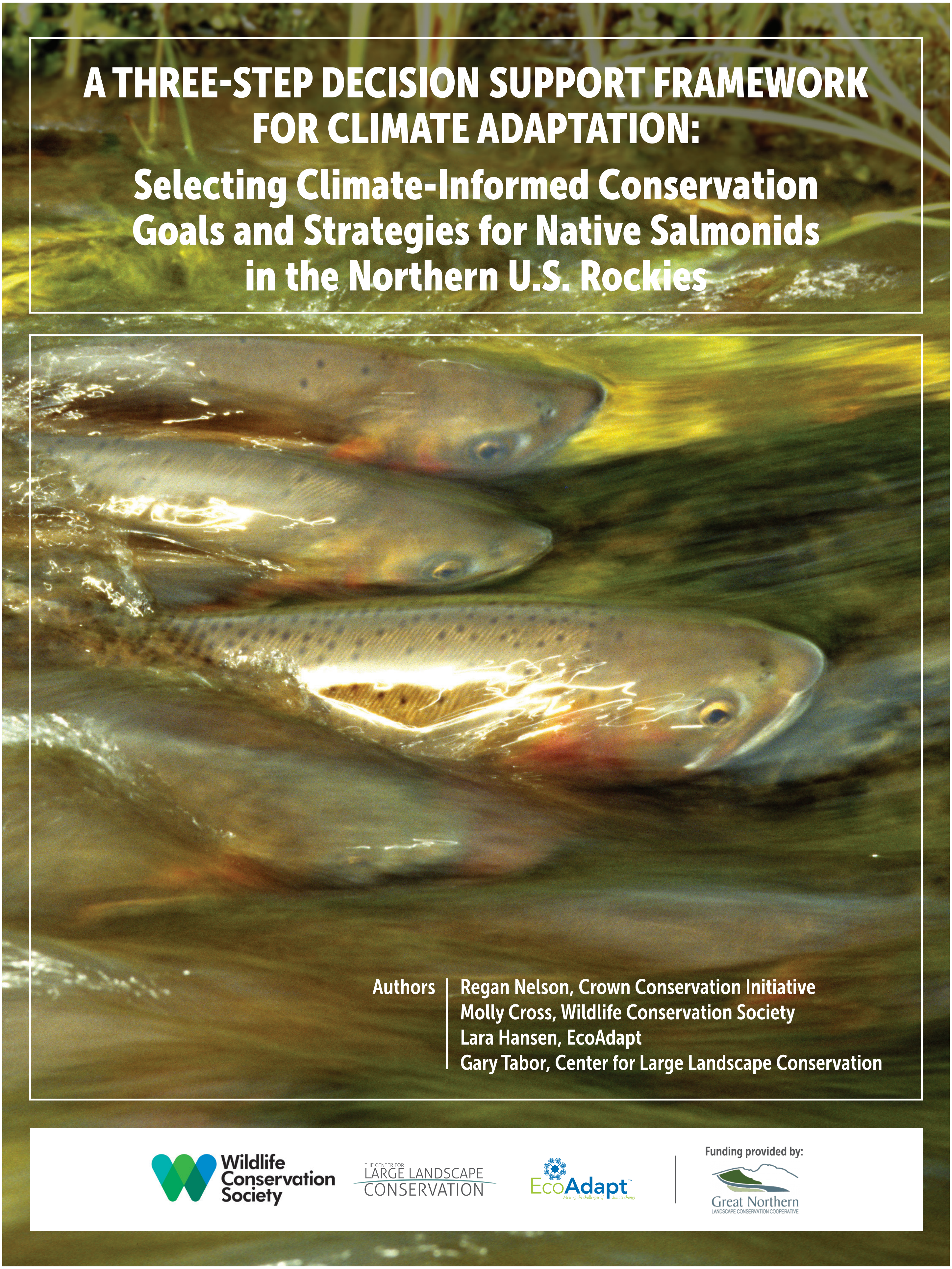

A THREE-STEP DECISION SUPPORT FRAMEWORK FOR CLIMATE ADAPTATION:

Selecting Climate-Informed Conservation Goals and Strategies for Native Salmonids in the Northern U.S. Rockies

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Table of Contents

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Version 2 (this version includes a correction to the instructions for moving between Step 1 and Step 2 of the decision support framework, on the bottom of Page 9)

Summary

The impact of climate change on cold-water ecosystems—and the cold-adapted native salmonids present in these systems—is the subject of a substantial body of research.. Recently, scientists have developed a number of datasets and analyses that provide insight into projections of climate change effects on native salmonid populations in the northern U.S. Rockies region. Alongside this research, a number of management options for helping native salmonids respond to the effects of climate change—also known as 'climate adaptation' strategies and actions—have been identified by scientists and managers in the region. These analyses and climate adaptation options offer valuable information to managers charged with making difficult decisions about where and how to best conserve and restore the region's native salmonids given the challenges posed by shifting climatic conditions. Yet managers in the region continue to identify challenges in applying available information on climate change impacts, particularly in determining forward-looking conservation goals and selecting appropriate actions from the long menu of available climate adaptation options.

To augment this research and compilation of climate-informed management options, we have developed a decision support framework aimed at helping managers think critically about how to apply climate information to their management decisions. Specifically, our framework is meant to help managers:

1) articulate an appropriate conservation goal for cold-adapted native salmonid populations taking into account the impacts of climate change on habitat suitability, threats from non-native fish, and connectivity;

2) consider the climate adaptation strategies that might best support that goal; and

3) identify actions that are available to implement the chosen strategies.

Given the complexity and uncertainty of conserving cold-adapted species in an era of rapid climate change and the limited resources available for conservation, choices about where to invest conservation dollars require defensible and transparent decision making. The three-step decision framework we provide here is meant to be a starting point to help managers document how they have incorporated information on climate change into their management decisions and prioritization of limited resources. The process used to develop the framework for native salmonids can be used to tailor decision support for additional conservation targets of interest. Ultimately, managers can integrate this climate change thinking into existing conservation strategies and management plans, alongside the myriad other regulatory, social, economic and locally-driven factors and mandates that influence management decisions.

I. Introduction

Public land managers are becoming increasingly accountable for considering climate change in their management decisions (e.g., USFS 2011; DOI 2014; Executive Order 13653). This accountability increases the need for transparency in how managers and planners are using climate change science to set management goals and select actions for implementation. At the same time, the recent proliferation of climate change research makes navigating and interpreting relevant information increasingly more complex. Therefore, there is a growing need for tools that can help natural resource managers incorporate climate change into their management decisions while clearly documenting the logic, assumptions and information underlying those decisions.

The importance of considering climate change in the management of climate-sensitive species and ecosystems is evident in the northern U.S. Rocky Mountains, where warming over the past century occurred at almost twice the rate of the global average (Pederson et al. 2010). This considerable rate of warming is already affecting efforts to conserve the region's iconic and highly valued native cold-water salmonids, such as bull trout (*Salvelinus confluentus*), westlope cutthroat trout (*Oncorhynchus clarki lewisi*) and Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*). Native salmonid populations require a combination of cold, clean, complex and connected habitats that are free of non-native competitors and predators (Box 1). In response to concerns about managing native salmonids as climate changes, researchers have developed targeted datasets and analyses that provide empirically based, spatially explicit climate change projections for cold-adapted fish species in portions of the northern U.S. Rockies region (e.g., Isaak et al. 2015; Jones et al. 2014; Al-Chokhachy et al. 2013; see also Appendix A). These datasets, along with other analyses of the vulnerability of watersheds to climate change (Appendix A) provide important information and context for understanding the potential impacts of climate change on native salmonid species and communities and their habitats across the region.

Box 1. Climate Change Effects on Native Trout

The impact of climate change on cold-water ecosystems in the northern U.S. Rockies—and the cold-adapted native salmonids present in these systems—has been well studied (e.g., see Rieman and Isaak 2010, Kovach et al. 2016, Young et al. In Press for recent syntheses). This work includes empirical and experimental work in both the field and laboratory, and modeling efforts that address both fine and coarse scale dynamics and patterns. While it is beyond the scope of this report to summarize this substantial body of literature, a few recent syntheses and research papers informed the development of this decision support framework (e.g., Rieman and Isaak 2010; Young et al. In Press; and others listed in the Literature Cited and Additional References section of this report. From these assessments, the following climate change factors are of particular relevance to native salmonids in the region:

- Warmer stream temperatures
- Lower late summer flows
- Earlier peak flows in spring
- Increased winter peak flows and scouring events
- More frequent and severe summertime dry periods and multi-year droughts
- Larger, more frequent and more intense wildfires

These climate change factors could influence many aspects of the life history of native salmonids in the region, including:

- Loss or shift in the distribution of thermally suitable habitat with sufficient flows (e.g., Kovach et al. 2016; Isaak et al. 2015; Al-Chokhachy et al. 2013; Haak et al. 2010a; Williams et al. 2009; Rieman et al. 2007);
- Increased competition, predation and introgression with nonnative fish species (e.g., Muhlfeld et al. 2014; Al-Chokhachy et al. 2014; Al-Chokhachy et al. 2013; Wenger et al. 2011a; Wenger et al. 2011b);
- Increased threat of negative effects from disturbances such as winter scouring events and uncharacteristically large and severe wildfires (e.g., Luce et al. 2012; Haak et al. 2010a; Williams et al. 2009);
- Decreased genetic diversity (e.g., Kovach et al. 2015);
- Loss of connectivity between thermally suitable areas leading to increased isolation and loss of migratory life histories (Peterson et al. 2013a; Williams et al. 2009); and
- Increased incidence and virulence of diseases (Rahel et al. 2008).

Although some native salmonid populations like cutthroat trout may experience some benefits from warming, such as increased growth potential (Al-Chokhachy et al. 2013), these benefits may be offset by concomitant increases in the growth and invasion potential of non-native species as streams warm (e.g., Wenger et al. 2011b). Stream temperature models and thermal niche studies suggest that some stream reaches are currently too cold for native trout (Isaak et al. 2015); conditions may become more suitable in these stream reaches where native salmonid growth is cold-limited and where non-native fish are not present (Isaak et al. 2016).

Given concerns about how climate change may influence thermal suitability of streams for native salmonids, researchers are investigating ways of measuring and modeling current and future stream temperatures, and other habitat and habitat network characteristics, under different climate scenarios (Appendix A). While not the only type of data that is relevant for working through the decision support framework presented in this report, this body of research is useful for thinking about management goals and actions for native trout in the face of a changing climate, and have been used for spatially-explicit decision making (e.g., Peterson et al. 2013b).

Alongside this growing body of scientific information, a number of management strategies and actions for helping native salmonid species respond to the effects of climate change—also known as 'climate adaptation' strategies and actions—have been identified by scientists and managers in the region (Halofsky et al. In Press; CAP 2014; Nelson 2014; Cross et al. 2013; Rieman and Isaak 2010; Miller et al. 2009). This available body of climate science and proposed climate adaptation strategies and actions focused on native cold-water fisheries provides managers with a wealth of information relevant to decision-making. Yet managers in the region continue to identify challenges in applying available information on climate change impacts, particularly in determining forward-looking conservation goals and selecting appropriate climate adaptation actions from the long menu of available options (Cross et al. 2013). The most challenging management decisions revolve around the effective prioritization and allocation of limited resources given climate change impacts (Box 2). Climate change adds a new dimension to the prioritization of conservation investments for native salmonids, as suitable habitats shift or shrink, and physical and biological changes create novel environments, alter food web dynamics, and facilitate non-native species invasions (Rieman and Isaak 2010). Managers increasingly need to make tough decisions about where – and where not – to strategically invest in conservation.

To aid managers in using climate science and assessments while documenting the logic, assumptions and information that underlie their decision-making, we developed a decision support framework that seeks to help managers overcome several challenges, including to:

1) articulate an appropriate conservation goal for cold-adapted native salmonid populations taking into account the impacts of climate change on habitat suitability, threats from non-native fish, and connectivity;

2) consider the climate adaptation strategies that might best support that goal; and

3) identify actions that are available to implement the chosen strategies.

The following sections of this report are designed to guide managers through this decision-making process. In Section II, we provide an overview of the climate adaptation planning frameworks and decision support concepts that informed our development of the decision support framework. In Section III, we describe our overall approach to developing the decision support framework, and how we tailored it to support climate-informed decisions related to native salmonid conservation. We present the decision support framework for native salmonids in Section IV, and in Section V we discuss the opportunities and limitations of the framework, and encourage continued refinement of this tool.

Box 2. **Prioritization of Native Trout Conservation in the Context of Climate Change**

Given the reality of insufficient time, money and capacity to adequately address the vast conservation needs across large landscapes, managers are often encouraged to use a structured approach to determining landscape-level or range-wide goals and priorities (e.g., Bottrill et al. 2009). For native trout conservation, Haak et al. (2010b) and Haak and Williams (2012) advocate that the prioritization of investments be:

1) done at a broad-scale,

2) consider both core and peripheral populations, and

3) promote representation (e.g., by protecting and restoring genetic, life history and geographic diversity), resilience (e.g., by having sufficiently large populations and intact habitats to facilitate recovery from rapid environmental change), and redundancy (e.g., by saving a sufficient number of populations so that some can be lost without jeopardizing the species).

Rieman and Isaak (2010) recommend that managers explicitly consider climate change vulnerabilities at a watershed-level scale when prioritizing actions, since efforts that treat isolated stream reaches without addressing watershed-scale limiting factors alongside future climate impacts are more likely to fail in the long term. Additionally, Verboom and others (2010) suggest core habitats may need to be larger than was historically the case to support populations due to increasing environmental variability under climate change.

While the decision framework presented here is not intended to be a stand-alone tool for prioritizing conservation at a landscape scale, it can be used to identify populations that may be a relatively higher or relatively lower priority from a climate change perspective. This information can then be integrated with other factors that influence prioritization, such as meta-population goals, legal or regulatory mandates, and societal and economic values.

II. Concepts Informing the Decision Support Framework

This decision support framework was developed over a series of workshops and in-person meetings, held to gather input from public land managers on tools that might best assist them in critically evaluating and documenting how decisions are made with regard to how and where (and where not) to invest in native salmonid conservation and restoration. During these meetings, managers stressed their preference for a tool that facilitated decision-making rather than being prescriptive. This suggested that the most effective tool would assist managers in developing and documenting their logic, but would avoid dictating exactly what actions to take. Based on this feedback, we designed a decision support framework that builds on:

1) established approaches to climate adaptation planning (e.g., Cross et al. 2012; Stein et al. 2014),

2) the U.S. Forest Service's Climate Project Screening Tool (Morelli et al. 2012),

3) climate change-informed "decision tree" frameworks (e.g., Oliver et al. 2012; Shoo et al. 2013), and

4) recommended management approaches to support the adaptation of native salmonid populations to climate change in the U.S. Rockies (Rieman and Isaak 2010).

The decision support framework presented here is designed to help users with several steps in a typical climate change adaptation planning process (Figure 1): to identify key climate change vulnerabilities facing particular populations or places, clarify conservation goals in light of those vulnerabilities, and to identify strategies and action that align with those climate-informed goals and are most appropriate for implementation in particular places on the landscape.

To help managers document the logic they used to revise goals and to select appropriate climate adaptation actions, the decision support framework draws on the approach laid out in the USFS's Climate Project Screening Tool (Morelli et al. 2012). The Climate Project Screening Tool instructs managers to look at climate change trends while answering 'key questions' related to how climate change might influence the effectiveness and design of proposed and current management projects. Managers are then asked to determine whether they should continue with the project without modification, modify the project in some way, or discontinue the project. The decision support framework presented here builds on the Climate Project Screening Tool approach by incorporating aspects of decision-tree-type tools (e.g., Oliver et al. 2012; Shoo et al. 2013), that offer an additional level of guidance on how the users' answers to key climate change-related questions might steer them towards particular modifications to their project goals and actions.

Common Steps in Climate Adaptation Planning

Figure 1. *Climate adaptation planning cycle (from Stein et al. 2014). The decision support framework presented here is primarily designed to support steps 2-5.*

More specific to native salmonid conservation and climate adaptation in the U.S. Rockies, Rieman and Isaak (2010) made a number of recommendations for managers to consider when prioritizing limited resources. They urged managers to evaluate native salmonid populations as fundamental units of conservation. They also proposed that managers assess the relative vulnerability of populations and habitats to climate change, and to clarify management goals and objectives for each population based on such an assessment. Finally, they encouraged managers to favor actions robust to uncertainty.

These concepts, tools, and recommendations grounded and informed the development of the decision support framework, and our efforts to tailor it for use in setting conservation goals and strategies for native salmonids in the northern U.S. Rockies.

III. Methodology for Developing the Decision Support Framework

Below we provide an overview of the process we used to develop the decision support framework (Figure 2), and details on how we tailored it to support native salmonid conservation decisions in the northern U.S. Rockies. While the tool presented in Section IV is specific to native salmonid conservation, the general process can be can be adapted to other conservation targets of concern. To tailor the decision support framework for a given conservation target, users should review available data, analyses, and research on climate change impacts. We also recommend including expert input from scientists, managers, and other local knowledge holders. To develop the decision support framework for native salmonids, we reviewed the scientific literature listed in the Literature Cited and Additional References section and consulted with fisheries researchers working in the northern U.S. Rockies, and hydrology, fisheries, fire and ecosystem specialists from the Custer Gallatin National Forest.

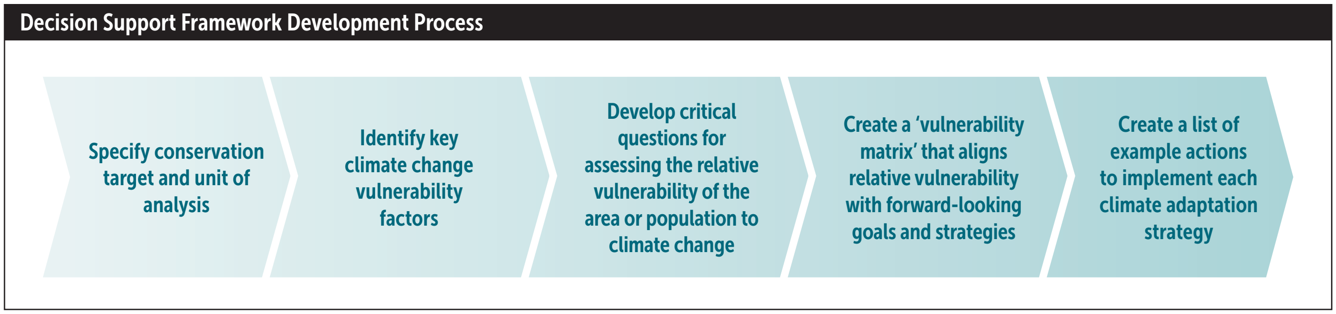


Figure 2. *Overview of the process used to develop the decision support framework for setting forward-looking conservation goals and selecting climate adaptation strategies and actions.*

We initiated the process (Figure 2) by **specifying a conservation target and unit of analysis.** For cold water-adapted salmonids native to the northern U.S. Rockies, we chose to focus on populations as the unit of analysis for the decision support framework. Rieman and Isaak (2010) recommend an emphasis on populations, rather than individual stream reaches or habitats, when setting conservation priorities since the ultimate goal is to determine the nature and amount of conservation work that is needed to ensure that complete populations of native fish can persist as climate changes.

Next, we **identified the key climate change vulnerability factors** influencing the selected conservation target. Climate change research, data and analyses, alongside expert-based knowledge of local systems, are valuable resources for identifying the myriad ways that climate change might directly or indirectly impact the conservation target of interest. While the factors that lead to climate change vulnerabilities can be extensive, for the purposes of this tool, it is important to select the factors that represent the greatest threats to the conservation target. According to Stein et al. (2014), key vulnerabilities represent those vulnerabilities that pose the greatest risk to achieving conservation goals. Based on our review of the papers and reports in the Literature Cited and Additional Resources section and additional discussions with local fisheries biologists and managers, we identified three key climate change vulnerabilities of particular importance to native salmonid conservation:

- **Habitat suitability:** Climate change can lead to the loss of thermally suitable habitat, altered and/or insufficient stream flows, and increases in the extent and severity of disturbances (Young et al. In Press, Rieman and Isaak 2010). Climate change may also alter the timing and amount of water used by humans (i.e., for irrigation, or residential or industrial use), in ways that can effect instream flows for fish. Management actions that improve degraded habitats, restore ecosystem processes, and reduce withdrawals for human use can potentially moderate these climate impacts on habitat suitability (Isaak et al. 2015; Rieman and Isaak 2010; Williams et al. 2009).

- **Threats from non-native fish:** Climate change can increase the competitive advantage for non-native fish species and facilitate increased hybridization with native salmonids (Al-Chokhachy et al. 2014; Muhlfeld et al. 2014). Under the right conditions, management actions can prevent, delay or eliminate threats from non-native species (Fausch et al. 2009).

- **Connectivity:** Genetic and demographic connectivity of populations is achieved through adequate habitat connectivity. Climate change can lead to loss of connectivity between thermally suitable areas, leading to increased isolation. Climate change-driven fragmentation can be exacerbated by man-made barriers that isolate or fragment populations (Peterson et al. 2013a; Williams et al. 2009).

Once critical climate change vulnerability factors were identified, **we developed critical questions for assessing and ranking the relative vulnerability of the area or population to climate change.** These critical questions are designed to help managers document their logic and understanding of the expected magnitude and likelihood of climate change effects on the conservation target of interest. They also help determine the relative vulnerability of the selected population or place to climate change. For native salmonids, the critical questions related to each of the three key vulnerabilities were drawn from the literature review and discussions with experts. Qualitative levels of vulnerability for each climate change factor are shown in Figure 3. The tool assumes that vulnerability increases as climate change pushes habitat to become less suitable, and non-native fish and population isolation to become more of a problem.

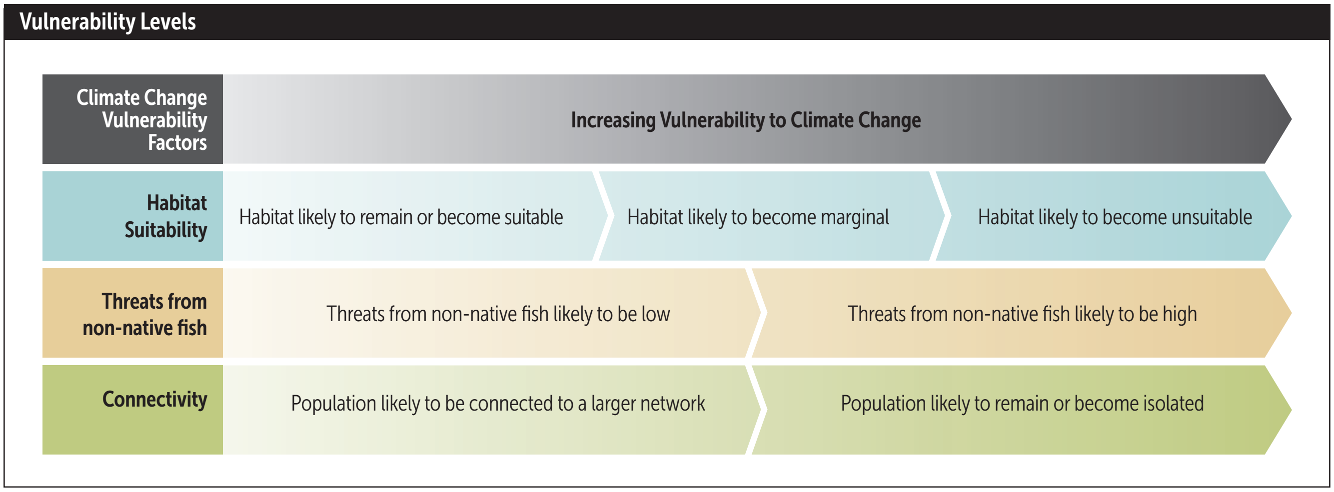


Figure 3*. Vulnerability levels for three key climate change factors influencing native salmonids: impacts on habitat suitability, non-native fish, and connectivity.*

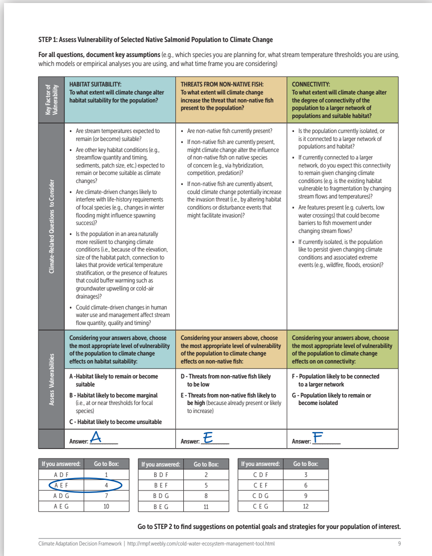
Using the vulnerability levels, **we created a 'vulnerability matrix' that aligns relative vulnerability with forward-looking goals and strategies.** An understanding of potential climate change impacts facing a conservation target is important for clarifying and refining appropriate – and achievable – management goals. For example, if climate change vulnerability is low, then existing conservation goals and strategies that aim to protect and maintain the current population or ecosystem might continue to be appropriate. On the other hand, if the level of vulnerability is high, managers may need to consider new or different strategies for achieving their current goal, or may choose to adjust conservation goals for a given population or area by focusing on different targets. After aligning relative vulnerability with forward-looking goals, we matched those vulnerabilities and goals with climate adaptation strategies culled from the peer reviewed literature and summary reports from climate adaptation planning workshops held in the region.

For native salmonids, the tool assumes that the value of the population being assessed for achieving evolutionary goals (i.e.., maintaining genetically pure populations and genetic diversity) and ecological goals (i.e., maintaining the capacity of a population to be resilient and adaptive to change) (Fausch et al. 2006 and Rieman et al. 2010) decreases as climate change vulnerability increases. This does not mean that vulnerable populations have no value for native salmonid conservation; even with some level of vulnerability, the population may be important to support meta-population recovery and genetic diversity. There are also uncertainties about how native salmonid populations will respond to climate change so there is no guarantee that vulnerable populations will be lost. That said, for populations that are considered relatively highly vulnerable to climate change, the tool encourages managers to consider whether they might adjust their management goals to focus on other targets (e.g., non-native sport fish, or non-fish targets), including allowing or even actively facilitating the transition of the population to a new state.

Lastly, we **created a list of example actions to implement each climate adaptation strategy.** This list is not meant to be exhaustive, but rather to provide example actions that managers can consider alongside other ideas they or others have developed. To tailor the tool for native salmonids, we collected example actions that were discussed by managers and scientists during climate adaptation planning workshops, in addition to ideas from the peer-reviewed literature.

Using these components, we developed a three-step decision support framework that is built around native salmonid populations, and helps to distinguish relative vulnerability to climate change to clarify appropriate management goals and select among potential climate adaptation strategies and actions.

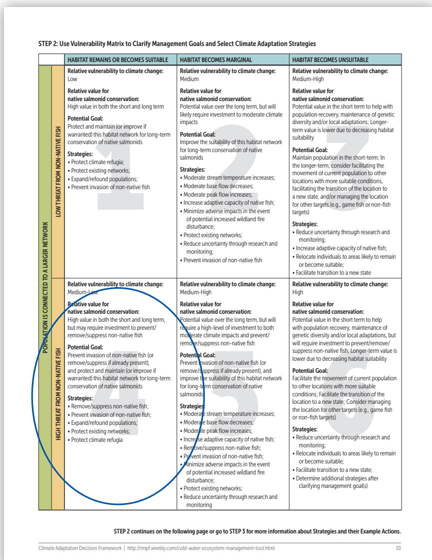
IV: A 3-Step Decision Support Framework for Selecting Climate Change-Informed Goals, Strategies and Actions for Native Salmonids



The decision support framework involves three steps:

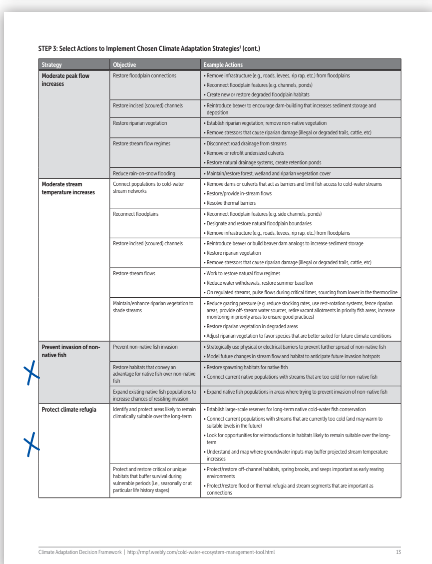
STEP 1: Assess Vulnerability of Selected Native Salmonid Population to Climate Change
Select a native salmonid population of interest and assess the vulnerability of the population to each of three climate change factors: impacts on habitat suitability, threats from non-native fish, and connectivity. Consider and document your answers to climate-related questions designed to help assess vulnerabilities, including the data and information that you consulted. Finally, select the overall vulnerability level for each climate change factor. Appendix A offers a non-exhaustive list of data and analyses that may be useful in STEP 1.

Once vulnerability rankings have been selected for each of the three climate change factors, go to STEP 2.



STEP 2: Use Vulnerability Matrix to Clarify Management Goals and Select Climate Adaptation Strategies
Using the assessment of climate change vulnerabilities in STEP 1 for the population of interest, locate the corresponding box in the STEP 2 matrix. Each box in the matrix is linked to one of twelve possible combinations of key factors of vulnerability. In each box, the tool provides general statements of the relative vulnerability and relative value of the population to native salmonid conservation, and suggests potential management goals that reflect the population's vulnerability and value. It also lists climate adaptation strategies that align with that goal, given particular sources of climate change vulnerability.

Once the appropriate box on the STEP 2 matrix has been identified, along with the list of climate adaptation strategies for achieving the potential goal for the population of interest, move to STEP 3.



STEP 3: Select Actions to Implement Chosen Climate Adaptation Strategies
Look up each of the strategies suggested in the STEP 2 matrix in the STEP 3 reference table. The STEP 3 reference table provides additional details about each strategy, including the strategy's objective(s) and a non-exhaustive list of example actions that could be used to implement the strategy.

To get started, select a native salmonid population of interest and go to STEP 1.

STEP 1: Assess Vulnerability of Selected Native Salmonid Population to Climate Change

For all questions, document key assumptions (e.g., which species you are planning for, what stream temperature thresholds you are using, which models or empirical analyses you are using, and what time frame you are considering)

<table>
<tr><th>Key Factor of Vulnerability</th><th>HABITAT SUITABILITY:
To what extent will climate change alter habitat suitability for the population?</th><th>THREATS FROM NON-NATIVE FISH:
To what extent will climate change increase the threat that non-native fish present to the population?</th><th>CONNECTIVITY:
To what extent will climate change alter the degree of connectivity of the population to a larger network of populations and suitable habitat?</th></tr>
<tr><td>Climate-Related Questions to Consider</td><td>• Are stream temperatures expected to remain (or become) suitable?
• Are other key habitat conditions (e.g., streamflow quantity and timing, sediments, patch size, etc.) expected to remain or become suitable as climate changes?
• Are climate-driven changes likely to interfere with life-history requirements of focal species (e.g., changes in winter flooding might influence spawning success)?
• Is the population in an area naturally more resilient to changing climate conditions (i.e., because of the elevation, size of the habitat patch, connection to lakes that provide vertical temperature stratification, or the presence of features that could buffer warming such as groundwater upwelling or cold-air drainages)?
• Could climate-driven changes in human water use and management affect stream flow quantity, quality and timing?</td><td>• Are non-native fish currently present?
• If non-native fish are currently present, might climate change alter the influence of non-native fish on native species of concern (e.g., via hybridization, competition, predation)?
• If non-native fish are currently absent, could climate change potentially increase the invasion threat (i.e., by altering habitat conditions or disturbance events that might facilitate invasion)?</td><td>• Is the population currently isolated, or is it connected to a larger network of populations and habitat?
• If currently connected to a larger network, do you expect this connectivity to remain given changing climate conditions (e.g. is the existing habitat vulnerable to fragmentation by changing stream flows and temperatures)?
• Are features present (e.g. culverts, low water crossings) that could become barriers to fish movement under changing stream flows?
• If currently isolated, is the population like to persist given changing climate conditions and associated extreme events (e.g., wildfire, floods, erosion)?</td></tr>
<tr><td rowspan="2">Assess Vulnerabilities</td><td>Considering your answers above, choose the most appropriate level of vulnerability of the population to climate change effects on habitat suitability:</td><td>Considering your answers above, choose the most appropriate level of vulnerability of the population to climate change effects on non-native fish:</td><td>Considering your answers above, choose the most appropriate level of vulnerability of the population to climate change effects on on connectivity:</td></tr>
<tr><td>A -Habitat likely to remain or become suitable
B - Habitat likely to become marginal (i.e., at or near thresholds for focal species)
C - Habitat likely to become unsuitable</td><td>D - Threats from non-native fish likely to be low
E - Threats from non-native fish likely to be high (because already present or likely to increase)</td><td>F - Population likely to be connected to a larger network
G - Population likely to remain or become isolated</td></tr>
<tr><td></td><td>Answer: __________</td><td>Answer: __________</td><td>Answer: __________</td></tr>
</table>

If you answered:	Go to Box:
A D F	1
A E F	4
A D G	7
A E G	10

If you answered:	Go to Box:
B D F	2
B E F	5
B D G	8
B E G	11

If you answered:	Go to Box:
C D F	3
C E F	6
C D G	9
C E G	12

Go to STEP 2 to find suggestions on potential goals and strategies for your population of interest.

STEP 2: Use Vulnerability Matrix to Clarify Management Goals and Select Climate Adaptation Strategies

		HABITAT REMAINS OR BECOMES SUITABLE	HABITAT BECOMES MARGINAL	HABITAT BECOMES UNSUITABLE
POPULATION IS CONNECTED TO A LARGER NETWORK	LOW THREAT FROM NON-NATIVE FISH	1 **Relative vulnerability to climate change:** Low **Relative value for native salmonid conservation:** High value in both the short and long term **Potential Goal:** Protect and maintain (or improve if warranted) this habitat network for long-term conservation of native salmonids **Strategies:** • Protect climate refugia; • Protect existing networks; • Expand/refound populations; • Prevent invasion of non-native fish	2 **Relative vulnerability to climate change:** Medium **Relative value for native salmonid conservation:** Potential value over the long term, but will likely require investment to moderate climate impacts **Potential Goal:** Improve the suitability of this habitat network for long-term conservation of native salmonids **Strategies:** • Moderate stream temperature increases; • Moderate base flow decreases; • Moderate peak flow increases; • Increase adaptive capacity of native fish; • Minimize adverse impacts in the event of potential increased wildland fire disturbance; • Protect existing networks; • Reduce uncertainty through research and monitoring; • Prevent invasion of non-native fish	3 **Relative vulnerability to climate change:** Medium-High **Relative value for native salmonid conservation:** Potential value in the short term to help with population recovery, maintenance of genetic diversity and/or local adaptations; Longer-term value is lower due to decreasing habitat suitability **Potential Goal:** Maintain population in the short-term; In the longer-term, consider facilitating the movement of current population to other locations with more suitable conditions, facilitating the transition of the location to a new state, and/or managing the location for other targets (e.g., game fish or non-fish targets) **Strategies:** • Reduce uncertainty through research and monitoring; • Increase adaptive capacity of native fish; • Relocate individuals to areas likely to remain or become suitable; • Facilitate transition to a new state
POPULATION IS CONNECTED TO A LARGER NETWORK	HIGH THREAT FROM NON-NATIVE FISH	4 **Relative vulnerability to climate change:** Medium-Low **Relative value for native salmonid conservation:** High value in both the short and long term, but may require investment to prevent/remove/suppress non-native fish **Potential Goal:** Prevent invasion of non-native fish (or remove/suppress if already present), and protect and maintain (or improve if warranted) this habitat network for long-term conservation of native salmonids **Strategies:** • Remove/suppress non-native fish; • Prevent invasion of non-native fish; • Expand/refound populations; • Protect existing networks; • Protect climate refugia	5 **Relative vulnerability to climate change:** Medium-High **Relative value for native salmonid conservation:** Potential value over the long term, but will require a high-level of investment to both moderate climate impacts and prevent/remove/suppress non-native fish **Potential Goal:** Prevent invasion of non-native fish (or remove/suppress if already present), and improve the suitability of this habitat network for long-term conservation of native salmonids **Strategies:** • Moderate stream temperature increases; • Moderate base flow decreases; • Moderate peak flow increases; • Increase adaptive capacity of native fish; • Remove/suppress non-native fish; • Prevent invasion of non-native fish; • Minimize adverse impacts in the event of potential increased wildland fire disturbance; • Protect existing networks; • Reduce uncertainty through research and monitoring	6 **Relative vulnerability to climate change:** High **Relative value for native salmonid conservation:** Potential value in the short term to help with population recovery, maintenance of genetic diversity and/or local adaptations, but will require investment to prevent/remove/suppress non-native fish; Longer-term value is lower due to decreasing habitat suitability **Potential Goal:** Facilitate the movement of current population to other locations with more suitable conditions; Facilitate the transition of the location to a new state; Consider managing the location for other targets (e.g., game fish or non-fish targets) **Strategies:** • Reduce uncertainty through research and monitoring; • Relocate individuals to areas likely to remain or become suitable; • Facilitate transition to a new state; • Determine additional strategies after clarifying management goal(s)

STEP 2 continues on the following page or go to STEP 3 for more information about Strategies and their Example Actions.

STEP 2: Use Vulnerability Matrix to Clarify Management Goals and Select Climate Adaptation Strategies (cont.)

		HABITAT REMAINS OR BECOMES SUITABLE	HABITAT BECOMES MARGINAL	HABITAT BECOMES UNSUITABLE
POPULATION REMAINS OR BECOMES ISOLATED	LOW THREAT FROM NON-NATIVE FISH	7 **Relative vulnerability to climate change:** Medium-Low **Relative value for native salmonid conservation:** Potential value for providing genetic diversity and/or local adaptations in both the short and long term, but will likely require investment to address fragmentation **Potential Goal:** Evaluate representativeness of this population across the landscape, and determine what level of protection/reconnection to other habitats is warranted **Strategies:** • Reconnect fragmented networks; • Protect climate refugia; • Minimize adverse impacts in the event of potential increased wildland fire disturbance; • Expand population; • Prevent invasion of non-native fish	8 **Relative vulnerability to climate change:** Medium **Relative value for native salmonid conservation:** Potential value for providing genetic diversity and/or local adaptations, but will likely require investment to moderate climate impacts and address fragmentation **Potential Goal:** Evaluate representativeness of this population across the landscape, and determine what level of protection/restoration/active management is warranted **Strategies:** • Reconnect fragmented networks; • Moderate stream temperature increases; • Moderate base flow decreases; • Moderate peak flow increases; • Increase adaptive capacity of native fish; • Minimize adverse impacts in the event of potential increased wildland fire disturbance; • Reduce uncertainty through research and monitoring; • Prevent invasion of non-native species	9 **Relative vulnerability to climate change:** Medium-High **Relative value for native salmonid conservation:** Potential value in short-term for providing genetic diversity and/or local adaptations, but will likely require investment to address fragmentation; Longer-term value is lower due to decreasing habitat suitability **Potential Goal:** Maintain population in the short-term; In the longer-term, consider facilitating the movement of current population to other locations with more suitable conditions, facilitating the transition of the location to a new state, and/or managing the location for other targets (e.g., game fish or non-fish targets) **Strategies:** • Reduce uncertainty through research and monitoring; • Increase adaptive capacity of native fish; • Relocate individuals to areas likely to remain or become suitable; • Facilitate transition to a new state
	HIGH THREAT FROM NON-NATIVE FISH	10 **Relative vulnerability to climate change:** Medium **Relative value for native salmonid conservation:** Potential value, but may will likely require investment to prevent/remove/suppress non-native fish and address fragmentation **Potential Goal:** Evaluate representativeness of this population across the landscape, and determine what level of protection, reconnection to other habitats, and management on non-native fish is warranted **Strategies:** • Reconnect fragmented networks; • Protect climate refugia; • Minimize adverse impacts in the event of potential increased wildland fire disturbance; • Expand population; • Prevent invasion of non-native fish	11 **Relative vulnerability to climate change:** Medium-High **Relative value for native salmonid conservation:** Lower value, and will likely require a high-level of investment to moderate climate impacts, prevent/remove/suppress non-native fish, and address fragmentation **Potential Goal:** Facilitate the movement of current population to other locations with more suitable conditions; Facilitate the transition of the location to a new state; Consider managing the location for other targets (e.g., game fish or non-fish targets) **Strategies:** • Reduce uncertainty through research and monitoring; • Relocate individuals to areas likely to remain or become suitable; • Facilitate transition to a new state; • Determine additional strategies after clarifying management goal(s)	12 **Relative vulnerability to climate change:** High **Relative value for native salmonid conservation:** Low value **Potential Goal:** Facilitate the movement of current population to other locations with more suitable conditions; Facilitate the transition of the location to a new state; Consider managing the location for other targets (e.g., game fish or non-fish targets) **Strategies:** • Reduce uncertainty through research and monitoring; • Relocate individuals to areas likely to remain or become suitable; • Facilitate transition to a new state; • Determine additional strategies after clarifying management goal(s)

Go to STEP 3 for more information about Strategies and their Example Actions.

STEP 3: Select Actions to Implement Chosen Climate Adaptation Strategies[1]

Strategies are listed in alphabetical order.

Strategy	Objective	Example Actions
Expand/refound populations	Increase population size and number of populations to recover large, interconnected populations	• Expand populations at or below minimum viable population size • Refound new populations in areas expected to be climatically suitable
Facilitate transition to a new state	Allow colonization by new species that may be better suited to new environments and still provide some ecological function and value	• Remove barriers to invasion • Introduce new species
Increase adaptive capacity of native fish	Increase resilience of native fish populations to warming stream temperatures and flow changes	• Identify and restore "warm-adapted" populations of native trout • Consider limiting angler pressure on native fish in streams that are at or near temperature thresholds • Replicate and supplement native fish populations • Remove non-native fish
	Increase native fish health	• Increase public education to eliminate disease vectors • Treat or remove infected/diseased fish • Eliminate or control pollutants or contaminants
	Conserve genotypic/phenotypic diversity	• Conserve or restore a diverse representation of habitats across river basins • Maintain large population sizes to minimize loss of genetic variability and adaptive potential.
Minimize adverse impacts in the event of potential increased wildland fire disturbance	Identify and minimize negative effects to areas most vulnerable to fire impacts	• Develop a geospatial layer of debris flow potential for pre-fire planning • Manage natural fuel conditions and unplanned wildfire effects through fuel management actions and/or use of unplanned wildfire ignitions to minimize negative effects (severity and extent) of fire.
	Restore areas adversely affected by fire	• Inventory disturbed areas for candidate sites for riparian and upland vegetation restoration • Restore and re-vegetate burned areas to store sediment and maintain channel geomorphology
Moderate base flow decreases	Restore or replicate stream flows	• Remove or breach dams • Increase storage of water in floodplains by encouraging natural flooding and groundwater infiltration • On regulated streams, pulse flows during critical times, sourcing from lower in the thermocline
	Reduce water withdrawals and/or water diversions	• Increase efficiency of irrigation techniques • Explore potential to combine sprinkler and flood irrigation to capture increasing spring floods (and recharge groundwater supplies) and then switch to more efficient sprinkler irrigation when stream flows are lower • Consider alternative water supplies for public land operations to retain in-stream flows • Legally secure water rights/agreements for in-stream flows • Reform water laws to enable increased acquisition of in-stream water rights • Explore the use of water trusts/funds to increase investments in the protection of watershed health and function • Use water pricing to encourage water conservation • Where water diversions exist, ensure fish ladders avoid entrainment of native trout
	Restore riparian vegetation	• Establish native riparian vegetation • Remove non-native riparian vegetation
	Increase natural water storage in groundwater aquifers	• Reintroduce beaver and/or install artificial beaver-mimic dams where compatible with fish conservation goals • Increase off-channel habitat and protect refugia in side channels • Protect wetland-fed streams which maintain higher summer flows • Maintain/restore forest and wetland vegetation cover • Reduce road density

STEP 3: Select Actions to Implement Chosen Climate Adaptation Strategies[1] (cont.)

Strategy	Objective	Example Actions
Moderate peak flow increases	Restore floodplain connections	• Remove infrastructure (e.g., roads, levees, rip rap, etc.) from floodplains • Reconnect floodplain features (e.g. channels, ponds) • Create new or restore degraded floodplain habitats
	Restore incised (scoured) channels	• Reintroduce beaver to encourage dam-building that increases sediment storage and deposition
	Restore riparian vegetation	• Establish riparian vegetation; remove non-native vegetation • Remove stressors that cause riparian damage (illegal or degraded trails, cattle, etc)
	Restore stream flow regimes	• Disconnect road drainage from streams • Remove or retrofit undersized culverts • Restore natural drainage systems, create retention ponds
	Reduce rain-on-snow flooding	• Maintain/restore forest, wetland and riparian vegetation cover
Moderate stream temperature increases	Connect populations to cold-water stream networks	• Remove dams or culverts that act as barriers and limit fish access to cold-water streams • Restore/provide in-stream flows • Resolve thermal barriers
	Reconnect floodplains	• Reconnect floodplain features (e.g. side channels, ponds) • Designate and restore natural floodplain boundaries • Remove infrastructure (e.g., roads, levees, rip rap, etc.) from floodplains
	Restore incised (scoured) channels	• Reintroduce beaver or build beaver dam analogs to increase sediment storage • Restore riparian vegetation • Remove stressors that cause riparian damage (illegal or degraded trails, cattle, etc)
	Restore stream flows	• Work to restore natural flow regimes • Reduce water withdrawals, restore summer baseflow • On regulated streams, pulse flows during critical times, sourcing from lower in the thermocline
	Maintain/enhance riparian vegetation to shade streams	• Reduce grazing pressure (e.g. reduce stocking rates, use rest-rotation systems, fence riparian areas, provide off-stream water sources, retire vacant allotments in priority fish areas, increase monitoring in priority areas to ensure good practices) • Restore riparian vegetation in degraded areas • Adjust riparian vegetation to favor species that are better suited for future climate conditions
Prevent invasion of non-native fish	Prevent non-native fish invasion	• Strategically use physical or electrical barriers to prevent further spread of non-native fish • Model future changes in stream flow and habitat to anticipate future invasion hotspots
	Restore habitats that convey an advantage for native fish over non-native fish	• Restore spawning habitats for native fish • Connect current native populations with streams that are too cold for non-native fish
	Expand existing native fish populations to increase chances of resisting invasion	• Expand native fish populations in areas where trying to prevent invasion of non-native fish
Protect climate refugia	Identify and protect areas likely to remain climatically suitable over the long-term	• Establish large-scale reserves for long-term native cold-water fish conservation • Connect current populations with streams that are currently too cold (and may warm to suitable levels in the future) • Look for opportunities for reintroductions in habitats likely to remain suitable over the long-term • Understand and map where groundwater inputs may buffer projected stream temperature increases
	Protect and restore critical or unique habitats that buffer survival during vulnerable periods (i.e., seasonally or at particular life history stages)	• Protect/restore off-channel habitats, spring brooks, and seeps important as early rearing environments • Protect/restore flood or thermal refugia and stream segments that are important as connections

STEP 3: Select Actions to Implement Chosen Climate Adaptation Strategies[1] (cont.)

Strategy	Objective	Example Actions
Protect existing networks	Identify existing networks and potential threats to them (e.g. non-native invasion, stream temp fragmentation)	• Establish large-scale reserves for long-term native cold-water fish conservation • Address threats to the network
Reconnect fragmented networks	Identify opportunities for reconnecting fragmented networks	• Remove instream barriers • Replace or retrofit culverts that will not function well during future low base flows • Maintain or reconnect large networks of habitat
Reduce uncertainty through research and monitoring	Improve systematic data collection and access across management and political boundaries	• Initiate and/or expand collaborative data collection and sharing that spans agencies and geographical boundaries, to ensure climate-trout research occurs at appropriate scales • Ensure published data is accessible in appropriate data repositories • Create, maintain and use cross-boundary databases for monitoring data • Strategically improve and standardize monitoring efforts • Conduct strategic sampling that targets locations of higher biological or climatic interest (e.g. areas with the highest rates of climate change)
	Transition research and monitoring toward population dynamics and sensitivity analyses	• Examine/study how climatic variation influences population dynamics (not just demography/ growth/phenology) in light of ecological context • Determine how climate change indirectly affects native trout populations (e.g. through exacerbating interactions between native and non-native trout; through influencing disease dynamics, etc.)
	Monitor changes in aquatic food web dynamics	• Assess food webs for baseline data; monitor food web dynamics in space and time
Relocate individuals to areas likely to remain or become suitable	Maintain gene flow, establish self-sustaining populations, and buffer potential for catastrophic losses	• Transport individuals to existing but otherwise inaccessible habitats likely to remain or become suitable as climate changes
Remove/suppress non-native fish	Remove or suppress non-native fish	• Remove or control non-native fish (via electrofishing, chemical removal, genetic swamping) • Encourage increased harvest of non-natives

[1] Sources: Halofsky et al. In Press, CAP 2014, Nelson 2014, Raymond et al. 2014, Cross et al. 2013, Rieman and Isaak 2010, Miller et al. 2009.

V. Discussion

Decision aids such as the one presented here create value for managers largely through the process of rigorously and systematically considering, answering and documenting responses to critical question, and considering how climate change vulnerability can vary across populations.. As a result, this decision framework is offered largely as a starting point for managers to explore and document their thinking on how the effects of climate change might lead to shifts in their conservation goals, and how climate adaptation strategies and actions can be applied in pursuit of those goals. Ultimately, managers can integrate this targeted climate change perspective with the myriad other policy, regulatory, social, economic and locally-driven factors and mandates that influence management decisions.

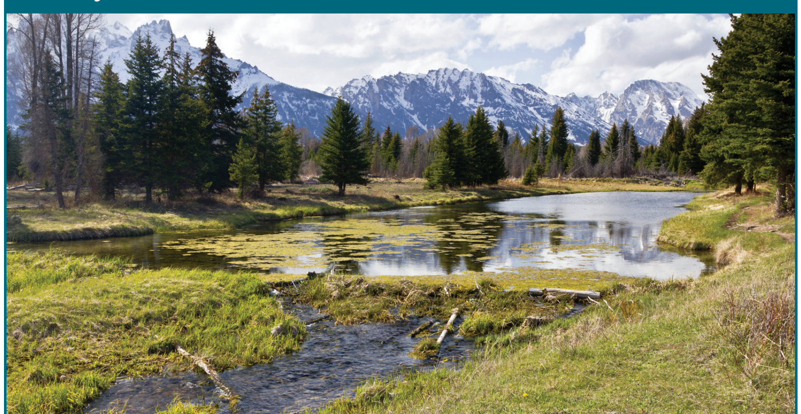
A primary purpose of the decision support framework is to provide a structured process for translating available climate data and research into forward-looking management goals, strategies and actions, to inform where and why managers might take particular actions. For native salmonids in the northern U.S. Rockies, the tool creates a bridge between the multitude of research efforts on climate change effects on cold-water fish and various efforts to identify climate adaptation strategies and actions, with a goal of catalyzing the implementation of climate adaptation actions. It highlights critical questions to help managers assess the vulnerability of native salmonid populations to climate change, and illustrates how answers to those climate-related questions might encourage different management paths.

The information and suggestions provided in the decision support framework are intended to stimulate dialog and discussion among managers and scientists about how climate change might influence decisions, rather than offer a single or definitive answer. As managers and scientists work with the information provided in this three-step decision framework, they may choose to add to or adjust the vulnerability factors and questions in STEP 1, modify the suggested goals and strategies in the vulnerability matrix in STEP 2, or add to the list of example actions for implementing particular strategies presented in STEP 3. In this way, we intend the decision support framework to be a "living" tool that can be modified to meet users' needs, or reflect an evolving understanding of climate change effects on native salmonids and our ability to ameliorate climate-related threats.

The framework offers a tool for transparently documenting how managers use climate change data and information in their conservation decisions. This documentation helps mangers fulfill agency mandates for considering climate change, such as those described in the USFS Climate Scorecard (USFS 2011). It also provides information that can be used in NEPA documents or other venues for justifying why particular management actions have been chosen for implementation. This not only helps managers defend their decisions to others within or outside their agency, but it provides a record for those decisions that lasts even after individual decision-makers move on from their current position. Resource specialists on the Custer Gallatin National Forest who informed the development of the framework and its application to native salmonids indicated that they envision using the tool during inter-disciplinary team meetings, to offer climate change information alongside other considerations when resource specialists present recommendations to line managers on specific land management decisions. They also suggested it could be used during interagency cutthroat trout Geographic Management Unit/regional conservation planning, and within local and regional drought and water management planning. Lastly, they see the general approach of this decision support framework as useful for fisheries conservation planning more broadly, not just for cold water-adapted native salmonids.

This decision framework is not intended to address all of the issues managers might need to consider when making decisions, in particular because it was developed in the absence of explicit considerations of regulatory, social, economic, and other

Summary Points



- The decision support framework provides a structured process for translating available climate science into forward-looking management goals, strategies and actions.
- It is designed to help managers document their logic on how climate change information or data has informed where and why they have chosen to take particular actions.
- This climate-informed thinking can be integrated alongside other regulatory, social and economic considerations to prioritize the allocation of limited resources.
- The approach used to develop the decision support framework for native salmonid conservation can be used to design similar tools for other species or ecosystems of conservation concern.

constraints. Information and ideas developed while working through this framework can, however, be folded into standard decision-making processes that consider factors such as current hotspots of conservation value or need, regulatory mandates, opportunities for taking conservation actions, and estimates of return on investment (i.e., conservation value per dollar spent).

Alongside use of this decision support framework, managers should also consider range-wide and landscape-level goals for native salmonid species in the aggregate; that is, how goals for individual populations roll-up to a landscape-level distribution of populations (Schindler et al. 2010). Although the tool is designed to be applied at the population level, it is important to step back and look across multiple populations after applying the decision framework, to look at how relative vulnerabilities, and suggested goals and actions, vary across a jurisdictional unit or larger landscape. It also may be possible to map climate change vulnerabilities (related to the key factors of habitat suitability, threats from non-native fish, and connectivity) across a landscape of interest or a species' range, and then use the decision support framework presented here to map corresponding management goals and strategies across that landscape. Whether applied at a population-by-population level or used in conjunction with landscape-scale information on climate vulnerabilities, the decision support tool offers information that can feed into decisions about where on the landscape to prioritize investments in particular management actions.

Although the decision support framework presented here was tailored to address needs identified by USFS managers at the Custer Gallatin National Forest, it is designed to add value to anyone thinking about native salmonid conservation decisions in the face of climate change. Ultimately, we feel the over-arching approach of the framework (discussed in Section III and illustrated in Figure 2) could be used to develop similar decision support tools for other systems or issues of interest to managers and conservationists.

Incorporating climate change into management decisions, and advancing climate adaptation thinking to action, is a process and no one single source of information or decision support tool can offer all of the guidance and information needed to design and implement climate-informed management practices. The framework presented here attempts to link several existing pieces of climate adaptation information (e.g., climate-related data and research, with results from climate adaptation planning workshops) as a tool to support managers in their efforts to proactively prepare for the effects of climate change and enhance their ability to achieve long-term conservation outcomes for native salmonids.

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VII. Appendix A

A non-exhaustive list of data, analyses and research available to support application of the decision support framework (in addition to other resources listed in the Literature Cited and Additional References section of the report).

Project Title	Project Description	Project Contacts
NorWeST (Northwest Stream Temperatures) Stream Temperature Database, Model, and Climate Scenarios	A comprehensive, interagency stream temperature database developed from contributions by >100 natural resource organizations that contains >200,000,000 hourly temperature records. The data have been used to develop a model that makes accurate predictions of mean August temperatures at 1 km resolution for all streams and rivers in the American West. Temperature data and model outputs are available in user-friendly geospatial formats that include .pdf files and ArcGIS shapefiles for regional stream temp database; maps and descriptive summaries of stream temp under historic and future climate scenarios; maps showing the precision of temp model outputs. Website: http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html	• Dan Isaak, US Forest Service • Charlie Luce, US Forest Service • Dave Nagel, US Forest Service
Climate Shield Cold-Water Refuge Streams for Native Trout	Species distribution models that make stream-scale predictions of population occurrence for cutthroat trout and bull trout throughout the northwestern U.S. Modeled scenarios include a range of climatic conditions and brook trout prevalence levels. Potential climate refugia are stream reaches with <11°C mean August temperature that also meet minimum size and channel slope criteria. Outputs are available in user-friendly geospatial formats that include .pdf files and ArcGIS shapefiles. Website: http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html; Reference: Isaak et al. 2015	• Dan Isaak, US Forest Service • Mike Young, US Forest Service
Predicting Effects of Climate Change on Aquatic Ecosystems in the Crown of the Continent Ecosystem	Vulnerability assessments for Bull Trout and Westslope Cutthroat Trout have been completed for the Transboundary Flathead and are being extended across the entire Crown of the Continent. Involves daily stream temperature modeling at a 22m resolution across the Crown of the Continent region. Reference: Jones et al. 2014	• Clint Muhlfield, US Geological Survey • Leslie Jones, US Geological Survey
Helping managers develop and implement a consistent method to prioritize conservation and identify climate adaptation strategies for Yellowstone cutthroat trout	Developing a conservation framework for Yellowstone Cutthroat Trout (YCT) that prioritizes conservation populations based on existing threats and future threats from climate change. Multiple models and approaches will are being used to assess climate change impacts on YCT, including NorWeST stream temp models (see above). Reference: Al-Chokhachy et al. 2013	• Robert Al-Chokhachy, US Geological Survey • Brad Shepard, B.B. Shepard and Associates
Watershed-level climate change vulnerability assessments for Custer Gallatin National Forest and Greater Yellowstone Area	An assessment of the vulnerability of watersheds within the Custer Gallatin National Forest and Greater Yellowstone Area to climate change. The analysis combines factors that represent the underlying sensitivities of watersheds (e.g., slope, aspect, elevation, soils and geology) with various measures of exposure to changing climate conditions (e.g., changes in streamflow, snowpack and average summer temperature). The analyses are conducted at the 6th code HUC watershed scale, and cover portions of Montana, Wyoming and Idaho.	• Custer Gallatin National Forest analysis - Scott Barndt, US Forest Service • Greater Yellowstone Area analysis - Louis Wasniewski, US Forest Service
Assessment of watersheds in the Upper Missouri Headwaters and Northern Rockies for their potential to retain late-season snowpack and sustain late-season flows	Factors such as elevation, aspect, and slope were used to identify high-elevation areas with low solar insolation in June where snowpack persists longest. Those sub-basins that are likely to retain relatively more late-season snow, and therefore provide inputs to late-season stream flows, even as snowmelt occurs earlier temperatures warm. These analyses have been conducted at 30m resolution and can be summarized at a 6th or 5th order code HUC (hydrological unit code) to compare relative climate resilience and prioritize restoration investment.	• Rebekah Levine, University of Montana-Western • Nathan Korb, The Nature Conservancy