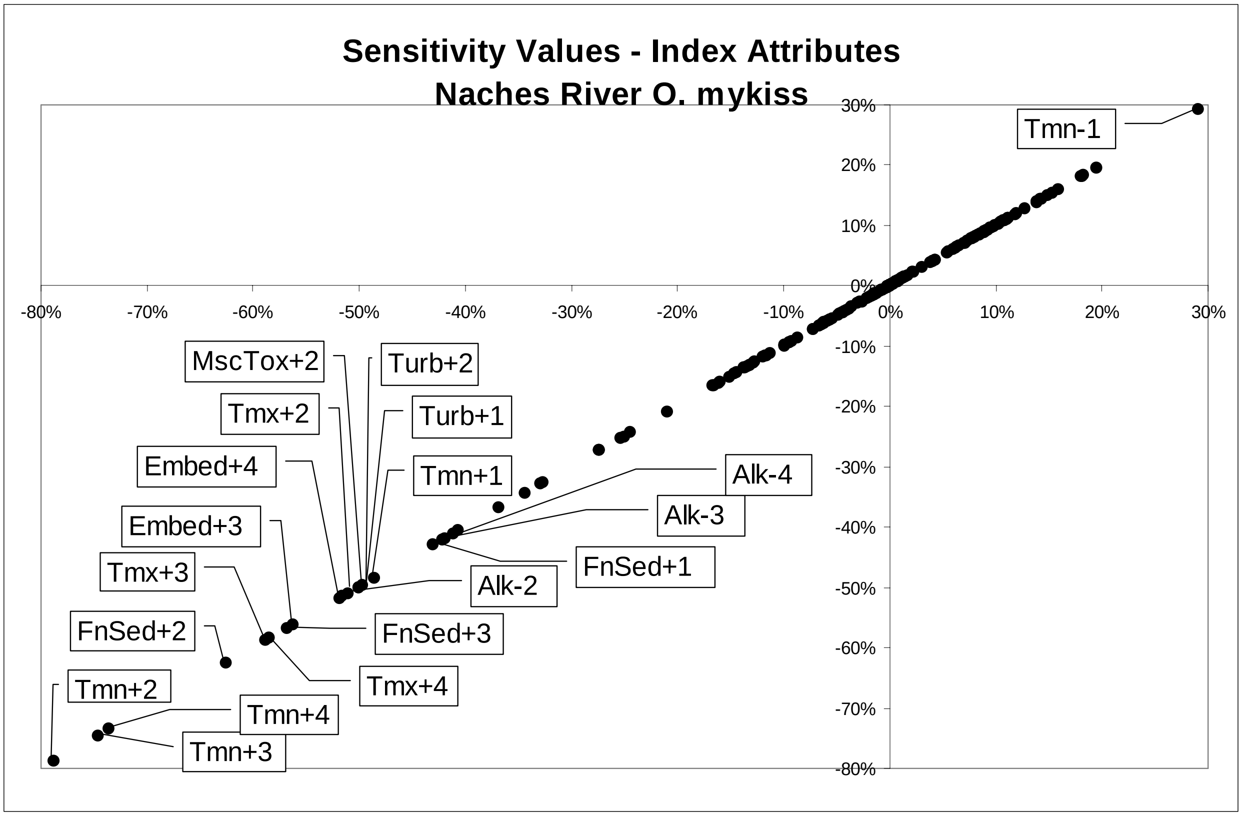

Figure 5: Sensitivity of the Index Attributes for Naches River steelhead.

The attributes with the largest impact on population abundance considered independently of parameter change were *Dissolved oxygen, Embeddedness, Dissolved heavy metals, Miscellaneous toxins, Temperature-daily maximum, Temperature-daily minimum, Turbidity, Fine sediment, and Alkalinity.* Complete results are listed alphabetically by environmental attribute for all three populations in Appendix C.

Actual Non-Proportional Attributes

American River Spring Chinook

The American River spring Chinook population was most sensitive to *Channel length* (Figure 6 and Table 3). As would be expected, abundance decreased markedly in response to decreasing *Channel length* and vice versa. The population was also significantly negatively sensitive to *Width maximum* and *Width minimum.* The population was also significantly positively sensitive to *Channel length*, *Width maximum* and *Width minimum*.

Channel length, Width maximum, and *Width minimum* also caused the largest absolute changes in abundance considered independently of the magnitude of parameter change.

Attribute	Sensitivity American River spring Chinook	Attribute	Sensitivity Naches River spring Chinook	Attribute	Sensitivity Naches River steelhead
ChnLength-10	-101%	**ChnLength-10**	-101%	**ChnLength-5**	-102%
ChnLength-5	-101%	**ChnLength-5**	-101%	**ChnLength-10**	-102%
ChnLength-100	-100%	**ChnLength-100**	-100%	**ChnLength-25**	-100%
WidthMin-100	-100%	**WidthMin-100**	-100%	**ChnLength-100**	-100%
WidthMx-100	-100%	**WidthMx-100**	-100%	**WidthMx-100**	-100%
ChnLength-25	-100%	**ChnLength-25**	-100%	**Gradient-100**	-100%
WidthMx-25	-72%	**WidthMx+10**	72%	**WidthMin-100**	-97%
WidthMx-10	-71%	**WidthMx+5**	79%	**ChnLength+10**	98%
WidthMx+5	66%	**ChnLength+10**	98%	**ChnLength+100**	100%
WidthMx+25	68%	**ChnLength+100**	100%	**ChnLength+25**	100%
WidthMx+10	69%	**ChnLength+25**	100%	**ChnLength+5**	100%
ChnLength+10	98%	**ChnLength+5**	101%		
ChnLength+100	100%				
ChnLength+25	100%				
ChnLength+5	101%				

Table 3: Sensitivity for the actual non-proportional attributes that were two standard deviations from the mean for the three Yakima Basin populations.

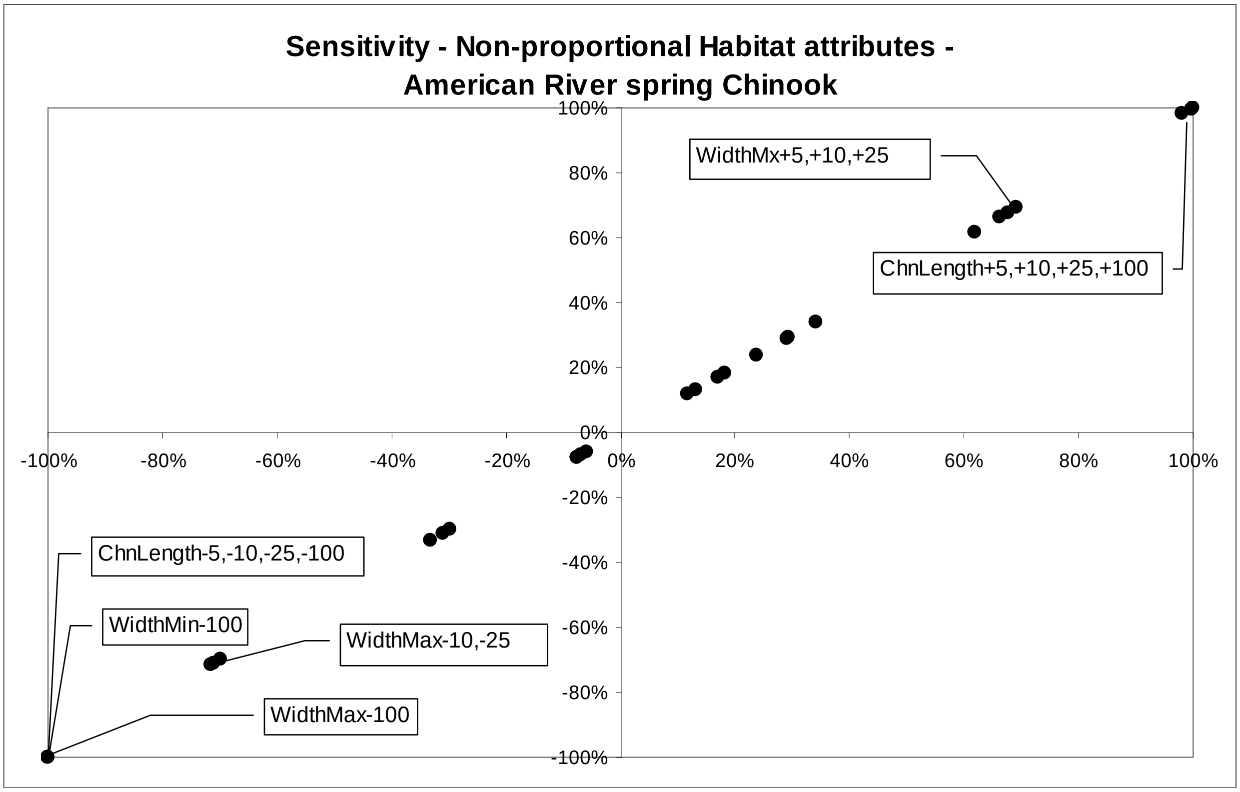

Figure 6: Sensitivity of the non-proportional habitat attributes for the American River spring Chinook.

Naches River Spring Chinook

Naches River spring Chinook were most sensitive (both negatively and positively) to the same three attributes identified for American River spring Chinook: *Channel length*, *Width maximum*, and *Width minimum* (Figure 7 and Table 3). These three attributes also produced the largest absolute changes in abundance independently of the magnitude of parameter change.

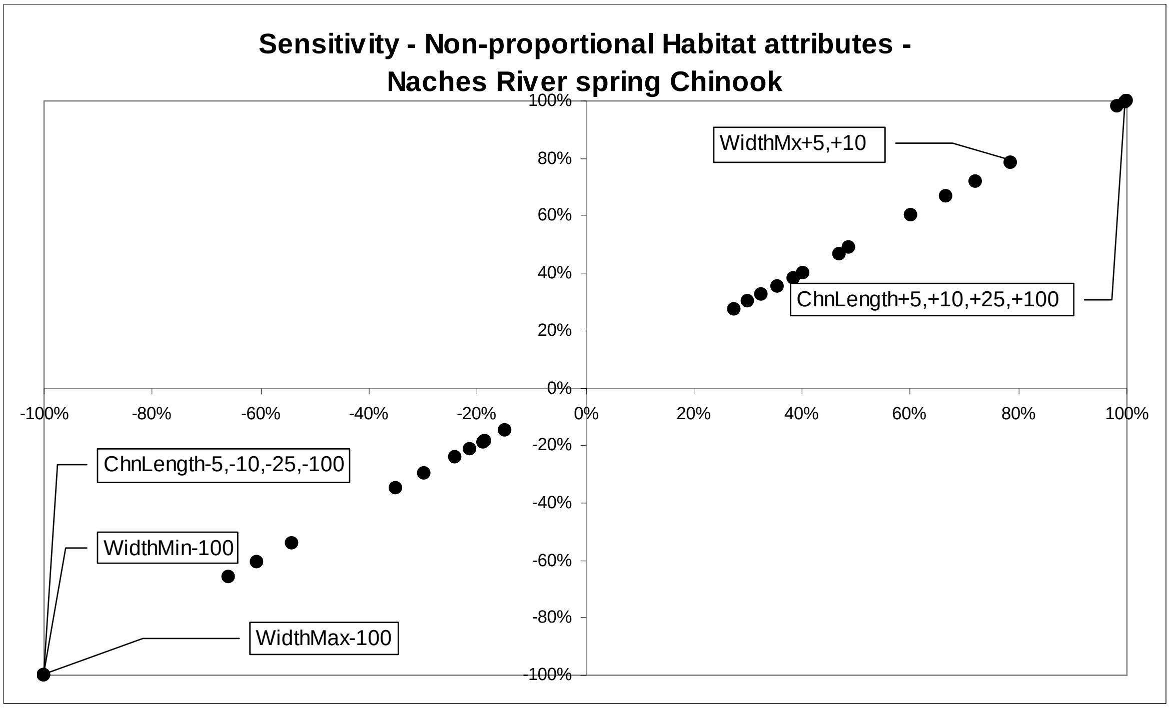

Figure 7: Sensitivity of the non-proportional habitat attributes for the Naches River spring Chinook.

Naches River Steelhead

Naches River steelhead were most sensitive (both positively and negatively) to *Channel length* (Figure 8 and Table 3). The population was significantly negatively sensitive to *Width maximum*, *Width minimum* and to *Gradient* (abundance decreased as gradient decreased). Naches steelhead were significantly positively sensitive to *Channel length*, *Width maximum*, and *Width minimum.* Without consideration of the magnitude of parameter change, the abundance of Naches steelhead was most impacted by *Channel length* and *Gradient.* Complete results are listed alphabetically by actual non-proportional attribute for all three populations in Appendix D.

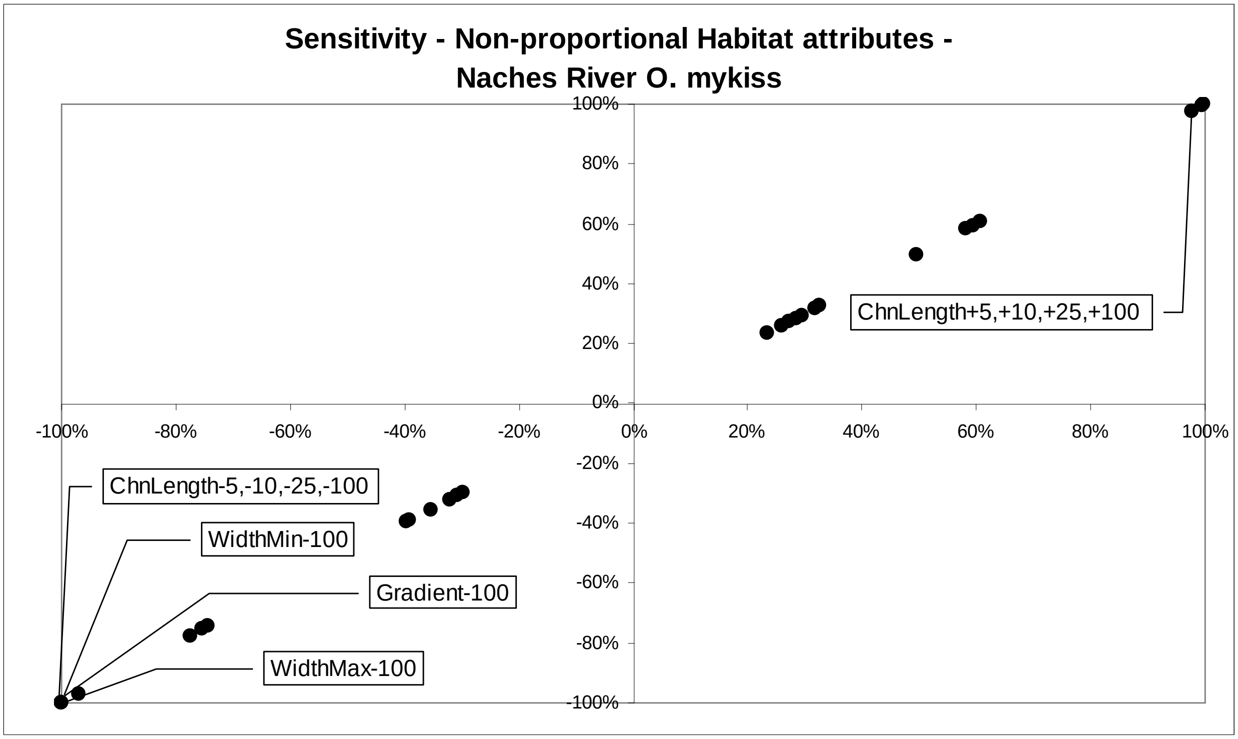

Figure 8: Sensitivity of the non-proportional habitat attributes for the Naches River steelhead.

Actual Proportional Attributes

American River Spring Chinook

American River spring Chinook were most negatively sensitive to *Habitat-backwater pools* and *Habitat-primary pool* (Figure 9 and Table 4). The abundance of this population decreased most rapidly as the proportions of these two habitat attributes were systematically decreased. In the same way, American River spring Chinook were also most positively sensitive to *Habitat-backwater pools* and *Habitat-primary pool* because systematic increases in these attributes resulted in the largest abundance increases. The attributes toward which the population was least sensitive were *Habitat-pool tailouts* and *Habitat-off channel.*

Independently of the magnitude of parameter changes, changes in *Habitat-backwater pools* and *Habitat-primary pool* produced the largest changes in population abundance.

Attribute	Sensitivity American River spring Chinook	Attribute	Sensitivity Naches River spring Chinook	Attribute	Sensitivity Naches River steelhead
HabBckPl-10	-18.0%	**HabBckPl-5**	-8.1%	**HabPool-10**	-0.9%
HabBckPl-5	-16.6%	**HabBckPl-10**	-6.8%	**HabPool-25**	-0.6%
				HabPool-100	-0.5%
				HabPool-5	-0.4%

Table 4: Sensitivity for the actual proportional attributes that were two standard deviations from the mean for the three Yakima Basin populations.

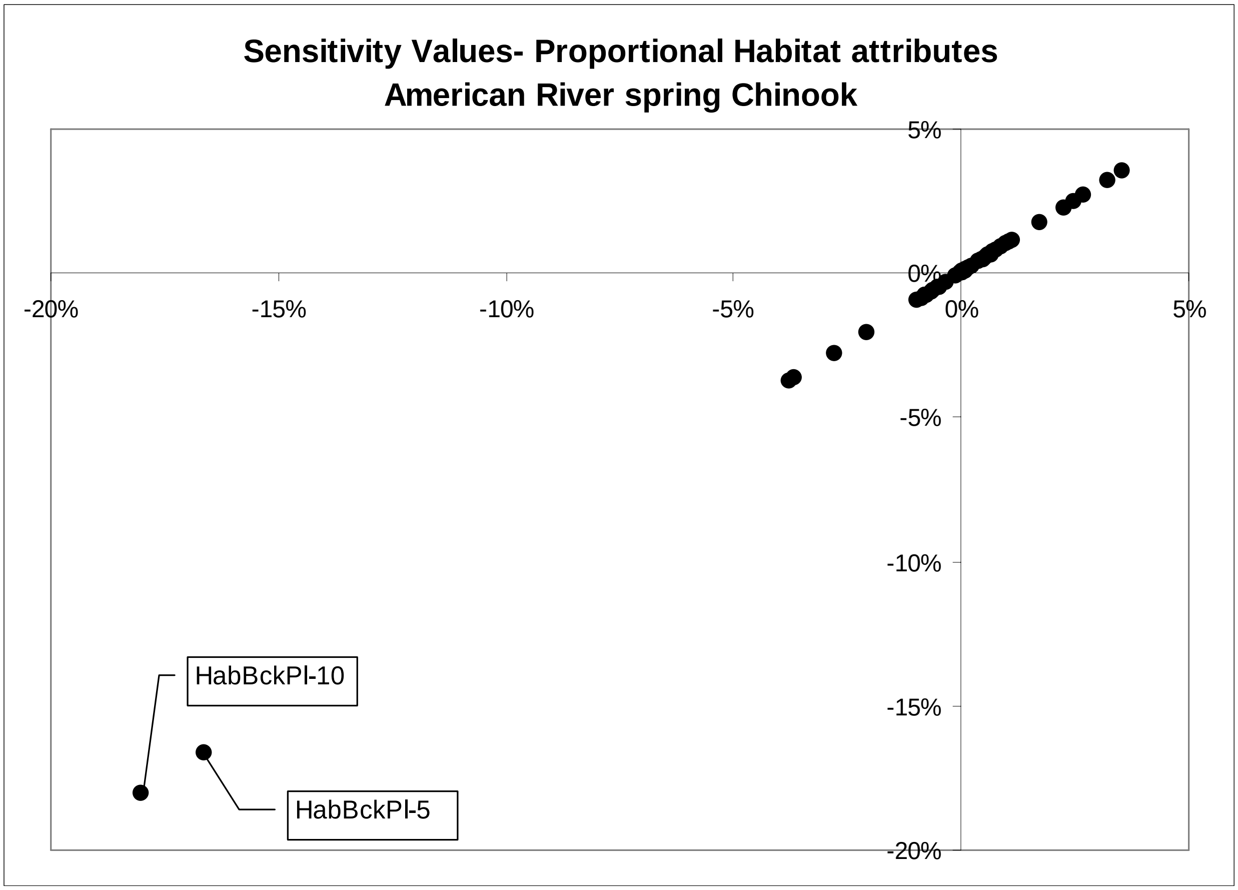

Figure 9: Sensitivity of the proportional habitat attributes for the American River spring Chinook.

Naches River Spring Chinook

Like American River spring Chinook, Naches River spring Chinook are most sensitive, in both the positive and negative senses, to *Habitat-backwater pools* and *Habitat-primary pool* (Figure 10 and Table 4). Unlike the American River population, Naches spring Chinook were also positively sensitive to decreasing proportions of *Habitat-backwater pools,* although the degree of positive sensitivity was not significant.

The attribute toward which the Naches population was least sensitive was *Habitat-off-channel*. Independently of the magnitude of parameter changes, changes in *Habitat-backwater pools*, *Habitat-primary pool* and (in contrast to the American River population) *Habitat-small cobble*[2] caused the greatest changes in Naches spring Chinook abundance.

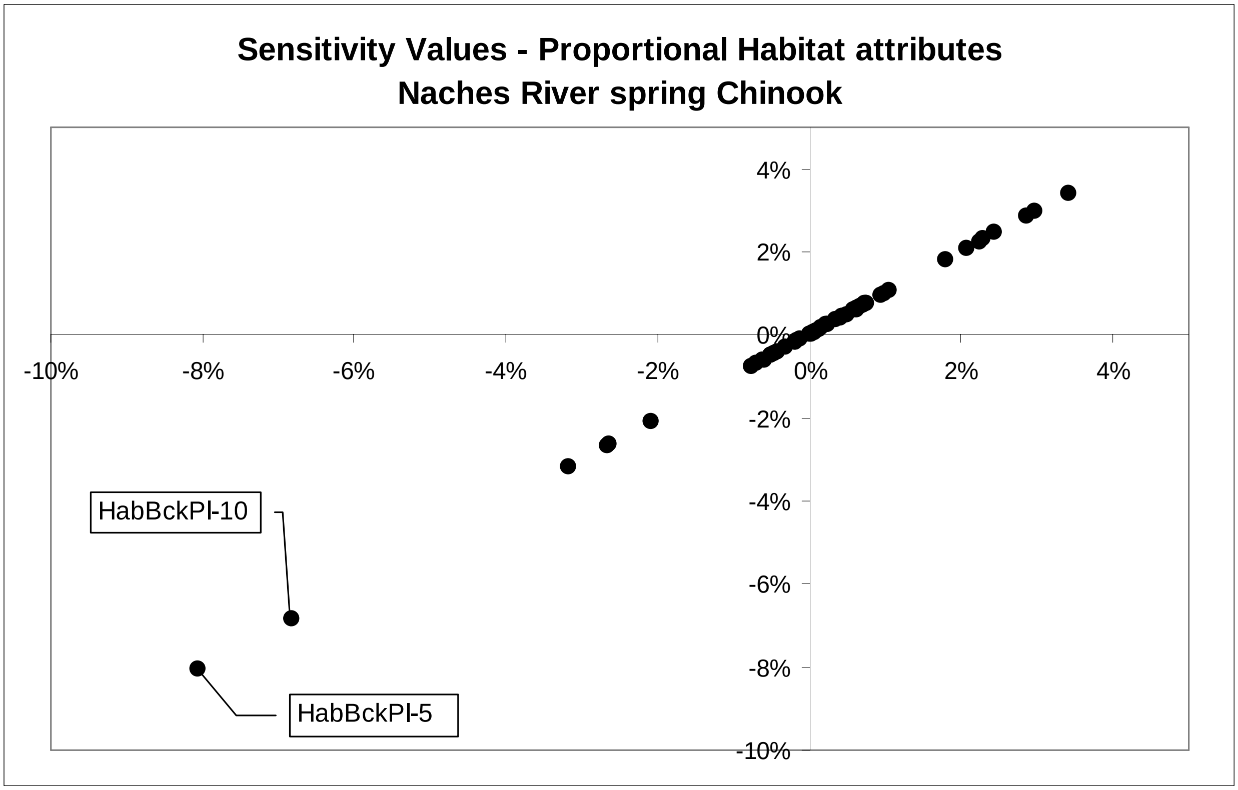

Figure 10: Sensitivity of the proportional habitat attributes for the Naches River spring Chinook.

Naches River Steelhead

Naches River steelhead showed the largest negative sensitivity to decreases in *Habitat-primary pool* (Figure 11 and Table 4). Although large positive sensitivity values were observed in response to increases in *Habitat-pool tailouts* and to decreases in *Habitat –large cobble*[3], these values were not significant. The attribute toward which the population was least sensitive was *Habitat-off-channel*.

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[2] Riffles with small cobble/gravel substrate.

[3] Riffles with large cobble/boulder substrate.

Independently of the magnitude of parameter changes, changes in *Habitat-primary pool* and *Habitat-small cobble* had the greatest impact on population abundance. Complete results are listed alphabetically by actual proportional attribute for all three populations in Appendix E.

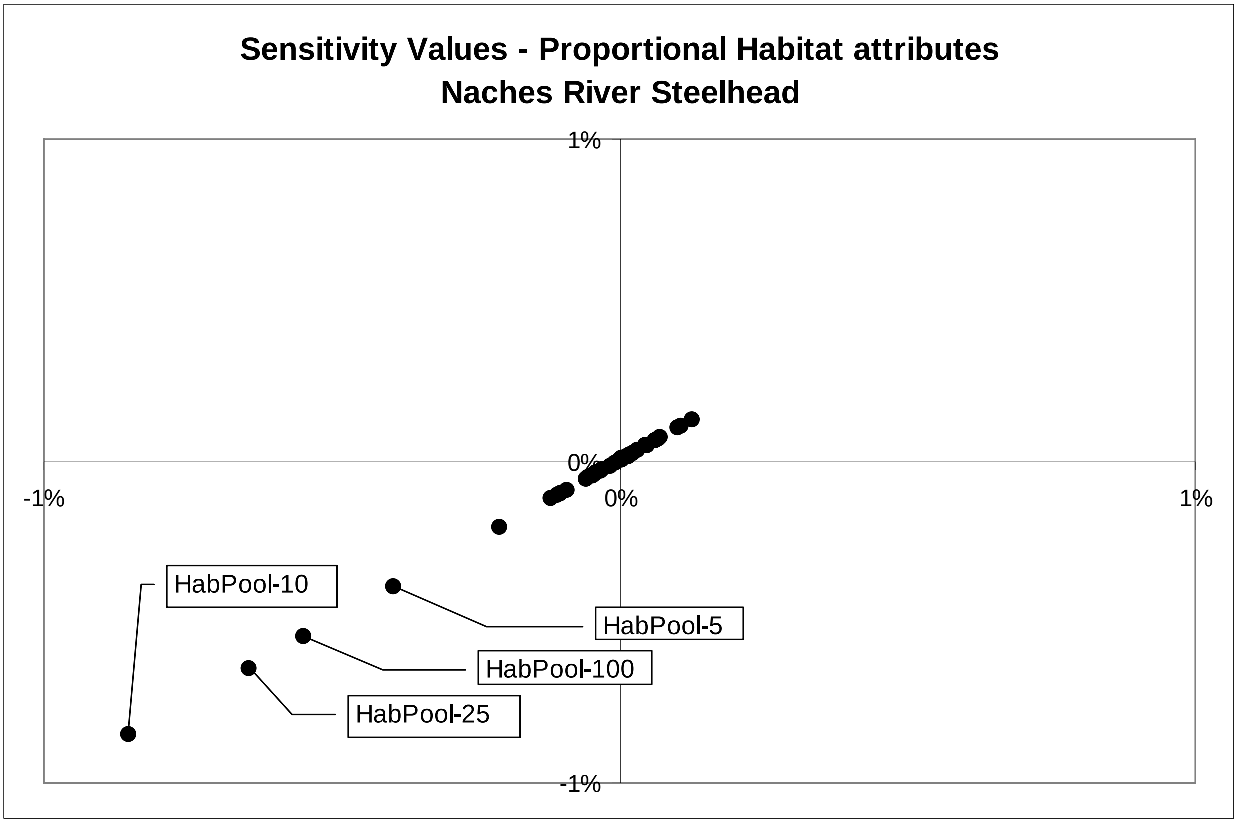

Figure 11: Sensitivity of the proportional habitat attributes for the Naches River steelhead.

Obstructions

The abundance of all three populations was strongly affected by changes in the *Obstructions* attribute (Figure 12). Impacts on Naches River spring Chinook were larger than for either American River spring Chinook or Naches River steelhead for all magnitudes of *Obstructions* changes. In addition, the change in juvenile abundance was greater than the change in equilibrium adult abundance for all populations. Results of the obstruction analyses are presented in Appendix F.

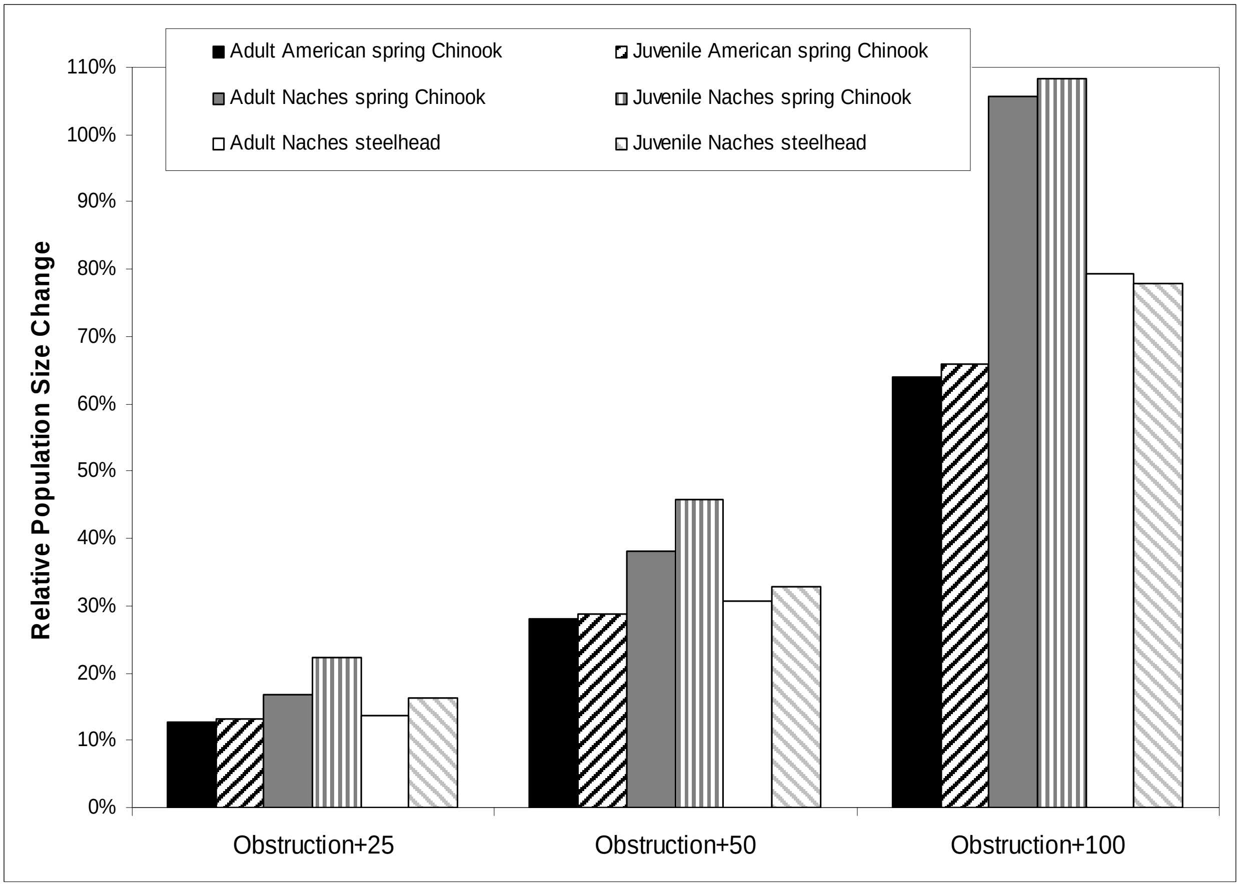

Figure 12: Population abundance change with added obstructions for three Yakima River populations.

Highest Relative Population Change from Initial One-step Change in Attribute Value.

Attributes that produced the largest impacts when changed by the initial (i.e. smallest) increment were examined in this analysis. Such attributes could be considered important since relatively small positive or negative changes in their values had disproportionately large impacts on affected populations.

For American River spring Chinook, the attributes that caused the most change in relative population size in the initial scenario alteration were *Temperature-daily maximum*(+1), *Alkalinity*(-1), *Turbidity*(+1), and *Miscellaneous toxins*(+1) *(*Figure 13 and Table 5).

Attribute	Relative Population Change American River spring Chinook	Attribute	Relative Population Change Naches River spring Chinook	Attribute	Relative Population Change Naches River steelhead
TMx+1	-60%	**TMx+1**	-76%	**Turb+1**	-52%
Alk-1	-56%	**Turb+1**	-44%	**FnSed+1**	-41%
Turb+1	-44%	**Alk-1**	-41%	**Alk-1**	-41%
MscTox+1	-32%	**TMx-1**	46%	**TMn+1**	-39%
TMn+1	-27%			**MscTox+1**	-33%
Alk+1	23%			**TMx+1**	-31%
				TMn-1	29%

Table 5: Initial Attribute Value Change (either +-1 or+-0.05%) effects on relative population change for those attributes that were two standard deviations from the mean.

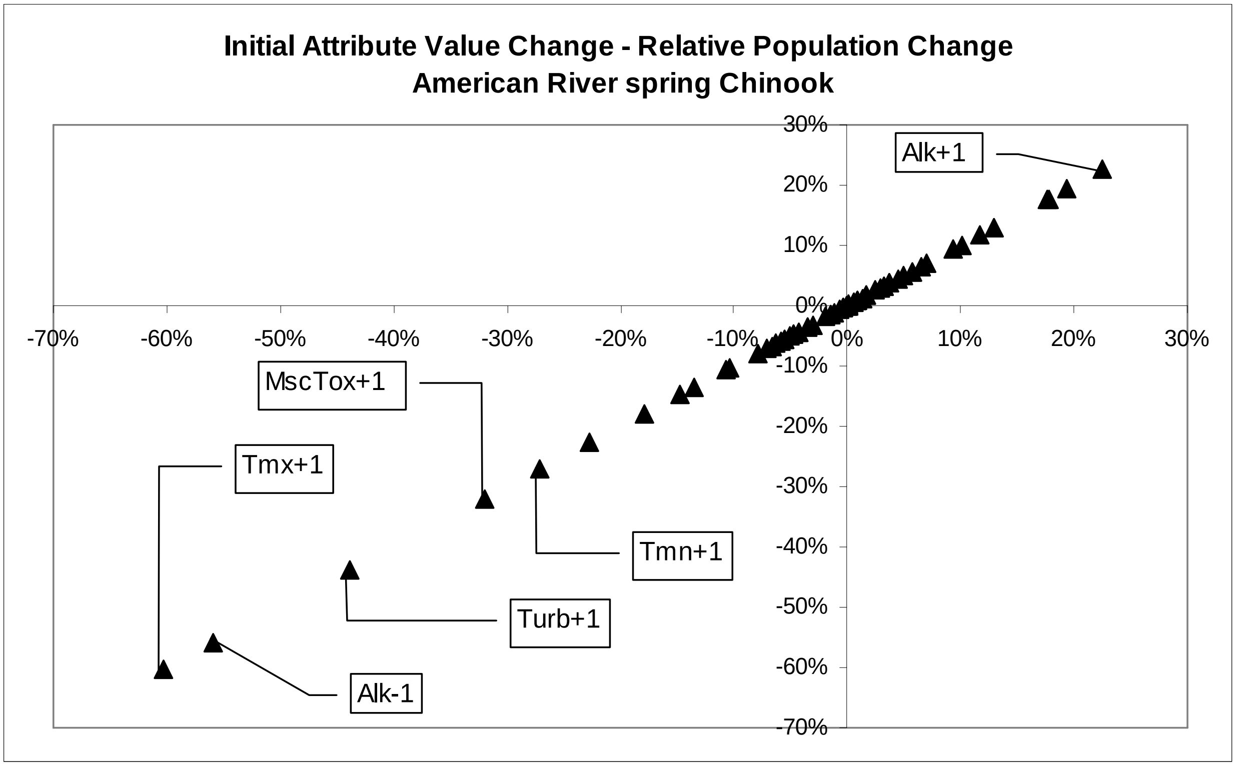

Figure 13: Effect of initial change in attribute value (either +-1 or +-5%) on change in relative population abundance for American River spring Chinook.

For Naches River spring Chinook, the attributes that caused the most change in abundance in the initial value changes were *Temperature-daily maximum*(+1, –1), *Turbidity*(+1), and *Alkalinity*(-1) (Figure 14 and Table 5).

For Naches River steelhead, the attributes that caused the most change in abundance in the initial value changes were *Turbidity*(+1), *Fine sediment*(+1), *Alkalinity*(-1), *Temperature-daily maximum*(+1), *Temperature-daily minimum*(+1, -1), and *Miscellaneous toxins*(+1), *(*Figure 15 and Table 5). Complete results are listed alphabetically by all attributes' initial change for all three populations in Appendix G.

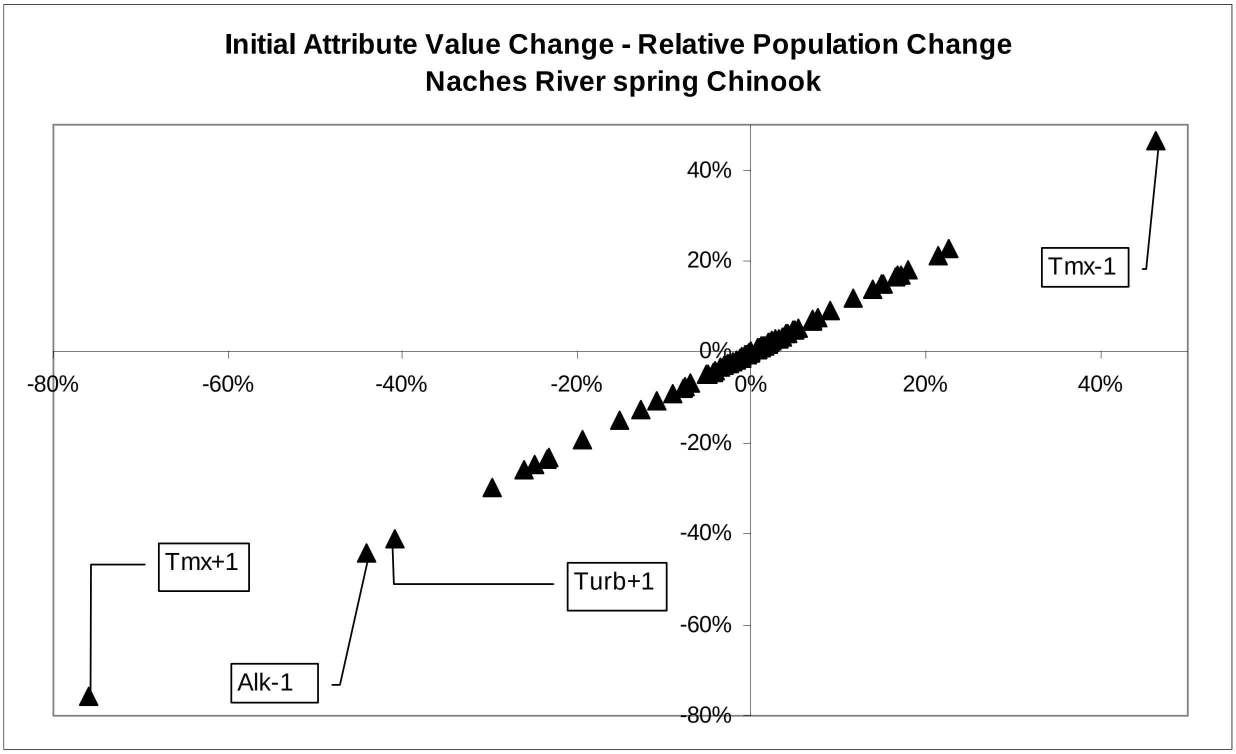

Figure 14: Effect of initial change in attribute value (either +-1 or +-5%) on change in relative population abundance for Naches River spring Chinook.

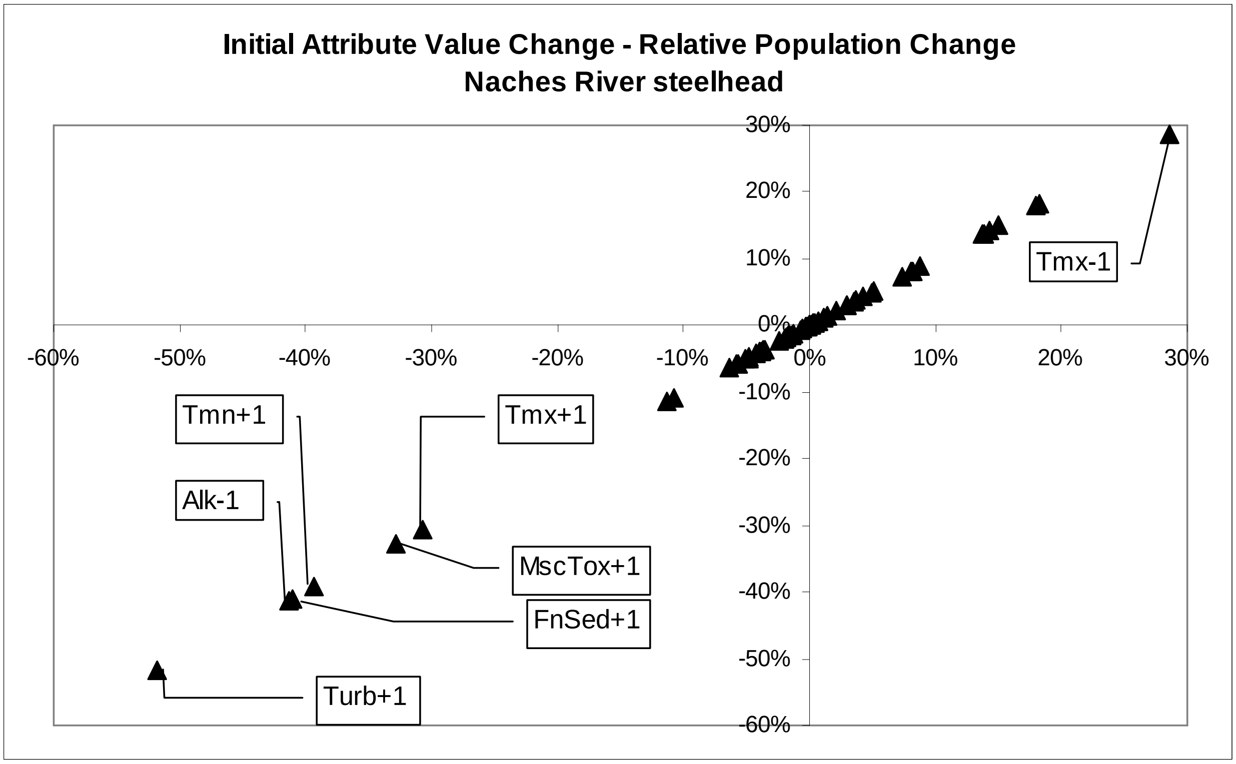

Figure 15: of initial change in attribute value (either +-1 or +-5%) on change in relative population abundance for Naches River steelhead

All Attributes Combined

The sensitivity results for all of the attributes are displayed together in Appendix H. The attributes caused abundance changes of greater than 80% or less than 1% are listed in Table 6.

	Change in Attribute Value (either index or percent)		
Environmental Attributes with >80% Relative Population Abundance Change	**American River spring Chinook**	**Naches River spring Chinook**	**Naches River steelhead**
Width Maximum	-(100)	-(100)	-(100)
Width Minimum	-(100)	-(100)	-(100)
Turbidity	+(3,2)	+(3,2)	+(3,2)
Temperature Daily Maximum	+(4,3)	+(4,3)	+(4,3)
Temperature Daily Minimum	+(4,3,2)	+(4,3,2)	+(4,3,2)
Obstructions		+(100)	
Miscellaneous Toxins	+(4,3,2)	+(4,3,2)	+(4,3,2)
Metals in Water Column	+(4)	+(4)	+(4,3)
Habitat - Backwater Pools	+(100)	+(100)	
Gradient			+(100)
Habitat - Primary Pools		+(100)	
Fine sediment	+(3)	+(3)	+(3,2)
Embeddedness	+(4,3)	+(4,3)	+(4,3)
Dissolved Oxygen	+(4)	+(4)	+(4)
Channel Length	+(100),-(100)	+(100),-(100)	+(100),-(100)
Alkalinity	-(2,3,4)	-(2,3,4)	-(2,3,4)

	Change in Attribute Value (either index or percent)		
Environmental Attributes with <1% Relative Population Abundance Change	**American River spring Chinook**	**Naches River spring Chinook**	**Naches River steelhead**
Benthic Richness			-(1,2,3)
Dissolved Oxygen	-(1,2)	-(1,2)	-(1,2)
Embeddedness	-(1,2)		-(1,2)
Fine Sediment	-(1,2,3,4)		
Fish Pathogens			-(1,2,3)
Flow - Diel Variation	+(4,3,2,1),-(1,2)	+(3,2,1)	+(4,3,2,1),-(1,2)
Flow - Intraannual Variation	+(4,3,2,1),-(1,2)	+(4,3,2,1)	+(4,3,2,1),-(1,2,3,4)
Flow - Interannual Variation in High Flows	+(2,1),-(1,2,3,4)	+(1)	+(4,3,2,1),-(1,2,3,4)
Flow - Interannual Variation in Low Flows	+(4,3,2,1),-(1,2,3,4)		-(1)
Gradient	+(5),-(5,10)	+(5)	
Habitat - Backwater Pools			+(10,5),-(5,10)
Habitat - Beaver Ponds	+(5),-(5,10)	-(5,10)	+(10,5),-(5,10)
Habitat - Glides			+(100,25,10,5),-(5,10,25,100)
Habitat - Large Cobbles			+(25,10,5),-(5,10,25)
Habitat - Off-channel Habitat Factor	+(100,25,10,5),-(5,10,25,100)	+(100,25,10,5),-(5,10,25,100)	+(100,25,10,5),-(5,10,25,100)
Habitat - Pool Tailouts	+(25,10,5),-(5,10)	+(5)	+(10,5),-(5,10)
Habitat - Primary Pools			+(25,10,5)
Habitat - Small Cobble			+(25,10,5),-(5,10)
Harassment	+(1),-(1,2,3,4)	+(1)	
Hatchery Fish outplants	+(4,3,2,1)	+(4,3,2,1)	
Hydrologic Regime - Natural	+(4,3,2,1),-(1)	+(4,3,2,1)	+(4,3,2,1)

Table 6: Environmental Attributes toward which test populations were highly or minimally sensitive in terms of equilibrium abundance.

Comparison between American River and Naches River Spring Chinook

The sensitivities of the American River and Naches River spring Chinook displayed a high correlation coefficient (r = 0.9698). The attributes *Salmon carcasses(+1,+2), Temperature-daily maximum(+1, -1,-2,-3,-4), Alkalinity(-1), Confinement-hydro(+1,-1,-2,-3), Fine sediment(-1), Gradient(-5,-10,-25,-100)* and *Width Maximum(-5)* showed the greatest differences in sensitivity between the two populations (Table 7 and Figure 16). The attributes *Habitat–small cobble(-25,+100), Temperature-daily maximum(+3,+4), Embeddedness(+4), Turbidity(+3), Miscellaneous toxins(+3,+4), Dissolved oxygen(+4), Metals in water column(+4), Hatchery fish outplants(+1), Width minimum and maximum(-100)* showed the least difference in sensitivities.

Attribute	**Sensitivity American River spring Chinook**	**Sensitivity Naches River spring Chinook**	**Difference in Sensitivity**
SCarc+1	-39%	-6%	**33%**
Gradient-5	18%	49%	**31%**
SCarc+2	-36%	-7%	**29%**
TMx-1	19%	46%	**27%**
Gradient-10	17%	38%	**21%**
Gradient-25	13%	33%	**19%**
TMx-2	13%	32%	**19%**
ConfHy-1	9%	28%	**19%**
ConfHy-2	8%	25%	**17%**
TMx+1	-64%	-81%	**17%**
ConfHy+1	-13%	-29%	**16%**
TMx-3	11%	28%	**16%**
FnSed-1	1%	17%	**16%**
TMx-4	11%	27%	**16%**
WidthMx-5	-70%	-54%	**16%**
Gradient-100	12%	27%	**16%**
Alk-1	-56%	-41%	**15%**
ConfHy-3	7%	22%	**15%**

Table 7: Differences that were more than two standard deviations away from the mean difference for American River spring Chinook and Naches River spring Chinook.

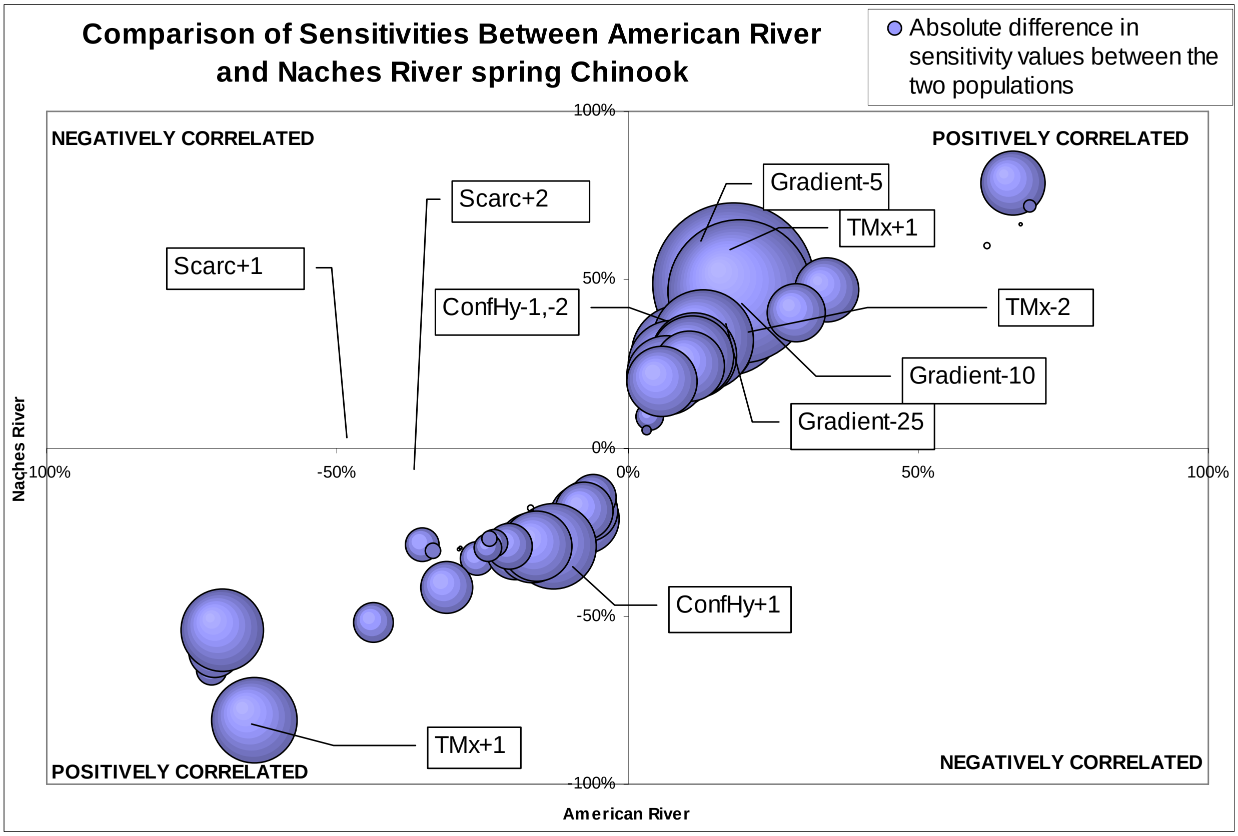

Figure 16: Comparison of differences in sensitivity between spring Chinook populations. Larger bubbles imply a larger absolute difference in sensitivity.

Comparison between Naches Spring Chinook and Naches River Steelhead

The sensitivities of Naches River spring Chinook and steelhead displayed a lower correlation coefficient (r = 0.7742) than was observed between Naches and American River spring Chinook. The attributes *Gradient(all), Temperature-daily maximum(+1),* and *Width maximum(+5)* showed the greatest differences in sensitivity between the two populations (Table 7 and Figure 17). The attributes *Channel length(-100), Dissolved oxygen(+4), Embeddedness(+4), Metals in water column(+4), Miscellaneous toxins(+3,+4), Temperature-daily maximum(+3,+4), Turbidity(+3),* and *Width maximum(-100)* showed the least difference in sensitivities between the two species.

Attribute	Sensitivity Naches River spring Chinook	Sensitivity Naches River steelhead	Difference in Sensitivity
Gradient-100	27%	-100%	**127%**
Gradient-5	49%	-77%	**126%**
Gradient-10	38%	-76%	**114%**
Gradient-25	33%	-74%	**107%**
Gradient25	-21%	59%	**81%**
Gradient10	-19%	58%	**77%**
Gradient5	-15%	61%	**75%**
Gradient100	-19%	50%	**68%**
WidthMx+5	79%	29%	**49%**
TMx+1	-81%	-33%	**48%**

Table 8: Differences that were more than two standard deviations away from the mean difference for Naches River spring Chinook and Naches River steelhead.

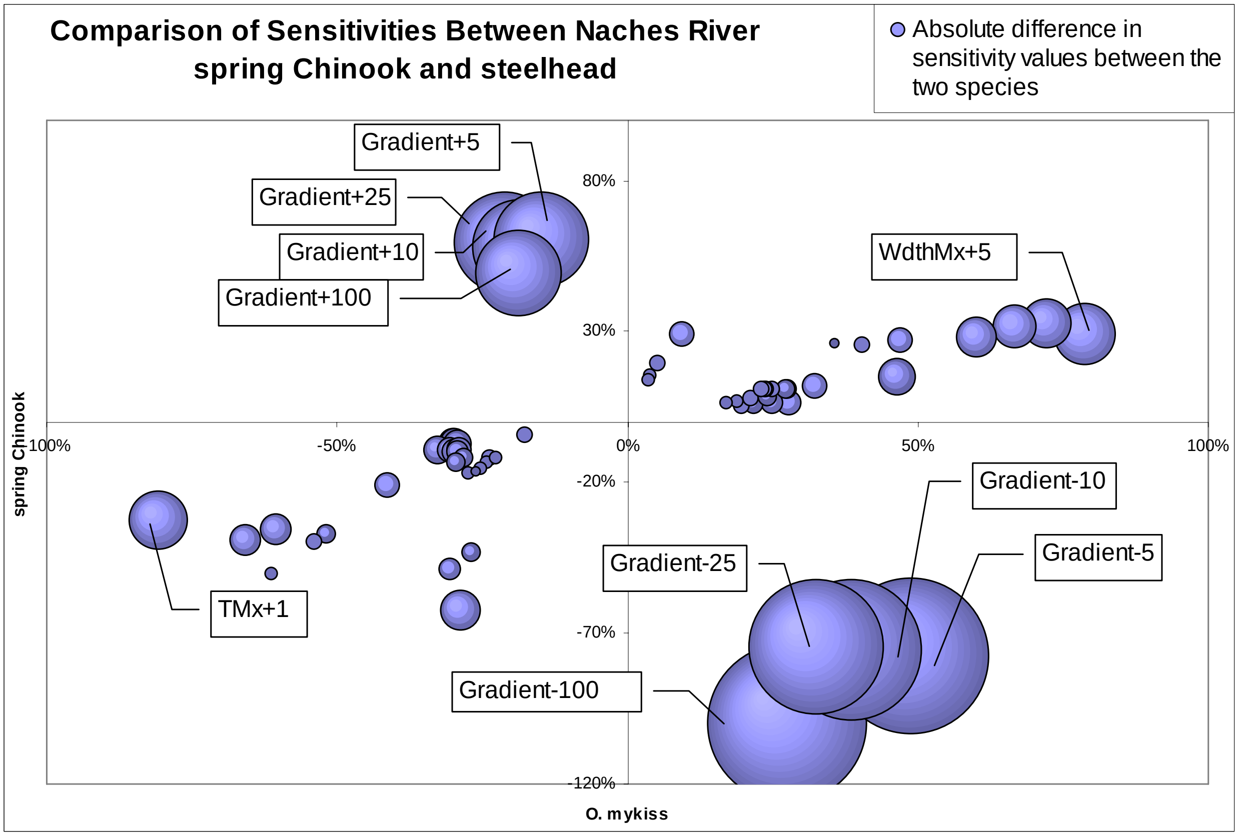

Figure 17: Comparison of differences in sensitivity between Naches River populations. Larger bubbles imply a larger absolute difference in sensitivity.

Discussion

Conclusions from this sensitivity analysis are intended to help guide Reclamation in the use of the EDT model when evaluating treatment alternatives in the Yakima sub-basin. This report cannot, nor intends, to instruct in the basics of EDT. We caution the reader to become familiar with EDT and its' documentation before applying the results of this study. Results from this analysis generally reflect the biological rules at the heart of the EDT model. However, results from this analysis are only applicable to the Yakima sub-basin and the populations evaluated for two reasons. First, model sensitivity is strongly dependent on the initial baseline attribute rating. Second, sensitivity is dependent on population life history. We investigated three categories of attributes: index, actual non-proportional, and actual proportional. For each of these categories, we will discuss the "most sensitive" attributes.

The Index attributes for which al three focal populations were most sensitive were *Temperature-daily maximum*, *Temperature- daily minimum*, *Alkalinity (negative increments)*, *Miscellaneous toxins*, *Fine sediment,* and *Turbidity*. The sensitivity of each of these varied by river and species. We discuss these contrasts after we specifically consider why each of these parameters should be important to Yakima populations given known habitat conditions in the sub-basin and the habitat requirements of the species.

We considered *Temperature-daily maximum* and *Temperature-daily minimum* to be the most sensitive attributes because they had the highest impacts on all three populations. These temperature attributes are measures of the monthly maximum and minimum water temperatures within a reach. Shifts in maximum and minimum temperatures within the stream can have profound effects on species composition of both vertebrates and invertebrates. Salmonids have definite ranges of tolerance and optimal temperatures at different life stages. Increased water temperatures in the mainstem and tributaries affect habitat suitability for spawning and rearing. Extremely cold water temperatures during winter can cause stress, poor growth, and death (Bjornn and Reiser 1991, McCullough 1999). Within the EDT model, maximum and minimum temperature are the primary factors affecting the EDT Level 3 survival factor "Temperature" during most active and inactive life stages (see Appendix A). The Temperature survival factor, in turn, affects the productivity of every salmonid life stage. The maximum and minimum temperature attributes also modify the Level 3 survival factors Predation, Pathogens, and Sediment during some life stages, thereby compounding the impacts of temperature on productivity. Water temperatures can approach lethal levels for anadromous salmonids in the Yakima sub-basin (Vaccaro 1986: Tables 16-18). Accordingly, because of the harsh temperature regime in the Yakima sub-basin and the synergistic impacts of temperature on other attributes, it is reasonable that *Temperature-daily maximum* and *Temperature-daily minimum* were found to be most sensitive in this analysis.

All focal populations were highly sensitive to alkalinity and miscellaneous toxic substances. *Alkalinity* is the acid neutralizing capacity (ANC) of the water. Alkalinity is broadly correlated with the productive capacity of streams, with respect to both primary production and fish production (McFadden and Cooper 1962, Ptolemy 1993). Because it stimulates the production of food organisms, alkalinity is positively correlated with salmon and steelhead carrying capacity. In terms of the mechanisms of the EDT model, *Alkalinity* affects the Level 3 survival factors "Food" and "Competition" which, in turn, affect the maximum density attainable for each life stage and thus the carrying capacity of the watershed (Lestelle et al. 2004). By definition, miscellaneous toxic pollutants within the water column are capable of killing fish at any life stage given sufficient concentrations and exposure. The extreme sensitivity of the focal populations to alkalinity and miscellaneous toxic substances is therefore reasonable because of the strong impacts on capacity of the former and the potentially lethal effects of the latter.

The *Fine sediment* attribute indexes the percentage of fine sediments within salmonid spawning substrates (pool tail-outs, glides, and small-cobble/gravel riffles). Fine sediment particles affect the survival of incubating salmonid eggs and alevins by reducing the rate of oxygen exchange and by entombment. Fine sediment can also affect the benthos, reducing both species diversity and production (Rittmueller 1986, Chapman and McLeod 1987, Bjorn and Reiser 1991, Kondolf 2000). In the EDT model, fine sediment affects the survival factor "Sediment Load", which has a major potential impact on productivity through egg incubation.

The *Turbidity* attribute indexes the severity of impact to salmonids attributable to the combined impact of the duration and concentration of suspended particles. High levels of suspended sediments have been shown to affect fish behavior (e.g., halt feeding) and physiology (e.g., impair ventilation), causing stress and, if prolonged, reducing survival (Newcombe and Jensen 1996). Turbidity affects all free-swimming salmonid life stages. In the EDT model, *Turbidity* contributes to the "Sediment Load" survival factor (Lestelle et al. 2004).

All focal populations were significantly negatively sensitive to *Fine sediment* under the highest increment scenario (+3). Such a result is to be expected, because a +3 scenario would likely result in more than 30% fines in all reaches, a situation that would profoundly depress incubation survival and severely compromise summer rearing. The impacts of *Fine sediment* and *Turbidity* on the three focal populations are not limited to conditions within the Naches and American rivers. Many juvenile spring Chinook and steelhead migrate out of their natal rivers as subyearling parr or as pre-smolt migrants during the late fall and winter of their first year of life (Fast et al. 1991). These fish, which may represent the bulk of a year-class, rear and overwinter in the middle and lower Yakima mainstem, areas in which the impact of fine sediment and turbidity are known to be high (Haring 2001). The EDT model captures these life history details, and the impacts it predicts for Naches and American River populations are consistent with observed and documented habitat/survival relationships.

The high sensitivity of focal populations to changes in *Channel length*, *Width maximum*, and *Width minimum* were expected for all three populations. Increasing the size of the stream reaches simply provides more habitat for each life stage, increasing carrying capacity and mean abundance.

Some of the attributes toward which the focal populations were relatively insensitive included *Hydrologic regime natural*, *Hydrologic regime regulated*, all flow attributes and *Habitat-off-channel*. The low sensitivity of the focal populations to *Hydrologic regime natural* is expected because changing the value of this attribute simply shifts the hydrograph from one pattern to another – e.g., from rainfall, to snowmelt. The model captures this effect by using a different set of rule curves to compute survival factors. Most of these rule curves are unchanged by hydrologic regime.

The relative insensitivity of the populations to flow parameters, however, is significant because the flow attributes are the most obvious conditions that Reclamation could change with new water storage and flow management procedures. The relative insensitivity of EDT to flow reflects the precision with which environmental attributes are defined in EDT. In EDT, flow attributes are defined strictly in hydraulic and/or hydrological terms. While the narrowly hydraulic or hydrological impacts of flow are not large, the indirect and/or delayed impacts of flow on environmental variables, such as temperature, predation and competition, riparian function, bed scour and sediment transport, can be enormous. Although the EDT model is capable of evaluating the response of a focal population to the suite of impacts expected several decades after a major hydrographic change, it cannot predict the specific attributes that a hydrological change will affect. The indirect effects of a major hydrological alteration must be determined independently and entered into the model as changes to non-flow attributes. Therefore, a practitioner using EDT to estimate benefits to salmon production attributable to the restoration or partial restoration of a normative hydrograph must be prepared to specify the time horizon over which impacts are to be evaluated, as well as the identity and degree of impact expected for non-flow attributes.

As mentioned, the focal populations were also insensitive to *Habitat-off-channel*. Off-channel habitat consists of groundwater channels, seasonally flooded wetlands, floodplain ponds, and the channels that connect them to the main channel or a side channel. These habitat types provide important rearing areas for some salmonid species, especially coho salmon (Peterson and Reid 1984). The insensitivity of spring Chinook and steelhead populations in this analysis to *Habitat-off-channel* was expected because the version of the model tested did not treat off-channel features as habitat for these species. Although a growing body of evidence (Sommer et al.2001, Brown 2002) indicates that chinook salmon juveniles do in fact make use of off-channel habitat, and particularly seasonally flooded wetlands, it is still generally accepted that steelhead make little use of off-channel habitat (Everest et al. 1984; Pearsons et al. 1996; Sedell at al. 1984).

The relatively poor correlation (r = 0.7742) between the sensitivities of Naches spring Chinook and steelhead was driven by interspecific differences in the sensitivity to gradient (see Figure 16). Following Johnson et al. (1988), EDT predicts higher densities of juvenile steelhead in streams with steeper gradients (Table 8). Conversely and also consistent with documented observations (Hillman and Miller 2002; Petrosky and Holubets 1988), EDT predicts spring Chinook juvenile densities decline with increasing gradient. Accordingly, the Naches steelhead population was highly positively sensitive to increasing gradient while both spring Chinook populations were highly negatively sensitive. These disparities determined the low correlation coefficient in attribute sensitivity between these two populations.

This systematic sensitivity analysis (SSA) of the EDT model assisted in determining how sensitive the population abundance estimates were to improvement or degradation of the Yakima River basin habitat, which we hope will give managers and scientists an additional tool to use when applying EDT. Carl Walters (1986) said that “the value of modeling in fields like biology has not been to make precise predictions, but rather to provide clear caricatures of nature against which to test and expand experience.” In this analysis, the responses to modeled scenarios made sense biologically, and the overall pattern of sensitivity was useful in highlighting parameters requiring greater precision in modeling and monitoring.

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Appendix A: Environmental quality attributes with attribute type and initial values.

Level 2 Environmental Quality Attribute	Level 3 Category	Description	Pattern Driven?	Index / Actual Value Attribute	Initial Average Value
Alkalinity (Alk)	Water Quality	Alkalinity or acid neutralizing capacity.	No	Index	2.06
Bed Scour (BdSc)	Stream Structure	Average depth of bed scour in spawning areas, during annual peak flood event (or over 10-year period).	Yes	Index	1.96
Benthos Community Richness (BnRch)	Biological Community	Measure of the diversity and production for the macroinvertebrate community.	No	Index	0.76
Channel Length (ChnLength)	Actual Value	Length of the primary channel contained with the stream reach in miles.	No	Actual Non-Proportion	3.24
Confine-Natural (Conf)	Stream Structure	Ratio between the width of the valley (natural features only) and the bankfull channel width.	No	Index	1.59
Confine-Hydromodifications (ConfHy)	Stream Structure	The extent to which flow is impeded by structures in the stream channel. Includes channelization, incision, bridges, etc.	No	Index	1.88
Dissolved Oxygen (DO)	Water Quality	Average dissolved oxygen within the water column.	Yes	Index	0.06
Embeddedness (Emb)	Stream Structure	The extent to which large gravels are buried in fine sediment. Only applies to riffle and pool tailouts with gravels.	No	Index	2.06
Fine Sediment (FnSed)	Stream Structure	Percentage of fine sediment in spawning substrate.	No	Index	2.22
Fish Community Richness (FshComRch)	Biological Community	Measure of the richness of the fish community.	No	Index	2.05

Level 2 Environmental Quality Attribute	**Level 3 Category**	**Description**	**Pattern Driven?**	**Index / Actual Value Attribute**	**Initial Average Value**
Fish Pathogens (FshPath)	Biological Community	The presence of fish pathogens including IHNV for sockeye and kokanee, proximity to hatchery fish releases, and whirling disease.	No	Index	0.83
Fish Species Introductions (FshSpIntro)	Biological Community	The extent of introductions of exotic fish.	No	Index	0.48
Flow Diel (FlowDiel)	Biological Community	Average diel variation in flow during a month. Can indicate level of urbanization or “flashiness”.	Yes	Index	0.19
Flow High (FlowHi)	Hydrology	Relative average peak annual discharge.	Yes	Index	1.87
Flow Intra-Annual (FlowIntra)	Hydrology	Variation in annual flow, or flashiness, during the primary runoff season.	Yes	Index	2.22
Flow Low (FlowLo)	Hydrology	Relative average daily flow change in low flow seasons.	Yes	Index	2.24
Gradient (Gradient)	Hydrology	The average gradient of the main channel of the reach.	No	Actual Non-Proportion	1.67
Habitat – Backwater pools (HabBckPl)	Actual Value	Percentage of backwater pools in the reach.	No	Actual Proportion	0.52
Habitat – Beaver ponds (HabBvr)	Actual Value	Percentage of beaver ponds in the reach.	No	Actual Proportion	0.46
Habitat – Glide (HabGlide)	Actual Value	Percentage of glides in the reach.	No	Actual Proportion	33.90
Habitat – Large cobble riffles (HabLgCob)	Actual Value	Percentage of large cobble riffles in the reach.	No	Actual Proportion	16.70
Habitat – Off Channel Factor (HabOffCh)	Actual Value	Multiplier for estimating off channel habitat, as an expression of the total habitat in the reach.	No	Actual Proportion	10.63
Habitat – Primary pools (HabPool)	Actual Value	Percentage of primary pools in the reach.	No	Actual Proportion	16.61
Habitat – Pool tailouts (HabPoolTail)	Actual Value	Percentage of pool tailouts in the reach.	No	Actual Proportion	3.07
Habitat – Small cobble riffles (HabSmCob)	Actual Value	Percentage of small cobble riffles in the reach.	No	Actual Proportion	32.40

Level 2 Environmental Quality Attribute	Level 3 Category	Description	Pattern Driven?	Index / Actual Value Attribute	Initial Average Value
Harassment (Harrass)	Actual Value	Reach proximity to human population center as indication of extent of poaching and harassment of fish.	No	Index	1.72
Hatchery Fish Outplants (HatchOut)	Biological Community	Magnitude of hatchery releases of juvenile fish.	No	Index	1.21
Hydrologic Regime Natural (HydNat)	Biological Community	Natural flow regime (seasonal pattern of flow over the year).	No	Index	2.54
Hydrologic Regime Regulated (HydReg)	Hydrology	The change in the hydrograph caused by the operation of flow regulation facilities.	No	Index	2.55
Icing (Ice)	Hydrology	Average extent and magnitude of icing events over 10-year period.	Yes	Index	0.47
Metal Pollutant in Soils (MetSoil)	Stream Structure	The extent of heavy metals in stream sediments and soils adjacent to the stream.	No	Index	0.00
Metal Water Column (MetWat)	Water Quality	The extent of dissolved heavy metals in the water column.	No	Index	0.00
Miscellaneous Pollutant Water/Toxins (MscTox)	Water Quality	Extent of pollutants (other than heavy metals) in the water column.	No	Index	0.34
Nutrient Enrichment (Nutrient)	Water Quality	The extent of nutrient enrichment (N and P) from anthropogenic activities.	Yes	Index	0.89
Obstructions (Obstruction)	Obstructions	Obstructions to fish migration	Yes	Actual Non-proportional	-
Predation Risk (Predate)	Water Quality	Per capita risk for small and large fish of predation by species, due to a manmade structure.	Yes	Index	2.16
Riparian Function (RpFx)	Biological Community	How much riparian function has been altered within the reach.	No	Index	1.15
Salmon Carcass SCarc)	Stream Structure	Relative abundance of anadromous salmonid carcasses by watershed.	No	Index	3.87

Level 2 Environmental Quality Attribute	**Level 3 Category**	**Description**	**Pattern Driven?**	**Index / Actual Value Attribute**	**Initial Average Value**
Temperature- Daily Maximum (TMx)	Water Quality	Max duration and heat of water temperature within the stream reach during a month.	Yes	Index	2.64
Temperature-Daily Minimum (TMn)	Water Quality	Minimum duration and heat of water temperature within the reach during a month.	Yes	Index	2.29
Temperature Spatial Variation (TSV)	Water Quality	Extent of water temperature variation as influenced by inputs of groundwater, tributaries, or thermal stratifications in deep pools.	Yes	Index	3.30
Turbidity (Turb)	Stream Structure	Severity of suspended sediment within a reach.	Yes	Index	1.54
Water Withdrawal (Wdrwl)	Hydrology	Number and size of water withdrawals in the stream reach.	Yes	Index	0.46
Width Maximum (WidthMx)	Actual Value	Average width of the wetted channel during high flow month.	Yes	Actual Non-proportional	173.40
Width Minimum (WidthMn)	Actual Value	Average width of the wetted channel during low flow month.	Yes	Actual Non-proportional	105.32
Wood (Wood)	Stream Structure	Amount of large woody debris (greater than 0.1 meter in diameter and 2.0 meters in length) in the reach.	No	Index	2.72

Appendix B: Yakima River Basin reaches used for the sensitivity analysis. Reaches in bold are obstructions on the river.

ReachName

Yakima R.-1A
Yakima R.-1B
Yakima R.-1D
Yakima R.-1E
Yakima R.-1F
Yakima R.-2
Yakima R.-2A
Yakima R.-2C
Yakima R.-2D
Yakima R.-2E
Yakima R.-3
Yakima R.-4
Yakima R.-4A
Yakima R.-5
Yakima R.-5B
Yakima R.-5D
Corral Canyon Cr.
Snipes Cr.-1
Spring Cr.
Snipes Cr.-2
Marion Drain-1
Marion Drain-3
Wanity Slough
Marion Drain-4
Harrah Drain
Sulphur Cr.
Satus Cr.-1
Satus Cr.-2
Satus Cr.-3
Satus Cr.-4
Satus Cr.-5
Satus Cr.-6
Satus Cr.-7
Mule Dry Cr.
Dry Cr. (Satus)-1
Dry Cr. (Satus)-2
Logy Cr.
Bull Cr.
Kusshi Cr.
Wilson Charlie Cr.
Toppenish Cr.-1
Toppenish Cr.-2
Toppenish Cr.-3
Toppenish Cr.-4
Toppenish Cr.-5
Toppenish Cr.-6
Toppenish Cr.-7
Toppenish Cr.-8
Toppenish Cr.-9
Toppenish Cr.-10
Toppenish Cr.-11
Simcoe Cr.-1
Simcoe Cr.-2
Simcoe Cr.-3
Simcoe Cr.-5
Simcoe Cr.-6
Willy Dick Canyon Cr.-1
Willy Dick Canyon Cr.-2
Willy Dick Canyon Cr.-3
NF Toppenish Cr.-1
NF Toppenish Cr.-2

ReachName (Cont.)

Ahtanum Cr. NF-5
Ahtanum Cr. NF-6
Foundation Cr.
Nasty Cr.
MF Ahtanum Cr.
Ahtanum Cr. SF-1
Ahtanum Cr. SF-2
Wide Hollow Cr.-1
Wide Hollow Cr.-3
Wide Hollow Cr.-4
Spring Branch Cr.
Wenas Cr.-1
Wenas Cr.-1a
Wenas Cr.-2
NF Wenas Cr.
SF Wenas Cr.
Naches R.-1
Naches R.-1a
Naches R.-1b
Naches R.-1c
Naches R.-2A
Naches R.-2C
Naches R.-3
Naches R.-4
Naches R.-5
S Naches Channel
Cowiche Cr.-1
Cowiche Cr.-2
SF Cowiche Cr.-1
SF Cowiche Cr.-2
Reynold Cr
NF Cowiche Cr.
Buckskin Slough
Tieton R.-1
Tieton R.-2
Tieton R.-3
Tieton R.-4
Tieton R.-5
Oak Cr.
Wildcat Cr.
NF Tieton R.-1
NF Tieton R.-2
NF Tieton R.-3
NF Tieton R.-3B
NF Tieton R.-4
NF Tieton R.-5
Indian Cr. (NF Tieton)
Clear Cr.
SF Tieton R.-1
SF Tieton R.-2
SF Tieton R.-3
SF Tieton R.-4
Rattlesnake Cr.-1
Rattlesnake Cr.-2
Rattlesnake Cr.-3
Rattlesnake Cr.-4
Rattlesnake Cr.-5
Little Rattlesnake Cr.
NF Rattlesnake Cr.
Hindoo Cr.
Nile Cr.

ReachName (Cont.)

Bumping R.-1
Bumping R.-2a
Bumping R.-3a (Bumping Lake Reach 1)
Bumping R.-3b (Bumping Lake Reach 2)
Bumping R.-4
Deep Cr.
American R.-1
American R.-2
American R.-3
American R.-3A
American R.-3B
American R.-4
American R.-4A
American R.-5
American R.-6
American R.-6A
American R.-6B
Kettle Cr.
Miner Cr.
Morse Cr.
Rainier Fork
Union Cr.
Yakima R.-9B
Yakima R.-10
Yakima R.-11
Yakima R.-11A
Yakima R.-11B
Yakima R.-11C
Yakima R.-12
Yakima R.-13
Yakima R.-13B
Yakima R.-14
Yakima R.-15
Yakima R.-16
Yakima R.-17
Yakima R.-17A
Yakima R.-17B
Yakima R.-18
Yakima R.-19B (Lake Easton)
Yakima R.-20
Yakima R.-21
Yakima R.-22B (Keechelus Lake)
Umtanum Cr.
Wilson Cr.-1
Wilson Cr.-2
Wilson Cr.-3
Wilson Cr.-4
Bull Ditch
Wilson Cr.-4A
Wilson Cr.-5
Wilson Cr.-6
East Branch Wilson Cr.-1
East Branch Wilson Cr.-2
Wilson Cr.-7
Wilson Cr.-8
Wilson Cr.-9
Wilson Cr.-10
Wilson Cr.-11
Cherry Cr.-1
Cherry Cr.-2
Cherry Cr.-3

ReachName (Cont.)

Manastash Cr.-8
Manastash Cr.-9
Manastash Cr.-10
NF Manastash Cr.
SF Manastash Cr.-1
SF Manastash Cr.-2
SF Manastash Cr.-3
Taneum Cr.-1
Taneum Cr.-2
Taneum Cr.-3
Taneum Cr.-4
Taneum Cr.-5
Taneum Cr.-6
NF Taneum Cr.
SF Taneum Cr.
Swauk Cr.-1
Swauk Cr.-2
Swauk Cr.-3
Swauk Cr.-4
Williams Cr.
Iron Cr.
Cle Elum R.-1
Cle Elum R.-2B (Lake Cle Elum)
Cle Elum R.-3
Cle Elum R.-4
Cle Elum R.-5
Cle Elum R.-6
Cle Elum R.-7
Cle Elum R.-8
Cle Elum R.-9
Cle Elum R.-10
Cle Elum R.-11
Cle Elum R.-12
Cooper R.
Waptus R.-1
Waptus R.-2
Waptus R.-3
Waptus R.-4
Waptus R.-5
Little Cr.-1
Little Cr.-2
Big Cr.-1
Big Cr.-2
Big Cr.-3
Big Cr.-4
Big Cr.-5
Big Cr.-6
Tucker Cr.-1
Tucker Cr.-2
Kachess R.-1
Kachess R.-2B (Kachess Lake first reach)
Kachess R.-3 (Kachess Lake second reach)
Kachess R.-4
Box Canyon Cr.
Cabin Cr.
Gold Cr.
Teanaway R.-1
Teanaway R.-2
NF Teanaway R.-1
NF Teanaway R.-2
NF Teanaway R.-3

Appendix C: Index Attributes with summary statistics.

Attribute	Sensitivity American Spring Chinook	Sensitivity Naches Spring Chinook	Sensitivity Naches Steelhead	Relative Change American Spring Chinook	Relative Change Naches Spring Chinook	Relative Change Naches Steelhead
Alk-4	-43%	-44%	-42%	-88%	-91%	-86%
Alk-3	-43%	-44%	-42%	-88%	-91%	-86%
Alk-2	-48%	-51%	-50%	-84%	-88%	-86%
Alk-1	-56%	-41%	-41%	-56%	-41%	-41%
Alk+1	23%	17%	18%	23%	17%	18%
Alk+2	18%	13%	18%	30%	22%	30%
Alk+3	16%	11%	16%	31%	22%	31%
BdSc-4	1%	1%	1%	3%	3%	2%
BdSc-3	1%	1%	1%	3%	3%	2%
BdSc-2	1%	2%	1%	2%	3%	2%
BdSc-1	1%	2%	1%	1%	2%	1%
BdSc+1	-2%	-2%	1%	-1%	-2%	1%
BdSc+2	-2%	-4%	-5%	-3%	-7%	-9%
BdSc+3	-2%	-5%	-6%	-3%	-11%	-12%
BdSc+4	-2%	-6%	-6%	-3%	-12%	-13%
BnRch-3	3%	4%	1%	2%	3%	1%
BnRch-2	3%	5%	1%	2%	3%	1%
BnRch-1	4%	6%	2%	2%	2%	1%
BnRch+1	-5%	-4%	-4%	-5%	-4%	-4%
BnRch+2	-6%	-5%	-5%	-12%	-10%	-10%
BnRch+3	-8%	-6%	-6%	-20%	-17%	-16%
BnRch+4	-9%	-7%	-7%	-28%	-23%	-23%
Conf-4	3%	8%	8%	5%	12%	12%
Conf-3	3%	9%	9%	5%	12%	12%
Conf-2	4%	10%	10%	5%	11%	11%
Conf-1	5%	12%	13%	3%	7%	7%
Conf+1	-10%	-13%	-13%	-8%	-11%	-11%
Conf+2	-15%	-19%	-13%	-22%	-28%	-19%
Conf+3	-18%	-21%	-14%	-36%	-42%	-27%
Conf+4	-23%	-25%	-15%	-54%	-61%	-36%
ConfHy-4	6%	20%	6%	11%	37%	10%
ConfHy-3	7%	22%	6%	11%	37%	10%
ConfHy-2	8%	25%	6%	10%	32%	8%
ConfHy-1	9%	28%	7%	7%	21%	5%
ConfHy+1	-13%	-29%	-7%	-10%	-23%	-6%
ConfHy+2	-16%	-29%	-9%	-22%	-42%	-13%
ConfHy+3	-19%	-31%	-9%	-37%	-58%	-18%
ConfHy+4	-26%	-33%	-9%	-55%	-69%	-20%

Attribute (continued)	**Sensitivity American Spring Chinook**	**Sensitivity Naches Spring Chinook**	**Sensitivity Naches Steelhead**	**Relative Change American Spring Chinook**	**Relative Change Naches Spring Chinook**	**Relative Change Naches Steelhead**
DO-2	3%	13%	4%	0%	1%	0%
DO-1	3%	13%	4%	0%	1%	0%
DO+1	-4%	-5%	-4%	-4%	-5%	-4%
DO+2	-15%	-17%	-11%	-29%	-34%	-22%
DO+3	-25%	-26%	-24%	-75%	-77%	-73%
DO+4	-25%	-25%	-25%	-100%	-100%	-100%
Emb-2	0%	1%	0%	1%	2%	0%
Emb-1	0%	1%	0%	1%	2%	0%
Emb+1	-31%	-41%	-21%	-6%	-8%	-4%
Emb+2	-44%	-52%	-37%	-36%	-42%	-30%
Emb+3	-54%	-55%	-57%	-92%	-93%	-96%
Emb+4	-52%	-52%	-52%	-100%	-100%	-100%
FlowDiel-2	0%	0%	0%	0%	0%	0%
FlowDiel-1	0%	0%	0%	0%	0%	0%
FlowDiel+1	0%	0%	0%	0%	0%	0%
FlowDiel+2	0%	0%	0%	0%	0%	0%
FlowDiel+3	0%	0%	0%	0%	0%	-1%
FlowDiel+4	0%	0%	0%	0%	-1%	2%
FlowHi-4	0%	1%	0%	0%	1%	0%
FlowHi-3	0%	1%	0%	0%	1%	0%
FlowHi-2	0%	1%	0%	0%	1%	0%
FlowHi-1	0%	1%	0%	0%	1%	0%
FlowHi+1	0%	0%	0%	0%	0%	0%
FlowHi+2	0%	-1%	0%	-1%	-3%	0%
FlowHi+3	-1%	-2%	0%	-3%	-4%	0%
FlowHi+4	-1%	-2%	0%	-3%	-4%	0%
FlowIntr-4	1%	1%	0%	1%	2%	0%
FlowIntr-3	1%	1%	0%	1%	2%	0%
FlowIntr-2	0%	1%	0%	1%	2%	0%
FlowIntr-1	1%	2%	0%	1%	2%	0%
FlowIntr+1	0%	0%	0%	0%	0%	0%
FlowIntr+2	0%	0%	0%	0%	-1%	0%
FlowIntr+3	0%	0%	0%	0%	-1%	0%
FlowIntr+4	0%	0%	0%	0%	-1%	0%
FlowLo-4	0%	1%	0%	0%	2%	1%
FlowLo-3	0%	1%	0%	0%	2%	1%
FlowLo-2	0%	1%	1%	0%	2%	1%
FlowLo-1	0%	2%	1%	0%	2%	1%
FlowLo+1	0%	-1%	-1%	0%	-1%	-1%
FlowLo+2	0%	-2%	-2%	0%	-3%	-3%
FlowLo+3	0%	-2%	-2%	0%	-3%	-3%
FlowLo+4	0%	-2%	-1%	0%	-3%	-3%

Attribute (continued)	**Sensitivity American Spring Chinook**	**Sensitivity Naches Spring Chinook**	**Sensitivity Naches Steelhead**	**Relative Change American Spring Chinook**	**Relative Change Naches Spring Chinook**	**Relative Change Naches Steelhead**
FnSed-4	0%	8%	9%	1%	17%	20%
FnSed-3	0%	8%	9%	1%	17%	20%
FnSed-2	1%	9%	11%	1%	17%	20%
FnSed-1	1%	17%	18%	1%	17%	18%
FnSed+1	-24%	-27%	-43%	-23%	-26%	-41%
FnSed+2	-35%	-29%	-63%	-57%	-46%	-100%
FnSed+3	-56%	-55%	-56%	-100%	-97%	-100%
FshComRch-4	6%	7%	4%	12%	15%	9%
FshComRch-3	6%	7%	4%	12%	14%	8%
FshComRch-2	5%	6%	4%	10%	12%	7%
FshComRch-1	6%	7%	4%	6%	7%	4%
FshComRch+1	-5%	-5%	-4%	-5%	-4%	-4%
FshComRch+2	-3%	-4%	-4%	-6%	-7%	-8%
FshComRch+3	-3%	-3%	-4%	-6%	-7%	-9%
FshPath-3	3%	4%	0%	2%	3%	0%
FshPath-2	3%	4%	0%	2%	3%	0%
FshPath-1	3%	5%	1%	2%	3%	0%
FshPath+1	-6%	-8%	-1%	-6%	-8%	-1%
FshPath+2	-17%	-18%	-4%	-33%	-35%	-8%
FshPath+3	-13%	-15%	-6%	-36%	-40%	-17%
FshPath+4	-11%	-13%	-6%	-36%	-40%	-19%
FshSpIntro-3	14%	17%	10%	7%	8%	5%
FshSpIntro-2	13%	16%	9%	6%	8%	4%
FshSpIntro-1	12%	14%	8%	5%	5%	3%
FshSpIntro+1	-7%	-7%	-5%	-7%	-7%	-5%
FshSpIntro+2	-8%	-8%	-6%	-16%	-17%	-11%
FshSpIntro+3	-8%	-8%	-6%	-22%	-24%	-18%
FshSpIntro+4	-7%	-8%	-6%	-26%	-29%	-22%
Harass-4	0%	1%	1%	1%	3%	2%
Harass-3	0%	2%	1%	1%	3%	2%
Harass-2	0%	2%	1%	1%	2%	2%
Harass-1	0%	2%	1%	0%	2%	1%
Harass+1	0%	-1%	-2%	0%	-1%	-2%
Harass+2	-1%	-2%	-3%	-1%	-3%	-5%
Harass+3	-1%	-2%	-3%	-3%	-5%	-6%
Harass+4	-2%	-2%	-3%	-3%	-5%	-6%
HatchOut-4	12%	14%	8%	15%	17%	10%
HatchOut-3	12%	14%	8%	13%	15%	9%
HatchOut-2	13%	15%	9%	10%	11%	7%
HatchOut-1	16%	18%	9%	7%	8%	4%
HatchOut+1	0%	0%	-3%	0%	0%	-2%
HatchOut+2	0%	0%	-2%	0%	0%	-3%
HatchOut+3	0%	0%	-1%	0%	0%	-3%
HatchOut+4	0%	0%	-1%	-1%	0%	-3%

Attribute (continued)	Sensitivity American Spring Chinook	Sensitivity Naches Spring Chinook	Sensitivity Naches Steelhead	Relative Change American Spring Chinook	Relative Change Naches Spring Chinook	Relative Change Naches Steelhead
HydNat-3	1%	7%	8%	2%	19%	22%
HydNat-2	1%	4%	5%	1%	7%	11%
HydNat-1	1%	2%	2%	1%	2%	2%
HydNat+1	0%	1%	0%	0%	1%	0%
HydNat+2	0%	0%	0%	0%	1%	0%
HydNat+3	0%	0%	0%	0%	1%	0%
HydNat+4	0%	0%	0%	0%	1%	0%
HydReg-3	0%	0%	0%	0%	1%	0%
HydReg-2	0%	0%	0%	0%	1%	0%
HydReg-1	0%	1%	0%	0%	1%	0%
HydReg+1	0%	1%	0%	0%	1%	0%
HydReg+2	0%	0%	0%	0%	1%	0%
Ice-2	1%	2%	1%	1%	1%	0%
Ice-1	1%	3%	1%	1%	1%	0%
Ice+1	-1%	-1%	-1%	-1%	-1%	-1%
Ice+2	-1%	-1%	-1%	-2%	-3%	-1%
Ice+3	-1%	-2%	-1%	-4%	-5%	-2%
Ice+4	-2%	-2%	-1%	-6%	-6%	-3%
MetSoil+1	-1%	0%	-1%	-1%	0%	-1%
MetSoil+2	-2%	-1%	-2%	-3%	-3%	-4%
MetSoil+3	-3%	-3%	-4%	-10%	-10%	-11%
MetSoil+4	-10%	-10%	-14%	-39%	-39%	-55%
MetWat+1	-2%	-1%	-2%	-2%	-1%	-2%
MetWat+2	-9%	-8%	-9%	-18%	-17%	-17%
MetWat+3	-24%	-25%	-27%	-72%	-74%	-82%
MetWat+4	-25%	-25%	-25%	-100%	-100%	-100%
MscTox-3	11%	12%	10%	4%	4%	3%
MscTox-2	11%	12%	11%	4%	4%	3%
MscTox-1	15%	16%	14%	4%	4%	3%
MscTox+1	-32%	-30%	-33%	-32%	-30%	-33%
MscTox+2	-48%	-47%	-50%	-95%	-95%	-100%
MscTox+3	-34%	-34%	-34%	-100%	-100%	-100%
MscTox+4	-27%	-27%	-27%	-100%	-100%	-100%
Nutrient-4	0%	1%	0%	0%	1%	0%
Nutrient-3	0%	1%	0%	0%	1%	0%
Nutrient-2	0%	2%	0%	0%	1%	0%
Nutrient-1	0%	2%	0%	0%	1%	0%
Nutrient+1	0%	0%	0%	0%	0%	0%
Nutrient+2	-1%	0%	0%	-1%	-1%	0%
Nutrient+3	-1%	-1%	0%	-2%	-2%	-1%
Nutrient+4	-1%	-1%	0%	-3%	-2%	-1%
Predate-3	2%	3%	2%	5%	7%	5%
Predate-2	2%	3%	2%	5%	6%	4%
Predate-1	4%	5%	3%	4%	5%	3%
Predate+1	-14%	-15%	-6%	-14%	-15%	-6%
Predate+2	-29%	-30%	-7%	-53%	-55%	-12%
Predate+3	-29%	-30%	-7%	-53%	-55%	-12%

Attribute (continued)	**Sensitivity American Spring Chinook**	**Sensitivity Naches Spring Chinook**	**Sensitivity Naches Steelhead**	**Relative Change American Spring Chinook**	**Relative Change Naches Spring Chinook**	**Relative Change Naches Steelhead**
RpF(x)-4	11%	23%	11%	12%	26%	12%
RpF(x)-3	11%	24%	11%	12%	26%	12%
RpF(x)-2	12%	24%	11%	12%	25%	12%
RpF(x)-1	13%	25%	11%	9%	18%	8%
RpF(x)+1	-15%	-24%	-12%	-15%	-23%	-11%
RpF(x)+2	-18%	-24%	-13%	-34%	-47%	-26%
RpF(x)+3	-20%	-24%	-15%	-52%	-62%	-38%
RpF(x)+4	-21%	-24%	-16%	-60%	-68%	-46%
SCarc-4	9%	9%	8%	36%	33%	32%
SCarc-3	11%	10%	10%	33%	31%	30%
SCarc-2	14%	12%	12%	28%	25%	24%
SCarc-1	18%	15%	14%	18%	15%	14%
SCarc+1	-39%	-6%	-13%	-5%	-1%	-2%
SCarc+2	-36%	-7%	-14%	-5%	-1%	-2%
TMn-4	2%	4%	14%	7%	9%	38%
TMn-3	3%	4%	15%	7%	9%	38%
TMn-2	3%	5%	19%	6%	9%	36%
TMn-1	4%	9%	29%	4%	9%	29%
TMn+1	-33%	-31%	-49%	-27%	-25%	-39%
TMn+2	-66%	-73%	-79%	-82%	-90%	-98%
TMn+3	-61%	-67%	-75%	-82%	-90%	-100%
TMn+4	-61%	-66%	-74%	-82%	-90%	-100%
TMx-4	11%	27%	11%	25%	62%	25%
TMx-3	11%	28%	11%	25%	62%	24%
TMx-2	13%	32%	12%	24%	59%	22%
TMx-1	19%	46%	15%	19%	46%	15%
TMx+1	-64%	-81%	-33%	-60%	-76%	-31%
TMx+2	-51%	-61%	-50%	-78%	-94%	-77%
TMx+3	-59%	-59%	-59%	-100%	-100%	-100%
TMx+4	-58%	-58%	-58%	-100%	-100%	-100%
TSV-4	3%	9%	7%	11%	30%	23%
TSV-3	4%	11%	7%	11%	29%	20%
TSV-2	5%	13%	8%	9%	24%	16%
TSV-1	6%	15%	9%	6%	15%	9%
TSV+1	-14%	-23%	-12%	-5%	-9%	-5%
TSV+2	-15%	-27%	-17%	-10%	-18%	-11%
TSV+3	-14%	-26%	-17%	-10%	-18%	-11%
TSV+4	-14%	-25%	-16%	-10%	-18%	-11%
Turb-3	8%	10%	9%	13%	15%	15%
Turb-2	9%	10%	10%	13%	15%	15%
Turb-1	12%	14%	14%	12%	14%	14%
Turb+1	-44%	-44%	-52%	-44%	-44%	-52%
Turb+2	-48%	-42%	-51%	-93%	-82%	-100%
Turb+3	-41%	-41%	-41%	-100%	-100%	-100%

Attribute (continued)	Sensitivity American Spring Chinook	Sensitivity Naches Spring Chinook	Sensitivity Naches Steelhead	Relative Change American Spring Chinook	Relative Change Naches Spring Chinook	Relative Change Naches Steelhead
Wdrwl-4	0%	0%	0%	0%	0%	0%
Wdrwl-3	0%	0%	0%	0%	0%	0%
Wdrwl-2	0%	0%	0%	0%	0%	0%
Wdrwl-1	0%	0%	0%	0%	0%	0%
Wdrwl+1	0%	0%	0%	0%	0%	0%
Wdrwl+2	0%	-1%	0%	0%	-1%	-1%
Wdrwl+3	0%	-1%	-1%	-1%	-2%	-2%
Wdrwl+4	-1%	-1%	-2%	-2%	-4%	-8%
Wood-4	7%	17%	6%	19%	46%	17%
Wood-3	7%	19%	7%	18%	44%	17%
Wood-2	9%	21%	8%	16%	37%	14%
Wood-1	11%	24%	9%	10%	23%	8%
Wood+1	-16%	-30%	-10%	-11%	-19%	-6%
Wood+2	-20%	-29%	-10%	-22%	-31%	-10%
Wood+3	-23%	-28%	-12%	-28%	-34%	-14%
Wood+4	-24%	-30%	-13%	-31%	-38%	-17%

Minimum	-66.4%	-80.7%	-78.8%	-100.0%	-100.0%	-100.0%
Average	-6.3%	-5.2%	-5.2%	-11.3%	-9.9%	-9.5%
Standard Deviation	17.8%	20.5%	18.1%	30.2%	33.8%	31.2%
Median	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Maximum	22.8%	46.4%	29.1%	35.7%	62.1%	37.7%
Average-2 Std Dev	-41.8%	-46.1%	-41.4%	-71.7%	-77.5%	-71.9%
Average+2 Std Dev	29.2%	35.7%	31.0%	49.1%	57.6%	52.8%

Appendix D: Non-proportional Habitat Attributes

Attribute	Sensitivity American Spring Chinook	Sensitivity Naches Spring Chinook	Sensitivity Change Naches Steelhead	Relative Change American Spring Chinook	Relative Change Naches Spring Chinook	Relative Change Naches Steelhead
ChnLength-100	-100%	-100%	-100%	-100%	-100%	-5%
ChnLength-25	-100%	-100%	-100%	-25%	-25%	-10%
ChnLength-10	-101%	-101%	-102%	-10%	-10%	-25%
ChnLength-5	-101%	-101%	-102%	-5%	-5%	-100%
ChnLength+5	101%	101%	100%	5%	5%	-100%
ChnLength+10	98%	98%	98%	10%	10%	-100%
ChnLength+25	100%	100%	100%	25%	25%	-97%
ChnLength+100	100%	100%	100%	100%	100%	-4%
Gradient-100	12%	27%	-100%	12%	27%	-8%
Gradient-25	13%	33%	-74%	3%	8%	-19%
Gradient-10	17%	38%	-76%	2%	4%	-2%
Gradient-5	18%	49%	-77%	1%	2%	-10%
Gradient5	-6%	-15%	61%	0%	-1%	-4%
Gradient10	-7%	-19%	58%	-1%	-2%	-8%
Gradient25	-8%	-21%	59%	-2%	-5%	-2%
Gradient100	-7%	-19%	50%	-7%	-19%	-3%
WidthMin-100	-100%	-100%	-97%	-100%	-100%	24%
WidthMin-25	-33%	-35%	-32%	-8%	-9%	3%
WidthMin-10	-31%	-30%	-30%	-3%	-3%	6%
WidthMin-5	-30%	-24%	-31%	-1%	-1%	1%
WidthMin+5	34%	47%	27%	2%	2%	28%
WidthMin+10	29%	40%	26%	3%	4%	1%
WidthMin+25	29%	36%	26%	7%	9%	8%
WidthMin+100	24%	30%	24%	24%	30%	3%
WidthMx-100	-100%	-100%	-100%	-100%	-100%	50%
WidthMx-25	-72%	-66%	-39%	-18%	-16%	6%
WidthMx-10	-71%	-61%	-35%	-7%	-6%	15%
WidthMx-5	-70%	-54%	-40%	-3%	-3%	3%
WidthMx+5	66%	79%	29%	3%	4%	10%
WidthMx+10	69%	72%	33%	7%	7%	100%
WidthMx+25	68%	67%	32%	17%	17%	25%
WidthMx+100	62%	60%	28%	62%	60%	5%

Minimum	-101.3%	-101.2%	-102.0%	-100.0%	-100.0%	-100.0%
Average	-3.0%	1.0%	-8.9%	-3.4%	-2.8%	-6.5%
Standard Deviation	67.2%	68.7%	69.8%	38.8%	39.3%	41.9%
Median	3.0%	6.3%	-3.2%	0.3%	0.8%	-0.1%
Maximum	101.3%	101.3%	100.4%	100.0%	100.0%	99.9%
Average-2 Std Dev	-137.5%	-136.5%	-148.5%	-81.0%	-81.4%	-90.2%
Average+2 Std Dev	131.5%	138.4%	130.7%	74.1%	75.8%	77.3%

Appendix E: Proportional Habitat Attributes

Attribute	Sensitivity American Spring Chinook	Sensitivity Naches Spring Chinook	Sensitivity Naches Steelhead	Relative Change American Spring Chinook	Relative Change Naches Spring Chinook	Relative Change Naches Steelhead
HabBckPl-10	-18%	-7%	0%	-9%	-3%	0%
HabBckPl-5	-17%	-8%	0%	-7%	-3%	0%
HabBckPl5	4%	3%	0%	18%	17%	0%
HabBckPl10	3%	3%	0%	32%	30%	-1%
HabBckPl25	2%	2%	0%	62%	56%	-1%
HabBckPl100	1%	1%	0%	111%	94%	-4%
HabBvr-10	1%	2%	0%	0%	1%	0%
HabBvr-5	0%	3%	0%	0%	1%	0%
HabBvr5	0%	0%	0%	1%	1%	0%
HabBvr10	0%	0%	0%	4%	2%	-1%
HabBvr25	0%	0%	0%	6%	4%	-1%
HabBvr100	0%	0%	0%	7%	5%	-4%
HabGlide-100	-1%	-1%	0%	-33%	-26%	0%
HabGlide-25	-1%	-1%	0%	-15%	-11%	0%
HabGlide-10	-1%	0%	0%	-7%	-4%	0%
HabGlide-5	-1%	0%	0%	-3%	-2%	0%
HabGlide5	1%	1%	0%	3%	3%	0%
HabGlide10	1%	1%	0%	7%	6%	0%
HabGlide25	1%	0%	0%	14%	12%	0%
HabGlide100	0%	0%	0%	26%	23%	1%
HabLgCob-100	1%	1%	0%	10%	13%	2%
HabLgCob-25	1%	1%	0%	8%	8%	1%
HabLgCob-10	1%	1%	0%	3%	4%	0%
HabLgCob-5	0%	1%	0%	1%	2%	0%
HabLgCob5	-1%	-1%	0%	-3%	-3%	0%
HabLgCob10	0%	0%	0%	-5%	-5%	-1%
HabLgCob25	0%	0%	0%	-12%	-10%	-1%
HabLgCob100	0%	0%	0%	-27%	-26%	-3%
HabOffCh-100	0%	0%	0%	0%	1%	0%
HabOffCh-25	0%	0%	0%	0%	1%	0%
HabOffCh-10	0%	0%	0%	0%	1%	0%
HabOffCh-5	0%	1%	0%	0%	1%	0%
HabOffCh5	0%	0%	0%	0%	1%	0%
HabOffCh10	0%	0%	0%	0%	1%	0%

HabOffCh25	0%	0%	0%	0%	1%	0%
HabOffCh100	0%	0%	0%	0%	1%	0%

Attribute (continued)	Sensitivity American Spring Chinook	Sensitivity Naches Spring Chinook	Sensitivity Naches Steelhead	Relative Change American Spring Chinook	Relative Change Naches Spring Chinook	Relative Change Naches Steelhead
HabPool-25	-3%	-3%	-1%	-33%	-32%	-8%
HabPool-10	-4%	-3%	-1%	-30%	-26%	-7%
HabPool-5	-4%	-3%	0%	-18%	-13%	-2%
HabPool5	3%	2%	0%	13%	12%	0%
HabPool10	2%	2%	0%	22%	20%	0%
HabPool25	2%	2%	0%	41%	43%	0%
HabPool100	1%	1%	0%	74%	88%	-2%
HabPoolTail-10	0%	0%	0%	0%	1%	0%
HabPoolTail-5	0%	0%	0%	0%	1%	0%
HabPoolTail5	0%	0%	0%	0%	-1%	0%
HabPoolTail10	0%	0%	0%	1%	-2%	1%
HabPoolTail25	0%	0%	0%	0%	-4%	1%
HabPoolTail100	0%	0%	0%	-12%	-19%	2%
HabSmCob-100	1%	1%	0%	34%	32%	-7%
HabSmCob-25	1%	1%	0%	16%	16%	-2%
HabSmCob-10	1%	1%	0%	6%	7%	-1%
HabSmCob-5	1%	1%	0%	3%	3%	-1%
HabSmCob5	-1%	-1%	0%	-4%	-3%	0%
HabSmCob10	-1%	-1%	0%	-7%	-7%	0%
HabSmCob25	-1%	-1%	0%	-16%	-15%	1%
HabSmCob100	0%	0%	0%	-34%	-34%	1%

Minimum	-18.0%	-8.1%	-0.9%	-34.3%	-34.5%	-9.1%
Average	-0.5%	0.0%	0.0%	3.7%	3.9%	-0.8%
Standard Deviation	3.5%	1.9%	0.2%	24.6%	23.4%	2.2%
Median	0.1%	0.2%	0.0%	0.1%	0.7%	0.0%
Maximum	3.5%	3.4%	0.1%	110.7%	94.4%	1.7%
Average-2 Std Dev	-7.4%	-3.8%	-0.4%	-45.6%	-42.9%	-5.2%
Average+2 Std Dev	6.5%	3.8%	0.3%	52.9%	50.7%	3.6%

Appendix F: Relative population abundance change for the Obstruction attribute.

Attribute	**Adult American spring Chinook**	**Juvenile American spring Chinook**	**Adult Naches spring Chinook**	**Juvenile Naches spring Chinook**	**Adult Naches steelhead**	**Juvenile Naches steelhead**
Obstruction+25	**13%**	**13%**	**17%**	**22%**	**14%**	**16%**
Obstruction+50	**28%**	**29%**	**38%**	**46%**	**31%**	**33%**
Obstruction+100	**64%**	**66%**	**106%**	**108%**	**79%**	**78%**

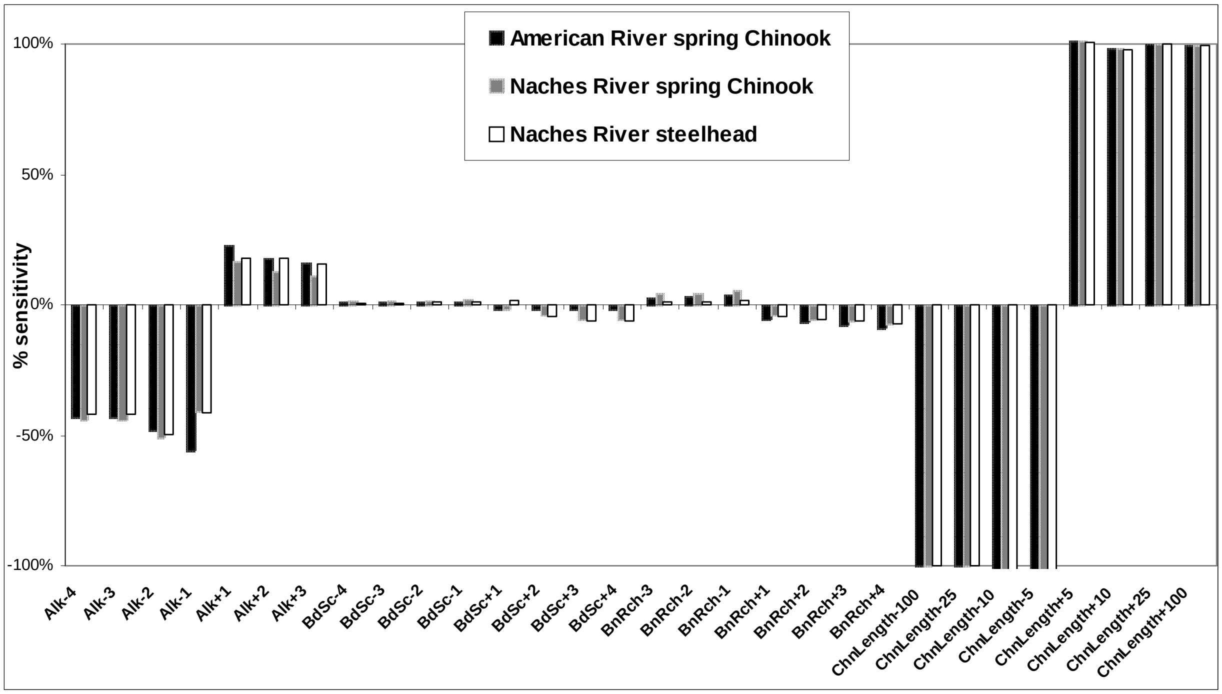
Appendix G: Initial change in value (either +-1 or +-5%) for each attribute.

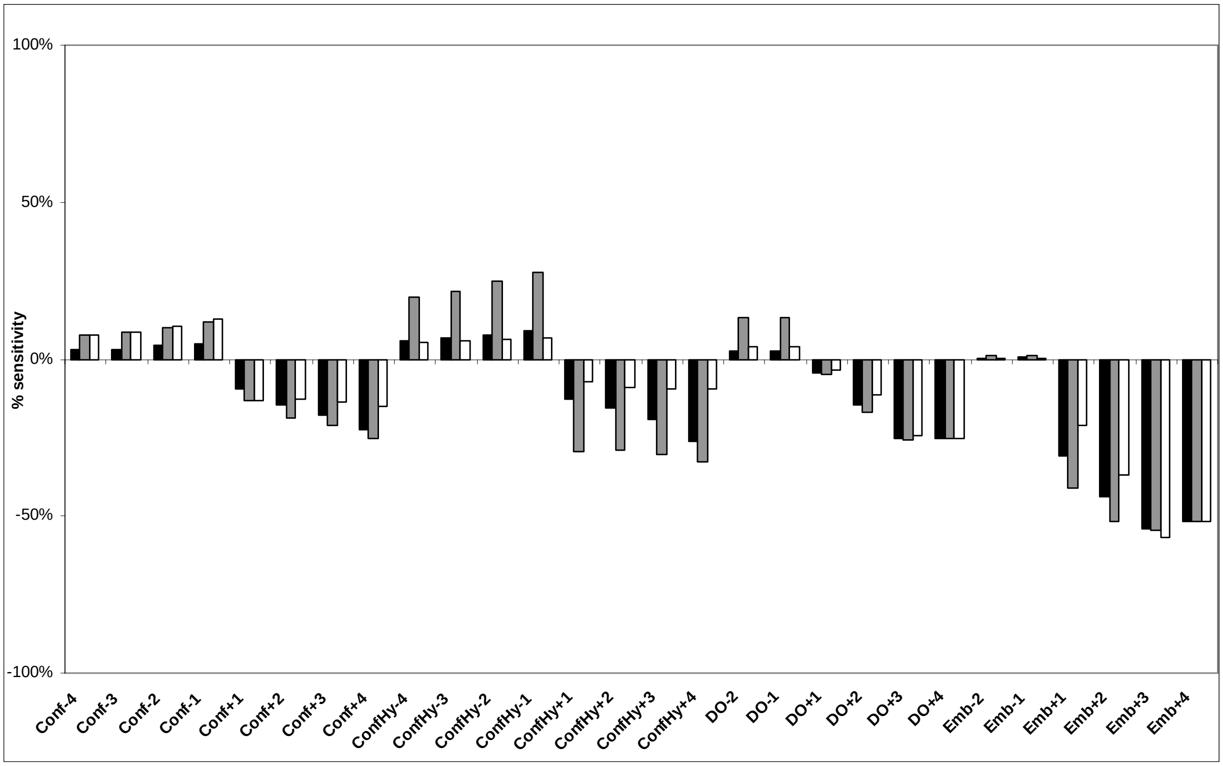
Attribute	Relative Population Change - American River spring Chinook	Relative Population Change - Naches River spring Chinook	Relative Population Change - Naches River steelhead
Alk-1	-56%	-41%	-41%
Alk+1	23%	17%	18%
BdSc-1	1%	2%	1%
BdSc+1	-1%	-2%	1%
BnRch-1	2%	2%	1%
BnRch+1	-5%	-4%	-4%
ChnLength-5	-5%	-5%	-5%
ChnLength+5	5%	5%	5%
Conf-1	3%	7%	7%
Conf+1	-8%	-11%	-11%
ConfHy-1	7%	21%	5%
ConfHy+1	-10%	-23%	-6%
DO-1	0%	1%	0%
DO+1	-4%	-5%	-4%
Emb-1	1%	2%	0%
Emb+1	-6%	-8%	-4%
FlowDiel-1	0%	0%	0%
FlowDiel+1	0%	0%	0%
FlowHi-1	0%	1%	0%
FlowHi+1	0%	0%	0%
FlowIntr-1	1%	2%	0%
FlowIntr+1	0%	0%	0%
FlowLo-1	0%	2%	1%
FlowLo+1	0%	-1%	-1%
FnSed-1	1%	17%	18%
FnSed+1	-23%	-26%	-41%
FshComRch-1	6%	7%	4%
FshComRch+1	-5%	-4%	-4%
FshPath-1	2%	3%	0%
FshPath+1	-6%	-8%	-1%
FshSpIntro-1	5%	5%	3%
FshSpIntro+1	-7%	-7%	-5%

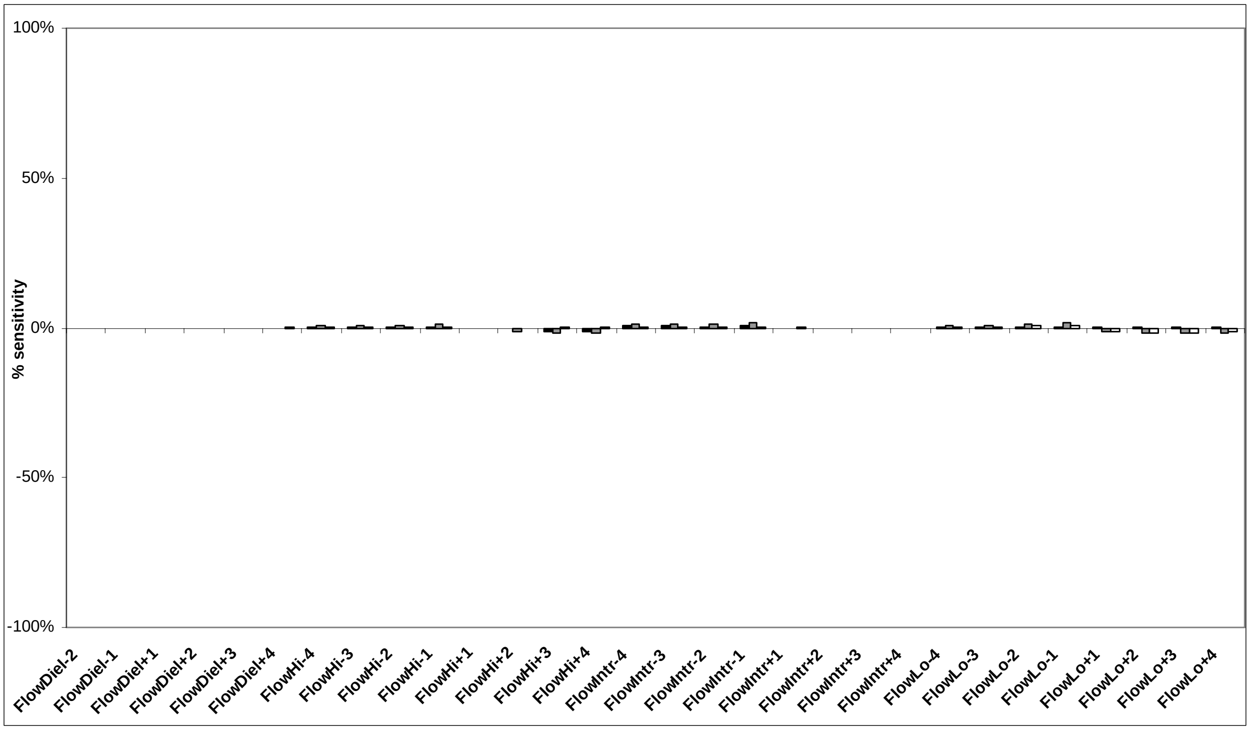
Attribute (continued)	**Relative Population Change - American River spring Chinook**	**Relative Population Change - Naches River spring Chinook**	**Relative Population Change - Naches River steelhead**
Gradient-5	1%	2%	-4%
Gradient5	0%	-1%	3%
HabBckPl-5	-7%	-3%	0%
HabBckPl5	18%	17%	0%
HabBvr-5	0%	1%	0%
HabBvr5	1%	1%	0%
HabGlide-5	-3%	-2%	0%
HabGlide5	3%	3%	0%
HabLgCob-5	1%	2%	0%
HabLgCob5	-3%	-3%	0%
HabOffCh-5	0%	1%	0%
HabOffCh5	0%	1%	0%
HabPool-5	-18%	-13%	-2%
HabPool5	13%	12%	0%
HabPoolTail-5	0%	1%	0%
HabPoolTail5	0%	-1%	0%
HabSmCob-5	3%	3%	-1%
HabSmCob5	-4%	-3%	0%
Harass-1	0%	2%	1%
Harass+1	0%	-1%	-2%
HatchOut-1	7%	8%	4%
HatchOut+1	0%	0%	-2%
HydNat-1	1%	2%	2%
HydNat+1	0%	1%	0%
HydReg-1	0%	1%	0%
HydReg+1	0%	1%	0%
Ice-1	1%	1%	0%
Ice+1	-1%	-1%	-1%
MetSoil+1	-1%	0%	-1%
MetWat+1	-2%	-1%	-2%
MscTox-1	4%	4%	3%
MscTox+1	-32%	-30%	-33%
Nutrient-1	0%	1%	0%
Nutrient+1	0%	0%	0%
Obstruction+25	13%	17%	14%

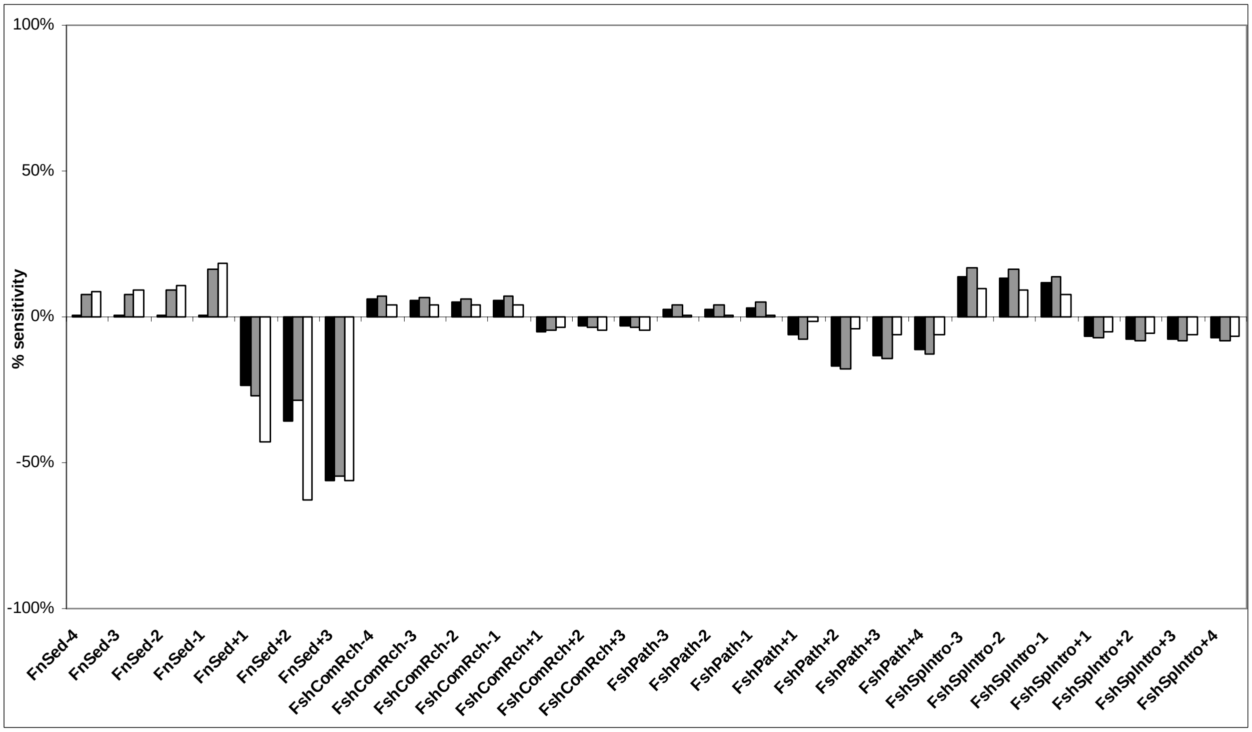
Attribute (continued)	**Relative Population Change - American River spring Chinook**	**Relative Population Change - Naches River spring Chinook**	**Relative Population Change - Naches River steelhead**
Predate-1	4%	5%	3%
Predate+1	-14%	-15%	-6%
RpF(x)-1	9%	18%	8%
RpF(x)+1	-15%	-23%	-11%
SCarc-1	18%	15%	14%
Scarc+1	-5%	-1%	-2%
TMn-1	4%	9%	29%
TMn+1	-27%	-25%	-39%
TMx-1	19%	46%	15%
TMx+1	-60%	-76%	-31%
TSV-1	6%	15%	9%
TSV+1	-5%	-9%	-5%
Turb-1	12%	14%	14%
Turb+1	-44%	-44%	-52%
Wdrwl-1	0%	0%	0%
Wdrwl+1	0%	0%	0%
WidthMin-5	-1%	-1%	-2%
WidthMin+5	2%	2%	1%
WidthMx-5	-3%	-3%	-2%
WidthMx+5	3%	4%	1%
Wood-1	10%	23%	8%
Wood+1	-11%	-19%	-6%
Minimum	-60.4%	-75.9%	-51.8%
Average	-2.1%	-1.1%	-1.5%
Standard Deviation	12.8%	14.9%	12.0%
Median	0.1%	0.7%	0.0%
Maximum	22.5%	46.4%	28.5%
Average-2 Std Dev	-27.7%	-30.9%	-25.5%
Average+2 Std Dev	23.5%	28.8%	22.5%

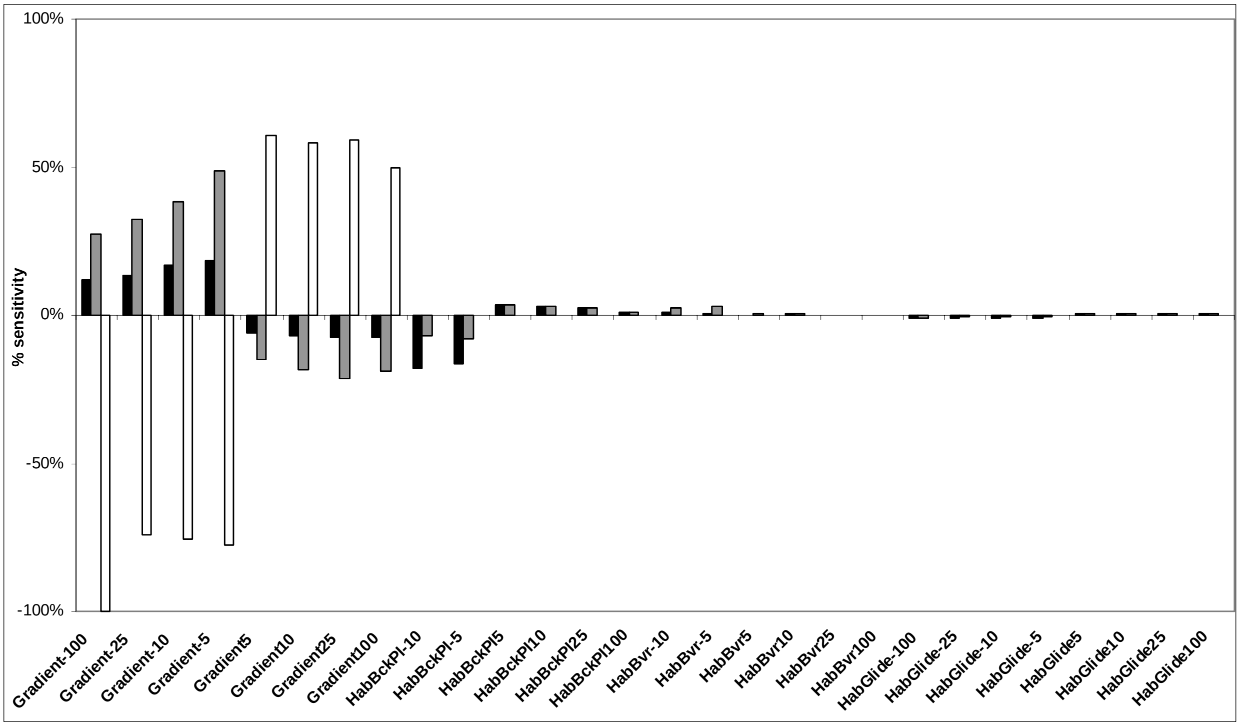
Appendix H: Sensitivity for all attributes for all populations.

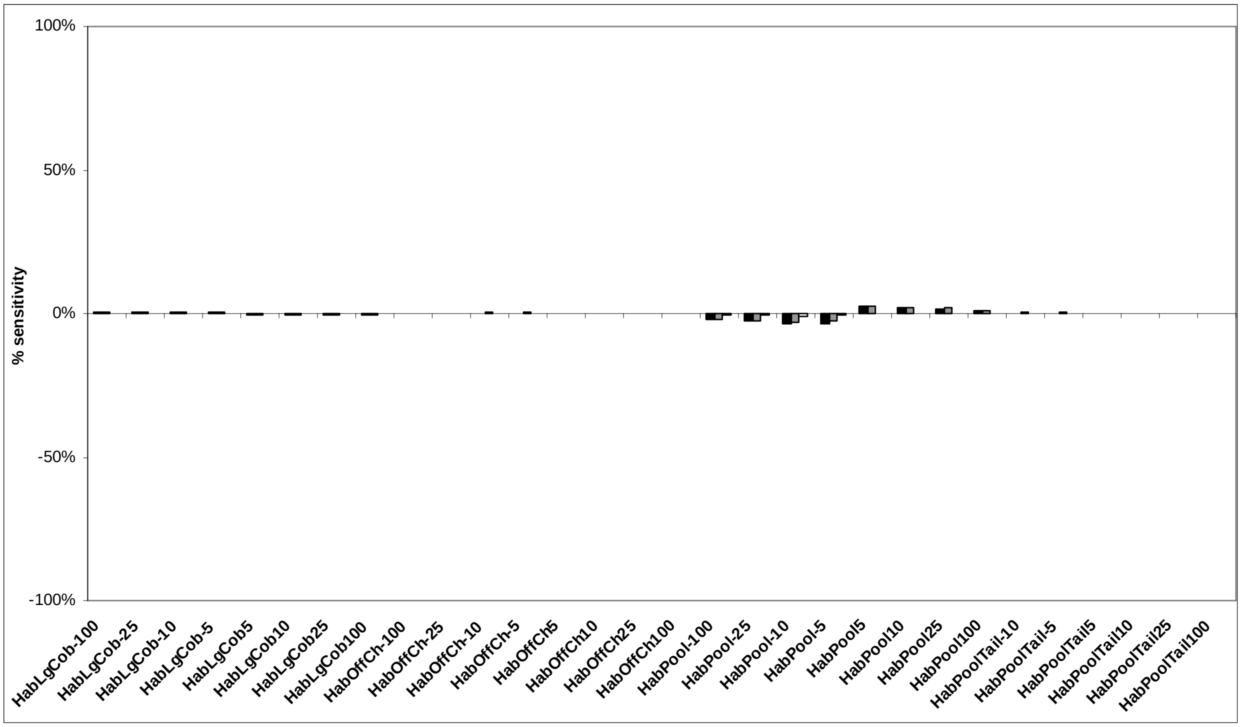


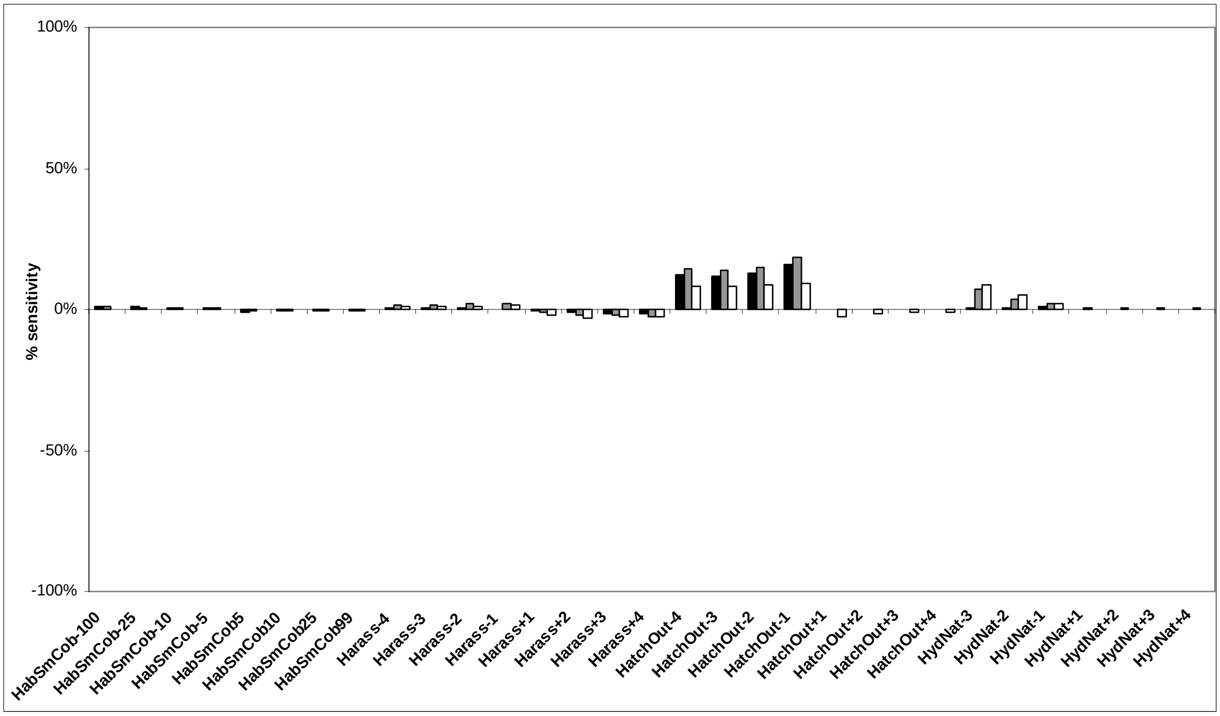


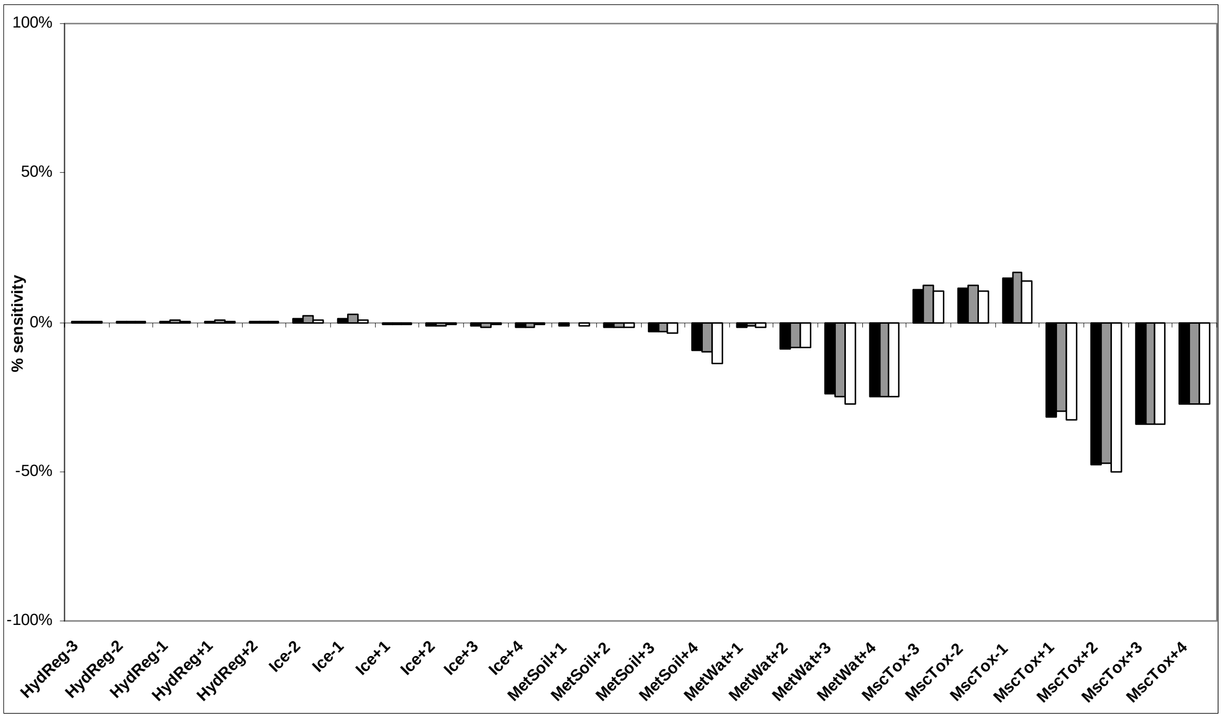

100%
50%
0%
-50%
-100%
% sensitivity
FlowDiel-2
FlowDiel-1
FlowDiel+1
FlowDiel+2
FlowDiel+3
FlowDiel+4
FlowHi-4
FlowHi-3
FlowHi-2
FlowHi-1
FlowHi+1
FlowHi+2
FlowHi+3
FlowHi+4
FlowIntr-4
FlowIntr-3
FlowIntr-2
FlowIntr-1
FlowIntr+1
FlowIntr+2
FlowIntr+3
FlowIntr+4
FlowLo-4
FlowLo-3
FlowLo-2
FlowLo-1
FlowLo+1
FlowLo+2
FlowLo+3
FlowLo+4

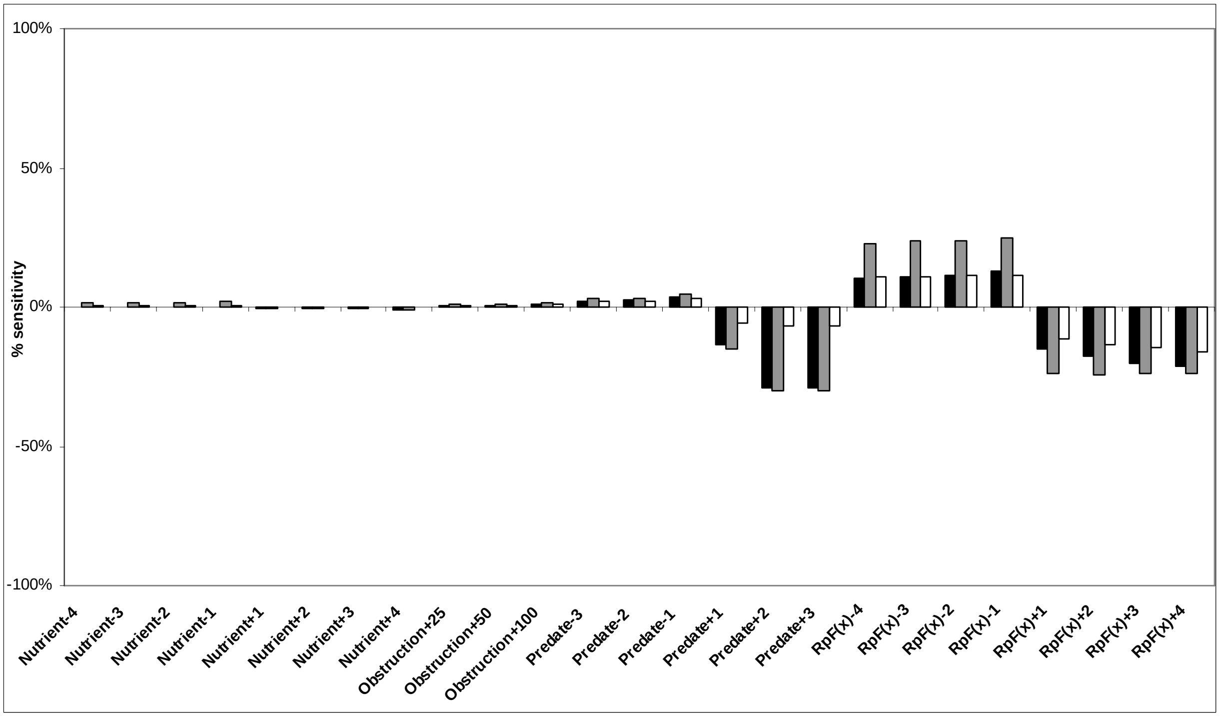

100%
50%
0%
-50%
-100%
% sensitivity
FnSed-4
FnSed-3
FnSed-2
FnSed-1
FnSed+1
FnSed+2
FnSed+3
FshComRch-4
FshComRch-3
FshComRch-2
FshComRch-1
FshComRch+1
FshComRch+2
FshComRch+3
FshPath-3
FshPath-2
FshPath-1
FshPath+1
FshPath+2
FshPath+3
FshPath+4
FshSpIntro-3
FshSpIntro-2
FshSpIntro-1
FshSpIntro+1
FshSpIntro+2
FshSpIntro+3
FshSpIntro+4

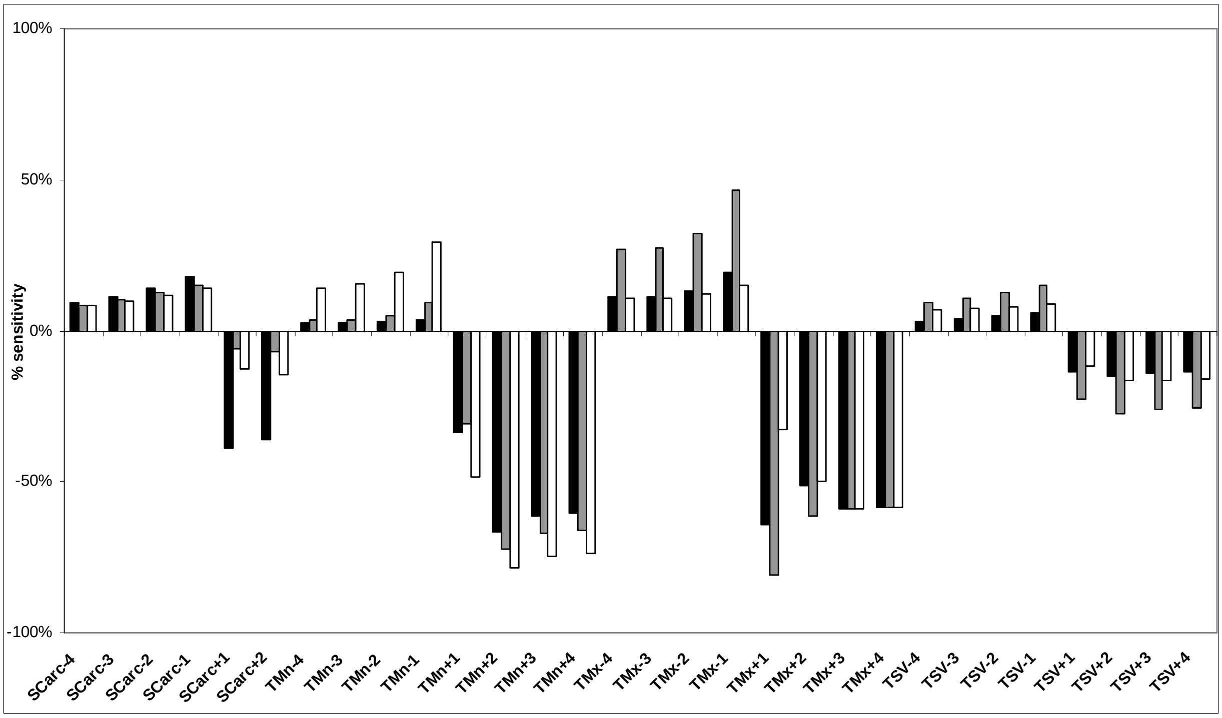

100%
50%
0%
-50%
-100%
% sensitivity
Gradient-100
Gradient-25
Gradient-10
Gradient-5
Gradient5
Gradient10
Gradient25
Gradient100
HabBckPl-10
HabBckPl-5
HabBckPl5
HabBckPl10
HabBckPl25
HabBckPl100
HabBvr-10
HabBvr-5
HabBvr5
HabBvr10
HabBvr25
HabBvr100
HabGlide-100
HabGlide-25
HabGlide-10
HabGlide-5
HabGlide5
HabGlide10
HabGlide25
HabGlide100

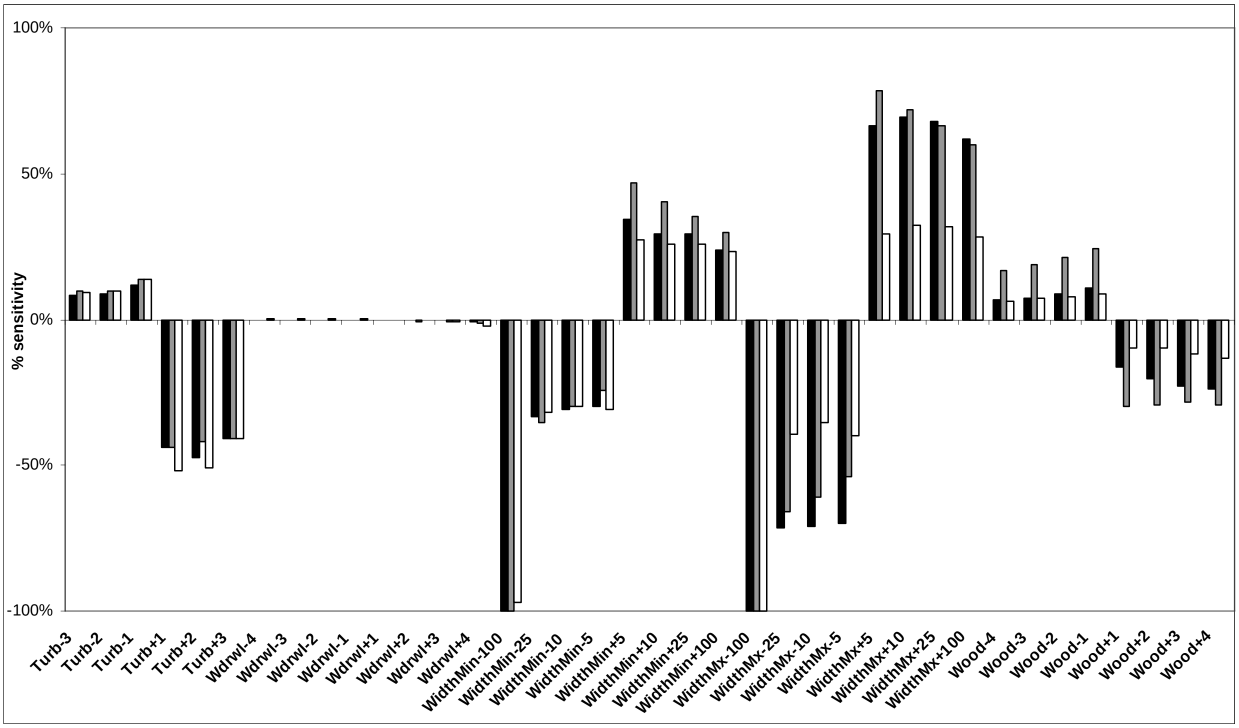

100%
50%
0%
-50%
-100%
% sensitivity
HabLgCob-100
HabLgCob-25
HabLgCob-10
HabLgCob-5
HabLgCob5
HabLgCob10
HabLgCob25
HabLgCob100
HabOffCh-100
HabOffCh-25
HabOffCh-10
HabOffCh-5
HabOffCh5
HabOffCh10
HabOffCh25
HabOffCh100
HabPool-100
HabPool-25
HabPool-10
HabPool-5
HabPool5
HabPool10
HabPool25
HabPool100
HabPoolTail-10
HabPoolTail-5
HabPoolTail5
HabPoolTail10
HabPoolTail25
HabPoolTail100


100%
50%
0%
-50%
-100%
% sensitivity
HabSmCob-100
HabSmCob-25
HabSmCob-10
HabSmCob-5
HabSmCob5
HabSmCob10
HabSmCob25
HabSmCob99
Harass-4
Harass-3
Harass-2
Harass-1
Harass+1
Harass+2
Harass+3
Harass+4
HatchOut-4
HatchOut-3
HatchOut-2
HatchOut-1
HatchOut+1
HatchOut+2
HatchOut+3
HatchOut+4
HydNat-3
HydNat-2
HydNat-1
HydNat+1
HydNat+2
HydNat+3
HydNat+4


100%
50%
0%
-50%
-100%
% sensitivity
HydReg-3
HydReg-2
HydReg-1
HydReg+1
HydReg+2
Ice-2
Ice-1
Ice+1
Ice+2
Ice+3
Ice+4
MetSoil+1
MetSoil+2
MetSoil+3
MetSoil+4
MetWat+1
MetWat+2
MetWat+3
MetWat+4
MscTox-3
MscTox-2
MscTox-1
MscTox+1
MscTox+2
MscTox+3
MscTox+4


100%
50%
0%
-50%
-100%
% sensitivity
Nutrient-4
Nutrient-3
Nutrient-2
Nutrient-1
Nutrient+1
Nutrient+2
Nutrient+3
Nutrient+4
Obstruction+25
Obstruction+50
Obstruction+100
Predate-3
Predate-2
Predate-1
Predate+1
Predate+2
Predate+3
RpF(x)-4
RpF(x)-3
RpF(x)-2
RpF(x)-1
RpF(x)+1
RpF(x)+2
RpF(x)+3
RpF(x)+4


100%
50%
0%
-50%
-100%
% sensitivity
SCarc-4
SCarc-3
SCarc-2
SCarc-1
SCarc+1
SCarc+2
TMn-4
TMn-3
TMn-2
TMn-1
TMn+1
TMn+2
TMn+3
TMn+4
TMx-4
TMx-3
TMx-2
TMx-1
TMx+1
TMx+2
TMx+3
TMx+4
TSV-4
TSV-3
TSV-2
TSV-1
TSV+1
TSV+2
TSV+3
TSV+4


100%
50%
0%
-50%
-100%
% sensitivity
Turb-3
Turb-2
Turb-1
Turb+1
Turb+2
Turb+3
Wdrwl-4
Wdrwl-3
Wdrwl-2
Wdrwl-1
Wdrwl+1
Wdrwl+2
Wdrwl+3
Wdrwl+4
WidthMin-100
WidthMin-25
WidthMin-10
WidthMin-5
WidthMin+5
WidthMin+10
WidthMin+25
WidthMin+100
WidthMx-100
WidthMx-25
WidthMx-10
WidthMx-5
WidthMx+5
WidthMx+10
WidthMx+25
WidthMx+100
Wood-4
Wood-3
Wood-2
Wood-1
Wood+1
Wood+2
Wood+3
Wood+4