Assessing species and area vulnerability to climate change for the Oregon Conservation Strategy: Willamette Valley Ecoregion

Zachary L. Steel, Marit Wilkerson, Patrick Grof-Tisza, and Kathryn Sulzner
zacksteel@gmail.com, mlwilkerson@ucdavis.edu, pgroftisza@ucdavis.edu, kate@ecovetinternational.com
Conservation Management Program
University of California, Davis

Table of Contents

Executive Summary

In response to the rapid onset of global climate change, many government and non-governmental conservation organizations are focusing resources on developing management strategies to assess biodiversity vulnerability and develop adaption strategies for a changing world. An important first step for resource managers is to identify which species, habitats, or other management units are most vulnerable to alterations their environment. Assessing vulnerability allows for prioritization of climate change adaptation efforts and development of specific strategies that promote persistence of conservation targets. The growing need to assess vulnerability has fueled the development of assessment tools such as NatureServe‟s Climate Change Vulnerability Index (CCVI). CCVI and similar approaches are designed to quickly identify which species are likely to be most affected by projected climate change and provide a means of determining key factors of vulnerability.

In this study, we used NatureServe‟s CCVI to conduct a vulnerability assessment on 46 focal species across seven broad taxonomic groups within the Willamette Valley Ecoregion of Oregon. For the same ecoregion, we conducted a preliminary assessment of sensitivity to non-climate threats and climate change vulnerability for 27 Conservation Opportunity Areas (COAs). Our assessment of COAs also provides an initial guideline for future place-based climate change vulnerability analyses.

Part I: Species vulnerability findings

Using a mid-century (2050) medium climate change scenario that predicts an ecoregion-mean increase of 1.97°C (3.54°F) and a precipitation increase of 1.65%, all species received a score of low to moderately vulnerable. However, when running the index using a prediction of more extreme climate change with a mean temperature increase of 2.39°C (4.31°F) and a mean precipitation increase of 18.28%, 54% of the species were predicted to be moderately to extremely vulnerable with 11% receiving the highest vulnerability score. Of the 46 species and subspecies assessed, the four most vulnerable to climate change were Coastal Cutthroat Trout (Southwest Columbia River ESU; *Oncorhynchus clarkii pop. 2*), Chinook Salmon (Lower Columbia River ESU, Fall Run; *Oncorhynchus tshawytscha pop. 22*), Way-side Aster (*Aster vialis*), and Fender's Blue Butterfly (*Icaricia icarioides fendereri*). Among the species assessed, invertebrates, fishes, and plants tended to be the most vulnerable groups on average. The ecological parameters that most contributed to climate change sensitivity were inferred limitations in temperature tolerance, negative response to disturbance regimes, dependence on current precipitation/hydrologic regimes, dependence on specific habitat attributes, and dependence on cooler microsites within habitats. Our results provide a ranking of species vulnerability that can be used for prioritization of conservation efforts and a means for developing management strategies. A diverse range of options for addressing the threat of climate change for the species assessed are highlighted in the discussion of this report.

Part II: Place-based vulnerability findings

We first ranked the 27 Conservation Opportunity Areas (COAs) based on their sensitivity to non-climate change stressors and then used that sensitivity scoring in conjunction with climate change sensitivity parameters to develop vulnerability scores for each COA. We used both non-climate change stressors in addition to climate change sensitivity parameters because - unlike the Strategy Species addressed in Part I of this report - the COAs are not currently ranked based on other stressors such as invasive species. Final vulnerability scores allowed us to rank COAs from highest to least priority with respect to predicted climate change impacts. Climate change sensitivity parameters used to build our model were drawn from existing literature on habitat or place-based vulnerability. These parameters can easily be modified or expanded upon with additional expertise. Based on this analysis, we determined that the most vulnerable COAs were not vulnerable due to the same ecological/geographic characteristics. However, we found that across all COAs, non-climate change stressors had a significant impacted on the overall vulnerability score. In other words, in many cases non-climate factors may remain more threatening to the conservation places than climate change. In addition to presenting our results we suggest and discuss further ways this type of place-based vulnerability assessment could be used and improved.

Acknowledgements

We would like to acknowledge our main partners: Defenders of Wildlife and Oregon Department of Fish and Wildlife. Specifically, we thank Sara O'Brien (Defenders), Holly Michael (ODFW), and Art Martin (ODFW) for their advice, assistance, and support. This project would not have been possible without the guidance and energy of Mark Schwartz of UC Davis and all the participants of the Conservation Management Program of UC Davis. We thank Fraser Shilling of UC Davis for his role as our project advisor. We thank Katie Theoharides, formerly of Defenders, for helping to initiating project ideas and support. We give many thanks to Michael Case of University of Washington and Evan Girvetz of The Nature Conservancy for lending their expertise. Without the data and data management assistance provided by the Oregon Biodiversity Information Center of Portland State University, this project could not have been completed. Specifically we thank Lindsey Wise, Susan Vrilakas, and Jimmy Kagan (all of OBIC) for their assistance.

Key Concepts and Acronyms

Adaptation - refers to adjustments in human or ecological systems in response to climate change. In this context adaptation does not refer to the evolutionary process by which populations and species change over time.

Adaptive Capacity - The ability of a focal species or system to cope with or take advantage of environmental changes and moderate potential damages.

Exposure - The projected change of climate experienced by focal species or systems across the geographic area considered.

Sensitivity - The degree to which a focal species or system responds to a threat, either adversely or beneficially, given exposure.

Vulnerability - The degree to which a species or system is unable to cope with the adverse effects of climate change, including climate variability and extremes.

CCSM – The Community Climate System Model

CCVI - Climate Change Vulnerability Index

COA - Conservation Opportunity Areas

ESU – Evolutionarily Significant Unit

GCM – Global Circulation Model

GIS – Geographic Information Systems

GISS – The Goddard Institute for Space Studies global circulation model

IPCC - International Panel on Climate Change

IPSL – The Institut Pierre Simon Laplace global circulation model

OCS - Oregon Conservation Strategy

ODFW – Oregon Department of Fish and Wildlife

UKMO – The United Kingdom Met Office HadCM3.1 global circulation model

Introduction

Informing the Oregon Conservation Strategy

The rapid onset of global climate change is now a widely accepted reality and is expected to significantly alter natural and human-dominated ecosystems in the decades to come (Solomon et al. 2007). While mitigation of climate change remains the most effective way of reducing climate-related threats to biodiversity, some amount of current and future change is inevitable and climate adaptation will also be necessary to conserve many species. Thus, many governmental and non-governmental conservation organizations are focusing resources on developing management strategies to better understand the threat of climate change and help biodiversity adapt as conditions change.

Adaptation[1] efforts will benefit from existing policies and strategies but will require the incorporation of climate science and projected impacts into future conservation planning (Michael and O'Brien 2008). An important first step is to identify the processes, habitats, and species most vulnerable to projected changes (Lawler et al. 2008, AFWA 2009, Baron et al. 2009). Determining which ecosystem components are most susceptible will inform the prioritization, monitoring, and management actions needed to facilitate adaption in the coming decades (Figure 1).

The study presented here examines climate change in the Willamette Valley Ecoregion of the state of Oregon; focusing on the ecoregion's Strategy Species and Conservation Opportunity Areas as identified by the Oregon Conservation Strategy (OCS). Graduate students from the University of California, Davis conducted this study as part of the university‟s Conservation Management Program in consultation with the Defenders of Wildlife and the Oregon Department of Fish and Wildlife. The findings presented are intended to inform future updates of the OCS and other conservation efforts as Oregon continues to incorporate climate science into its conservation management practices.

[1] Adaptation in this context refers to adjustments in human or ecological systems in response to climate change rather than the evolutionary process by which populations and species change over time.

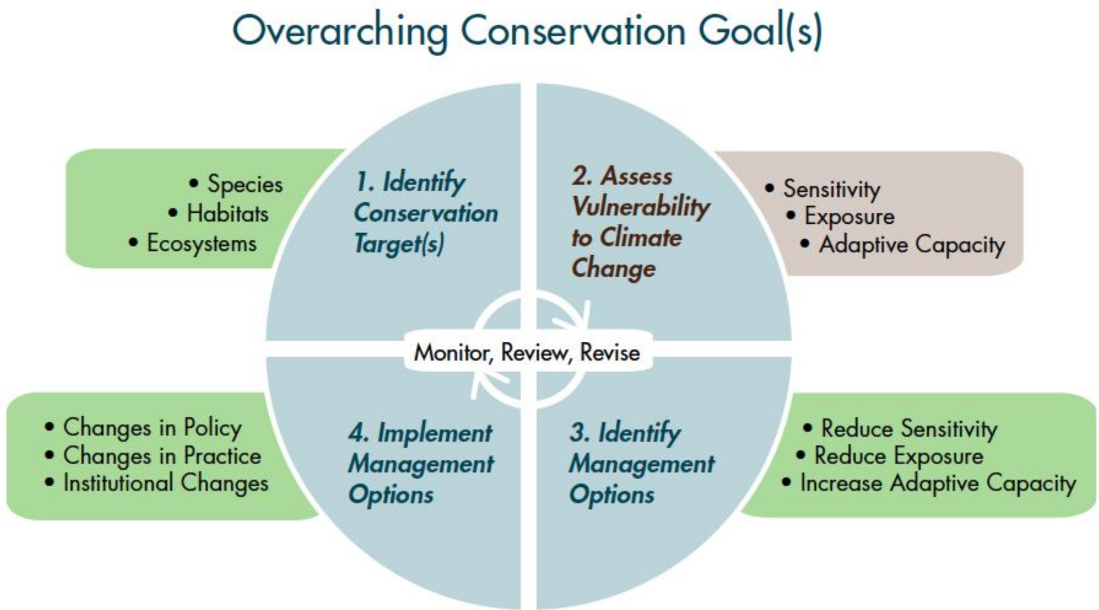


Figure 1. Generalized climate change adaptation framework from Glick et al. (2011). The project presented here focuses on steps 1-3, especially on step 2; step 4 and continued reiteration of all steps will occur through the actions and participation of multiple Willamette Valley stakeholders.

Climate change and its impacts in Oregon

Changes in temperature and precipitation due to climate change are already taking place across the Pacific Northwest (GCRP 2009). In Oregon over the past 100 years, temperatures have risen by 0.8° C (1.5°F) and precipitation has generally increased across the state. The most dramatic increases have been observed in the Cascade Range and lower levels of precipitation were observed along the northern coast of Oregon (Lawler et al. 2008). Such changes are expected to continue throughout the foreseeable future with a likely increase of 2.2 to 5.6°C (4 to 10°F) in the Pacific Northwest over the next 100 years (GCRP 2009). Potential changes in precipitation are less well understood than temperature, but precipitation is expected to show a general increase across the state during the winter and decrease during the summer (Lawler et al. 2008).

These changes in temperature and precipitation will likely have cascading effects on many facets of Oregon‟s ecology. Such effects include but are not limited to, increased frequency and intensity of fire due to drier fuel loads, increased risk of drought and heat waves, and reductions in snowpack leading to changes in stream-flow patterns and alterations of freshwater systems (Lawler et al. 2008, Michael and O'Brien 2008, Doppelt et al. 2009).

A growing body of evidence shows that species are already responding to climatic shifts in a variety of ways. For example, progressively earlier springs in recent decades have been associated with phenological changes such as advanced migration timing, earlier breeding and flowering, and changes in clutch size (Crick et al. 1997, Winkler et al. 2002, Parmesan and Yohe 2003, Mills 2005, Parmesan 2006). Climate change is also believed to be causing species range shifts (e.g., Tingley et al. 2009) with species generally moving poleward and upward in elevation as the climate warms (Parmesan 2006), though exceptions are likely (e.g., Crimmins et al. 2011).

Given the likely acceleration of climate change into the next century, we can expect to see even greater changes leading to novel community compositions and alterations of abiotic processes (Westerling et al. 2006, Stralberg et al. 2009). Such changes will profoundly impact the ecology of Oregon and the Willamette Valley Ecoregion, and will necessarily influence future policies and management decisions for the region.

Current climate science in the Willamette Valley

Multiple state and local government agencies, non-governmental organizations (NGOs), and academic institutions are collaborating throughout Oregon to find ways to help the state"s economy, lands, and species adapt to climate change. These efforts are especially notable within the populous Willamette Valley. While the goal of many such efforts is to address climate stressors on human communities, here we focus on research and planning efforts that target non-human biodiversity. Among the programs, think-tanks, and organizations focused on climate change in this region are the inter-state efforts of the Western Governors" Association (governmental), the Defenders of Wildlife (NGO), the Oregon Global Warming Commission (governmental), the Climate Leadership Initiative (academic), the University of Washington (academic), and others.

Many groups have focused on general recommendations for management and policy and for climate change research. The Western Governors" Association has made available multiple resolutions and informational reports on climate change effects in the western states, offering suggestions from climate-change related monitoring (WGA 2010) to emphasizing the need for conservation linkages (WGA 2008). Oregon, Idaho, and Washington are collaborating on a pilot project aimed to develop a transboundary wildlife mapping tool that will aid future conservation planning efforts. In 2007, Oregon"s legislature created the Oregon Global Warming Commission to reduce greenhouse gas emissions within Oregon and prepare the state for the current and future effects of changing climate. The Commission"s Subcommittee on Fish, Wildlife, and Habitat Adaptation drew up a 2008 report outlining general statewide management and policy guidelines (Michael and O'Brien 2008). Defenders of Wildlife is partnering with state agencies in Oregon and across the US to update State Wildlife Action Plans to reflect climate change impacts. To date, many efforts have focused at the state level with limited intra-state specificity. In the academic world, faculty, staff, and student researchers are working to inform planning and policy actions through the advancement of climate science research. The Climate Leadership Initiative, a collaboration between the Resource Innovation Group and the University of Oregon, has outlined specific climate change impacts and implications for the Upper Willamette River Basin (Doppelt et al. 2009) and is hosting Climate Future Forums to develop a similar report for the Lower and Middle Willamette River Basin (OCCRI 2010). The completed Upper Willamette report has a relatively high degree of specificity that includes listing individual species and habitats that may be vulnerable to climate change (e.g., Douglas fir and high elevation alpine habitat). The report was based on findings from downscaled climate change models from the International Panel on Climate Change (IPCC), a locally developed vegetation map, and an expert panel (Doppelt et al. 2009). Another study conducted by University of Washington, The Nature Conservancy, and US Geological Survey has a broader geographic scope and focuses on climate change impacts in the Pacific Northwest states of Idaho, Washington and Oregon

(Lawler 2010). This ongoing study aims to assess species and habitat sensitivity with the goal of producing tools and reports useful to managers in the Willamette Valley and elsewhere in the region. Such projects will be especially informative to managers as they work to incorporate climate research into the conservation plan outlined in the OCS (Theoharides et al. 2009).

The climate science planning, research, and implementation efforts conducted in the Willamette Valley are ongoing and multi-faceted and the research presented here is designed to complement these efforts. By using a suite of species as the basis for our climate change vulnerability research, we attempt a level of local specificity that is relevant for Willamette Valley managers while also providing insight into general vulnerability patterns. We hope that our findings will be useful to researchers and practitioners within and beyond the Willamette Valley and the state of Oregon. Our species vulnerability assessment differs from many other on-going projects by not relying on expert-panels but rather on NatureServe‟s Climate Change Vulnerability Index (CCVI) and available data on local climate, species distribution and species life history. This assessment seeks to not only provide legitimate, defensible options for managing under climate change but also to serve as a framework for conducting vulnerability assessments in a data-poor and time-limited environment. In Part II of this report we provide a regionally specific but widely applicable preliminary framework for assessing place-based climate change vulnerability.

Part I. Species Vulnerability Analysis

Steel, Z. L., Wilkerson, M., Grof-Tisza, P., Sulzner, K.

1. Background

1.1 What are vulnerability assessments?

In light of evidence demonstrating the effects of climate change on ecosystems and species, resource managers are faced with the challenge of identifying which species and habitats are most vulnerable to predicted alterations of environmental conditions (Parmesan and Galbraith 2004). Vulnerability assessments are rooted in a long history of risk and hazard analysis and are rapidly evolving to keep pace with technological and scientific advancements (Turner et al. 2003).

Although vulnerability can be assessed for any relevant threat, here we discuss the components of vulnerability in the context of climate change only. Vulnerability to climate change, as recently defined by the International Panel on Climate Change (Fischlin et al. 2007), is

> *…the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.*

Dissecting this definition, vulnerability has three principle components: **exposure, sensitivity,** and **adaptive capacity**. This definition distinguishes between and incorporates both external (i.e., exposure) and internal (i.e., sensitivity and adaptive capacity) factors. In the context of climate change vulnerability assessments, **exposure** is the projected change of climatic variables (most often temperature and precipitation) across the geographic area considered. **Sensitivity** is the degree to which a focal system responds to the threat, either adversely or beneficially, given exposure. Factors such as species life history characteristics or observed past responses to a threat can be used to determine sensitivity. For example, a habitat generalist‟s ability to switch between food items decreases its sensitivity to a changing climate where vegetation communities are likely to shift. **Adaptive capacity** is the ability to cope with or take advantage of climate change-induced stressors to moderate potential damages (Fischlin et al. 2007, Young et al. 2010, Glick et al. 2011). Like sensitivity, adaptive capacity is directly linked to life history traits such as those that enable an adaptive response to a changing environment (e.g., dispersal ability and genetic diversity) (Fischlin et al. 2007, Young et al. 2010). Thus, the *potential* impacts to a system are based on the magnitude of exposure and its inherent sensitivity and the system‟s adaptive capacity ameliorates the *realized* impacts (Figure 2).

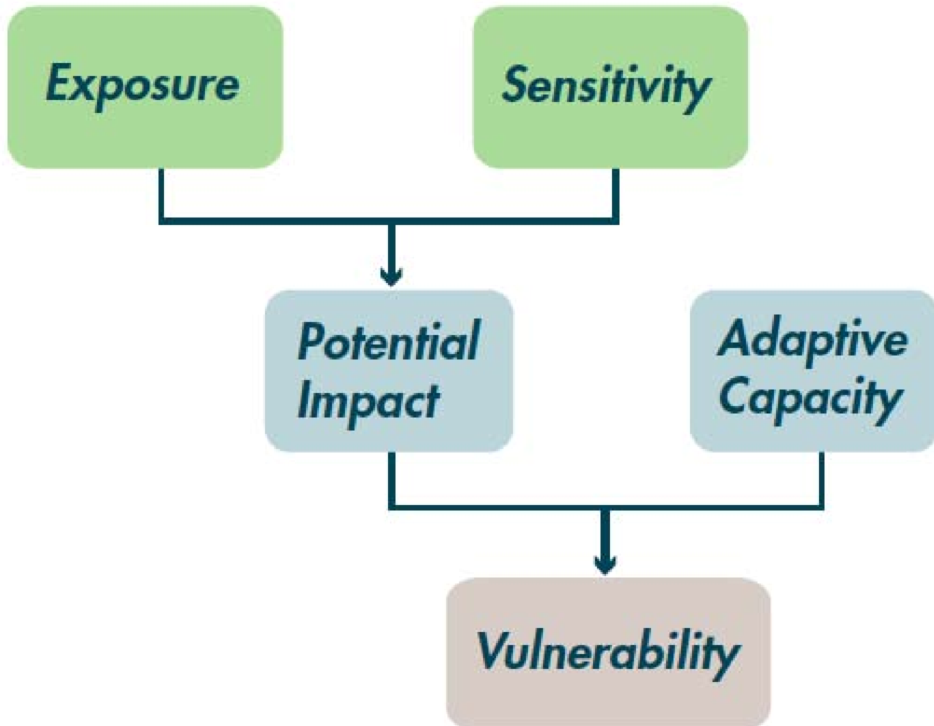


Figure 2. A generalized model of vulnerability. From Glick et al. (2011).

Approaches to assessing climate change vulnerability are still being developed and refined. Most assessments to date rely on expert panels, analytic models, or a combination of both to quantify species vulnerability (Ogden and Innes 2009, Nelitz et al. 2010). For this assessment we use the NatureServe Climate Change Vulnerability Index (CCVI), which relies on spatial and life history data to model relative vulnerability of each species considered.

1.2 Project objectives

Working in conjunction with Defenders of Wildlife and the Oregon Department of Fish and Wildlife, our objectives were as follows:

1) Assess the relative vulnerability of Willamette Valley Strategy Species to climate change.
2) Identify which life history parameters most influence species" sensitivity to climate change.
3) Provide potential management options and adaptation strategies for the Willamette Valley Ecoregion.
4) Explore elements of uncertainty in the analysis, drawing attention to areas where knowledge gaps exist.

2. Methods

2.1 Focal species and data sources

Our study assessed the vulnerability of the Willamette Valley Ecoregion"s Strategy Species as defined by the Oregon Conservation Strategy. We used the Climate Change Vulnerability Index (CCVI[2]) to evaluate 46 of the ecoregion"s 59 strategy species. A lack of species distribution or life history information prevented our evaluation of the remaining 13 species. Data types required for our assessment include: Past climatic data on temperature and precipitation for Oregon, future projections of temperature and precipitation for the state, a map of the Wildland-Urban Interface, species distribution maps and information on species life histories.

Table 1. Willamette Valley Ecoregion strategy species (ODFW 2005). Italicized species were not assessed in this study due to a lack of available distribution or life history information.

Mammals	**Fish**	**Fish Cont.**
California Myotis	Bull Trout	*Steelhead (Middle Columbia River ESU, winter run)*
Townsend"s Big-eared Bat	Chinook Salmon (Lower Columbia R. ESU, spring run)	*Steelhead (Oregon Coast ESU, summer run)*
Western Gray Squirrel	Chinook Salmon (Lower Columbia River ESU, fall run)	Steelhead (Oregon Coast ESU, winter run)
Plants	*Chinook Salmon (Snake River ESU, spring/summer run)*	*Steelhead (Snake River Basin ESU)*
Bradshaw"s Desert Parsley	*Chinook Salmon (Upper Willamette River ESU, fall run)*	Steelhead (Southwest Washington ESU, winter run)
Golden Paintbrush	Chinook Salmon (Upper Willamette R. ESU, spring run)	Steelhead (Upper-Willamette River ESU, winter run)
Howellia	*Coastal Cutthroat Trout (Oregon coast ESU)*	*Western Brook Lamprey*
Kincaid"s Lupine	Coastal Cutthroat Trout (SW WA/Columbia R. ESU)	**Birds**
Nelson"s Checker-mallow	*Coastal Cutthroat Trout (Upper Willamette River ESU)*	Acorn Woodpecker
Peacock Larkspur	Coho Salmon (OR Coast ESU)	Chipping Sparrow
Wayside Aster	Coho Salmon (Lower Columbia R./SW WA Coast ESU)	Common Nighthawk
White Rock Larkspur	*Oregon Chub*	Canada Goose *(Dusky subsp.)*
White-topped Aster	*Pacific Lamprey*	Grasshopper Sparrow
Willamette Daisy	Steelhead (Lower Columbia River ESU, summer run)	Willow Flycatcher *(Little subsp.)*
Amphibians & Reptiles	Steelhead (Lower Columbia River ESU, winter run)	Vesper Sparrow *(Oregon subsp.)*
Northern Red-legged Frog	*Steelhead (Middle Columbia River ESU, summer run)*	Short-eared Owl
Foothill Yellow-legged Frog		White-breasted Nuthatch *(Slender billed subsp.)*
Northwestern Pond Turtle		Horned Lark (Streaked subsp.)
Western Painted Turtle		Western Bluebird
Western Rattlesnake		Western Meadowlark
Invertebrates		Purple Martin *(Western subsp.)*
American Grass Bug		Yellow-breasted Chat
Fender"s Blue Butterfly		
Taylor"s Checkerspot Butterfly		
Willamette Floater		

As recommended by CCVI documentation, we obtained spatial data on future climate projections as well as past precipitation from the online tool Climate Wizard (Girvetz et al. 2009), past temperature data from the CCVI tool (Young et al. 2010), and a Wildland-Urban Interface coverage from the Silvis Laboratory (Radeloff et al. 2005). Species range maps, were provided by the Oregon Biodiversity Information Center (ORBIC 2010) and the Natural

[2] CCVI can be downloaded at http://www.natureserve.org/prodServices/climatechange/ccvi.jsp

Resources Information Management Program of Oregon Department of Fish and Wildlife (ODFW 2010). All spatial data were imported and manipulated in a Geographic Information System (GIS). Information on species life history characteristics was obtained from a number of sources including published articles, state and federal agency reports, online databases, and in a few cases, expert opinion (Appendix C). The NatureServe conservation status was also determined for each target species based on the National Heritage Program"s global, national, and state ranking systems (NatureServe 2010).

Species range maps were created using point/polygon occurrence data and a sub-watershed (6th level hydrologic unit as defined by USGS) map obtained from the Oregon Biodiversity Information Center (ORBIC 2010). In cases where a species had been observed within a sub-watershed, the sub-watershed was included in the species" range. All occupied sub-watersheds were included to create each species" Oregon range, which was subsequently clipped to create the Willamette Valley range (Figure 3). For aquatic species, we used ready-made range maps provided by the Oregon Biodiversity Information Center (ORBIC 2010), which show occupancy of river segments for many of the study species. Our method of creating range maps for terrestrial species was relatively conservative as it relies on verified collections and sightings of species and may underestimate species distribution across the state and the Willamette Valley.

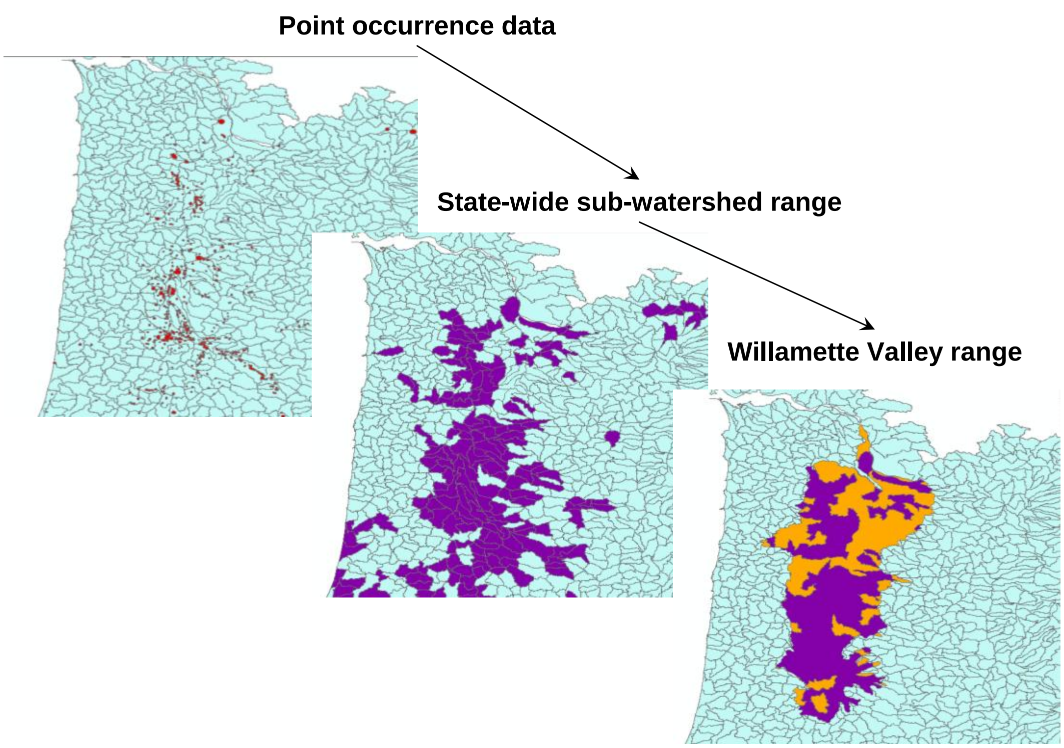


Figure 3. Illustration of range map creation (using Northwestern Pond Turtle as an example). Oregon sub-watersheds are shown in blue, point/polygon occurrence data in red (top-left) and watersheds that intersected with occurrence data are shown in purple (center and bottom-right). Species range maps were restricted to the Willamette Valley Ecoregion, shown in orange (bottom-right).

2.2 How the Climate Change Vulnerability Index (CCVI) works

There are four main components of the CCVI tool (Young et al. 2010): 1) Direct exposure to local temperature and precipitation change, 2) indirect exposure to climate change, 3) species‟ sensitivity to climate change, and 4) any existing documented/modeled responses to the threat (Figure 4).

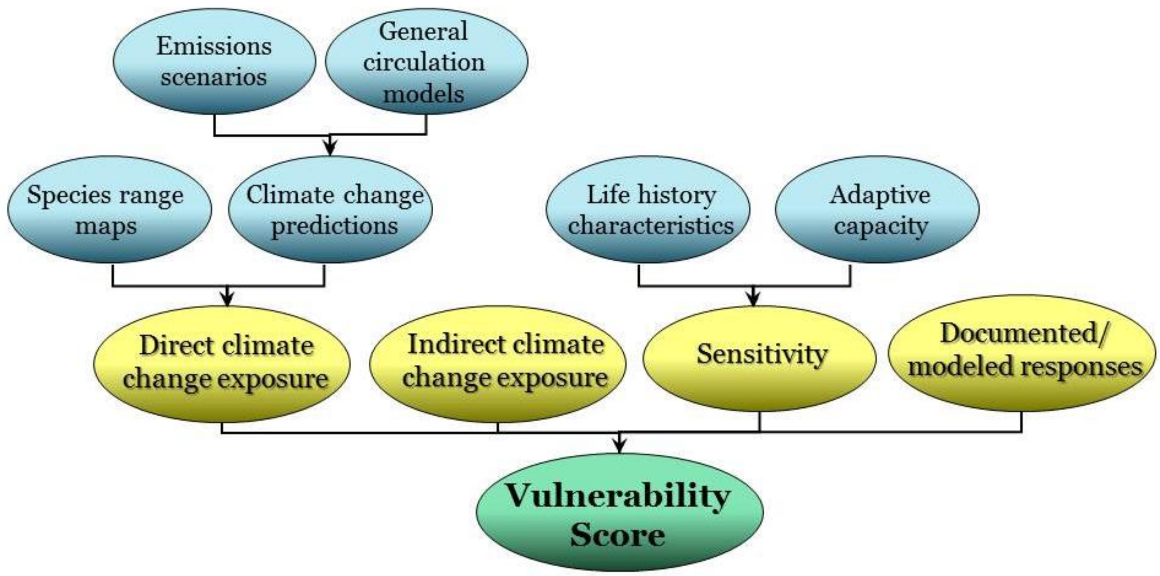


Figure 4. CCVI data scheme. Input data from the user are shown in blue circles; these feed into the four main components of the tool (yellow), which in turn produces a vulnerability score (green). Note that the CCVI differs slightly from the generalized vulnerability model (Figure 2) in that adaptive capacity is considered a component of sensitivity.

Direct exposure

Direct exposure is calculated as the proportion of each species range that is exposed to different magnitudes of temperature and precipitation change. This was calculated in a GIS by overlaying each species range with a climate projection surface classified by magnitude bins (classes from a continuous variable of change of either precipitation or temperature) as specified by the CCVI (Figure 5).

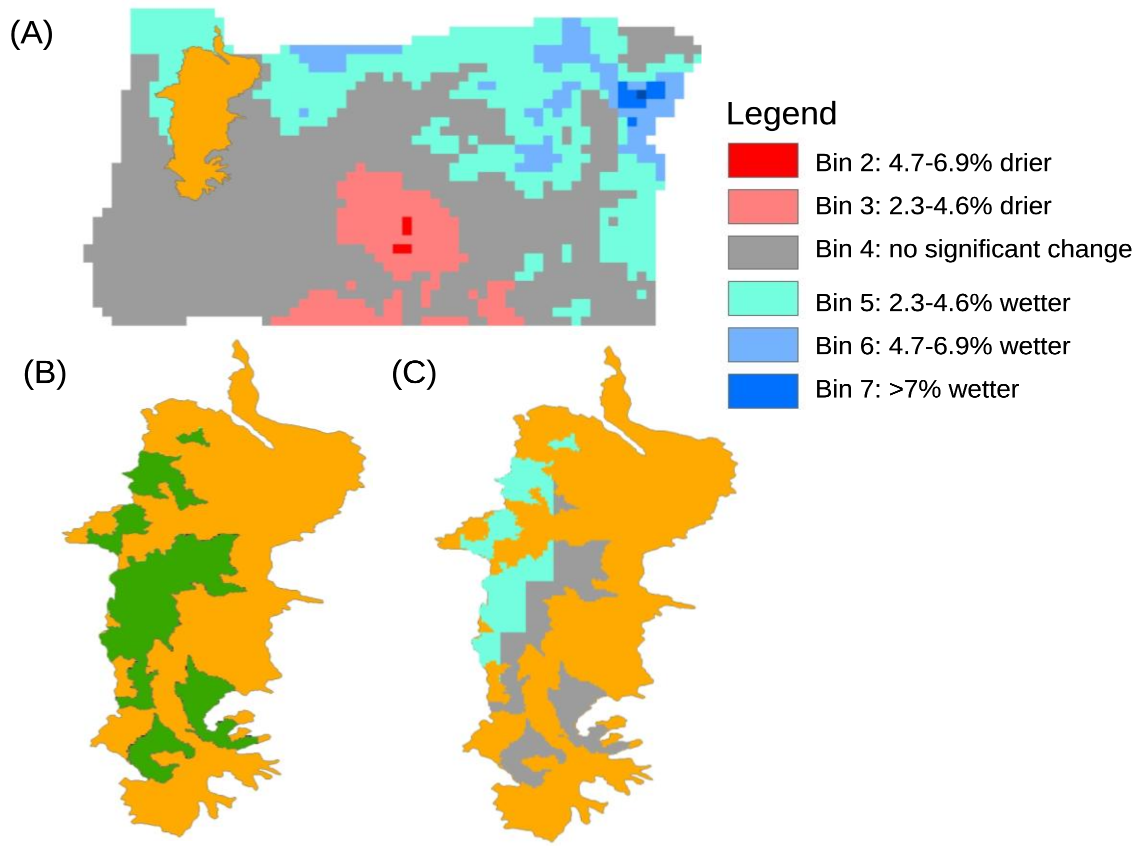


Figure 5. Example of quantification of direct exposure using magnitude levels recommended by the CCVI. (A) The precipitation exposure estimated across Oregon according to an ensemble of Global Circulation Models and the A1B emissions scenario (IPCC 2000). Magnitude bins of expected precipitation change are illustrated in shades of red and blue and the Willamette Valley Ecoregion is shown in orange. (B) The range (green) of Kincaid's Lupine (*Lupinus oreganus*) within the Willamette Valley Ecoregion. (C) The precipitation exposure of the lupine over its range. 59% of its range falls within no significant change (bin 4); 41% falls within 2.3-4.6% wetter (bin 5).

Indirect exposure

To represent indirect exposure to temperature and precipitation change, the CCVI incorporates four extrinsic factors that may influence a species" distribution and its likelihood to shift its range in response to climate change. These factors are: 1) The degree to which a species" range would be affected by sea level rise, 2) the extent to which large natural topographic and geographic barriers impede range shifts, 3) the extent to which anthropogenic barriers impede range shifts, and 4) the predicted impact that climate change mitigation efforts related to land-use change would have on species ecology and movement (Young et al. 2009). The degree to which each of these indirect factors affect species vulnerability is scored according to the CCVI guidelines (Young et al., 2010).

Species Sensitivity

Sensitivity to climate change was assessed by examining each species" resiliency and adaptive capacity to climate change in the context of seventeen life history characteristics described in NatureServe"s CCVI guidelines (Young et al. 2010). Each life history characteristic may either increase a species" sensitivity or confer greater resiliency to climate impacts (i.e., decrease sensitivity). For example, a species with a generalist diet can switch between food sources if one is diminished due to climate change (decreasing sensitivity), whereas a diet specialist species cannot (increasing sensitivity). Description of life history characteristics most relevant to our study species can be found in Table 2 below and complete description of characteristics considered by CCVI can be found in Young et al. (2010).

Table 2. Index parameters used to assess species sensitivity*. Complete descriptions and instructions for scoring can be found in CCVI documentation (Young et al. 2010).

Parameter Name	Parameter Description
Indirect Exposure Parameters	
Natural Barriers	The impact of topographic or geographic barriers on the species' ability to track climate envelope shifts.
Anthropogenic Barriers	The impact of anthropogenic barriers on the species' ability to track climate envelope shifts.
Climate Change Mitigation	The predicted impact of future land use changes for climate change mitigation.
Sensitivity Parameters	
Dispersal	Typical dispersal distances traveled by the species' propagules.
Macro Temperature	Inferred temperature tolerance at a broad scale. Based on approximate mean seasonal temperature variation (i.e., difference between highest and lowest mean monthly temperatures) of occupied cells.
Micro Temperature	Dependence on microsites within the habitat such as those that are cooler than the surrounding environment (e.g., frost pockets, north-facing slopes).
Macro Precipitation	Inferred precipitation/hydrologic regime tolerance at a broad scale. Based on approximate mean annual precipitation variation of occupied cells.
Micro Precipitation	Dependence on specific precipitation/hydrologic regimes and/or aquatic/wetland habitats.
Disturbance	Response (i.e., change in population distribution and/or abundance) to expected shifts in disturbance regimes due to climate change (e.g., fires, floods, pathogen outbreaks, etc.).
Ice/snow	Dependence on ice or snow associated habitats such as sea ice or glaciers.
Physical Habitat	Degree of specificity in habitat requirements (e.g. soil/substrate, geology etc.) for one or more portions of a species' life cycle.
Other Spp for Habitat	Dependence on other species to develop habitat for completion of any life cycle stage.
Diet	Diet flexibility of the species (i.e., Dietary specialist vs. generalist). (Animals only)
Pollinators	Dependence on other species for pollination. (Plants only)
Other Spp for Distribution	Dependence on other species for propagule dispersal.
Other Mutualism	Other forms of mutualism not explicitly considered by another parameter.
Migrations and Movements	Ability to move/migrate according to environmental conditions and flexibility of migration routes.
Genetic Variation	Measured genetic variation as compared to related taxa.
Bottlenecks	Evidence of recent (within 500 years) reduction of genetic variation due to a bottleneck.
Phenological Response	Ability to adjust phenological events in response to changing seasonal dynamics.

* The CCVI attempts to cover a broad range of life history traits that may influence species vulnerability. However, these parameters are not exhaustive; additional or alternative parameters may improve future analyses.

Sensitivity subscores are assigned to each life history category based on the best available knowledge of how that parameter will contribute to the species" response to climate change. The subscores in CCVI are based on a variable scale ranging from „decreased vulnerability" to greatly „increased vulnerability" (Young et al. 2010).

Documented/Modeled responses
At the time of this study, responses to past climate change and modeled responses to future changes for Willamette Valley Strategy Species were largely undocumented. Thus, we could not complete an adequate assessment of this category and omitted this optional component of the CCVI from our analysis.

Vulnerability rating
An overall climate vulnerability score is calculated as a sum of the exposure-weighted sensitivity subscores[3] and presented as a qualitative vulnerability rating; one of five descriptive categories (Table 3). We elected to present vulnerability results in numerical format, rather than the existing categorical descriptions, as we felt this better conveys the relative vulnerability between species or taxa.

Table 3. Vulnerability scores and CCVI definitions.

CCVI Categories	CCVI Category Definitions	Numerical Scores
Extremely Vulnerable	Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.	1
Highly Vulnerable	Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.	2
Moderately Vulnerable	Abundance and/or range extent within geographical area assessed likely to decrease by 2050.	3
Not Vulnerable/Presumed Stable	Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease substantially by 2050). Actual range boundaries may change.	4
Not Vulnerable/Increase Likely	Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.	5

2.3 Sensitivity parameters

Fourteen of the possible seventeen parameters representing the climate-relevant biophysical drivers were used to determine the sensitivity of each species, independent of its exposure to climate change (for definitions of parameters see Table 2). To quantify the influence of each life history parameter on a species" overall sensitivity, we used numerical equivalents to the categorical sensitivity scores (Table 4). In cases where a species was given a mixed score for a given parameter, the average numerical score was used. For example, a categorical vulnerability score of "Somewhat Increased (1) – Neutral (0)" is given a numerical score of 0.5. We used

[3] For a complete explanation of how each parameter subscore is weighted see Young et al. 2010.

these values to establish mean sensitivity subscores of each life history parameter for all study species and for higher taxonomic groups. By evaluating these sensitivity subscores before they were weighted by climate exposure, we identified the traits that make a species most prone to climatic changes, independent of the magnitude and direction of projected climate change.

Table 4. Categorical to numeric sensitivity score conversion.

Categorical Score	Numerical Score
Greatly Increase	3
Increase	2
Somewhat Increase	1
Neutral	0
Somewhat Decrease	-1
Decrease	-2

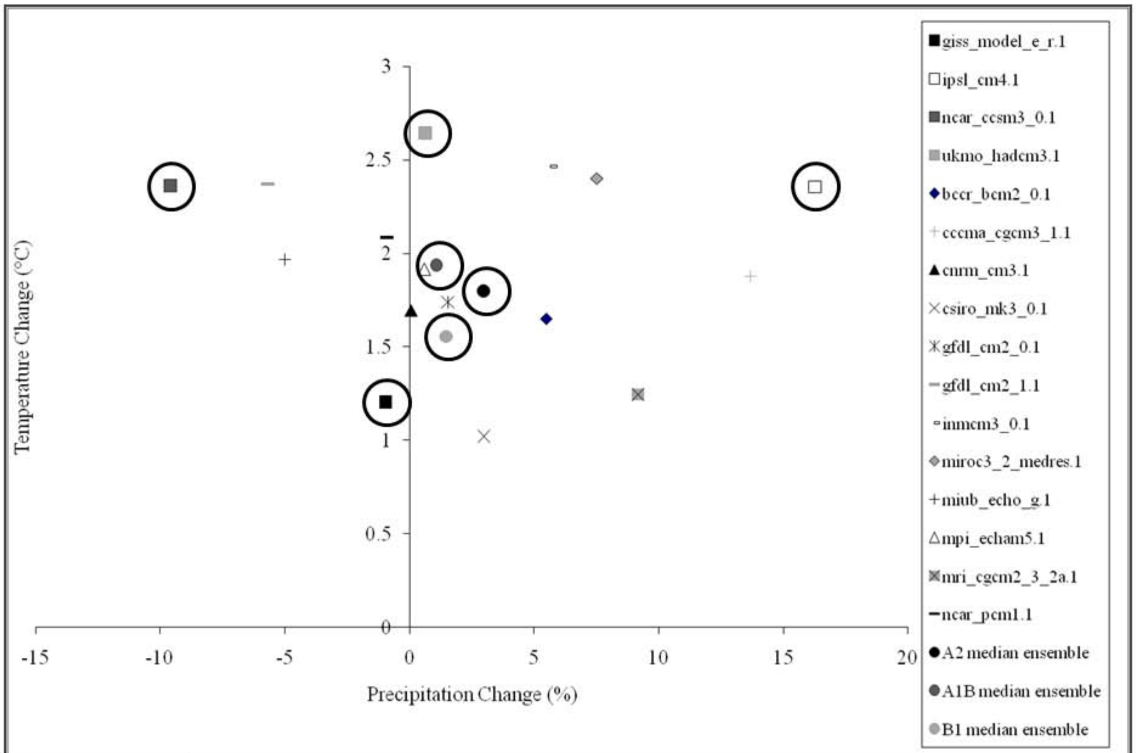
2.4 Addressing model uncertainty

Vulnerability assessments that incorporate climate projections (as opposed to sensitivity alone) have the advantage of being spatially and temporally explicit and can help identify the most vulnerable species given a specific geographic, ecologic and/or policy context (Fussel and Klein 2006). However, as with any analysis of future impacts or risks, there are uncertainties that must be considered. There are two main components of uncertainty involved in climate change vulnerability assessments: 1) The ability to predict future climate change and 2) limitations in our understanding of species life history as it pertains to their responses to climatic shifts (Patt et al. 2005, Lawler et al. 2010).

Climate uncertainty

Climate uncertainty can be further partitioned into three components: 1) Internal variability of the climate system, 2) model response uncertainty, and 3) emissions scenario uncertainty (Hawkins and Sutton 2009). Internal variability describes the natural fluctuations at the decadal scale, which are independent of anthropogenic climate change. Model response uncertainty refers to the variation among global circulation models (GCM) predictions given the same levels of radiative forcing (Glick et al. 2011). Emissions scenario uncertainty refers to the range of possible emissions levels and the subsequent future radiative forcing due to unknown changes in future human population growth, energy use, and technology (IPCC 2000).

To conduct an analysis of the effect of model response and emission scenario uncertainty on species vulnerability scoring, we kept species" sensitivity scoring constant while varying the climate input (i.e., exposure). A recent report from the Association of Fish and Wildlife Agencies (2009) recommends analyzing impacts of more than one future climate/ecological condition in order to build robust adaptation strategies. We assessed the influence of model response uncertainty on species vulnerability by running the CCVI for all species under four different GCMs. We then assessed the influence of emissions scenario uncertainty by running the CCVI for all species using climate ensembles of three different emissions scenarios (Figure 6). Internal variability makes up a significant part of projection uncertainty only a decade or two into the future before anthropogenic climate change greatly outpaces any natural annual and decadal fluctuations (Hawkins and Sutton 2009). Since our study focuses on a 2050 time horizon, we do not attempt to quantify the affect of internal variability on species vulnerability here.



Scenario	Global Circulation Model				
	Median Ensemble	GISS (Warm/Same)	UKMO (Hot/Same)	CCSM (Hot/Dry)	IPSL (Hot/Wet)
B1	•				
A1B	•	•	•	•	•
A2	•				

Figure 6. The distribution of temperature and precipitation projections for 16 GCMs at the centroid of the Willamette Valley Ecoregion. GCMs used for our analysis are marked as squares and circled. GISS forecasts a moderate temperature increase and negligible precipitation changes, UKMO forecasts a high temperature increase and negligible precipitation change, CCSM forecasts a high temperature increase and large decrease in precipitation, and IPSL forecasts a high temperature increase and a large increase in precipitation. The median ensembles of three emission scenarios are also shown, represented as small circles within the larger circles.

We make no assumptions regarding the probability of any individual climate simulation; thus, the four GCMs and three emissions scenario ensembles chosen are meant to encompass the range of variability represented across the multitude of plausible future climates. To fully reflect the sensitivity of species vulnerability to differing GCMs, we chose four models that represented the "bookends" of temperature and precipitation change specific to the Willamette Valley (this method of selecting plausible extremes is standard practice for scenario planning, for example see Cayan et al. 2008). The GCMs used include: GISS_e_r_1 (GISS) that forecasts moderate warming and negligible precipitation change, UKMO-HadCM3.1 (UKMO) that forecasts high temperature increases and negligible precipitation change, near_CCSM_0.1 (CCSM) that forecasts high temperature increases and a large reduction in precipitation, and IPSL-cm4.1 (IPSL) that forecasts high temperature increases and large precipitation increases (Maurer et al. 2007) (Figure 6). These four model realizations were assessed using a mid-range emissions scenario (A1B) (Solomon et al. 2007) to isolate potential GCM effects[4]. To reflect the sensitivity of species vulnerability to differing emissions scenarios, we used three standard IPCC emissions scenarios: A gradual reduction of emissions over the next century (B2), a leveling-off of emissions by mid-21st century (A1B), and a continued increase in emissions through the end of the 21st century (A2) (IPCC 2000). To isolate the effect of emissions, all emissions scenarios were run using a median ensemble of the 16 GCMs (i.e., at each grid cell, the median projected value from all models is used to create a mosaic of climate forecasts) available from Climate Wizard (Girvetz et al. 2009).

As a metric of climate confidence (i.e., the influence of climate uncertainty on a species" vulnerability score), we examined the range of vulnerability scores calculated across the four GCM simulations for a given species. Range was calculated as the difference between the highest and lowest vulnerability scores under the different climate scenarios. For species whose vulnerability score did not change across all four climate scenarios, (range = 0), a "Very High" climate confidence score was assigned. For those species whose vulnerability scores had a range of 1, a confidence score of "High" was assigned. For ranges of 2 and 3, scores of "Moderate" and "Low" were assigned, respectively (Table 3). We then used regression analysis to compare the ranges of vulnerability results with the mean vulnerability score.

Species life history uncertainty

In order to account for variability of the type and quality of life history data available across species, CCVI permits that as many as six of the sensitivity categories may be left blank while still enabling the final vulnerability calculation. Similarly, one of the four indirect climate change exposure categories may be left blank if species data pertaining to that category is inadequate. In cases where the evaluator lacks specific information to choose between life history subcategories, the CCVI software allows multiple vulnerability subcategories to be selected for each life history (e.g., neutral and somewhat increase). When calculating the final vulnerability score, a Monte Carlo simulation of 1000 runs is performed to account for different outcomes resulting from the selection of multiple vulnerability subcategories. A "confidence in species information" score, from "Low to "Very high", is given based on this simulation. When different combinations result in varied vulnerability scores, a lower confidence score is given (Young et al. 2010).

[4] Note that the recommended use of a medium climate scenario may underestimate species vulnerability given the current pace of global emissions.

3 Results

3.1 Which OCS Strategy Species and Taxa are most vulnerable to climate change?

A vulnerability assessment of 46 Willamette Valley Strategy Species or subspecies under the baseline climate scenario (A1B moderate emissions scenario and 16 climate-model ensemble) resulted in vulnerability scores ranging from lowest vulnerability (5) to moderate vulnerability (3). Under the baseline scenario, no species received a highly vulnerable (2) or most vulnerable (1) score. The species with moderate vulnerability scores included five fish Evolutionarily Significant Units (ESU), one plant species, and the invertebrate species assessed (Table 5).

When running all species through the index using a more extreme climate scenario characterized by greater warming and increases in precipitation,[5] our study species predictably showed greater vulnerability. Vulnerability scores under this scenario ranged from the lowest vulnerability score (5) to the highest vulnerability score (1). Four of the species predicted to be most vulnerable under the baseline scenario remained at the top of the list under the extreme climate scenario, albeit with a higher vulnerability score. These (sub)species are Southwest Washington/Columbia River ESU of the Coastal Cutthroat Trout, Lower Columbia River Chinook Salmon (fall run), Way-side aster, and Fender"s Blue Butterfly; all of which received a score of highest vulnerability (1). Also noteworthy is the change of vulnerability score of Howellia, which was given a low vulnerability (4) score under the baseline scenario but had the highest vulnerability score (1) under the extreme scenario (Table 5).

[5] The extreme climate scenario used in this case is described by the IPSL climate model. The CCSM3 model shows similar warming but has large decreases in precipitation (as opposed to the increases in precipitation predicted under IPSL) (Figure 6). The CCSM3 model resulted in very similar CCVI results as the IPSL because the index tests species" sensitivity to changes in precipitation, regardless of sign. The Southwestern Washington Steelhead (Winter Run) is the only species where results differed between the two extreme models. The species received the highest vulnerability score (1) under the CCSM3 model and the high vulnerability score (2) under the IPSL model.

Table 5. Study species ranked from most vulnerable to least vulnerable according to the baseline climate scenario (ensemble of models) scores followed by the extreme scenario (IPSL model) scores. Conservation rankings are taken from NatureServe and represent current threats and species condition. Species are given a global (G), state (S) and infraspecific taxon (T) ranks where applicable. An H indicates that the species may be extirpated from the area. The most relevant ranking for the study species, subspecies or population is listed here. Climate confidence and CCVI species information confidence are also listed as measures of uncertainty of results (see definitions of confidence metrics in uncertainty section above).

Common Name	Scientific Name	Taxon	Conservation Rank	Baseline Scenario	Extreme Scenario	Climate Confidence	Species Info Confidence
Coastal Cutthroat Trout (Southwest Columbia River ESU)	*Oncorhynchus clarkii (pop. 2)*	Fish	T3	3	1	Low	Very High
Chinook Salmon (Lower Columbia River ESU, Fall Run)	*Oncorhynchus tshawytscha (pop. 22)*	Fish	T2	3	1	Low	High
Way-side Aster	*Aster vialis*	Plant	S3	3	1	Moderate	Very High
Fender's Blue Butterfly	*Icaricia icarioides fendereri*	Invert	T1	3	1	Moderate	Very High
Steelhead (Southwest Washington ESU, Winter Run)	*Oncorhynchus mykiss (pop. 23)*	Fish	T3	3	2	Low	Low
Taylor's Checkerspot Butterfly	*Euphydryas editha taylori*	Invert	T1	3	2	Moderate	Very High
Chinook Salmon (Lower Columbia River ESU, Spring Run)	*Oncorhynchus tshawytscha (pop 21)*	Fish	T2	3	2	Moderate	Moderate
Steelhead (Lower Columbia River ESU, Winter Run)	*Oncorhynchus mykiss (pop 14)*	Fish	T2	3	2	Moderate	Very High
Howellia	*Howellia aquatilis*	Plant	S1	4	1	Low	High
Peacock Larkspur	*Delphinium xpavonaceum*	Plant	S1	4	2	Moderate	Very High
Bull Trout	*Salvelinus confluentus*	Fish	T2	4	2	Moderate	Very High
Chinook Salmon (Upper Willamette River ESU, Spring Run)	*Oncorhynchus tshawytscha (pop 16)*	Fish	T2	4	2	Moderate	Very High
Oregon Chub	*Oregonichthys crameri*	Fish	S2	4	2	Moderate	Very High
Coho Salmon (Lower Columbia River/SW Washington Coast ESU)	*Oncorhynchus kisutch (pop 1)*	Fish	T2	4	2	Moderate	Moderate

Table 5. Continued.

Common Name	Scientific Name	Taxon	Conservation Rank	Baseline Scenario	Extreme Scenario	Climate Confidence	Species Info Confidence
Coho Salmon (Oregon Coast ESU)	*Oncorhynchus kisutch (pop 3)*	Fish	T2	4	2	Moderate	Very High
Steelhead (Lower Columbia River ESU, Summer Run)	*Oncorhynchus mykiss (pop. 26)*	Fish	T2	4	2	Moderate	Moderate
Kincaid's Lupine	*Lupinus oreganus var. kincaidii*	Plant	T2	4	2	Moderate	Moderate
Nelson's Checker-mallow	*Sidalcea nelsoniana*	Plant	S2	4	2	Moderate	Very High
White Rock Larkspur	*Delphinium leucophaeum*	Plant	S2	4	2	Moderate	Very High
Golden Paintbrush	*Castilleja levisecta*	Plant	SH	4	2	Moderate	Very High
Willamette Daisy	*Erigeron decumbens*	Plant	S1	4	3	High	Very High
Steelhead (Oregon Coast ESU, Winter Run)	*Oncorhynchus mykiss (pop 15)*	Fish	T2	4	3	High	Very High
Bradshaw's Desert Parsley	*Lomatium bradshawii*	Plant	S2	4	3	High	Very High
White Topped Aster	*Aster curtus*	Plant	S2	4	3	High	Very High
Foothill Yellow-legged Frog	*Rana boylii*	Amph	S2-3	4	3	High	Very High
Steelhead (Upper Willamette River ESU, Winter Run)	*Oncorhynchus mykiss (pop. 20)*	Fish	T2	4	4	Very High	Very High
Northwestern Pond Turtle	*Clemmys marmorata marmorata*	Reptile	T3	4	4	Very High	Very High
Townsend's Big-eared Bat	*Corynorhinus townsendii*	Mammal	T2	4	4	Very High	Very High
Western Gray Squirrel	*Sciurus griseus*	Mammal	S4	4	4	Very High	Very High
Northern Red-legged Frog	*Rana aurora*	Amph	S3-4	4	4	Very High	Very high
Western Painted Turtle	*Chrysmys picta bellii*	Reptile	T5	4	4	Very High	Very High

Table 5. Continued.

Common Name	Scientific Name	Taxon	Conservation Rank	Baseline Scenario	Extreme Scenario	Climate Confidence	Species Info Confidence
Streaked Horned Lark	*Eremophila alpestris strigata*	Bird	T2	4*	5	High	Moderate
Acorn Woodpecker	*Melanerpes formicivorus*	Bird	S3	4*	5	High	Moderate
California Brown Bat	*Myotis californicus*	Mammal	S3	4*	5	Very High	Very High
Canada Goose	*Branta canadensis occidentalis*	Bird	S5	5	5	High	Moderate
Vesper Sparrow (Oregon Subspecies)	*affinis*	Bird	T3	5	5	Very High	High
Purple Martin	*Progne subis*	Bird	S2	5	5	Very High	Very High
Grasshopper sparrow	*Ammodramaus savannarum*	Bird	S2	5	5	Very High	Very High
Short-eared Owl	*Asio flammeus*	Bird	S3	5	5	Very High	Low
Chipping Sparrow	*Spizella passerina*	Bird	S4	5	5	Very High	Very High
Willow Flycatcher	*Empidonax traillii*	Bird	S4	5	5	Very High	Very High
White-breasted Nuthatch (Slender-billed Subspecies)	*Sitta carolinensis*	Bird	S4	5	5	Very High	Very High
Western Bluebird	*Sialia mexicana Swainson*	Bird	S4	5	5	Very High	Very High
Western Meadowlark	*Sturnella neglecta*	Bird	S4	5	5	Very High	Very High
Yellow-breasted Chat	*Icteria virens*	Bird	S4	5	5	Very High	Very High
Common Nighthawk	*Chordeiles minor*	Bird	S5	5	5	Very High	Very High

* The CCVI allows for the possibility that some species will benefit from climate change. For some bird species we see a decrease in vulnerability under a more extreme scenario suggesting these species may benefit from increased warming.

3.2 Willamette Valley taxon mean vulnerability

The assessed species or subspecies are unevenly distributed across seven broad taxonomic groups: Birds (14), mammals (3), reptiles (2), amphibians (2), plants (10), fishes (13) and invertebrates (2)[6]. Among these seven taxa, Willamette Valley Strategy Species invertebrates received the lowest mean score, indicating highest relative vulnerability. Following invertebrates, fishes and plants are shown to be most vulnerable to climate change among those species assessed. Amphibians, reptiles and mammals all received mean vulnerability scores of 4 in the baseline scenario. Birds received the lowest mean score of all taxa, indicating lowest relative vulnerability to climate change (Figure 7).

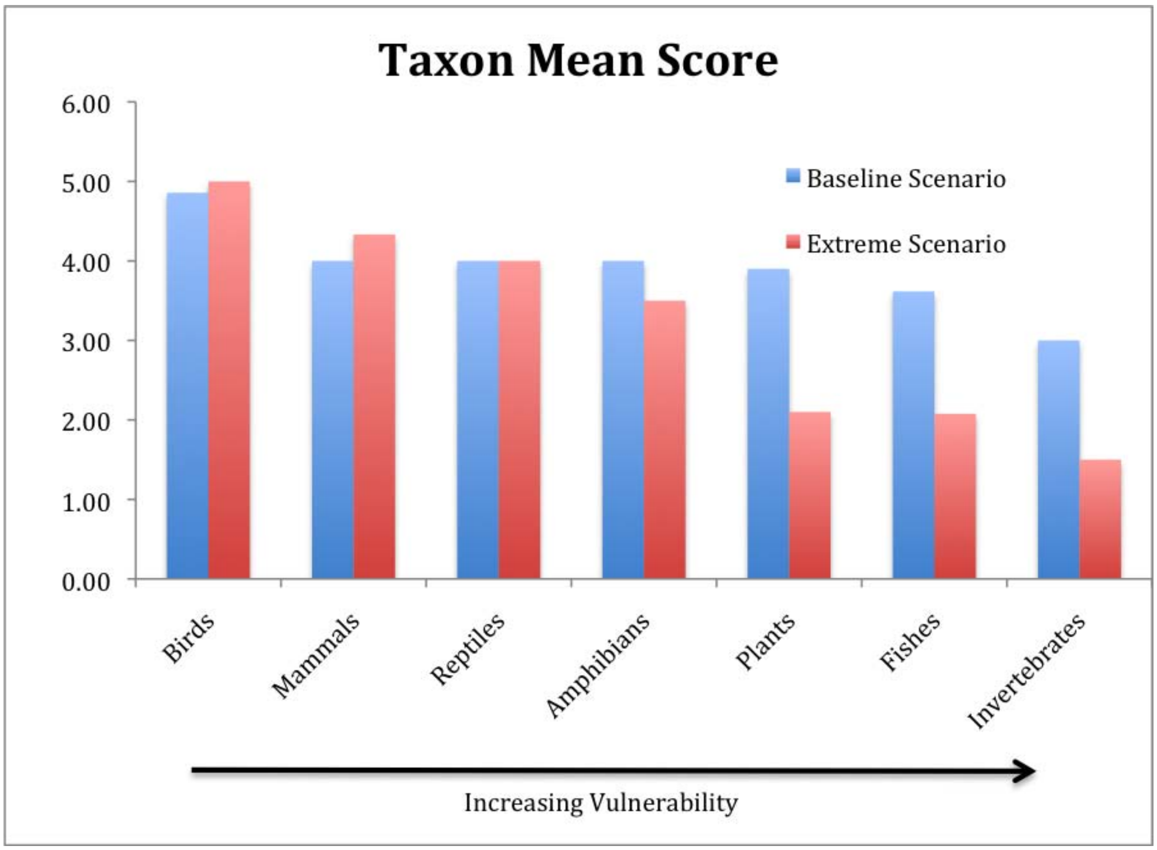


Figure 7. Average score of assessed species for each of the seven major taxa. Taxa are listed left to right beginning with the least vulnerable and ending with the most vulnerable. The baseline climate scenario is described by an ensemble of 16 climate models and the extreme scenario is one of a high degree of warming and increased precipitation described by the IPSL climate model.

[6] Because of this uneven distribution and limited sample size within each taxa, our results only represent those species assessed and not the broader taxa.

3.3 Which sensitivity parameters most influenced vulnerability scores?

By converting sensitivity subscores from the life history parameters into numeric values, we are able to aggregate sensitivities for all study species and taxa. An aggregation of all 46 study species reveals that the macro temperature (an indication of temperature tolerance at a broad scale), disturbance, micro precipitation (dependence on specific precipitation or hydrologic regimes), physical habitat, and micro temperature parameters most contributed to an increase in climate change sensitivity. On average, the natural barriers, dispersal ability and macro precipitation parameters most contributed to a decrease in climate change sensitivity (Figure 8). Definitions of each sensitivity parameter are presented in Table 2 above.

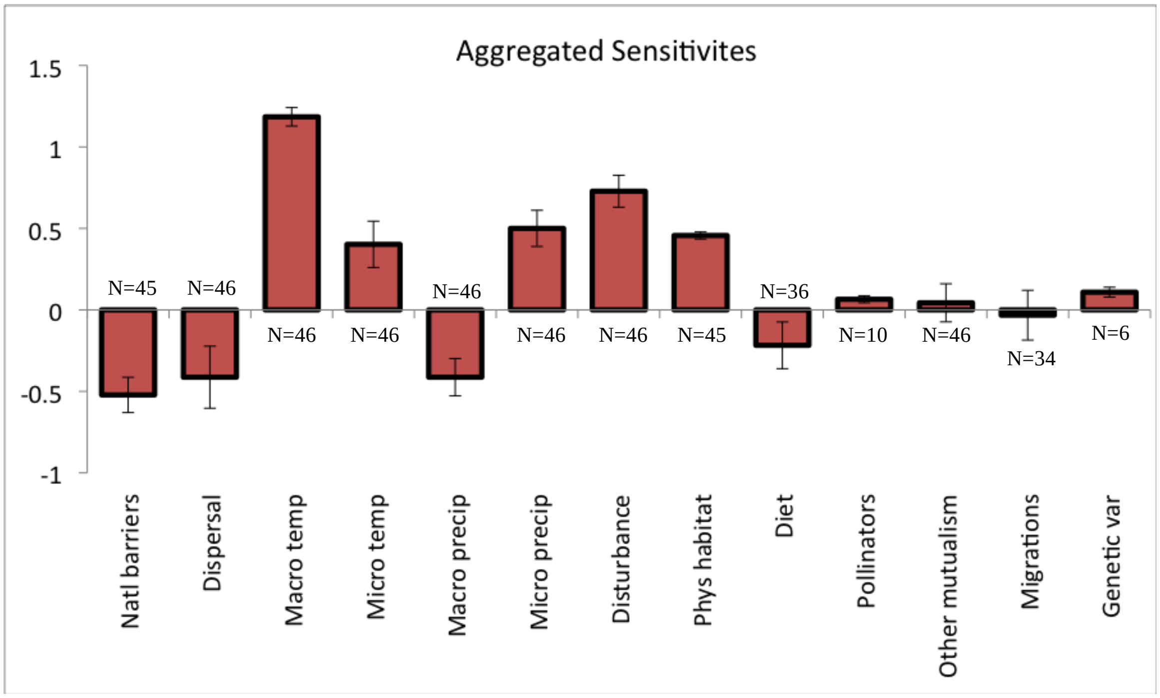


Figure 8. Aggregated species sensitivities to climate change. Positive values indicate an increase in sensitivity to climate change and negative values indicate a decrease in sensitivity. Scores presented here are the average for all 46 species. Because not all species received scores for each parameter, only those parameters that were scored for more than one species are included here.

The influence of each parameter on climate sensitivity varies for each species and between taxa (see Figure 9 for taxa sensitivities and Appendix A for individual species sensitivity scores).

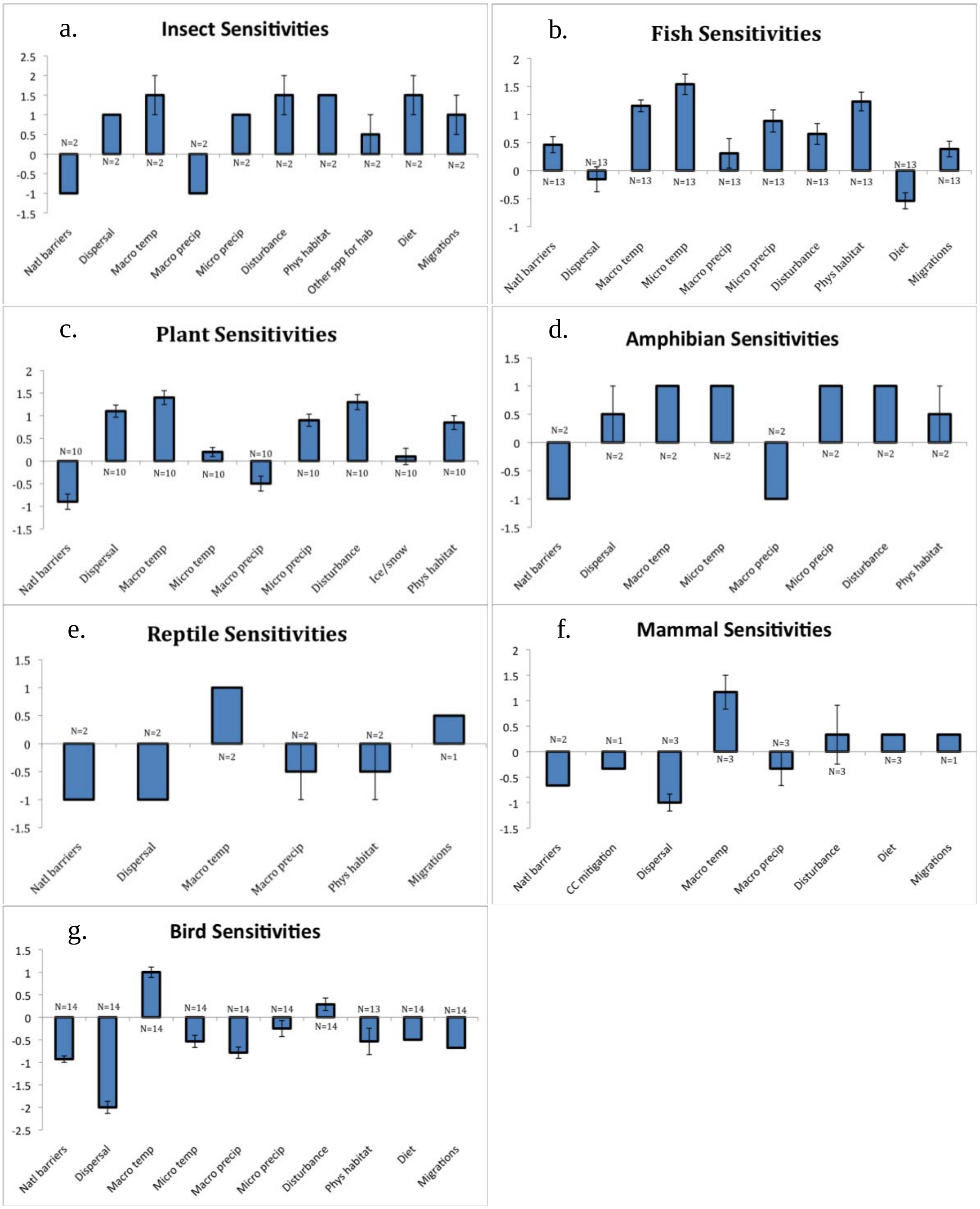


Figure 9. Average sensitivity scores for a) 2 insects, b) 13 fishes, c) 10 plants, d) 2 amphibians, e) 2 reptiles, f) 3 mammals, and g) 14 birds. Positive values indicate an increased sensitivity and negative values indicate decreased sensitivity on average.

3.4 Estimating model uncertainty

To quantify confidence in our results we used two metrics: 1) The impact of climate uncertainty on species vulnerability scores, and 2) our confidence in the species life history information used.

Climate uncertainty
Our results show a general decrease in climate confidence as vulnerability scores increase (Figure 10). Thus, for those species likely to be most affected by climate change, our ability to estimate the magnitude of that affect is limited by our understanding of the magnitude of future temperature and precipitation change.

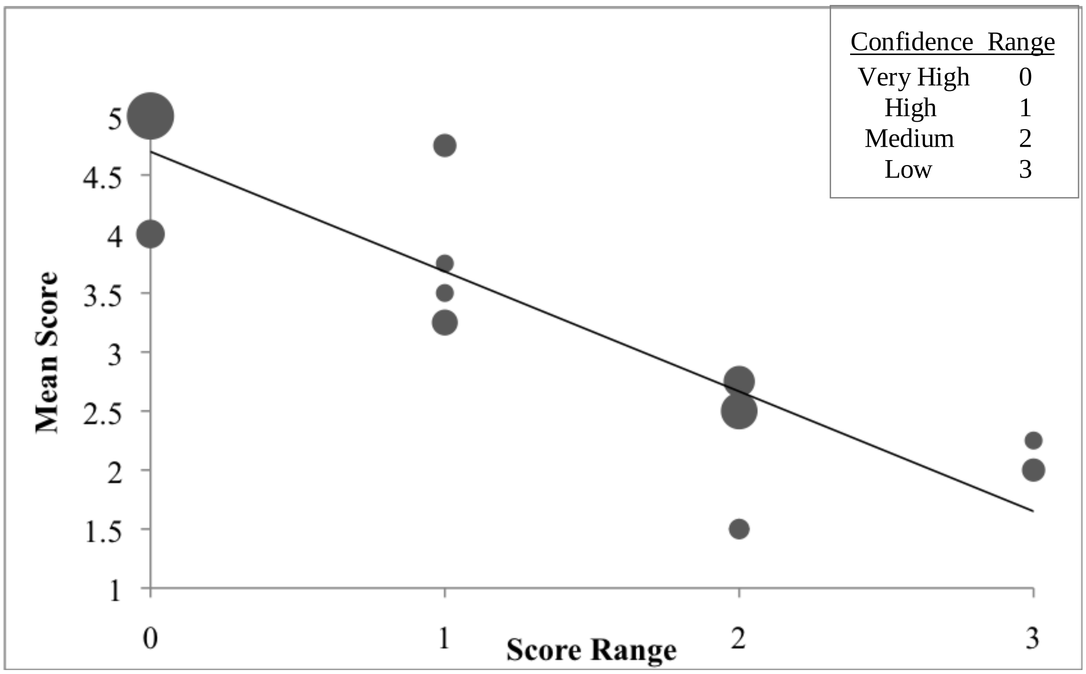


Figure 10. The relationships between mean vulnerability scores and vulnerability score ranges across four GCMs. Pearson‟s correlation coefficient is r = -0.9011. High mean scores and high score ranges indicate low vulnerability and low climate confidence respectively. The size of the circles corresponds with the number of species receiving the same mean score and score range at that point.

The effect of emission scenario choice on vulnerability score was also assessed for low (B1), medium (A1B) and high (A2) scenarios (Figure 6), while keeping GCM effect constant (using a 16 model ensemble). However, under these three scenarios the final vulnerability score varied for only 11 of the 46 assessed species, giving a vulnerability score range of 1 (our equivalent of "High" confidence). For all other species the final vulnerability score did not vary among the emissions scenarios (i.e., range = 0 or a "Very High" confidence). No species showed a range of more than 1 when varying only emissions scenario. Because of the minimal impact of emissions scenario on vulnerability score uncertainty, GCM variation alone was used as our metric for climate confidence.

Species life history uncertainty

To measure confidence in species life history information, we used the scoring system built into the CCVI described above and in Young et al. (2010). Among the species assessed, there appears to be no relationship between species vulnerability and species information confidence (Figure 11). However, low scores reflect ambiguity of available species life history knowledge as it relates to the sensitivity parameters used in the CCVI and does not account for any complete lack of information. For example, we were not able to assess the vulnerability of 13 Willamette Valley Strategy Species due to the lack of either life history or range information. Because these species were not evaluated for this report they are also not included in the analysis of uncertainty.

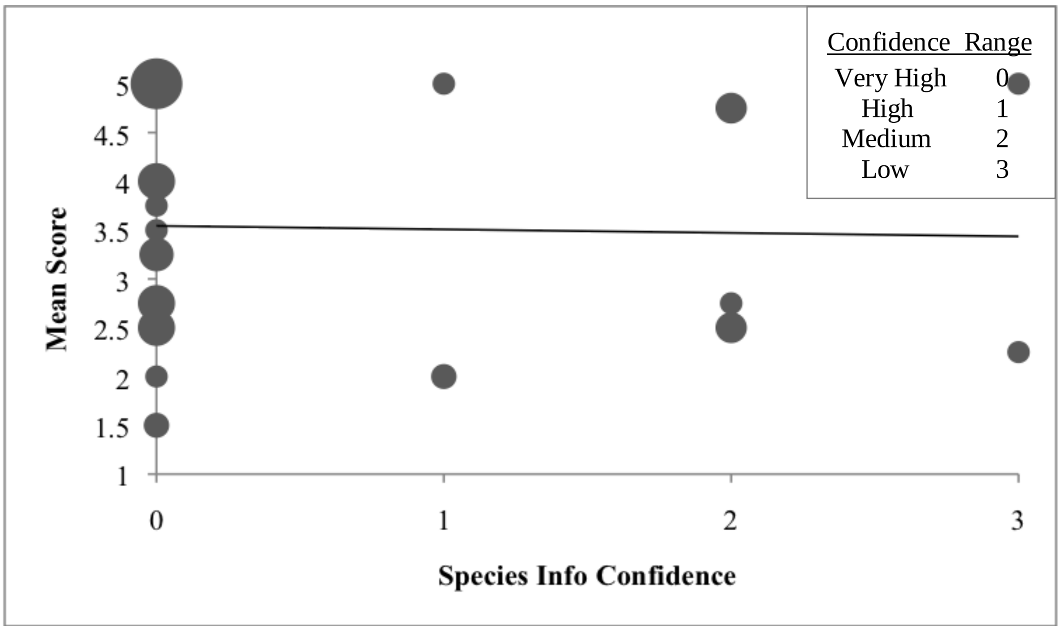


Figure 11. The relationships between species information confidence and mean vulnerability scores across four GCMs. Pearson‟s correlation coefficient is r = -0.02877. The size of the circles corresponds with the number of species receiving the same mean score and species information confidence score at that point.

4. Discussion

4.1 Prioritization of adaptation effort using vulnerability assessments

In this assessment, we determined which of 46 Willamette Valley OCS Strategy Species and corresponding taxa were most vulnerable to climate change. We also assessed which life history characteristics most influenced a species" vulnerability by aiding or inhibiting adaptation to climate change. While social, economic, and political factors will undoubtedly also influence conservation actions (Knights and Cowley 2007), vulnerability assessments offer an objective, science-based approach that can help managers prioritize conservation effort and dollars in the coming decades. Furthermore, the identification of those life history characteristics which most contribute to a species vulnerability will help managers select strategies and actions that best advance the conservation goals of the Willamette Valley.

As is often done in biodiversity conservation, planning and funds can be directed toward only the highest priority species, as active management of all affected species can be prohibitively expensive. This may be an effective approach for the Willamette Valley if several highly vulnerable animals or plants can serve as flagship species, garnering public support and long-term investment in climate adaptation efforts. On the other hand, a conservation plan focused at the taxa level, may more broadly encompass the needs of all 46 Strategy Species as well as other vulnerable animals and plants not assessed here. However, managing for climate adaptation at the taxa level becomes challenging when addressing particularly diverse groups and when composite species are likely to respond to climate change in disparate ways. For example, while the two Willamette Valley invertebrate species assessed (both butterflies) shared many of the biophysical drivers of climate vulnerability, other invertebrates within the region are likely to respond very differently. Species such as butterflies are considerably more sensitive to climate change (Hastie et al. 2003, Thomas et al. 2006) than other invertebrates such as mosquitoes and ticks, which are predicted to undergo range expansion under certain climate scenarios (Gubler et al. 2001, Wilson 2001, Harvell et al. 2002). Therefore, when managing for climate adaptation at the taxa level, it becomes important to clarify which species are being targeted within a taxa and to understand how management actions will affect the entire ecological community.

Regardless of the unit of focus, the CCVI tool and our results provide a method of prioritization that coupled with local knowledge can inform species management in the face of climate change. This may be especially valuable for drawing attention to species that are highly vulnerable to climate change, but are given lower priority when considering only non-climate change threats (e.g., Coastal Cutthroat Trout and Way-side Aster; Table 5). By exposing such discrepancies, vulnerability assessments can assist in restructuring management priorities in a manner that reflects both traditional conservation threats and climate vulnerability.

4.2 Sensitivities and implications for management

By parsing out which ecological parameters in the CCVI most affect sensitivity scores (by species, taxa, and overall), we were able to highlight specific management options that may help mitigate the consequences of climate change. Both parameters that increase and decrease sensitivity are discussed below and the life history characteristics they reflect can be viewed as challenges and opportunities, respectively. The list of management options presented here are not exhaustive but range from well-known to rarely-attempted strategies extracted from published articles, books and white papers. We do not attempt to recommend specific management actions for the Willamette Valley but hope to illustrate the range of possibilities for managers and to foster the development of novel strategies to help wildlife adapt to climate change.

Managers have a choice about what types of management adaptations or solutions they implement when facing the challenges of climate change. According to Heller & Zavaleta (2009), a “complete” management plan would span the range from risk-averse to risk-tolerant. An example of a risk-averse strategy would be for managers to focus on relieving non-climate stressors that are relatively well understood (Inkley et al. 2004, Fischlin et al. 2007), thereby increasing resilience to novel threats such as climate change. Species translocation would qualify as a *risk-tolerant strategy* (Cole et al. 2010) as it involves dramatic and largely irreversible alterations of ecological communities. *Middle-of-the-road strategies* could entail relaxing genetic guidelines in restoration practices (i.e., mixing of genetic diversity between populations with disparate climatic histories) (Heller and Zavaleta 2009, Cole et al. 2010). *Risk-averse strategies* could be viewed as short-term and reactive whereas risk-tolerant strategies may be more long-term and proactive (Heller and Zavaleta 2009, Cole et al. 2010, Miles et al. 2010). All have pros and cons and strategy selection will necessarily depend upon local ecology knowledge, time pressures, and economic considerations. The management options outlined below span this range of risk-averse to risk-tolerant.

4.2.1 All Taxa

The following ecological parameters most prominently increased or decreased sensitivity to climate change across all taxa assessed. For full definitions of CCVI parameters see Table 2 and CCVI documentation (Young et al. 2010).

Increase sensitivity:

- Macro Temperature - minimal exposure to past temperature variation
- Disturbance - dependence on specific disturbance regimes
- Micro Precipitation - sensitivity to changes in precipitation or hydrology
- Physical Habitat – requires specific habitat types

Decrease sensitivity:

- Natural Barriers – limited natural barriers to dispersal
- Dispersal – high ability to disperse to new areas
- Macro Precipitation – has been exposed to high variation of past precipitation

Increase sensitivity:

Macro Temperature
CCVI uses the parameter Macro Temperature as a proxy for tolerance of temperature changes on the broad scale (both spatially and temporally). Within the Willamette Valley, Strategy Species‟ populations have experienced relatively small inter-annual fluctuations in temperature over the past 50 years. For those species adapted to such stability, any dramatic shifts in the temperature regime brought on by climate change could be detrimental. This may be especially true for those species or populations whose entire life cycle is completely contained within the Willamette Valley. Two management options have the potential to counter this sensitivity: 1) Increase connectivity so that species can track their appropriate temperature niche (Moritz et al. 2008, Heller and Zavaleta 2009, Mawdsley et al. 2009, Lindenmayer et al. 2010) and introduce novel genotypes from remote populations that have experienced broader temperature variation in the past (Cole et al. 2010).

Of course, the most direct way to mitigate rising temperatures is to reduce carbon emissions globally, thus reducing the amount of change within the Willamette Valley and elsewhere. In fact, mitigation of emissions is essential to slow the rate of climate change and allow adaptation efforts to be successful (Hansen and Hoffman 2011). Unfortunately, reducing emissions effectively and quickly is difficult and largely beyond the purview of local managers. Therefore, large-scale efforts to reduce emissions should focus on policy initiatives at the state and national levels.

Also, it should be noted that Macro Temperature measures whether the expected temperature change is within the study species‟ realm of experience and can only indirectly assess whether a species can tolerate any actual increase. Thus, the increase in sensitivity across all taxa indicates that research into physiological tolerance of species would be very informative. Additionally, an assessment of past temperature exposure across the species‟ range, rather than just within the Willamette Valley would provide a better understanding of this indirect estimation of thermal tolerance for the entire species.

Disturbance
Many study species (including the butterflies, amphibians and most plant species assessed) depend on disturbance regimes such as seasonal fires and/or floods, which will likely be altered by climate change. Within the Willamette Valley, perhaps the most notable disturbance regime change is a predicted increase fire frequency and severity (Doppelt et al. 2009). Trying to maintain the “normal” fire regime indefinitely may prove ineffective and expensive if environmental changes are significant (Cole et al. 2010). However, doing so in the short-term with prescribed burns, may be a time-gain strategy for managers to plan adequately for longer-term changes (Cole et al. 2010). Protecting fire refugia (i.e., areas where fire will likely not occur) may also help species resist changes in fire regime (Cole et al. 2010, Lindenmayer et al. 2010). Additionally, experimental and observational post-disturbance research, would help managers better understand study species‟ response to alterations in disturbance regimes and plan for future disturbance events such as fires (Lindenmayer et al. 2010). For example, such

research could help determine if a change in timing or location of prescribed fires would be beneficiary (Cole et al. 2010).

The disturbance category also encompasses increased pest or disease outbreaks. We found little literature on how Willamette Valley species are likely to be affected by such disturbances, thus more research should be conducted regarding this potential stressor. Two prominent examples of a diseases of concern include the chytrid fungus which is already severely impacting amphibian populations across the US (Hopkins 2007, Kilpatrick et al. 2010), and sudden oak death which is affecting oak-dominated systems along the Pacific Coast (Rizzo and Garbelotto 2003). Research into early detection, identification of high contact areas, and containment plans, as is currently being undertaken on a global scale by the USAID"s Emerging Pandemic Threats Program (http://www.usaid.gov/), could help reduce the impact on sensitive species for major diseases of concern.

Micro Precipitation
Many Willamette Valley species depend on a strongly seasonal precipitation regime and/or habitats characterized by a specific hydrological regime such as wetland, riparian or aquatic areas. It is expected that precipitation timing, quantity, and form (i.e., from snow to rain) will be affected by climate change and that species sensitive to such changes will be negatively impacted. Restoring natural flooding or water retention within the landscape may help alleviate some of the stressors associated with this problem. Examples of management actions include, but are not limited to, altering water impoundments, diversions, or livestock grazing (Cole et al. 2010).

Physical Habitat
A number of strategy species require specific physical habitat characteristics, such as soil type, physical features (e.g., cliffs), or aquatic habitat. This dependence on specific physical habitats for species within the plant, invertebrate, amphibian, and fish taxa may hinder their ability to disperse and thrive elsewhere. If the species" current habitats are altered by climate change, they may have no easy refuge. Potential management options include active translocation of threatened species and alleviation of non-climate threats that reduce the availability of critical habitat likely altered by climate change.

Decrease sensitivity:

Natural Barriers
With the exception of fish, for all taxa in the Willamette Valley, the dispersal or migration of individuals are not limited by large natural features such as coastline or mountain ranges. The fact that these species are not restricted to an island or an isthmus may enable them to track their appropriate climatic niche in the coming decades provided anthropogenic barriers are removed or softened. The lack of large-scale natural barriers can be viewed as an opportunity for managers as it suggests that maintaining landscape connectivity may be sufficient for species adaptation through range shifts without resorting to more drastic measures such as species translocation.

Anthropogenic barriers such as roads, intensive agricultural and urban areas will likely be more problematic for climate-sensitive species than large natural barriers. While CCVI includes an additional parameter to assess anthropogenic barriers, we believe the tool underestimates their importance in its current version. Therefore we believe that a reduction of the impact of anthropogenic barriers and an increase in landscape connectivity remains critical in the Willamette Valley.

Maintaining landscape connectivity may be achieved for some mobile species through the use of larger-scale landscape linkages (e.g., corridors), stepping-stones, stopover areas (for migratory waterfowl), and "softening" of the matrix (Hannah et al. 2002, Heinz Center 2008, Heller and Zavaleta 2009, Mawdsley et al. 2009, Cole et al. 2010). Softening of the matrix may be preferable for non-mobile species and where expensive land-acquisition makes traditional linkages difficult. Such steps can include the incorporation of conservation principals into agricultural or resource extraction practices, the use of buffer zones, and the use of landowner conservation easements (Hannah et al. 2002, Donald and Evans 2006, Fischlin et al. 2007, Heller and Zavaleta 2009). For fish species, removing barriers such as dams would greatly aid their ability to track climatic changes (Heller and Zavaleta 2009). Finally, protecting or establishing reserves and semi-natural areas close to existing protected areas would greatly facilitate dispersal within the Willamette Valley‟s reserve network (Lindenmayer et al. 2010). Planners and managers should keep in mind that different types of species require different types and levels of connectivity; in other words, one size does not fit all (e.g., Minor and Lookingbill 2010).

Dispersal
Many taxa, especially birds, have a great potential to disperse long distances and evade the worst effects of climate change. If landscape connectivity and stopover areas are maintained (see above) long-ranging species may be able to adapt to rapidly changing conditions without the need for controversial measures such as species translocation.

Macro Precipitation
The fact that many of the Strategy Species‟ have experienced sizeable inter-annual precipitation fluctuations within the valley in the past may signal an ability to adapt to future changes in the precipitation regime at the broad scale. No immediate management actions are suggested by results to address this parameter. However, negative responses by similar species or populations in areas expected to experience greater shifts in precipitation could provide early warnings for related Willamette Valley species.

Management options synopsis (for all taxa):

- Encourage policy and regulatory initiatives limiting regional and national greenhouse gas emissions
- Reduce greenhouse gas emissions from machinery and buildings under local control
- Increase landscape connectivity: Remove physical barriers such as dams, construct road crossing structures, strategically-placed landscape linkages/corridors, stepping stones, stopover areas, intra-reserve refugia, and softening of the agricultural and urban matrix

- Research physiological capacity of species in the valley to survive at increased temperatures and research climate exposure of species in its widest recent range (if range extends outside of valley) to assess genetic/phenotypic capacity for adaptation
- Use prescribed burns to maintain "normal" fire regime in the short-term
- Conduct post-fire research to assess species‟ response to different fire magnitudes and intensities
- Conduct research into the likelihood of pest/disease outbreaks in valley and set-up early detection systems and response plans
- Restore the natural flood regime and increase water retention capacities of sensitive systems
- Protect existing reserves and establish new protected areas close to current reserves as well as increase conservation practices outside of protected areas

4.2.2 Invertebrate Strategy Species

Increase sensitivity:

- Diet – limited by a specific diet
- Physical Habitat – requires specific habitat types
- Dispersal – poor dispersal ability
- Migrations and movements - short/uncommon migratory patterns
- Macro Temperature - minimal exposure to past temperature variation
- Micro Precipitation - sensitivity to changes in precipitation or hydrology

Decrease sensitivity:

- Natural Barriers – limited natural barriers to dispersal
- Macro Precipitation - exposed to high variation of past precipitation

Increased sensitivity:

Diet and Physical Habitat

The two butterfly species that make up the invertebrate category in this assessment have specialized diets that require a small number of grassland forbs for nectar sources (e.g., *Castilleja levisecta*) (Wilson et al. 1997, Vaughan and Black 2002, Black and Vaughan 2005, Kaye et al. 2010, NatureServe 2010). Linked to dietary specificity is the species‟ reliance on specific host plants for oviposition (Wilson et al. 1997, Black and Vaughan 2005, Kaye et al. 2010). For example, Taylor‟s checkerspot almost exclusively oviposits on *Lupinus kincaidii* (Kincaid"s lupine[7]). Augmentation through active cultivation and restoration of butterfly host plants is one principal way that managers could aid these species as they experience new stressors associated with climate change. Already, Benton County officials (Kaye et al. 2010) are planning on planting key forb species in both restored and "new" habitats for these two butterfly species. This would help address sensitivities related to diet, physical habitat, dispersal, and migration of these Strategy Species.

Dispersal and Migration
Likely due to their habitat and dietary dependencies, these two species are not known to disperse long distances (up to 1.5 km, but as low as 100m) and do not migrate regularly (Wilson et al. 1997, Kaye et al. 2010). In addition to establishing "new" habitat, currently occupied areas could be connected to ensure that butterflies can disperse as needed in response to climate change pressures. For butterflies, increasing connectivity using stepping stones may be a feasible alternative to classic corridors/linkages (Schultz 1998, Öckinger and Smith 2008). In the case of Fender"s blue butterfly, research indicates that increasing connectivity between small patches may be better for some populations than large, isolated patches (Schultz and Crone 2005).

Macro Temperature
Like other Willamette Valley species, these two butterflies have had limited exposure to wide temperature fluctuations within their valley ranges in the past 50 years. This suggests that valley populations may lack the physiological plasticity required to adapt to changing temperatures in the coming decades, although direct measurements of physiological tolerance are lacking. For a more complete discussion of Macro Temperature see the All Taxa section above. Limited temperature tolerance would be more of an issue in the summer than the winter for this taxa because of timing of oviposition and larval emergence, two highly crucial and environmentally-sensitive events that only occur in warm months (Wilson et al. 1997, Black and Vaughn 2005, Kaye et al. 2010). On the other hand, butterfly species, in general, may be better able to adapt to rapidly changing climate because their generation time per year is relatively short (Altermatt 2010).

Micro Precipitation
Butterfly ecology is highly sensitive to the timing of precipitation events. Thus significant changes in average timing and quantity of seasonal precipitation leading to flooding or drought may severely decrease butterfly populations (Murphy and Weiss 1992). This sensitivity mainly stems from the fact that altered precipitation disrupts the timing between larval/pupal development and senescence of the host plant (Murphy and Weiss 1992). Research should be conducted to better understand the optimal timing for these butterfly species and the effect that altered precipitation will have at the population level.

---

[7] Note that Kincaid"s Lupine was found to have a relatively low vulnerability (4) under the baseline climate scenario and a relatively high vulnerability (2) under an extreme scenario (Table 4). Thus the magnitude of future climate change may be critical for this plant species and the insect species that depend on it.

Decrease sensitivity:

Disturbance
Upland grassland habitats required by these species are maintained by a regular fire regime. However, climate change may increase the frequency and severity of fires beyond current levels leading to increased larval mortality of butterfly species (Benton Vaughan and Black 2002, Kaye et al. 2010). Maintaining viable habitat with a strong forb component and preventing shrub encroachment or build-up of thatch via prescribed burns could be used to counter these changes and decrease fire severity, if not also frequency (Wilson et al. 1997, Heinz Center 2008, Kaye et al. 2010). It should be noted that there are trade-offs to prescribed burning for butterfly management (e.g., inappropriate timing or intensity can negatively impact butterfly populations at crucial life stages) and this requires a greater understanding of grassland dynamics and recovery after fire (Schultz and Crone 1998).

Natural Barriers
Theoretically, the two species considered here may be able to move northward within the Willamette Valley and beyond into Washington State since they are not impeded by large natural barriers. Furthermore, Battisti et al. (2005) and Davies et al. (2005) suggested that climate change may in some cases enable low temperature-limited butterflies to increase their range northwards as winter temperature extremes lessen. Planting host species in "new" areas north of the butterflies" current range could help enable such a range shift (Kaye et al. 2010) provided essential link with host/larval plant species is not disrupted due to differential responses to temperature and precipitation shifts (Parmesan 2006, Pelini et al. 2010).

Macro Precipitation
Exposure to a large range of mean annual precipitation (>40 inches or approximately 100cm) in the Willamette Valley over the past 50 years suggests that the butterfly species assessed are currently well adapted to a variable precipitation regime at the broad scale and may be relatively resilient to future changes in precipitation.

Management options synopsis (for invertebrates):

- Plant key host/larval plants for these two Strategy Species in current and restored habitat areas as well as habitats directly north of current ranges
- Manage fire so that a) it is present, but b) does not increase in severity or frequency especially during the larval life stage of Strategy Species
- Research effect of changing timing and quantity of precipitation on butterfly larvae/pupae and their host-plants
- Maintain landscape connectivity through stepping stones, corridors or alterations of land management practices
- Monitor butterfly species life history cycles to detect any changes in the number of generations per year.

4.2.3 Fish Strategy Species

Increase sensitivity:

- Macro Temperature - minimal exposure to past temperature variation
- Micro Precipitation - sensitivity to changes in precipitation or hydrology
- Physical Habitat – requires specific habitat types

Decrease sensitivity:

- Diet – Species are generalist feeders
- Dispersal – high dispersal ability

Increase sensitivity:

Macro Temperature
A warmer Oregon climate is likely to expose salmon to water temperatures higher than their recent (past 50 years) experience. For the fishes assessed, Macro Temperature parameter was the most influential in regards to the vulnerability scores; see All Taxa discussion above for options addressing this parameter. However, it should be noted that Macro Temperature refers to ambient rather than water temperature. Future versions of the CCVI that address water temperature directly would improve our understanding of how fishes will respond to a warming climate.

Micro Temperature
Many fish species including salmonids, are sensitive to increases in water temperature (Brett 1971). Brett and Glass (1973) demonstrated that salmonids have a 15^{o}C (59^{o}F) water temperature optimum for proper physiological function. Temperatures above this optimum can affect biological processes such as growth, swimming performance, timing of larval emergence, and survival of multiple life stages (Davis 1975). Because salmonids depend on cold water, areas of suitable habitat are constrained by any influx of warmer water. Riparian zone restoration and conservation can be used to maintain cooler water temperatures and re-establish normal sediment levels through a decrease in stored solar radiation (Hagans et al. 1986, USDA 1998). Additionally, cold water releases from upstream reservoirs can provide cool water to promote fish stock recruitment during spawning periods or critically warm periods (Yates et al. 2008).

Physical Habitat
Channel depth, water velocity, substrate size and other hydraulic parameters dictate habitat quality for salmonids (Connor et al. 1994). Optimal conditions that create refuge and foraging opportunities are often found in floodplains, which produce healthier juvenile salmonids as compared to those reared elsewhere (Jeffres et al. 2008). Currently, many rivers are channelized and flanked by levees, which effectively reduces connectivity with floodplain habitat**.** Climate change may change precipitation patterns in ways that alter stream dynamics and in turn, affect ecosystem processes. For example, a dry spring may reduce floodplain habitat, forcing adults to compete for low quality spawning areas. Restoring floodplains and developing policies that discourage channelization, debris removal, and other activities that impede floodplain function may

help support populations of Willamette Valley fish species (Spence et al. 1996, Scheerer 2002) as they face challenges associated with climate change.
Decrease sensitivity:

Diet
All fishes assessed are dietary generalists that feed at different trophic levels. This versatility suggests that if climate change leads to a reduction in one food source these Strategy Species will be able to shift to other sources that are unaffected or benefit from changing conditions. However, the maintenance of native terrestrial and aquatic prey populations through restoration of riparian zones (Ward 1998) or prevention of new riparian destruction will help sustain this factor of resilience to change. More specifically, salmon conservation efforts by Brosofkse et al. (1997) and Spence et al. (1996) in the Pacific Northwest suggest that riparian ecosystem function can be achieved by maintaining at least a 45 meter riparian buffer, with no timber extraction within 65 meters of the stream.

Dispersal
Salmonid fry disperse hundreds of meters both up and downstream enabling them to locate suitable habitat (Kahler et al. 2001) and potentially adapt to changing environmental conditions. One of the leading factors in pacific salmon decline is the construction of dams, which act as the predominant barrier to fish migration (Zeug et al. 2011). Therefore, dam removal and/or incorporation of fish ladders are among the best methods to restore river connectivity (Welch et al. 2008). If connectivity is achieved, unobstructed movement will allow salmon to reach spawning habitat and enhance gene flow, potentially aiding in climate change adaptation (Welch et al. 2008).

Management options synopsis (for fishes):

- Restoration of riparian zones (promote tree recruitment and natural vegetation retention)
- Strategic cold-water releases from dams in temperature sensitive times (spawning periods and hottest parts of the summer)
- Restore floodplains and floodplain connectivity
- Develop policies that discourage channelization, debris removal, and other activities that impede floodplain function
- Restore and maintain natural processes within the riparian zone to maintain fish prey communities (e.g., prevent timber extraction within an ample buffer)
- Dam removal or construction of fish ladders

4.2.4 Plant Strategy Species

Increase sensitivity:

- Dispersal – poor dispersal ability
- Macro Temperature - minimal exposure to past temperature variation
- Disturbance - dependence on specific disturbance regimes
- Micro Precipitation - sensitivity to changes in precipitation or hydrology
- Physical Habitats – requires specific habitat types

Decrease sensitivity:

- Natural Barriers – limited natural barriers to dispersal

Increase sensitivity:

Dispersal

Many plant species including the Strategy Species assessed here are dependent on wayward wind or animals to disperse propagules. Thus, long-distance dispersal events are rare and are such species are less able to adapt to climate change (CPC 2010, NatureServe 2010). For example, the wind-dispersed seeds of *Erigeron decumbens* (Willamette Daisy) on average spread less than 100 cm from the parent plant. Manual translocation northward and upward has been posited as a potential solution (Heinz Center 2008, Mawdsley et al. 2009) as have other methods of maintaining genetic diversity to promote adaptation to changing environmental conditions (Heller and Zavaleta 2009). Seed-banking to preserve genetic diversity is already being recommended, and for some Strategy Species has already been implemented (WNHP 1998, CPC 2010). Manual translocation should be considered carefully (see Box 1), especially as several of these plant species have specific physical habitat requirements that should be met (Mawdsley et al. 2009).

Box 1. Translocation or Assisted Migration and Disease

The manual relocation of species to areas outside of their natural range has been proposed as a means of assisting sessile or isolated species adapt to climate change. However, there are multiple ethical and ecological concerns regarding translocation that should be considered. These concerns include, but not limited to, the potential introduction of novel diseases, increased competition from introduced species and alteration or loss of genetic diversity.

Additionally, epidemiologic research increasingly shows that climate disturbances will likely increase the risk of diseases that are favored by warmer temperatures, or increased rainfall (Shuman 2010). Additionally, there is evidence that climactic shifts and other anthropogenic stressors are disrupting pathogen-host-reservoir dynamics, resulting in “smarter,” mutable pathogens (Wilson 2001, Harvell et al. 2002, Smith et al. 2009). In this ever-changing environment and increasing proximity of species that previously had no contact, microbes are quick to adapt and change, and can acquire the ability to infect multiple species, making assisted migration risky (Wilson 2001, Harvell et al. 2002, Smith et al. 2009). Subsequent introduction of novel pathogens from relocated species into native populations may lead to catastrophic disease outbreaks and subsequent population declines (Smith et al. 2009).

Thus, translocation or assisted migration should be considered with extreme caution and implemented only when more desirable options are unavailable (for more detail, see Ricciardi and Simberloff 2009). For a further review on pros and cons, see the Heinz Center report (2008).

Macro Temperature
Most of the plant species assessed are located within pockets of the Willamette Valley, and are not distributed throughout all valley habitats. This means that many species have experience little temperature variation within the past 50 years, suggesting their ability to adapt to temperature changes may be limited. Maintaining habitat heterogeneity, either by seeking out new protected lands, maintaining areas of current reserves with varied temperature regimes, or manually increasing minor topographic heterogeneity (e.g., bulldozing a small area to create depressions in which air temperatures may be lower), may help provide species with temperature "refuges" (Galatowitsch et al. 2009). Using seeds instead of seedlings (seeds have more time and capability to adapt to environmental cues than later life-stages) and incorporating wider genetic diversity in restoration efforts may facilitate gradual shifts in distribution to track temperature change (Galatowitsch et al. 2009, Cole et al. 2010).

Disturbance
Many of the assessed plant species are dependent on regular fire cycles to maintain grassland/prairie habitat or minimize litter build-up in woodland/forest habitat (Clark 1999, CPC 2010, NatureServe 2010). The natural fire regime that supports these species has already been disrupted by past and current fire suppression and climate change has to potential to further alter fire regimes. Only *Delphinium leucophaeum* (white rock larkspur) does not require fire-disturbed habitat (WNHP 1998). Prescribed burns could be used to mitigate any increase in fire severity and frequency associated with climate change (Inkley et al. 2004, Fischlin et al. 2007, Cole et al. 2010). However, this may be more of a short-term solution since it may lead to the persistence of "relict" species (which have not adapted to changing fire regimes) (Galatowitsch et al. 2009). Alternatively, fires may "provide an opportunity to facilitate establishment of current and future climate-adapted species and communities" (Spies et al. 2010). Instead of trying to restore habitat in its previous state, planting/seeding with different species or genetic alternates of species may help the habitat become more fire-adapted.

Micro Precipitation
Almost all of the Willamette Valley plant Strategy Species depend upon either standing water during certain parts of the year (e.g., *Lomatium bradshawii* and *Erigeron decumbens*) or conversely, require well-drained soils (e.g., *Delphinium pavonaceau* and *Aster curtus*) (WNHP 1998, CPC 2010, NatureServe 2010). As a wetland vernal plant, *Howellia aquatilis* is especially sensitive to changing precipitation (CPC 2010). To protect these water-dependent, drought-intolerant species in the short-term, rescue measures could be implemented. Such measures could include the installation of irrigation or drainage systems, alteration of water extraction practices to prevent reduction of water-tables, and/or restoration of natural floodplains (Peters and Darling 1985, Galatowitsch et al. 2009). Additionally, maintaining areas of environmental heterogeneity (see Macro Temperature above) may help provide precipitation refugia (Galatowitsch et al. 2009) in certain habitats. This could entail excavating small depressions where more rainwater or runoff could collect and pool for multiple days or weeks.

Physical Habitat
Many of the plant species assessed are dependent upon certain characteristics of physical habitat that are not determined by temperature or precipitation alone. For example, *Howellia aquatilis* (Howellia) requires fertile, highly organic soils and is associated with specific deciduous trees in vernal pools, *Eucephalus vialis* (Wayside Aster) has specific light requirements associated with forest/woodland habitat, and *Castilleja levisecta* (Golden Paintbrush) is associated with specific species of the genus *Festuca* (Wentworth 1997, Wogen 1998, CPC 2010, NatureServe 2010). Continued maintenance of open habitats (e.g., grasslands and gaps in forest/woodlands) will ameliorate the sensitivity of many plant species to climate change. Managers can use prescribed burns or cattle grazing to maintain this type of habitat (CPC 2010, NatureServe 2010). However, cattle grazing must be used with caution as species sensitive to trampling such as *Castilleja levisecta* could be harmed (NatureServe 2010).

Decrease sensitivity:

Natural Barriers
Like other taxa, the sensitivity of these plants to climate change may be reduced by the lack of large natural barriers. Theoretically, these plants will be able to shift their ranges northward within the valley or beyond and if managers maintain habitat connectivity. If a faster range shift is needed, then managers may want to consider manual translocation (but see Box 1 above) (Ricciardi and Simberloff 2009).

Management options synopsis (for plants):

- Manual translocation from current sites to “new” sites to track temperature changes
- Maintain genetic diversity (e.g., use seed-banking, and a wide range of genotypes for restoration)
- Preserve or create small-scale temperature and precipitation “refuges” (by maintaining areas with high topographical and environmental heterogeneity)
- Use seeds instead of seedlings in restoration
- Use prescribed fires to mimic natural fire regime
- Add irrigation/drainage systems and/or modify existing agricultural/urban systems to prevent lowering of the water table
- Maintain open areas in grassland or woodlands through fire or cattle grazing
- Maintain habitat connectivity using landscape linkages or softening the matrix; for biotically dispersed plants, a focus on increasing connectivity for major bird/mammal dispersers may be most effective

4.2.5 Amphibian Strategy Species

Increase vulnerability:

- Macro Temperatures - minimal exposure to past temperature variation
- Micro Temperature– dependence on cooler microsites within the greater habitat
- Micro Precipitation - sensitivity to changes in precipitation or hydrology at the local scale
- Disturbance - dependence on specific disturbance regimes

Decrease sensitivity:

- Macro Precipitation - exposed to high variation of past precipitation
- Natural Barriers – limited natural barriers to dispersal

Increase sensitivity:

Macro Temperature
Predicted increases in temperature may expose the northern red-legged frog (*R. aurora*) and the foothill yellow-legged frog (*R. boylii)* to water and air temperatures with which they have not evolved, thereby increasing their vulnerability; see All Taxa discussion above for options addressing this parameter.

Micro Temperature
Nussbaum et al. (1983) and Hayes & Jennings (1998) found that (*R. boylii)* prefers cooler, partially shaded streams. Restoring and maintaining riparian buffers can be realized to shade stream reaches and moderate water temperatures for amphibians (USDA 1998). Furthermore, this may decrease the risk of deleterious copepod infections, which are associated with warm water temperatures (Kupferberg et al. 2009).

Micro Precipitation
Given that amphibians have obligate aquatic life stages, they are highly vulnerable to changes in precipitation regimes. The Willamette Valley is predicted to become wetter generally, which on the whole will most likely benefit amphibian populations. However, the timing and rate of precipitation increase could have detrimental effects on early life states. For example, stochastic events such as an intense early spring flood could wash egg masses downstream as well as decrease the quality of larval habitat (Pearl 2005).

Disturbance
Any increase in flooding events and/or forest fires within riparian corridors associated with climate change could harm amphibian populations. Floods cause stream scouring which may negatively impact amphibian streambed hibernation sites. Increased sedimentation as a result of fires may decrease water quality to which amphibians are hypersensitive (Santos-Berra et al. 2004). Additionally, climate change may increase or change the diseases amphibians are exposed to in the future. Of particular concern for amphibians is the recent spread of the fungus *Batrachochytrium dendrobatidis* (chytrid) (Lötters et al. 2009). It is thought that temperatures at higher latitudes are shifting towards the growth optimum of chytrid, causing outbreaks which are linked to mass

amphibian extinctions (Pounds et al. 2006). Though Davidson et al. (2007) demonstrated that chytrid does not necessarily increase *R. boylii* mortality, it does increase their susceptibility to other stressors by decreasing their immune function. Restoring and maintaining spatially-connected habitat sites may diminish the risk of population extinction due to other disturbances such as fire (i.e., it spreads the risk over multiple sub-populations). In the event that such a disturbance results in the extinction of a sub-population, extirpated areas can be recolonized through immigrating from surviving areas (Brown and Kodricbrown 1977).

Decrease sensitivity:

Macro Precipitation
Amphibians have experienced a wide range of precipitation over the past 50 years suggesting they may be able to adapt to predicted precipitation increases within the Willamette Valley. Both amphibian species assessed here depend on habitat near permanent streams, pools, wetlands, and/or other bodies of water. Juveniles are frequently found in ephemeral pools and travel great distances over land during wet weather (Rathburn et al. 1993). This long-distance overland dispersal might be important for metapopulation dynamics, a theoretical model of population stability of a species existing in spatially separated subpopulations (Levins 1969, 1970). Thus, a seasonal increase in precipitation may help augment the amount of suitable habitat and promote regional population stability. In addition to maintaining and enhancing habitat connectivity, Marsh and Trenham (2001) recommend translocation as a cost effective means of spreading extinction risk for amphibian populations, although controversy over such an approach dictates caution should be taken when considering its use (Box 1).

Natural Barriers
Neither rivers nor short stretches of land impose movement constraints on amphibians and coastline and montane barriers are not an issue within the Willamette Valley. As such, both *R. aurora* and *R. bolyii* have the potential to track their climatic envelopes without significant intervention. Because most frog populations are thought to exist as part of a larger metapopulation (Marsh and Trenham 2001), unconstrained movement can decrease frogs‟ sensitivity to climate change (Griffiths et al. 2010).

Management option synopsis (for amphibians)

- Restore and maintain riparian buffer zones
- Restore and maintain spatially connected habitats in directions that will allow amphibians to track climate change
- Translocation given the known caveats

4.2.6 Reptile Strategy Species

Increase sensitivity:

- Migration and movements - short/uncommon migratory patterns
- Macro Temperatures - minimal exposure to past temperature variation

Decrease sensitivity:

- Dispersal – high ability to disperse to new areas
- Natural Barriers – limited natural barriers to dispersal

> **Box 2.** Migration and Movement versus Dispersal
>
> The way in which CCVI defines these two life history categories and describes how they influence sensitivity to climate change can be confusing and warrants further explanation. The fact that a species is capable of long-distance movement does not necessarily confer decreased sensitivity. In the Migration and Movement category, species that migrate to a single distinct or geographically restricted location are considered to be more sensitive to climate change if such locations are threatened by climate change. Likewise, species that are non-migratory are also considered vulnerable, as they are less able to respond to climactic alterations through movement into more favorable areas. In contrast, migratory behavior is considered an asset for species that regularly migrate long distances to broad geographical areas, as these species can rely on movement and greater niche flexibility to track their climate envelopes. Unlike the Migration and Movement category, which is very situation-dependent, increased dispersal ability is uniformly associated with decreased sensitivity. In the CCVI framework, it is inferred that species that disperse great distances will be more likely and able to move into new areas as a means to escape climate-induced stresses.

Increase sensitivity:

Migrations and Movements
Both the Northwestern pond turtle and the Western painted turtle are non-migratory species (Hayes et al. 1999, Gervais et al. 2009). As such, they are less likely to track their climate envelope. Possible management strategies that may alleviate this obstacle include measures that help increase or maintain genetic variability and the potential to genetically adapt to environmental changes (Hawkes 2008). Enabling adequate dispersal of juveniles by ensuring that habitat connectivity is maintained is one way to aid in this goal (Markham 1996, Hawkes 2008). A more controversial and risk-tolerant approach is relocation/assisted migration (Box 1).

Macro Temperature
Typical of many reptiles and characteristic of the two turtle species that we assessed, temperature is important for the sex determination of offspring. Thus, there is considerable concern that climate-induced temperature alterations will affect sex ratios, creating a disproportionate number of females with even small increases in temperature

of less than 2°C (Janzen 1994, Lovich 2003, Gervais et al. 2009, Rosenburg et al. 2009). Larger increases in temperature could theoretically eliminate males entirely (Janzen 1994). Management strategies that may help address these issues include: 1) Securing ample terrestrial and aquatic cool-area refugia within the a species‟ current range to escape warmer temperatures (Hawkes 2008), 2) restoring riparian areas and removing water diversions to help regulate water quality and temperature, while taking precautions to ensure that exposed areas are still available for basking, nesting, and foraging (Gervais et al. 2009, Rosenburg et al. 2009), and 3) developing hatcheries to control temperature regulated sex ratios if more extreme measures are deemed necessary (Hawkes 2008).

Decrease sensitivity:

Dispersal
The topic of dispersal is an under-researched area for both turtle species assessed (Gervais et al. 2009). Although daily movements between aquatic and terrestrial areas are generally limited for both turtle species, rare accounts of individuals dispersing distances of 2-5km in aquatic environments have been documented (Hayes et al. 1999, Gervais et al. 2009, Rosenburg et al. 2009). This potential ability to disperse over larger distances decreases their sensitivity to climate impacts, as they should have some ability to shift their range if climate conditions threaten their persistence. Thus, maintaining connectivity within urban landscapes as well as on private lands through education and incentive programs would be beneficial (Gervais et al. 2009, Rosenburg et al. 2009).

Natural Barriers
Given the topography of the Willamette Valley Ecoregion, large natural barriers are generally not impediments to species‟ movement. Roadways, fences, and urban infrastructure likely pose greater challenges (Gervais et al. 2009, Rosenburg et al. 2009). Thus, removing anthropogenic obstacles for the purpose of maintaining habitat connectivity is critical.

Management options synopsis (for reptiles):

- Protect terrestrial and aquatic thermal refugia within the current range of these species while maintaining important basking, nesting, and foraging sites
- Riparian restoration and removal of water diversions similar to that recommended for salmonids
- Increase connectivity to promote dispersal and maintain genetic variability (e.g., create roadway/fence crossings for terrestrial passage)
- Develop hatcheries to control temperature-regulated sex ratios
- Create incentive programs for land owners as most of prime turtle habitat in the Willamette Valley is found on private lands
- Relocation/assisted migration

4.2.7 Mammal Strategy Species

Increase sensitivity:

- Diet – reliance on specific diet or seasonality of food availability
- Macro Temperatures - minimal exposure to past temperature variation
- Disturbance - dependence on specific disturbance regimes
- Migration and Movements - short/uncommon migratory patterns

Decrease sensitivity:

- Natural Barriers – limited natural barriers to dispersal
- Dispersal – high ability to disperse to new areas

Increase sensitivity:

Diet

The mammalian species assessed here do not depend upon specific food sources, but their diets are subject to seasonality and prey that may be largely affected by climate change. Western gray squirrels eat a variety of seeds, nuts, acorns and fungi (Fimbel 2004). Acorns and conifer seeds from Oregon white oaks and Douglas fir, in particular, provide key sources of energy, but the availability of these two foods varies from season to season and is largely dependent on temperature and precipitation (Fimbel 2004). Thus, while these squirrels are dietary generalists (Fimbel 2004), they may be taxed in the long-term if climatic shifts alter nut and seed production of these critical tree species. Similarly, while both the California brown bat and Townsend big-eared bat have diets comprised of a variety of invertebrates including moths, midges, beetles, and other insects, Lepidopterans constitute the mainstay of their diets (Blood et al. 1998). This heavy reliance on certain moth species may pose a problem as current research suggests that many Lepidopteran species are already shifting their ranges in response to climate alterations (Parmesan 2006). For the Western gray squirrel, possible mitigation options to address food supply issues include minimizing competition for food sources with invasive species such as the Eastern gray squirrel (*Sciurus carolinensis*). This goal may be achieved by restoring oak-conifer forests and providing suitable snags and nesting sites situated at least one kilometer away from more developed areas (favored by the Eastern gray squirrel) (Fimbel 2004). Additionally, increasing the abundance of alternative food sources less affected by temperature such as Bigleaf maple (*Acer macrophyllum),* Oregon ash (*Fraxinus latifolia*), and Indian plum (*Oemleria cerasiformis),* would alleviate dietary constraints if primary food sources become less plentiful (Ryan and Carey 1995, Fimbel 2004). Furthermore, for the two bat Strategy Species, reducing the use of insecticides within and around their habitat may help increase the abundance of less climate-impacted insects and moth species (Jones et al. 2009).

Macro Temperature

Within the Willamette Valley, mammalian Strategy Species‟ populations have experienced relatively small fluctuations in temperature over the past 50 years. For those species adapted to such stability, any dramatic shifts in the temperature regime brought on by climate change could be detrimental. Consequently as temperatures rise, daily activity levels, food supply, reproduction, as well as timing and length of hibernation (in the case of the two bat species) may be compromised (Humphries et al. 2002, Mistry and Moreno-Valdez 2008). Strategies for this addressing this sensitivity parameter are discussed above under Macro Temperature for All Taxa.

Disturbance Regimes
The Western gray squirrel and both bat species prefer low density oak-conifer forest stands and rely on seasonal fire regimes to reduce levels of underbrush (Erickson and West 2003, Fimbel 2004). In the short-term, prescribed burns and forest thinning may help maintain optimal vegetation density (Erickson and West 2003, Fimbel 2004, Hayes and Loeb 2007), but care should be taken to minimize direct disturbance during these interventions (Fimbel 2004). Additionally, disease outbreaks due to Western equine encephalitis virus (WEEV), which has been documented in the Western gray squirrels of this region (Fimbel 2004), may become more frequent as both the range and optimal transmission period of vector-borne pathogens like WEEV are theorized to increase with warmer temperatures (Patz et al. 1996, Patz and Reisen 2001).

Migrations and Movements
All three mammal species assessed are non-migratory and remain in the Willamette Valley Ecoregion year-round (Harris 1999, Fimbel 2004, Tomlinson 2011). Although both bat species are capable of longer distance movement (Harris 1999, Tomlinson 2011), they rely on hibernation, rather than migration, to withstand harsh environmental conditions and may be less likely to shift their ranges in response to climate change.

Decrease sensitivity:

Dispersal/ Natural Barriers
Both of these parameters lessened the sensitivity to climate change of the three mammals assessed. Because the Western gray squirrel and both bat species are able to disperse relatively large distances they have the potential to shift their distribution to escape climate impacts (but see caveats above). Using movement as a strategy to respond to shifting climactic conditions is further aided by the absence of natural barriers. Thus, management plans directed toward ensuring that these conditions persist will promote greater resiliency in face of climate change. While large natural barriers to movement are limited in the Willamette Valley, working with private land owners and public planners to restore habitat connectivity and minimize anthropogenic barriers through public education campaigns will aid in dispersal and will facilitate movement into more suitable climatic environments if such shifts are necessary.

Management options synopsis (for mammals):

- Minimizing the competition for food sources between native and invasive mammals (e.g., In the case of the Western gray squirrel, restoring oak-conifer forests and providing suitable snags and nesting sites away from more densely settled areas preferred by the Eastern gray squirrel)
- Increasing the abundance of alternative food sources less affected by temperature changes

- Reduce the use of insecticides in areas where moth prey species are impacted
- Provide greater habitat connectivity across private lands and in urban settings
- Reduce human disturbance near bat hibernacula (through public education campaigns)
- Prescribed burns and vegetation thinning to maintain optimal vegetation density while minimizing disturbance at key hibernation times
- Riparian restoration with removal of water diversions
- Maintenance of nearby water sources

4.2.8 Bird Strategy Species

Increase sensitivity:

- Macro Temperatures - minimal exposure to past temperature variation
- Disturbance - dependence on specific disturbance regimes

Decrease sensitivity:

- Dispersal – high ability to disperse to new areas
- Natural Barriers – limited natural barriers to dispersal

Increase sensitivity:

Macro Temperature

Because climate models predict a general increase in temperatures throughout Oregon it is expected that Oregon birds will be exposed to temperatures outside of recent norms. Addressing global greenhouse gas emissions at the local level is challenging, but see All Taxa section above for management options.

Disturbance

Like many other taxa, birds can be negatively impacted by changes in disturbance regimes associated with climate change. Fire management actions, such as controlled burns and mechanical fuel reduction, can help reduce any potential increase in fire while mimicking natural fire regimes (Husari and McKelvey 1996). However, such actions can be disruptive or may destroy nesting sites and should be conducted outside of the primary breeding season when possible (Bagne and Purcell 2009). Likewise, a shift in timing of spring floods could disrupt nesting of some riparian birds. However, given that flows in Willamette Valley waterways are already highly regulated, this is not likely to be a great problem for birds into the future.

Decrease sensitivity:

Dispersal/Natural Barriers

In general, birds are able to move easily across the landscape and are largely uninhibited by topographic or geographic barriers. Therefore, these two index parameters show a reduction in sensitivity or increased adaptive capacity. Land managers can help ensure this adaptive capacity is realized by preserving suitable habitat for vulnerable bird species within their current and future ranges.

Management options synopsis (for birds):

- Use prescribed fires to maintain the natural fire regime but do so outside of the primary breeding season
- Maintain landscape connectivity over short and long distances so that birds can track climate change

4.3 Managing Despite Uncertainty

Climate science and the practice of using climate change vulnerability assessments, remains in its infancy. Vulnerability assessments can be an important tool for strengthening conservation management plans in an era of climate change, but uncertainties and limitations should be recognized and incorporated. Thus, such assessments should be used as one part of an iterative process, where management plans and actions are adjusted as our mechanistic understanding of the relationship between climate change and species of concern increases. Management decisions made under uncertainty are best if they are reversible, take incremental steps, promote further learning, and have the capacity to shift as situations change (Millar et al. 2007). This is especially important for those species with vulnerability scores that change significantly depending on global circulation model (GCM) chosen for the analysis. For example, many fish species assessed for the Willamette Valley Ecoregion received low and moderate climate confidence scores revealing a limited ability to accurately assess their relative vulnerability (Table 5). Therefore, management actions intended for these species should reflect this uncertainty by remaining flexible as new information becomes available. For species with low climate confidence, managers should be especially cautious when considering irreversible actions such as translocation (Ricciardi and Simberloff 2009) or triage (i.e., abandoning conservation efforts) of apparently "doomed species" (Schwartz et al. 2006). As uncertainty over our future emissions decreases, climate models improve, and approaches to assessing climate vulnerability are refined, such assessments should be repeated to improve and update ongoing management plans.

Our ability to assess species vulnerability is also limited by our understanding of species life histories as they relate to climate adaptation. As noted above, for 13 Strategy Species and 4 bird subspecies in the Willamette Valley (Table 1), available information was insufficient to conduct an accurate vulnerability assessment. An expansion of our knowledge of these poorly understood species is needed to better inform management actions designed to aid adaptation to climate change. Likewise, for those species where a complete vulnerability assessment was possible, gaps in our understanding remain (e.g., for many species, observations of responses to past climate change do not exist). These gaps can be used to indicate areas of future research needed to improve our understanding of species vulnerability and potential responses to climate change.

4.4 Next steps and project value

- The report presented here relied heavily on peer-reviewed and otherwise publicly available data. While the use of peer-reviewed literature allows for greater accessibility of tools such as the CCVI, the use of local knowledge of biodiversity populations and conservation areas is also needed to form local management plans. Other species and habitat assessments have used expert panels to address the question of vulnerability to climate change (e.g., Glick et al. 2011). Such assessments have their own disadvantages, but incorporating expert knowledge from Willamette Valley biologists would enhance our tool-based approach, reduce uncertainty inherent in climate change assessments, and ultimately increase the likelihood that adaptation strategies will prove successful in the coming decades. In February 2011, we hosted a stakeholder meeting at the ODFW headquarters in Salem, Oregon. Participants from local conservation-minded organizations agreed that a combination of tool- and expert-based knowledge would be beneficial to the conservation efforts in this region. The participants largely concluded that using a tool like NatureServe‟s CCVI provides a good overview and some narrower insight, but for some specific issues and species, the addition of local knowledge will be crucial.

- A crucial next step is to undergo an exercise of scenario planning where the range of possible future climate conditions are considered as well as a variety of management approaches appropriate under different circumstances. The use of scenario planning has been advocated by several reviews on climate change management adaptations (e.g., Theoharides et al. 2009, Glick et al. 2011). This strategy allows for the evaluation of alternative management approaches (Fuller et al. 2008) and helps address the inherent uncertainty involved with conservation management in an age of climate change (Peterson et al. 2003).

- Expanding the geographic scope and focusing on the data gaps that our project highlighted could also augment our approach. Our tool-based species assessment could easily be applied to other Oregon ecoregions and help achieve both ecoregion-specific detail and inform statewide issues. In doing so, this could highlight any differences in species prioritization and adaptation needs across the state or between Strategy Species populations. For an exploration of this idea and consideration of how altering the extent could change prioritization, see Box 3 below.

- The lack of range information for four Strategy Species (the Willamette floater, Pacific Lamprey, Western brook lamprey, and Western rattlesnake) prevented us from assessing their vulnerability to climate change using the CCVI. We highly recommend that more attention be paid to the range of these species as any vulnerability approach incorporating spatial information will require some level of species occurrence knowledge.

- The research presented in this report represents a significant addition to the knowledge of species and taxa vulnerability within the Willamette Valley. We believe it will prove invaluable for the next revision of the OCS as climate change is incorporated into its management priorities and actions. Of course, vulnerability assessments have their weaknesses (for more detail, see Patt et al. 2005) which is why we stress that our analysis and results provide suggestions and guidance rather than definitive answers. In addition to the species prioritization and management adaptation options presented, the detailing of the necessary resources, the description of our step-by-step process of implementation and analysis, and the careful scrutiny of areas of uncertainty provides insight into the ever-improving field of climate change vulnerability assessments.

Box 3. Vulnerability at different scales

The vulnerability scores presented in this report and any subsequent implication of prioritization are specific to the Willamette Valley and the scale employed in the analysis (i.e., ecoregion). Because the magnitude and form of climate change will vary across the globe as well as across the state of Oregon (Girvetz et al. 2009), species will experience different levels of exposure to climate change in different parts their ranges which will in turn affect their vulnerability (Figure 12). Likewise, wide-ranging species have historically experienced greater variation in temperature and precipitation than species with narrow ranges. Both future exposure to climate change and historic climatic experience (represented by Macro Temperature and Precipitation in this study) influence the vulnerability of a species. Therefore, a species‟ vulnerability score may also vary depending on the portion of the species‟ range considered. For example, a species may show high vulnerability in parts of its range where climate change is expected to be more extreme or where historic climatic variation is limited, while it may appear less vulnerable in areas where climate change is expected to be limited or there is a history of large climate variation. Such spatial variation of vulnerability may affect how a species is managed across its greater range.

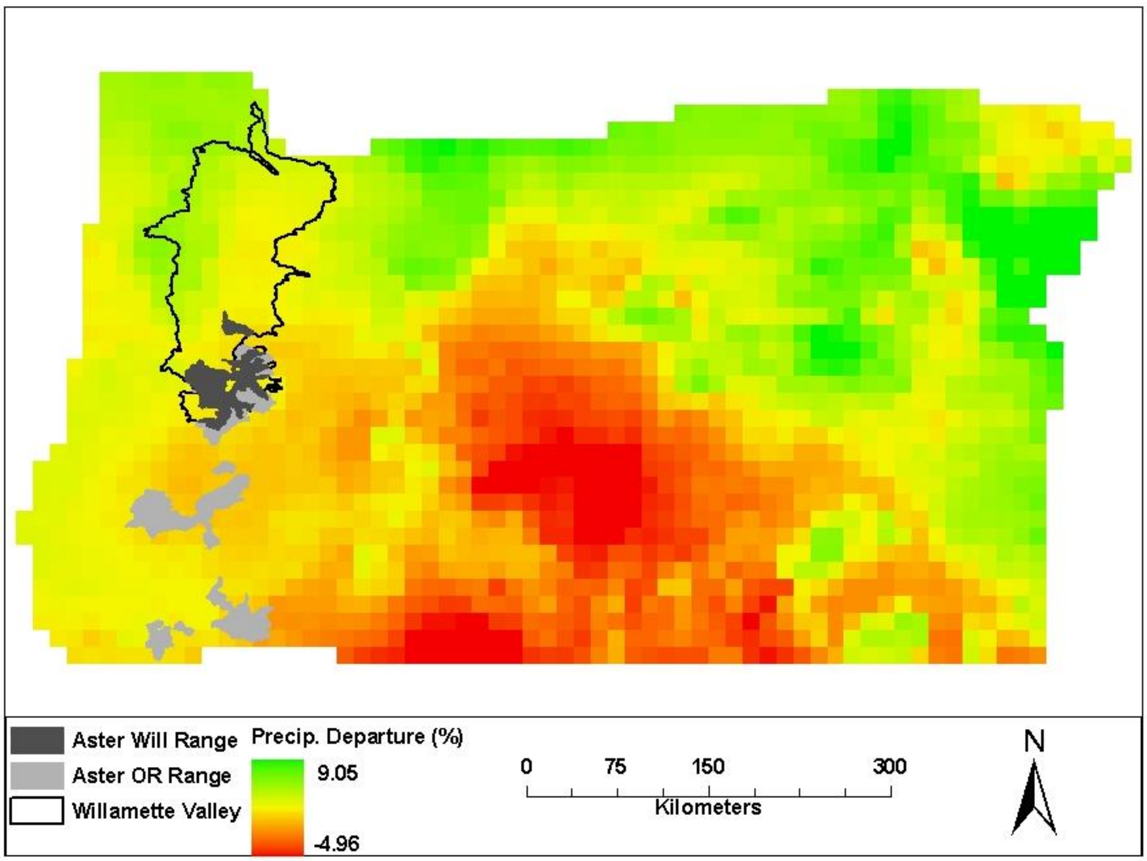


Figure 12. Illustration of geographic variation of projected precipitation change under a medium emissions scenario and a medium ensemble of climate models. The Willamette Valley and Oregon State ranges of Way-side Aster are provided as an example.

Box 3. Continued.

In order to test how the vulnerability of the 46 focal species varied at different spatial extents, we compared scores using species ranges limited to the Willamette Valley Ecoregion with vulnerability scores using the species‟ Oregon-wide range. Life history parameters and the climate scenario (baseline scenario) remained the same for both runs.

Of the 46 species tested, seven were determined to be more vulnerable within the Willamette Valley than across the state. In each case, the vulnerability score changed by one level (e.g., from 3 to 4) when changing the extent from the Willamette Valley to Oregon (Table 6). For those species whose range maps are confined to the Willamette Valley (e.g., seven of the ten plant species), a change of extent cannot impact the vulnerability score because the past and projected exposure has not changed.

Table 6. Species whose vulnerability scores differ between the Willamette Valley and Oregon extents. A score of 3 represents moderately vulnerability, 4 is low vulnerability and 5 is lowest vulnerability.

Common Name	Scientific Name	Taxon	Willamette	Oregon
Chinook Salmon (Lower Columbia River ESU, Fall Run)	*Oncorhynchus tshawytscha (pop. 22)*	Fish	3	4
Steelhead (Lower Columbia River ESU, Winter Run)	*Oncorhynchus mykiss (pop 14)*	Fish	3	4
Steelhead (Southwest Washington ESU, Winter Run)	*Oncorhynchus mykiss (pop. 23)*	Fish	3	4
Way-side Aster	Aster vialis	Plant	3	4
Acorn Woodpecker	Melanerpes formicivorus	Bird	4	5
Western Gray Squirrel	Sciurus griseus	Mammal	4	5
Townsend's Big-eared Bat	Corynorthinus townsendii	Mammal	4	5

These preliminary results suggest that the extent of the study region used is an important factor in species vulnerability, and that the study area should reflect the conservation goals and management units of the region assessed. For example, if the goal is to maintain persistence of the Way-side Aster anywhere in the state of Oregon, less management intervention may be necessary than if the goal is to conserve the species within the Willamette Valley.

In addition to assessing the effects of scale on species vulnerability, a similar comparison conducted between geographically distinct areas at the same scale (for example, Oregon‟s eight ecoregions) may constitute the next step in identifying spatial variation of vulnerability within a species‟ range. Such an exercise could identify areas of high vulnerability where conservation challenges are greatest and areas of low vulnerability where there remains opportunity for relatively easy climate adaptation. For example, bull trout in the Willamette Valley are not ranked as highly vulnerable to climate change but expert opinion voiced at a stakeholders meeting in February 2011 in Salem maintained that the vulnerability of this species would likely increase in other ecoregions (i.e., within the Cascades). This is based on the fact that bull trout are more common in rivers outside of the Willamette Valley where water temperature may be impacted more by climate change and where cold water is needed for the critical life-stage of incubation.

PART II: Place-based Vulnerability Analysis

Grof-Tisza, P.,* M. Wilkerson, Z. Steel, and K. Sulzner

*First two authors are the principal and equal contributors. Following authors are in alphabetical order.

1. Background

In Part II of this report, we describe the development of a preliminary method for assessing place-based vulnerability in the Willamette Valley as the CCVI tool does not extend to habitats or conservation places. We use "conservation place" as a generalized term that refers to a particular portion of space designated for conservation purposes. The focal conservation places in this report are what the Oregon Conservation Strategy (OCS) classifies as Conservation Opportunity Areas (COAs) (ODFW 2005, pp. 21-22). COAs are geographic areas where conservation actions may most effectively contribute to the region‟s conservation goals. Not all land within is formally protected but the entire area is prioritized for conservation efforts. To reduce confusion of terms, we use the word "place" when referring to broader aspects of vulnerability analysis and "COA" when referring to the specific steps and results for this particular analysis.

The method presented here is a first step in developing a framework for place-based climate vulnerability analyses. This preliminary work does not provide comprehensive guidelines for such analyses, but rather demonstrates the usefulness of place-based vulnerability assessments. We hope this first iteration will generate useful dialogue and prompt greater research in this sector.

Past and ongoing projects focusing on habitat and/or place-based vulnerability analyses encompass varied objectives and approaches. In New Mexico, government officials took a relatively simple approach by assessing the number of focal species that fell within key conservation areas predicted to be strongly impacted by climate change (Enquist and Gori 2008). More complex and time-consuming processes may involve building detailed but generalizable frameworks for system vulnerability (Glick et al. 2011) analogous to NatureServe‟s CCVI. In the Pacific Northwest, a consortium of academics and NGO scientists have created a multi-pronged approach that combines an expert panel with models of climate change-induced vegetation and animal distribution shifts (Lawler 2010). Assessing habitat and place-based vulnerability can integrate various components of a system such as species composition and interactions, ecosystem function, and direct human impacts. This can enable managers to pinpoint which parts of their system are most or least sensitive to climate change.

The approach presented here incorporates both habitat and species vulnerability and takes into account other conservation land issues that will impact an area‟s response to climate change. Identifying which conservation places are vulnerable to climate shifts and determining which factors contribute to their vulnerability is essential for developing

effective climate-adaptation strategies. Knowing which conservation places may be more vulnerable than others will also help in prioritizing efforts across the focal region.
The novelty of this framework is that it compares the vulnerability of ***places*** of conservation value that differ widely in characteristics including size, habitat and species composition, as well as exposure to multiple stressors. This approach provides a tool for managers, who must coordinate conservation efforts over larger spatial scales and/or who manage complex reserve networks.

Our two primary goals for the place-based climate vulnerability component of this report were to develop priority rankings of the COAs based on their 1) sensitivity to non-climate change stressors and 2) predicted vulnerability to climate change. In part I, we did not address sensitivity to non-climate change stressors since much data concerning specie"s non climate-change sensitivities has already been complied (e.g. Conservation Rankings from NatureServe). In contrast, a vulnerability assessment of conservation places in the Willamette Valley that incorporates both non-climate and climate drivers has yet to take shape.

2. Methods

2.1 Overview of parameters

There were two main components within this study: 1) Sensitivity to non-climate change (non-CC) stressors and 2) Climate change (CC) vulnerability. Both non-CC stressors and CC parameters were included in the final priority ranking of COAs (i.e. component 1 becomes a parameter in the evaluation of component 2; Figure 13). We evaluated three non-CC parameters for component 1 and five CC parameters for component 2. Parameters are the different elements that contribute to the degree to which a conservation place is sensitive to non-CC stressors and to climate change (see below for further detail). These can be measured quantitatively and/or qualitatively. In this analysis, we transformed qualitative measures into quantitative measures to calculate a final numerical ranking.

2.2 Selecting parameters

Parameters for the sensitivity to non-CC stressors and CC vulnerability assessments were selected using two criteria: 1) The existence of a record of the parameter"s use in similar analyses (i.e., precedent in the literature) and 2) The application of the parameter is feasible within our model framework. Literature searches yielded a short list of papers and case studies assessing climate change vulnerability of conservation areas. From this list of references, sensitivity and vulnerability parameters were extracted and evaluated against criterion 2 above (Table 7). Parameters such as *Habitat intrinsic dispersal rate*, *Vulnerability to phenological change*, and *Vulnerability to human maladaptive responses,* used by Odgen and Innes (2009), met criterion 1 and 2 but were not included in our assessment due to the lack of information directly addressing strategy habitats within the COAs. This preliminary look into place-based CC vulnerability demonstrates the relative youth of this field of study and highlights the need for more research focused on the impacts of climate change at the community and ecosystem scales that is readily publicly accessible. More research in this sector, as well as detailed local knowledge, would allow for the incorporation of additional, better informed parameters in future assessments and thus, a more complete understanding of place-based vulnerability to climate change.

Table 7. Conservation place factors often considered in climate change sensitivity and vulnerability analyses and associated references.

Conservation place factors	References
Elevation*	(Doppelt et al. 2009, MDFW and MCCS 2010)
Latitude*	(AFWA 2009, MDFW and MCCS 2010, Glick and Stein 2011)
Predicted temperature increase*	(AFWA 2009, MDFW and MCCS 2010, Glick and Stein 2011)
Predicted precipitation change*	(AFWA 2009, MDFW and MCCS 2010, Glick and Stein 2011)
Changes in abundance and ranges of invasive species	(Michael and O'Brien 2008, Doppelt et al. 2009, Odgen and Innes 2009 , Glick and Stein 2011)
Potential for emergence of novel ecological communities	(AFWA 2009, Odgen and Innes 2009, Glick and Stein 2011)
Potential for species movement/landscape permeability*	(Odgen and Innes 2009, MDFW and MCCS 2010, Glick and Stein 2011)
Redundancy/response diversity within functional groups	(Glick and Stein 2011)
Non-CC stressors*	(Doppelt et al. 2009, MDFW & MCCS 2010)
Vulnerability of ecosystem services*	(Michael and O'Brien 2008, Doppelt et al. 2009, Odgen and Innes 2009)
Nutrient cycling	(Michael and O'Brien 2008)
Current rate of species/habitat loss	(Doppelt et al. 2009, MDFW and MCCS 2010)
Sensitivity of species/habitats to climate change within conservation places*	(Michael and O'Brien 2008, AFWA 2009, Glick and Stein 2011)
Hydrologic regime (floods)*	(Michael and O'Brien 2008, Doppelt et al 2009)
Changes in fire intensity and frequency*	(Odgen and Innes 2009, Glick and Stein 2011)
Disease*	(Michael and O'Brien 2008, MDFW and MCCS 2010)
Insect outbreaks	(Michael and O'Brien 2008, Odgen and Innes 2009, MDFW and MCCS 2010)
Interaction between mutualistic species*	(Doppelt et al. 2009)
Potential changes in phenology	(Odgen and Innes 2009)
Potential changes in productivity	(Odgen and Innes 2009)
Potential changes in economic opportunities	(Odgen and Innes 2009)
Potential changes in land values and land-use options	(Odgen and Innes 2009)

* denote factors incorporated into this assessment

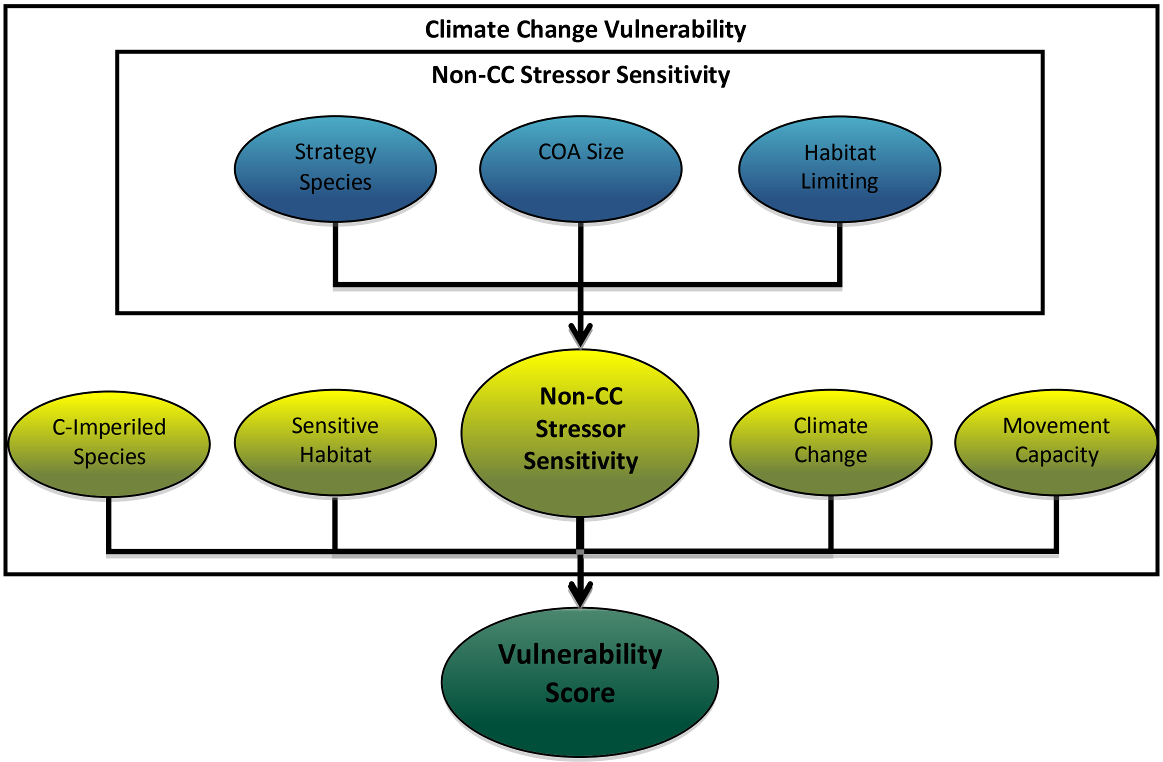


Figure 13. Conceptual model of parameter structure for assessing non-Climate Change Stressor Sensitivity and Climate Change Vulnerability.

2.2.1 Sensitivity to non-climate changes stressors (non-CC sensitivity)

Non-CC sensitivity parameters were used to calculate a baseline prioritization of the COAs. These parameters reflect current, human-related threats and factors that could influence the sensitivity of a COA. Each of the following parameters has a subscore of 1, 2, or 3 with 3 signifying the highest level of sensitivity. The parameters used here reflect only one way in which COAs could be prioritized based on non-CC sensitivity. Local managers could use different and/or additional non-CC parameters to determine baseline prioritization of COAs.

Strategy Species
The COAs were chosen as priority landscapes, where conservation actions will most beneficially impact strategy species and habitats. Given this criterion for COA selection, we assigned higher prioritization to COAs containing more strategy species.

The number of Strategy Species was calculated by overlaying species‟ range maps (generated in Part I) with COA boundaries. Where overlap existed, the species is considered present within the COA. All present species were summed to calculate a „Strategy Species total‟ for each COA. The resulting total species number was used to place each COA into one of three classes. The three classes were evenly distributed between the greatest[8] number of Strategy Species within a COA and the least (Table 8).

Table 8. Total Strategy Species classes and corresponding COA subscore

Total Strategy Species classes	Strategy Species subscore
5-13	1
14-21	2
22-30	3

Area

The size of a conservation place (i.e. its geographic area) is an important and commonly cited factor for reserve selection and design (e.g., Shafer 1999). A larger protected place typically has greater habitat and species diversity and can enable species to move about more easily to meet their daily and seasonal ecological needs (Shafer 1999). Having a greater representation of key habitats and species (also known as a conservation "portfolio") is considered important for biodiversity within and between protected places (Heinz Center 2008) . The overall size of a COA will also likely play a large role in the ability of system to resist and/or adapt to climate change (Scott et al. 2002, Pyke and Fischer 2005, Hannah et al. 2007).

The area (in acres) of each COA was measured using ArcGIS. The area values were put into one of three classes (Table 9).

Table 9. COA area classes and corresponding subscores

COA area classes	Area subscore
56,939 acres or greater	1
27,756-56,938 acres	2
571-28,755 acres	3

Habitat Limiting Factors

A multitude of factors including poor water quality, invasive species, and altered disturbance regimes, threaten Oregon Strategy Habitats and limit Strategy Species" population growth and persistence. The list of habitat limiting factors detailed in the OCS (Table 10) was used to calculate this particular parameter. We totaled the number of habitat limiting factors per COA (dependent on the number of Strategy Habitats within

[8] The Willamette River Floodplain (WRF) is substantially larger than the other COAs. Consequently, WRF generally had considerably higher data values than the other COAs. To prevent skewing of class sizes, the second highest value was used to calculate class size for the following parameters: Strategy Species, Area, Habitat Limiting Factors, and Climate-Imperiled Strategy Species.

the COA) and then divided the range of total habitat limiting factors into three equal classes (Table 11).

Table 10. Willamette Valley Ecoregion COA limiting factors as defined by the OCS.

COA Limiting Factors	
Water quantity	Altered fire regime
Water quality	Land use conversion
Invasive species	Land mgmt conflicts
Water temp	Recreational impacts
Sedimentation	Loss of floodplain function
Loss of connectivity	Habitat degradation
Loss of complexity	Habitat Loss

Table 11. Habitat Limiting Factor classes and subscores

Total habitat limiting factors classes	Habitat limiting factors subscore
8-15	1
16-23	2
24-31	3

2.2.2 Climate change vulnerability (CC vulnerability)

The second stage of our analysis assesses the vulnerability of each COA to projected climate change impacts. These parameters incorporate theories concerning the effects of climate change on species, habitats, and ecosystems as well as climate change modeling projections (Figure 13). By including non-CC stressor sensitivity (see section 2.2.1) as a parameter of CC vulnerability, non-CC stressors are incorporated into the overall vulnerability of a COA (i.e., non-CC stressor sensitivity is nested within CC vulnerability). Each of the following parameters has a score of 1, 2, or 3 with 3 signifying the highest level of sensitivity.

Movement Capability

Climate change has been associated with past alterations of species ranges and will likely continue to influence range shifts in the future (Peters and Darling 1985). Conservation places designated for current priorities and species distributions may fail to provide sufficient suitable habitat as environmental conditions are altered by climate change (Araújo et al. 2004, Hannah et al. 2007). Additionally, many species may need to disperse outside of conservation areas to track suitable environmental conditions (Peters and Darling 1985). Because our ability to directly assess current or future species movement capacity is limited, we used the quantity of suitable habitat adjacent to a COA‟s boundary as a proxy for species movement potential.

We applied the development scenarios from the Willamette River Basin Planning Atlas (Hulse et al. 2002) to characterize potential future habitat adjacent to each COA. The Atlas project incorporated current policies and regulations affecting the Willamette Valley‟s environment and natural resources to build development/conservation scenarios for the year 2050. These scenarios were meant to reflect a range of alternative futures for the valley and map out potential areas of natural resource use, natural habitat, roads, residential housing, commercial development, etc. The authors did not incorporate climate change impacts but were focused solely on projected economic, political, and social changes. The three scenarios included 1) a Planned Trend scenario, which assumes a continuation of "existing long-term plans and policies", 2) a Development scenario, which assumes a "greater reliance on market-oriented approaches", and 3) a Conservation scenario, which assumes the incorporation of policies that "prioritize ecological services".

Since the COAs defined in the OCS are largely permanent (personal communication, Michael, H.), we wanted to measure how much movement capability species may have between the COAs and the surrounding landscape. We used the land use/land cover (LULC) classes in the Planned Trend scenario and grouped them into two broad categories: Habitat and non-habitat. Non-habitat was defined as the LULC categories, which had high levels of human use and were assumed to be poor habitat; it also included suburban/urban development areas, agriculture, and natural resource extraction areas (i.e., conifer woodlot). Habitat was defined as the LULC categories, which were comprised of forest and other natural land cover (other than natural *resources*). After re-categorization, we calculated in ArcGIS the percent of habitat surrounding the COA‟s boundary (within .5 miles) that was habitat vs. non-habitat. Subscores were determined based on division of percent habitat into three equal classes (Table 12).

Table 12. Movement Capability classes and subscore

Surrounding habitat classes	Movement Capability subscore
$x \leq 33\%$	3
$33\% < x \leq 66\%$	2
$x > 66\%$	1

Climate-Imperiled Strategy Species
Given that one goal of COAs is to promote the persistence of Strategy Species, COAs that contain a higher percentage of species vulnerable to climate change (i.e. climate-imperiled Strategy Species) were considered to be more sensitive. We define climate-imperiled species as those species receiving a CCVI score of extremely to moderately vulnerable (1-3; Table 4 in Part I). To mimic the procedure recommended for species by CCVI, we used the species vulnerability results under the medium A1B climate scenario (Table 5 in Part I).

The percent of climate-imperiled Strategy Species was calculated by dividing the total number of imperiled species per COA by the total number of imperiled species for all COAs. The resulting percentages of imperiled Strategy Species were used to place each COA into one of three classes (Table 13).

Table 13. Climate-Imperiled Strategy Species classes and corresponding subscores

Total Climate-Imperiled Strategy Species classes	Climate-Imperiled Strategy Species subscore
0-16	3
17-33	2
34-50	1

Climate Change Exposure
Part of the definition of vulnerability is the exposure of a species, habitat, or ecosystem to climate change (Fischlin et al. 2007). To determine exposure for the COAs, we used 2050 climate projections generated by Climate Wizard (Zganjar et al. 2009) and the temperature and precipitation change categories recommended for the species vulnerability analysis in part I (Young et al. 2010). We used CCVI"s recommended climate projection for the year 2050, based on the IPCC AIB emissions scenario and the General Circulation Model ensemble average.

All of the COAs assessed fell within the same range of predicted temperature change (≤ 3^{o} F). Because of this, we focused on differences in projected precipitation change to determine differences in exposure between COAs. Precipitation changes fell into two categories: -1 to +1% wetter than average or 1 to 3% wetter than average (annually). The first category is the minimal amount of precipitation change possible; the second category represents more significant change. COAs that had less than or equal to 33% of their extent within the greater change category were given a ranking of 1, greater than 33% or less than/equal to 67% in the greater change category were given a score of 2, and greater than 67% in the greater change category were given a score of 3 (Table 14).

Table 14. Climate Change Exposure classes and corresponding subscores

COA area with greater precipitation change classes	Climate Exposure subscore
x ≤ 33%	1
33% < x ≤ 66%	2
x > 66%	3

Sensitive Habitat
We used four Strategy Habitats defined in the OCS: riparian, oak woodland, wetland, and grassland. We incorporated GIS maps of Strategy Habitats created by Oregon Department of Fish and Wildlife (ODFW 2010) into our analysis. (Note: Freshwater is also an OCS Strategy Habitat but was not included because spatial data was not available). These maps were then used to calculate the percentage of COA area comprised of each Strategy Habitat.

To assess the relative habitat vulnerability to climate change, we developed a list of criteria based on other habitat vulnerability analyses (see references in Table 7). Those criteria and subsequent habitat categorization are listed in Table 15. We had limited source data to draw upon for these habitat vulnerability questions and proposed categorizations (see references in Table 15), and we acknowledge that there are many more nuanced ways to ask and answer these vulnerability topics. However, our list and answers provide a first-pass at assessing Strategy Habitat Vulnerability within the Willamette Valley and offer insight into how our findings might affect COA prioritization with respect to climate change. Based upon our assessment of habitat vulnerability, we gave oaks a ranking of 0, grasslands a ranking of 1, and riparian/wetland/aquatic a ranking of 2. Those numbers were chosen based on the fact that oak woodlands may not only be insensitive to climate change but also may, in fact, do better with currently predicted climate change impacts. Thus, we determined that that habitat should just have a zero-sum subscore and subsequently, each successive level of vulnerability ("vulnerable" and "very vulnerable") started after that zero subscore.

Table 15. Strategy Habitat vulnerability criteria and categorization[9]. “Yes” responses point toward increase vulnerability of that habitat due to climate change impacts. “Yes, somewhat” point toward suggested but not explicit potential increased vulnerability of that habitat. “No” responses point toward neutral or decreased vulnerability. “Unknown” responses point to our inability to determine an appropriate response due to lack of literature. Qualitative scoring for each habitat was based on the ratio of yes to no responses taking into consideration the number of unknown responses for that habitat. Each question was given equal weight in determining the qualitative score. Quantitative scoring was based on the ranking of the qualitative subscores.

Questions*	Riparian	Oak woodland	Wetland	Grassland
Is the habitat sensitive to warming temperatures?	Yes	No	Yes	Unknown
Is the habitat sensitive to predicted changing precipitation patterns?	Yes	No	Yes	Yes
Is the habitat at the southern edge of its geographic extent?	No	No	No	No
Is the habitat sensitive to changing fire regimes?	No	Yes	No	Yes
Are the component species of the habitat sensitive to climate change?	Yes	No	Yes	Unknown
Is the community structure intertwined?	Yes, somewhat	Yes	Unknown	Yes, somewhat
Number of positively-vulnerable responses	3.5	2	3	2.5
Number of negatively-vulnerable responses	2	4	2	1
Qualitative score	Very vulnerable	Not vulnerable	Very vulnerable	Vulnerable
Quantitative score	2	0	2	1
References	(ODFW 2005, PAWG 2008, Doppelt et al. 2009, ODOT 2010, Halofsky 2011)	(Thompson et al. 1998, Doppelt et al. 2009, Boyer 2010, ODOT 2010)	(Lawler et al. 2008, Doppelt et al. 2009, ODOT 2010, Halofsky 2011)	(ODFW 2005, Doppelt et al. 2009, Vesely and Rosenberg 2010)

9 The references listed in Table 15 for habitat vulnerability assessments also included three additional questions that we did not evaluate due to lack of relevancy for our study area, paucity of information, or because the question was addressed elsewhere in our analysis. Those questions were: 1) Is the habitat at relatively high elevation? 2) Is the habitat sensitive to pest/disease outbreaks? and 3) How permeable is the landscape?

After ranking the habitats and determining the area of each as a percentage of each COA, we then ranked the COAs with respect to how much sensitive habitat each contained. To do this, we used a multi-tiered system to calculate that final subscore (Figure 14).

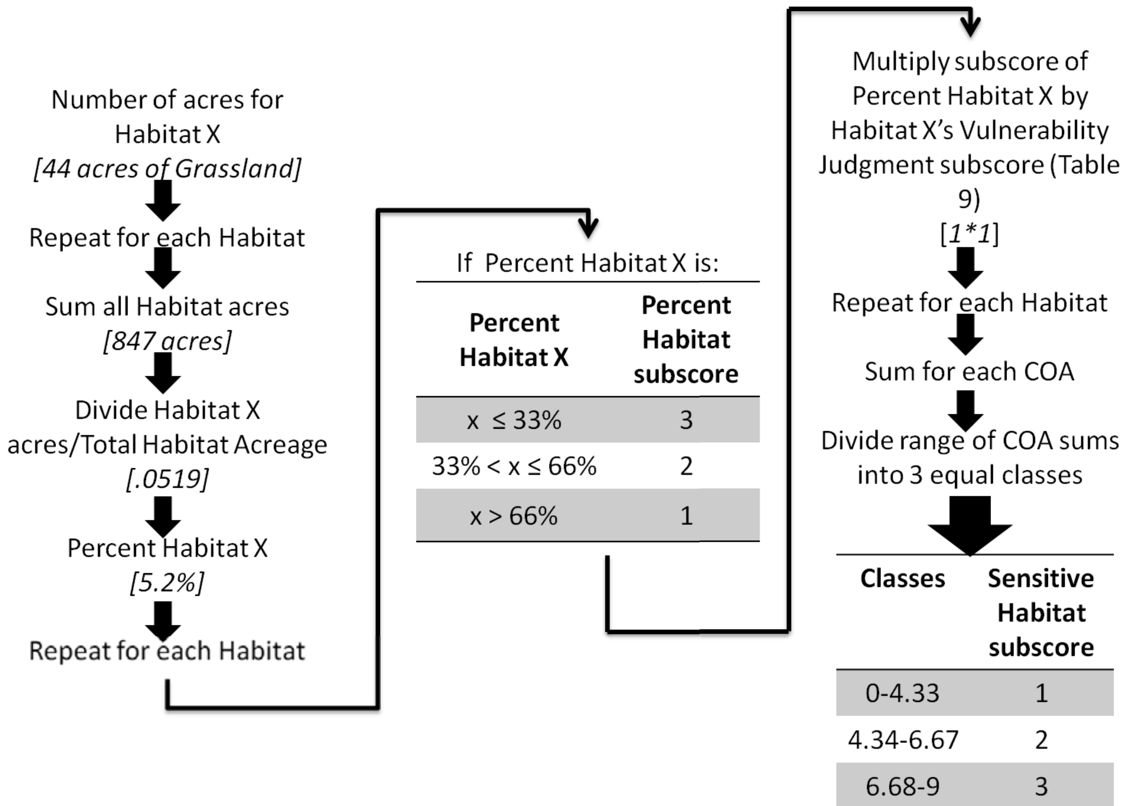


Figure 14. Method of scoring Sensitive Habitat subscore. Example from WV-01 Colombia River Bottomlands" Grassland habitat is in italics within brackets.

2.3 Prioritizing COAs based on final sensitivity and vulnerability scores

To calculate a COAs" final non-CC sensitivity and CC-vulnerability scores, we summed all parameter subscores. Thus, the non-CC sensitivity score, for each COA, is the sum of its three parameter subscores. The CC-vulnerability score, for each COA, is the sum of its five parameter subscores. Without previous knowledge of the relative importance of each parameter on climate change vulnerability, we chose to weight all parameters equally. As with the subscores for each parameter, this was achieved by developing a three class scoring system for each parameter with the 1st class representing "least sensitive" and the "most sensitive" represented by the 3rd.

Using this scoring system, the overall non-CC stressors sensitivity and CC vulnerability scores for each COA provide a means to rank the COAs relative to one another in terms of their sensitivity to non-CC stressors and CC vulnerability. Accordingly, this relative ranking serves as a basis of conservation effort prioritization.

2.4 Assessing individual parameter influence

Similar to our analysis of life history parameters in Part I of this report, we quantified the influence of each parameter on a COA‟s overall vulnerability score. We used the individual parameter scores (1, 2, or 3 for all parameters) multiplied by the frequency of each of those scores for each parameter to calculate the quantitative influence of each parameter. This enabled us to determine which parameters make COAs more or less vulnerable to climate change and other stressors generally.

3. Results

3.1 Which COAs are most sensitive to non-climate change stressors?

Table 16. Conservation opportunity areas ranked from highest to lowest sensitivity

Conservation Opportunity Area	Strategy Species	Area	Habitat limiting factors	Non-CC stressor sensitivity
Calapooia River	3	3	3	**9**
Coburg Ridge area	3	3	3	**9**
Finley-Muddy Creek area	3	3	3	**9**
Habeck Oaks	3	3	3	**9**
Kingston Prairie Area	3	3	3	**9**
Lower and North Santiam Rivers	3	3	3	**9**
Luckiamute River	3	3	3	**9**
McKenzie River	3	3	3	**9**
Salem Hills-Ankeny NWR	3	3	3	**9**
Basket Butte	2	3	3	**8**
Corvallis area	3	2	3	**8**
Lower Little Pudding River	2	3	3	**8**
Mohawk River	2	3	3	**8**
Tualatin River	2	3	3	**8**
Yamhill Oaks	2	3	3	**8**
Airlie Oaks	2	3	2	**7**
Clackamas River Area	3	3	1	**7**
Columbia River Bottomlands	3	2	2	**7**
Sandy River Area	2	3	2	**7**
West Eugene	3	1	3	**7**
Willamette River Floodplain	3	1	3	**7**
Amity Oaks	1	3	2	**6**
One Horse Slough-Beaver Creek	1	2	3	**6**
Smith-Bybee Lakes	2	3	1	**6**
Upper Siuslaw area	2	3	1	**6**
Airlie Savanna	1	3	1	**5**
Bank Swamp	1	3	1	**5**

3.2 Which COAs are most vulnerable to climate change?

Table 17. Conservation opportunity areas ranked from most to least vulnerable. Two COAs were not assessed due lack of GIS data for either the Movement capability and/or Sensitive habitat parameters. These are marked with NA.

Conservation Opportunity Area	Movement capability	Imperiled species	CC exposure	Sensitive habitat	Non-CC stressor sensitivity ranking	CC vulnerability
Calapooia River	3	2	1	3	3	**12**
Columbia River Bottomlands	2	3	3	2	2	**12**
Willamette River Floodplain	3	3	1	3	2	**12**
Basket Butte	3	1	3	1	3	**11**
Finley-Muddy Creek area	3	2	1	2	3	**11**
Habeck Oaks	3	1	3	1	3	**11**
Lower and North Santiam Rivers	3	1	1	3	3	**11**
Luckiamute River	2	2	2	2	3	**11**
McKenzie River	2	3	1	2	3	**11**
Mohawk River	2	3	1	2	3	**11**
Sandy River Area	3	3	1	2	2	**11**
Tualatin River	3	1	2	2	3	**11**
Airlie Oaks	3	1	3	1	2	**10**
Coburg Ridge area	1	3	1	2	3	**10**
Corvallis area	1	2	2	2	3	**10**
Lower Little Pudding River	2	1	1	3	3	**10**
Yamhill Oaks	2	1	3	1	2	**10**
Kingston Prairie Area	2	1	1	2	3	**9**
One Horse Slough-Beaver Creek	2	1	1	3	2	**9**
Salem Hills-Ankeny NWR	3	1	1	1	3	**9**
Smith-Bybee Lakes	3	2	2	1	2	**9**
West Eugene	2	2	1	2	2	**9**
Amity Oaks	2	1	3	1	1	**8**
Clackamas River Area	2	2	1	1	2	**8**
Airlie Savanna	1	1	3	1	1	**7**
Bank Swamp	2	1	3	NA	1	**NA**
Upper Siuslaw area	NA	1	1	NA	1	**NA**

3.3 Which individual parameters most influenced vulnerability scores?

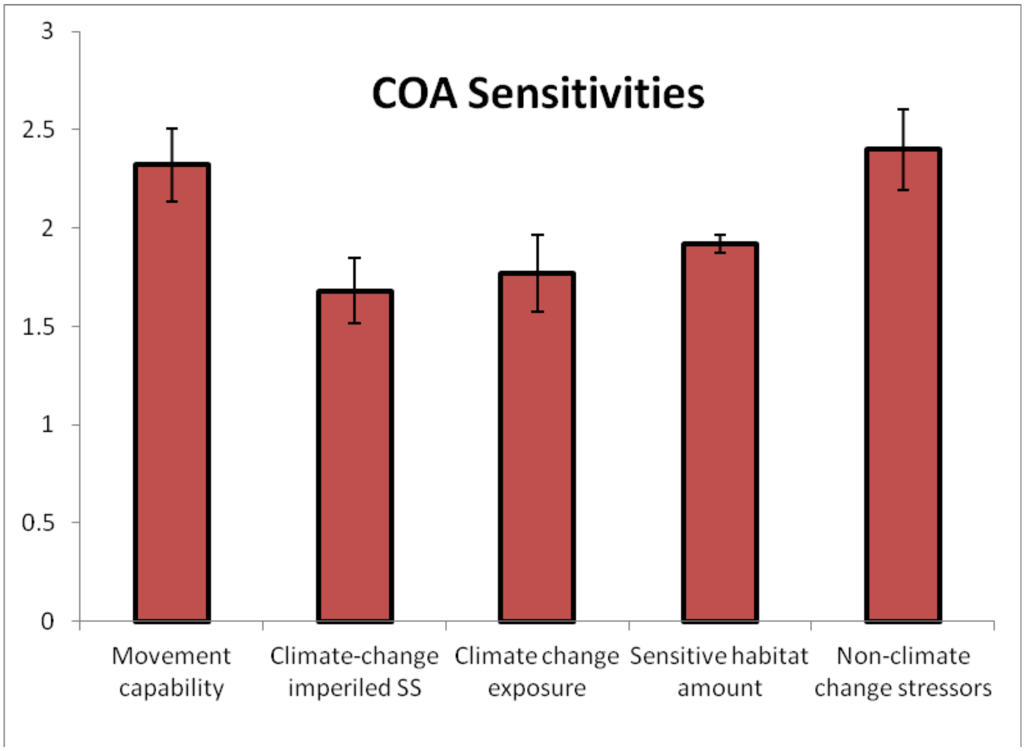


Figure 15. Aggregated COA sensitivities to climate change parameters. Greater values indicate a larger increase in the climate change vulnerability. Scores presented here are the average for all 27 COAs.

4. Discussion

4.1 Characteristics of high-priority COAs

Tables 16 and 17 demonstrate how our place-based approach can provide a ranked list of conservation areas. Results from this and similar assessments can help managers prioritize conservation efforts across focal areas based on their relative vulnerability to climate change and sensitivity to other stressors. The step-by-step process may also help managers determine *why* a particular place may be more vulnerable than others by revealing which parameters contributed the most to its vulnerability (Figure 15).

Non-climate change stressors sensitivity
Eight COAs received the highest possible ranking prior to the incorporation of climate change effects (Table 16). All of these COAs received a 3 (the highest subscore) for each parameter. All had high numbers of Strategy Species, a relatively small area, and a high number of Habitat Limiting Factors. As there were only three parameters in this part of our analysis, there was smaller variation in scoring and characterization of high-priority COAs than there was when climate change impacts were considered.

Climate change vulnerability
The Calapooia River, Columbia River Bottomlands, and Willamette Valley Floodplain COAs had the highest climate change vulnerability scores (Table 17). The lack of pattern in specific-parameter influence on vulnerability score suggests that these three COAs are vulnerable to climate change for distinct reasons. There was no parameter in particular that uniformly or overwhelmingly influenced climate change vulnerability for the most vulnerable COAs.

The Willamette River Floodplain is the largest COA making it more sensitive with respect to certain parameters. A conservation area of such great size is more likely to contain climate-imperiled Strategy Species as well as climate-imperiled Strategy Habitats. Indeed, according to our calculated results, the Willamette River Floodplain does have a relatively large number of climate-imperiled Strategy Species and Habitats. On the other hand, its large area decreases its overall vulnerability for the Area parameter in the non-CC sensitivity component (see section 2.2.1). This COA exemplifies the idea that in some cases, a particular characteristic (e.g., larger area) can make a conservation place more vulnerable to climate change (e.g., greater number of vulnerable prioritized species), while in other cases, that same characteristic can decrease its vulnerability (e.g., stronger conservation "portfolio" that can help with stability and/or adaptability of entire area). An additional factor that increases this COA�
s overall CC vulnerability is that, by 2050, a large proportion of its boundary may be surrounded by development/agriculture, which may prevent species from moving outside the Willamette River Floodplain.

The Columbia River Bottomlands is ranked highly vulnerable largely due to the fact that it is the only COA without a single low (1) subscore. It has a relatively large number of climate-imperiled Strategy Species, and it (along with seven other COAs) is predicted to experience the highest amount of precipitation change within the valley. It received medium subscores (2) for the other three parameters of direct movement capability, sensitive habitat amount, and non-CC sensitivity.

Unlike the Floodplain, the Calapooia River is small relative to most other COAs, but as its name implies, it encompasses a high percentage of riparian area, one of the most vulnerable Strategy Habitats. The Calapooia River also may be highly constrained by projected development/agriculture around its boundaries. Its multiple, non-CC stressors (Table 16) give it a high baseline sensitivity which feeds into its overall climate-change vulnerability ranking.

4.2 How does climate change impact COA prioritization?

Incorporating climate change into our analysis changed the prioritization ranking of several COAs. When using only our three non-CC sensitivity parameters, eight COAs received the highest score possible (9) (Table 16). After incorporating CC parameters, two COAs (Willamette Valley Floodplain and Calapooia River) received the highest score of 12 (Table 17). The Willamette Valley Floodplain had not been in the top ranking when only non-CC sensitivity was considered. In addition, three of the highest ranked COAs in the non-CC sensitivity analysis did not appear in the top two ranks of the climate change analysis: Coburg Ridge Area, Kingston Prairie Area, and Salem Hills-Ankeny NWR. This shift in prioritization as predicted climate change impacts are included into the analysis demonstrates that climate change is an essential factor for managers to consider when prioritizing time and resources within conservation places.

4.3 Sensitivities and implications for management

By taking a critical look at the influence of individual parameters on the final climate change vulnerability score, we can elucidate the biophysical drivers behind COA vulnerability. As seen in Part I, this could influence the type and prioritization of management actions taken in individual COAs and across the valley‟s COA network.

On average, the Non-CC Stressor subscore increased the overall COA vulnerability score more than any other model parameter (Figure 15). 56% of assessed COAs had the highest Non-CC Stressor subscore (3), meaning that the majority of COAs are facing significant, ongoing non-climactic stressors. This suggests that managers in the Willamette Valley may want to focus primarily on conservation efforts aimed at those particular threats. This idea has been put forth by several other climate change adaptation reports and papers (e.g., Heinz Center 2008, AFWA 2009).

The next most influential parameter was Movement Capability (Figure 15). 42% of assessed COAs had the highest Movement Capability subscore (3). By 2050, many COAs are projected to be surrounded by development and/or agriculture, possibly hindering species‟ movement outside COAs. To counter that potential boundary problem, managers might want to carefully monitor development and agriculture trends, targeting habitat conservation efforts around COAs that are likely to experience increasing human impact. This could involve more focused attention on methods of "softening the matrix," such as planting hedgerows in agricultural landscapes or riparian restoration (Heinz Center 2008).

The Climate-Imperiled Strategy Species and Climate Exposure parameters contributed the least to the overall COA vulnerability score (Figure 15). The majority of COAs did not have many Strategy Species that are predicted to be vulnerable to climate change. In addition, most COAs are not predicted to experience relatively high levels precipitation changes. However, it should be noted that we used a relatively conservative climate change projection in the design of this parameter. Therefore, temperature and precipitation changes may actually be much greater and more varied across the valley.

The parameters used in this analysis provide a workable and easily adaptable framework of place-based climate change assessment. Our analysis and results represent a first step toward developing strategies addressing non-climate stressors as well as predicted climate-induced impacts. With the incorporation of more specific and locally relevant model parameters in future place based assessments, managers can hone in on more detailed management actions that address COA vulnerability.

4.4 Next steps and project value

- Future iterations of this framework would greatly benefit from collaboration with local experts and managers. One criticism of climate change vulnerability analyses discussed during a stakeholder meeting at the ODFW headquarters in Salem, Oregon in February 2011, is that they are often too large in scale (e.g., regional) and inflexible to be valuable to local managers. The inflexibility of some assessment tools may prevent the incorporation of local factors, which may be of high concern for stake-holders. Acknowledging this potential weakness, we strove to make our framework adaptable with the capacity to accommodate additional parameters as well as greater input in the scoring of current parameters. Discussions with managers could elucidate what additional parameters would better meet their specific and local needs. Local expert opinion regarding how habitats or species may respond to a changing climate could improve and strengthen the scoring of parameters such as habitat sensitivity (see *Sensitive habitat amount per COA* parameter, section *2.3.2*).

- Invasive species can be a major factor in the displacement or local extirpation of focal species and alter community structure and/or ecosystem function (Chown et al. 2009, Vila and Ibanez 2011). This potential sensitivity parameter was cited by multiple vulnerability sources (Table 7). Given their substantial impacts, invasive species warrant incorporation into future vulnerability frameworks. Unfortunately, there was limited information regarding the identity and location of invasives within the Oregon Conservation Strategy. Consequently, we could only account for the presence of invasives (i.e., species unknown) within the COAs and therefore, subsumed this significant factor under the Habitat Limiting Factors parameter. We recommend that future versions include a stand-alone invasive species parameter.

- The ability of organisms to track climate change is likely to become an increasingly critical component of species" survival (Parmesan 2006, Tingley et al. 2009) Development scenarios can be used to assess the future availability of undeveloped habitat, which may be critical to facilitate species" movement due to climate change pressures. The Movement Capability parameter of this report is based on one probable development scenario for the Willamette Valley. Projected development around the COAs significantly affected vulnerability scores. Examining how the other two development scenarios described in the Oregon Planning Atlas (more unregulated development vs. stronger land conservation) affect COA vulnerability ranking would better inform managers of how future development might impact COAs and the species within.

- Connectivity within and potential connectivity among COAs should be assessed and incorporated into this framework. Admittedly, this objective is much easier advised than executed and is largely context dependent. For example, achieving connectivity for a particular bird species may be quite different than for a species easily hindered by barriers such as roads. Due to the difficulty in assessing true connectivity, it was not included in this preliminary work. However, published research regarding the efficacy of differing types of wildlife linkages for particular species (e.g., Rosenberg et al. 1997, Haddad et al. 2003, Anderson and Jenkins 2006) and advancements in least cost path analysis and other connectivity measures (e.g., Kindlmann and Burel 2008, Kadoya 2009) provide a means to begin at least considering connectivity in future climate change vulnerability assessments.

- The OCS identified key conservation places on which many Strategy Species depend. These conservation places will become increasingly valuable in the face of global change and thus warrant assessment-informed management such as that discussed here. However, few examples of place-based vulnerability assessments exist. As such, this preliminary framework was intended to fill this gap, aiding managers who must coordinate conservation efforts over multiple conservation areas such as a reserve network. Due to the paucity of published literature regarding ecological community response to climate change, this first iteration only considers a handful of important factors pertinent to climate change vulnerability of conservation places. As more climate change research becomes available, more factors, including those listed above, can be added to this framework to incorporate local-specificity and increase model effectiveness. In the interim, this framework can serve as a springboard to generate discussion regarding the value of place-based climate change vulnerability assessments and spur similar investigations.

References

AFWA. 2009. Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans & Other Management Plans. A Collaboration of the Association of Fish & Wildlife Agencies" Climate Change and Teaming With Wildlife Committees.

Altermatt, F. 2010. Climatic warming increases voltinism in European butterflies and moths. Proceedings of the Royal Society B-Biological Sciences **277**:1281-1287.

Anderson, A. B. and C. N. Jenkins. 2006. Applying Nature's Design: Corridors as a Strategy for Biodiversity Conservation. Colombia University Press, New York, Chichester, West Sussex.

Araújo, M. B., M. Cabeza, W. Thuiller, L. Hannah, and P. H. Williams. 2004. Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. Global Change Biology **10**:1618-1626.

Bagne, K. E. and K. L. Purcell. 2009. Lessons learned from prescribed fire in Ponderosa Pine forests of the Southern Sierra Nevada. Pages 679-690 *in* Proceedings of the Fourth International Partners in Flight Conference: Tundra to Tropics.

Baron, J. S., L. Gunderson, C. D. Allen, E. Fleishman, D. McKenzie, L. A. Meyerson, J. Oropeza, and N. Stephenson. 2009. Options for National Parks and Reserves for Adapting to Climate Change. Environmental Management **44**:1033-1042.

Battisti, A., M. Stastny, S. Netherer, C. Robinet, A. Schopf, A. Roques, and S. Larsson. 2005. Expansion of geographic range in the pine processionary moth caused by increased winter temperatures. Ecological Applications **15**:2084-2096.

Black, S. H. and d. M. Vaughan. 2005. Species Profile: *Icaricia icarioides fenderi*. The Xerces Society for Invertebrate Conservation, Portland, OR.

Black, S. H. and D. M. Vaughn. 2005. Species profile: *Euphydryas edith taylori*.*in* M. Vaughan and S. H. Black, editors. Red List of Pollinator Insects of North America. The Xerces Society for Invertebrate Conservation, Portland, OR.

Blood, D. A., M. Hames, A. Graham, R. Pawlas, and L. Friis. 1998. Townsend's big-eared bat. Ministry of Environment, Lands, and Parks, Victoria, B.C.

Boyer, L. 2010. Willamette Valley Oak Savanna Habitat. Heritage Seedlings Inc.. Available at: http://www.heritageseedlings.com/PDF/stewardship/WillametteValleyOakSavannaHabitat.pdf, Salem, OR.

Brett, J. R. 1971. Energetic responses of salmon to temperature- study of some thermal relations in physiology and freshwater ecology of sockeye salmon (*Oncorhynchus-nerka*). American Zoologist **11**:99-&.

Brett, J. R. and N. R. Glass. 1973. Metabolic rates and critical swimming speeds of sockeye salmon (*Oncorhynchus-nerka*) in relation to size and temperature. Journal of the Fisheries Research Board of Canada **30**:379-&.

Brosofske, K. D., J. Q. Chen, R. J. Naiman, and J. F. Franklin. 1997. Harvesting effects on microclimatic gradients from small streams to uplands in western Washington. Ecological Applications **7**:1188-1200.

Brown, J. H. and A. Kodricbrown. 1977. Turnover rates in insular biogeography- effect of immigration on extinction. Ecology **58**:445-449.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree, and K. Hayhoe. 2008. Climate change scenarios for the California region. Climatic Change **87**:S21-S42.

Chown, S. L., D. Spear, J. E. Lee, and J. D. Shaw. 2009. Animal introductions to southern systems: lessons for ecology and for policy. African Zoology **44**:248-262.

Clark, D. L. 1999. Demographic analysis of *Erigeron decumbens* var *decumbens*: an endangered plant species of the Willamette Valley, Oregon, 1999 Field Studies. USFWS, Western Oregon NWR Refuge Complex.

Cole, D., N. L. Stephenson, and C. I. Millar. 2010. Responding to climate change: a toolbox of management strategies. Pages 179-196 *in* D. N. Cole and L. Yung, editors. Beyond Naturalness: Rethinking Park and Wilderness Stewardship in an Era of Rapid Change. Island Press.

Connor, W. P., E. Connor, and B. D. Arnsberg. 1994. Estimating fall chinook salmon spawning habitat availability in the lower Clearwater River, Idaho.*in* Idaho Chapter of the American Fisheries Society, McCall, Idaho.

CPC. 2010. National Collection of Endangered Plants. Center for Plant Conservation, St. Louis MO.

Crick, H. Q. P., C. Dudley, D. E. Glue, and D. L. Thomson. 1997. UK birds are laying eggs earlier. Nature **388**:526-526.

Crimmins, S. M., S. Z. Dobrowski, J. A. Greenberg, J. T. Abatzoglou, and A. R. Mynsberge. 2011. Changes in climatic water balance drive downhill shifts in plant species' optimum elevations. Science **331**:324-327.

Davidson, C., M. F. Benard, H. B. Shaffer, J. M. Parker, C. O'Leary, J. M. Conlon, and L. A. Rollins-Smith. 2007. Effects of chytrid and carbaryl exposure on survival, growth and skin peptide defenses in foothill yellow-legged frogs. Environmental Science & Technology **41**:1771-1776.

Davies, Z. G., R. J. Wilson, T. M. Brereton, and C. D. Thomas. 2005. The re-expansion and improving status of the silver-spotted skipper butterfly (*Hesperia comma*) in Britain: a metapopulation success story. Biological Conservation **124**:189-198.

Davis, J. C. 1975. Minimal dissolved-oxygen requirements of aquatic life with emphasis on Canadian species- Review. Journal of the Fisheries Research Board of Canada **32**:2295-2332.

Donald, P. F. and A. D. Evans. 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. Journal of Applied Ecology **43**:209-218.

Doppelt, B., R. Hamilton, C. D. Williams, M. Koopman, and S. Vynee. 2009. Preparing for climate change in the Upper Willamette River Basin of Western Oregon: co-beneficial planning for communities and ecosystems. Climate Leadership Initiative.

Enquist, C. and D. Gori. 2008. Implications of Recent Climate Change on Conservation Priorities in New Mexico., The Nature Conservancy and Wildlife Conservation Society, Santa Fe, NM.

Erickson, J. L. and S. D. West. 2003. Associations of bats with local structure and landscape features of forested stands in western Oregon and Washington. Biological Conservation **109**:95-102.

Fimbel, C. 2004. Strategies for enhancing western gray squirrels on Fort Lewis. The Nature Conservancy.

Fischlin, A., G. F. Midgley, J. T. Price, R. Leemans, B. Gopal, C. Turley, M. D. A. Rounsevell, O. P. Dube, J. Tarazona, and A. Velichko. 2007. Climate Change 2007. Working Group II report: Impacts, Adaptations, and Vulnerability. IPCC, Cambridge, United Kingdom and New York, NY, USA.

Fuller, M. M., L. J. Gross, S. M. Duke-Sylvester, and M. Palmer. 2008. Testing the robustness of management decisions to uncertainty: Everglades restoration scenarios. Ecological Applications **18**:711-723.

Fussel, H. M. and R. J. T. Klein. 2006. Climate change vulnerability assessments: An evolution of conceptual thinking. Climatic Change **75**:301-329.

Galatowitsch, S., L. Frelich, and L. Phillips-Mao. 2009. Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America. Biological Conservation **142**:2012-2022.

GCRP. 2009. Global Climate Change Impacts in the United States. U. S. Global Change Research Program, Cambridge, New York.

Gervais, J., D. Rosenburg, S. Barnes, C. Puchy, and E. Stewart. 2009. Conservation assessment for the Western painted turtle in Oregon (*Chrysemys picta bellii*). USDI Bureau of Land Management and Fish and Wildlife Service, USDA Forest Service Region 6, Oregon Department of Fish and Wildlife, City of Portland Metro.

Girvetz, E. H., C. Zganjar, G. T. Raber, E. P. Maurer, P. Kareiva, and J. J. Lawler. 2009. Applied Climate-Change Analysis: The Climate Wizard Tool. Plos One **4**:Article No.: e8320.

Glick, P., B. A. Stein, and N. A. Edelson, editors. 2011. Scanning the Conservation Horizon: A guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

Griffiths, R. A., D. Sewell, and R. S. McCrea. 2010. Dynamics of a declining amphibian metapopulation: Survival, dispersal and the impact of climate. Biological Conservation **143**:485-491.

Gubler, D. J., P. Reiter, K. L. Ebi, W. Yap, R. Nasci, and J. A. Patz. 2001. Climate variability and change in the United States: Potential impacts on vector- and rodent-borne diseases. Environmental Health Perspectives **109**:223-233.

Haddad, N. M., D. R. Bowne, A. Cunningham, B. J. Danielson, D. J. Levey, S. Sargent, and T. Spira. 2003. Corridor use by diverse taxa. Ecology **84**:609-615.

Hagans, D. K., W. E. Weaver, and M. A. Madej. 1986. Long term on-site and off-site effects of logging and erosion in the Redwood Creek Basin in Northern California. National Council of Air and Streams, New York, New York.

Halofsky, J. E. P., D.L.; O'Halloran, K.A.; Hawkins Hoffman, C., eds. 2011. Adapting to climate change at Olympic National Forest and Olympic National Park, Gen. Tech. Rep., U.S. Dept of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Hannah, L., G. Midgley, S. Andelman, M. Araújo, G. Hughes, E. Martinez-Meyer, R. Pearson, and P. Williams. 2007. Protected area needs in a changing climate. Frontiers in Ecology and the Environment **5**:131-138.

Hannah, L., G. F. Midgley, and D. Millar. 2002. Climate change-integrated conservation strategies. Global Ecology and Biogeography **11**:485-495.

Hansen, L. J. and J. R. Hoffman. 2011. Climate Savvy: Adapting Conservation and Resource Management to a Changing World. Island Press, Washington D.C.

Harris, J. 1999. California myotis.*in* J. Harris and R. Duke, editors. California Wildlife Habitat Relationships System. California Department of Fish and Game, California Interagency Wildlife Task Group.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D. Samuel. 2002. Ecology - Climate warming and disease risks for terrestrial and marine biota. Science **296**:2158-2162.

Hastie, L. C., P. J. Cosgrove, N. Ellis, and M. J. Gaywood. 2003. The threat of climate change to freshwater pearl mussel populations. Ambio **32**:40-46.

Hawkes, L. 2008. Developing an approach to adaptation in the insular Caribbean: the hawksbill turtle as an indicator species. World Wildlife Fund, MacArthur Foundation.

Hawkins, E. and R. Sutton. 2009. The potential to narrow uncertainty in regional climate predictions. . Bulletin of the American Meteorological Society **90**:1095-+.

Hayes, D. W., K. R. McAllister, S. A. Richardson, and D. W. Stintson. 1999. Washington State Recovery Plan for the Western pond turtle. Washington Department of Fish and Wildlife.

Hayes, J. P. and S. C. Loeb. 2007. The influences of forest management on bats in North America. Pages 207-235 *in* M. J. Lacki, J. P. Hayes, and A. Kurta, editors. Bats in forests: conservation and management. Johns Hopkins University Press, Baltimore, Maryland.

Hayes, M. P. and M. R. Jennings. 1998. Habitat correlates of distribution of the California red-legged frog (*Rana aurora*) and the foothill yellow-legged frog (*Rana boylii*). Pages 144-158 *in* USFS, editor. Management of amphibians, reptiles, and small mammals in North America.

Heinz Center (H. John Heinz III Center for Science, E., and the Environment). 2008. Strategies for Managing the Effects of Climate Change on Wildlife and Ecosystems. Washington, D.C.

Heller, N. E. and E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation **142**:14-32.

Hopkins, W. A. 2007. Amphibians as models for studying environmental change. Ilar Journal **48**:270-277.

Hulse, D., S. Gregory, and J. Baker, editors. 2002. Willamette River Basin Planning Atlas: Trajectories of Environmental and Ecological Change. Oregon State University Press, Corvallis, OR.

Humphries, M. M., D. W. Thomas, and J. R. Speakman. 2002. Climate-mediated energetic constraints on the distribution of hibernating mammals. Nature **418**:313-316.

Husari, S. J. and K. S. McKelvey. 1996. Fire-management policies and programs. University of California, Davis.

Inkley, D. B., M. G. Anderson, A. R. Blaustein, V. R. Burkett, B. Felzer, B. Griffith, J. Price, and T. L. Root. 2004. Global climate change and wildlife in North America. Bethesda, Maryland, USA.

IPCC. 2000. Emission Scenarios. Intergovernmental panel on climate change, Geneva, Switzerland.

Janzen, F. J. 1994. Climate change and temperature-dependent sex determination in reptiles. Proceedings of the National Academy of Sciences of the United States of America **91**:7487-7490.

Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes **83**:449-458.

Jones, G., D. S. Jacobs, T. H. Kunz, M. R. Willig, and P. A. Racey. 2009. Carpe noctem: the importance of bats as bioindicators. Endangered Species Research **8**:93-115.

Kadoya, T. 2009. Assessing functional connectivity using empirical data. Population Ecology **51**:5-15.

Kahler, T. H., P. Roni, and T. P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences **58**:1947-1956.

Kaye, T., C. Menke, M. Michaud, R. Schwindt, and L. Wisehart. 2010. Benton County Prairie Species Habitat Conservation Plan. www.co.benton.or.us/parks/hcp. Institute for Applied Ecology.

Kilpatrick, A. M., C. J. Briggs, and P. Daszak. 2010. The ecology and impact of chytridiomycosis: an emerging disease of amphibians. Trends in Ecology & Evolution **25**:109-118.

Kindlmann, P. and F. Burel. 2008. Connectivity measures: a review. Landscape Ecology **23**:879-890.

Kupferberg, S. J., A. Catenazzi, K. Lunde, A. J. Lind, and W. J. Palen. 2009. Parasitic Copepod (Lernaea cyprinacea) Outbreaks in Foothill Yellow-legged Frogs (Rana boylii) Linked to Unusually Warm Summers and Amphibian Malformations in Northern California. Copeia:529-537.

Lawler, J. 2010. Climate Change Sensitivity Database. Accessed at: http://courses.washington.edu/ccdb/drupal/. University of Washington.

Lawler, J. J., M. Mathias, A. E. Yahnke, and E. H. Girvetz. 2008. Oregon's biodiversity in a changing climate. Report prepared for the Climate Leadership Initiative, University of Oregon.

Lawler, J. J., T. H. Tear, C. Pyke, M. R. Shaw, P. Gonzalez, P. Kareiva, L. Hansen, L. Hannah, K. Klausmeyer, A. Aldous, C. Bienz, and S. Pearsall. 2010. Resource management in a changing and uncertain climate. Frontiers in Ecology and the Environment **8**:35-43.

Levins, R. 1969. Some Demographic and Genetic Consequences of Environmental Heterogeneity for Biological Control. Bulletin of the ESA **15**:237-240.

Levins, R. 1970. Extinctions. Pages 77-107 Some Mathematical Questions in Biology: Lectures on Mathematics in the Life Sciences. American Mathematical Society, Providence, Rhode Island.

Lindenmayer, D. B., W. Steffen, A. A. Burbidge, L. Hughes, R. L. Kitching, W. Musgrave, M. S. Smith, and P. A. Werner. 2010. Conservation strategies in

response to rapid climate change: Australia as a case study. Biological Conservation **143**:1587-1593.
Lötters, S., J. Kielgast, J. Bielby, S. Schmidtlein, J. Bosch, M. Veith, S. Walker, M. Fisher, and D. Rödder. 2009. The Link Between Rapid Enigmatic Amphibian Decline and the Globally Emerging Chytrid Fungus. EcoHealth **6**:358-372.
Lovich, J. 2003. Turtles and global climate change.*in* Workshop: Impacts of climate change and land use in the southwestern United States. USGS Western Ecological Research Center, University of California, Riverside, CA.
Markham, A. 1996. Potential impacts of climate change on ecosystems: A review of implications for policymakers and conservation biologists. Climate Research **6**:179-191.
Marsh, D. M. and P. C. Trenham. 2001. Metapopulation dynamics and amphibian conservation. Conservation Biology **15**:40-49.
Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy. 2007. Fine-resolution climate projections enhance regional climate change impact studies. Eos Trans **88**:504.
Mawdsley, J. R., R. O'Malley, and D. S. Ojima. 2009. A Review of Climate-Change Adaptation Strategies for Wildlife Management and Biodiversity Conservation. Conservation Biology **23**:1080-1089.
MDFW and MCCS. 2010. Climate Change and Massachusetts Fish and Wildlife. Massachusetts Division of Fisheries and Wildlife and Manomet Center for Conservation Sciences.
Michael, H. and S. O'Brien. 2008. Preparing Oregon's Fish, Wildlife, and Habitats for Future Climate Change: A Guide for State Adaptation Efforts. Defenders of Wildlife and Oregon Department of Fish and Wildlife, West Linn and Salem, Oregon.
Miles, E. L., M. M. Elsner, J. S. Littell, L. W. Binder, and D. P. Lettenmaier. 2010. Assessing regional impacts and adaptation strategies for climate change: the Washington Climate Change Impacts Assessment. Climatic Change **102**:9-27.
Millar, C. I., N. L. Stephenson, and S. L. Stephens. 2007. Climate change and forests of the future: Managing in the face of uncertainty. Ecological Applications **17**:2145-2151.
Mills, A. M. 2005. Changes in the timing of spring and autumn migration in North American migrant passerines during a period of global warming. Ibis **147**:259-269.
Minor, E. S. and T. R. Lookingbill. 2010. A Multiscale Network Analysis of Protected-Area Connectivity for Mammals in the United States. Conservation Biology **24**:1549-1558.
Mistry, S. and A. Moreno-Valdez. 2008. Climate change and bats: vampire bats offer clues to the future. Bats Magazine.
Moritz, C., J. L. Patton, C. J. Conroy, J. L. Parra, G. C. White, and S. R. Beissinger. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science **322**:261-264.
Murphy, D. and S. B. Weiss. 1992. Effects of climate change on biological diversity in Western North America: species losses and mechanisms.*in* R. L. Peters and T. E. Lovejoy, editors. Global Warming and Biological Diversity. Hamilton Printing, Casteton, New York.

NatureServe. 2010. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1.*in* NatureServe, editor., Arlington, VA.
Nelitz, M., K. Wieckowski, M. Porter, K. Bryan, F. Poulsen, and D. Carr. 2010. Evaluating the vulnerability of freshwater fish habitats to climate change and identifying regional adaptation strategies in the Cariboo-Chilcotin. Report prepared for Fraser Salmon and Watersheds Program., ESSA Technologies Ltd.
Nussbaum, R. A., J. E. D. Brodie, and R. M. Storm. 1983. Amphibians and Reptiles of the Pacific Northwest. University Press of Idaho, Moscow, Idaho.
OCCRI. 2010. Research Projects. Oregon Climate Change Research Institute.
Öckinger, E. and H. Smith. 2008. Do corridors promote dispersal in grassland butterflies and other insects? Landscape Ecology **23**:27-40.
ODFW. 2005. Oregon Conservation Strategy. Oregon Department of Fish and Wildlife, Salem, Oregon.
ODFW. 2010. Natural Resources Information Management Program.
ODOT. 2010. The Oregon Climate Change Adaptation Framework. Oregon Department of Transportation, Portland, OR.
Ogden, A. E. and J. L. Innes. 2009. Application of Structured Decision Making to an Assessment of Climate Change Vulnerabilities and Adaptation Options for Sustainable Forest Management. Ecology and Society **14**:11.
ORBIC. 2010. Rare, Threatened and Endangered Species Element Occurrence Digital Data Set. Oregon Biodiversity Information Center, program of the Institute for Natural Resources, Portland, OR.
Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology Evolution and Systematics **37**:637-669.
Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature **421**:37-42.
Patt, A., R. J. T. Klein, and A. d. l. Vega-Leinert. 2005. Taking the uncertainty in climate-change vulnerability assessment seriously. C. R. Geoscience **337**:411-424.
Patz, J. A., P. R. Epstein, T. A. Burke, and J. M. Balbus. 1996. Global climate change and emerging infectious diseases. Journal of the American Medical Association **275**:217-223.
Patz, J. A. and W. K. Reisen. 2001. Immunology, climate change and vector-borne diseases. Trends in Immunology **22**:171-172.
PAWG. 2008. Leading the Way: Preparing for the Impacts of Climate Change in Washington. Recommendations of the Preparation and Adaptation Working Groups. Preparation and Adaptation Working Groups, Washington Dept. of Ecology. Available online at: http://www.ecy.wa.gov/climatechange/InterimReport/climate_08-C-PAWG.pdf, Olympia, WA.
Pearl, C. A. 2005. Rana aurora (Baird and Girard, 1852[b]) Northern red-legged frog. Pages 528-520 *in* M. Lannoo, editor. Amphibian Declines: the Conservation Status of United States Species. University of California Press, Berkeley.
Pelini, S. L., J. A. Keppel, A. E. Kelley, and J. J. Hellmann. 2010. Adaptation to host plants may prevent rapid insect responses to climate change. Global Change Biology **16**:2923-2929.

Peters, R. L. and J. D. S. Darling. 1985. The greenhouse effect and nature reserves. Bioscience **35**:707-717.
Peterson, G. D., G. S. Cumming, and S. R. Carpenter. 2003. Scenario planning: a tool for conservation in an uncertain world. Conservation Biology **17**:358-366.
Pounds, J. A., M. R. Bustamante, L. A. Coloma, J. A. Consuegra, M. P. L. Fogden, P. N. Foster, E. La Marca, K. L. Masters, A. Merino-Viteri, R. Puschendorf, S. R. Ron, G. A. Sanchez-Azofeifa, C. J. Still, and B. E. Young. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. Nature **439**:161-167.
Pyke, C. R. and D. T. Fischer. 2005. Selection of bioclimatically representative biological reserve systems under climate change. Biological Conservation **121**:429-441.
Radeloff, V. C., R. B. Hammer, S. I. Stewart, J. S. Fried, S. S. Holcomb, and J. F. McKeefry. 2005. The Wildland-Urban Interface in the United States. Ecological Applications **15**:799-805.
Rathburn, G. B., M. R. Jennings, T. G. Murphy, and N. R. Siepel. 1993. Status and ecology of sensitive aquatic vertebrates in lower San Simeon and Pico creeks, San Luis Obispo County, California.*in* USFWS, editor., National Ecology Research Center, San Simeon, California.
Ricciardi, A. and D. Simberloff. 2009. Assisted colonization is not a viable conservation strategy. Trends in Ecology & Evolution **24**:248-253.
Rizzo, D. M. and M. Garbelotto. 2003. Sudden oak death: endangering California and Oregon forest ecosystems. Frontiers in Ecology and the Environment **1**:197-204.
Rosenberg, D. K., B. R. Noon, and E. C. Meslow. 1997. Biological corridors: Form, function, and efficacy. Bioscience **47**:677-687.
Rosenburg, D., J. Gervais, D. Vesely, S. Barnes, L. Holts, R. Horn, R. Swift, L. Todd, and C. Yee. 2009. Conservation assessment of the Western pond turtle in Oregon (*Actinemys marmorata*). USDI Bureau of Land Management and Fish and Wildlife Service, USDA Forest Service Region 6, Oregon Department of Fish and Wildlife, City of Portland Metro.
Ryan, L. A. and A. B. Carey. 1995. Biology and management of the Western Gray Squirrel and Oregon White Oak woodlands; with emphasis on the Puget Trough. US Deptartment of Agriculture. Forest Service, Pacific Northwest Research Station, Portland, OR.
Scheerer, P. D. 2002. Implications of floodplain isolation and connectivity on the conservation of an endangered minnow, Oregon chub, in the Willamette River, Oregon. Transactions of the American Fisheries Society **131**:1070-1080.
Schultz, C. B. 1998. Dispersal Behavior and Its Implications for Reserve Design in a Rare Oregon Butterfly. Conservation Biology **12**:284-292.
Schultz, C. B. and E. E. Crone. 1998. Burning Prairie to Restore Butterfly Habitat: A Modeling Approach to Management Tradeoffs for the Fender's Blue. Restoration Ecology **6**:244-252.
Schultz, C. B. and E. E. Crone. 2005. Patch Size and Connectivity Thresholds for Butterfly Habitat Restoration
Tamaño del Fragmento y Umbrales de Conectividad para la Restauración del Hábitat de Mariposas. Conservation Biology **19**:887-896.

Schwartz, M. W., L. R. Iverson, A. M. Prasad, S. N. Matthews, and R. J. O'Connor. 2006. Predicting extinctions as a result of climate change. Ecology (Washington D C) **87**:1611-1615.

Scott, D., J. R. Malcolm, and C. Lemieux. 2002. Climate change and modelled biome representation in Canada's national park system: implications for system planning and park mandates. Global Ecology and Biogeography **11**:475-484.

Shafer, C. L. 1999. National park and reserve planning to protect biological diversity: some basic elements. Landscape and Urban Planning **44**:123-153.

Shuman, E. K. 2010. Global Climate Change and Infectious Diseases. New England Journal of Medicine **362**:1061-1063.

Smith, K. F., K. Acevedo-Whitehouse, and A. B. Pedersen. 2009. The role of infectious diseases in biological conservation. Animal Conservation **12**:1-12.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. M. (eds). 2007. Climate change 2007. Working Group 1 report: The Physical Science Basis. . IPCC, Cambridge, United Kingdom and New York, NY, USA.

Spence, B. C., G. A. Lomincky, R. M. Hughes, and R. P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp, Corvallis, OR.

Spies, T. A., T. W. Giesen, F. J. Swanson, J. F. Franklin, D. Lach, and K. N. Johnson. 2010. Climate change adaptation strategies for federal forests of the Pacific Northwest, USA: ecological, policy, and socio-economic perspectives. Landscape Ecology **25**:1185-1199.

Stralberg, D., D. Jongsomjit, C. A. Howell, M. A. Snyder, J. D. Alexander, J. A. Wiens, and T. L. Root. 2009. Re-Shuffling of Species with Climate Disruption: A No-Analog Future for California Birds? Plos One **4**.

Theoharides, K., G. Barnhart, and P. Glick. 2009. Climate Change Adaptation across the Landscape: A survey of federal and state agencies, conservation organizations and academic institutions in the United States. The Association of Fish and Wildlife Agencies, Defenders of Wildlife, The Nature Conservancy, The National Wildlife Federation.

Thomas, C. D., A. M. A. Franco, and J. K. Hill. 2006. Range retractions and extinction in the face of climate warming. Trends in ecology & evolution (Personal edition) **21**:415-416.

Thompson, R. S., S. W. Hostetler, P. J. Bartlein, and K. H. Anderson. 1998. A strategy for assessing potential future changes in climate, hydrology, and vegetation in the western United States. USGS.

Tingley, M. W., W. B. Monahan, S. R. Beissinger, and C. Moritz. 2009. Birds track their Grinnellian niche through a century of climate change. Proceedings of the National Academy of Sciences of the United States of America **106**:19637-19643.

Tomlinson, D. 2011. Bats and Migration. Organization for Bat Conservation.

Turner, B. L., R. E. Kasperson, P. A. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, J. X. Kasperson, A. Luers, M. L. Martello, C. Polsky, A. Pulsipher, and A. Schiller. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the United States of America **100**:8074-8079.

USDA. 1998. Stream corridor restoration: principles, processes, and practice. Federal Interagency Stream Restoration Working Group.
Vaughan, M. and S. H. Black. 2002. Petition to emergency list Taylor's (Whulge) checkerspot butterfly (*Euphydryas editha taylori*) as an endangered species under the U.S. Endangered Species Act.*in* X. Society, C. f. B. Diversity, O. N. R. Council, F. o. t. S. Juans, and N. E. Alliance, editors.
Vesely, D. G. and D. K. Rosenberg. 2010. Wildlife conservation in the Willamette Valley's remnant prairies and oak habitats: A research synthesis. Interagency Special Status Sensitive Species Progam, US Forest Service/Bureau of Land Management, Portland, OR.
Vila, M. and I. Ibanez. 2011. Plant invasions in the landscape. Landscape Ecology **26**:461-472.
Ward, J. V. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. Biological Conservation **83**:269-278.
Welch, D. W., E. L. Rechisky, M. C. Melnychuk, A. D. Porter, C. J. Walters, S. Clements, B. J. Clemens, R. S. McKinley, and C. Schreck. 2008. Survival of Migrating Salmon Smolts in Large Rivers With and Without Dams. Plos Biology **6**:2101-2108.
Wentworth, J. 1997. Castilleja levisecta, A threatened South Puget Sound Prairie Species. Natural Heritage Program.
Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. Science **313**:940-943.
WGA. 2008. Wildlife Corridors Initiative. Western Governors' Association.
WGA. 2010. Climate Adaptation Priorities for the Western States: Scoping Report. Western Governors' Association.
Wilson, M. L. 2001. Ecology and infectious disease. Pages 283-324 *in* J. L. Aron and J. A. Patz, editors. Ecosystem Change and Public Health. Johns Hopkins University Press, Baltimore, MD.
Wilson, M. V., P. C. Hammond, and C. B. Schultz. 1997. The interdepedence of native plants and Fender's blue butterfly. Native Plant Society of Oregon, Corvallis, Oregon.
Winkler, D. W., P. O. Dunn, and C. E. McCulloch. 2002. Predicting the effects of climate change on avian life-history traits. Proceedings of the National Academy of Sciences of the United States of America **99**:13595-13599.
WNHP. 1998. Reference Desk of the Washington Natural Heritage Program. Washington State Department of Natural Resources.
Wogen, N. S. 1998. Management Recommendations for Wayside Aster (*Aster vialis* [Bradshaw] Blake). Bureau of Land Management.
Yates, D., H. Galbraith, D. Purkey, A. Huber-Lee, J. Sieber, J. West, S. Herrod-Julius, and B. Joyce. 2008. Climate warming, water storage, and Chinook salmon in California's Sacramento Valley. Climatic Change **91**:335-350.
Young, B., E. Byers, K. Gravuer, K. Hall, G. Hammerson, and A. Redder. 2010. Guidelines for Using the NatureServe Climate Change Vulnerability Index: Release 1.2. NatureServe.

Zeug, S. C., L. K. Albertson, H. Lenihan, J. Hardy, and B. Cardinale. 2011. Predictors of Chinook salmon extirpation in California‟s Central Valley. Fisheries Management and Ecology **18**:61-71.
Zganjar, C., E. Girvetz, and G. Raber. 2009. ClimateWizard.

Appendix A – Data Tables

Table A-1. Sensitivity scores for Willamette Valley Strategy Species. Abbreviations signify the following: Dec – decrease sensitivity, SD – somewhat decrease, N – neutral, SI – somewhat increase, Inc – increase, U – unknown, and N/A – not applicable.

	Natl barriers	**Anth barriers**	**Dispersal**	**Macro temp**	**Micro temp**	**Macro precip**	**Micro precip**	**Disturbance**	**Ice/snow**	**Phys habitat**	**Other spp for hab**	**Diet**	**Pollinators**	**Other mutualism**	**Migrations**	**Genetic var**	**Phenol response**
Ammodramaus savannarum	SD	N	SI	SI	SI	SD	N	SI	N	SD	N	N	N/A	N	Dec	U	U
Asio flammeus	SD	N	N	SI	SI	SD	N	N	N	N-SD	N	N	N/A	N	SD-Dec	U	U
Aster curtus	SD	N	Dec	SI	N-SD	N	SI	SI	N	N	N	N/A	N	N	N/A	U	U
Aster vialis	SD	N	Dec	SI	N-SD	SD	SI	SI	N	SI	N	N/A	SI	N	N/A	SI	U
Branta canadensis	SD	N	Dec	SI	N	SD	N	N	N	N-SD	N	N	N/A	N	SI	U	U
Castilleja levisecta	SD	N	Dec	SI	N-SD	SD	SI-N	Inc-SI	N	Inc-SI	N	N/A	N	SI	N/A	U	U
Chordeiles minor	SD	N	Dec	SI	N	N	N	N	N	SD	N	N	N/A	N	Dec	U	U
Chrysmys picta bellii	SD	N	Dec	SI	N-SD	SD	SI	SI	N	N	N	N	N/A	N	N	U	U
Clemmys marmorata marmorata	SD	N	Dec	SI	SD	SD	SI	SI	N	N	N	N	N/A	N	N	U	U
Corynorhinus townsendii	SD	N	Dec	SI	N-SD	N	N	SI	N	SI	N	SI	N/A	N	U	U	N
Delphinium leucophaeum	SD	N	Dec	SI	N-SD	SD	SI	SI	N	SI	N	N/A	N	N	N/A	U	U
Delphinium xpavonaceum	SD	N	Dec	SI	SD	SD	SI	SI	N	N	N	N/A	SI	N	N/A	SI	U
Epidonax traillii	SD	N	Dec	SI	SD	SD	N	N	N	SD	N	N	N/A	N	Dec	U	U
Eremophila alpestris strigata	SD	N	Dec	SI	N-SD	SD	N	Inc-SI	N	SI	N	SD	N/A	N	N	U	U

Table A-1. Continued.

	Natl barriers	Anth barriers	Dispersal	Macro temp	Micro temp	Macro precip	Micro precip	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other mutualism	Migrations	Genetic var	Phenol response
Erigeron decumbens	SD	N	Dec	SI	N	SD	SI	SI	N	SI	N	N/A	N	N	N/A	U	U
Euphydryas editha taylori	N	N	Dec	SI	SD	SD	SI	Inc	N	SI	N	SI	N/A	N	SI	U	U
Howellia aquatilis	SI-N	N	N-SD	SI	Inc	SD	SI-N	Inc-SI	SI	SI	N	N/A	N	SI	N/A	SI	U
Icaricia icariodes fendereri	SI-N	N	SI-N	SI	Inc-SI	N	SI	SI	N	Inc	SI	Inc	N/A	N	SI	U	U
Icteria virens	SI-N	N	SI-N	SI	Inc	N	SD	SI-N	N	U	N	SD	N/A	N	N-SD	U	U
Lomatium bradshawii	SI-N	N	SI-N	SI	Inc	SD	SI-N	Inc-SI	N	SI	N	N/A	N	N	N/A	N	U
Lupinus oreganus var. kincaidii	SI-N	N	N-SD	SI	Inc-SI	SI	SI-N	Inc-SI	N	SI	N	N/A	SI	N	N/A	SI	U
Melanerpes formicivorus	SI-N	N	SI-N	SI	Inc-SI	N	N	N	N	N-SD	N	SD	N/A	N	SI	U	U
Myotis californicus	SI-N	N	SI-N	SI	Inc-SI	SI	N	N	N	SD	N	N	N/A	N	U	U	U
Oncorhynchus clarkii (pop 2)	SI-N	N	SI-N	SI	N	Inc-N	Inc-SI	SI-N	N	Inc	N	N	N/A	N	N	U	U
Oncorhynchus kisutch (pop 1)	SI-N	N	N-SD	Inc	Inc-SI	SI	SI-N	SI-N	N	SI	N	N	N/A	N	N	U	U
Oncorhynchus kisutch (pop 3)	N	N	SD	SI	Inc	N	SI-N	SI-N	N	SI	N	N	N/A	N	N	U	U
Oncorhynchus mykiss (pop 14)	SI-N	N	N-SD	SI	Inc-SI	SI	Inc	Inc	N	Inc	N	SD	N/A	N	N	U	U
Oncorhynchus mykiss (pop 15)	SI-N	N	SD	Inc	Inc-SI	Inc	SI-N	SI-N	N	Inc-SI	N	SD	N/A	N	N	U	U
Oncorhynchus mykiss (pop 20)	SI-N	N	SD	SI	Inc-SI	SD	SI-N	SI-N	N	Inc-SI	N	SD	N/A	N	N	U	U
Oncorhynchus mykiss (pop 23)	SD	N	SI	Inc-SI	N	SD	SI-N	SI-N	N	Inc-SI	N	SD	N/A	N	N	U	U

Table A-1. Continued.

	Natl barriers	Anth barriers	Dispersal	Macro temp	Micro temp	Macro precip	Micro precip	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other mutualism	Migrations	Genetic var	Phenol response
Oncorhynchus mykiss (pop 26)	SD	N	SI	Inc-SI	N	SD	SI-N	SI-N	N	Inc-SI	N	SD	N/A	N	N	U	U
Oncorhynchus tshawytscha (pop 16)	U	N	SD	Inc-SI	N	N	SI-N	SI-N	N	SI	N	N	N/A	N	SI	U	U
Oncorhynchus tshawytscha (pop 21)	SD	N	SD	SI	N	N	SI-N	SI-N	N	SI	N	N	N/A	N	SI	U	U
Oncorhynchus tshawytscha (pop 22)	SD	N	SD	SI	N	SD	SI	SI-N	N	SI	N	N	N/A	N	SI	U	U
Oregonichthys crameri	SD	N	N	Inc-SI	SI	SD	SI	Inc-SI-N	N	N	N	SD	N/A	N	SI	U	U
Pooecetes gramineus affinis	SD	N	N	Inc-SI	SI	SD	SI-N	N	N	N-SD	N	SD	N/A	N	N	U	U
Progne subis	SD	N	SI	Inc-SI	SI-N	SD	SD	SI-N	N	N-SD	N	N	N/A	N	N-SD	U	U
Rana aurora	SD	N	SI	SI	SI-N	N	SI	SI	N	N	N	N	N/A	N	N	U	U
Rana boylii	SD	N	SI	SI	SI-N	N	SI	SI	N	SI	N	N	N/A	N	N	U	U
Salvelinus confluentus	SD	N	SI	Inc-SI	SI-N	SD	Inc	SI-N	N	SI	N	SD	N/A	N	SI	U	U
Sciurus griseus	N	N	SI	Inc-SI	N	SD	N	N	N	N	N	N	N/A	N	SI	U	N
Sialia mexicana	SD	N	SI	Inc-SI	N	SD	SD	N	N	SD	N	SD	N/A	N	N	U	U
Sidalcea nelsoniana	SD	N	SI	Inc-SI	N	N	Inc	Inc	N	SI	N	N/A	N	N	N/A	SI	U
Sitta carolinensis	SD	N	SI	Inc-SI	N	N	N	N	N	SD	N	SD	N/A	N	N	U	U
Spizella passerina	SD	N	SI	Inc-SI	N	N	N	N	N	N-SD	N	SD	N/A	N	SD-Dec	U	U
Sturnella neglecta	SD	N	Inc	Inc-SI	N	SD	SD	SI-N	N	N-SD	N	N	N/A	N	SD-Dec	U	U

Table A-2. Vulnerability scores across three emissions scenarios and four climate models. Scores run from 1 (highest vulnerability) to 5 (lowest vulnerability).

	Emissions Scenarios			Climate Models					
Scientific Name	**B1**	**A1B**	**A2**	**CCSM**	**GISS**	**IPSL**	**UKMO**	**Mean**	**Range**
Aster vialis	3	3	3	1	3	1	1	2.14	2
Icaricia icarioides fendereri	3	3	3	1	3	1	1	2.14	2
Oncorhynchus clarkii (pop 2)	4	3	3	1	4	1	2	2.57	3
Oncorhynchus tshawytscha (pop 22)	4	3	3	1	4	1	2	2.57	3
Oncorhynchus mykiss (pop 23)	4	3	3	1	4	2	2	2.71	3
Oncorhynchus mykiss (pop 14)	3	3	3	2	4	2	2	2.71	2
Howellia aquatilis	4	4	3	1	4	1	2	2.71	3
Oncorhynchus tshawytscha (pop 21)	4	3	3	2	4	2	2	2.86	2
Euphydryas editha taylori	4	3	3	2	4	2	3	3.00	2
Oncorhynchus kisutch (pop 3)	4	4	3	2	4	2	2	3.00	2
Salvelinus confluentus (pop 2)	4	4	4	2	4	2	2	3.14	2
Oncorhynchus tshawytscha (pop 16)	4	4	4	2	4	2	2	3.14	2
Oncorhynchus mykiss (pop 26)	4	4	4	2	4	2	2	3.14	2
Lupinus oreganus var. kincaidii	4	4	4	2	4	2	2	3.14	2
Sidalcea nelsoniana	4	4	4	2	4	2	2	3.14	2
Castilleja levisecta	4	4	3	2	4	2	3	3.14	2
Delphinium xpavonaceum	4	4	4	2	4	2	3	3.29	2
Oregonichthys crameri	4	4	4	2	4	2	3	3.29	2
Oncorhynchus kisutch (pop 1)	4	4	4	2	4	2	3	3.29	2
Delphinium leucophaeum	4	4	4	2	4	2	3	3.29	2
Erigeron decumbens	4	4	4	3	4	3	3	3.57	1
Oncorhynchus mykiss (pop 15)	4	4	4	3	4	3	3	3.57	1
Lomatium bradshawii	4	4	4	3	4	3	3	3.57	1
Rana boylii	4	4	4	3	4	3	3	3.57	1
Aster curtus	4	4	4	3	4	3	4	3.71	1
Rana aurora	4	4	4	4	4	4	3	3.86	1
Oncorhynchus mykiss (pop 20)	4	4	4	4	4	4	4	4.00	0
Clemmys marmorata marmorata	4	4	4	4	4	4	4	4.00	0
Corynorhinus townsendii	4	4	4	4	4	4	4	4.00	0
Sciurus griseus	4	4	4	4	4	4	4	4.00	0
Chrysmys picta bellii	4	4	4	4	4	4	4	4.00	0
Eremophila alpestris strigata	4	4	4	5	4	5	5	4.43	1
Melanerpes formicivorus	4	4	5	5	4	5	5	4.57	1
Branta canadensis	4	5	4	5	4	5	5	4.57	1
Myotis californicus	4	4	5	5	5	5	5	4.71	1

Table A-2. Continued.

	Emission Scenarios			Climate Models					
Scientific Name	**B1**	**A1B**	**A2**	**CCSM**	**GISS**	**IPSL**	**UKMO**	**Mean**	**Range**
Pooecetes gramineus affinis	5	5	5	5	5	5	5	5.00	0
Progne subis	5	5	5	5	5	5	5	5.00	0
Ammodramaus savannarum	5	5	5	5	5	5	5	5.00	0
Asio flammeus	5	5	5	5	5	5	5	5.00	0
Spizella passerina	5	5	5	5	5	5	5	5.00	0
Empidonax traillii	5	5	5	5	5	5	5	5.00	0
Sitta carolinensis	5	5	5	5	5	5	5	5.00	0
Sialia mexicana Swainson	5	5	5	5	5	5	5	5.00	0
Sturnella neglecta	5	5	5	5	5	5	5	5.00	0
Icteria virens	5	5	5	5	5	5	5	5.00	0
Chordeiles minor	5	5	5	5	5	5	5	5.00	0

Appendix B - Challenges

Challenges are commonly encountered throughout the planning, execution, and writing stages of scientific investigations. Unfortunately, it is equally common to not document these challenges, leaving no roadmap to assist future researches in circumventing pitfalls previously discovered. By providing this appendix, we wish to facilitate future related research by highlighting the issues we encountered and to provide justifications for decisions made between alternative paths. We hope that this discussion of additional challenges not already outlined in the main text will be useful for those who intend to conduct similar vulnerability analyses, especially if using the NatureServe Climate Change Vulnerability Index (CCVI).

- Determining appropriate climate change projections

Any assessment addressing future threats must contend with multiple layers of uncertainty. This is especially true in the case of climate change where the magnitude and form of future environmental shifts is not fully understood. With this uncertainty in mind, we attempted to present the range of possible vulnerability scenarios by using multiple 2050 climate models, altering both emissions scenarios and general circulation models. We suggest that such an approach be used in all future assessments of climate change vulnerability. Relying on a single middle-of-the-road future climate model does not necessarily represent the most likely climate future and fails to demonstrate the range of potential responses by species of interest.

- Building range maps

To use the CCVI tool, range maps of all focal species are needed. Obtaining this data was difficult and time consuming because managers have not yet had the time or the data to create range maps for many Strategy Species. A few species, such as the plant *Castilleja levisecta*, had modeled range maps based on occurrence probability. However, we decided not use those since so few species had such detailed modeled range maps. Since one of our goals was to prioritize Strategy Species based on their relative vulnerability to the other Strategy Species within the Willamette Ecoregion, we decided to build range maps using the same baseline data and map resolution for all species. We made several assumptions in building our range map: a) that the occurrence data we received from the Oregon Biodiversity Center was the most accurate and up-to-date data available; b) that we could scale up from point-data to the sub-watershed level (i.e., if one occurrence had been marked for a sub-watershed, the range of the species extended to that entire sub-watershed); and c) that the sub-watershed level was a useful and ecologically relevant map scale for all terrestrial species. Having different base assumptions could alter the final vulnerability score and relative ranking for multiple species. We encourage future researchers to a) both fully acknowledge their all data assumptions and b) experiment with different base assumptions.

- Ecological and species range data gaps

Six species and eight fish ESU"s could not be assessed due to a lack of any range data, including occurrences. In addition, multiple listed Strategy birds in the Valley are subspecies rather than parent species, and we did not have occurrence data for five of those subspecies so we used the occurrence data for the parent species instead. In addition to range data, it was difficult to find life history information for several species such as the Willamette Floater. Due to that paucity of available information, they were not assessed in this analysis. A more general and widespread lack of information for almost all species also required us to make inferences in order for us to assess life history parameters in ways compatible with the CCVI definitions. However, the CCVI tool allows users to document their uncertainty when making such judgment calls, and this uncertainty is reflected in the final vulnerability score. For other researchers or research groups who intend to use the CCVI for rare, understudied organisms, we suggest identifying and collaborating with species experts from the beginning of the project to better obtain the information needed to run the index.

- Learning curve of Climate Wizard

The most time-consuming part of using CCVI was learning how to calculate climate exposure results and automate the process for many species. The time required for this stage of the assessment depends on the skill of the GIS analyst and his/her familiarity with CCVI. Preparation of climate projections, automation of exposure calculations, and computation of results for 46 species under 7 different climate runs took approximately 60 hours of work time. A graduate student with approximately 1 year of GIS experience and limited coding ability conducted this analysis. Employing an experienced GIS analyst or someone competent in GIS with past experience using CCVI could significantly reduce work time for this aspect of the project.

- Limitations of CCVI for aquatic systems

In its current version the CCVI is more effective at assessing the vulnerability of terrestrial species than aquatic species. There are a number of reasons for this:

1) The distribution of riverine species are often expressed linearly.Because the CCVI calculates climate exposure based on percentage of a species" range affected, this added some complications,

2) The climate parameters of average annual ambient temperature and precipitation are less directly relevant to aquatic species especially where waterways are highly regulated,

3) The differences between the movement/migration and dispersal parameters are not immediately clear for salmonids, which have a rather different life history than many terrestrial organisms (e.g., anadromism), and

4) The CCVI defines anthropogenic barriers by the amount of intensive land use surrounding a species" range (i.e., using the Wildland-Urban Interface). It does not account for dams and other impediments for aquatic connectivity.

- Coarse resolution

The CCVI "calibrates" its results based on the predicted temperature and precipitation changes (according to a medium emissions scenario) across the United States. Thus for small geographic areas with relatively narrow predicted changes, vulnerability results will also be narrow. In the case of the Willamette Valley, the region is expected to see less temperature increase than much of the US. For this reason we saw only low (5) to moderate (3) vulnerability scores under a medium climate scenario. While this may correctly show that the species within our study area will be less affected than those in other areas, it limits our ability to rank vulnerability of the species whose scores fall within this small range. Using multiple climate scenarios to create a continuous vulnerability score (e.g., the mean score using runs from four GCMs) will help address this coarse resolution issue.

Appendix C – Species Life History References

Ashton, D. T., A. J. Lind, and K. E. Schlick. 1997. Foothill Yellow-Legged Frog (*Rana boylii*) Natural History. USDA Forest Service, Pacific Southwest Reserach Station, Redwood Sciences Laboratory, Arcata, CA.

Auduban, N. H. 2009. Project Nighthawk. New Hampshire Auduban, Concord, NH. http://nhbirdrecords.org/bird-conservation/Nighthawk-main.htm.

Audubon, N. 2010. Hudson River Valley Priority Birds. Common Nighthawk. Audubon New York, http://ny.audubon.org.

BFCI. 2006a. Fender's blue butterfly *Icaricia icarioides fenderi*. The Butteryfly Conservation Initiative, http://www.butterflyrecovery.org/species_profiles/fenders_blue/.

BFCI. 2006b. Taylor's (Whulge) Checkerspot Butterfly *Euphydryas editha taylori*. The Butteryfly Conservation Initiative, http://www.butterflyrecovery.org/species_profiles/profiles.php?id=28.

Black, S. H. and d. M. Vaughan. 2005. Species Profile: *Icaricia icarioides fenderi*. The Xerces Society for Invertebrate Conservation, Portland, OR.

Brown, S. L. 2000. *Rana aurora* (On-line), Animal Diversity Web. http://animaldiversity.ummz.umich.edu/site/accounts/information/Rana_aurora.html.

Clampitt, C. A. 1987. Reproductive Biology of *Aster curtus* (Asteraciae), a Pacific Northwest endemic. American Journal of Botany **74**:941-946.

Clark, L. D. 2000. Demographic Analysis of *Erigeron decumbens* var *decumbens:* an endangered plant species of the Willamette Valley, Oregon, 1999 Field Studies, prepared for USFWS. Western Oregon NWR Refuge Complex.

CPC. 2010. CPC National Collection Plant Profile. Center for Plant Conservations, St. Louis, MO. http://www.centerforplantconservation.org.

Crawford-Miksza, L. K., D. A. Wadford, and D. P. Schnurr. 1999. Molecular epidemiology of enzootic rabies in California. Journal of Clinical Virology **14**:207-219.

Didiuk, A. B., J. M. Macartney, and L. A. Gregory. 2004. COSEWIC status report on the western rattlesnake *Crotalus oreganus* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa.

Douglas, G. W. and J. M. Illingworth. 1997. Status of the White-top Aster, *Aster curtus* (Asteraceae). Canadian Field-Naturalist **111**:622-627.

Erickson, J. L. and D. S. West. 2002. Associations of bats with local structure and landscape features of forested stands in Western Oregon and Washington. Biological Conservation **109**:95-102.

Fimbel, C. 2004. Strategies for enhancing Western Gray Squirrels on Fort Lewis. The Nature Conservancy.

Gisler, S. D. 2004. Developing biogeographically based population introduction protocols for at-risk Willamette Valley plant species. Report to US Fish and Wildlife Service, Portland Oregon. Native Plant Conservation Program, Oregon Department of Agriculture, Salem, OR.

Graham, D. 1997. Western Painted Turtle (*Chrysemys picta belli*). D. Backlund and S. Thompson editors. South Dakota Department of Game, Fish and Parks, Pierre, SD.
Haegen, W. M. V., G. R. Orth, and L. M. Aker. 2005. Ecology of the Western Gray Squirrel in south-central Washington. Wildlife Science Division, Washington Department of Fish and Wildlife.
Harris, J. 1999. California myotis.*in* J. Harris and R. Duke, editors. California Wildlife Habitat Relationships System. California Department of Fish and Game, California Interagency Wildlife Task Group.
Hunt, P. D. 1996. Appendix A: Species Profiles - Birds. Common Nighthawk (*Chordeiles minor*). New Hampshire Wildlife Action Plan:A-408.
IPFW. 2010. IPFW Center for Reptile and Amphibian Conservation and Management. Indiana-Purdue University Fort Wayne, http://herpcenter.ipfw.edu/Index.htm.
Jennings, M. R. and M. P. Hayes. 1994. Amphibian and reptile species of special concern of California. Page 255. California Department of Fish and Game, Rancho Cordova, CA.
Koenig, W. D., P. B. Stacey, m. T. Stanback, and R. L. Mumme. 1995. Acorn Woodpecker (*Melanerpes formicivorus*). Cornell Lab of Ornithology, Ithaca. http://bna.birds.cornell.edu/bna/species/194.
Middleton, A. L. 1998. Chipping Sparrow (*Spizella passerina*). Cornell Lab of Ornithology, Ithaca. http://bna.birds.cornell.edu/bna/species/334.
NAPD. 2010. Taylor's Checkerspot *Euphydryas editha taylori*. Benton County Natural Areas and Parks Department, Corvalli, OR. http://www.co.benton.or.us/parks/hcp/taylorscheckerspot.php.
NatureServe. 2010. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. http://www.natureserve.org/explorer.
Nedeau, E., A. K. Smith, and J. Stone. Freshwater Mussels of the Pacific Northwest. U.S. Fish and Wildlife Service, Vancouver, WA.
NPSO. 2010. Oregon's Rare & Endangered Plants. Native Plant Society of Oregon, http://www.npsoregon.org/.
OSU. 2010. Oregon Flora Project. Oregon State University, Corvallis, OR. http://www.oregonflora.org.
Paczek, S. 2004. Grasshopper Sparrow *Ammodramus savannarum*. British Columbia, Ministry of Environment, Victoria, BC.
Patterson, J. 2008. An analysis of Spring Bird Migration Phenology in Kansas. Kansas State University, Manhattan, KS.
Pearl, C. A. *Rana aurora*, Northern Red-legged Frog. USGS Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon. http://www.amphibiaweb.org/cgi-bin/amphib_query?where-genus=Rana&where-species=aurora.
Poulin, R. G., S. D. Grindal, and R. M. Brigham. 1996. Common Nighthawk (*Chordeiles minor*). The Birds of North America, Washington D.C.
Ryan, L. A. 1997. Ecology of the Western Gray Squirrel in the south Puget Sound.*in* P. V. Dunn and K. Ewing, editors. Ecology and Conservation of the south Puget Sound. The Nature Conservancy, Seattle, WA.
Ryan, L. A. and A. B. Carey. 1995. Biology and management of the Western Gray Squirrel and Oregon White Oak woodlands; with emphasis on the Puget Trough.

US Deptartment of Agriculture. Forest Service, Pacific Northwest Research Station, Portland, OR.
Sarell, M. and M. McCartney. 2004. Western Rattlesnake *Crotalus oreganus*. British Columbia, Minitsry of Environment.
Sedgwick, J. A. 2000. Willow Flycatcher (*Empidonax trailli*). Cornell Lab of Ornithology, Ithaca. http://bna.birds.cornell.edu/bna/species/533.
Siske, R., E. Hansen, and M. Roll. 2009. Northwestern Pond Turtle (*Actinemys marmorata marmorata*). T. Associates editor Yolo Natural Heritage Program.
Stebbins, R. C. 2010. CaliforniaHerps.com: A guide to the Amphibians and Reptiles of California. http://www.californiaherps.com.
Thomas, B. M., C. R. Ely, J. S. Sedinger, and R. E. Trost. 2002a. Canada Goose (Branta canadensis). http://bna.birds.cornell.edu/bna/species/682.
Thomas, B. M., C. R. Ely, J. S. Sedinger, and R. E. Trost. 2002b. Canada Goose (*Branta canadensis*). Cornell Lab of Ornithology, Ithaca. http://bna.birds.cornell.edu/bna/species/682.
TPW. 2009. Townsend's Big-eared Bat (Plecotus townsendii). Texas Parks and Wildlife, Austin, TX. http://www.tpwd.state.tx.us/huntwild/wild/species/townsendbigear/.
Vaughan, M. and S. H. Black. 2002. Petition to Emergency List Taylor's (Whulge) Checkerspot Butterfly (*Euphydryas editha taylori*) as an Endangered Species Under the U.S. Endangered Species Act. The Xerces Society.
Vickery, P. D. 1996. Grasshopper Sparrow (*Ammodramus savannarum*). Cornell Lab of Ornithology, Ithaca. http://bna.birds.cornell.edu/bna/species/239.
WDNR. 1997. Delphinium leucophaeum Greene. Washington Department of Natural Resources, Washington Natural Heritage Program and Bureau of Land Management, http://www1.dnr.wa.gov/nhp/refdesk/fguide/pdf/dele.pdf.
Whitaker, J. O., C. Maser, and E. L. Keller. 1977. Food habits of bats of Western Oregon. Northwest Science **51**.
Wilson, M. V. 2007. Perspectives: Fender's blue butterfly. Oregon State University, http://people.oregonstate.edu/~wilsomar/Persp_FBB.htm.
Wilson, M. V., P. C. Hammond, and C. B. Schultz. 1997. Interdependence of Native Plants and Fenders Blue Butterfly. Native Plant Society of Oregon, Corvallis, OR.