Pacific Lamprey Climate Change Vulnerability Assessment

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Introduction

Pacific Lamprey (*Entosphenus tridentatus*) are a native anadromous species that, like salmon, historically returned to spawn in large numbers in watersheds along the west coast of the United States. Currently, populations have declined in abundance and are restricted in distribution throughout Washington, Oregon, Idaho, and California (Luzier et al. 2011, Goodman and Reid 2012, Clemens et al. 2017). Threats to Pacific Lamprey occur in much of their range and include restricted mainstem and tributary passage, reduced flows and dewatering of streams, stream and floodplain degradation, degraded water quality, and changing marine and climate conditions (Luzier et al. 2011, Goodman and Reid 2012, Clemens et al. 2017). In light of these threats, partners including Native American tribes; federal, state, and local agencies; developed the Pacific Lamprey Conservation Initiative (hereafter, referred to as the Initiative) to work collaboratively to conserve and restore Pacific Lamprey by reducing threats and improving their habitats (USFWS 2012).

The landscape level approach of the Initiative is a three part process: an Assessment and Template for Conservation Measures (Assessment); a Conservation Agreement; and Regional Implementation Plans. The Assessment was completed in October 2011 (Luzier et al 2011) and December 2012 (Goodman and Reid 2012), and the Conservation Agreement was signed by numerous tribal, state, and federal partners on June 20, 2012 (USFWS 2012). The partners are currently developing regional plans for implementing conservation actions.

One of the key areas of uncertainty identified through the Initiative (and our multiple partners) was the impact of climate change on Pacific Lamprey and how these effects would influence the priorities for restoration actions (Luzier et al. 2011, Goodman and Reid 2012). Therefore, a consistent and thorough climate change vulnerability assessment is extremely important to guide restoration actions across the riverscapes for Pacific Lamprey.

We conducted a pilot climate change vulnerability assessment to help illustrate the importance for informing Pacific Lamprey restoration activities (Schaller and Wang 2011). In the pilot study we used the NatureServe Climate Change Vulnerability Index (Young et al. 2011) by applying the readily available (at the time) downscaled environmental changes for air temperature and moisture (Figure 1). These environmental parameters have been typically applied for assessing vulnerability of terrestrial species. We consulted with the NatureServe experts on the appropriateness of our application of the NatureServe Climate Change Vulnerability Index to Pacific Lamprey (Bruce Young personal communication May 2012). The expert opinion was that the general approach of the application to Pacific Lamprey was appropriate, however they pointed out that more detailed information on downscaled changes to hydrologic conditions was available from climate change projection models. They believed incorporating more specific hydrologic changes would greatly improve the assessment of climate change impacts for Pacific Lamprey.

Based on the expert opinions, we modified the NatureServe Climate Change Vulnerability Index (CCVI) to accommodate more specific information on changes in stream conditions such as hydrologic regime and stream temperature. This modified tool provided a scoring system for indexing Pacific Lamprey vulnerability to the impacts of climate change. We broadly applied this system to Pacific Lamprey with existing information provided by the downscaled climate predictions. We defined Pacific Lamprey sensitivity to direct exposure for specific environmental changes such as hydrologic regime and stream temperature.

Changes in the hydrologic regime, as measured by the change in hydrograph timing, would affect multiple life stages for lamprey (Figure 2). Downstream movement in juvenile Pacific Lamprey coincides with increases in stream discharge (Dawson et al. 2015; Beamish and Levings 1991). Earlier peak flows could prematurely move juvenile lamprey (during their downstream migration) to estuary and ocean environments. This could result in exposing lamprey to saline conditions prior to animals making physiological changes needed to accommodate osmoregulatory function. Changes in outmigration timing in salmon and steelhead populations cause smolt mortality as well as probable delayed mortality of subsequent life stages (Budy et al. 2002; Petrosky and Schaller 2010; Scheuerell et al. 2009).

Along with discharge, temperature is an important cue for initiation of downstream migration (Dawson et al. 2015; Potter and Huggins 1973). Increased water temperatures both in magnitude and timing have the potential to affect multiple life stages for Pacific Lamprey (Figure 2). For example, increased stream temperatures potentially could increase respiration rates for adult lamprey that are holding before spawning. These increased respiration rates come at an energetic cost that could cause increases in pre-spawning mortality or could decrease egg production and viability resulting in a reduction of reproductive rates for these populations (Rodriguez-Muňoz et al. 2003; Dawson et al. 2015). Water temperature is a critical cue in the metamorphosis of lampreys. Temperature influences the onset of metamorphosis, the rate of development during metamorphosis and the incidence of metamorphosis within a population (Dawson et al. 2015). Metamorphosing sea lamprey exposed to a large change in temperature (from 8°C to 21°C) were smaller than metamorphosing lamprey exposed to a smaller change in temperature (from 8°C to 13°C) possibly because of the energetic cost to maintaining body size in warmer temperatures (Dawson et al. 2015; Holmes and Youson 1997; Holmes and Lin 1994). In a study by Holmes and Youson (1998) the optimal temperature for metamorphosis appeared to be 21°C when comparing to 9, 13, 17, 21 and 25°C (Dawson et al. 2015). The incidence of metamorphosis decreased from 80% at 21°C to 58% at 25°C (Holmes and Youson 1997). Higher than optimal temperature of 21°C is expected to decrease the incidence of metamorphosis (Holmes and Youson 1998). Additionally, long term studies show that low temperatures in the winter are necessary to ensure that physiological conditioning (increase in lipid concentration) occurs (Dawson et al. 2015; Lowe et al. 1973; O'Boyle and Beamish 1977) prior to rising temperatures in the spring and onset of metamorphosis. Studies on the effect of water temperature on rearing larval lamprey show higher mortality of larvae as temperatures increase above 27 °C (Uh and Whitesel 2016). In a study by Meeuwig et al. (2005) survival of embryonic and newly hatched Pacific Lamprey larvae was highest at 18°C when compared to 10, 14 and 22°C. Survival at 22°C was significantly lower than the other temperatures (Meeuwig et al. 2005).

In addition, climate change may indirectly (indirect exposure) affect Pacific Lamprey through land use changes resulting from human responses to climate change and sea level rise. The sensitivity of Pacific Lamprey to direct environmental changes along with indirect exposure allowed us to score the vulnerability of Pacific Lamprey to climate change.

We evaluated the climate change vulnerability risk for Pacific Lamprey in 15 rivers of the west coast of the U.S. (Table 1). These river basins ranged from Northern California to the Canadian border. We evaluated this risk under two different carbon emission scenarios (which include carbon emission, carbon concentration, and land use trajectories; van Vuuren et al. 2011) and for two time periods (mid-century 2040 – 2069 and end of century 2070-2099). We compared and contrasted climate change vulnerability risk for Pacific Lamprey across the 15 river basins to guide restoration actions and inform monitoring and evaluation needs.

Methods

The Nature Serve CCVI calculator is a tool that provides a scoring system for indexing species vulnerability to the impacts of climate change. The general description of the CCVI approach for Pacific Lamprey was taken from Nature Serve Guidelines (Young et al. 2011). The CCVI calculator divides the CCVI into two components; the exposure to climate change across the range of the species within the assessment area and the sensitivity of the species to climate change (Young et al. 2011). The index represents exposure to climate change as a modifier of species sensitivity. If the climate in an assessment area will not change much, none of the sensitivity factors will influence the index score and the species is likely to score at the less vulnerable end of the range. Conversely a large change in temperature or moisture availability will amplify the effect of any related sensitivity and will influence the index to score at the high end of vulnerability.

Direct exposure is measured by examining the magnitude or predicted temperature and moisture change across the range of species within the assessment area. The direct exposure is predicted by ten Global Climate Models (GCM) under two future carbon emission scenarios (Representative Concentration Pathway (RCP) 4.5 optimistic and RCP 8.5 pessimistic).

As described in Young et al. 2011, sensitivities are composed of two categories: indirect exposure and species sensitivity. Indirect exposure characterizes the impact of sea level rise, natural and anthropogenic barriers, and land use changes from human response to climate change on the species of interest. Species sensitivities characterize how biological and ecological attributes could influence how vulnerable a species is to climate change. The range of the species in the assessment area is best applied to something ranging from the size of watershed (at the hydrologic unit code [HUC] 4 (Seaber et al. 1987)) to the size of a western U.S. state. We calculated the CCVI for two time periods; mid-century (2040-2069) and end of century (2070-2099).

The NatureServe calculator integrates these pieces to generate a CCVI. The calculator combines information on exposure and sensitivity to produce a numerical sum. The sum or score is converted into a categorical index by comparing it to threshold values. The six possible indices are extremely vulnerable, highly vulnerable, moderately vulnerable, presumed stable, increase likely and insufficient evidence.

Modification of CCVI technique to accommodate Pacific Lamprey

We made the following modifications to estimate vulnerability indices for lamprey:

1) For direct exposure inputs we incorporated the most current downscaled air temperature data (CMIP5 August means (Taylor et al. 2012)) converted to stream temperature and hydrologic timing. These replace the general air temperature and moisture metrics used in the NatureServe CCVI. In order to incorporate the exposure input distributions into Section A of the NatureServe calculator, we conducted a sensitivity analysis on the method for creating distributions from downscaled temperature results and how this would affect the CCVI. Specifically, we analyzed how selection of the value for the most vulnerable end of the bin of exposure distribution affects the exposure score (using 0.7 or 0.8 as the upper end value) and how the starting point of the distribution (90^{TH} versus 95^{th} percentile of historic August mean stream temperature for the insignificant/low bin) also impacted the exposure score.
2) In the sensitivity section we removed sensitivities that were not applicable to lamprey and added thermal and hydrologic timing niches to the list of sensitivity factors. These are the following factors applied to assess lamprey: dispersal and movements; thermal niche; hydrologic niche; dependence on specific disturbance regimes; dependence on other species to generate habitat; dietary versatility; forms part of an interspecific interaction; and measured genetic variation.
3) Pacific Lamprey climate change vulnerability risk was assessed for 15 HUC 4 basins across much of the species range in the coterminous U.S. (Table 1). We selected these basins over the distribution of Pacific Lamprey in the U.S. to represent the ecological and environmental conditions that lamprey experience. The 15 basins selected each had specific downscaled climate predictions to capture variation in exposure experienced by lamprey. In addition, we grouped the basins into larger geographic groupings (LGG) to capture similar ecological and environmental conditions as compared to the full range of basins (Table 1). These geographic groupings helped to facilitate analysis of Pacific Lamprey climate change vulnerability.

4) We modified the CCVI model to run multiple basins and climate scenarios at once.

Direct Exposure

The Intergovernmental Panel on Climate Change (IPCC) gathers and reviews global climate models (GCMs). The ensemble of the GCMs is called the Coupled Model Intercomparison Project (CMIP). CMIP3 is the model ensemble released in 2010 (Meehl et al. 2007). CMIP5 is the model ensemble released in 2013 (Taylor et al. 2012). The CMIP5 and CMIP3 datasets each contain output from a large number of GCMs. The IPCC notes that, for both large-scale climate patterns and the magnitudes of climate change, there is overall consistency between the projections based on CMIP3 and CMIP5. Differences in global temperature projections are largely attributable to a change in carbon emission scenarios. In our previous pilot study (Schaller et al. 2013) we used CMIP3. We used CMIP5 outputs to develop the downscaled stream temperature and hydrologic data for exposure inputs in this study.

GCMs project large scale climate patterns (including precipitation, evaporation, and temperature) for the earth under two different carbon emission scenarios (RCP 4.5 and RCP 8.5). The RCP 4.5 is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level (Clarke et al. 2007; Smith and Wigley 2006; Wise et al. 2009). The RCP 8.5 scenario is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels (Riahi et al. 2007). The GCM model outputs are downscaled for hydrology and temperature for the CMIP5 multi-model dataset. There are 10 GCMs used in the CMIP5 ensemble. We used three of the model outputs (NorESM1-M, bcc-csm1-1-m, and CSIRO-Mk3-6-0) to bound the potential future hydrologic and stream temperature conditions. The NorESM1-M GCM is the Norwegian Earth System model used for predicting climate under varying carbon emission scenarios (Bentsen et al. 2013). The bcc-csm1-1-m is a short-term climate prediction model system under varying carbon emission scenarios (Ding et al. 2000, Climate System Modeling Division 2005). The CSIRO-Mk3-6-0 climate system model is used for predicting climate under varying carbon emission scenarios (Gordon et al. 2002). We selected these three models out of the ten possible GCMs in CMIP5 to represent the median (bcc-csm1-1-m), optimistic conditions (NorESM1-M), and pessimistic (CSIRO-Mk3-6-0) hydrologic conditions for future projections.

<u>Hydrologic Timing</u>

The vulnerability assessment for Pacific Lamprey requires estimates of daily historical and future flows for our 15 basins. The CMIP5 downscaled runoff and baseflow data were routed via a stream network to produce estimates of average daily flow for each of the selected HUC 4 basins across the region (Table 1). This stream flow routing was produced by the Climate

Impacts Group for the 15 basins using the Variable Infiltration Capacity (VIC) model (Climate Impacts Group 2015). Inputs were from three CMIP5 GCM projections (defined above) spanning the historical period 1951-2006, mid-century (2040-2069), and end of century (2070-2099) for both a low and high carbon emission scenario (RCPs 4.5 and 8.5, respectively).

In order to develop direct exposure for hydrologic timing we needed to compare future to historic distributions of hydrologic mean dates. The hydrologic mean date, for each year, represents the date when 50% of the volume of the river for the water year passes a downstream location in each of the 15 basins we evaluated. The yearly hydrologic mean date is calculated in the following steps: 1) for each day of the water year, calculate the daily proportion of discharge by dividing the daily discharge by the total discharge for the water year; 2) multiply the proportion by the Julian date for each day of the water year; and 3) calculate the mean date by summing all daily results in step 2 (daily prop. x Julian date) over the water year.

To accomplish this for the three selected GCMs and for both RCP 4.5 and RCP 8.5 climate change scenarios, we conducted the following steps:

1. Calculated hydrologic mean dates for each year in the historic period 1951 – 2006
2. Calculated historic grand mean of the annual hydrologic mean dates from 1951-2006
3. Calculated how many days the yearly hydrologic mean date (for years 1951-2006) deviates from the historic grand mean. This is termed the days of deviation. The days of deviation each year for 1951-2006, constitutes the historic distribution for days of deviation.
4. Created bins, using the historic days of deviation, to bound what lamprey have historically experienced in the 15 basins.
    a. Bin 1 - Low/Insignificant - Days of deviation from grand mean (by HUC) within or equal to two standard deviations from historic distribution of deviation days (1951-2006) for the HUC.
    b. Bin 2 - Medium Low - Days of deviation from grand mean (by HUC) outside of two standard deviations from historic distribution of deviation days (1951-2006) or equal to the 5^{th} or 95^{th} percentile for the HUC.
    c. Bin 3 - Medium High- Days of deviation from grand mean (by HUC) outside of the 5^{th} or 95^{th} percentile for historic distribution of deviation days (1951-2006) or equal to 5^{th} or 95^{th} percentile in the Larger Geographic Grouping (LGG).
    d. Bin 4 - High - Days of deviation from grand mean (by HUC) outside of the 5^{th} and 95^{th} percentile for historic distribution of deviation days (1951-2006) in the LGG 0r equal to the 5^{th} and 95^{th} percentile in the U.S. geographic range of lamprey (range).

e. Bin 5 - Very High - Days of deviation from grand mean (by HUC) outside 5th and 95 percentile for historic distribution of deviation days (1951-2006) over the range.

5. From the downscaled GCM average daily flow we calculated the projected future hydrologic mean date for each year of the mid-century 2040-2069 and end century 2070-2099. Next we calculated how many days the yearly hydrologic mean date (for years 2040-2099) deviates from the historic grand mean. This is termed the days of deviation. The days of deviation for each year 2040-2069 constitutes the mid-century future projected distribution for days of deviation. The days of deviation for each year 2070-2099 constitutes the end of century future projected distribution for days of deviation.
6. The future projected distribution was constructed by placing annual days of deviation (for mid-century and end of century) into the historic bins developed in Step 4 above. These distributions are used as the exposure inputs into Section A of calculator tab in the NatureServe CCVI model.

<u>Stream Temperature</u> (Converted from CMIP5 Air Temperature)

The vulnerability assessment for Pacific Lamprey requires estimates of daily historical and future August stream temperatures for our 15 basins. For this direct exposure we focused on August stream temperatures because they historically represent the warmest monthly temperatures recorded annually for the 15 basins we assessed.

We calculated August mean air temperatures from CMIP5 downscaled daily August air temperatures for each of the selected HUC 4 basins across the region (Table 1). These mean temperatures are from the mouth of each basin. Inputs were a set of three CMIP5 GCM projections (defined above) spanning the historical period 1951-2006, mid-century (2040-2069), and end of century (2070-2099) for both a low and high greenhouse gas scenario (RCPs 4.5 and 8.5, respectively). We then converted air temperature in to stream temperature.

Using CMIP3 downscaled air temperature, the NorWeST group developed a stream temperature data base and models for characterizing changes from historic conditions to those for projected climate scenarios. Dan Isaak of NorWeST group provided parameters to convert the change in air temperatures to water temperatures (https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). They accomplished this by building a temperature model that is fit to all the stream data within each unit to produce an air temperature conversion parameter that represents historical climate runs (Hostetler et al. 2011). Figure 3 provides the geographic coverage and Figure 4 provides the conversion parameters from air to stream temperature. Using these parameters we converted the August mean air temperatures to August mean stream temperatures for outputs from the three CMIP5 GCM projections (defined above) spanning the historical period 1951-2006, mid-century (2040-

2069), and end of century (2070-2099) for both a low and high greenhouse gas scenario (RCPs 4.5 and 8.5, respectively).

In order to develop direct exposure for stream temperatures we needed to compare future to historic distribution of August mean stream temperature. To accomplish this for the three selected GCMs and for both RCP 4.5 and RCP 8.5 climate change scenarios, we conducted the following steps:

1. Calculated August mean stream temperature for each year of the projected historic dataset (1951 – 2006)
2. Calculated historic grand mean for August stream temperature from the annual August mean temperatures from 1951-2006
3. Calculated how many degrees the August mean each year (1951-2006) deviates from historic grand mean. This is termed the degrees of deviation. The degrees of deviation calculated for August in the years 1951-2006, constitutes the historic distribution for the degrees of deviation.
4. In order to inform the criteria for constructing the bins to develop historic and future distributions for temperature exposure inputs we ran a sensitivity analysis. We ran the simulations for bcc-csm 1-1-m evaluating the effect of the criteria for the upper end of temperature exposure score (.7 and .8 values) to the CCVI. And the starting point for the bins, 90th percentile versus 95th percentile. We ran simulations to evaluate these sensitivities for BCC 4.5 and 8.5 mid and end. For all combinations the majority of the 15 populations have no or small difference between 0.7 to 0.8 and 90 to 95% (Table 2). So we used 95% and 0.7 for the resulting CCVI scores. Given the results of the sensitivity analyses, we ran all the remaining simulations at the temperature exposure score of 0.7 and at the 95th percentile of historic temperature.
5. Created bins, using the historic distribution for degrees of deviation, to bound what lamprey have experienced in the 15 basins (HUCs):
    a. Bin 1 – Low/Insignificant – Degrees of deviation from grand mean (by HUC) is inside or equal to the HUC's 95th percentile of the historic distribution of degrees of deviation (1951-2006).
    b. Bin 2 - Medium Low – Degrees of deviation from grand mean is greater than the HUC's 95th percentile or less than or equal to the HUC's 99th percentile of the historic distribution of degrees of deviation (1951-2006).
    c. Bin 3 – Medium High - Degrees of deviation from grand mean is greater than the HUC's 99th percentile or less than or equal to the highest 99th percentile (for a HUC) in the Larger Geographic Grouping (LGG) of the historic distribution of degrees of deviation (1951-2006).
    d. Bin 4– Degrees of deviation from grand mean is greater than the LGG's 99th percentile or less than or equal to the highest 99th percentile (for a HUC) in the range of the historic distribution of degrees of deviation (1951-2006).

  e. Bin 5– Degrees of deviation from grand mean is greater than the highest 99th percentile (for a HUC) in the range of the historic distribution of degrees of deviation (1951-2006).

6. Step 5 - From the three GCMs downscaled temperature data (air temperature converted to stream temperature) we calculated projected future August mean stream temperature for each year of the mid-century 2040-2069 and end of century 2070-2099. Next we calculated how many degrees the yearly August mean (for years 2040-2099) deviates from the historic grand mean. This is termed the degrees of deviation. The yearly degrees of deviation for 2040-2069 constitute the mid-century future projected distribution. The yearly degrees of deviation for 2070-2099 constitute the end of century future projected distribution.
7. Step 6 - The future projected distribution was constructed by placing annual degrees of deviation (for mid-century and end of century) into the historic bins developed in Step 4 above. These distributions are used as the exposure inputs into Section A of calculator tab in the NatureServe CCVI model.

Sensitivities

Sensitivities are composed of two categories; indirect exposure and species sensitivity. Indirect exposure characterizes the impact of sea level rise, natural and anthropogenic barriers, and land use changes from human response to climate change on the species of interest (Young et al. 2011). Species sensitivities characterize how biological and ecological attributes could influence how vulnerable a species is to climate change.

To define the sensitivity of Pacific Lamprey we used a combination of approaches. We used research, monitoring and evaluation data from Luzier et al. 2009 and Luzier et al. 2011. The 2009 publication describes regional differences in Pacific Lamprey biology, population structure, habitat preferences and threats. Luzier et al. 2011 is the Assessment and Template for Conservation Measures, first phase of the Initiative, which outlines population demographics, threats and overall risk for Pacific Lamprey throughout the U.S. range. In addition to these documents, we used professional judgment from lamprey field experts on the Lamprey Technical Workgroup, and the Initiative Conservation Team. We used this information to inform the answers to questions for section B (indirect exposure) and section C (sensitivities) that are inputs to the NatureServe CCVI These inputs are placed into number categories: greatly increase vulnerability, increase vulnerability, somewhat increase vulnerability, neutral, somewhat decrease vulnerability, and decrease vulnerability.

Indirect Exposure

Exposure to sea level rise - For each basin we chose level of vulnerability from Greatly Increase to Somewhat decrease based on percentage of range subject to sea level rise (see Section B1 for bin definition pg 16; Young et al. 2011)

Distribution relative to natural barriers - For each basin we chose level of vulnerability from Greatly Increase to Neutral based on status of natural barriers and lamprey's ability to shift for climate change(see Section B2 for bin definition pgs 18-19; Young et al. 2011).

Distribution relative to anthropogenic barriers - For each basin we chose level of vulnerability from Greatly Increase to Neutral based on status of anthropogenic barriers and lamprey's ability to shift for climate change (see Section B2 for bin definition pgs 18-19; Young et al. 2011).

Predicted impact of land use changes from human response to climate change - For each basin we chose level of vulnerability from Increase to Decrease based on the natural history requirements of lamprey and compatibility with mitigation (see Section B3 for bin definition pgs 20-21; Young et al. 2011).

Species Sensitivity

Dispersal and Movements - For each basin we chose level of vulnerability from Greatly Increase to Decrease based on ability of lamprey to disperse and move (see Section C1 for bin definition pgs 22-24; Young et al. 2011)

Historical Thermal Niche - Historical thermal niche measures large scale temperature variation that a species has experienced in recent historical times (Young et al. 2011). We scored this sensitivity using the following steps:

1. Used converted August air temperature to stream temperatures for years 1951-2006 (historic).
2. Calculated the difference between historic August 95th percentile stream temperature and August 5th percentile stream temperature.
3. Created equal bins using August stream temperature 20th percentile and August max stream temperature to bound what lamprey have experienced in the 15 basins.
   a. Greatly Increase : <1.17 degrees of temperature variation
   b. Increase: equal to 1.17 or less than or equal to 1.50
   c. Somewhat Increase: equal to 1.51 or less than or equal to 1.83
   d. Neutral: equal to 1.84 or less than or equal to 2.15
   e. Somewhat Decrease: >2.15

4. For each basin the level of vulnerability was determined based on how much temperature variation lamprey have experienced historically (1951-2006) (see Section C2ai for bin definition pgs 24-25; Young et al. 2011)

Physiological Thermal Niche - For each basin we chose level of vulnerability from Greatly Increase to Somewhat Decrease based percentage of occurrences or range restricted to cold environments (see Section C2aii for bin definition pg 25; Young et al. 2011)

Historical Hydrologic Niche - Historical hydrological niche measures large scale hydrologic timing variation that a species has experienced in recent historic times. We modified this sensitivity from precipitation (described in Young et al. 2011) to hydrologic timing to accommodate more specificity of impacts to aquatic species. We scored this sensitivity using the following steps.

1. Calculated the standard deviation for days of deviation from mean Julian date for the historic period 1951-2006. We calculated two sets of bins to incorporate uncertainty concerning the historic hydrologic niche scores.
2. Create bins using both 5 and 95th
   a. Greatly Increase : <5.25 days of deviation from mean
   b. Increase: equal to 5.25 or less than or equal to 16
   c. Somewhat Increase: equal to 16.1 or less than or equal to 26
   d. Neutral: equal to 26.1 or less than or equal to 35.84
   e. Somewhat Decrease: >35.85
3. Create bins using both 1 and 99th
   a. Greatly Increase : <5.09 days of deviation from mean
   b. Increase: equal to 5.09 or less than or equal to 17.49
   c. Somewhat Increase: equal to 17.5 or less than or equal to 29.9
   d. Neutral: equal to 29.91 or less than or equal to 42.29
   e. Somewhat Decrease: >42.29
4. For each basin two levels of vulnerability were used (one score for each set of bins) based on how much variation in hydrologic timing lamprey have experienced historically (1951-2006) (see Section C2bi for bin definition pg 26; Young et al. 2011).

Physiological thermal niche - For each basin we chose level of vulnerability from Greatly Increase to Somewhat Decrease based percentage of occurrences or range dependent on specific hydrologic timing regime (see Section C2bii for bin definition pgs 27-28; Young et al. 2011).

Dependence on specific disturbance regime likely to be impacted by climate change - For each basin we chose level of vulnerability from Increase to Decrease based on level of response by lamprey to disturbance regime and climate change interaction (see Section C2c for bin definition pgs 28-29; Young et al. 2011).

Dependence on other species to generate habitat - For each basin we chose level of vulnerability from Greatly Increase to Neutral based on lamprey's dependence on another species or multiple species to generate habitat (see Section C4a for bin definition pgs 31-32; Young et al. 2011).

Dietary versatility - For each basin we chose level of vulnerability from Increase to Somewhat Decrease based on lamprey's dietary versatility (see Section C4b for bin definition pg 32; Young et al. 2011).

Forms part of another interspecific interaction - For each basin we chose level of vulnerability from Increase to Neutral based on how lamprey need to be involved in interspecific relationships (see Section C4e for bin definition pg 33; Young et al. 2011).

Measured genetic variation - For each basin we chose level of vulnerability from Increase to Somewhat Decrease based on level of genetic variation in lamprey compared to other aquatic species (see Section C5a for bin definition pg 33; Young et al. 2011).

Simulations

Once we parameterized the NatureServe calculator based on the description of steps above for direct exposure and sensitivities (species and indirect exposure), we ran simulations to capture a range of future conditions. Each simulation provides an estimate of CCVI, which captures future conditions based on the GCM and carbon scenario used to develop the exposure inputs to the NatureServe calculator. These simulations estimate CCVIs for each of the 15 HUCs (that span the selected geographic range for Pacific Lamprey in the US) for two time periods. The following are the steps we implemented:

For calculating CCVIs, we limited our simulations to three GCMs representing median, optimistic and pessimistic projected downscaled exposure. From the ten GCMs, we selected the following models that represent the median hydrologic conditions (bcc-csm1-1-m), optimistic conditions (NorESM1-M), and pessimistic (CSIRO-Mk3-6-0). However, bcc-csm1-1-m and NorESM1-M average stream temperature downscaled projections generated similar exposure levels and were slightly more pessimistic than CSIRO-Mk3-6-0.

The GCMs project climate patterns under two different carbon emission scenarios; both a low and high greenhouse gas scenario (RCPs 4.5 and 8.5, respectively; Van Vuuren et al., 2011).

We calculated CCVIs for each of the 15 HUCs at both the Mid-Century (1940-1969) and end of century (1970 – 2099) time frame, using the GCM inputs described above for RCP 4.5 and 8.5.

Results

Results by GCM

<u>bcc-csm 1-1-m</u>

Simulations were run for GCM bcc-csm 1-1-m for carbon emission scenarios RCP 4.5 and 8.5 for mid-century (2040-2069) and end of century (2070-2099) for 15 basins.

For RCP 4.5 mid-century the CCVI scores averaged 5.52 (Moderately Vulnerable (MV)). The highest score was for the Umpqua at 9.49 (Highly Vulnerable (HV)) and the lowest score was for the Klickitat at 2.660 (Presumed Stable (PS)). For end of century the CCVI scores averaged 6.51 (MV). The highest score was for the Umpqua at 12.17 (Extremely Vulnerable (EV)) and the lowest score was for the Klickitat at 3.34 (PS) (Table 3, Figure 5).

For RCP 8.5 mid-century the CCVI scores averaged 6.27 (MV). The highest score was for the Umpqua at 11.02 (EV) and the lowest score was for the Klickitat at 2.66 (PS). For end of century the CCVI scores averaged 7.08 (HV). The highest score was for the Umpqua at 12.17(EV) and the lowest score was for the Klickitat at 3.34 (PS) (Table 3, Figure 5).

When we evaluated the results for the two time periods , the CCVI scores for bcc-csm 1-1-m on average increase from mid-century to end of century for both emission scenarios. When we evaluated the results by emission scenario, CCVI scores for bcc-csm 1-1-m increased on average from RCP 4.5 to 8.5 for both mid-century and end of century simulations. The two exceptions are the Umatilla and Asotin HUCs, however, these are so minor they did not yield a change in the vulnerability index (Table 3). The variation in CCVI scores among HUCs increases from mid-century to end of century, and also increases from RCP 4.5 to 8.5 emission scenarios.

<u>CSIRO-Mk3-6-0</u>

Simulations were run for GCM CSIRO-Mk3-0 for carbon emission scenarios RCP 4.5 and 8.5 for mid- (2040-2069) and end of century (2070-2099) for 15 basins.

For RCP 4.5 mid-century the CCVI scores averaged 6.60 (MV). The highest score was for the Umpqua at 11.02 (EV) and the lowest score was for the Klickitat at 2.66 (PS). For end of century the CCVI scores averaged 6.68 (MV). The highest score was for the Umpqua at 12.17 (EV) and the lowest score was for the Klickitat 2.66 (PS) (Table 4, Figure 6).

For RCP 8.5 mid-century the CCVI scores averaged 6.86 (MV). The highest score was for the Umpqua at 12.17 (EV) and the lowest score was for the Klickitat at 3.34 (PS). For the end of century the CCVI scores averaged 7.52 (HV). The highest score was for the Umpqua at 13.66 (EV) and the lowest score was for the Klickitat at 3.34 (PS) (Table 4, Figure 6).

When we evaluated the results for the two time periods, the CCVI scores for CSIRO-Mk3-6-0 increase on average from mid-century to end of century for both emission scenarios. The three exceptions are for the Necanicum, Yakima, and Smith HUCs, however, two of these are so minor they did not yield a change in the vulnerability index (Table 4). The one exception was the Yakima, which was downgraded one category from EV to HV under the 4.5 RCP emission scenario.

When we evaluated the results by emission scenario, the CCVI scores for the CSIRO-Mk3-6-0 also increased on average from RCP 4.5 to 8.5 for both time periods. The two exceptions occur under the RCP 4.5 scenario are for the Necanicum, and Smith HUCs, however, these exceptions are so minor they did not yield a change in the vulnerability index (Table 4). The variation in CCVI scores among HUCs increases from mid-century to end of century, and also increases from RCP 4.5 to 8.5 emission scenarios.

<u>NORESM1-M</u>

Simulations were run for GCM NORESM1-M for carbon emission scenarios RCP 4.5 and 8.5 for mid-century (2040-2069) and end of century (2070-2099) for 15 basins.

For RCP 4.5 mid-century the CCVI scores averaged 5.29 (MV). The highest score was for the Umpqua at 8.00 (HV) and the lowest score was for the Klickitat at 2.66 (PS). For end of century the CCVI scores averaged 6.43 (MV). The highest score was for the Umpqua at 12.17 (EV) and the lowest score was for the Klickitat at 2.66 (PS) (Table 5, Figure 7).

For RCP 8.5 mid-century the CCVI scores averaged 6.19 (MV). The highest score was for the MF Umpqua at 10.64 (EV) and the lowest score was for the Klickitat at 2.66 (PS). For end of century the CCVI scores averaged 7.36 (HV). The highest score was for the Umpqua at 13.66 (EV) and the lowest score was for the Klickitat at 3.34 (PS) (Table 5, Figure 7).

When we evaluated the results for the two time periods, the CCVI scores for NORESM1-M increase on average from mid-century to end of century for both emission scenarios. When we evaluated the results by emission scenario, the CCVI scores for NORESM1-M increased on average from RCP 4.5 to 8.5 for both mid-century and end of century simulations. The variation in CCVI scores among HUCs increases from mid-century to end of century, and also increases from RCP 4.5 to 8.5 emission scenarios.

Results over GCMs

Simulation results were analyzed for the 15 basins for all three GCMs, RCP 4.5 and 8.5 and mid-century and end of century.

Overall, the three GCMs represented the median hydrologic conditions (bcc-csm1-1-m), optimistic conditions (NorESM1-M), and pessimistic (CSIRO-Mk3-6-0). The results were consistent for RCP 4.5 mid and end of century and RCP 8.5 mid-century. However, for RCP 8.5

end of century, bcc-csm1-1-m the CCVI scores where slightly more optimistic than NorESM1-M. The CCVI results calculated from the selected models for the most part adhere to pessimistic and optimistic hydrologic designations. We believe these three models provide reasonable contrast to bound projected future exposure conditions.

For RCP 4.5 mid-century the CCVI scores averaged 5.29 (MV) for NorESM1-M; 5.52 for bcc-csm 1-1-m (MV) and 6.60 for CSIRO-Mk3-6-0 (MV). The highest score was for the Umpqua at 11.02 (EV) using CSIRO-Mk3-6-0 and the lowest score was for the Klickitat at 2.66 (PS)for all three GCMs. Most CCVI scores for RCP 4.5 mid-century were in the MV category. CSIRO-Mk3-6-0 CCVI scores were highest in all basins. In eight basins, scores were lowest for NorESM1-M (Table 6). In four basins scores were equal for NorESM1-M and bcc-csm 1-1-m. In three basins, scores were higher in NorESM1-M than in bcc-csm 1-1-m. In ten basins the overall vulnerability ranking changed categories over models (Table 6, Figure8).

For RCP 4.5 end of century the CCVI scores averaged 6.43 (MV) for NorESM1-M; 6.51 for bcc-csm 1-1-m (MV) and 6.68 for CSIRO-Mk3-6-0 (MV). All averages are in MV. The highest score was for the Umpqua at 12.17 (EV) for all three GCMs and the lowest score was 2.66 for the Klickitat, for NorESM1-M and CSIRO-Mk3-6-0. Most CCVI scores for RCP 4.5 end of century were in the MV category. CSIRO-Mk3-6-0 CCVI scores were highest in seven basins. CCVI scores for bcc-csm 1-1-m were highest in seven basins. NorESM1-M CCVI scores were highest in one basin. In one basin, NorESM1-M and CSIRO-Mk3-6-0 scores were equal and higher than bcc-csm 1-1-m. All models had equal scores in two basins. In four basins the overall vulnerability ranking changed categories over models (Table 7, Figure 9).

For RCP 8.5 mid-century the CCVI scores averaged 6.19 (MV) for NorESM1-M; 6.27 for bcc-csm 1-1-m (MV) and 6.86 for CSIRO-Mk3-6-0 (MV). All averages are in MV. The highest score was for the Umpqua at 12.17 (EV) using CSIRO-Mk3-6-0 and the lowest score was 2.66 for the Klickitat, using NorESM1-M and bcc-csm 1-1-m. Most CCVI scores for RCP 8.5 mid-century were in the MV category. CSIRO-Mk3-6-0 CCVI scores were highest in nine basins. CCVI scores for bcc-csm 1-1-m were highest in three basins. In six basins, NorESM1-M and bcc-csm 1-1-m scores were equal. All models had equal scores in three basins. In five basins the overall vulnerability ranking changed categories over models (Table 8, Figure 10).

For RCP 8.5 end of century the CCVI scores averaged 7.36 (HV) for NorESM1-M; 7.08 for bcc-csm 1-1-m (HV) and 7.53 for CSIRO-Mk3-6-0 (HV). All averages are in HV. The highest score was for the Umpqua at 13.66 (EV) for both NorESM1-M and CSIRO-Mk3-6-0 and the lowest score was 3.34 for the Klickitat basin, for all three GCMs. The CCVI scores for RCP 8.5 end-century were mostly in the in the HV and EV categories. CSIRO-Mk3-6-0 CCVI scores were highest in six basins. CCVI scores for bcc-csm 1-1-m were highest in one basin. In three basins two CCVI scores were equal. All models had equal scores in seven basins. In four basins the overall vulnerability ranking changed categories over models (Table 9, Figure 11).

When we evaluated the results for the two time periods, on average the CCVI scores increased from mid-century to end of century for all of the GCMs. In RCP 4.5 for bcc-csm 1-1-m and NORESM1-M, these score changes result in a category increase from MV to HV. However, in RCP 8.5 the CCVI scores are high starting in mid-century so the category remains in HV for the end of century. When we evaluated the results by emission scenario, on average the CCVI scores increased from RCP 4.5 to 8.5 for all of the GCMs. In mid-century on average, these score changes resulted in a category increase from MV to HV for bcc-csm 1-1-m and NORESM1-M. However, for CSIRO-Mk3-6-0 the CCVI scores are high starting in RCP 4.5 so the category remains in HV for RCP 8.5. In end of century on average, the CCVI scores are high starting in RCP 4.5 so the category remains in HV for RCP 8.5.

Discussion

Once widespread along the West Coast of North America, Pacific Lamprey (Entosphenus tridentatus) abundance is well below historical levels and distribution has contracted within the U.S. range. One of the key areas of uncertainty identified through the Initiative was the impact of climate change on Pacific Lamprey and how these effects would influence the priorities for restoration actions (Luzier et al. 2011, Goodman and Reid 2012). Therefore, a consistent and thorough climate change vulnerability assessment is extremely important to guide restoration actions across the riverscapes for Pacific Lamprey (Wang and Schaller 2015). In the previous pilot study of Pacific Lamprey climate change vulnerability the input data was from the CMIP3 ensemble GCM for the A1b and A2 emission scenarios. Since then, the IPCC generated new projections in the CMIP5 project for ten different GCMs. We were able to modify the NatureServe CCVI calculator to accommodate the more recent climate predictions from the IPCC. We used the downscaled information from their climate study and customized the calculator to more directly characterize hydrologic and stream temperature changes in 15 rivers occupied by Pacific Lamprey in the western U.S. These river basins ranged from Northern California to the Canadian border. These stream temperature and hydrologic factors were used in assessing climate change vulnerability because they typically influence survival and productivity of aquatic species (Potter and Huggins 1973; Holmes and Lin 1994; Holmes and Youson 1998; Petrosky and Schaller 2010; and Scheuerell et al. 2009). Through this customization we were successful at consistently scoring the vulnerability of Pacific Lamprey to climate change over a range of river basins in western U.S. We believe this modified tool for calculating CCVI provided an improvement over approaches that purely use professional judgment or indirect measures of environmental change such as air temperature and moisture indices (used in previous pilot study). By evaluating changes in stream temperature and hydrologic conditions due to climate change, this approach more directly assessed the climate change impacts to Pacific Lamprey vulnerability risk. In this modified approach, we evaluated this risk under two different carbon emission scenarios (van Vuuren et al. 2011) and for two time periods (mid-Century 2040 – 2069 and end of century 2070-2099). Compared to the pilot study, we were able to assess climate change vulnerability at a finer basin scale that better matches with downscaled hydrologic information and is more spatially informative for identifying stream restoration actions.

We greatly improved the efficiency of the model by developing the capability to simultaneously run simulations for multiple basins, carbon emission scenarios, and time periods. This allowed us to accurately and directly compare the CCVI results among basins over time under different carbon emission scenarios.

In order to modify the model from using air temperature to directly incorporating stream temperature, we conducted a sensitivity analysis to optimize model performance. The majority of the 15 populations had no or small difference in CCVI score for bcc-csm 1-1-m at the upper end of the temperature exposure score of 0.7 and at the 95^{th} percentile of historic temperature; therefore, we used this more conservative model structure for all simulations. In other words, using this model structure we are confident that we did not overestimate the risk levels.

We believe the three GCMs used in this study provided reasonable contrasts to bound projected future exposure conditions over the range of basins we examined, because the results were generally consistent with NorESM1-M being the most optimistic and CSIRO-Mk3-6-0 being the most pessimistic. Therefore using these three GCMs, we were able to capture the range in exposure produced from the ten GCMs in the CMIP5 study.

The CCVI scores increased from mid-century to end of century for all three GCMs. One exception occurred for CSIRO-Mk3-6-0 in the Yakima HUC where the CCVI decreased in risk category from EV to HV under the RCP 4.5 scenario from mid- century to end of century (Table 10). This exception was due to the anomaly that hydrologic timing was more similar to that of the historic hydrologic timing for end of century than for the mid-century; resulting in a lower CCVI score for the Yakima basin only. Regardless of the GCM or geographic location of the HUC, Pacific Lamprey vulnerability to climate change exhibited increases from mid-century to end of century. Because we observe this consistent pattern of increasing risk over time, we recommend that restoration efforts should focus on actions that address key threats such as passage barriers, dewatering and floodplain degradation. In order to mitigate this risk by end of century, these actions should be implemented early in the mid-century. These types of restoration actions could address these threats in a shorter time span, than other types of actions that may take decades to restore channel or stream function.

The CCVI scores generally increased when going from carbon emission scenarios RCP 4.5 to 8.5 in all three GCMs for both mid- century and end of century which shows that stream temperature and hydrologic conditions appear to degrade under increasing carbon emissions.

If we continue to observe carbon emission levels associated with the RCP 8.5, Pacific Lamprey will be at greater risk to climate change impacts.

In all three GCMs, the Umpqua and Yakima were the most vulnerable HUCs. Their CCVIs were in the EV risk category for the 8.5 emission scenarios by the end of century. The Umpqua had relatively low variation (compared to the other HUCs) in its historic stream temperature and hydrologic timing, which contributed to the high CCVI score. The impact of where anthropogenic barriers are located relative to historic lamprey distribution in the Yakima HUC appears to have played a large role in the high CCVI score.

The Skagit, Methow, Asotin, and Selway were the next most vulnerable HUCs. In the majority of simulations for the three GCMs in the 8.5 emission scenarios, their CCVIs go to HV risk category by the end of century. The Skagit also had relatively low variation (compared to the other HUCs) in its historic stream temperature and hydrologic timing compared to projected values under climate change which contributed to the higher CCVI score. The impact of where anthropogenic barriers are located relative to historic lamprey distribution in the Asotin and Selway HUCs appears to have played a large role in their higher CCVI scores. The Methow had both low variation in historic hydrologic timing and impacts from anthropogenic barriers, which contributed to its higher CCVI score.

The most stable HUC is the Klickitat, where the CCVIs are PS for all GCMs, RCPs, and time periods. The Klickitat had wide variation in historic stream temperature and relatively less impact from anthropogenic barriers. Additionally, there is not a lot of change predicted for hydrologic timing through the end of century for both RCP 4.5 and 8.5.

The next most stable HUCs are Sandy, Tualatin, Chehalis, Necanicum, Umatilla, Smith and Eel; where the CCVIs stay in MV from mid- century to end of century in both 4.5 and 8.5 emission scenarios for all three GCMs (Table 10). All of these HUCs have more historic variation in stream temperature and hydrologic timing compared to the HUCs showing more vulnerability to climate change. Even though the Umatilla has similar impact from anthropogenic barriers when compared to HUCs with higher CCVI scores, it is relatively less vulnerable due to high historic variation in stream temperature.

How can CCVI information help inform restoration priorities?

Our results reveal that the Umpqua HUC consistently exhibited the highest level of climate change vulnerability for all three GCMs and both emission scenarios. The Umpqua HUC is included in the South Coast Oregon Regional Implementation Plan (RIP) of the Pacific Lamprey Conservation Agreement (Coates and Poirier 2017).

Here we provide an example of how the CCVI study can be coupled with RIP findings to identify priority and timing of restoration work and projects. In the RIP, the following key threats have been identified for the Umpqua:

1. Dewatering and Flow Management

Water withdrawals for irrigation, municipal, or residential purposes leave many watersheds in the South Coast sub-region dewatered or with inadequate flow during summer and fall months. In recent years early cessation of rains, below average snow packs, and above average air temperature have further contributed to reduced stream flows in much of the region. Low flow conditions may reduce spawning habitat availability, prevent access to backwater or side channel habitats, create low water barriers, and may contribute to mortality if incubating eggs or burrowing larvae are dewatered or exposed to a high temperature or low oxygen environment.

2. Stream and Floodplain Degradation

Stream and floodplain degradation is widespread throughout the South Coast sub-region. Within lowlands, wetlands and side channels have been channelized, diked, diverted or drained to prevent flooding, create farmland or pastures, and provide land for commercial and residential development. In upland areas, historic and ongoing timber practices, agriculture, road construction, and urbanization have deforested or altered the function and diversity of riparian vegetation. Suction dredge mining is of particular concern in the South Umpqua, Umpqua, and Illinois River. This practice may increase sedimentation and turbidity, alter stream channel topography, disturb and destabilize spawning and rearing habitat, kill incubating eggs and larvae, and may re-suspend contaminants such as mercury or other heavy metals in the water body.

In order to mitigate the risk from climate change toward the end of century, actions will be prioritized that can rapidly reduce the impact of these threats. In the Umpqua, actions that can increase flow, create backwater habitat, restore riparian vegetation and reduce stream disturbances from dredge mining may have a higher likelihood of mitigating the increasing risk from climate change impacts by the end of century.

All 15 basins from the CCVI study have corresponding RIPs. A framework could be developed from the Umpqua example on how to couple CCVI results with RIPs to systematically and consistently inform restoration priorities and monitoring and evaluation needs.

The present CCVI modeling covers 15 basins of the western U.S., which represent a large geographic scope of Pacific Lamprey distribution. However, now that it is anticipated that additional downscaled climate change information will become available; the analysis can be expanded to additional basins. There is a possibility that this expansion of the geographic groupings may alter the species sensitivities used in this analysis, and this could increase or decrease the CCVI scores for populations across the range in future climate change vulnerability assessments.

Again, one of the key areas of uncertainty identified by our multiple partners through the Initiative was the impact of climate change on Pacific Lamprey and how these effects would influence the priorities for restoration actions. We identified stream temperature and hydrologic timing as environmental exposures that influence Pacific Lamprey vulnerability. Using downscaled temperature and hydrology projections we applied the NatureServe Climate Change Vulnerability Index for consistently scoring the vulnerability of Pacific Lamprey to future climate change across the Pacific coast of the United States. The findings revealed the patterns of vulnerability for Pacific Lamprey across their U.S. range are informative for guiding restoration activities.

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Table 1. The 15 basins (HUC 4) used for Pacific Lamprey Climate Change vulnerability assessment from the downscaled GCMs.

Basin	LGG	HUC code
Umpqua	Oregon Coast	17100303
Chehalis	Oregon Coast	17100104
Necanicum	Oregon Coast	17100201
Klickitat	Columbia/Snake	17070105
Umatilla	Columbia/Snake	17070103
Yakima	Columbia/Snake	17030003
Methow	Columbia/Snake	17020008
Asotin	Columbia/Snake	17060103
Selway	Columbia/Snake	17060302
MF Salmon	Columbia/Snake	17060203
Sandy	Lower Columbia/Willamette	17080001
Tualatin	Lower Columbia/Willamette	17090010
Skagit	Puget Sound	17110007
Smith	Northern California	18010210
SF Eel	Northern California	18010106

Table 2. Sensitivity analysis of input bin values used in constructing the distributions for direct stream temperature exposure.

	Numeric score			
	bcc-csm1-1-m_4.5_mid_95%_0.7	bcc-csm1-1-m_4.5_mid_95%_0.8	bcc-csm1-1-m_4.5_mid_90%_0.7	bcc-csm1-1-m_4.5_mid_90%_0.8
Umpqua	7.82	7.82	9.18	7.82
chehalis	3.91	3.00	4.84	4.84
Necanicur	5.32	5.32	6.26	5.32
Klickitat	4.33	4.33	4.66	4.66
Umatilla	6.07	6.07	7.25	6.65
Yakima	8.18	8.18	9.09	9.09
Methow	6.66	6.66	7.32	7.32
Asotin	7.66	7.66	8.65	8.65
Selway	8.65	7.99	9.33	8.65
MF Salmo	9.98	8.66	9.98	9.98
Sandy	5.32	4.74	5.92	5.32
Tualatin	4.58	4.00	5.17	4.58
Skagit	9.19	8.17	9.19	9.19
Smith	5.24	4.00	6.51	5.24
SF Eel	3.50	3.50	6.18	6.18

	Numeric score			
	bcc-csm1-1-m_4.5_end_95%_0.7	bcc-csm1-1-m_4.5_end_95%_0.8	bcc-csm1-1-m_4.5_end_90%_0.7	bcc-csm1-1-m_4.5_end_90%_0.8
Umpqua	10.01	8.65	10.01	10.01
chehalis	4.93	4.93	4.93	4.93
Necanicur	6.26	5.32	6.26	6.26
Klickitat	5.51	5.18	5.85	5.51
Umatilla	6.07	6.07	7.25	6.65
Yakima	9.09	8.18	10.02	9.09
Methow	8.51	8.51	9.19	8.51
Asotin	8.65	7.66	8.65	8.65
Selway	10.18	9.52	10.86	10.86
MF Salmo	11.17	11.17	11.17	11.17
Sandy	5.32	4.74	5.92	5.92
Tualatin	5.32	5.32	5.92	5.32
Skagit	9.19	9.19	10.18	9.19
Smith	6.60	5.32	6.60	6.60
SF Eel	6.18	4.82	6.18	6.18

	Numeric score			
	bcc-csm1-1-m_8.5_mid_95%_0.7	bcc-csm1-1-m_8.5_mid_95%_0.8	bcc-csm1-1-m_8.5_mid_90%_0.7	bcc-csm1-1-m_8.5_mid_90%_0.8
Umpqua	9.18	9.18	9.18	9.18
chehalis	4.84	4.84	4.84	4.84
Necanicum	6.26	6.26	6.26	6.26
Klickitat	4.66	4.66	5.00	4.66
Umatilla	5.58	5.00	6.75	6.17
Yakima	9.09	8.18	10.02	9.09
Methow	8.51	8.51	9.19	9.19
Asotin	7.49	7.49	8.51	7.49
Selway	10.86	10.18	11.52	11.52
MF Salmon	11.17	11.17	12.53	11.17
Sandy	5.92	5.32	5.92	5.92
Tualatin	5.17	4.58	5.17	5.17
Skagit	9.19	9.19	10.18	10.18
Smith	6.60	6.60	6.60	6.60
SF Eel	6.18	4.82	6.18	6.18

	Numeric score			
	bcc-csm1-1-m_8.5_end_95%_0.7	bcc-csm1-1-m_8.5_end_95%_0.8	bcc-csm1-1-m_8.5_end_90%_0.7	bcc-csm1-1-m_8.5_end_90%_0.8
Umpqua	10.01	10.01	11.33	11.33
chehalis	5.83	5.83	4.93	4.93
Necanicur	7.16	6.26	7.16	7.16
Klickitat	6.18	6.18	6.18	6.18
Umatilla	7.82	7.82	7.82	7.82
Yakima	10.93	10.93	10.93	10.93
Methow	9.85	9.85	9.85	9.85
Asotin	10.66	10.66	10.66	10.66
Selway	11.52	11.52	11.52	11.52
MF Salmo	11.17	11.17	13.85	13.85
Sandy	6.49	6.49	6.49	6.49
Tualatin	5.75	5.75	5.75	5.75
Skagit	10.18	10.18	10.18	10.18
Smith	6.60	6.60	7.83	7.83
SF Eel	6.18	4.82	7.50	7.50

	Index score			
	bcc-csm1-1-m_4.5_mid_95%_0.7	bcc-csm1-1-m_4.5_mid_95%_0.8	bcc-csm1-1-m_4.5_mid_90%_0.7	bcc-csm1-1-m_4.5_mid_90%_0.8
Umpqua	HV	HV	HV	HV
chehalis	PS	PS	MV	MV
Necanicur	MV	MV	MV	MV
Klickitat	MV	MV	MV	MV
Umatilla	MV	MV	HV	MV
Yakima	HV	HV	HV	HV
Methow	MV	MV	HV	HV
Asotin	HV	HV	HV	HV
Selway	HV	HV	HV	HV
MF Salmo	HV	HV	HV	HV
Sandy	MV	MV	MV	MV
Tualatin	MV	PS	MV	MV
Skagit	HV	HV	HV	HV
Smith	MV	PS	MV	MV
SF Eel	PS	PS	MV	MV

	Index score			
	bcc-csm1-1-m_4.5_end_95%_0.7	bcc-csm1-1-m_4.5_end_95%_0.8	bcc-csm1-1-m_4.5_end_90%_0.7	bcc-csm1-1-m_4.5_end_90%_0.8
Umpqua	EV	HV	EV	EV
chehalis	MV	MV	MV	MV
Necanicur	MV	MV	MV	MV
Klickitat	MV	MV	MV	MV
Umatilla	MV	MV	HV	MV
Yakima	HV	HV	EV	HV
Methow	HV	HV	HV	HV
Asotin	HV	HV	HV	HV
Selway	EV	HV	EV	EV
MF Salmo	EV	EV	EV	EV
Sandy	MV	MV	MV	MV
Tualatin	MV	MV	MV	MV
Skagit	HV	HV	EV	HV
Smith	MV	MV	MV	MV
SF Eel	MV	MV	MV	MV

	Index score			
	bcc-csm1-1-m_8.5_mid_95%_0.7	bcc-csm1-1-m_8.5_mid_95%_0.8	bcc-csm1-1-m_8.5_mid_90%_0.7	bcc-csm1-1-m_8.5_mid_90%_0.8
Umpqua	HV	HV	HV	HV
chehalis	MV	MV	MV	MV
Necanicum	MV	MV	MV	MV
Klickitat	MV	MV	MV	MV
Umatilla	MV	MV	MV	MV
Yakima	HV	HV	EV	HV
Methow	HV	HV	HV	HV
Asotin	HV	HV	HV	HV
Selway	EV	EV	EV	EV
MF Salmon	EV	EV	EV	EV
Sandy	MV	MV	MV	MV
Tualatin	MV	MV	MV	MV
Skagit	HV	HV	EV	EV
Smith	MV	MV	MV	MV
SF Eel	MV	MV	MV	MV

	Index score			
	bcc-csm1-1-m_8.5_end_95%_0.7	bcc-csm1-1-m_8.5_end_95%_0.8	bcc-csm1-1-m_8.5_end_90%_0.7	bcc-csm1-1-m_8.5_end_90%_0.8
Umpqua	EV	EV	EV	EV
chehalis	MV	MV	MV	MV
Necanicur	HV	MV	HV	HV
Klickitat	MV	MV	MV	MV
Umatilla	HV	HV	HV	HV
Yakima	EV	EV	EV	EV
Methow	HV	HV	HV	HV
Asotin	EV	EV	EV	EV
Selway	EV	EV	EV	EV
MF Salmo	EV	EV	EV	EV
Sandy	MV	MV	MV	MV
Tualatin	MV	MV	MV	MV
Skagit	EV	EV	EV	EV
Smith	MV	MV	HV	HV
SF Eel	MV	MV	HV	HV

Table 3. Pacific Lamprey CCVI simulations using downscaled bcc-csm1-1-m_ model exposure.
Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin.
Comparison for _95%_0.7 for mid to end of century and RCP 4.5 to RCP 8.5

	bcc-csm1-1-m_4.5_mid	bcc-csm1-1-m_4.5_end	bcc-csm1-1-m_8.5_mid	bcc-csm1-1-m_8.5_end		4.5 end - 4.5 mid	8.5 end - 8.5 mid	8.5 mid - 4.5 mid	8.5 end - 4.5 end
Umpqua	9.49	12.17	11.02	12.17		2.69	1.16	1.53	0.00
Chehalis	4.16	5.34	4.84	6.00		1.18	1.16	0.68	0.66
Necanicum	4.66	5.42	5.42	6.16		0.77	0.74	0.77	0.74
Klickitat	2.66	3.34	2.66	3.34		0.68	0.68	0.00	0.00
Umatilla	4.99	4.99	4.33	5.99		0.00	1.66	-0.66	1.00
Yakima	8.35	9.17	9.17	10.85		0.83	1.68	0.83	1.68
Methow	6.16	7.84	7.84	8.85		1.69	1.01	1.69	1.01
Asotin	5.99	6.65	5.66	7.99		0.66	2.33	-0.33	1.34
Selway	6.65	8.01	8.35	8.68		1.36	0.33	1.70	0.67
MF Salmon	7.98	9.00	9.00	9.00		1.02	0.00	1.02	0.00
Sandy	3.99	3.99	4.33	4.66		0.00	0.33	0.34	0.67
Tualatin	3.33	3.99	3.67	4.00		0.66	0.33	0.34	0.01
Skagit	7.52	7.52	7.52	8.26		0.00	0.74	0.00	0.74
Smith	3.41	4.26	4.26	4.26		0.85	0.00	0.85	0.00
SF Eel	3.50	6.01	6.01	6.01		2.51	0.00	2.51	0.00
min	**2.66**	**3.34**	**2.66**	**3.34**					
max	**9.49**	**12.17**	**11.02**	**12.17**					
average	**5.52**	**6.51**	**6.27**	**7.08**					
Standard Dev	**2.111**	**2.439**	**2.410**	**2.581**					

	bcc-csm1-1-m_4.5_mid	bcc-csm1-1-m_4.5_end	bcc-csm1-1-m_8.5_mid	bcc-csm1-1-m_8.5_end					
Umpqua	HV	EV	EV	EV					
Chehalis	MV	MV	MV	MV					
Necanicum	MV	MV	MV	MV					
Klickitat	PS	PS	PS	PS					
Umatilla	MV	MV	MV	MV				No Change	
Yakima	HV	HV	HV	EV					
Methow	MV	HV	HV	HV					
Asotin	MV	MV	MV	HV				No Change	
Selway	MV	HV	HV	HV					
MF Salmon	HV	HV	HV	HV					
Sandy	PS	PS	MV	MV					
Tualatin	PS	PS	PS	PS					
Skagit	HV	HV	HV	HV					
Smith	PS	MV	MV	MV					
SF Eel	PS	MV	MV	MV					

Table 4. Pacific Lamprey CCVI simulations using downscaled CSIRO model exposure.
Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin.
Comparison for _95%_0.7 for mid to end of century and RCP 4.5 to RCP 8.5.

	Numeric score								
	CSIRO_4.5_mid _95%_0.7	CSIRO_4.5_end _95%_0.7	CSIRO_8.5_mid _95%_0.7	CSIRO_8.5_end _95%_0.7		4.5 end - 4.5 mid	8.5 end - 8.5 mid	8.5 mid - 4.5 mid	8.5 end - 4.5 end
Umpqua	11.02	12.17	12.17	13.655		1.155	1.49	1.16	1.49
Chehalis	4.84	5.5	4.84	5.995		0.66	1.16	0.00	0.50
Necanicum	5.42	5.0075	5.01	5.75		-0.4125	0.74	-0.41	0.74
Klickitat	2.66	2.66	3.34	3.34		0	0.00	0.68	0.68
Umatilla	5.99	5.99	5.99	5.99		0	0.00	0.00	0.00
Yakima	10.85	9.655	10.85	10.845		-1.19	0.00	0.00	1.19
Methow	7.66	7.655	7.16	8.845		0	1.69	-0.50	1.19
Asotin	7.33	7.33	7.33	7.99		0	0.66	0.00	0.66
Selway	7.32	7.32	7.32	8.68		0	1.36	0.00	1.36
MF Salmon	9.00	9	11.01	11.01		0	0.00	2.01	2.01
Sandy	4.66	4.66	4.66	5.34		0	0.68	0.00	0.68
Tualatin	3.67	4.66	4.66	4.66		0.99	0.00	0.99	0.00
Skagit	8.26	8.2575	8.26	8.2575		0	0.00	0.00	0.00
Smith	4.34	4.26	4.26	5.1675		-0.0825	0.91	-0.08	0.91
SF Eel	6.01	6.0125	6.01	7.25		0	1.24	0.00	1.24
min	**2.66**	**2.66**	**3.34**	**3.34**					
max	**11.02**	**12.17**	**12.17**	**13.66**					
average	**6.60**	**6.68**	**6.86**	**7.52**					
Standard Deviation	**2.484**	**2.449**	**2.694**	**2.785**					
	CISRO_4.5_mid _95%_0.7	CISRO_4.5_end _95%_0.7	CISRO_8.5_mid _95%_0.7	CISRO_8.5_end _95%_0.7		4.5 end -4.5 mid	8.5 end - 8.5 mid	8.5 mid - 4.5 mid	8.5 end - 4.5 end
Umpqua	EV	EV	EV	EV					
Chehalis	MV	MV	MV	MV					
Necanicum	MV	MV	MV	MV		No Change		No Change	
Klickitat	PS	PS	PS	PS					
Umatilla	MV	MV	MV	MV					
Yakima	EV	HV	EV	EV		1 category			
Methow	HV	HV	HV	HV					
Asotin	HV	HV	HV	HV					
Selway	HV	HV	HV	HV					
MF Salmon	HV	HV	EV	EV					
Sandy	MV	MV	MV	MV					
Tualatin	PS	MV	MV	MV					
Skagit	HV	HV	HV	HV					
Smith	MV	MV	MV	MV		No Change		No Change	
SF Eel	MV	MV	MV	HV					

Table 5. Pacific Lamprey CCVI simulations using downscaled NORESM1-M model exposure									
Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin.									
Comparison for _95%_0.7 for mid to end of century and RCP 4.5 to RCP 8.5									
	Numeric score								
	NORESM1-M_4.5_mid_95%_0.7	NORESM1-M_4.5_end_95%_0.7	NORESM1-M_8.5_mid_95%_0.7	NORESM1-M_1_8.5_end_95%_0.7		4.5 end -4.5 mid	8.5 end - 8.5 mid	8.5 mid - 4.5 mid	8.5 end - 4.5 end
Umpqua	8.00	12.17	10.64	13.66		4.170	3.015	2.640	1.485
Chehalis	4.16	5.34	4.84	6.00		1.175	1.155	0.680	0.660
Necanicum	3.50	5.01	5.01	5.75		1.508	0.743	1.508	0.743
Klickitat	2.66	2.66	2.66	3.34		0.000	0.680	0.000	0.680
Umatilla	4.33	4.67	5.00	5.00		0.340	0.000	0.670	0.330
Yakima	7.98	10.02	8.83	10.85		2.040	2.015	0.850	0.825
Methow	6.65	7.16	7.16	8.85		0.510	1.685	0.510	1.685
Asotin	5.66	6.65	7.33	7.99		0.990	0.660	1.670	1.340
Selway	6.99	7.32	7.32	8.68		0.330	1.360	0.330	1.360
MF Salmon	7.98	9.00	9.00	11.01		1.020	2.010	1.020	2.010
Sandy	3.33	4.33	3.67	4.66		1.000	0.990	0.340	0.330
Tualatin	3.33	3.67	3.67	4.00		0.340	0.330	0.340	0.330
Skagit	6.75	8.26	7.49	8.26		1.508	0.765	0.742	0.000
Smith	3.33	4.34	4.26	5.17		1.018	0.908	0.935	0.825
SF Eel	4.66	5.93	6.01	7.25		1.275	1.238	1.358	1.320
min	**2.66**	**2.66**	**2.66**	**3.34**					
max	**8.00**	**12.17**	**10.64**	**13.66**					
average	**5.29**	**6.43**	**6.19**	**7.36**					
Standard Deviatior	**1.95**	**2.60**	**2.29**	**2.93**					
	NorESM_1_4.5_mid_95%	NorESM_1_4.5_end_95	NorESM_1_8.5_mid_95	NorESM_1_8.5_end_95%_		4.5 end -4.5 mid	8.5 end - 8.5 mid	8.5 mid - 4.5 mid	8.5 end - 4.5 end
Umpqua	HV	EV	EV	EV					
Chehalis	MV	MV	MV	MV					
Necanicum	PS	MV	MV	MV					
Klickitat	PS	PS	PS	PS					
Umatilla	MV	MV	MV	MV					
Yakima	HV	EV	HV	EV					
Methow	MV	HV	HV	HV					
Asotin	MV	MV	HV	HV					
Selway	MV	HV	HV	HV					
MF Salmon	HV	HV	HV	EV					
Sandy	PS	MV	PS	MV					
Tualatin	PS	PS	PS	PS					
Skagit	MV	HV	HV	HV					
Smith	PS	MV	MV	MV					
SF Eel	MV	MV	MV	HV					

Table 6. Pacific Lamprey CCVI simulations using downscaled for 3 GCMs model exposure.

Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin.

Comparison for 3GCMS at _95%_0.7 for mid-century and RCP 4.5

	Numeric score					
	NorESM_1_4.5 _mid_95%_0.7	bcc-csm1-1-m_4.5_mid _95%_0.7	CSIRO_4.5_mid _95%_0.7		(bcc-csm1-1-m) - (NorESM_1)	(CSIRO) - (bcc-csm1-1-m)
Umpqua	8.00	9.49	11.02		1.49	1.53
Chehalis	4.16	4.16	4.84		0.00	0.68
Necanicum	3.50	4.66	5.42		1.16	0.77
Klickitat	2.66	2.66	2.66		0.00	0.00
Umatilla	4.33	4.99	5.99		0.66	1.00
Yakima	7.98	8.35	10.85		0.36	2.50
Methow	6.65	6.16	7.66		-0.50	1.50
Asotin	5.66	5.99	7.33		0.33	1.34
Selway	6.99	6.65	7.32		-0.34	0.67
MF Salmon	7.98	7.98	9.00		0.00	1.02
Sandy	3.33	3.99	4.66		0.66	0.67
Tualatin	3.33	3.33	3.67		0.00	0.34
Skagit	6.75	7.52	8.26		0.76	0.74
Smith	3.33	3.41	4.34		0.08	0.94
SF Eel	4.66	3.50	6.01		-1.16	2.51
min	**2.66**	**2.66**	**2.66**			
max	**8.00**	**9.49**	**11.02**			
average	**5.29**	**5.52**	**6.60**			
Standard Deviatior	**1.95**	**2.11**	**2.48**			

	NorESM_1_4.5 _mid_95%_0.7	bcc-csm1-1-m_4.5_mid _95%_0.7	CISRO_4.5_mid _95%_0.7			
Umpqua	HV	HV	EV			
Chehalis	MV	MV	MV			
Necanicum	PS	MV	MV			
Klickitat	PS	PS	PS			
Umatilla	MV	MV	MV			
Yakima	HV	HV	EV			
Methow	MV	MV	HV		No Change	
Asotin	MV	MV	HV			
Selway	MV	MV	HV		No Change	
MF Salmon	HV	HV	HV			
Sandy	PS	PS	MV			
Tualatin	PS	PS	PS			
Skagit	MV	HV	HV			
Smith	PS	PS	MV			
SF Eel	MV	PS	MV		1 Category	

Table 7. Pacific Lamprey CCVI simulations using downscaled for 3 GCMs model exposure.
Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin.
Comparison for 3GCMS at _95%_0.7 for end of century and RCP 4.5

Numeric score

	NorESM_1_4.5_end_95%_0.7	bcc-csm1-1-m_4.5_end_95%_0.7	CSIRO_4.5_end_95%_0.7		(bcc-csm1-1-m) - (NorESM_1)	(CSIRO) - (bcc-csm1-1-m)
Umpqua	12.17	12.17	12.17		0.00	0.00
Chehalis	5.34	5.34	5.50		0.00	0.17
Necanicum	5.01	5.42	5.01		0.41	-0.41
Klickitat	2.66	3.34	2.66		0.68	-0.68
Umatilla	4.67	4.99	5.99		0.32	1.00
Yakima	10.02	9.17	9.66		-0.85	0.49
Methow	7.16	7.84	7.66		0.68	-0.19
Asotin	6.65	6.65	7.33		0.00	0.68
Selway	7.32	8.01	7.32		0.69	-0.69
MF Salmon	9.00	9.00	9.00		0.00	0.00
Sandy	4.33	3.99	4.66		-0.34	0.67
Tualatin	3.67	3.99	4.66		0.32	0.67
Skagit	8.26	7.52	8.26		-0.74	0.74
Smith	4.34	4.26	4.26		-0.08	0.00
SF Eel	5.93	6.01	6.01		0.08	0.00
min	**2.66**	**3.34**	**2.66**			
max	**12.17**	**12.17**	**12.17**			
average	**6.43**	**6.51**	**6.68**			
Standard Deviatior	**2.60**	**2.44**	**2.45**			

	NorESM_1_4.5_end_95%_0.7	bcc-csm1-1-m_4.5_end_95%_0.7	CISRO_4.5_end_95%_0.7			
Umpqua	EV	EV	EV			
Chehalis	MV	MV	MV			
Necanicum	MV	MV	MV			No Change
Klickitat	PS	PS	PS			No Change
Umatilla	MV	MV	MV			
Yakima	EV	HV	HV		1 Category	
Methow	HV	HV	HV			No Change
Asotin	MV	MV	HV			
Selway	HV	HV	HV			No Change
MF Salmon	HV	HV	HV			
Sandy	MV	PS	MV		1 Category	
Tualatin	PS	PS	MV			
Skagit	HV	HV	HV		No Change	
Smith	MV	MV	MV		No Change	
SF Eel	MV	MV	MV			

Table 8. Pacific Lamprey CCVI simulations using downscaled for 3 GCMs model exposure. Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin. Comparison for 3GCMS at _95%_0.7 for mid-century and RCP 8.5

	Numeric score					
	NorESM_1_8.5_mid_95%_0.7	bcc-csm1-1-m_8.5_mid_95%_0.7	CSIRO_8.5_mid_95%_0.7		(bcc-csm1-1-m) - (NorESM_1)	(CSIRO) - (bcc-csm1-1-m)
Umpqua	10.64	11.02	12.17		0.37	1.16
Chehalis	4.84	4.84	4.84		0.00	0.00
Necanicum	5.01	5.42	5.01		0.41	-0.41
Klickitat	2.66	2.66	3.34		0.00	0.68
Umatilla	5.00	4.33	5.99		-0.67	1.66
Yakima	8.83	9.17	10.85		0.34	1.68
Methow	7.16	7.84	7.16		0.68	-0.68
Asotin	7.33	5.66	7.33		-1.67	1.67
Selway	7.32	8.35	7.32		1.03	-1.03
MF Salmon	9.00	9.00	11.01		0.00	2.01
Sandy	3.67	4.33	4.66		0.66	0.33
Tualatin	3.67	3.67	4.66		0.00	0.99
Skagit	7.49	7.52	8.26		0.02	0.74
Smith	4.26	4.26	4.26		0.00	0.00
SF Eel	6.01	6.01	6.01		0.00	0.00
min	**2.66**	**2.66**	**3.34**			
max	**10.64**	**11.02**	**12.17**			
average	**6.19**	**6.27**	**6.86**			
Standard Deviatior	**2.29**	**2.41**	**2.69**			

	NorESM_1_8.5_mid_95%_0.7	bcc-csm1-1-m_8.5_mid_95%_0.7	CISRO_8.5_mid_95%_0.7			
Umpqua	EV	EV	EV			
Chehalis	MV	MV	MV			
Necanicum	MV	MV	MV			No Change
Klickitat	PS	PS	PS			
Umatilla	MV	MV	MV		No Change	
Yakima	HV	HV	EV			
Methow	HV	HV	HV			No Change
Asotin	HV	MV	HV		1 Category	
Selway	HV	HV	HV			No Change
MF Salmon	HV	HV	EV			
Sandy	PS	MV	MV			
Tualatin	PS	PS	MV			
Skagit	HV	HV	HV			
Smith	MV	MV	MV			
SF Eel	MV	MV	MV			

Table 9. Pacific Lamprey CCVI simulations using downscaled for 3 GCMs model exposure. Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin. Comparison for 3GCMS at _95%_0.7 for end of century and RCP 8.5

	Numeric score					
	NorESM_1_8.5 _end_95%_0.7	bcc-csm1-1-m_8.5_end_95% _0.7	CSIRO_8.5_end _95%_0.7		(bcc-csm1-1-m) - (NorESM_1)	(CSIRO) - (bcc-csm1-1-m)
Umpqua	13.66	12.17	13.66		-1.49	1.49
Chehalis	6.00	6.00	6.00		0.00	0.00
Necanicum	5.75	6.16	5.75		0.41	-0.41
Klickitat	3.34	3.34	3.34		0.00	0.00
Umatilla	5.00	5.99	5.99		0.99	0.00
Yakima	10.85	10.85	10.85		0.00	0.00
Methow	8.85	8.85	8.85		0.00	0.00
Asotin	7.99	7.99	7.99		0.00	0.00
Selway	8.68	8.68	8.68		0.00	0.00
MF Salmon	11.01	9.00	11.01		-2.01	2.01
Sandy	4.66	4.66	5.34		0.00	0.68
Tualatin	4.00	4.00	4.66		0.00	0.66
Skagit	8.26	8.26	8.26		0.00	0.00
Smith	5.17	4.26	5.17		-0.91	0.91
SF Eel	7.25	6.01	7.25		-1.24	1.24
min	**3.34**	**3.34**	**3.34**			
max	**13.66**	**12.17**	**13.66**			
average	**7.36**	**7.08**	**7.52**			
Standard Deviatior	**2.93**	**2.58**	**2.78**			

	NorESM_1_8.5 _end_95%_0.7	bcc-csm1-1-m_8.5_end	CISRO_8.5_end _95%_0.7			
Umpqua	EV	EV	EV		No Change	
Chehalis	MV	MV	MV			
Necanicum	MV	MV	MV			No Change
Klickitat	PS	PS	PS			
Umatilla	MV	MV	MV			
Yakima	EV	EV	EV			
Methow	HV	HV	HV			
Asotin	HV	HV	HV			
Selway	HV	HV	HV			
MF Salmon	EV	HV	EV		1 Category	
Sandy	MV	MV	MV			
Tualatin	PS	PS	MV			
Skagit	HV	HV	HV			
Smith	MV	MV	MV		No Change	
SF Eel	HV	MV	HV		1 Category	

Table 10 . Summary of CCVI risk categores by GCM in both RCP 4.5 and 8.5 carbon emission scenarios for mid and end of century time periods.

	CISRO_4.5_mid	CISRO_4.5_end	CISRO_8.5_mid	CISRO_8.5_end	bcc-csm_4.5_mid	bcc-csm_4.5_end	bcc-csm _ 8.5_mid	bcc-csm_8.5_end	NorESM_1_4.5_mid	NorESM_1_4.5_end	NorESM_1_8.5_mid	NorESM_1_8.5_end
Umpqua	EV	EV	EV	EV	HV	EV	EV	EV	HV	EV	EV	EV
chehalis	MV	MV	MV	MV	MV	MV	MV	MV	MV	MV	MV	MV
Necanicum	MV	MV	MV	MV	MV	MV	MV	MV	**PS**	MV	MV	MV
Klickitat	**PS**	**PS**	**PS**	**PS**	PS	PS	PS	PS	**PS**	**PS**	**PS**	**PS**
Umatilla	MV	MV	MV	MV	MV	MV	MV	MV	MV	MV	MV	MV
Yakima	EV	HV	EV	EV	HV	HV	HV	EV	HV	EV	HV	EV
Methow	HV	HV	HV	HV	MV	HV	HV	HV	MV	HV	HV	HV
Asotin	HV	HV	HV	HV	MV	MV	MV	HV	MV	MV	HV	HV
Selway	HV	HV	HV	HV	MV	HV	HV	HV	MV	HV	HV	HV
MF Salmon	HV	HV	EV	EV	HV	HV	HV	HV	HV	HV	HV	EV
Sandy	MV	MV	MV	MV	**PS**	**PS**	MV	MV	**PS**	MV	**PS**	MV
Tualatin	**PS**	MV	MV	MV	**PS**	**PS**	**PS**	**PS**	**PS**	**PS**	**PS**	**PS**
Skagit	HV	HV	HV	HV	HV	HV	HV	HV	MV	HV	HV	HV
Smith	MV	MV	MV	MV	**PS**	MV	MV	MV	**PS**	MV	MV	MV
SF Eel	MV	MV	MV	HV	**PS**	MV	MV	MV	MV	MV	MV	HV

Most Vulnerable	(yellow)
Most stable	(green)

Figure 1. Pacific Lamprey NatureServe Climate Change vulnerability index results for mid and end of century time periods using the CMIP3 downscaled moisture and air temperature from ensemble model under the A1b and A2 carbon emission scenarios (Schaller and Wang 2011).

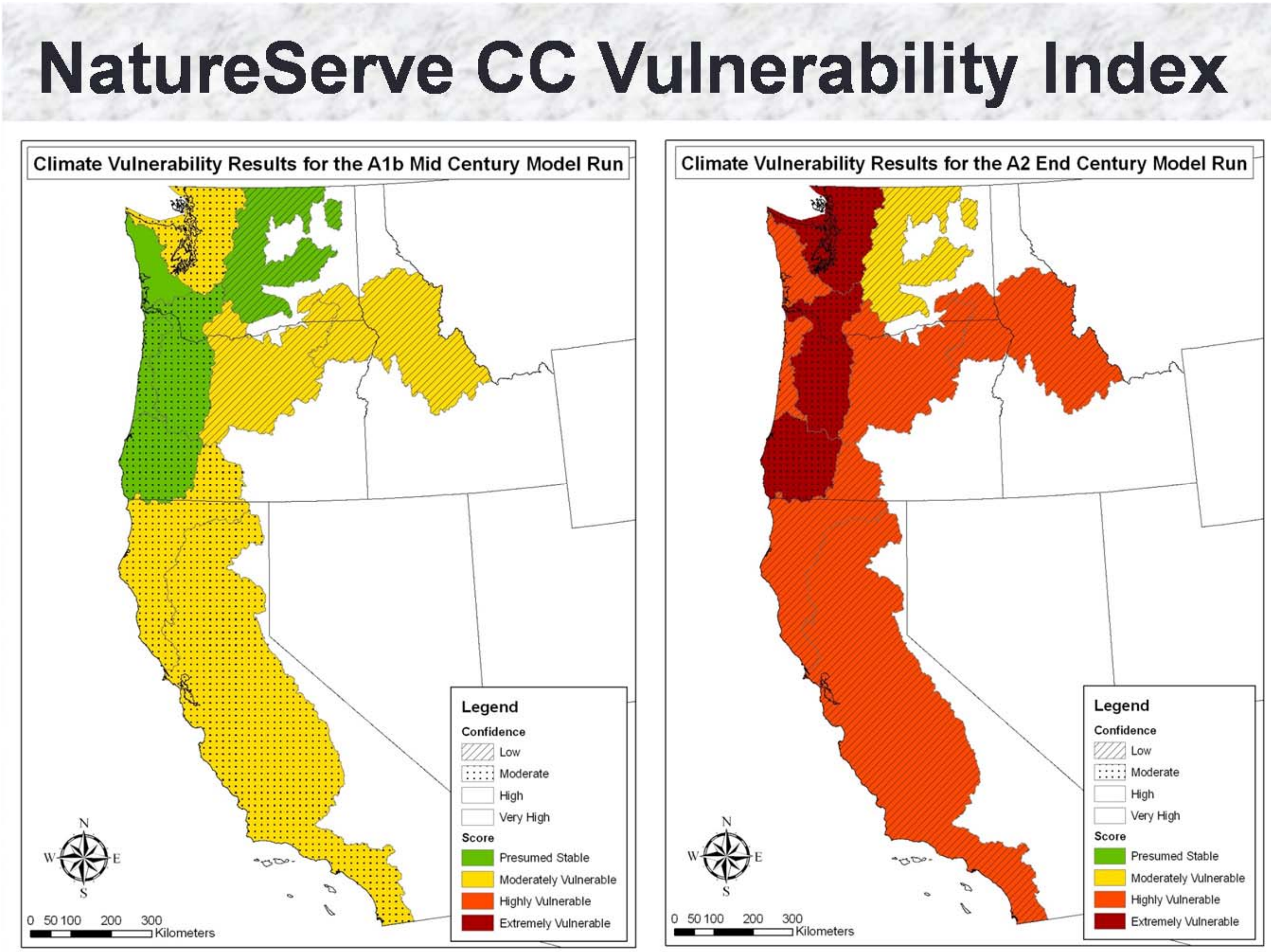


Figure 2. Diagram of Pacific Lamprey life-stages that may be sensitive to exposure from changes in hydrologic timing and stream temperature due to climate change impacts.

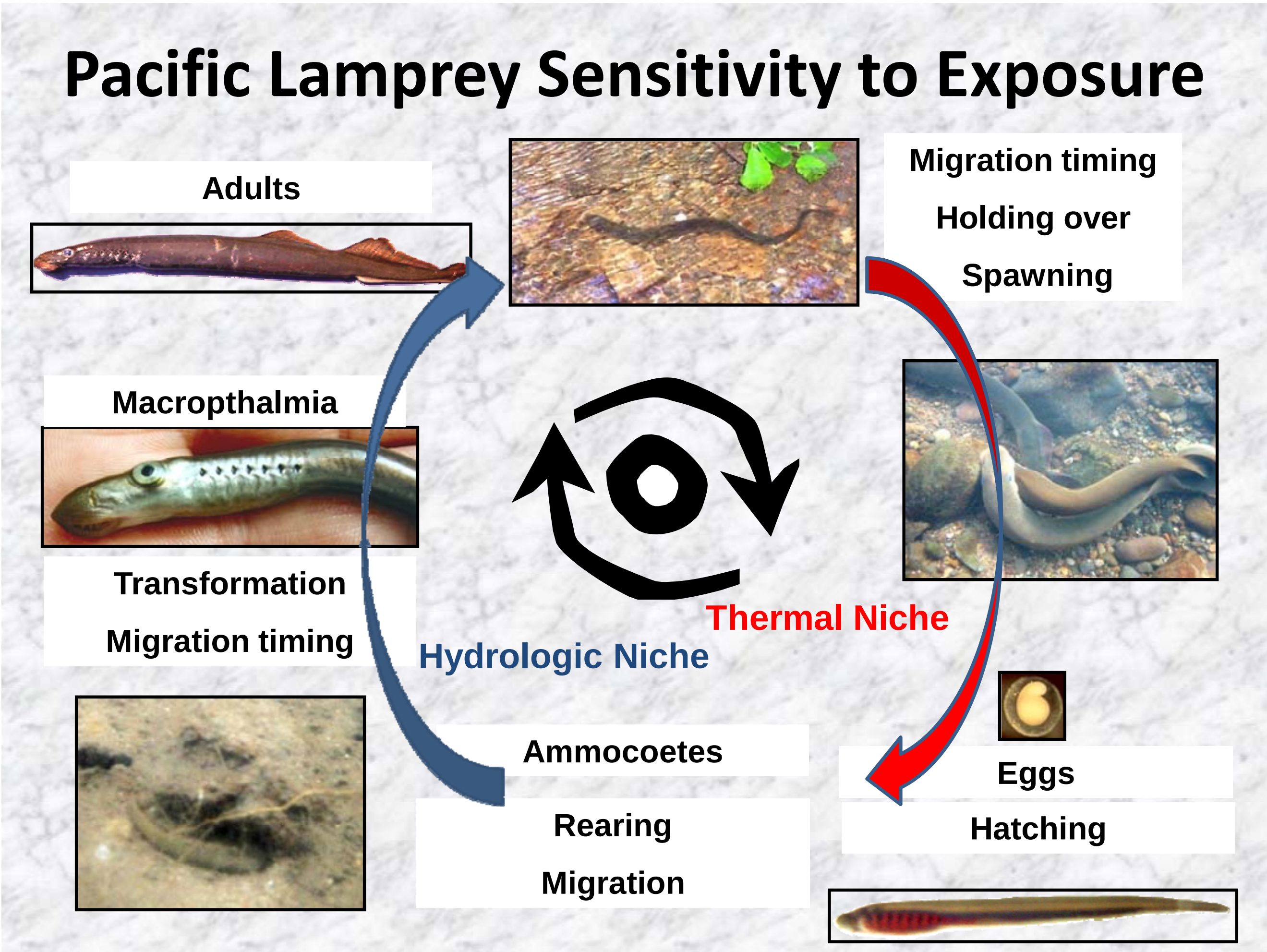


Figure 3. The NorWeST modeled basins for stream temperature in the west from Dan Isaak.

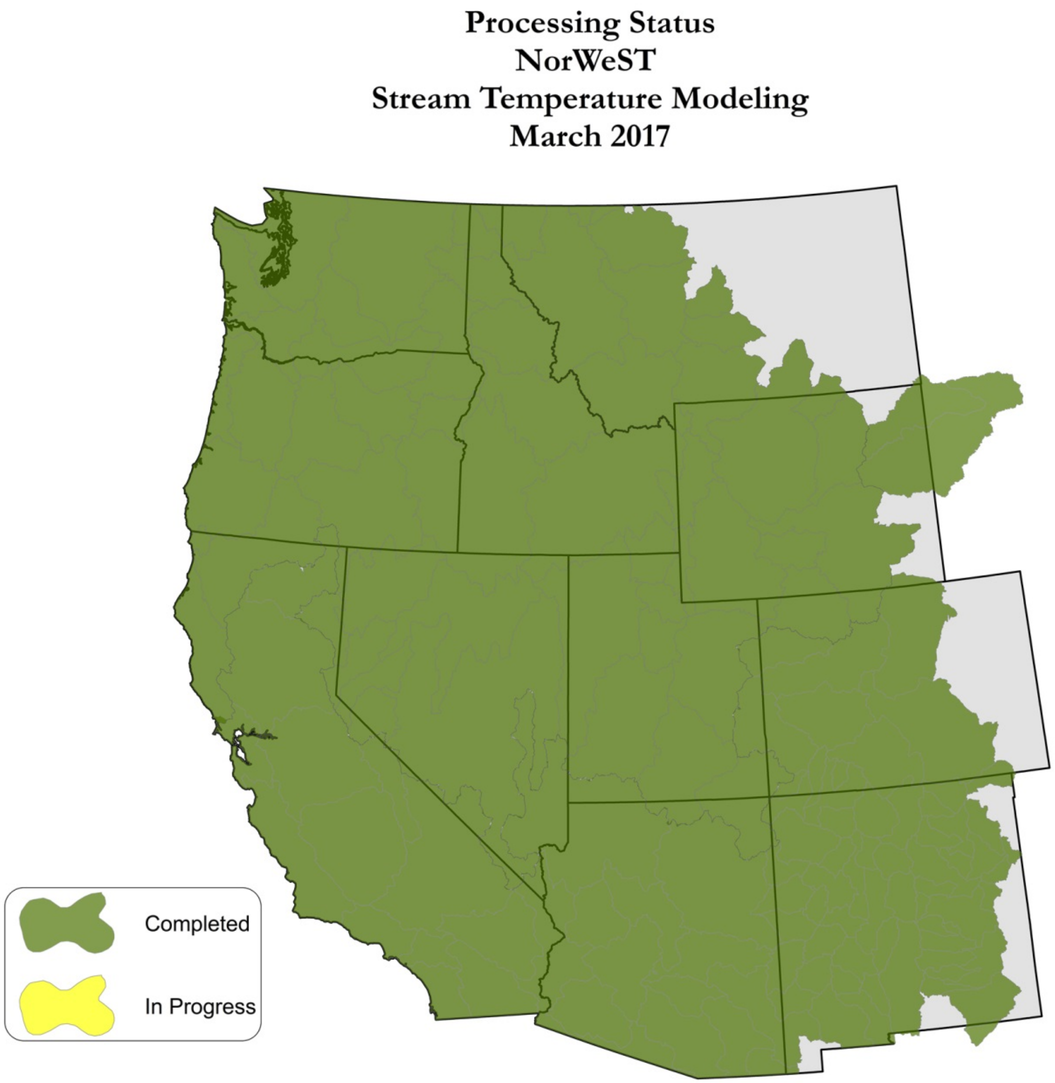
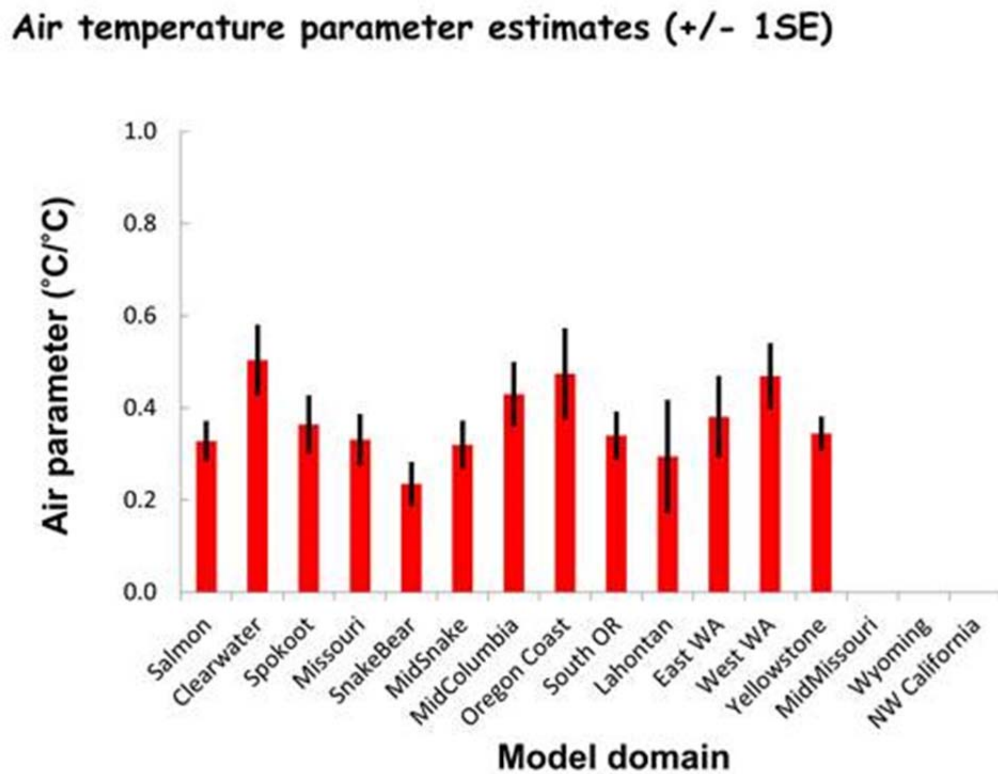


Figure 4. The air/stream temperature relations to convert CMIP5 air temperature to stream temperature for CCVI estimates (D. Isaak NorWeST 2015)



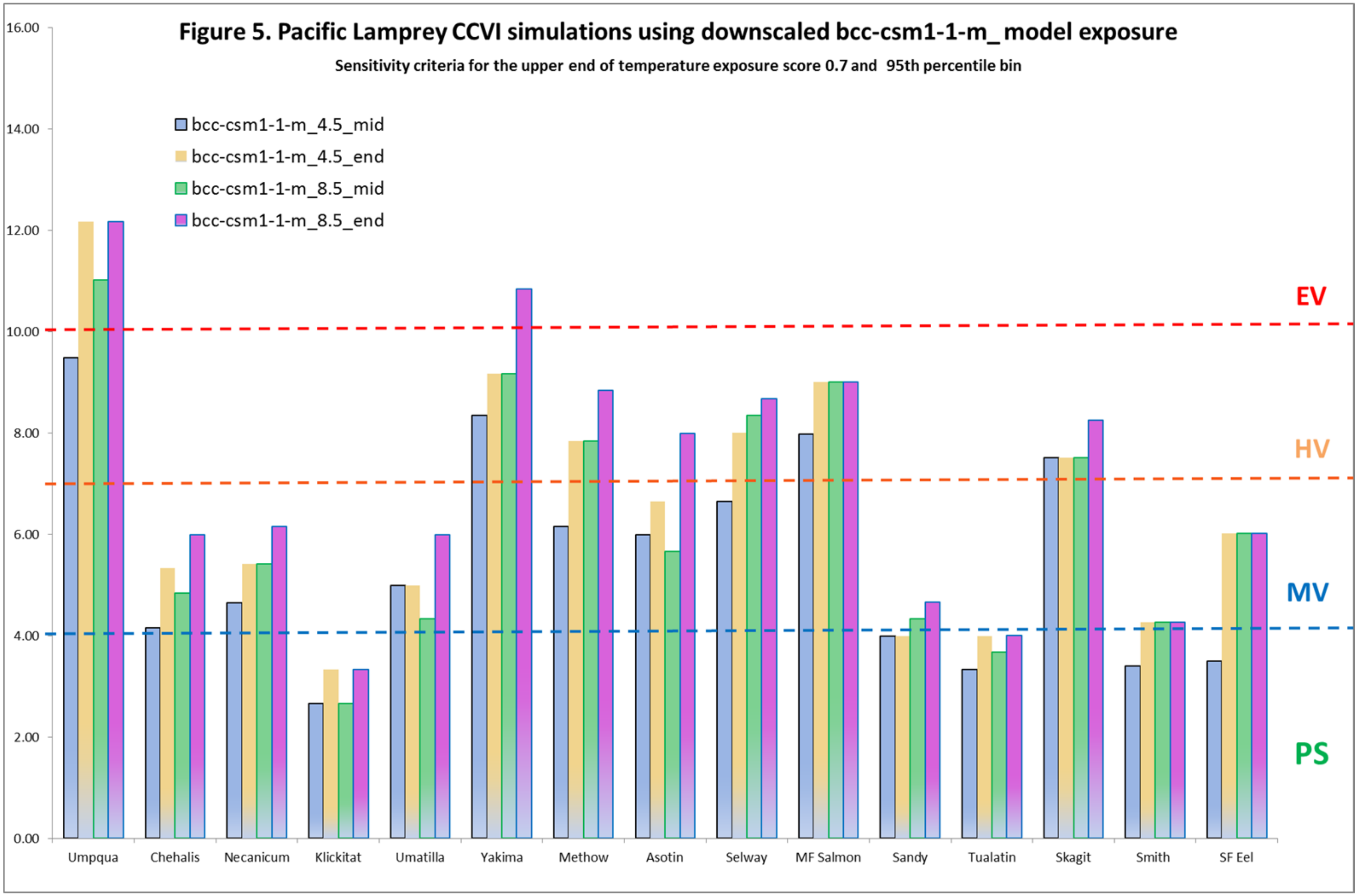


Figure 5. Pacific Lamprey CCVI simulations using downscaled bcc-csm1-1-m_ model exposure
Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin
bcc-csm1-1-m_4.5_mid
bcc-csm1-1-m_4.5_end
bcc-csm1-1-m_8.5_mid
bcc-csm1-1-m_8.5_end
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
EV
HV
MV
PS
Umpqua
Chehalis
Necanicum
Klickitat
Umatilla
Yakima
Methow
Asotin
Selway
MF Salmon
Sandy
Tualatin
Skagit
Smith
SF Eel

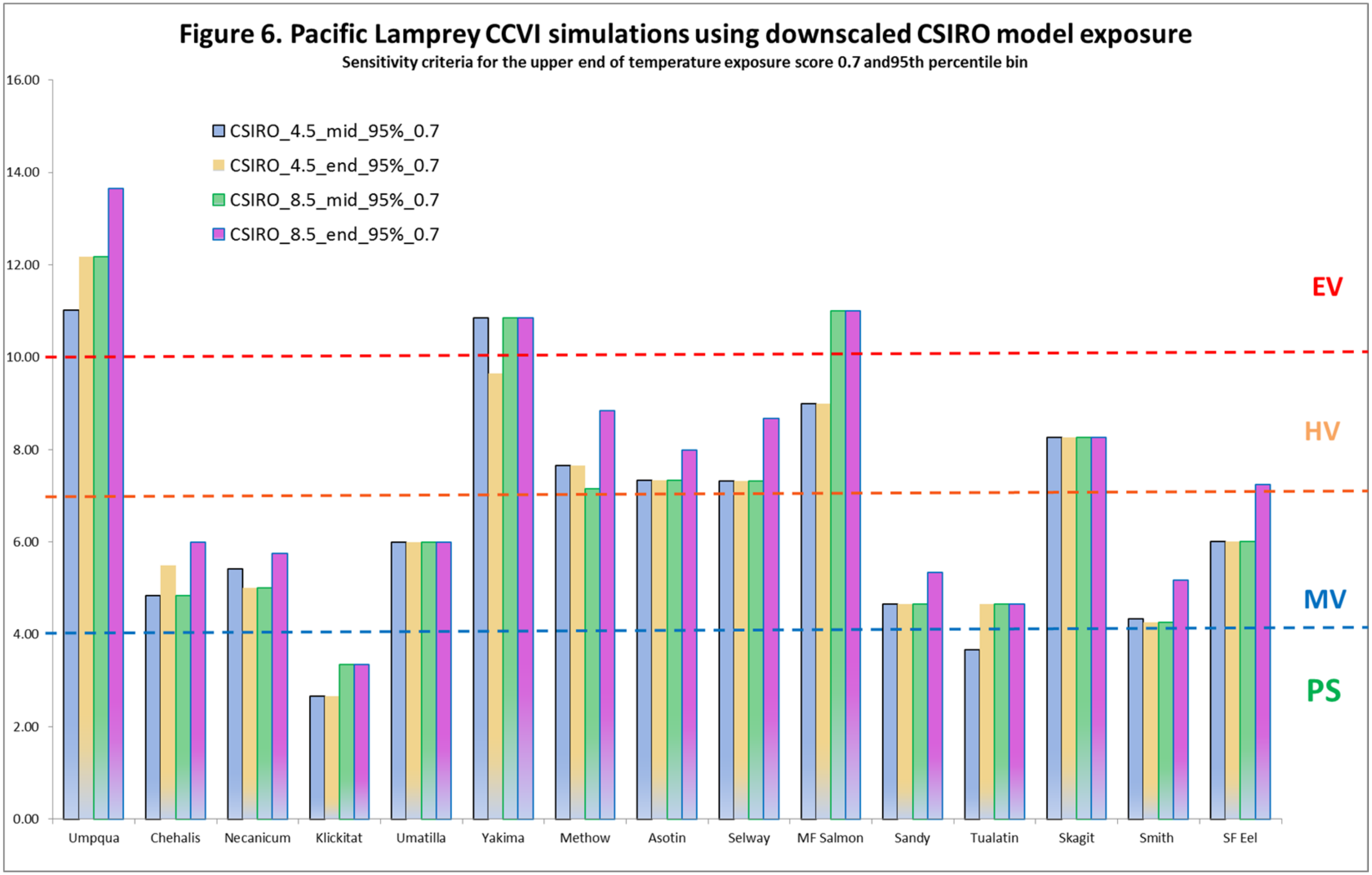


Figure 6. Pacific Lamprey CCVI simulations using downscaled CSIRO model exposure
Sensitivity criteria for the upper end of temperature exposure score 0.7 and95th percentile bin
CSIRO_4.5_mid_95%_0.7
CSIRO_4.5_end_95%_0.7
CSIRO_8.5_mid_95%_0.7
CSIRO_8.5_end_95%_0.7
EV
HV
MV
PS
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Umpqua
Chehalis
Necanicum
Klickitat
Umatilla
Yakima
Methow
Asotin
Selway
MF Salmon
Sandy
Tualatin
Skagit
Smith
SF Eel

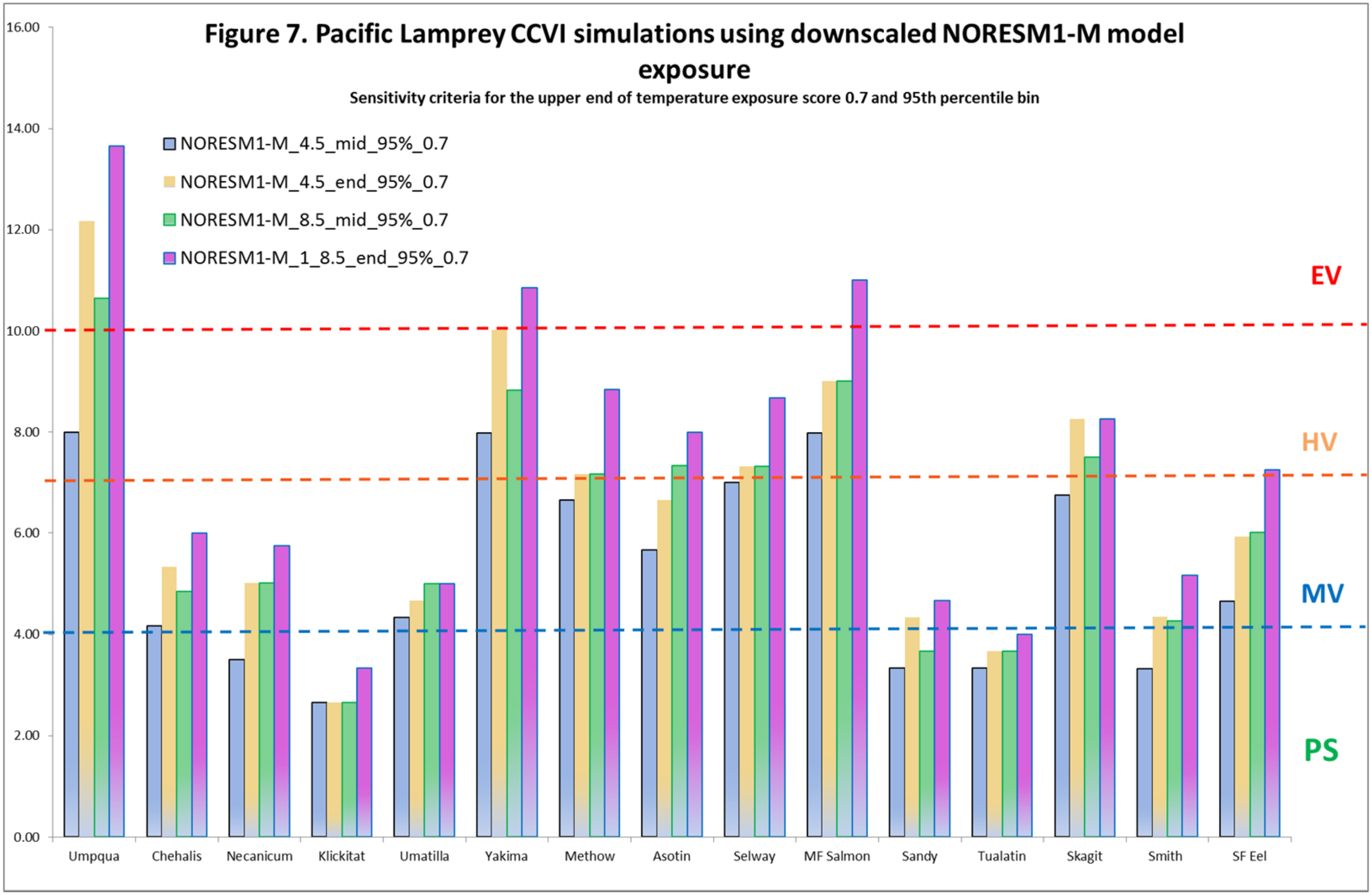


Figure 7. Pacific Lamprey CCVI simulations using downscaled NORESM1-M model exposure
Sensitivity criteria for the upper end of temperature exposure score 0.7 and 95th percentile bin
NORESM1-M_4.5_mid_95%_0.7
NORESM1-M_4.5_end_95%_0.7
NORESM1-M_8.5_mid_95%_0.7
NORESM1-M_1_8.5_end_95%_0.7
EV
HV
MV
PS
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Umpqua
Chehalis
Necanicum
Klickitat
Umatilla
Yakima
Methow
Asotin
Selway
MF Salmon
Sandy
Tualatin
Skagit
Smith
SF Eel

Figure 8. Pacific Lamprey CCVI simulations - Comparison for 3GCMS at 95% and 0.7 for mid-century and RCP 4.5

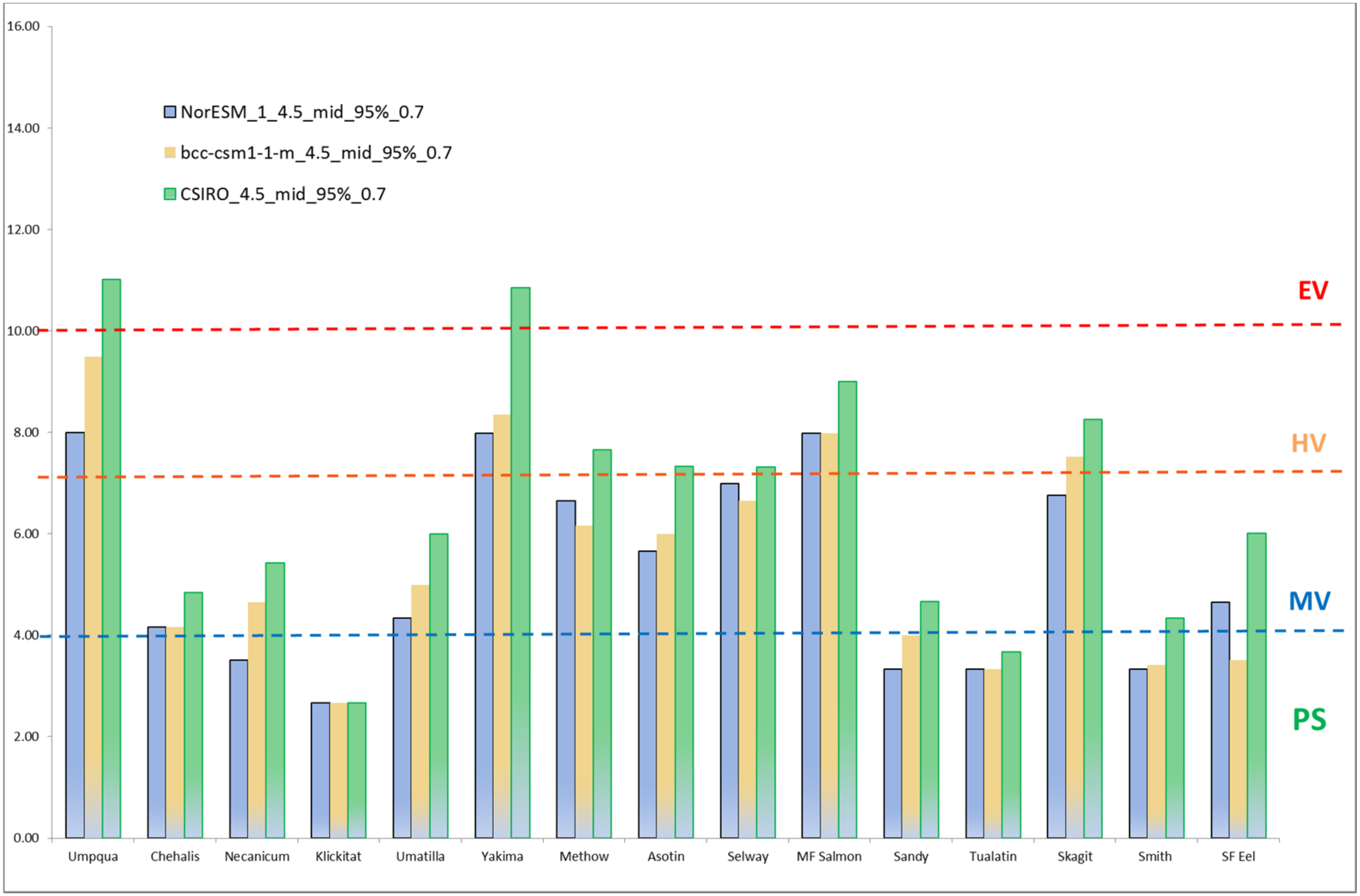


Figure 9. Pacific Lamprey CCVI simulations - Comparison for 3GCMS at 95% and 0.7 for end of century and RCP 4.5

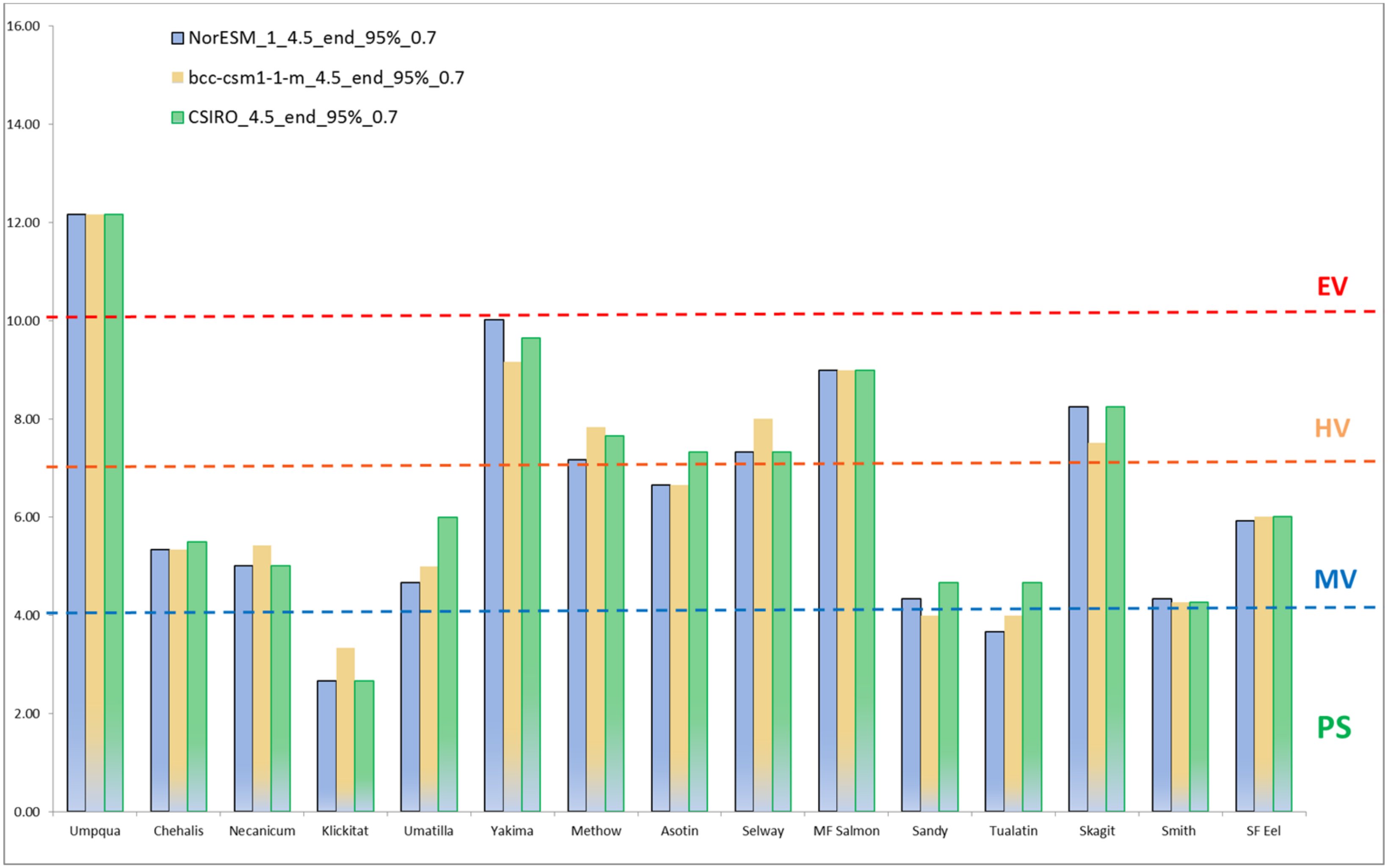


Figure 10. Pacific Lamprey CCVI simulations - Comparison for 3GCMS at 95% and 0.7 for mid-century and RCP 8.5

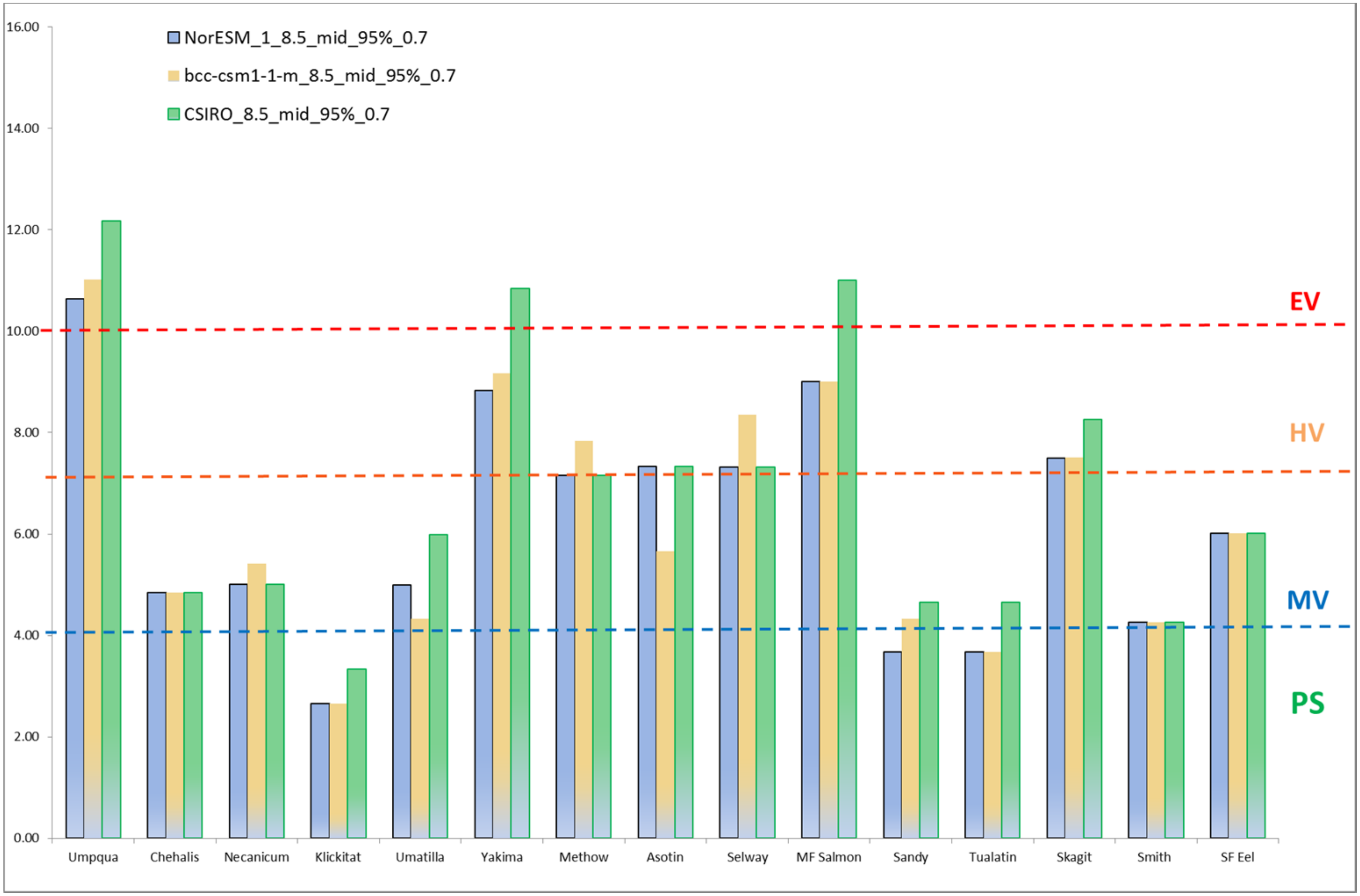


Figure 11. Pacific Lamprey CCVI simulations - Comparison for 3GCMS at 95% and 0.7 for end of century and RCP 8.5