Bull Trout Recovery:
Monitoring and Evaluation Guidance
Volume II

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Columbia River Fisheries Program Office
1211 SE Cardinal Court, Suite 100
Vancouver, WA 98683

Prepared by
The Bull Trout Recovery Monitoring and Evaluation Technical Group (RMEG)
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Contributors

Tracy Bowerman
Utah State University
College of Natural Sciences
Watershed Sciences Department, 5290 Old Main Hill
Logan, UT, 84322, USA

Phaedra Budy
Utah Cooperative Fish and Wildlife Research Unit
Utah State University, 5290 Old Main Hill
Logan, UT, 84322, USA

Shaun Clements, Steve Jacobs
Oregon Department of Fish & Wildlife
Corvallis Research Lab
28655 Highway 34
Corvallis, OR, 97333, USA

Denise Hawkins
United States Fish & Wildlife Service
Abernathy Fish Technology Center
1440 Abernathy Creek Rd.
Longview, WA, 98632, USA

Philip Howell
USDA Forest Service
Forestry and Range Sciences Laboratory
1401 Gekeler Lane
La Grande, OR 97850, USA

Dan Isaak
USDA Forest Service
Rocky Mountain Research Station
Boise, ID, 83702, USA

David P. Larsen
Pacific States Marine Fisheries Commission
c/o United States Environmental Protection Agency
Western Ecology Division, 200 SW 35th Street
Corvallis, Oregon 97333, USA

David Marmorek, Marc Porter, Darcy Pickard, Katy Bryan
ESSA Technologies Ltd., Suite 600-2695 Granville Street
Vancouver, British Columbia V6J 5C6, CANADA

Kevin Meyer
Idaho Department of Fish and Game
600 South Walnut Street
Boise, ID, 83707

Clint Muhlfeld
USGS - Northern Rocky Mountain Science Center
Glacier Field Office, Glacier National Park
West Glacier, Montana 59938, USA

Howard Schaller, Tim Whitesel*, Paul Wilson
United States Fish & Wildlife Service, Columbia
River Fisheries Program Office, 1211 SE Cardinal
Court, Suite 100, Vancouver, Washington 98683,
USA

*** Corresponding author:** timothy_whitesel@fws.gov
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Introduction

Beginning in 1998 the FWS listed four Distinct Population Segments (DPSs) bull trout (*Salvelinus confluentus*) as threatened under the ESA. Subsequently, five DPSs were identified and combined into one, coterminous DPS that was considered threatened. In 2002, the FWS published draft Recovery Plans for three of the original DPSs (Columbia, Klamath and St. Mary Belly). In 2004, the FWS published draft Recovery Plans for the remaining two DPSs (Jarbidge, Coastal-Puget Sound). The development of guidance on how to monitor and evaluate recovery, specifically related to recovery criteria, was specifically called for in the draft recovery plans. As a result of this, a Recovery Monitoring and Evaluation Group (RMEG) was established in 2003 to begin to develop this guidance.

The ESA requires that the FWS conduct status reviews every five years after a species is listed. Thus, in 2005, a 5-year review was initiated for bull trout. Due to the uncertainty about the outcome of the 5-year review as well as the associated workload, recovery planning was postponed. After some deliberation between the FWS and agency partners, it was determined that an application of the IUCN's, NatureServe model (http://www.natureserve.org/explorer/) was an appropriate tool to help assess the status of bull trout. Working with partners, the FWS completed a 5-year review in 2008 and determined that the coterminous DPS of bull trout remained threatened. During this time, RMEG continued to work to develop guidance on monitoring and evaluation. In 2008 the RMEG also published the first version of a document to guide aspects of monitoring and evaluation associated with recovery (USFWS 2008) (http://www.fws.gov/columbiariver/publications/080310_M&E_guidance_FINAL_2.pdf).

Concurrent with the 5-year review, multiple tasks associated with bull trout conservation were also conducted. Whether the conservation of bull trout is best served by bull trout being grouped as one DPS or multiple DPSs was also uncertain. Thus, the FWS worked with partners to complete (in 2009) a re-evaluation of the bull trout population structure. This re-evaluation, which used new information on population structure (see Ardren et al. 2011) as well as criteria from the Service's DPS policy, resulted in the FWS deciding to split bull trout into six Recovery Units (RUs). These Recovery Units are roughly equivalent to major evolutionary (or conservation) units (Whitesel et al. 2004) of bull trout.

In addition to evaluating population structure, the FWS also concluded (in 2010) a re-proposal of bull trout critical habitat. The FWS has proposed 33 Critical Habitat Units; 118 core areas; and approximately 600 local populations. Given that the 5-year review and population structure analysis, are complete, and redesignation of critical habitat of critical habitat was close to being complete, the FWS reinitiated recovery planning in 2010. For recovery purposes, the bull trout population units discussed above will need to be assessed in the years ahead, ideally informed by the NatureServe approach and relative to specific recovery criteria. Thus, RMEG activities reported here were designed to directly link to these criteria and the NatureServe evaluation. Ultimately, bull trout listing decisions will be evaluated at the DPS level, and the status of RUs will be important in these determinations.

RMEG

The original draft recovery plans indicated that monitoring and evaluation (M&E) was required to assess recovery. M&E was required to assess recovery action effectiveness and to assess the status of bull trout populations. However, the original draft recovery plans were unclear about 1) how where and when to monitor bull trout and their habitats, as well as 2) which analytical techniques for evaluation provided adequate statistical soundness and rigor. Thus, the RMEG[1] was assembled to begin to provide guidance on these questions. The RMEG consists of members with skills in (for example) population dynamics, char biology, biometrics and experimental design. The RMEG has broad geographic representation, with members who work in the states of Oregon, Washington, Idaho, and Montana. The RMEG is chaired by the FWS and independently facilitated.

Originally, the RMEG was asked to provide guidance on a variety of questions associated with recovery. Specific questions directly related to recovery criteria included:

1) how to monitor distribution,
2) how to determine and measure population connectivity,
3) how to monitor trends in abundance, and
4) how to measure abundance.

To provide guidance on these specific questions, a number of related questions had to be addressed. These related questions included:

1) what are the population boundaries of interest,
2) what are the best sampling designs or frameworks,
3) which life stages can be used for monitoring,
4) how can monitoring be done at multiple scales (i.e. local populations, core areas), and
5) how can monitoring be done so that results can be rolled up across scales.

These were the topics the RMEG began to address and summarized in its initial guidance document:
(http://www.fws.gov/columbiariver/publications/080310_M&E_guidance_FINAL_2.pdf)

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[1] RMEG Charter: (http://www.fws.gov/columbiariver/publications/RMEG_Charter_2003.pdf)

There has been broad agreement among agency partners that the NatureServe approach used by the FWS for the 5-year review was suitable for the purpose of assessing status and can provide the basis for future assessments, including recovery. This essentially represented a new mandate for the RMEG to redirect their analyses (i.e., for the next 5-year review) with a mind to the NatureServe process and the associated IUCN categorizations of population status and risk. Thus, the RMEG worked closely with FWS and partners on technical analyses to support the development of new recovery criteria that are associated with NatureServe categorizations. In particular, RMEG activities were designed to inform the selection of recovery criteria, with specific attention to the measurability and sensitivity of various metrics. Final recovery criteria will be used by the FWS to inform future evaluations of bull trout recovery.

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Chapter 1: Population Structure

Overview: Current recovery planning efforts for bull trout rely, in part, on the answers to questions associated with the population structure of bull trout. For recovery planning purposes, the population structure of bull trout has been hierarchically structured. Local populations are the smallest groupings of individual bull trout being used in recovery planning. Local populations can exist independently or interact to function as a metapopulation. Core areas (or the biological equivalent of metapopulations) can exist independently or interact to function as a Distinct Population Segments (or the biological equivalent of evolutionary units). The RMEG was tasked with beginning to develop methods (e.g., GIS, genetic, and habitat-based rules) for delineating core areas accurately and consistently as well as to continue the development of methods for delineating patches that represent local populations (see USFWS 2008).

1.1. The History of Core Area Delineation during Bull Trout Recovery Planning

1.1.1 Introduction

The draft recovery plan identified 118 core areas of bull trout (see USFWS 2002). In general, core areas were delineated using the best professional judgment of different groups of regional biologists and managers. However, specifically how core areas were delineated, what information was considered, and how the information was applied is unclear. Thus, the objective of this chapter was to summarize the history of core area delineations.

A core area of bull trout has been defined as the geographical area best approximating the range in which a single local population or group of local populations, with a level of genetic linkage consisting of periodic, occasional dispersal or straying that is sufficient for refounding support and contributing some genetic diversity exists . A core area must contain at least one local population but may contain multiple local populations. A local population is defined as a group of individuals having close demographic and genetic linkage; for example, the adults commonly interbreed, its abundance fluctuates as a unit, and the same forces in space and time influence its persistence. A core area is the combination of core habitat and a core population (one or more local populations) which constitutes the basic unit on which to gauge recovery. The information below describes how core areas were previously defined in the draft recovery plan (USFWS 2002) and criteria that were used in their delineation. It also includes relevant information from the Science Team (Whitesel et al. 2004) review of the draft recovery plan and recent comments from RMEG regarding proposed changes in core areas for the revised recovery plan.

1.1.2 Chapter 1 of the Draft Recovery Plan

Much of basis for core area delineations is described in the following excerpts from Chapter 1 of the Draft Recovery Plan (USFWS 2002).

Draft Recovery Plan, Introduction

For this recovery plan, bull trout have been grouped into distinct population segments, recovery units, core areas and local populations. Core areas are composed of one or more local populations, recovery units are composed of one or more core areas, and a distinct population segment is composed of one or more recovery units. With genetic theory, bull trout can be grouped into population units that share an evolutionary legacy, termed metapopulations and local populations (Kanda and Allendorf 2001). Metapopulations are composed of one or more local populations.

The recovery plan considers local populations of bull trout to be partially isolated, but have some degree of gene flow among them. Such groups meet the definition of (Meffe and Carrol 1994) and function as (Dunham and Rieman 1999) a metapopulation. The intent of the recovery plan is to have core areas reflect the metapopulation structure of bull trout. Within a bull trout metapopulation, local populations are expected to function as one demographic unit (Hanski and Gilpin 1997). All local populations within a bull trout metapopulation would be at a common risk of extinction and have a relatively high degree of genetic relatedness (Kanda and Allendorf 2001). In theory, bull trout metapopulations can be composed of two or more local populations. However, Rieman and Allendorf (2001) have suggested that between 5 and 10 local populations are necessary for a bull trout metapopulation to function effectively.

Draft Recovery Plan, Core Area Definition

The recovery plan defined core area as: The combination of core habitat (*i.e.*, habitat that could supply all elements for the long term security of bull trout) and a core population (a group of one or more local bull trout populations that exist within core habitat) which constitutes the basic unit on which to gauge recovery within a recovery unit. Core areas require both habitat and bull trout to function, and the number (replication) and characteristics of local populations inhabiting a core area provide a relative indication of the core area’s likelihood to persist. A core area represents the closest approximation of a biologically functioning unit for bull trout.

Draft Recovery Plan, Core Habitat Definition

The recovery plan defined core habitat as: Habitat that encompasses spawning and rearing habitat (resident populations), with the addition of foraging, migrating, and overwintering habitat if the population includes migratory fish. Core habitat is defined as habitat that contains, or if restored would contain, all of the essential physical elements to provide for the security of and allow for the full expression of life history forms of one or more local populations of bull trout. Core habitat may include currently unoccupied habitat if that habitat contains essential elements for bull trout to persist or is deemed critical to recovery.

Draft Recovery Plan, Core Population Definition

The recovery plan defined core population as: A group of one or more bull trout local populations that exist within core habitat.

1.1.3 Draft Recovery Unit Chapters

Most of the individual recovery unit chapters repeat the same general definition of core area from Chapter 1 above but do not describe any specific criteria or rationale used to identify the core areas within those recovery units.

Coastal Puget Sound Management Unit

> This unit includes the following additional description of core areas. The components of fully functioning core areas include:
>
> a) Habitat sufficiently maintained or restored to provide for the persistence of broadly distributed local populations supporting the migratory life form within each core area. The term "broadly distributed" implies that local populations are able to access and are actively using habitat that fully provides for spawning, rearing, foraging, migrating, and overwintering needs at recovered abundance levels.
>
> d) Habitat within, and where appropriate, between core areas, is connected so as to provide for the potential of the full expression of migratory behavior (particularly anadromy), allow for the refounding of extirpated populations, and provide for the potential of genetic exchange between populations.

St. Mary-Belly River, Clark Fork River and Kootenai River

> These draft plans distinguished between simple and complex core areas. Simple core areas were similar to those described for other recovery units, which were larger in terms of area, drainage network, and abundance of the populations, while complex core areas were not considered large enough to support the number of populations and abundance levels of simple core areas.

Core area designation was based on the documented historical distribution of bull trout, supplemented by more recent research findings. Determinations were based on reproductive isolation of bull trout present in these systems. In this recovery unit, a distinction has been made between two types of core areas—simple and complex core areas—based mostly on the size, connectedness, and complexity of the associated watershed and the degree of natural population isolation. We designated simple and complex core areas. Complex core areas were generally based in smaller watersheds and typically contain migratory populations of bull trout that have become naturally isolated, with restricted upstream spawning and rearing habitat. Complex core areas each include one identified local population of bull trout and generally do not contain habitat of sufficient size and complexity to accommodate the multiple local populations found in simple core areas.

Clark Fork River

In this recovery unit, a distinction has been made between two types of core areas—simple and complex core areas—based mostly on the size, connectedness, and complexity of the associated watershed and the degree of natural population isolation. For purposes of recovery in this unit, the Clark Fork Recovery Unit Teams divided the entire unit into simple and complex core areas, based mostly on the size, connectedness, and complexity of the watershed. The distinction does not infer a different level of importance for recovery purposes.

Simple core areas in the Clark Fork Recovery Unit are typically located in watersheds of major river systems, often contain large lakes or reservoirs, and have migratory corridors that usually extend 50 to 100 kilometers (30 to 60 miles) or more. In the Clark Fork Recovery Unit, core areas were most easily delineated for adfluvial populations (*e.g.*, typically the lake where adults reside and interconnected watershed upstream). For fluvial or anadromous populations, delineating core areas requires that some judgment calls be made in determining the extent of historical and current connectivity of migratory habitat, while considering natural and manmade barriers, survey and movement data, and genetic analysis. For resident populations, we must consider whether local populations are remnants from previously existing migratory bull trout and whether reconnecting fragmented habitat would restore a migratory core area.

Many of the small isolated populations in the Clark Fork Recovery Unit (defined as complex core areas) are essentially stranded local populations that have apparently persisted for a very long time, even thousands of years, at population levels very similar to current levels. Complex core areas are based in smaller watersheds and typically contain adfluvial populations of bull trout that have become naturally isolated, with restricted upstream spawning and rearing habitat extending less than 50 kilometers (30 miles). Each complex core area includes one identified local population of bull trout and is not believed to contain sufficient size and complexity to accommodate 5 or more local populations with 100 or more adults to meet the abundance criteria defined above for simple core areas. Most complex core areas have the potential to support fewer than a few hundred adult bull trout, even in a recovered condition. In extreme cases, complex core areas may include small isolated lakes that occupy as little as 10 surface hectares (25 acres) and that are connected to 100 meters (about 100 yards) or less of accessible spawning and rearing habitat. In most cases, these conditions are natural, and, in some situations, these bull trout have probably existed for thousands of years with populations that seldom exceed 100 adults.

Kootenai River

This draft plan made similar distinctions to those in the Clark Fork plan.

St. Mary-Belly River

This plan included this additional general guidance for core area designation.

The Recovery Team provided guidance to recovery unit teams to assist in determining the boundaries of core areas. The guidance included the following: (1.) Spatial scale of core areas are typically represented by 4th-field hydrologic unit codes (HUCs), or aggregates of 4th-field HUCs, unless evidence of natural isolation (*e.g.*, a natural barrier or presence of a lake supporting adfluvial bull trout) supports designation of a smaller core area. (2.) Core area boundaries are conservative, *i.e*. the largest areas likely constituting a core area should be designated as a single core area when doubt exists about the extent of bull trout movements and use of habitats. Data collected that indicate a core area should be split would be considered a refinement to the original core area designation in response to new information. (3.) Core areas do not overlap.

That guidance ensured that core areas were identified using a consistent approach.

1.1.4 Science Team Report

The Science Team report (Whitesel et al. 2004) focused primarily on the general relationship of metapopulation theory to core areas rather than the consistency or appropriateness of how individual core areas were designated. Although there is substantial genetic evidence to indicate that populations of bull trout are often highly divergent and structured, the degree to which they function as metapopulations and the type of structure (e.g., classical, Levins-type; source-sink; mainland-island; stepping stone) is uncertain. Some have suggested that an isolation-by-distance model is most appropriate for salmonids in general and bull trout in particular. In most core areas, there is little available evidence, other than considerations of geography, with which to determine with certainty to what degree the local populations within a core area act as a metapopulation, or which of the models of metapopulation structure is the best approximation of the behavior of the core area. In addition, the extent to which the current structure reflects historical versus recent (or natural versus anthropogenic) events is unknown. Aggregations of bull trout populations that once may have acted as metapopulations may now be too fragmented, depressed, or contracted to be recognized as metapopulations today. Despite those uncertainties, there are potentially serious and detrimental consequences to management and monitoring of incorrect assumptions about metapopulation structure.

They offered the following considerations in determining whether core areas reflect metapopulation structure:

1. Is there evidence for subdivided habitat? If so, is habitat subdivision a result of continuously varying environmental conditions (e.g. temperature) or abrupt discontinuities (e.g. passage barriers)? For what kind of biological response are habitats patches defined?

2. What is the spatial distribution and connectivity of habitats including how are they positioned on the landscape and within the stream network?

3. Is there empirical evidence for genetic structuring or population subdivision? In addition to gene frequencies, evidence may come from mark-recapture experiments, telemetry, or other data.

4. How do fish move around the habitat? Is there evidence for source-sink or other processes? What is the role of dispersal (i.e. fish born in one area breed in another)?

5. Is there evidence for correlated population dynamics? Is there synchrony in population behavior or, for example, correlated changes in population abundance, demographic parameters, or patterns of persistence?

1.1.5 References

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1.2. The Sensitivity of the NatureServe Assessment Approach to the Core Area Structure of Bull Trout

1.2.1 Introduction

The draft recovery plan for bull trout (USFWS 2002) defined a core area as the combination of core habitat and a core population that constitutes the basic unit on which to gauge recovery within a recovery unit[2]. By definition, core areas require both habitat and bull trout to function. A core area is intended to identify the closest approximation of a biological grouping of bull trout that function as one demographic unit. In essence, a core area is intended to reflect metapopulation structure (Hanski and Gilpin 1997). In general, core areas are most easily represented graphically (on a map) by a polygon that encompasses areas of spawning and early rearing for local populations and the habitat that connects these local populations.

The draft recovery plan identified 118 core areas of bull trout (see USFWS 2002). These core areas are located within the continental USA which is currently classified as one Distinct Population Segment (DPS). In general, core areas were delineated using the best professional judgment of different groups of regional biologists and managers. Due to the inherent subjectivity of such an effort, there can be quite a discrepancy in core area size. The Yakima Core Area is the largest core area at approximately 1,587,950 hectares whereas the Isabel Lake Core Area is the smallest core area at approximately 515 hectares in size (or more than a 3,000-fold difference). In addition, there can also be quite a discrepancy in the number of core areas within subbasins of similar size and condition. The John Day River subbasin has approximately 2.1 M hectares of bull trout habitat that has been divided into three core areas. Alternatively, the Grande Ronde River subbasin has approximately 1.1 M hectares of bull trout

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[2] Bull Trout Core Area (*noun*): *"The geographical area best approximating the range in which a single local population or group of local populations, with a level of genetic linkage consisting of periodic, occasional dispersal or straying that is sufficient for refounding support and contributing some genetic diversity exists . A Core Area must contain at least one local population but may contain multiple local populations. A local population is defined as a group of individuals having close demographic and genetic linkage; for example, the adults commonly interbreed, its abundance fluctuates as a unit, and the same forces in space and time influence its persistence. A Core Area is the combination of core habitat and a core population (one or more local populations) which constitutes the basic unit on which to gauge recovery."*

habitat that is currently classified as one core area. Thus, it is unclear whether all core areas were delineated consistently and accurately.

Currently, the NatureServe assessment approach is used to evaluate the status of bull trout (see USFWS 2008). Information regarding each core area is updated through regular and consistent input from local and regional biologists. This information is used to assign a relative score and rank, or risk assessment, to each core area. One approach to evaluating the status of a given DPS, which would generally be composed of multiple core areas, is to derive a DPS score and rank from integrated core area scores and ranks. See Chapter 2 for detailed discussion on techniques to develop a composite DPS score from component core area scores. Regardless of how a DPS score is derived from core area scores, it is possible that the accurate delineation of core areas and whether there are fewer or more core areas within a given DPS may influence the overall assessment of DPS. Recovery biologists are uncertain whether and how the integration of the core area scores from the NatureServe assessment approach into a DPS score and rank is sensitive to the number of core areas in a given DPS. Thus, the objective of this investigation is to begin to explore whether the NatureServe assessment approach appears to be sensitive to combining or dividing existing core areas within a DPS.

1.2.2 Methods

Study Area

We evaluated the Mid-Columbia Recovery Unit (MCRU). Although the Mid-Columbia is currently defined as a Recovery Unit, for all practical purposes it can also be considered a DPS (see Whitesel et al. 2004, Ardren et al. 2011). In general, the geographic scope of the MCRU includes the northcentral part of Idaho, the northeastern part of Oregon, and essentially all of Washington east of the Cascade mountain range crest. The MCRU is currently composed of 26 core areas. Given the current core area structure, for core areas that are composed of stream segments (non-lakes or reservoirs), the Yakima core area is the largest (approximately 1,587,950 hectares) and the Little Minam River core area is the smallest (7,685 hectares). The Yakima core area is more than 200 times larger than the Little Minam Core Area. The Fish Lake Core Area (NF Clearwater River) is the absolute smallest (approximately 1,449 hectares) in the MCRU.

Original Core Areas

In 2008, a status assessment of each core area in the MCRU was completed (USFWS 2008). The status of these 26 core areas was evaluated using the NatureServe assessment approach. For each core area, the NatureServe assessment approach considered the extent of occupancy, number of local populations, abundance, short-term trend in abundance, long-term trend in abundance as well as scope and severity of threats. It was possible to associate uncertainty with any of these various inputs. Thus, the approach captured this uncertainty by generating a low score and a high score for each core area. In our analysis, we used the previously determined low and high score as well as derived and used an average score ([low score + high score] / 2) (Table 1).

Table 1. NatureServe assessment scores (potential range 0-5.5) for the original 26 core areas in the Mid-Columbia Recovery Unit. These scores were generated from the 2008 status assessment.

Core Area	Low Score	High Score	Average Score
Fish Lake (Lochsa R.)	1.69	2.23	1.96
Fish Lake (NF Clearwater R.)	1.69	2.23	1.96
Lochsa R.	2.78	2.88	2.83
Clearwater R. (lower & MF)	1.34	2.09	1.72
Clearwater R. (NF)	2.98	3.51	3.25
Selway R.	2.88	2.98	2.93
Clearwater R. (SF)	1.80	2.23	2.02
Sheep Ck.	0.69	1.01	0.85
John Day R. (NF)	1.63	1.63	1.63
John Day R. (MF)	1.49	1.49	1.49
John Day R. (upper)	1.48	1.48	1.48
Umatilla R.	1.27	1.27	1.27
Granite Ck.	0.69	1.01	0.85
Grande Ronde R.	2.19	2.19	2.19
L. Minam R.	1.29	1.29	1.29
Imnaha R.	1.94	1.94	1.94
Powder R.	2.05	2.05	2.05
Entiat R.	1.61	1.61	1.61
Methow R.	2.16	2.16	2.16
Wenatchee R.	2.20	2.20	2.20
Yakima R.	2.35	2.57	2.47
Tucannon R.	1.27	1.27	1.27
Asotin Ck.	0.64	0.64	0.64
Walla Walla R.	1.82	2.02	1.92
Touchet R.	1.27	1.27	1.27
Pine-Indian-Wildhorse complex	1.83	1.83	1.83

Combining Core Areas

To simulate redefining the core area structure of the MCRU so that fewer core areas exist, currently defined core areas were combined at two levels. A minor combination was generated by combining the 26 original core areas to form 21 core areas (81% of the number of original core areas). This was accomplished by keeping 16 of the original core areas and generating five new core areas that each combined two of the original core areas. A major combination was generated by combining the 26 original core areas to form 10 new core areas (38% of the number of original core areas). This was accomplished by generating 10 new core areas that each combined 2-4 of the original core areas. None of the original core areas were maintained under the major combination scenario.

We used existing inputs to the NatureServe assessment approach to generate inputs for the new core areas. The original inputs associated with extent of occupancy, number of local populations, and abundance were summed to generate new inputs for the new, combined core areas. For example, the original Sheep Creek and Granite Creek core areas each had one local population. When these two core areas were combined, the new core area had two local populations. The original inputs associated with trends in abundance (for example stable or increasing) and threats (for example high or low) did not lend themselves to simple summing. In these cases, two general approaches were used to generate inputs for the new, combined core areas. When the inputs for the original core areas were the same, the input for the new, combined core area was left the same and matched the original assignments. For example, the inputs for the scope of threats in the original Grande Ronde and Little Minam Core Areas were both high. When these two core areas were combined, the new core area was also assigned a high for input into the scope of threats. When the inputs for the original core areas were the different, the input for the new, combined core area was interpolated from the original assignments. For example, the input for the short-term trend in the original Fish Lake (Lochsa) Core Area was DF, declining or increasing (illustrating uncertainty), and in the original Lochsa Core Area was E, stable. When these two core areas were combined, the new core area was assigned a short-term trend of stable (E). As part of the interpolation process, core areas could be weighted unequally. For example, the inputs for the severity of threats in the original Grande Ronde and Little Minam Core Areas were moderate and high, respectively. However, the Grande Ronde Core Area is approximately 10 times larger than the Little Minam Core Area. Thus, when these two core areas were combined, the new core area was assigned a moderate severity of threats. Based on this exercise, a table was generated to describe the estimated relationship between inputs to original core areas and inputs to combined core areas (Table 2). To generate scores for the new, combined core areas, inputs that were developed for combined core areas were used in the NatureServe assessment approach.

Table 2. The relationship used to divide single core areas into multiple core areas. The frequency table was used to assign categories to new core areas. For example, if a single core area had a threat input of L (low) and this core area was being divided into multiple core areas, 71% of the time those new core areas would have a threat of L and 29% of the time the new core areas would have a threat of M (medium).

		Multiple core areas categories							
Variable	**Single core area category**	**A**	**B**	**C**	**D**	**E**	**F**	**U**	**H**
Extent of occupancy	X, Z, A, B, C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	D	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00
	DE	0.00	0.00	0.33	0.67	0.00	0.00	0.00	0.00
	E	0.00	0.13	0.13	0.60	0.13	0.00	0.00	0.00
	F, G, H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Number of local	Z, A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	AB	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.69	0.31	0.00	0.00	0.00	0.00	0.00	0.00
	BC	0.44	0.56	0.00	0.00	0.00	0.00	0.00	0.00
	C	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
	D, E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Abundance	X, Z, A, B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C	0.14	0.29	0.57	0.00	0.00	0.00	0.00	0.00
	CD	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
	D	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00
	DE	0.33	0.00	0.33	0.33	0.00	0.00	0.00	0.00
	E	0.21	0.36	0.14	0.21	0.07	0.00	0.00	0.00
	F, G, H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trend in abundance	A, B, C, D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	DE	0.00	0.00	0.00	0.63	0.35	0.13	0.00	0.00
	E	0.00	0.00	0.00	0.11	0.44	0.11	0.33	0.00
	EF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	DF	0.00	0.00	0.00	0.38	0.25	0.38	0.00	0.00
	FH	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50
	DH	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.33
	DU	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00

		I	L	M	H	U
Threats	I	0.00	0.00	0.00	0.00	0.00
	L	0.00	0.71	0.29	0.00	0.00
	M	0.00	0.09	0.27	0.45	0.18
	H	0.00	0.00	0.06	0.82	0.12
	U	0.00	0.00	0.00	0.00	0.00

Dividing Core Areas

To simulate redefining the core area structure of the MCRU so that it contains more core areas, currently defined core areas were divided at two levels. A minor division was generated by dividing the 26 original core areas to form 53 core areas (204% of the number of original core areas). This was accomplished by keeping 14 of the original core areas and generating 39 new core areas. The 39 new core areas resulted from dividing 12 of the original core areas into 2-6 new core areas. A major division was generated by dividing the 26 original core areas to form 121 new core areas (465% of the number of original core areas). This was accomplished by keeping eight of the original core areas and generating 113 new core areas. The 113 new core areas resulted from dividing 18 of the original core areas into 2-16 new core areas. In general, the original core areas that were maintained were associated with lakes, the smallest of the core areas or those with only one local population.

How much a core area was divided was associated with the size of the original core area. To generate an approximate 2-fold increase in core area numbers (the minor division) the number of estimated local populations in an original core area was divided by approximately 2.5. The whole number result of this equation was the number of core areas that the original core area was used to create. For example, the original Lochsa River core area was estimated to have seven local populations. That number of local populations was divided by 2.5, resulting in a (rounded) whole number solution of three. Thus, the original core area was divided into three new core areas. To generate an approximate 4.5-fold increase in core area numbers (the major division) the original core area was divided into the minimum number of local populations that were estimated to be present. For example, the original South Fork Clearwater River core area was estimated to have at least five local populations. Thus, the original core area was divided into five new core areas.

To generate inputs for the new, divided core areas, we used the results from combining core areas. Initially, we examined the relationships that emerged from combining relatively small units into relatively larger units. As a relatively simple example, a combined core area with four local populations could have resulted from two original core areas with one and three local populations, respectively. Alternatively, the two original core areas could have each had two local populations. Other alternatives are that the combined core area could have resulted from three or four original core areas with some combination of local populations (Table 3). We examined this type of information, generated their relative frequency of occurrences, and interpolated for cases where data was absent (Table 2).

Table 3. Hypothetical example of how a combined core area (CA) with four local populations could have been derived.

Number of local populations					
Combined	**Original CA 1**	**Original CA 2**	**Original CA 3**	**Original CA 4**	**Frequency**
4	2	2			40%
4	1	3			20%
4	1	1	2		20%
4	1	1	1	1	20%

This information demonstrated how small units combined into large units. We used this relationship to estimate, conversely, how relatively large units might divide into relatively small units. Again, from this relatively simple example, we could ask the following question. If we divided a core area with four local populations into two smaller core areas, how many local populations would each new core area have? From the information in Table 3 (for example), we would have assumed that a) 67% of the time each new core area should be assigned two local populations while b) 33% of the time one core area should be assigned one local population and the other local population should be assigned three local populations. This approach, and the information in Table 2, were used to assign inputs to new core areas that resulted from dividing original core areas. To generate scores for the new, divided core areas, inputs that were estimated for divided core areas were used in the NatureServe assessment approach.

Deriving a Recovery Unit value from Core Area values

<u>Simple Means</u>

We used the NatureServe assessment approach to generate four new sets of core area scores, one set of scores for each combination scenario and one set of scores for each division scenario. For each scenario, we calculated the mean core area score to derive an overall MCRU score. We assumed all core areas had equal value and, in essence, assigned the scores for each core area an equal weight. For each of the five scenarios (original, minor combination, major combination, minor division and major division), we derived MCRU scores (core area means) from the high, low, and average scores from each core area. We used Student's t-test to compare scores of the original MCRU scenario to the two combined and two divided MCRU scenarios. Within each score category (high, low, average), we conducted four planned comparisons (original scenario v. 1 – minor combination, 2 – major combination, 3 – minor division, 4 – major division). To evaluate whether there was any indication that changing core area structure could influence the recovery unit score, we evaluated significance at $\alpha = 0.10$. We used the method of Dunn-Sidak to adjust for planned comparisons of non-independent data (see Sokal and Rohlf 1995). We also wanted to evaluate whether the scenarios could result in a change in the MCRU rank. The protocols in the NatureServe assessment approach were used to convert the mean score for the MCRU to a rank. For this exercise, scores were converted to S ranks. Using NatureServe terminology, S ranks are described as subnational ranks (units smaller than a nation, such as Canada or the United States of America). Although S ranks often represent a state or provincial unit, they may represent other units that are also smaller than a nation. Given that Recovery Units are smaller than the United States of America but often include areas from multiple states, it was reasonable to designate these as S ranks for the purpose of this exercise. For the same comparisons described above, we asked whether any of the scenarios resulted in the MCRU being in a different rank category than the original scenario.

Aggregation Rule Set

We used the same four sets of core area scores discussed earlier (one set of scores for each combination scenario and one set of scores for each division scenario) in an alternative evaluation. For each scenario, we applied a specific rule set (see Chapter 2) to aggregate the Core Area information for the MCRU and determine whether the Recovery Unit would be in a recovered condition. This analysis defined Complex Core Areas as those with > 2 local populations and Simple Core Areas as those with 1 or 2 local populations. In addition, we identified 9 Major Watersheds, defined as the Management Units that were defined in the Draft Recovery Plan (USFWS 2002), in the MCRU. Briefly, for a recovery unit to be in a recovered condition, the rule set required that 1) all Complex Core Areas have a NatureServe score of ≥ 2.5, 2) at least 1 Core Area in each Major Watershed have a NatureServe Score of ≥ 3.5 and 3) at least 50% of the Simple Core Areas have a NatureServe score ≥ 2.5. Using these rules to define recovery, we evaluated the recovered condition of the MCRU under the current core area structure as well as the two combination and two division scenarios.

1.2.3 Results

<u>Simple means</u>

Original Core Areas

As an output of the NatureServe assessment approach for the original core area structure, core area scores ranged from 0.64 in the Asotin Creek Core Area to 3.51 in the NF Clearwater River Core Area. The mean of the high scores was 1.89 ± 0.13 (SE) (Figure 1). The mean of the low scores was 1.73 ± 0.13. The mean of the average scores was 1.81 ± 0.12. All of these scores corresponded to a NatureServe rank of S2.

Minor Combination

As an output of the assessment for a minor lumping, core area scores ranged from 0.64 in the Asotin Creek Core Area to 3.51 in the combined NF Clearwater River Core Area. The mean of the high scores was 1.98 ± 0.14. The mean of the low scores was 1.85 ± 0.13. The mean of the average scores was 1.92 ± 0.14. None of the minor combination scores differed from the original core area scores. All of the scores corresponded to the same NatureServe rank, S2, as the original core areas.

Major Combination

As an output of the assessment for a major lumping, core area scores ranged from 1.47 in the combined Asotin Creek/Tucannon River Core Area to 3.87 in the combined Clearwater River Core Area. The mean of the high scores was 2.54 ± 0.23. The mean of the low scores was 2.35 ± 0.18. The mean of the average scores was 2.45 ± 0.20. All of the major combination scores were a significantly greater than the original core area scores. The high score corresponded to a rank of S3, an increase from the rank of the original core areas. The average score corresponded to a rank of S2S3, also an increase from the rank of the original core areas. The low score corresponded to the same NatureServe rank, S2, as the original core areas.

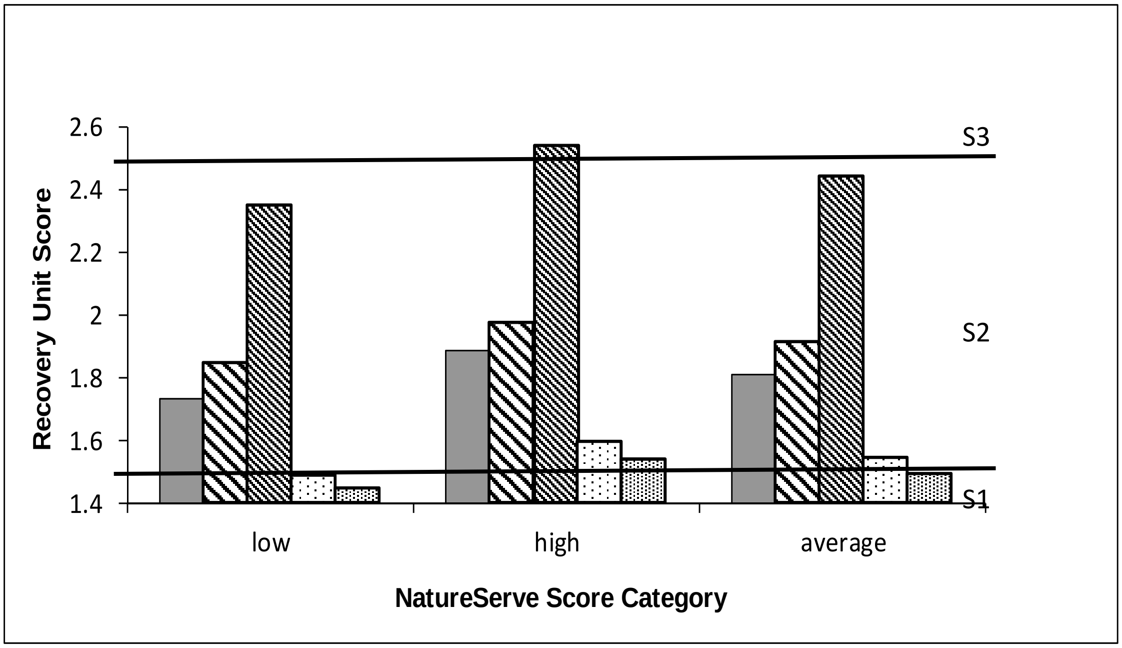

Figure 1. The potential impact to the Mid-Columbia Recovery Unit status assessment from combining or dividing existing core areas. Scores are derived from the NatureServe assessment approach and are relative measures. Recovery Unit scores are the mean of core area scores. The NatureServe assessment approach yields a low and high score category, which was also averaged. S1, S2 and S3 are NatureServe ranks. = original core areas, = minor combination, = major combination, = minor division, = major division.

Minor Division

As an output of the assessment for the minor division, core area scores ranged from 0.26 in a divided Imnaha Core Area to 3.20 in both a divided Yakima and NF Clearwater Core Areas. The mean of the high scores was 1.60 ± 0.09. The mean of the low scores was 1.49 ± 0.10. The mean of the average scores was 1.55 ± 0.09. None of the minor division scores differed from the original core area scores. The low score corresponded to a rank of S1, a decrease from the rank of the original core areas. The average score corresponded to a rank of S1S2, also a decrease from the rank of the original core areas. The high score corresponded to the same NatureServe rank, S2, as the original core areas.

Major Division

As an output of the assessment for a major division, core area scores ranged from 0.00 in divided Powder and Grande Ronde Core Areas to 3.20 in divided Yakima and NF Clearwater Core Areas. The high and average scores differed were significantly less than the original core area scores. The low score did not differ from the original core area scores. All of the major division scores corresponded to a rank of S1, a decrease from the rank of the original core areas.

Aggregation Rule Set

Original Core Areas

Originally there were 26 core areas in the MCRU, 19 (73%) of these were complex and 7 (27%) were simple. In addition, there were 9 major watersheds in the MCRU. Of the 19 Complex Core Areas, 4 (21%) achieved a NatureServe score ≥ 2.5 (Table 4). None of the Major Watersheds contained a Complex Core Area with a NatureServe score ≥ 3.5. Of the 7 Simple Core Areas, 0 (0%) achieved a NatureServe score ≥ 2.5. Using the current Core Area structure, the MCRU did not achieve a recovered condition.

Table 4. The recovered condition (RC) of the Mid Columbia Recovery Unit after applying the aggregation rule set to various core area (CA) scenarios (MiC = minor combination, MaC = major combination, MiD = minor division, MaD = major division). CCA = Complex Core Area. SCA = Simple Core Area. WS = Major Watersheds. %CCA = % of total CCA with a NatureServe (NS) score ≥ 2. 5. %WS = % of WS possessing at least one CCA with a NS score ≥ 3.5. %SCA = % of total SCA with a NS score ≥ 2. 5. N = not in a recovered condition.

CA Scenario	# CCAs	# SCAs	# WS	% CCA	% WS	% SCA	RC
Original	19	7	9	21	0	0.0	N
MiC	18	3	9	17	0	0.0	N
MaC	9	1	9	33	0	0.0	N
MiD	13	40	9	31	0	2.5	N
MaD	30	91	9	57	0	3.0	N

Minor Combination

The minor combination resulted in 21 core areas in the MCRU, 18 (86%) of these were complex and 3 (14%) were simple (Table 4). The 9 major watersheds were unchanged. Of the 18 Complex Core Areas, 3 (17%) achieved a NatureServe score ≥ 2.5. None of the Major Watersheds contained a Complex Core Area with a NatureServe score ≥ 3.5. Of the 3 Simple Core Areas, 0 (0%) achieved a NatureServe score ≥ 2.5. Using the current core area structure, the MCRU did not achieve a recovered condition. In general, the minor combination of core areas resulted in the MCRU being perhaps slightly further from a recovered condition than the current combination.

Major Combination

The major combination resulted in 10 core areas in the MCRU, 9 (90%) of these were complex and 1 (10%) was simple (Table 4). The 9 major watersheds were unchanged. Of the 9 Complex Core Areas, 3 (33%) achieved a NatureServe score ≥ 2.5. None of the Major Watersheds contained a Complex Core Area with a NatureServe score ≥ 3.5. Of the 1 Simple Core Area, 0 (0%) achieved a NatureServe score ≥ 2.5. Using the current core area structure, the MCRU did not achieve a recovered condition. In general, the major combination of core areas resulted in the MCRU being somewhat closer to a recovered condition than the current combination.

Minor Division

The minor division resulted in 53 core areas in the MCRU, 13 (25%) of these were complex and 40 (75%) were simple (Table 4). The 9 major watersheds were unchanged. Of the 13 Complex Core Areas, 4 (31%) achieved a NatureServe score ≥ 2.5. None of the Major Watersheds contained a Complex Core Area with a NatureServe score ≥ 3.5. Of the 40 Simple Core Areas, 1 (2.5%) achieved a NatureServe score ≥ 2.5. Using the current core area structure, the MCRU did not achieve a recovered condition. In general, the minor division of core areas resulted in the MCRU being closer to a recovered condition than the current combination.

Major Division

The major division resulted in 121 core areas in the MCRU, 30 (25%) of these were complex and 91 (75%) were simple (Table 4). The 9 major watersheds were unchanged. Of the 30 Complex Core Areas, 17 (57%) achieved a NatureServe score ≥ 2.5. None of the Major Watersheds contained a Complex Core Area with a NatureServe score ≥ 3.5. Of the 91 Simple Core Areas, 3 (3.0%) achieved a NatureServe score ≥ 2.5. Using the current core area structure, the MCRU did not achieve a recovered condition. In general, the major division of core areas resulted in the MCRU being closer to a recovered condition than the current combination.

1.2.4 Discussion

Core area delineation can have a significant impact on recovery unit status assessments. This was evidenced from changes in both recovery unit scores and ranks that resulted from a major combination as well as major and minor divisions of core areas. Further evidence was suggested by the evaluation of aggregation rules, which tended to be more favorable in divided core area scenarios. This finding emphasizes the value of delineating core areas properly. Current recovery planning efforts are focused on identifying core area targets for recovery. Bull trout recovery will largely be evaluated at the level of the core area. Core area status is likely to be the primary input into recovery unit evaluations through, for example, the NatureServe assessment approach. Ideally, core areas should be defined to accurately reflect metapopulation structure, a measure of how bull trout are structured biologically (USFWS 2002).

Dividing or combining core areas (an increase or decrease the number of core areas in a recovery unit) can influence the overall recovery unit score. Changes to recovery unit scores were evident in both the major combination and major division of core areas. Combining relatively small core areas into relatively large core areas increased the recovery unit score. Conversely, dividing core areas into a relatively large number of small core areas decreased the recovery unit score. In terms of assessing the status of recovery units, this illustrates the potential for a bias from inappropriate combinations or divisions. Given that relatively large combinations tended to increase scores, in regard to recovery planning, this finding also suggests the potential value of connecting populations.

Dividing or combining core areas can also influence the overall recovery unit rank. Combining core areas increased the recovery unit rank whereas dividing core areas decreased the recovery unit rank. Given that scores and ranks derived from the NatureServe assessment approach are related, this was not unexpected. What was somewhat unexpected, however, was that scores could change significantly (see the low score of the major combination) but remain within a rank category. Conversely, scores could remain the same (statistically) but rank could change (see the low score of the minor division). Thus, independent of a change in the score, recovery unit rank can change. NatureServe ranks are designed to be related to an estimate of the risk of elimination (or extinction) (see www.natureserve.org). In general, the ranks range from critically imperiled to secure. Thus, it is important to note that changes in core area delineation can also, potentially, influence an assessment of extinction risk. In this exercise, for example, there were cases where changes in core area structure resulted in the presumed risk of extinction changing from imperiled to vulnerable or to critically imperiled.

As noted previously, combining or dividing core areas had a disparate impact on the recovery unit assessment. Combining core areas improved the recovery unit score. For example, even under the minor combination scenario, the low, high and average scores increased 7%, 5% and 6%, respectively. In contrast, dividing core areas reduced the recovery unit score. For example, in the minor division scenario the low, high and average scores decreased 14%, 15% and 15%, respectively. This pattern was consistent throughout this exercise. When considering the influence of core area delineation, relatively few and large core areas appear likely to result in a relatively good status whereas several and small core areas appear likely to result in a relatively poor status. To produce unbiased assessments of recovery units, this helps to emphasize the need to delineate core areas consistently. For conservation and recovery, this finding also supports the notion that having numerous local populations connected into a relatively large metapopulation helps minimize the risk of extinction.

Ultimately, if and how core area delineation impacts recovery unit status assessments will depend, in part, on how core area information is integrated for a recovery unit. It was noteworthy that recovery unit scores (core area averages) remained similar after minor changes to core areas. Thus, while changes to core area delineation can clearly influence recovery unit scores (core area averages), the changes may need to be relatively substantial. For this exercise, we used an unweighted average of core area scores to generate a recovery unit score. The overall pattern we observed gave some indication that more than a 2-fold increase or decrease in the number of core areas was required to observe a significant change in the recovery unit score. Other techniques or weighting scenarios may have different impacts on recovery unit assessments.

Alternative approaches to integrating core area scores into recovery unit assessments, such as the aggregation rule set, are being considered (see Chapter 2). Under this rule set, the original core area scenario was not in a recovered condition. Furthermore, none of the core area scenarios we investigated achieved a recovered condition. This suggests that the aggregation rule set may not be greatly influenced by or sensitive to how core areas are delineated. In general, at least one Complex Core Area in each watershed achieving a score of at least 3.5 was a significant impediment to the MCRU reaching a recovered condition. None of the core area scenarios resulted in a core area that scored at least 3.5. As expected, combinations of core areas increased the proportion of core areas that were complex. Otherwise, combined scenarios had little or no obvious influence on the assessment of whether the MCRU was in a recovered condition. Also as expected, divisions of core areas increased the proportion of core areas that were simple. Divided scenarios were the only cases where over 50% of the complex core areas yielded a NatureServe score of 2.5 or better. In addition, divided scenarios were the only cases where any simple core areas yielded a NatureServe score of 2.5 or better. Although there was some suggestion that (given existing core area scores) divided scenarios may result in a relatively positive assessment of a Recovery Unit, the MCRU did not reach a recovered condition in any of the scenarios. In addition, both divided scenarios resulted in only 25% of the core areas in the MCRU being complex. It is unclear whether such a reduction in the proportion of complex core areas may make it relatively difficult to ultimately achieve a recovered condition under the aggregated rule set.

These exercises help to illustrate that changes to core area delineation can influence recovery unit status assessments. Whether existing core areas have been accurately delineated or, in some cases, divided or combined excessively is unclear. Accurate and consistent delineation of core areas is the subject of Chapter 1.3. Until a consistent approach is available, it seems prudent to consider the risk associated with improperly delineating core areas. In terms of risk management, it may be more conservative to make the error of dividing one metapopulation into multiple core areas than it is to combine different metapopulations into one core area (see Figure 2).

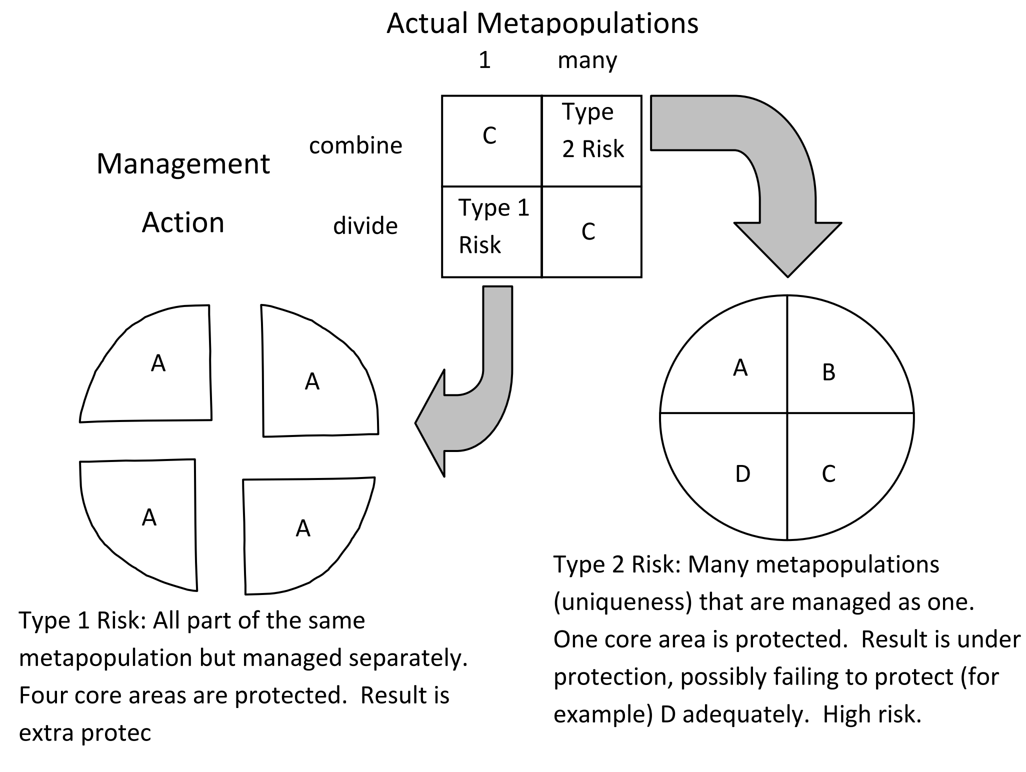

Figure 2. Risk assessment of errors in combining or dividing core areas.

1.2.5 References

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1.3. An Overall Rule Set to Delineate Core Areas

1.3.1 Introduction

The draft recovery plan identified 118 core areas of bull trout (see USFWS 2002). As described in Chapter 1.1, core areas were generally delineated using the best professional judgment of regional biologists and managers. This process was subjective in nature and resulted in a wide range of core area size and number. For example, the Yakima Core Area is approximately 1,587,950 hectares whereas the Isabel Lake Core Area is approximately 515 hectares. Thus, it appears that it may have been easier to delineate some core areas than others, some core areas may have been delineated more accurately than others, and that there was likely some inconsistency between how core areas were delineated. Accurate and consistent core area delineation can influence status assessments (see Chapter 1.2). As such, for recovery planning purposes, there is a need for the development of a method to consistently, and accurately, delineate core areas.

Chapter 1.1 describes how core areas were previously defined in the draft recovery plan (USFWS 2002), criteria that were used in their delineation, and also includes relevant information from the Science Team report (Whitesel et al. 2004). To address the considerations described in the 2002 Draft Recovery Plan and the Science Team report, we provide a general rationale for delineating core areas. The rationale is based on the availability of data and progress through a series of questions. The process that is detailed below essentially asked, "*How should one proceed to define core areas given a map of the range of bull trout*". To address this question, at least in the immediate future, we propose the following seven-step process. In the interest of time, and being able to assist ongoing recovery planning efforts that are on a specific timeline, a general rationale and process are provided below. A more detailed process to delineating core areas is necessary and will be further developed by RMEG. However, at this point, the approach below can be used by the recovery Technical Team (RTT) for considering current core area delineations and assembling information that can be used when criteria are finalized.

1.3.2 Potential Screening Process for Core Area Delineation: Rationale

A bull trout core area is defined as *"The geographical area best approximating the range in which a single local population or group of local populations, with a level of genetic linkage consisting of periodic, occasional dispersal or straying that is sufficient for refounding support and contributing some genetic diversity exists . A core area must contain at least one local population but may contain multiple local populations. A local population is defined as a group of individuals having close demographic and genetic linkage; for example, the adults commonly interbreed, its abundance fluctuates as a unit, and the same forces in space and time influence its persistence. A core area is the combination of core habitat and a core population (one or more local populations) which constitutes the basic unit on which to gauge recovery."* The initial assumption is that all local populations within a recovery unit are genetically independent, function as single, demographic units and each have a unit-specific risk of extinction. The process below can be used to look for evidence to reject any of these claims. If these claims can be rejected, this would provide evidence that certain local populations may be in the same metapopulation and, thus, be part of one core area.

1.3.3 Potential Screening Process for Core Area Delineation: Process

1. *Fundamental units.* Question: Have local populations been delineated?

    Define where the local, spawning populations and suitable habitat (e.g., patches) exist.

2. *Physical connectivity.* Question: Are fish from local populations physically able to move between spawning areas?

    Overlay information that describes groups of populations that are not connected: include man-made and natural barriers, habitat conditions, and distances that likely preclude or substantially reduce connectivity. Describe how connectivity has changed from what it may have been historically. When delineating core areas, it is currently not clear whether and how anthropogenic barriers should be considered. Thus, how anthropogenic barriers are being considered and any associated rationale should be clearly documented.

3. *Behavioral information.* Question: Does behavioral information associated with migration and dispersal exist?

    Is there any information showing that fish from local populations actually do move between spawning areas? Do local populations consist of migratory or resident forms? Overlay movement data including telemetry, tagging and weir observations, and sizes of adults and redds that describe connected populations.

4. *Population dynamics.* Question: Is there evidence for correlated population dynamics?

Is there synchrony in population behavior or, for example, correlated changes in population abundance, demographic parameters, or patterns of persistence?

5. *Genetic structure and gene flow.* Question: Is there genetic data to help inform how populations are grouped, or population structure?

Genetic data are available for some local populations in some core areas that can be used to show genetic relationships among populations and provide information about population structure. Although it appears unlikely that a specific genetic distance can be consistently applied across all recovery units to delineate core areas, existing data can be used to indicate relative genetic distances and differentiation among populations and may suggest appropriate divisions among core areas.

6. *Environmental characteristics.* Question: What are the physical and biological characteristics of the watersheds where the local populations occur?

Since core populations are genetically related, they would be expected to be adapted to similar environmental characteristics.

7. *Core Areas.* Question: What are the most appropriate and consistent CA boundaries?

Look for consistent clustering of populations based on the information above. Describe the core areas defined and the rationale used. Keep specific notes, information, and metadata on how questions 1-6 were answered and how conclusions about core areas were made.

1.3.4 Risk Assessment

It is unlikely that this interim process (or any process) will be 100% accurate. As such, there is some risk associated with making errors in core area delineations. In the absence of data (or areas with relatively little data) or if there is relatively large uncertainty, dividing a given area into relatively more rather than few core areas will likely be less risky. This approach will afford more protection of the population diversity and distribution of the species. However, if local populations that are genetically connected are divided into different core areas, the shared responses of the populations may not be well captured. This can be addressed by clearly describing any uncertainty associated with core area delineations and including recovery actions that address potential connectivity.

1.3.5 References

United States Fish and Wildlife Service (USFWS). 2002. Bull Trout (*Salvelinus confluentus*) Draft Recovery Plan. Portland, Oregon.

Whitesel, T.A. and 7 coauthors. 2004. Bull Trout Recovery Planning: A review of the science associated with population structure and size. Science Team Report # 2004-01, U.S. Fish and Wildlife Service, Regional Office, Portland, Oregon, USA.

1.4. An Evaluation of Specifically Problematic Core Areas

1.4.1 Introduction

As outlined in Chapter 1.1, core areas were defined as part of the Draft Recovery Plan (USFWS 2002). These core areas are being reviewed as part of the current recovery planning process and RMEG has been asked by the USFWS Recovery Technical Team (RTT) to evaluate several problematic core areas (referred to as fuzzy core areas) and several core areas where changes were being proposed. Specifically, RMEG was asked to: 1) evaluate the process proposed by the RTT to assess these fuzzy core areas, and 2) review the fuzzy core areas and proposed changes to these core areas in light of this process and the guidelines proposed in Chapter 1.3. The goal is consistency in delineating core areas across the range of bull trout and clear documentation of how the process was carried out.

1.4.2 Review of the RTT Process

One alternative approach proposed by the RTT (Fredenberg, personal communication, Table 1) involves a series of screens that include a consideration of physical (e.g. barriers), behavioral (e.g. migration) and genetic (e.g. gene flow) information. The screening process starts by assuming the entire DPS is one core area. One then looks for evidence to reject that notion, which would warrant breaking the DPS up into multiple core areas. For example, physical information can allow the determination of whether the fish could be structured as one core area or split into more than one core area (i.e. are migration corridors present). The screening process then continues through the various data inputs, dividing the core areas based on the answers to the series of questions. Core areas are thus determined through this iterative process of refinement.

In general, it was difficult for RMEG to evaluate the consistency of the application of the screening process outlined above and provided in Table 5. The RMEG review concluded that proposed changes reflected inconsistencies in the core area delineations, in core area and population definitions, and in what data were used (e.g., genetic) and how they were interpreted. As a result, some of the core area designations appear rather arbitrary. Specific comments are provided below (Table 5).

Table 5. Potential screens for core area determination (from Fredenberg, personal communication).

Draft Recovery Plan (2002) definition of core area: *"The combination of core habitat and a core population constituting the basic unit on which to gauge recovery. A core area represents the closest approximation of a biologically functioning unit for bull trout."*

1) Barriers

   a. Is immigration from upstream core areas possible? Likely?

   b. Is immigration from downstream core areas possible? Likely?

   c. Is emigration to upstream core areas possible? Likely?

   d. Is emigration to downstream core areas possible? Likely?

   e. Are there temporary or seasonal passage barriers immediately upstream (e.g., thermal, dewatered reaches, etc.)?

   f. Are there temporary or seasonal passage barriers immediately downstream (e.g., thermal, dewatered reaches, etc.)?

   Summation: If answers to most of the questions in 1a-1d (above) are NO then the habitat is likely sufficiently isolated that the patch probably qualifies as a core area; so long as patch size is adequate, both SR and FMO habitat is present and elements (PCEs) are there for long-term sustainability.

2) Genetics

   a. Is there a genetic baseline for this prospective core area?

   b. Is it comprehensive enough to adequately represent the diversity in the prospective core area?

   c. If yes to both, does that genetic data support a core area designation?

3) Life History

a. What is the primary bull trout life history form (adfluvial, fluvial, amphidromous, resident)? Is there a secondary form present?

b. Are there telemetry data, tagging movement studies, weir counts or other data establishing what the routine movement patterns of bull trout are in this core area? (Note: 1 or 2 cases of vagrancy may not represent a common strategy).

c. Are adequate amounts of both FMO & SR habitat included in the prospective core area for migratory fish?

d. Is the prospective core area artificially delineated (e.g., a major dam bisecting a formerly contiguous patch)? If so, assess the likelihood of adjacent core areas being rejoined within the life of the Recovery Plan (e.g., 25 years).

Summation: Consider the needs and varying life history strategies of the dominant migratory life history form in making a core area determination. Known movement patterns should support the determination. In cases where the near-term goal is to rejoin adjacent habitat patches (e.g., fish ladder) that were naturally joined, core area determination should support the Recovery Plan desired condition.

4) Common Sense

a. Apply a general rule of thumb: "Lump core areas unless splitting is justified by elements of this assessment." The reason for this approach is that bull trout are fundamentally migratory and the error of splitting patches into multiple core areas (when they should not have been) presents greater risk to the fish than the error of lumping core areas that should not be joined. With future refinement through best available science further dissection of large core areas can be more easily accommodated in the Recovery Planning framework than joining of disconnected core areas.

The RMEG review of the process identified three key questions about delineation of core areas.

1. Should core areas reflect historic ("natural"), current, or future potential structure and connectivity? Examples include anthropogenic changes, such as dams that

pose barriers to connectivity, and core areas that represent collections of small, isolated, resident populations. To what degree should core areas be purely biological vs. a management-oriented unit for recovery?

2. How should core areas be determined where there is little information on the structure and connectivity of the populations? The default in the absence of data appears to be to grouping populations into one core area (see (2.) general guidance from the St. Mary-Belly plan given in Chapter 1.1). In some cases this may be inconsistent with the recovery plan objective of maintaining diversity.
3. Do core areas include both spawning/juvenile rearing habitat (SR) and foraging, migrating, overwintering habitat (FMO)? If so, some core areas would overlap where different core populations share the same FMO (see (3.) general guidance from the St. Mary-Belly plan a given in Chapter 1.1). If not, this would appear to be inconsistent with the definitions of core area and habitat in the recovery plan introduction.

1.4.3 Review of Proposed Core Area Changes

Generally

The information provided by Koch (personal communication) pointed out a number of inconsistencies among the core area delineations, information used, questions regarding core area and population definitions, and in some cases the arbitrary appearance of how they were identified. Several of these entries indicate uncertainty about what the genetic data are and mean and suggest that there was no consistency in whether or how they were used. For example, Deschutes was originally identified as one core area despite substantial genetic difference between bull trout from the Metolius and Warm Springs/Shitike. Overall, the discussion about the Deschutes Core Area confirmed the need for an objective, systematic method or rule set for identifying core areas or populations that supports recovery plan objectives and conservation of the species.

Specifically

Willamette. The Middle Fork population was reestablished from McKenzie fish, not Metolius River fish. It is being proposed that Clackamas be reestablished from Metolius River fish. The Middle Fork and Clackamas prompt the question of how to deal with unnatural barriers and reintroductions in terms of core areas. Keeping the McKenzie River and Middle Fork Willamette River as one core area implies there will likely be gene flow and demographic linkage between the two populations, despite a long history of isolation due to dams. Presumably the goal is to link populations in a core area that are affected by shared stressors, are genetically connected, and therefore may share a connected response to recovery actions. As such, it seems reasonable to weight current connections heavily (especially if this information is to be used for recovery planning). If connectivity or circumstances change in the future, these can be considered in the next review. However, this also requires considering the tradeoff between i) a shared response under current conditions and ii) what is necessary or most helpful for recovery. In other words, it may be that the McKenzie and Middle Fork Willamette rivers as two core areas is appropriate with regard to how they will respond to actions but may be inappropriate with regard to how bull trout from these areas need to be connected so they can recover and persist (through a shared response).

John Day and Grande Ronde. The recommendation for the John Day River was to keep it as three core areas to be consistent with other core areas, while the Grande Ronde River remains as one. No rationale was given for keeping the Grande Ronde River as one. The multiple core areas in the John Day River seemed a somewhat different treatment than in other core areas (e.g. Grande Ronde River), however, this likely reflected differences in the amount of data. Specifically, the Grande Ronde River seemed like a decision based on lack of data. This may be the only solution in the Grande Ronde, since any other decision would be unsupported. If new data are available to suggest division they should be included.

Little Minam. It was proposed to include this with Grande Ronde Core Area. Relative to maintaining diversity and only combining populations that are connected, this may be inconsistent. It would help to know what information suggests that bull trout from the Little Minam move downstream and mix with the rest of the core area. Given the possibility that a barrier falls exists, at most there would likely be one-way gene flow (downstream). There is nothing to suggest the persistence of the Little Minam population is in any way linked to the rest of the Grand Ronde except for geographic proximity with Minam population(s). Also, there are genetic data for the Little Minam (see Spruell et al. 2003) that should be considered.

Hells Canyon-Powder. It appears that the default is to combine groups (areas) in the absence of compelling information to the contrary. This may not be consistent with the recovery plan objective of maintaining diversity. The Powder appears to be a collection of small, isolated resident populations that, as is, would not meet the definition of a metapopulation. It does not appear likely that there is physical connectivity, gene flow, demographic linkage, or migratory forms present. Although limited data may be available for the Powder, some genetic data is available for Pine, Powder, and Indian (ID) (see Spruell et al. 2003) and should be considered.

Clearwater. Well documented habitat type differences seem like a reasonable case for dividing this core area.

Klamath. The proposal was to delineate two core areas. For comparison, there was reference to other, combined areas that were defined as one core area. These areas appear to be, at least in part, defined as one core area due to lack of data. In comparison, the John Day (with multiple core areas) appears to be relatively data rich. Presumably, in the face of no data, it would be hard to justify how to split the Klamath core area.

Lower Columbia River Basins – Coastal. No changes were proposed at this time. Potential changes were pending the likely addition of new data. This approach seemed reasonable.

Clark Fork - Lake MacDonald. The proposal was to drop Lake McDonald as an independent core area and consider it off-channel habitat for Flathead lake core area. If the populations are connected to link their recovery and the habitat is considered in recovery planning, this appeared reasonable.

***Clark Fork - Lower Clark Fork*. ** Fish passage improvements at lower Clark Fork dams have increasingly reconnected core areas that were fragmented and originally designated as separate only because of these manmade obstacles. Based on the scientific evidence, a logical outgrowth of the 2002 Recovery Plan is to reconsolidate the Lower Clark Fork Core into Lake Pend Oreille. However, it was uncertain if the passage work has reconnected these populations sufficiently, so that without continued transport, the populations are still isolated. Recently, it has been demonstrated that 27% of the parentage of juveniles in two surveyed tributaries was due to transported fish.

Sophie Lake. Proposed elimination as a core area due to paucity of extant bull trout in U.S. waters. This may be consistent, but if the habitat is still necessary for the bull trout in the core area, it should be discussed in recovery planning.

Belly River. Proposed elimination as a core area due to paucity of extant bull trout in U.S. waters. This may be consistent, but if the habitat is still necessary for the bull trout in the core area, it should be discussed in recovery planning.

Core areas v. FMO. The draft recovery plan defined core area as "the combination of core habitat (*i.e.*, habitat that could supply all elements for the long term security of bull trout) and a core population" and core habitat as "habitat that encompasses spawning and rearing habitat (resident populations), with the addition of foraging, migrating, and overwintering habitat if the population includes migratory fish." Based on those definitions, it seems that FMO would be an essential part of the core areas, not a separate classification. In addition, some of the rationale suggests that core areas should be discrete (not overlap). In some cases FMO habitat of independent populations or metapopulations may overlap, particularly in larger main stem reaches, such as the Columbia and its tributaries. This leads to a possible conflict. The spawning areas within different core areas should be discrete. Perhaps these areas are the target of the non-overlap rationale (and FMO overlap is acceptable). If this is the case it should clearly be stated that multiple core areas could include overlapping FMO habitat, but spawning areas of different core areas should not overlap.

1.4.4 Review of Fuzzy Core Areas

Generally

The following review of fuzzy core areas is based on the information provided by Koch (personal communication) and a screening process described by Fredenberg (personal communication). The RMEG was asked to provide an evaluation of consistency, as well as for general utility. The analyses of various RTT members applying the screening process varied from fairly formal to fairly informal. Some of these analyses included discussion with relatively large amounts of supporting data whereas , others analyses had discussion with a relatively limited amounts of supporting data. In addition, some discussion was fairly quantifiable, other discussion was not quantifiable. Therefore, it wasn't possible to provide a detailed review on each of the outputs.

Specifically

Kootenai River downstream of Libby Dam and Hungry Horse Reservoir upstream of Hungry Horse Dam: The question was whether they are one or two core areas. The conclusion was that these are two core areas. This appeared to require factoring artificial barriers, and more importantly, how they impact fish behavior, into the equation as permanent and natural parts of the landscape. This led to various questions. While it seemed clear the barrier is there and not going away any time soon, is it equally as clear that the fish can persist given the dam? Should fish be moved above and below? For consistency of logic, what if the dam were so high or low in the system that very few fish existed in a very small area on one side of the dam (and thus, were unlikely to be able to persist)?

Bitterroot River: The question was whether this is its own core area or part of another? The conclusion was that this is its own core area. This case seemed to be informed by genetic data, suggesting an independent core area. The conclusion also seemed to be based on a potential, seasonal thermal barrier. This begged the question of how much weight should be put on these types of barriers (which should be explicitly discussed and documented). Using the Walla Walla as an example, the previous belief was that bull trout from the upper South Fork were isolated from using the mainstem Columbia River because of summer thermal issues. However, Anglin et al. (personal communication) discovered that these fish make it out to the Columbia River, especially in the winter, and that subadult migrations may be very significant.

Malheur: The question was whether the Malheur should be split into two core areas, NF Malheur Core Area and Upper Malheur mainstem Core Area, or kept as one core area? Some of the barrier information was focused on connectivity to other core areas not between these two areas. Genetic data supports delineation of two core areas.

Grande Ronde: The question was whether the Grande Ronde should remain as one core area or should the Wenaha and/or Wallowa be split out as separate core areas? Thus is related to the Little Minam Core Area question, as the Little Minam is within Grande Ronde subbasin. A possible proposal was to take the one (relatively large) core area that exists now and divide it into three core areas. This begs the question of why three core areas rather than four (Catherine Creek), five (Lookingglass Creek), or six (Indian Creek) core areas? Based on the responses to the questions in the screening process, it appeared that the conclusion was this should be one core area. The specific conclusion should be clarified.

Deschutes: The question was whether, given new trap and haul over the Pelton–Round Butte dams, it is appropriate to keep the Deschutes River basin as one core area. This begs the question of whether there any reason to separate Shitike and Warm Springs as a separate core areas. Genetic data do not provide strong support for delineation of multiple core areas, however, Shitike and Warm Springs are genetically different from Metolius.

Klickitat: It was not clear what question was being asked. We presumed the question was whether the Klickitat is it its own core area. If not, we assume it has to be part of some core area, presumably the White Salmon, Lewis River, Hood River, Deschutes River. A summary score from the screening process was not apparent. However, based on the responses to the questions in the process, it appeared that the conclusion was this is likely its own CA. The specific conclusion should be clarified.

1.4.5 Proposed Core Area Changes

The RMEG review concluded that proposed changes reflected inconsistencies in the core area delineations, in core area and population definitions, and in what data were used (e.g., genetic) and how they were interpreted. As a result, some of the core area designations appear rather arbitrary.

Some of the key questions identified include:

1. Should core areas reflect historical ("natural"), current, or future potential structure and connectivity? Examples include anthropogenic changes, such as dams that pose barriers to connectivity, and core areas that represent collections of small, isolated, resident populations. To what degree should core areas be purely biological vs. a management unit for recovery?

2. How should core areas be determined where there is little information on the structure and connectivity of the populations? The default in the absence of data appears to be to group populations in a core area (see (2.) general guidance from the St. Mary-Belly plan above). In some cases this may be inconsistent with the recovery plan objective of maintaining diversity.

3. Do core areas include both spawning/juvenile rearing habitat and foraging, migrating, overwintering habitat (FMO)? If so, some core areas would overlap where different core populations share the same FMO (see (3.) general guidance from the St. Mary-Belly plan above). If not, this would appear to be inconsistent with the definitions of core area and habitat in the recovery plan introduction.

1.4.6 References

Spruell, P, A.R. Hemmingsen, P.J. Howell, N. Kanda, and F.W. Allendorf. 2003. Conservation genetics of bull trout: geographic distribution of variation at microsatellite loci. Conservation Genetics 4: 17-29.

United States Fish and Wildlife Service (USFWS). 2002. Bull Trout (*Salvelinus confluentus*) Draft Recovery Plan. Portland, Oregon.

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Chapter 2: Aggregation of Core Area Assessments to Recovery Units

2.1 Background

The U.S. Fish and Wildlife (Service) is in the process of developing a recovery plan for bull trout. The goal of the Service's recovery plan is to remove threats and ensure sufficient distribution and abundance to recover bull trout throughout their range in the coterminous United States. In order to assess progress of recovery the Service will be identifying criteria in the new recovery plan. Recovery criteria are measurable and objective targets by which progress towards achievement of recovery can be measured. Recovery planning guidance (NMFS and USFWS 2010) recommends that recovery criteria be SMART: Specific, Measurable, Achievable, Realistic, and Time-referenced. It is recommended that recovery criteria be based in sound scientific rationale and reflect the biodiversity principles of resiliency, redundancy, and representation.

- *Resiliency involves ensuring that each population is sufficiently large to withstand stochastic events.*
- *Redundancy involves ensuring a sufficient number of populations to provide a margin of safety for the species to withstand catastrophic events*
- *Representation involves conserving the breadth of the genetic makeup of the species to conserve its adaptive capabilities.*

These recovery principles take into account the threats and physical or biological needs of bull trout throughout its range and focus on the range-wide recovery needs. This approach to developing recovery criteria should ensure adequate conservation of genetic diversity, life history features, and broad geographical representation of bull trout populations. There are a number of approaches being explored to achieve these recovery criteria principles that rely on threats- and demographics-based criteria to determine the relative risk of each core area, and ultimately, the Recovery Unit as a whole. In addition, using a simple, coarse, categorical viability scoring systems such as NatureServe is being explored. NatureServe integrates information from both threats-based and demographic criteria in a single systematic framework, and represents the conservation status of a core area (i.e., the risk of extirpation of bull trout in the core area) in a format that is consistent across recovery units. The NatureServe core area rank scores can then be assessed across a Recovery Unit to inform recovery criteria.

The Service worked with State, Federal and Tribal agency biologists to update bull trout status information for each of the 118 core areas identified in the 5 year review process (now 121 core areas). This updated information is documented in the Service's core area template documents for the demographic and threats information for each core area. From these data the Service and partners developed a relative ranking of risk for bull trout core areas range-wide using criteria in the updated NatureServe status assessment tool (NatureServe 2009). Each core area rank score can be compared to other core areas to gain an understanding of the relative risk of that core area. The scores for all bull trout core areas range from 0.26-3.62, which correspond to the status rank of severely imperiled to apparently secure.

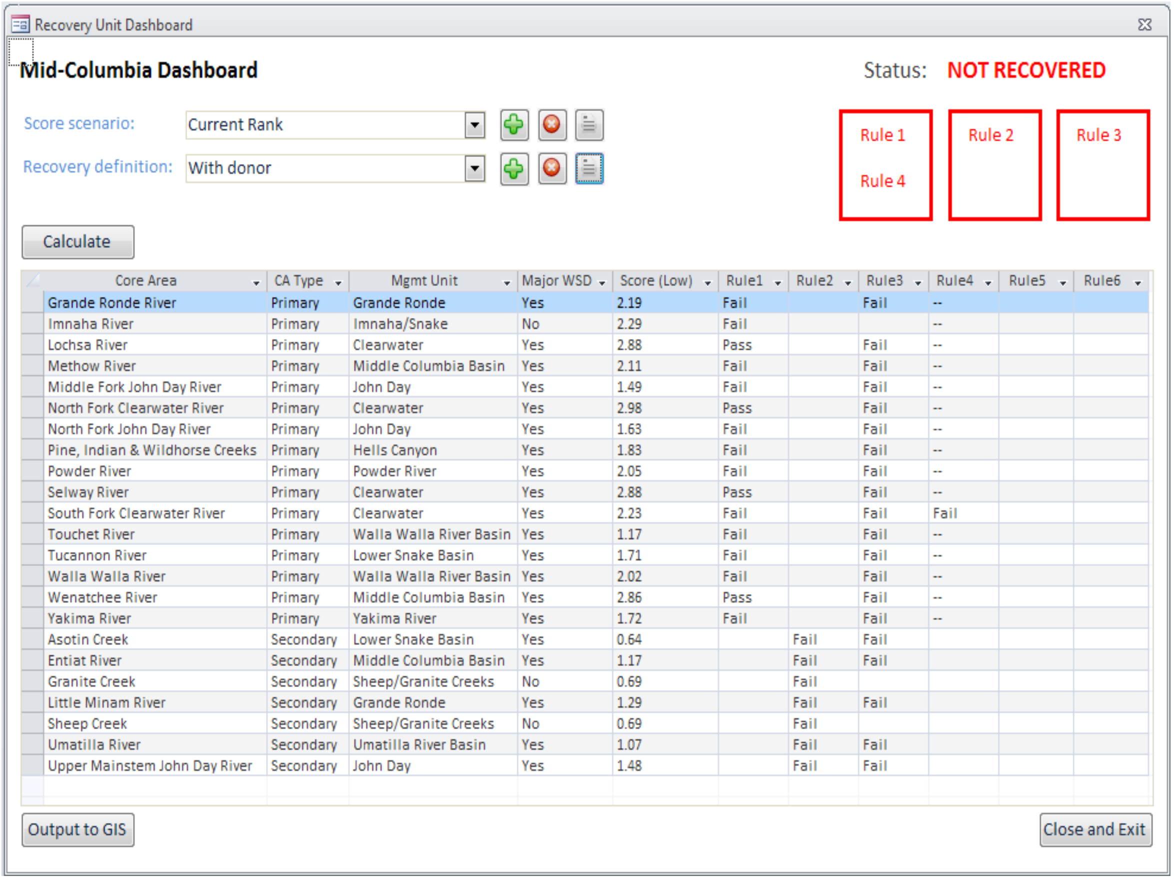
The Task 2 work group has focused our activities on how to aggregate Core Area (CA) assessments to inform status for the Recovery Unit (RU). More specifically, we are evaluating the robustness of the aggregation approaches through sensitivity analyses. We intend to evaluate a variety of rules for aggregating NatureServe scores (or component scores) from the CA level to an overall RU under a range of different scenarios. We have identified four important items to consider in the aggregation rules:

- *Score for each of the 4 attributes for a CA*
- *Spatial arrangement of CAs (e.g., connectivity)*
- *Size of CAs*
- *Uncertainty in demographic and threat data used to score the CAs*

2.2 Evaluation Tool

The work group is developing a simple form-driven tool to explore recovery unit status by evaluating alternative NatureServe score scenarios against alternative definitions of recovery. The gaming tool is being developed with a Microsoft Access backend.

The main screen of the application, the Recovery Unit Dashboard, allows a user to define score scenarios and recovery definitions as well as evaluate the recovery relative status of present score scenarios with the various recovery definitions (Figure 3).



Core Area	CA Type	Mgmt Unit	Major WSD	Score (Low)	Rule1	Rule2	Rule3	Rule4	Rule5	Rule6
Grande Ronde River	Primary	Grande Ronde	Yes	2.19	Fail		Fail	--		
Imnaha River	Primary	Imnaha/Snake	No	2.29	Fail			--		
Lochsa River	Primary	Clearwater	Yes	2.88	Pass		Fail	--		
Methow River	Primary	Middle Columbia Basin	Yes	2.11	Fail		Fail	--		
Middle Fork John Day River	Primary	John Day	Yes	1.49	Fail		Fail	--		
North Fork Clearwater River	Primary	Clearwater	Yes	2.98	Pass		Fail	--		
North Fork John Day River	Primary	John Day	Yes	1.63	Fail		Fail	--		
Pine, Indian & Wildhorse Creeks	Primary	Hells Canyon	Yes	1.83	Fail		Fail	--		
Powder River	Primary	Powder River	Yes	2.05	Fail		Fail	--		
Selway River	Primary	Clearwater	Yes	2.88	Pass		Fail	--		
South Fork Clearwater River	Primary	Clearwater	Yes	2.23	Fail		Fail	Fail		
Touchet River	Primary	Walla Walla River Basin	Yes	1.17	Fail		Fail	--		
Tucannon River	Primary	Lower Snake Basin	Yes	1.71	Fail		Fail	--		
Walla Walla River	Primary	Walla Walla River Basin	Yes	2.02	Fail		Fail	--		
Wenatchee River	Primary	Middle Columbia Basin	Yes	2.86	Pass		Fail	--		
Yakima River	Primary	Yakima River	Yes	1.72	Fail		Fail	--		
Asotin Creek	Secondary	Lower Snake Basin	Yes	0.64		Fail	Fail			
Entiat River	Secondary	Middle Columbia Basin	Yes	1.17		Fail	Fail			
Granite Creek	Secondary	Sheep/Granite Creeks	No	0.69		Fail				
Little Minam River	Secondary	Grande Ronde	Yes	1.29		Fail	Fail			
Sheep Creek	Secondary	Sheep/Granite Creeks	No	0.69		Fail				
Umatilla River	Secondary	Umatilla River Basin	Yes	1.07		Fail	Fail			
Upper Mainstem John Day River	Secondary	John Day	Yes	1.48		Fail	Fail			

Figure 3. Recovery Unit Dashboard – the main screen of the gaming application.

*Note that primary/secondary designations for CA types in this dashboard example are synonymous with simple/complex CA designations described in report text.

General workflow:

1. Fill in NatureServe spreadsheet for a specific scenario of interest (e.g., if all CAs had complete, high precision data vs. highly uncertain data (in some cases expert opinion);
2. Add the final calculated NatureServe rank scores as a score scenario in the gaming tool;
3. Define the rules for aggregating the core area scores to the recovery unit level by adding a recovery definition in the gaming tool;
4. Compare how well aggregation rules represent the collective status of the core areas for a RU under different definitions of recovery or recovery scenarios;
5. Output the gaming tool results to GIS to produce a map to visualize the distribution of the observed CA status across the entire RU;

Adding score scenarios

Users can add a new score scenario, delete or review existing scenarios (Figure 4). Core area names and scores (low) from the NatureServe Excel tool are copied and pasted into the Score Scenario form. Optionally, a note can be recorded to describe a core area's particular score.

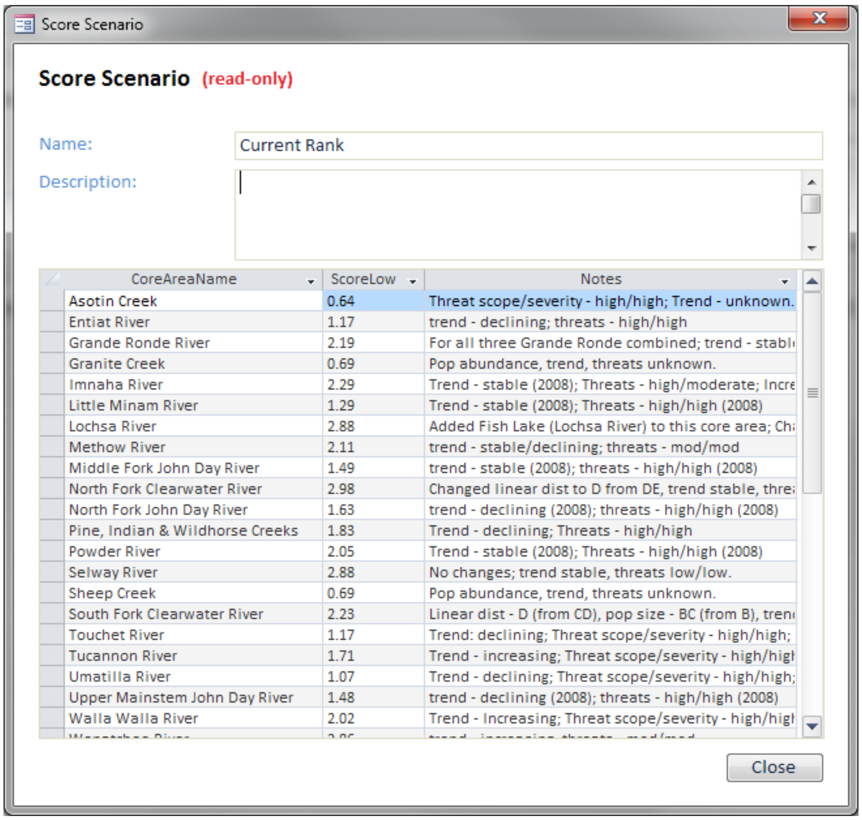


Figure 4. Review an existing score scenario.

Adding recovery definitions

Similarly, users can add a new recovery definition, delete or review existing recovery definitions (Figure 5). In the gaming tool's current implementation, a recovery definition is made up of one or more rules out of a total of 6 rules. The first 3 rules relate to a recovery definition independent of a donor rescue effect. A donor rescue effect is when a neighboring core area(s) are within close proximity of the source population so as to capture the potential of fish dispersing and spawning in that core area. To define recovery where donor rescue is enabled, the user turns on one or more of rules #4-6.

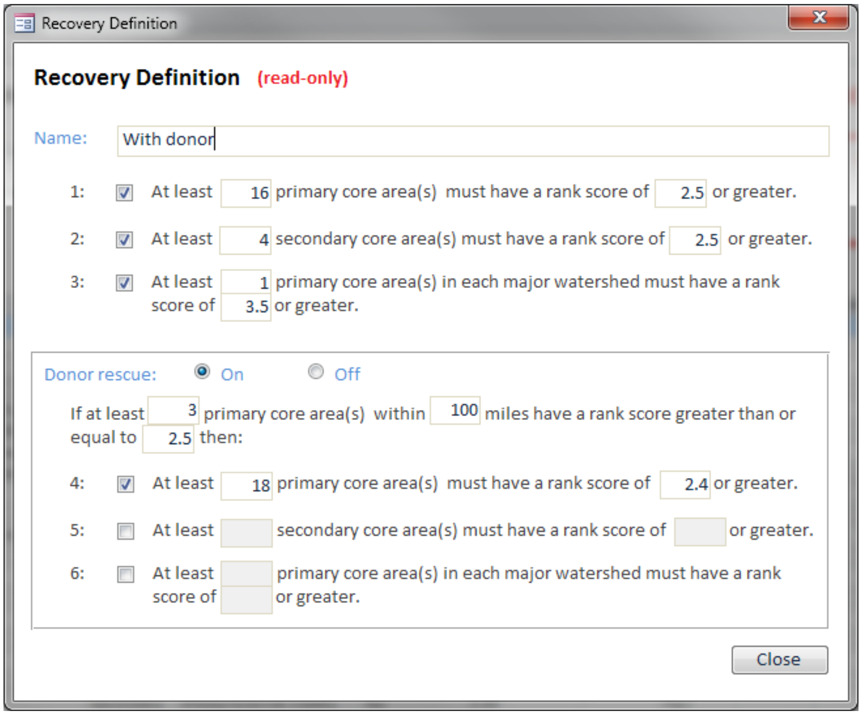


Figure 5. Review an existing recovery definition. *Note that primary/secondary designations for core areas in this example are synonymous with simple/complex CA designations described in report text.

Exploring model results at the CA level

Once a score scenario and a recovery definition have been added, the user clicks the ‘Calculate’ button to run the model and evaluate the NatureServe scores against the recovery definition rules. The results appear in the data grid on the recovery unit dashboard. Each row displays the individual rule results for a core area as well as some descriptive attributes for the core area to aid in the interpretation of the results. For example, Rule 1 applies only to simple core areas thus the Rule 1 cell will be blank for a complex core area. In regards to the donor rescue effect rules (#4-6), a core area can receive a result of either “Pass”, “Fail”, “- -“, or blank. Blank, again, means that the rule does not apply to the particular core area. A result of “- -“indicates that the rescue effect conditions were not met for the core area, thus the rule was not evaluated on the core area. For example, the rescue effect condition may have been defined as “at least 3 simple core areas within 100 miles have a rank score greater or equal to 2.5”. A core area with a result of “- -“ does not meet this condition.

Exploring model results at the RU level

In addition to exploring the performance of individual core areas against the various rules, the top right corner of the dashboard displays the overall result for the recovery unit via a status label (either “recovered” or “not recovered”) and 3 coloured boxes. One rule within each box must be green in order for the recovery unit to receive a “recovered” status. The colour of the box is determined by aggregating the results of the core units. For example, if rule 1 was defined as “at least 16 simple core areas must have a rank score of 2.5 or greater”, the Rule 1 label and first box will show green if the results grid contains 16 simple core areas that show “Pass” under the Rule 1 column. In the Figure 3 example, only 4 core areas have a score of 2.5 or greater and pass Rule 1. Thus, at the recovery unit level, Rule 1 is not met.

Exploring model results spatially

To aid in the spatial visualization of results, the button to ‘Output to GIS’ will create a table of the results grid which can be joined to a core area shapefile or feature class in ArcGIS. The user may then symbolize and explore the map as desired. An example of a map which can be produced from the gaming tool output, Figure 6 presents the current NatureServe ‘status quo’ scores for CAs in each RU.

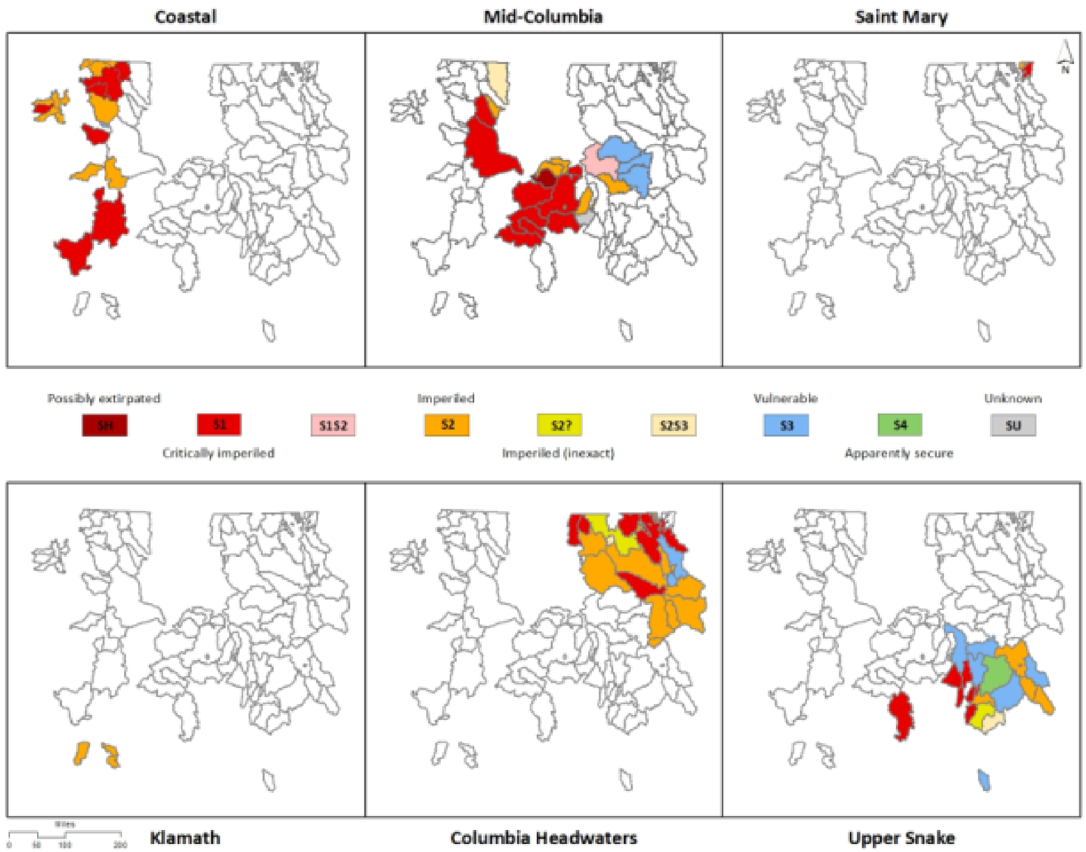


Figure 6. NatureServe current score for Core Areas (CAs) in each bull trout Recovery Unit (RU).

Future development

The next steps in developing the tool are to incorporate uncertainty scoring for existing threats and uncertainty scoring for the effectiveness of removing or altering those threats (e.g. some may get inherently worse in the future; climate change). The goal is for the tool to inform decisions of which core areas and what threats to remove, in order to approach the various recovery scenarios. Other options for tool development include the enhancement of the GIS component to automate the export of results and creation of results maps. Additionally, the gaming tool could be enhanced to allow direct manipulation of NatureServe scores. For example, the threats for a core area could be reduced and reflected in the NatureServe score. The user could then dynamically explore changing the threats to see what combination may meet or approach recovery criteria or explore the spatial arrangement of core area scores by changing specific categories of threats.

2.3 Uncertainty Scoring Mechanism

It is important to have an easy-to-understand approach to incorporate uncertainty into status assessments based on demographic and threat based information to inform recovery management decisions for bull trout. This exercise to incorporate uncertainty into status assessments is important for any of the approaches being explored to inform recovery criteria; demographics based, threats based, or using rank scores from a systematic framework like NatureServe that integrates demographic and threats information. The objective of this task is to provide guidance on how to score the uncertainty of assessments based on the input data. We have begun to assemble some of these uncertainty elements together and are developing simple scoring approaches for capturing relative uncertainty.

Uncertainty in Abundance and Trends in Abundance

Simple ratings (Table 6) for the relative quality of collected bull trout abundance data have been developed based on RMEG's assessment of sampling protocols (RMEG 2008) and approaches for scoring monitoring coverage suggested in CSMEP's Data Quality Guide (Marmorek et al. 2007).

Table 6. RMEG sampling data quality and coverage ratings for monitoring of bull trout abundance and trend in abundance (Quality Ratings: 5 = excellent, 4 = very good, 3 = good, 2 = fair, 1 = poor). Overall quality of the monitoring data available for a bull trout population will be a direct combination of the two ratings (i.e. Sampling Data Quality Rating + Monitoring Coverage Rating)

I) Sampling Protocol:

Bull Trout Lifestage	Sampling Technique	Biases	Sampling Design	Sampling Data Quality Rating
Migratory & resident adults	Trap counts – weir	▪ Positive bias for larger, migratory fish ▪ Negative bias for small, likely resident fish	Trap site	4
Migratory & resident adults	Mark-recapture	▪ Precision is sensitive to low capture and recapture rates	Trap/recapture/resight site or reach	4
Migratory and resident adults	Redd counts	▪ Positive bias for larger, migratory fish ▪ Negative bias for small, likely resident fish	Index Sites	2
			Probabilistic	3
			Census	4
Migratory and resident adults	Snorkel counts	▪ Strong and variable negative bias (depending on stream habitat conditions) ▪ Precision is sensitive to fish densities and spatial variability in distribution	Index Sites	2
			Probabilistic	3
			Census	4
Juveniles & resident adults	Electrofishing counts (depletion estimate)	▪ Possible negative bias	Index Sites	2
			Probabilistic	3
Juveniles & resident adults	Electrofishing counts (single pass removal)	▪ Strong and variable negative bias	Index Sites	1
			Probabilistic	2

II) Monitoring Coverage (coverage will be project specific):

Coverage	Coverage Rating
< 40% of target population	1
40 – 60% of target population	2
60 - 75% of target population	3
75 - 90% of target population	4
> 90% of target population	5

Uncertainty in Threats Assessment

How does uncertainty affect our understanding of the likely future status of a Core Area if we simply “remove” threats in threats based assessment approach or the NatureServe approach for evaluating recovery criteria? We attempted to capture two types of uncertainty:

A) Certainty that if the threat is present it is influential
B) Cumulative certainty that if the threat is removed, status will improve

Core area assessment templates, that populate the NatureServe approach or would inform a threats based criteria approach, include the following categories of “threats”:

- *Passage*
- *Dewatering and flow management*
- *Stream and floodplain degradation*
- *Water quality*
- *Harvest*
- *Disease*
- *Predation*
- *Climate Change*

Steps for threats uncertainty classification:

a) Reviewing the Service's core area template threat information we assigned each threat category with a score of high, medium, or low based on core area team ranking or systematic evaluation of the written descriptions of threats in the template.

b) Reassigned text categories of high (1), medium (0.5), low (0.25) threat status to numerical scores, to create a numerical weighting score.

c) For each threat category, using Walla Walla and John Day Core Areas as examples, assign a certainty score (between 1-0) that the threat category is influential.

For example, for the threat "Passage" (threat score of 0.5 or medium from the template assignment) we assumed that the threat is 100% influential. There is a preponderance of evidence that if bull trout attempt to migrate downstream and use the lower Walla Walla and Columbia during the late spring through early fall there are serious energetic or mortality consequences.

Therefore, the adjusted certainty score for the passage threat is:
A = 0.5*1.0 = 0.5

d) Next assumption was that if the barriers were removed, we were 75% sure the status would improve, because, we know there are other passage related limiting factors that would remain, and perhaps some new ones would arise. So the cumulative uncertainty score becomes:
B = 0.5* 0.75 = 0.4

e) We apply the uncertainty adjustments (A alone) to the "raw" individual threat score. The uncertainty adjusted scores are then summed across all the threat categories in the core area, and standardized to the overall threat scope and severity scores for the core area (scaled to the max possible sum of threats). An example of the results for threat score is as follows: score for the MF JDA is1.03 without adjusting for uncertainty, and the MF JDA score adjusted for uncertainty is 2.8 (Figure 7). This is a 32% reduction in the maximum threat score of the core area when accounting for the uncertainty that if the threats are present they are influential (A). The highest possible core area threat score is 0 and 5.5 if no threats were present in a core area.

f) Then we apply the same approach using the cumulative (A&B) uncertainty adjustments, which accounts for the individual threat influence and that if that threat was removed the status would improve. We accomplish this by summing the cumulative (A&B) uncertainty adjusted scores across all the threats, and standardizing the overall threat scope and severity scores for the core area (scaled to the max possible sum of threats). An example of the results for cumulative threat score is as follows: the score for the MF JDA is 1.03 without adjusting for uncertainty, the MF JDA score adjusted for uncertainty is 2.81, and the cumulative score (assuming threats are removed with uncertainty) for the MF JDA is 3.85. Another way to look at the effect of uncertainty is if we removed all threats for the MF JDA with complete certainty the overall threat score would be 5.5, when we account for the cumulative uncertainty the overall threat score is 3.85 which is 30% less than the maximum possible threat reduction (Figure 8).

The preliminary results for characterizing uncertainty of threats appear to be representative and robust across core areas (Figure 7). The approach for incorporating the effect of uncertainty on assumptions for threat removal follows a transparent approach and can be easily applied across the core areas (Figure 7, and Figure 8). The reduction in assumed effectiveness, when accounting for uncertainty in threats, from 18 to 37% and averaged nearly 30% for the core areas of the mid-Columbia recovery unit.

The issue of addressing uncertainty for demographic and threats based information used in core area and recovery unit status assessment is important. This will apply to the various recovery criteria development approaches, whether they use demographic or threats based approaches or a systematic framework that provides categorical viability scoring such as NatureServe. The issue of directly addressing uncertainty for this information is critical for guiding recovery actions, and learning which recovery measures are effective.

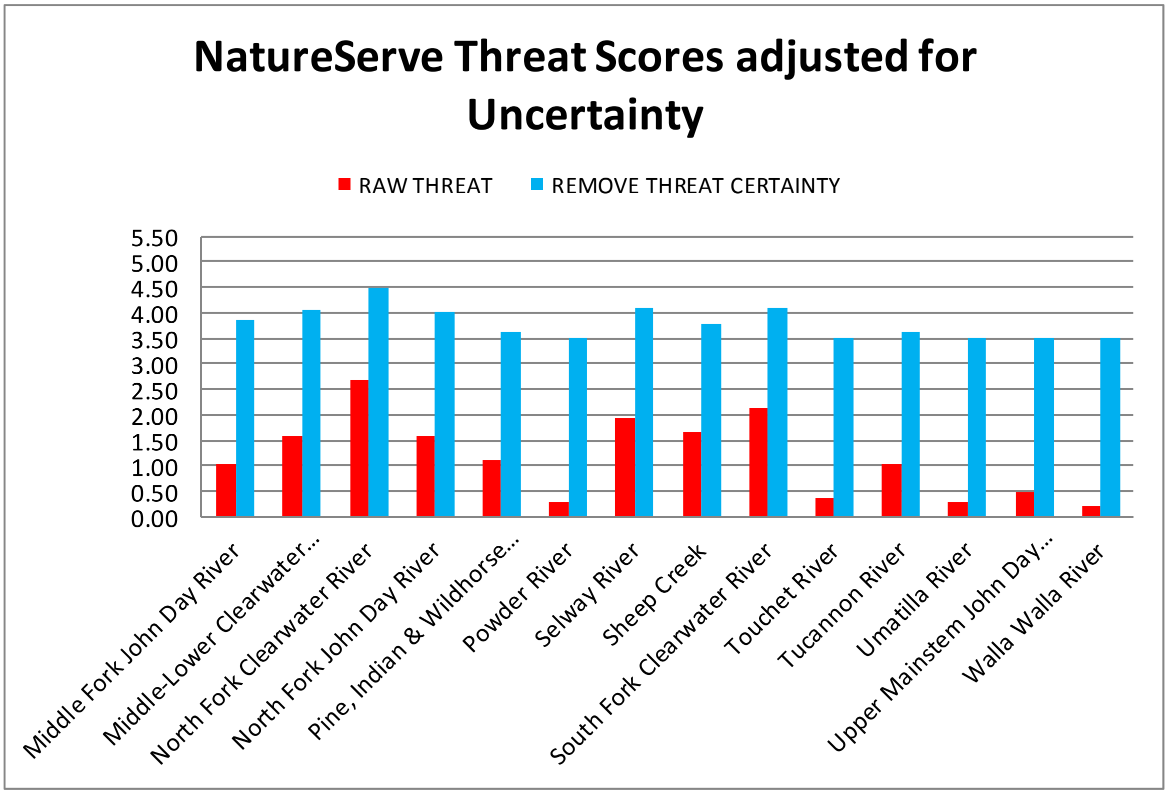


Figure 7. Contrasting threats for a core area assuming; all threats have equal certainty (raw score -red); and removing threats and adjusting the scores for the uncertainty by each category of threat and effectiveness of removal (blue).

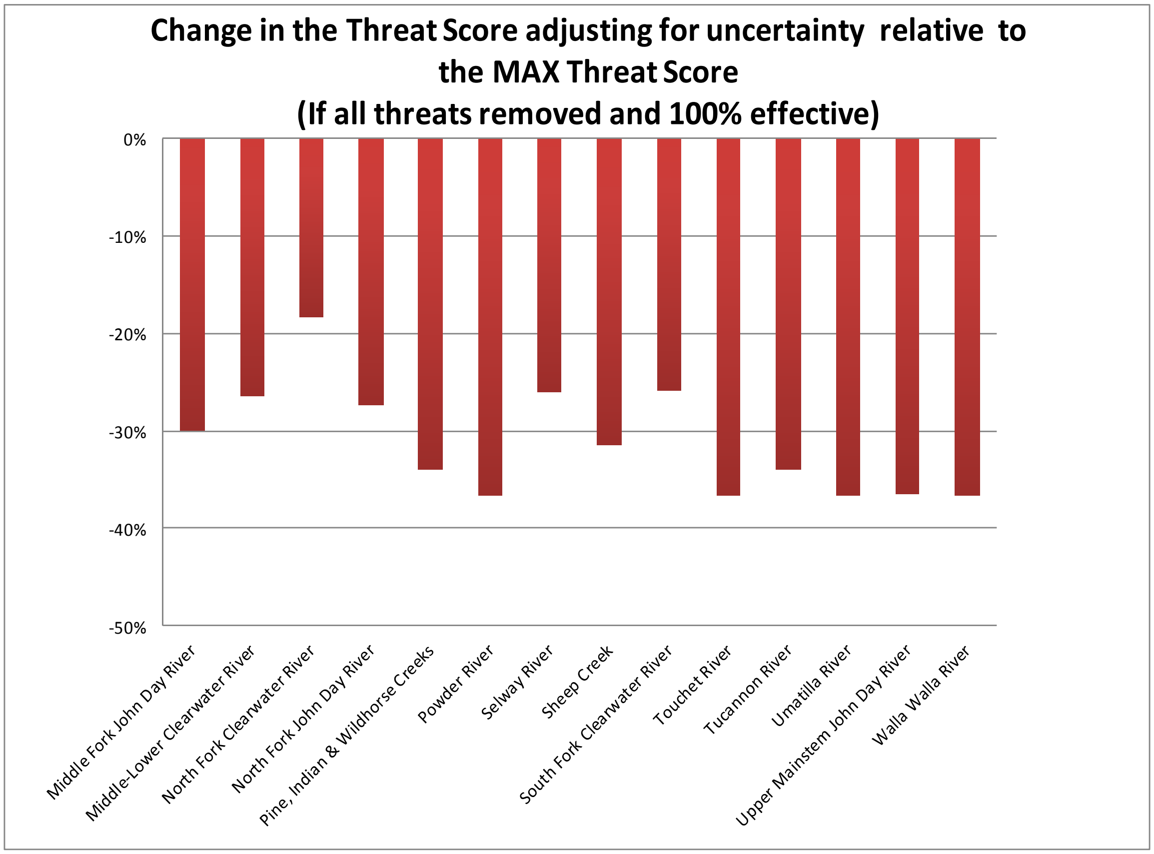


Figure 8. Contrasting the relative change in NatureServe rank scores incorporating uncertainty that if threats are removed there will be a response, from the maximum score that assumes 100% effectiveness of threat removal.

We have developed a method to link the threat uncertainty adjustments into the NatureServe rank calculations for risk of extirpation at the CA level. The approach adjusts NatureServe rank scores for the uncertainty scoring for existing threats and uncertainty scoring for the ability to remove or change those threats. The results of this work are summarized and discussed in a sensitivity analysis for Walla Walla and Touchet Core Areas in Task 3 PVA modeling (RMEG chapter 3 - Budy et al.). An example of applying the uncertainty adjustments to threats in the Walla Walla Core Area is illustrated by the following: the current CA assessment NatureServe status rank score is 1.92; rank score changes to 2.74 when changing all threats to low with absolute certainty; and the score reverts to 2.44 when we adjust the threats for the cumulative components of uncertainty. The confidence in this pattern of changing scores occurs because in this data-rich CA, we have abundant empirical data describing both the biological and habitat of the population as well as the certainty of the threats and the effectiveness of removal. In a different CA for which we have poorer data and understanding of threats we wanted to gain a better understanding of how robust the NatureServe rank system behaves. In RMEG chapter 3 we were able to biologically evaluate changes to NatureServe scores based on simulated -feasible changes in demographic rates using the PVA model for data intensive core areas. We were able to assess the sensitivity of the NatureServe scoring system to a range of inputs. These results suggest that the NatureServe scoring system is relatively robust to changes in the relative risk for core area populations with regards to threat removal. These robust results from data-rich areas are encouraging for broadly assessing the relative risk to bull trout core area populations (with less intensive data) using the NatureServe categorical viability scoring systems.

This approach will be integrated into the gaming tool to evaluate, what combination of core areas and their threat removals could be implemented to approach the various recovery scenarios, and to evaluate the spatial arrangement of core area scores when removing categories of threats for Recovery Units.

2.4 Alternative Recovery Unit Score Scenarios

A score scenario is defined by a completed set of NatureServe rank scores (Faber-Langendoen et al. 2009) for all CAs in the RU. The simple tool will allow decision makers to consider a range of potential scenarios. It will be helpful to perhaps start with very simple scenarios with obvious contrasts. These will be easier to interpret and provide useful starting bounds on the problem. Four considerations have been identified (See Section 1) as important to the overall RU status. We are beginning to create scenarios (Table 7) that will specifically test contrasts in these considerations.

Table 7. Description of RU scenarios to be investigated.

Scenario Name	Description	Presumed RU status
Status Quo	Current NatureServe Assessment of all CAs.	Unacceptable
Size_1	Scenario where most CAs are healthy except for a low (?)% (say 5?) of relatively **large** CAs.	Unacceptable
Size_2	Scenario where most CAs are healthy except for a low (?) %l (say 5?) of relatively **small** CAs.	Acceptable
Spatial_1	Scenario where large (?)% CAs are healthy except for a handful of CAs scattered among the RU (i.e., spread out spatially)	Acceptable
Spatial_2	Scenario where large (?%) CAs are healthy except	Unacceptable

	for a handful of CAs all located close together in the RU (i.e., a clump of unhealthy CAs)	
Uncertainty_1	Scenario where large (?)% CAs are healthy and we have 'high quality' information for all of them	Acceptable
Uncertainty_2	Scenario where large (?)%CAs are healthy but we have 'poor quality' information for all of them	Unacceptable

The ultimate task will be to evaluate what combination of observed data for the CAs will result in a change in rolled up NatureServe score for the RU. This will help in understanding the relative risk to the RU, based on the spatial arrangement of CAs and their individual NatureServe risk scores. This approach will be guided by sound scientific rationale and reflect the biodiversity principles of resiliency, redundancy, and representation. Therefore, the evaluation of aggregation approaches will provide information to help in better determining the status of an RU. If all CAs are doing very poorly, any aggregation rule should capture this at the RU level. It will be more important to determine how different aggregation rules perform for scenarios that approach the boundaries between unhealthy and healthy, based on the biodiversity principles.

2.5 Alternative Rules for Defining Recovery

The detail of a basic recovery definition, which captures the possible spatial arrangement of NatureServe core area scores, is identified in Table 8. The purpose of providing this example basic recovery definition for the Mid-Columbia Recovery unit is to stress the importance of spatial structure and diversity for the persistence of a population unit (see ICTRT 2007 for further discussion) such as a Recovery Unit. These reflect the biodiversity principles of resiliency, redundancy, and representation. This recovery definition will allow for evaluation of summary statistics for NatureServe scores across a RU, when spatial structure of the CA is an important element for recovery. In this exercise we differentiated between simple and complex core areas, the details for the core area designation are contained in Table 9. At the core area level, rank scores correspond to risk of extirpation, as described in Table 10. For this exercise, rank scores were converted to S ranks to reflect extirpation risk. Using NatureServe terminology, S ranks are described as subnational ranks (units smaller than a nation, such as Canada or the United States of America). Although S ranks often represent a state or provincial unit, they may represent other units that are also smaller than a nation. Given that Recovery Units are smaller than the United States of

America but often include areas from multiple states, it was reasonable to designate these as S ranks for the purpose of this exercise.

Table 8. Example of basic recovery scenario for the Mid-Columbia Recovery Unit.

MID COLUMBIA RECOVERY UNIT			
NatureServe Status Score	Applicable Core Areas	Current Completion Status	Needed to Meet Criteria
NatureServe Status Criteria 1. Bull trout populations have a calculated rank score which range is 2.5 or greater in each of the 18 primary core areas (core areas that support multiple local populations of bull trout>2 local pops.) and core area calculated rank score which range is 3.5 or greater in at least one primary core area in each major watershed (i.e Clearwater,Grande Ronde,Hells Canyon, John Day,Lower Snake, Middle Columbia,Powder,Umatilla, walla Walla, Yakima). Criterion should be compatible with sustainable viability of one or more core areas in each major watershed for at least 25 years??	1 Lochsa, 2 North Fork Clearwater River,3 Selway River, 4 South Fork Clearwater River, 5 Grande Ronde River, 6 Pine, Indian & Wildhorse Creeks, 7 Imnaha River, 8 Middle Fork John Day River, 9 North Fork John Day River, 10 Upper Mainstem John Day River, 11 Tucannon River, 12 Methow River, 13 Wenatchee River, 14 Powder River, 15 Umatilla River, 16 Touchet River, 17 Walla Walla River, 18 Yakima River	**Meet Targets for each Primary Core Area** (n=4): Lochsa River, North Fork Clearwater River, Selway River, and Yakima River **Failed to meet Targets for each primary core area (n=14):** 4 South Fork Clearwater River, 5 Grande Ronde River, 6 Pine, Indian & Wildhorse Creeks, 7 Imnaha River, 8 Middle Fork John Day River, 9 North Fork John Day River, 10 Upper Mainstem John Day River, 11 Tucannon River, 12 Methow River, 13 Wenatchee River, 14 Powder River, 15 Umatilla River, 16 Touchet River, and 17 Walla Walla River **Meet Targets for a primary core area in each management unit** (n=1): North Fork Clearwater River **Failed to meet Targets for a primary core area in each management unit** (n= 11):	**for each Primary Core Area:** (n= 14): 4 South Fork Clearwater River, 5 Grande Ronde River, 6 Pine, Indian & Wildhorse Creeks, 7 Imnaha River, 8 Middle Fork John Day River, 9 North Fork John Day River, 10 Upper Mainstem John Day River, 11 Tucannon River, 12 Methow River, 13 Wenatchee River, 14 Powder River, 15 Umatilla River, 16 Touchet River, and 17 Walla Walla River **for a primary core area in each management unit (n=11):**
NatureServe Status Score	Applicable Core Areas	Current Completion Status	Needed to Meet Criteria
NatureServe Status Criteria 2. For the 8 Satellite Bull trout populations (2 or less local populations) the calculated NatureServe rank score has a range which is 2.5 or greater (i.e Fish Lake (Lochsa River), Little Minam River, and Sheep Creek) in at least half of the 8 core areas.	Fish Lake (Lochsa River), Fish Lake (North Fork Clearwater River, Middle-Lower Clearwater River, Little Minam River, Asotin Creek, Entiat River, Granite Creek, and Sheep Creek	**Meet Targets: (n=0)** **Failed to meet targets (n=8):** Fish Lake (Lochsa River), Fish Lake (North Fork Clearwater River, Middle-Lower Clearwater River, Little Minam River, Asotin Creek, Entiat River, Granite Creek, and Sheep Creek	**Meet targets for Satelite Populations (n=4) e.g.** Fish Lake (Lochsa River), Little Minam River, Asotin Creek,and Entiat River,

Table 9. Simple and complex core areas contained in the Mid-Columbia RU. Simple core areas contain >2 local populations.

Managemment Unit (Recovery Plan Chapte	Core Area Name	Number of Local Populatior
Clearwater	North Fork Clearwater River	11
Clearwater	Selway River	10
Clearwater	Lochsa River	5
Clearwater	South Fork Clearwater River	5
Clearwater	Middle-Lower Clearwater River	1
Clearwater	Fish Lake (Lochsa River)	1
Clearwater	Fish Lake (North Fork Clearwater River)	1
Grande Ronde	Grande Ronde River	8
Grande Ronde	Little Minam River	1
Hells Canyon	Pine, Indian & Wildhorse Creeks	7
Imnaha / Snake	Imnaha River	4
John Day	Middle Fork John Day River	8
John Day	North Fork John Day River	6
John Day	Upper Mainstem John Day River	5
Lower Snake Basin	Tucannon River	8
Lower Snake Basin	Asotin Creek	2
Middle Columbia Basin	Methow River	8
Middle Columbia Basin	Wenatchee River	6
Middle Columbia Basin	Entiat River	2
Powder River	Powder River	10
Sheep / Granite Creeks	Granite Creek	1
Sheep / Granite Creeks	Sheep Creek	1
Umatilla River Basin	Umatilla River	3
Walla Walla River Basin	Walla Walla River	3
Walla Walla River Basin	Touchet River	3
Yakima River	Yakima River	13

Simple core areas (in yellow)	18
Complex core areas	8
Total	26

Table 10. Using the NatureServe approach at the Core Area level, rank scores and relative risk status.

Calculated Rank Score	Risk Category Number	Risk Status
<= 1.5	S1	critically imperiled
1.5 < calculated value <= 2.5	S2	imperiled
2.5 < calculated value <= 3.5	S3	vulnerable
3.5 < calculated value <= 4.5	S4	apparently secure
Calculated value <= 4.5	S5	secure

To describe the evaluation process for the Mid-Columbia RU example for a basic recovery scenario (described in Table 8) we described in the general steps. The rank score targets of 2.5

and 3.5 are used for illustrative purposes and need to be refined through further sensitivity analysis with the PVA model and biological justification based on biodiversity principles. The steps are as follows:

1. Define which core areas are simple versus complex (including deciding how many local populations determine the difference, in this case simple = 1 to 2 local populations).
2. Determine how many simple and complex core areas need to meet a potential score, and determine what that score should be (in this case, all complex core areas need to achieve a potential score of 2.5, but only half of the simple core areas need to achieve a potential score of 2.5).
3. Determine whether there are other criteria that need to be met, for example, to ensure that strongholds exist across the recovery unit (in this case, we specified that one core area per major watershed (management units as described in the 2002 Draft Bull Trout Recovery Plan) need to achieve a potential score of 3.5).
4. Calculate current NatureServe scores for each core area.
5. Calculate potential NatureServe scores for each core area given reduction of threats (with and without uncertainty) and/or demographic response
6. Define rules for changing/relaxing NatureServe rank score targets based on connectivity criteria to other core areas in the RU.

At the present stage of tool development, the user has the ability to modify the threshold values of individual rules and to enable and disable rules for a given recovery definition. In future development, the tool could be expanded to include alternative rule sets for defining recovery and exploring the impact of threat removal.

2.6 Results

The current core area ranks for the Mid-Columbia Recovery Unit displays a wide range of values, but predominated by an S1 and S2 rank value (Figure 9). The higher risk CAs tends to be clumped on the southern and western side of the Recovery Unit. The lower risk CAs are clumped along the eastern edge of the recovery unit. This clumping pattern of high risk CAs likely occurs because of the high level of threats within the CAs and heavily impeded connectivity among those CAs.

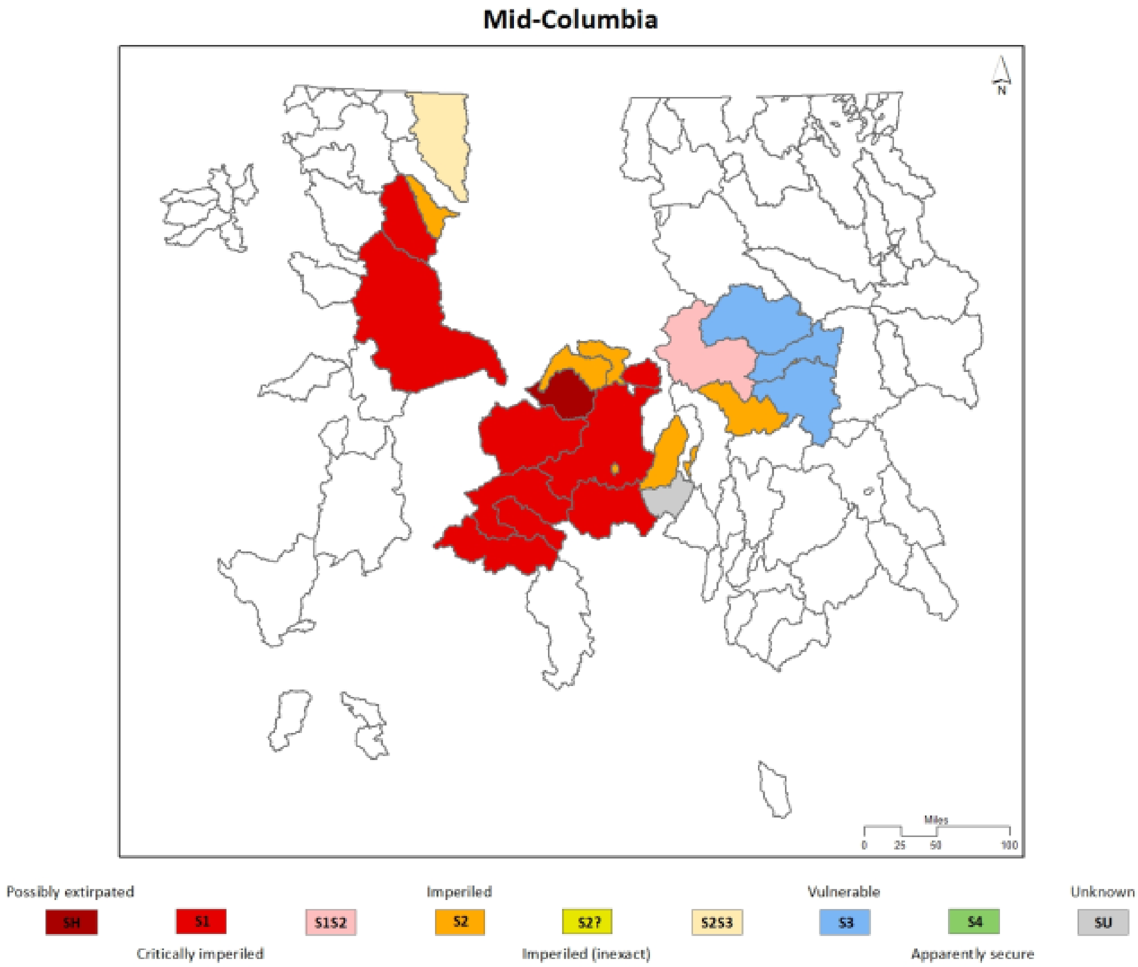


Figure 9. The current core area ranks for the Mid-Columbia recovery Unit.

Using the basic test recovery scenario identified in Table 8 to gauge success, we produced maps that show status quo scores relative to the test recovery scenario (Figure 10). We also evaluated the change in NatureServe ranks for the Mid-Columbia Recovery Unit if the threats were reduced to low or insignificant relative to the criteria in the test recovery scenario (Figure 11). Under the scenario we only evaluated the change in NatureServe scores relative to threat reduction alone, and did not evaluate a corresponding population response. These are alternative explored in sensitivity analyses contained in task 3 (PVA modeling) and task 2.

Mid-Columbia - Scenario 1 (Status Quo)

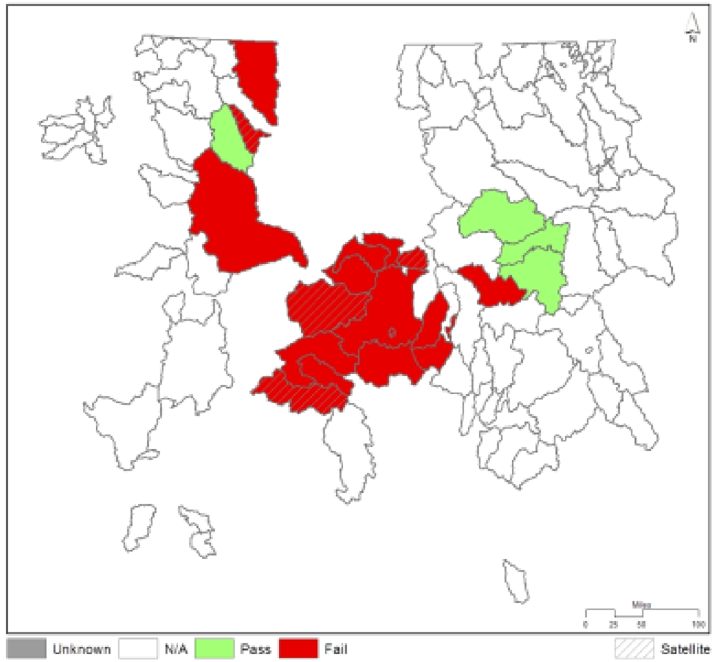


Figure 10. Map of Mid-Columbia recovery unit displaying whether each core area passed or failed the example recovery criteria under status quo conditions.

Mid-Columbia - Scenario 2 (Low/No Threats)

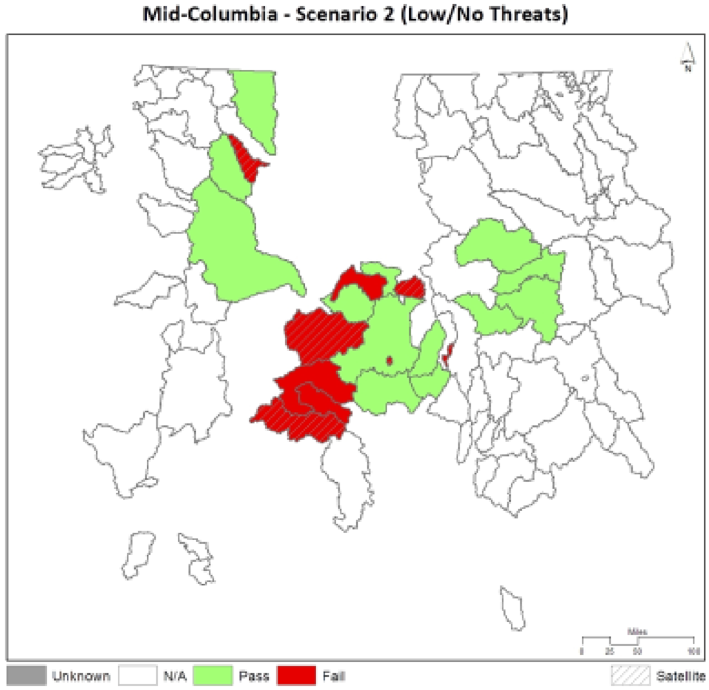


Figure 11. Map of Mid-Columbia recovery unit displaying if each core area passed or failed the example recovery criteria when reducing threats to a low impact level.

In addition, we evaluated the change in NatureServe ranks for the Mid-Columbia Recovery Unit if the threats were reduced to low or insignificant relative to the criteria in the test recovery scenario and if there was a rescue effect from CAs in close proximity (Figure 12).

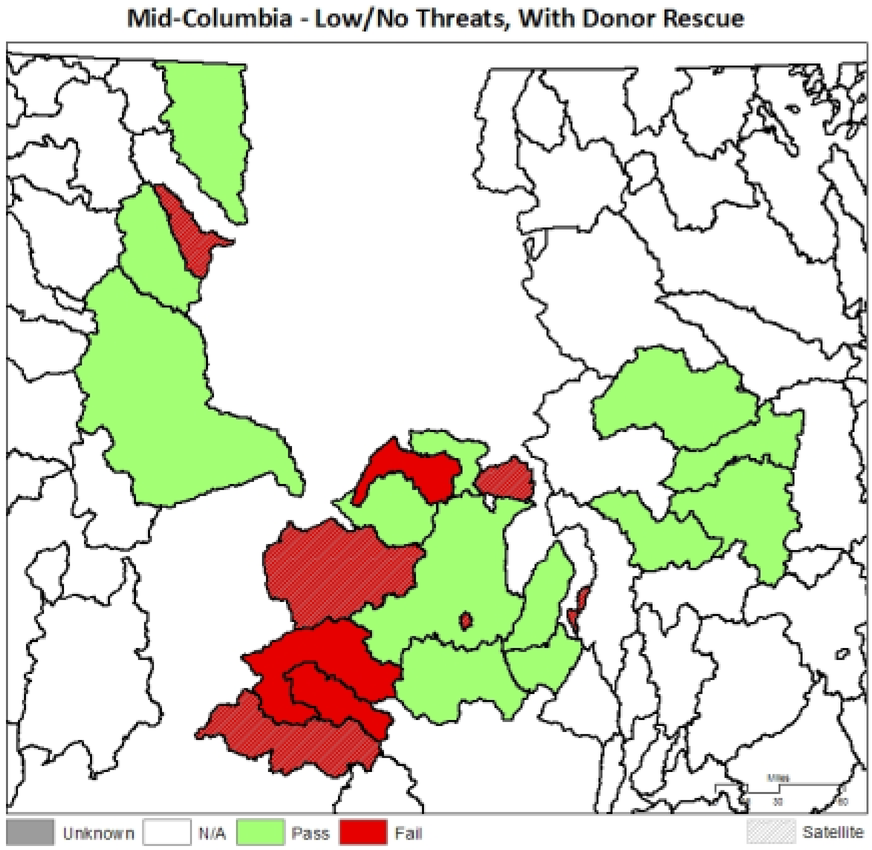


Figure 12. Map of Mid-Columbia recovery unit displaying if each core area passed or failed the example recovery criteria when reducing threats to a low impact level and assuming the potential for a rescue effect from CAs in close proximity.

The next steps are to determine how:

- *Each aggregation rule performs for the different recovery scenarios.*
- *Aggregation rules capture expert-based perceptions of RU 'status' or recovery scenarios.*
- *The strengths/weaknesses of different aggregation approaches (how well do they integrate elements of CA size, connectivity, data uncertainty, spatial arrangement etc.)*

We also plan to incorporate the threat uncertainty scoring approach used in the sensitivity analysis in Task 3 into the gaming tool to provide the ability to evaluate, which core areas and what threats to remove to approach the criteria for the various recovery scenarios.

2.7 Anticipated Products and Dates

Provide guidance on potential CA NatureServe score criteria and the aggregation rules for the RU. The detailed gaming tool for the Mid-Columbia RU should be available soon for scenario exploration and threat removal. Based on the feedback from the recovery Technical Team, we then plan to run these evaluations for the other recovery units.

Acknowledgements

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2.8 References

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Chapter 3: Population viability models for evaluating threats and extinction risks: How do we evaluate threat reduction and the utility of NatureServe?

3.1 Development of population viability models to evaluate the effect of threat reduction at Core Area scales.

3.1.1 Introduction

Population models are important tools for better understanding processes affecting imperiled species. Specifically, stage-based population models allow analysis of an organism's life cycle at specific life stages, and the fate of individuals is described in terms of transition probabilities among these stages (Caswell 2001). Stage-structured analyses allow researchers to evaluate population-level responses to perturbations (e.g., threats) at one or more life stages. In the framework of a population viability analysis, these quantitative methods can be used to identify vital rates and life stages that have the greatest impact on population viability, to evaluate the impact of management decisions on populations, and to assess the vulnerability of populations to extinction (Akcakaya 2004).

Stage-based analyses are well suited for assessing management impacts on bull trout populations because bull trout use different habitats at various life stages, and are therefore vulnerable to different threats throughout their life cycle. As such, understanding the influence of individual life stages on overall population growth rates is critical for making well-informed management decisions (Johnston et al. 2007).

We developed a bull trout population viability model based on stage-specific vital rates and long-term monitoring data. We applied this model to evaluate potential changes to two core areas, both within the Walla Walla Management Unit. These results could be used to compare a robust population viability analysis (PVA), based largely on empirical demographic data to a simple, coarse, categorical viability scoring systems such as NatureServe. We first developed a stage-structured population model for bull trout based on data from a long-term population study of a fluvial bull trout population (e.g., Al-Chokhachy and Budy 2008, Al-Chokhachy et al. 2009). We incorporated habitat variables to predict where spawning was likely to take place within a watershed, and predicted changes to habitat availability based on several different projections of stream temperature change associated with climate change. We used this empirically-based model to evaluate future changes in bull trout abundance and probability of extinction given different population growth rates, and we evaluated how removal of current threats could affect population growth rates and abundance. We compared results from this biologically-based quantitative assessment to previous NatureServe results from range-wide core area assessments (USFWS 2005a and b; and 2008). In addition, we evaluated future changes to bull trout demographic responses from the quantitative population modeling and contrasted these results with NatureServe Scores when current threats were removed in both cases (see chapter 2 for NatureServe approach). The results of our quantitative assessment from data-rich areas should help calibrate NatureServe scores to viability model metrics such as population growth rates and abundance. The calibration findings from our data-intensive areas can be used to gauge categorical NatureServe scores that have been applied across a broad geographic range and can help inform management decisions and recovery planning.

3.1.2 Methods

Primary data sources and study area

Population modeling relies heavily on estimates of vital rates (survival, growth, and fecundity) for the species in question. We used stage-specific estimates of survival based on a population of bull trout located in the South Fork Walla Walla River (SFWW) located in Northeastern Oregon (Figure 13), described in Al-Chokhachy and Budy (2008). We used estimates of fecundity, spawning probability, growth and subadult survival based on this same population (Budy et al. 2011), and compared these demographic rates with available published data (Johnston et al. 2007; Johnston and Post 2009). Estimates of egg-to-fry survival were based on several different studies of bull trout egg survival (Weaver and White 1985; Williamson 2006), including yet unpublished data from field experiments (Bowerman and Budy, in preparation). Data collected from Passive In-stream Antennae (PIA) throughout the watershed also informed other demographic rates where possible (e.g., probability of spawning).

We assessed potential scenarios of population viability for two core areas for which we had reliable redd count and habitat data, both in the Walla Walla Management Unit. The Touchet River Core Area is comprised of three spawning and rearing populations, but we considered it a single, distinct population in our analyses (henceforth Touchet CA). We evaluated two populations within the Walla Walla Core Area: the Mill Creek population (Mill) and the South Fork Walla Walla population (SFWW). We used data from these two populations to help parameterize the population model, and then combined them in a metapopulation framework to evaluate the Walla Walla Core Area (WW CA) as a whole. The WW CA is considered to have a third population but we omitted this from the analysis because almost no data exists for this population. All population models were conducted for both the WW and Touchet Core Areas.

Model formulation and estimation

We constructed a pre-breeding census, stage-based (Lefkovitch) matrix model (Caswell 2001) based on an annual time step. We used empirical estimates of growth, survival, and fecundity from nine years of data from intensive mark-recapture studies on bull trout in the Walla Walla River and tributaries to estimate vital rates for eight distinct size classes (Table 11). The eight-stage matrix model was represented by the following life-cycle diagram:

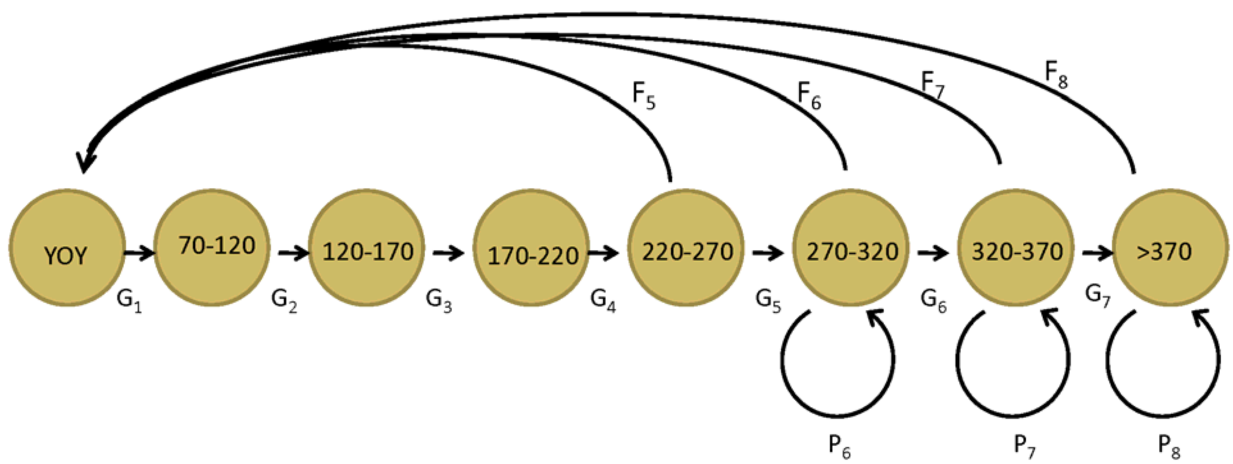

Figure 13. Eight-stage life-cycle diagram for fluvial bull trout based on data from the South Fork Walla Walla River population. Stages are based on total length (mm). *G* = probability of surviving and transitioning into the next size class; *P* = probability of surviving and remaining in the same size class; *F*= fertility, the number of young-of-year fish produced per female in each of the reproductive stage classes.

The first stage was age-based, representing young-of-year (age-0 fish), and the subsequent stages were based on size (Table 11), where each size class was chosen to best represent fish age, based on length-frequency analyses and growth rates (Budy et al. 2011). Fish transitioned from one stage into the next based on an average annual growth rate, determined from fish recaptured in the SFWW (Budy et al. 2011). The probability of a fish moving from one size class to the next (γ) was estimated based on observed changes in lengths of tagged bull trout that were recaptured after one year.

Table 11. Length-based stages for bull trout used in population models.

Stage	Name	Maximum total length (mm)

0	YOY	<70
1	Juvenile 1	70-119
2	Juvenile 2	120-169
3	Subadult 1	170-219
4	Subadult 2*	220-269
5	Adult 1**	270-319
6	Adult 2**	320-369
7	Large adult**	≥370

* Potentially reproductive, but at very low rates; not counted in population estimates.

** Reproductive size stages; rates based on length; counted in population estimates.

All mean annual survival estimates were based on empirical data (Al-Chokhachy and Budy 2008, Budy et al. 2010), with the exception of stage-0 (young-of-year), for which estimates are unavailable. We estimated annual survival for this stage class by back-calculating from the remaining matrix elements. We compared these results with estimates from age-0 survival for other fall-spawning species to ensure that estimates were within an expected range (e.g., Atlantic salmon, Cunjak and Therrien 1998; brown trout, Ombredane et al. 1998). Survival and growth probabilities were represented in the matrices by *Pi* , the probability of surviving and staying in the same size class, and *Gi* the probability of surviving and moving to the next size class such that

$$P_i = \sigma_i(1-\gamma_i) \quad (1)$$

$$G_i = \sigma_i\gamma_i \quad (2)$$

where *σi* is the survival probability and γi is the growth probability of size class i (Caswell 2001). Fertility (Fi) was estimated for mature size classes based on the following equation:

$$F_i = m_i B_i R S_0 \quad (3)$$

where mi indicates the average number of eggs produced by a female of the median length for each size class i, Bi is the probability of spawning for a female in size class i, R is the ratio between sexes, and S_0 stands for the probability of survival between egg deposition and fry emergence. The relationship between total length and fecundity was based on data collected from mature females in the SFWW population (n = 19; Budy et al. 2011). This relationship was best described by:

$$m_i = 0.008(length_i)^{2.0276} \quad (4)$$

where mi is the number of eggs per female for a fish of *median* length (TL, mm) in the size class i. Using both active and passive (PIA) mark-recapture data, we estimated the probability of spawning for each size class based on the proportion of marked bull trout observed making a spawning migration in the SFWW compared to the proportion of marked individuals within the same size class that did not migrate during spawning season. We assumed an equal sex ratio for all reproductively mature fish (i.e., 1:1). Estimates of egg-to-fry survival were based on research conducted in the Metolius River, Oregon (Bowerman et al., in preparation).

Model development and calibration

We first calibrated the matrix by adjusting individual parameter estimates within the range of empirical observations (95% confidence intervals) so that the combined matrix elements resulted in the observed long-term geometric rate of population growth (lambda, λ) for the SFWW population (λ~1; Budy et al. 2011). Second, we evaluated the relative abundance of each size class based on the stable age distribution from the matrix model and compared these values to observed relative abundances from mark-recapture analyses of the SFWW population (Budy at al. 2010). We used this comparison to establish a matrix that generated a population structure comparable to those observed in the study population. Finally, we established an initial population size for each core area based on a redd count data:

$$\text{Initial population size} = 2.2(\text{Number of redds}) \quad (5)$$

where the *Number of redds* is the maximum number of redds counted in an index survey of accessible known spawning habitat within the CA. We considered the maximum redd count a reasonable metric of population size because redd counts can underestimate the number of small resident adult bull trout (Al-Chokhachy et al. 2005). We estimated the number of fish per redd based on adult population counts at weirs in similar systems (Sankovich et al. 2003). We used redd counts to establish baseline population estimates because this was a common metric available for estimating abundance in all three core areas.

We estimated two different rates of population growth (lambda, λ) to use in the population viability analysis. Several different analyses suggest that long-term population trends are stable (e.g., $\lambda \sim 1$) for the SFWW bull trout population (Budy et al. 2011). We used this stable population growth rate for our base case scenarios in the PVA. However, in both the Touchet and WW CAs, redd counts from index reaches have decreased from 2001 to 2010. Based on this observed trend, we estimated a second population growth rate, where $\lambda = 0.9482$ (Figure 14). The synchrony in these patterns may indicate a cyclic pattern in population response to environmental or demographic variables, or all three populations may indeed be declining due to environmental impacts. We incorporated this population trend in our matrix model by decreasing subadult survival rates, based on recent estimates of subadult bull trout survival from Mill Creek (P. Howell, USFS, unpublished data). In the PVA, a scenario in which all three core area populations are declining could be thought of as a "worst case" scenario, and probable population estimates likely fall somewhere between this scenario and the base case.

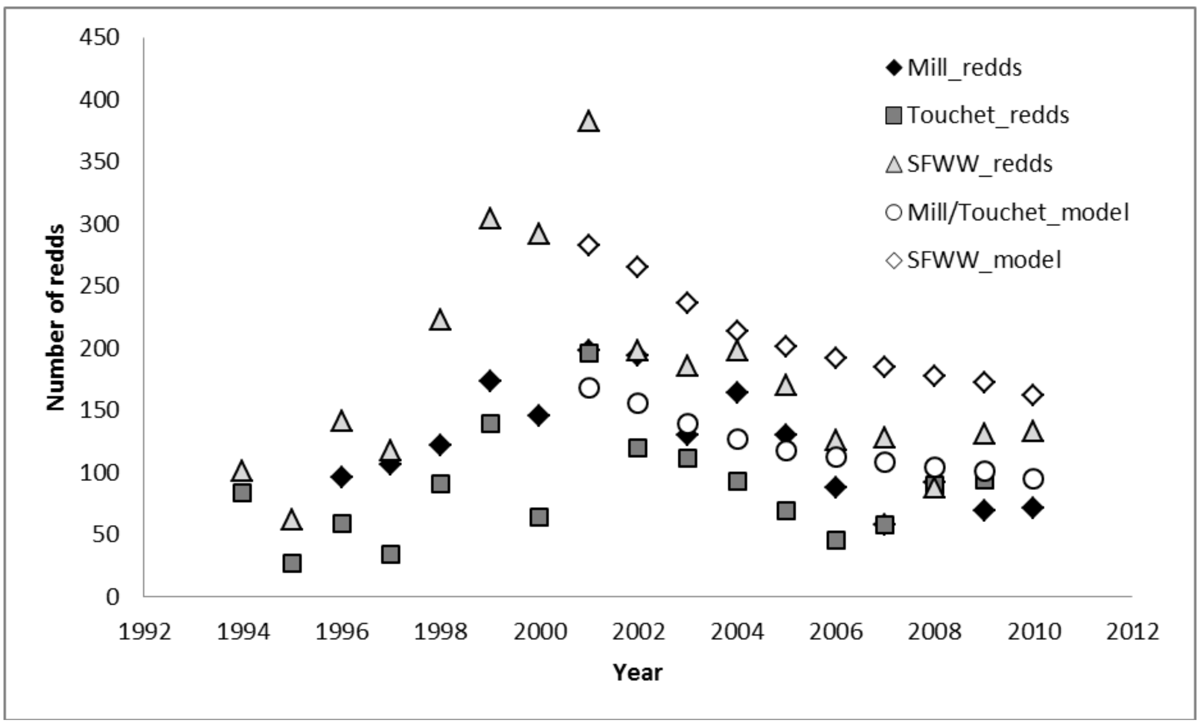

Figure 14. Number of redds based on surveys conducted in index sections for the Mill Creek, Touchet River, and South Fork Walla Walla River (SFWW) populations from 1994 through 2010. Modeled population sizes were estimated based on a declining population growth rate ($\lambda = 0.9482$) based on trends observed in Mill Creek abundance estimates 2001-2010.

Capacity function based on spawning habitat

We established a capacity function to estimate the maximum potential number of redds in each core area based on available habitat. Although density-dependent processes are likely to occur in bull trout populations, most habitats are currently impacted by numerous factors, making it difficult to isolate density-dependent effects. Currently, most habitats are likely well below historic carrying capacities if environmental threats were removed. We therefore developed a rule set to define different categories of spawning habitat based on physical habitat attributes. First, we used data from redd censuses (Mahoney et al. 2011) to designate stream reaches within the Walla Walla Basin in one of four spawning habitat categories based on the average number of redds observed and the type of stream: no spawning, low density mainstem, high density mainstem, and spawning tributaries. Next, we compiled physical habitat characteristics for the entire Walla Walla Basin, including streams used in the redd censuses. Stream reach characteristics were estimated based on 1:24,000 hydrography provided by StreamNet and developed by the local Subbasin Planning team and the Technical Outreach and Assistance Team for use in Mobrand Biometrics' Ecosystem Diagnosis and Treatment (EDT) analysis of 2002-2004 (See http://www.nwcouncil.org/edt/ for more detail). All environmental variables were taken directly from the Stream Reach Editor and applied at the stream reach scale (0.1-8 km length).

We used classification trees in R 2.13.0 (tree package) to analyze the relationship between spawning habitat category and numerous predictive environmental variables, such as channel slope, percent pools, scour, and maximum summer temperature. We used results from this analysis to establish discrete break-points for continuous predictor variables (e.g., elevation) and to define a rule set for each of the spawning habitat categories based on physical habitat measurements available on Streamnet. Next, we calculated the maximum redd density observed in each of the spawning habitat types to predict the maximum number of redds expected in each (Table 12). We applied the rule set to the entire Walla Walla Basin to predict the type of spawning habitat available throughout the basin (Figure 15). Finally, we estimated the maximum number of expected redds (total spawner capacity; K) of each core area based on:

$$K = \sum_{h}^{n}(L_h * D_L) \qquad (6)$$

where *L* indicates the length of stream, *D* is the maximum spawning density, and *h* represents the specific habitat type.

Table 12. Rule sets for defining four categories of spawning habitat. All spawning density data is based on bull trout redd censuses in the Walla Walla Basin, and physical habitat attributes are from the Ecosystem Diagnosis and Treatment (EDT) analysis (Mobrand Biometrics 2004).

Habitat type	Rule set	Mean width (m)	Max Density (redds/km)
No spawning	<700 m elevation		
	Or gradient <0.01725 and >0.0745	0	0
	Or max mean monthly temp >1.95 (rating)		
Low density spawning	Gradient <0.027 and >0.01725	13	6
	And max mean monthly temp <1.95 and >1		
High density spawning	Gradient >=0.027 and <0.0745	9	64
	And min (low flow) width >4.5 m		
Spawning tributary	Gradient >0.04 and <0.0745	1.5	19
	And min (low flow) width <4.5 m and >0 m		

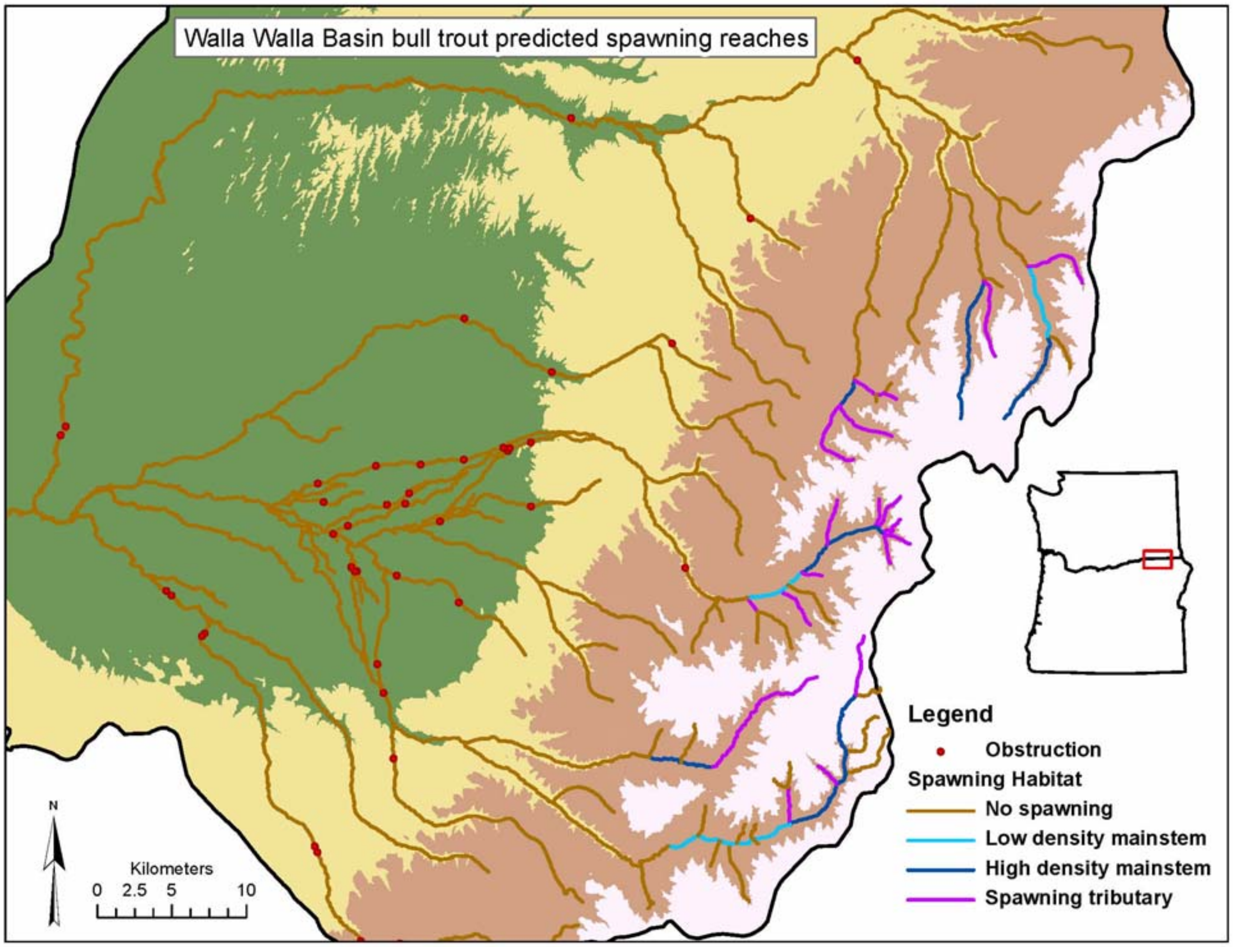

Figure 15. Predicted spatial extent and category of bull trout spawning habitat within the Walla Walla Basin Management Unit. Four categories of habitat are predicted based on habitat variables described in Table 12.

The rule set defining suitable spawning habitat correctly predicted spawning habitat in several tributaries to Mill Creek and the South Fork Touchet River where bull trout spawning has been observed but were not included in the initial modeling process. The rule set also predicted spawning habitat in the North Fork Walla Walla River, where bull trout redds may have been observed historically, but where bull trout are currently not expected to occur. The total predicted spawning habitat for the Touchet Core Area was 43.7 km and 66.9 km for the WW Core Area (Table 16). The corresponding estimated maximum adult (spawner) capacity was 2435 for the Touchet CA and 3260 for the WW CA based on maximum observed redd densities in Table 12. These current estimates of spawner capacity were used as a baseline population ceiling in the stochastic demographic model, so that under various threat removal scenarios, the population could increase up to the capacity and would stabilize there. We used the available habitat estimated under this rule set to predict changes to habitat and spawning capacity under several climate change scenarios.

Future climate change scenarios

We assessed potential impacts of climate change threats in the Walla Walla Basin by modeling changes in bull trout spawning habitat based on four different scenarios of stream warming. We used stream warming rates to estimate temperature-mediated loss of stream habitat and associated changes in total spawning capacity for the Touchet and WW CAs. First, we estimated the stream lapse rate in for the South Fork Walla Walla River , an estimate of the average change in temperature per change in elevation (C/ 100 m of elevation) from water temperature monitoring records at four different sites along the stream's profile. The lapse rate of 0.5 °C/100m was used in conjunction with channel slope and estimates of long-term rates of stream warming to estimate the rate at which a temperature isotherm would shift along the longitudinal profile of a stream (Isaak and Rieman, in preparation) as:

Isotherm shift rate (km/decade) = (stream warming rate/lapse rate)/(sin(channel slope)) (8)

A range of long-term stream warming rates were considered from 0.1 C/decade – 0.3 C/decade that are consistent with those observed in Western streams the past three decades (Isaak et al. 2010; Isaak et al. 2011; Table 13).

Table 13. Isotherm shift rates (stream km/decade) predicted for streams in the Walla Walla basin based on rates of long-term stream warming and percent channel slope.

	Stream warming rate (°C/decade)			
% Channel Slope	0.1	0.15	0.2	0.3
0.5	4.2	6.3	8.3	12.5
1	2.1	3.1	4.2	6.3
2	1.0	1.6	2.1	3.1
3	0.7	1.0	1.4	2.1
5	0.42	0.63	0.83	1.25
8	0.3	0.4	0.5	0.8

We multiplied isotherm shift rates (stream km/decade) by 2.5 to predict how far a temperature isotherm would shift in 25 years. To apply stream warming rates to habitat models, we assumed that the current downstream spawning and rearing distribution for bull trout is limited by a critical temperature threshold, and that the downstream limits of this distribution will track the upstream shift of an isotherm as stream temperatures increase. We applied isotherm shift rates to the known distribution of spawning habitat in both core areas, based on an average stream slope of 2% and 3% for low and high density mainstem habitat, respectively, and 5% for spawning tributary habitat. We used predictions of available spawning habitat from the capacity function as a baseline, and estimated changes in stream kilometers available for spawning across both core areas. We then applied maximum spawning density rates to predicted habitat availability to estimate total redd capacity for all three populations. The percent change between current habitat estimates and capacity compared to predictions based on climate scenarios were described by the difference between the current and climate scenario estimates divided by the current estimate.

Threat removal

We combined all parameters within a PVA framework to evaluate the effects of removing large-scale physical habitat threats under current and climate change scenarios. We modeled the population response to removing large threats known to occur in the Walla Walla Basin (Table 14). We estimated the effect magnitude of removing each threat based on expert opinion, and translated the population-level effect into changes to matrix vital rates based on informed understanding of demographic processes. We applied changes to demographic rates in the matrix to develop a set of matrices with which to evaluate threat removal under scenarios of stable or decreasing population trends.

Table 14. Threats to bull trout populations identified by core area assessments and included in current NatureServe assessments (scores). First, the magnitude of effect on population size was established based on expert opinion. Second, matrix parameters were changed to reach the associated effect magnitude based on informed understanding of demographic processes in the system.

Threat	Effect location	Effect on population size (N)	Changes to model
Dewater/flow mngmt	Middle/lower system	Large: ~25% increase after 25yrs if threat removed	Increase survival for all subadult and adult stages by 1%

Passage (dams, barriers etc.	Lower system	Large: ~25% increase after 25yrs if threat removed	Increase survival for all subadult and adult stages by 1%

Population viability analysis

We used the matrix model to run a population viability analysis in which we assessed the response of core area populations to changes in vital rates corresponding with population trend and response to threat removal. We conducted simulations with the computer program RAMAS metapop, a population viability analysis program developed by Applied Biomathematics (Burgman et al. 1993; Akcakaya 2004). We began all simulations with initial population abundances and projected changes to both core area populations after 25 years. We assessed several possible scenarios in which population trend was stable or declining, and threats were present or removed (Table 15) and evaluated changes to population size based on simulation results. Population abundance estimates represented the number of spawning adults (>270 mm TL in the stage-based model) in each core area. We used estimates of population size, linear occupancy distance, and population trend from each of these scenarios from the demographic PVAs to compare with values used in the NatureServe ranking process.

Table 15. Models used in population viability analysis used to evaluate future population status of bull trout populations in the Touchet and Walla Walla Core Areas.

Model Name	Model Description	Growth rate (λ)
Stable population	Stable trend for all populations	1
Large threat removed, stable trend	Survival increased from base case (1.0%)	1.009
Declining trend, threats constant	Subadult survival decreased (~15%)	0.9482
Large threat removed, declining trend	Survival increased from declining population (0.1%)	0.9574

Sensitivity Analysis of NatureServe categorical viability scoring to a range of inputs

To help us understand how uncertainty in input categories might affect NatureServe scoring, we conducted a sensitivity analysis by comparing NatureServe scores based on a range of biologically feasible inputs. We used modeling results from two primary scenarios from the PVA, and entered these variables into NatureServe to assess the sensitivity of NatureServe across a range of possible inputs. We began by comparing the base demographic rates based on robust analytical techniques and used in the PVA with the original NatureServe scoring based on the range-wide core area (CA) assessments used to inform bull trout population status and risk (USFWS 2005a, 2005b and 2008). NatureServe scores integrate information from both threats-based and demographic criteria in a single systematic framework, and represent the conservation status of a CA (i.e., the risk of extirpation of bull trout in the core area) in a format that is consistent across recovery units. We calculated NS scores using the same data that was included in the PVA for two possible scenarios which we believe probably envelope the current observed demographic rates within the two CAs considered here. We included a set of inputs to evaluate NS scores under a scenario in which the populations demonstrated stable population growth and associated population size, and a second demographic scenario in which population trend was decreasing at a rate estimated from recent observed trends, and population size decreased accordingly (Table 15). These demographic rate estimates constituted more specific inputs than the wider range of often qualitative information used in the original NS scoring. We then compared NS scores based on these two sets of demographic rates with the scores from the original NS core area assessments. Inputs from the PVA that were changed in NatureServe include population size (N), population growth rate (λ), linear distance of occupancy, and number of populations. We changed these inputs based on a range of possible outcomes from the PVA and assessed the relative change to NS scores based on this range of potential inputs, both with and without uncertainty included in the NS scoring system.

We also evaluated the response of NS scores to changes in inputs based on threat removal. We used the PVA model to estimate potential future demographic responses to removal of current threats, and projected these responses 25 years into the future. We used results from this model as inputs into NS. Doing so allowed us to incorporate a “demographic response” to threat removal into the NS scoring system. We compared these scores with scores based solely on the CA assessment, which did not include a demographic change when threats were removed. Changes to demographic parameters were results from removing threats in the PVA (see tables 14 and 15). We only modeled large threat removal in this case, because the effect of removing smaller threats would result in scores that fell between the stable population scenario with large threats removed, and the declining population scenario with large threats removed.

Assessing options for comparing true viability (PVA model) metrics (e.g., probability of extinction) with NatureServe (NS) rankings.

We conducted a literature review of research relating population models to NatureServe ranks. We then evaluated possible options for conducting such a comparison. Typical population model outputs include population size, rate of population change (λ), median time to extinction (with extinction often defined by a lower threshold value), and probability of extinction for a given time period. For metapopulations, additional output may include proportion of sites or area occupied, rate of change in proportion of occupied sites, colonization rate, and extinction rates. We explored how these types of results could be compared with NatureServe rank scores to evaluate where there may be critical information gaps in the NatureServe response, or discrepancies between demographic changes and a NatureServe rank. For this exercise, rank scores were converted to S ranks to reflect extirpation risk. Using NatureServe terminology, S ranks are described as subnational ranks (units smaller than a nation, such as Canada or the United States of America). Although S ranks often represent a state or provincial unit, they may represent other units that are also smaller than a nation. Given that Recovery Units are smaller than the United States of America but often include areas from multiple states, it was reasonable to designate these as S ranks for the purpose of this exercise.

3.1.3 Results

Climate change scenarios

For the entire Walla Walla Management Unit, predicted spawning habitat shifts due to climate warming after 25 years could range from a approximately 16% habitat loss with stream temperature warming of 0.1°C/decade to 50% loss with warming rates of 0.3 °C/decade (Table 1616). Under high rates of stream warming (0.3 °C/decade), habitat loss could be substantial; predictions suggest potential losses to spawning habitat of nearly 35% and 76% for the WW and Touchet CAs, respectively. Under the assumption that spawning habitat quality is limited by temperature, such habitat losses could be accompanied by potential decreases in spawning adult capacity of as much as 25% and 70% for the two CAs, respectively (

Table 17).

Table 16. Total available stream kilometers of habitat for each of the three populations in the Walla Walla Basin, and for redd count index areas only. Length of available stream habitat is based on the capacity component of the population model, with various scenarios of stream temperature warming applied.

Core area	Current	Stream warming rate (C/decade)			
		0.1	0.15	0.2	0.3
WW	66.9	58.6	54.5	50.0	43.7
Touchet	43.7	34.2	29.4	21.1	10.5

Table 17. Estimates of habitat carrying capacity based on current environmental conditions from capacity component of the population model. Population estimates are based on total available habitat, and spawning survey index sites only, across a range of stream temperature warming scenarios.

Core area	Current	Stream warming rate (C/decade)			
		0.1	0.15	0.2	0.3
WW	3260	2961	2906	2710	2453
Touchet	2435	1946	1782	1288	702

Population viability

Population viability modeling demonstrated a range of possible outcomes for the Walla Walla Management Unit as a whole, based on scenarios of stable or decreasing population growth rates and current threats vs. threat removal. Population projections based on current population estimates indicated that if population growth rates continue on the current short-term declining trend, in the absence of catastrophes and environmental stochasticity, population abundance could be reduced by as much as 75% for both core areas (Table 18). If population growth rates remain stable and threats are removed, PVA results predicted that population abundances could increase by approximately 25-28% in 25 years. In contrast, under the scenario of declining population trend coupled with threat removal, both core area populations are projected to decrease by nearly 70%. Based on the capacity function, removal of threats resulted in a greater range of habitat availability and predicted linear distance of occupancy.

Table 18. Results from population projections of 25 years based on four different scenarios.

Model #	Description	Population abundance		Linear distance occupancy (km)		Population trend (λ)	
		WW	Touchet	WW	Touchet	WW	Touchet
1	Stable population trend, current threats	1600	345	52	28.5	1	1
2	Declining population trend, current threats	387	83	52	28.5	0.948	0.948
3	Stable population trend, threats removed	2004	443	67	44	1.009	1.009
4	Declining population trend, threats removed	492	106	67	44	0.957	0.957

Sensitivity Analysis of NatureServe categorical viability scoring to a range of inputs

We observed relatively little variation in the relative risk ranks based on the NatureServe scores for the Walla Walla and Touchet Core Area assessments compared with scoring based on PVA inputs (. Comparison **of NatureServe ranks based on inputs from the original core area (CA) assessment for the Walla Walla River Core Area, and the empirically-based demographic Population Viability Assessment (PVA) model under a scenario in which the population trend is stable, and a second scenario in which the population trend is declining. Ranks were calculated based on current conditions, projected response of threat removal and corresponding demographic changes after 25 years, and the same projected response to threat removal with uncertainty included in the scoring system. NatureServe ranks correlate with a relative risk of extirpation: S1 = Critically imperiled, S2 = Imperiled, S3 = Vulnerable.**

; current CA assessments). The sensitivity analysis, in which we used PVA results (linear distance of occupancy, population size and trend) as inputs in the NS calculator, demonstrated general correspondence between the original NatureServe ranks and ranks based on the PVA analysis (Figure 16). Rankings based on three different types of inputs all fell within one category of one another (i.e., ranks did not change, or only moved to the adjacent rank when different inputs were used in the scoring system). The NS ranks based on both the CA assessments and both sets of demographic data placed the Touchet Core Area in a risk category of S1 (critically imperiled; Figure 16; **Error! Reference source not found.**; current CA assessments, scenario 3 and 4). For the Walla Walla Core Area, NS ranks based on inputs from the PVA were similar to the core area assessment, although the ranking based on the declining PVA scenario showed that under a situation of severe population decline, the Walla Walla Core Area might be scored as an S1, which is lower than its current rank of S2 (Imperiled; Figure 17; Table 19).

When threat removal was included in the scoring calculator, NS rankings based on the current CA assessment also demonstrated general correspondence with both sets of demographic inputs, which incorporated demographic changes to threat removal after 25 years. Both current NS scores and the PVA suggested that if threats were removed in the Touchet Basin, the relative risk might be reduced, and the ranking could change to a S2 (imperiled) or even an S3 (Vulnerable) if demographic rates were stable (Figure 17). When uncertainty was included in the scoring, the core area assessment score did not change, but both scores based on demographic inputs moved to the next lower rank. The sensitivity analysis in the Walla Walla core area also resulted in similar ranks among the three inputs when threat removal was incorporated, and when threat removal and uncertainty were included in the scoring system. For both comparisons, the ranks based on inputs from the declining PVA resulted in a lower rank than both sets of inputs from the core area assessment and the stable PVA (Figure 17). Additionally, for the Walla Walla Core Area, when uncertainty was included in the scoring process, scores from all three inputs were the same as scores under current conditions, with the declining PVA inputs resulting in a rank of S1, and both the core area assessment and stable PVA resulting in a rank of S2.

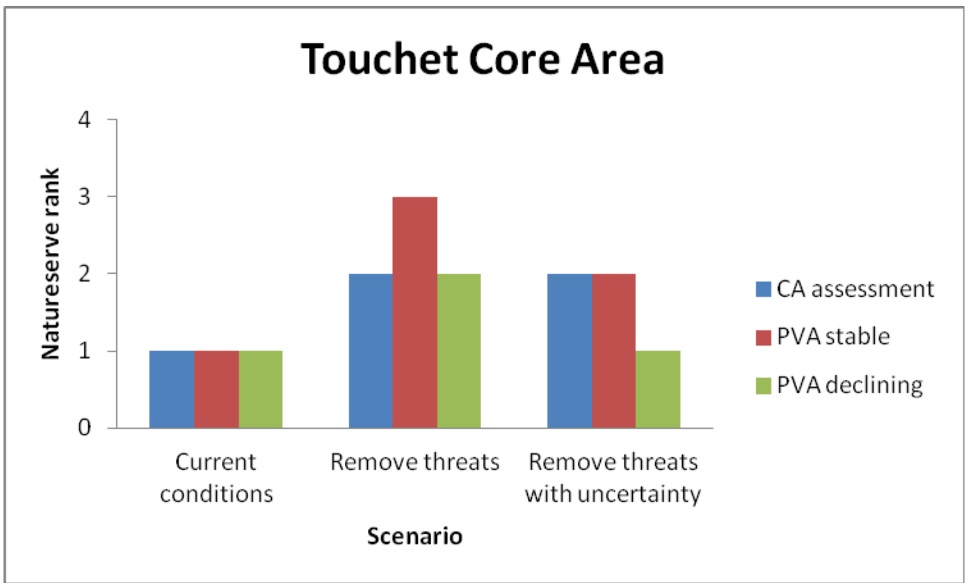

Figure 16. Comparison of NatureServe ranks based on inputs from the original core area (CA) assessment for the Touchet River Core Area, and the empirically-based demographic Population Viability Assessment (PVA) model under a scenario in which the population trend is stable, and a second scenario in which the population trend is declining. Ranks were calculated based on current conditions, projected response of threat removal and corresponding demographic changes after 25 years, and the same projected response to threat removal with uncertainty included in the scoring system. NatureServe ranks correlate with a relative risk of extirpation: S1 = Critically imperiled, S2 = Imperiled, S3 = Vulnerable.

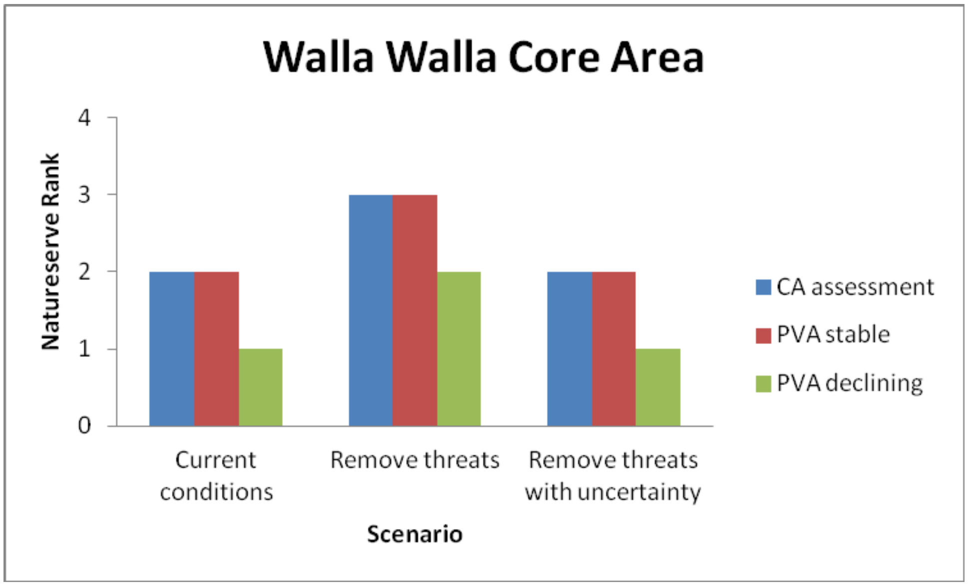

Figure 17. Comparison of NatureServe ranks based on inputs from the original core area (CA) assessment for the Walla Walla River Core Area, and the empirically-based demographic Population Viability Assessment (PVA) model under a scenario in which the population trend is stable, and a second scenario in which the population trend is declining. Ranks were calculated based on current conditions, projected response of threat removal and corresponding demographic changes after 25 years, and the same projected response to threat removal with uncertainty included in the scoring system. NatureServe ranks correlate with a relative risk of extirpation: S1 = Critically imperiled, S2 = Imperiled, S3 = Vulnerable.

Table 19. Comparison of NatureServe scores from core area assessment with NatureServe scores using demographic inputs from PVA analysis.

Core Area	Scenario	Average Numeric Overall NS Score	NS Rank From Ave Numeric Score
Touchet River	Current CA assessment	1.27	S1
Touchet River	1 -removing threats and adjusting scope & severity of threat scores	2.10	S2
Touchet River	2 - removing threats and adjusting scope & severity of threat scores with uncertainty	1.80	S2
Touchet River	3- using demographic parameters from stable PVA	1.49	S1
Touchet River	4- using demographic	0.53	S1

	parameters from declining PVA		
Touchet River	5- using demographic parameters from stable PVA, with threat removal and demographic response	2.54	S3
Touchet River	6- using demographic parameters from declining PVA, with threat removal and demographic response	1.57	S2
Touchet River	7- using demographic parameters from stable PVA, with threat removal and demographic response, uncertainty included	2.24	S2
Touchet River	8- using demographic parameters from declining PVA, with threat removal and demographic response, uncertainty included	1.27	S1
Walla Walla	Current CA assessment	1.92	S2
Walla Walla	1 -removing threats and adjusting scope & severity of threat scores	2.74	S3
Walla Walla	2 - removing threats and adjusting scope & severity of threat scores with uncertainty	2.44	S2
Walla Walla	3- using demographic parameters from stable PVA	1.60	S2
Walla Walla	4- using demographic parameters from declining PVA	0.83	S1
Walla Walla	5- using demographic parameters from stable PVA, with threat removal and demographic response	2.64	S3
Walla Walla	6- using demographic parameters from declining PVA, with	1.88	S2

	threat removal and demographic response		
Walla Walla	7- using demographic parameters from stable PVA, with threat removal and demographic response, uncertainty included	2.34	S2
Walla Walla	8- using demographic parameters from declining PVA, with threat removal and demographic response, uncertainty included	1.58	S2

Rank	Relative Risk of Extirpation
S1	Calculated value <=1.5 - Critically Imperiled
S2	1.5<calculated value <=2.5 - Imperiled
S3	2.5<calculated value <=3.5 - Vulnerable
S4	3.5<calculated value <=4.5 - Apparently Secure
S5	Calculated value <=4.5 - Secure

Assessing options for comparing true viability (PVA model) metrics (e.g., probability of exintction) with NatureServe (NS) rankings.

We found no published results relating population model outputs to NatureServe rank scores. Nor were there any published reports on the sensitivity of NatureServe to population model outputs. There were several papers published in the mid-2000s on the performance of protocols, such as NatureServe, to assess levels of threat faced by species. There were five papers explicitly evaluating three major protocols; IUCN Red List Categorization, NatureServe, and Florida Game and Freshwater Fish Commission (GF&FFC) protocol. The papers compared the output classifications among the major protocols (O'Grady et al. 2004a), compared the protocols to subjective judgment by experts (McCarthy et al. 2004), and evaluated the consistency of the protocols for variable users (Keith et al. 2004, Regan et al. 2005). (There was an interesting pattern to papers published explicitly on the performance of NatureServe; there were 5 papers published 2004–2005 with overlapping subsets of authors, and L. L. Master, the designer of NatureServe, on 3 of the papers.)

The fifth paper, which is most relevant to linking population model output to NatureServe rankings, evaluated the correlation between parameters that were inputs for the three major protocols and extinction risk (Table 1; O'Grady et al. 2004b). Based on population model outputs for 45 vertebrate taxa with adequate data, O'Grady et al. (2004b) found both population size and trend or percent change in population size were significantly related to extinction risk. None of the other parameters were significantly related to extinction risk, although there was also a significant population size × trend in population size interaction.

Table 20. Population, biological, and threat parameters, which are inputs for IUCN Red List Categorization, NatureServe, and Florida Game and Freshwater Fish Commission (GF&FFC) protocol (O'Grady et al. 2004b) that are used to assess levels of threat faced by species.

Category	Parameter	Used in NatureServe
Population	Population size (mature individuals)	Y
	Change in population size (trend or % change)	Y[a]
	Fluctuation in population size (CV)	N
Population and Meta-population	Range size (area of occupancy)	Y
	Range reduction (rate of change)	Y[a]
	Fragmentation into sub-populations	S[b]
Life History	Generation length	N
	Minimum age at which females first reproduce	N
	Number of offspring/breeding female/year	N
Biology	Ecological specialization	Y
	Taxonomic level	N
	Genetic uniqueness of taxon	N
Threat	Immediacy of threat	Y
	Legal protection	N
	Magnitude of threat	Y

	Percentage of taxon in reserve/s	N

[a] NatureServe allows a trend to be a change in population size, extent of occurrence, area of occupancy, number of occurrences, or ecological integrity of occurrences.
[b] S = similar. NatureServe has "Number of occurrences" factor, which can represent number of subpopulations, although not direct measure of fragmentation.

Further study is needed to evaluate the relationship between population model outputs (and potentially inputs) and NatureServe output ranks. Below is an example of a potential approach. Here, we assume that a reduction in harvest leads to an increase in survival (generic survival for now), with a concomitant increase in population size and decrease in probability of extinction, defined here as the probability of having <100 individuals in 10 years. The ideal result is a high correlation between change in population model outputs and NatureServe ranks. Note that because NatureServe inputs are categories, an increase in population size will not result in a change in rank until a higher category is achieved (e.g., population size categories include 1–50, 50–250, 250–1000, etc., so increasing from 180 to 245 will not change the input category or the output rank). In this example, two NatureServe inputs would be changed to reflect the reduction in harvest; the threat impact would be changed via reduction in threat severity category, and the population size category could be changed. Outputs from NatureServe may look something like the values below (**Error! Reference source not found.**).

Table 21. Theoretical outputs from a population model and related NatureServe ranks.

Scenario	Survival rate	Population size	Prob(<100 over 10yrs)	NatureServe rank
Base case	0.45	180	0.66	1.30
Harvest reduced 10%	0.47	198	0.53	1.30
Harvest reduced 15%	0.50	228	0.48	1.30
Harvest reduced 20%	0.52	262	0.43	2.15
Harvest reduced 25%	0.55	283	0.41	2.15

The relationship between population model outputs and NatureServe ranks could be qualitatively evaluated graphically using absolute or relative changes in population outputs versus NatureServe ranks (Figure 18), or quantitatively evaluated via rank analysis, and/or correlation or residual analysis. Because the ranks increase in a categorical manner, we will need to determine appropriate methods for correlation and residual analysis. Note that NatureServe can take a range of inputs. For example, if a 95% CI of population size covered 2 categories, both categories are input. However, there is no distributional allowance; that is, a 95% CI for population size of 240–500 would have the same 2 input categories as a 95% CI for population size of 100–260 (relevant categories are 1–50, 50–250, 250–1000).

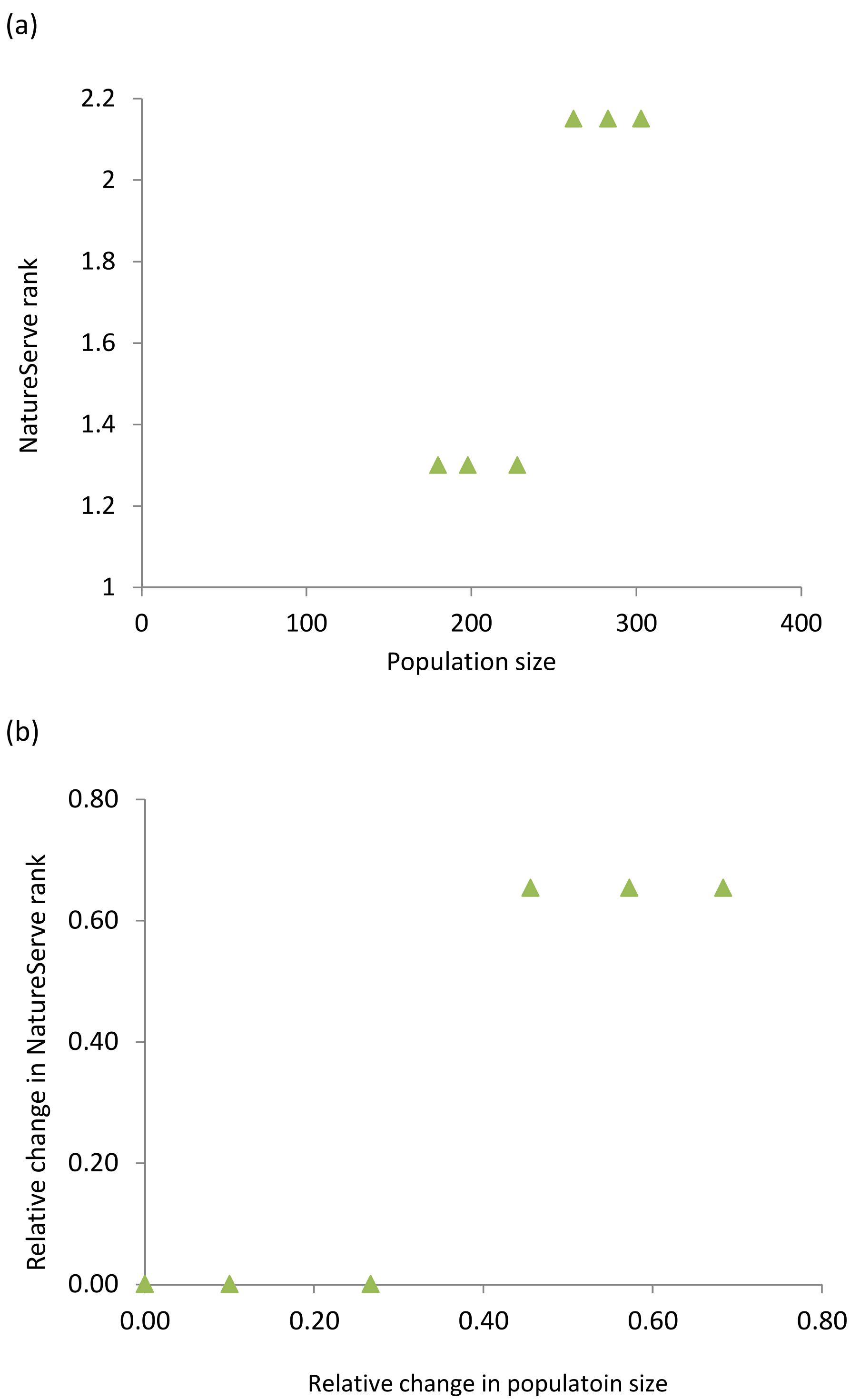

Figure 18. Example of population model output versus NatureServe output for (a) absolute and (b) relative [(base case value – scenario value)/base case value] values.

In addition to the effect of threat removal on abundance score, we might be interested in how the rank of threat removal varies among threats, between NatureServe and a PVA metric (e.g., population growth rate). In Figure 19, we show an example of the effect of changing the threat status in NatureServe, in the absence of a paired demographic change, on the NatureServe Score. Future work will need to: 1) include the development of a rule set to link threat status change in NatureServe with demographic status change in NatureServe, in order to make direct comparisons between NatureServe response and PVA model response practical (see hypothetical comparison below; Figure 19).

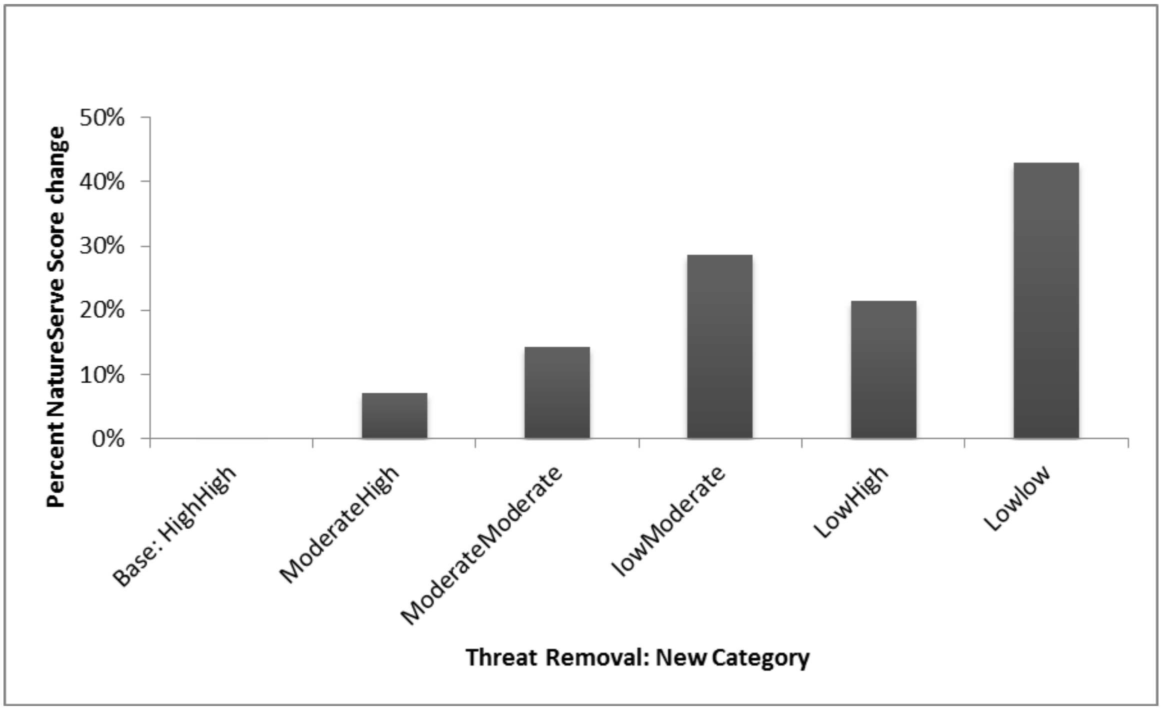

Figure 19. An example of the effect of changing the threat status in NatureServe, in the absence of a paired demographic change, on the NatureServe Score.

For example, in the hypothetical example below (Figure 20), the rank and magnitude of the effect of removing Threats 1, 3 and 4 are all similar between NatureServe and the PVA metric. In contrast, the rank effect of removing threats 2 and 5 varies dramatically in magnitude and rank order within a metric. This type of comparison might direct our attention to those threats for which there is lack of agreement and to identifying uncertainty in how the perceived threat is actually affecting the population. As indicated above, the ranks could also be correlated and residuals could be used for a somewhat quantitative analysis. See **Error! Reference source not found.** for a list of possible metrics that could be compared.

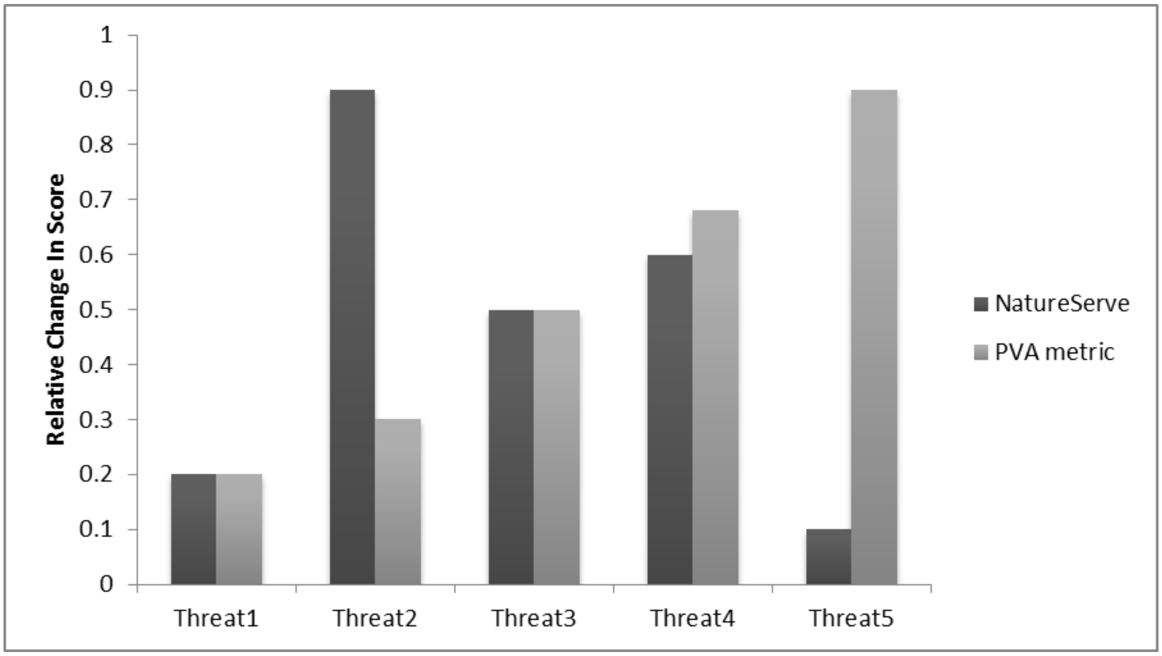

Figure 20. A hypothetical example of a comparison of the rank effect on the relative change in score between NatureServe and a PVA metric (e.g., p. of extinction) among five hypothetical threats.

3.1.4 Discussion

Life-cycle models provide a means for synthesizing data, studying how changes to vital rates can affect the dynamics of populations, evaluating the effect of environmental changes and management decisions, and predicting possible future outcomes (Kareiva et al. 2000; Scheuerell et al. 2006). The stage-based bull trout population model used in our population viability analysis is a valuable tool for evaluating the effect of potential changes in habitat availability and demographic rates on population abundance and spatial distribution. The viability model is flexible enough to accommodate a range of possible population types and changes to demographic parameters to reflect data from other sources. Furthermore, the model can be used to evaluate multiple populations simultaneously to scale from the individual population to a Core Area and Management Unit. The model was built from the best available empirical data, and was calibrated to reflect observed trends based on independent data. The model was used to explore a range of population projections based on various growth rates and habitat changes.

The scenarios used here may be used to evaluate possible future outcomes, but of course natural systems are dynamic and it is impossible to predict potential interactions between the numerous factors affecting bull trout populations. If bull trout spawning habitat is limited by stream temperature and spawning distributions track the upstream shift of a temperature isotherm change, spawning habitat availability in the Walla Walla Basin may decrease within the next 25 years. Due to the high rate of groundwater input in the spawning reaches of many of the streams included in our analysis (e.g., South Fork Walla Walla), we expect that stream temperature increases may be in the smaller range (0.1-0.15 °C/decade), but warming rates could be higher in streams such as the North Fork Walla Walla where solar inputs are greater and groundwater inputs fewer. Based on these predictions and current projections of bull trout populations that are below estimated capacity, spawning habitat is unlikely to be the sole limiting factor for many bull trout populations. However, stream temperature increases as a result of climate change could have other impacts not included in our model, including thermal stress on migrating adults and subadults lower in the system. Additionally, climate change could also impact bull trout populations in other ways, such as increased winter flows scouring redds or mobilizing fine sediment to impact egg and alevin survival.

By projecting the effect of different population growth rates (trends), we were able to evaluate a range of potential future population trajectories. If population growth rates continue along their current decline, both core areas in the Walla Walla Management Unit may face dramatic declines in abundance over the next 25 years, even in the absence of catastrophic events, climate change, or added anthropogenic impacts. However, there is some indication that long-term trends are stable, at least in the SFWW (Budy et al. 2011). Modeling the potential effect of threat removal provides a tool with which managers can evaluate the population response to changes in demographic rates. This stage-based population model provides a means to assess the relative effects of various management actions and may be used to help assess the performance for other population metrics, such as how realistic changes to demographic rates can impact NatureServe scores.

By evaluating changes to NatureServe scores based on simulated biologically-feasible changes in demographic rates, we were able to assess the sensitivity of the NatureServe scoring system to a range of inputs. The sensitivity analysis for NS scores to removing current threats demonstrated that the NS scoring system was fairly robust to ranking relative risk for the Touchet Core Area metapopulation. Overall, NatureServe rankings did not change, or moved into an adjacent rank, when inputs were changed to reflect a range of plausible biological values. Further, inclusion of threat removal into the ranking system showed similar results when only core area assessment information was used, compared to when demographic response to threat removal was added into the rank calculator. In the Walla Walla core area, including uncertainty into the scoring did result in lower ranks for all demographic inputs. This suggests that conservative management decisions should consider uncertainty in this type of ranking system, as the addition of uncertainty may result in a different estimate of relative risk. NatureServe rankings based on core area assessments can help demonstrate the potential changes to relative risks for populations, but true relative risk will only change if threat removal results in a positive demographic response. Thus, based on this first round of sensitivity analyses, NatureServe seems to do an adequate job characterizing the general risk to a core area, but the variability in ranks associated with projections of threat removal and uncertainty suggest that good monitoring and evaluation is needed to determine how the status of imperiled populations respond to management actions or environmental changes. Similarly, monitoring and evaluation will help managers evaluate changes to populations and will likely improve the precision of NatureServe inputs. This comparison has only been conducted for a two core areas within a single management unit, and additional comparisons will help us better understand the sensitivity of NS scores to the precision of inputs. In addition, recent research indicates a warming trend in Western streams (Isaak et al. 2011), and potential effects of climate change should be considered as potential threats to bull trout populations.

Future comparisons of PVA-based metrics such as probability of extinction with NS rankings (as described in the methods) will help us further assess the strengths and weaknesses of the NatureServe process. We have explored the literature and found few cases where simple, categorical NatureServe scores have been explicitly compared to population metrics from a PVA (population trend, probability of extinction etc.). Nonetheless, we have identified several possible cross walks between the two critical approaches including but not limited to: 1) comparing the relative ranks of response to a suite of threat removal scenarios (i.e., does removing a barrier always or often have the greatest effect in both a PVA and NatureServe), 2) comparing the relative change in the predicted size of the population (abundance) after a threat has been removed, and then asking if the abundance bin in NatureServe has changed, and 3) a series of slightly more quantitative approaches comparing ranked scores of population metric output from the PVA to NatureServe --such as regression between a PVA metric (e.g., probability of extinction) and NatureServe overall scores. The latter would include a concomitant evaluation of the residuals (situations where the output from the two approaches do not match up well). Each of these comparisons will necessarily be relative, in other words the effect of one threat removal relative to another. Although direct comparison of a population metric such as probability of extinction will never be possible given the framework of NatureServe (e.g., categorical, no biological linkages or feedback at the population level), we will be able to identify those threats and predicted responses where it appears there is a critical information gap in NatureServe that should be treated with caution when making management decisions.

Future Work

- *Full suite of threat removal model scenarios with parallel comparisons to NatureServe output using the gaming tool (See Chapter 2); to be completed at both Core Area (metapopulation) and Management Unit scales.*

- *Analysis of temporal aspects of recovery. Using the PVA, we will explore the effects of series of good and bad years on recovery after threat removal. We will sample from the empirical time series and use this information as book ends on uncertainty (e.g., ~alternating good and bad years versus consecutive good than bad years).*

- *Analysis of the effects of having poor demographic data available, as is common across the range of bull trout. Using the PVA, we will explore the effects of much less certainty in data quality and the effects of data gaps. We will re-sample the empirical time series, and simulate core areas for which we have no to little specific information (increased variability etc.), in terms of assessing the effect of threat removal. These PVA-based results will be directly compared to the effect of uncertainty… to be explored with NatureServe (see Chapter 2).*

- *Lastly, we will explore scaling the PVA up to a much bigger, more complex core area (metapopulation) such as the John Day, and again compare the effects of threat removal* *to NatureServe output. To do this, we will likely have to use a population-type categorical approach similar to Budy and Schaller (2007).*

- *Evaluation of the certainty that a population estimate is within a NatureServe bin. We will conduct a parametric bootstrap using the PVA model and output population size. For each iteration will randomly draw from the distribution of the vital rate input parameters, which will result in an output distribution of population sizes. We will run ^{3}1,000 iterations (that is, enough simulations to ensure the standard error is stable) and generate a probability distribution of the population sizes. From this distribution we will calculate the probability population size is within a given bin.*

Management Implications

- *We have developed a suite of robust population viability models (PVA) for bull trout populations based on some of the best available vital rate information (SF Walla Walla). These models allow us to capture much of the scope of population structure and limiting factors present across the range of bull trout. As such, these PVA models provide a critical analytical tool for assessing the relative effects of threat removal/reduction based on expected biological response. In addition, these PVAs provide a necessary ground-truthing mechanism for the more general, categorical (non-biological) approach inherent in NatureServe.*

- *Based on a preliminary assessment of the relative effect of each of the vital rates (e.g., growth, survival) on overall population trend (perturbation analysis), we observed general support for other research indicating that juvenile survival rates strongly influence overall population trend, but that the effect of increasing the number of large, fecund adults can also be influential.*

- *We have made considerable progress developing a meta-population model that will allow us to address the same types of scenarios as above, but at the core area level. In these scenarios, some population may be increasing while others are decreasing, yet the recovery criteria can be evaluated at the core area level and compared to the gaming tool output developed for NatureServe (See Chapter 2). Future work will focus on estimating and evaluating dispersal rates in the context of connectivity scenarios in NatureServe.*

- *Analysis of the sensitivity of NatureServe scores and ranks to a range of possible inputs shows that in some core areas, the NatureServe is fairly robust to changes in input, both for current conditions and when threat removal is incorporated into future projections.*

While NatureServe appears to be a useful planning tool, true relative risk will only change if populations have a positive response to threat removal. As such, continued monitoring and evaluation of populations is necessary to continue to evaluate risk of extinction. Likewise, in other populations, different inputs may result in a relatively wider range of NS rankings.

- *Future comparisons of PVA metrics and NS rankings will improve our understanding of the strengths and weaknesses of the NS process. Comparison of various population-level and viability metrics we help us identify those threats and predicted responses where it appears there is a critical information gap in NatureServe that should be treated with caution when making management decisions*

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3.2 Use of a large-scale bioclimatic model to evaluate potential effects of climate change on bull trout natal habitats in USFWS core areas.

3.2.1 Introduction

The effects of 20th Century climate change on the distributions of many plant and animal taxa are well documented (Parmesan and Yohe 2003; Root et al. 2003) and such shifts are expected to continue during the 21st Century as the climate continues to warm (IPCC 2007). Empirical evidence of distribution shifts in aquatic species is relatively limited (Heino et al. 2009), but extensive research documents trends in stream parameters associated with discharge and temperature (Stewart et al. 2005; Webb and Nobilis 2007; Luce and Holden 2009; Isaak et al. 2011; Leppi et al. 2011) and numerous linkages also exist between historical fish distributions and these parameters to suggest changes are likely (Brannon et al. 2004; ISAB 2007; McCullough et al. 2009). Moreover, many broad-scale bioclimatic models based on these historical associations forecast future changes that are large enough in certain instances to threaten the persistence of some fish species in portions of their range (Keleher and Rahel 1996; Kennedy et al. 2008; Williams et al. 2009; Wenger et al. 2011a; Almodovar et al. 2011) should climate warming proceed as most climate models now suggest (IPCC 2007; Mote et al. 2008). Two recent studies have addressed the potential effects of climate change on bull trout populations (Rieman et al. 2007; Isaak et al. 2010) and suggest this species may be especially vulnerable given a requirement for cold water temperatures, relatively large habitat networks, and population distributions that are often restricted and fragmented among the highest elevation reaches across river networks (Rieman and McIntyre 1995; Dunham and Rieman 1999; Wenger et al. 2011b).

In this task, we explore the application of a bioclimatic model that describes the relationship between juvenile bull trout distributions and mean annual air temperatures that Rieman et al. (2007) originally developed to assess the threat of future climate change across the Interior Columbia River Basin (ICRB). Details regarding model development are contained in Rieman et al. (2007) and here we simply use the model to quantify potential differences among USFWS core areas in climate sensitivity and vulnerability across the ICRB. Climate sensitivity is defined as the percent change in thermally suitable natal habitat between a historic and future climate scenario. Climate vulnerability is defined by the number of large thermal habitat patches that exist within a core area boundary as low, medium, or high as an index of likely persistence in a core area influenced by climate change. The approach does not consider threats associated with other natural or anthropogenic stresses, disturbance, or changing species communities, but generally assumes that vulnerability to all threats is mitigated by the size and extent of available habitat networks.

3.2.2 Methods

The models developed in Rieman et al. (2007) are multiple regressions that predict two attributes: 1) the lower elevation limit of juvenile bull trout (fish < 150 mm) based on data from 76 streams across the ICRB and 2) spatial trends in mean annual air temperature “normals” for 1961-1990 monitored at 191 climate stations across this same area. The juvenile bull trout model was used to map the lower elevation limit of historic bull trout populations based on the following predictive equation:

$$\textit{Lower limit (m)} = 18.693 - 190.80(\textit{latitude}) + 73.58(\textit{longitude}) \qquad (1)$$

This regression relationship accounted for 74% of the variation in bull trout lower elevation limits across the ICRB and a map of all areas exceeding this elevation is used to represent a historic climate scenario for bull trout in the ICRB (Figure 20, panel a).

The mean annual air temperature model was used to calculate the temperature lapse rate for the ICRB based on the following equation:

$$\textit{Annual air temperature} = 67.062 - 0.8618(\textit{latitude}) + 0.1193(\textit{longitude}) - 0.00625(\textit{elevation}) \qquad (2)$$

This regression relationship accounted for 89% of the variation in mean annual air temperatures across the ICRB and yielded a lapse rate estimate of 0.00625 °C/m. The lapse rate was used to calculate how much a future air temperature increase would raise the lower elevation limit of bull trout distributions, assuming that populations would track the same temperature isotherm that has presumably constrained past distributions.

The future climate scenario that was assessed represented a 1.6 °C increase in mean annual air temperatures, which is a mid-range scenario that is close to what most global climate models project will occur in the Pacific Northwest by middle of the 21st century (Mote et al. 2008). This amount of warming was translated using equation 2 to an elevation increase of 250 m in the lower elevation limit of juvenile bull trout (Figure 20, panel b). We then calculated the amount of thermally suitable habitat that occurred under each climate scenario within each of the 83

USFWS core areas across the ICRB (Figure 21). These core areas encompassed most or all of the Klamath, Mid-Columbia, Upper Snake, and Columbia Headwaters recovery units, but excluded the St. Mary and Coastal units because they were outside the domain modeled by Rieman et al. (2007).

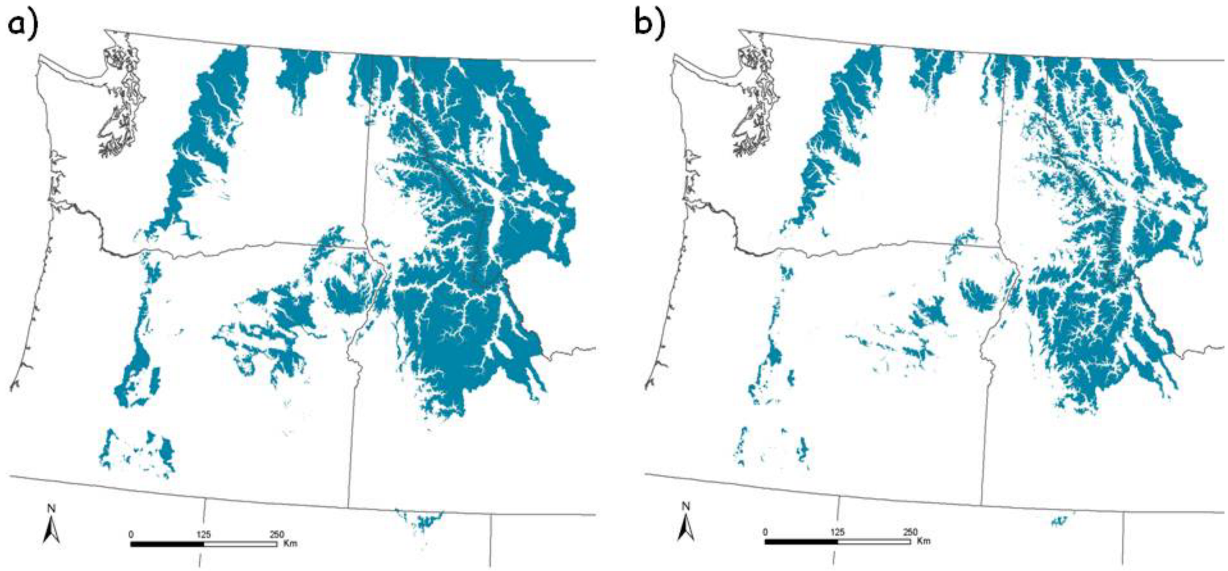

Figure 20. Distribution of thermally suitable natal bull trout habitats across the interior Columbia River Basin for the historic (panel a) and future climate scenarios (panel b). The historic scenario is based on the relationship between bull trout distributions and mean annual air temperature “normals” for the 1961-1990 period. The future scenario is based on an increase in annual air temperatures of 1.6°C and corresponds to an upward shift in the lower elevation limit of thermally suitable natal habitats of 250 m (from Rieman et al. 2007).

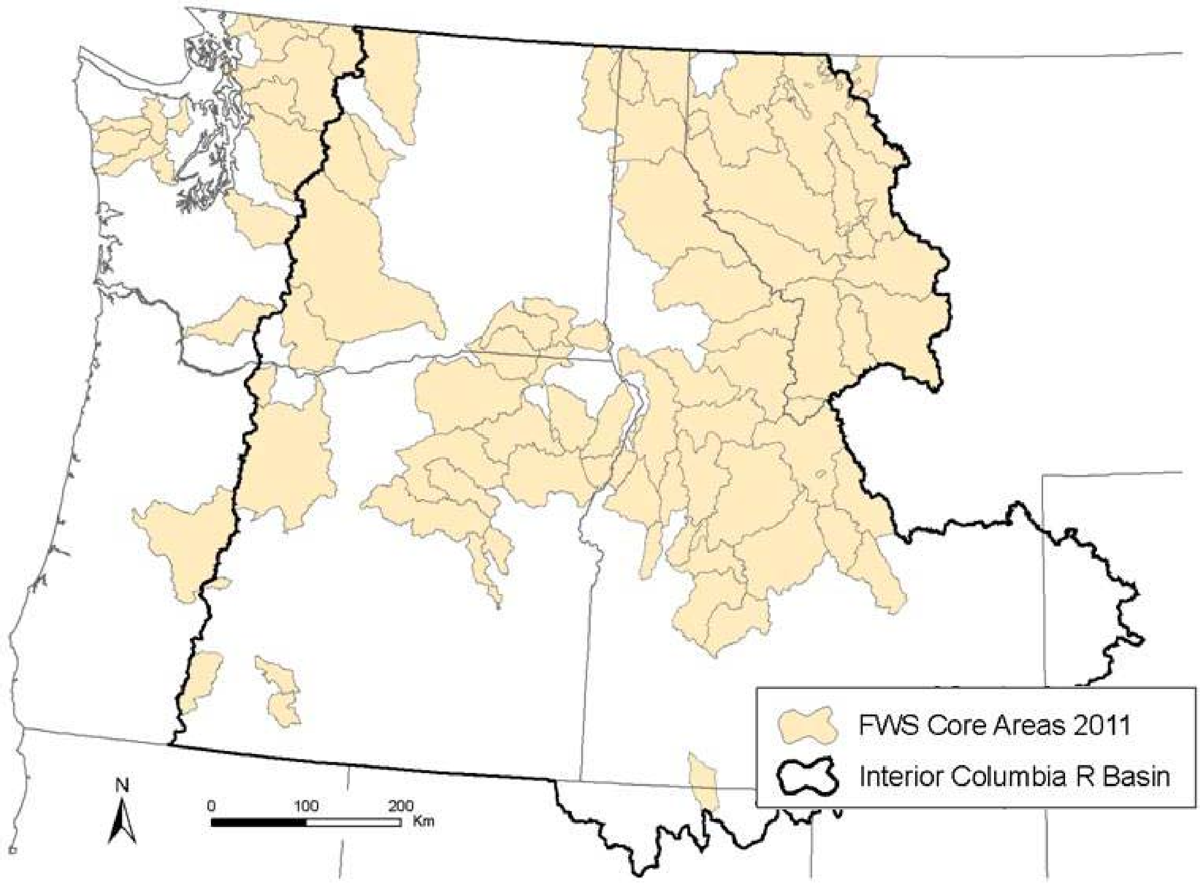

Figure 21. U.S. Fish and Wildlife Service core area boundaries within the interior Columbia River Basin used to summarize the Rieman et al. (2007) model predictions of bull trout habitat for the two climate scenarios considered.

The amount of thermally suitable habitat was summarized in two ways, by the total stream length within a core area and the number of contiguous habitat “patches” comprised of suitable stream lengths. The stream length summary was calculated by querying out those streams with watershed contributing areas > 500 ha (size threshold applied to filter out intermittent streams) that occurred at elevations above the lower elevation limit modeled in the historic and future climate scenarios. These stream lengths were quantified from synthetic networks derived using digital elevation models and TauDEM (Tarboton 1997) as described in Rieman et al. (2007). The habitat patch summary was calculated by binning each contiguous thermally suitable stream length and associated watershed contributing area into two size categories (large patches > 10,000 ha and medium patches >5,000 ha, < 10,000 ha). These habitat size categories have previously been linked to higher probabilities of bull trout occurrence and population persistence (Rieman and McIntyre 1995; Dunham and Rieman 1999) and were subsequently used to describe climate vulnerability as described below.

To assess the climate sensitivity of bull trout natal habitats in core areas, the change in thermally suitable stream length between historic and future scenarios was calculated and expressed as a percentage of the historical total. Climate vulnerability was defined relative to the number of large thermal habitat patches that exist within a core area boundary as low, moderate, or high to provide an index regarding the possibility that bull trout could be extirpated from a core area by climate change. Vulnerability categories follow the definitions for risk used in Rieman et al. (2007) as:

Low vulnerability: > 5 medium and large patches or > 2 large patches;

Moderate vulnerability: 1 - 4 medium and large patches or 1 large patch;

High vulnerability: no medium or large habitat patches.

By assessing sensitivity and vulnerability relative to changes between one historic and future scenario, we attempt to reduce the complexities associated with assessing multiple future scenarios and the assumptions inherent to each. Instead, our analysis simply assumes that the climate will continue to warm until at least the middle of the 21st Century (which is predicted by almost all global climate models) and that historical linkages between bull trout populations and climate will persist in the future. Both assumptions seem tenable and are necessary for this strategic assessment regarding how different core areas may be affected by climate change across the ICRB.

3.2.3 Results

Figure 22 summarizes the total stream kilometers that were thermally suitable for bull trout under the historic climate scenario and was derived by applying the core area boundaries (Figure 21) to the historic distribution map (Figure 20, panel a). Table 22 summarizes the average number of stream kilometers and large patches across all core areas for each climate scenario. The average climate sensitivity (% change between historic and future scenarios) was -48% based on suitable stream length and -60% based on the number of large patches (**Error! Reference source not found.**). Core areas that consisted mainly of individual lakes skewed the figures based on stream length, but exclusion of individual lake core areas with 0% or -100% sensitivities (Appendix A; Table 23) changed the average sensitivity only slightly to -55%. These averages mask considerable variation in sensitivities among core areas, which ranged from 0%

to -100% (excluding the lake core areas, sensitivities ranged from -21% to -100%) and are summarized in Figure 23 and Appendix A; Table 23). In general, core areas across Oregon and northern Idaho were predicted to be most sensitive to climate change, whereas core areas across central Idaho, northwest Montana, and northern Washington were less sensitive. Vulnerability, indexed by the number of large thermal habitat patches available to bull trout, was low or moderate for most core areas in the historical scenario except in portions of Oregon and southeast Washington (Figure 24). Vulnerability increased in the future scenario and core areas across most of Oregon, as well as northern and western Idaho, were rated as highly vulnerable.

Table 22. Descriptive summaries of thermally suitable natal bull trout habitats averaged across U.S. Fish and Wildlife Service core areas within the interior Columbia River Basin for historic and future climate scenarios. See text for details regarding climate scenarios. Results for individual core areas are in Appendix A; Table 23.

		Climate scenario		
Habitat metric		**Historic**	**Future**	**Climate sensitivity (% change)**
Stream kilometers	Core area average	451	235	-48%
	Core area total	37,459	19,456	-48%
Habitat patches > 5,000 ha	Core area average	4.74	1.89	-60%
	Core area total	398	159	-60%

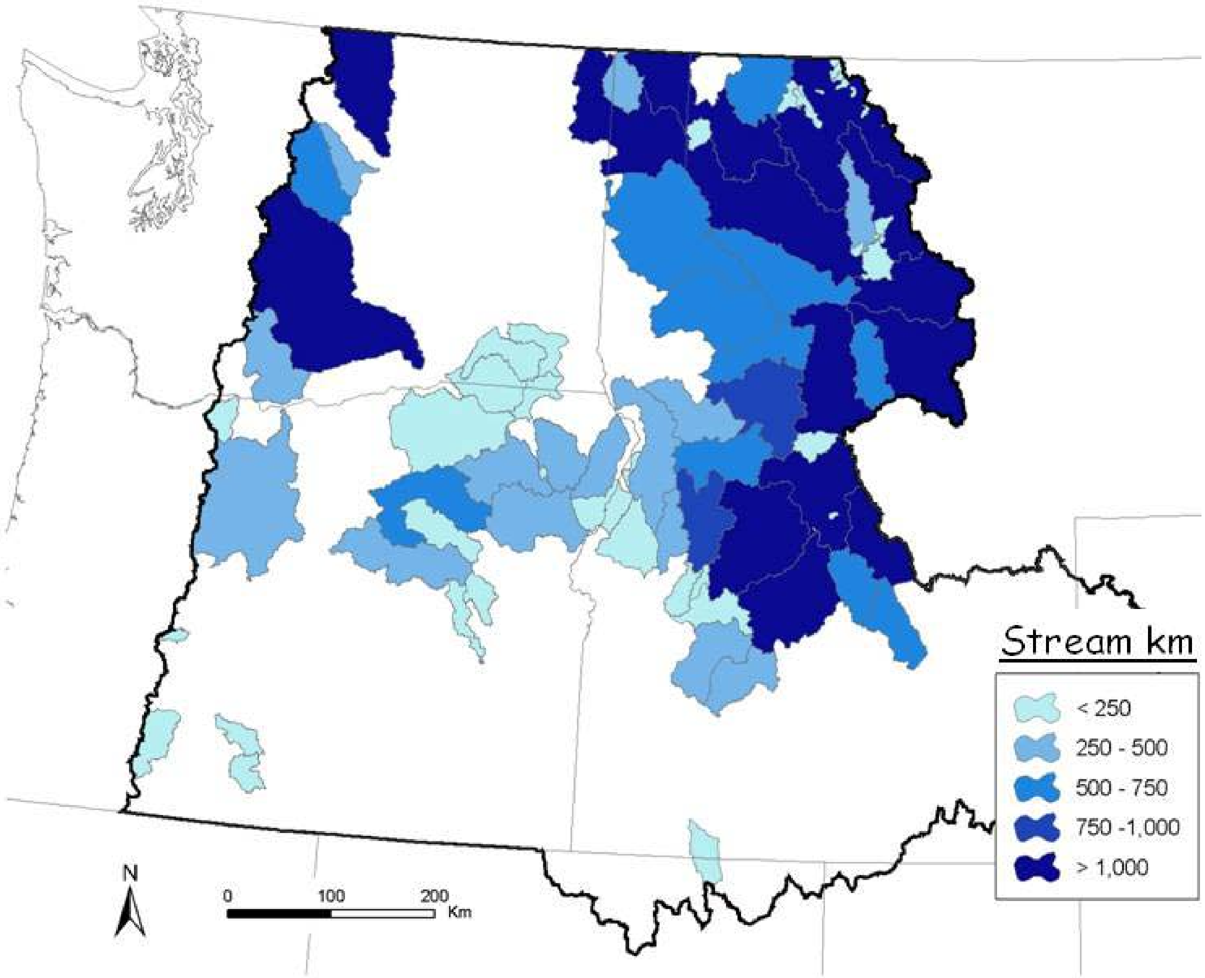

Figure 22. Stream kilometers of thermally suitable bull trout natal habitat predicted to occur within core area boundaries across the interior Columbia River Basin for the historical climate scenario.

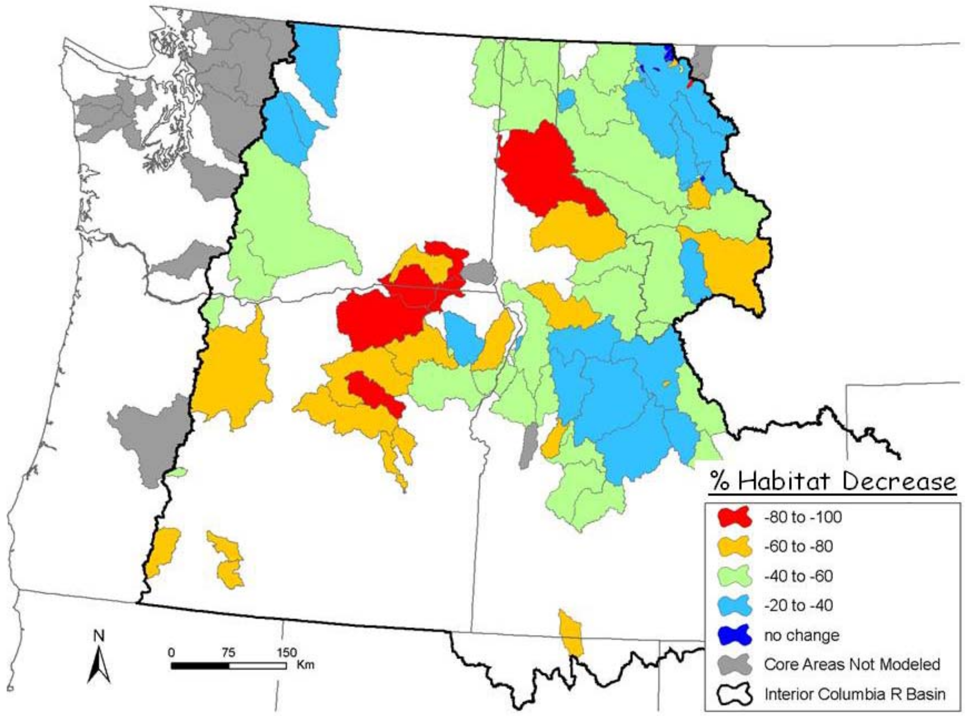

Figure 23. Climate sensitivity expressed as the percent reduction in historical natal habitats for core areas across the interior Columbia River Basin. Results are based on an increase in mean annual air temperatures of 1.6°C and a corresponding upward shift in the lower elevation limit of thermally suitable natal habitats of 250 m (from Rieman et al. 2007).

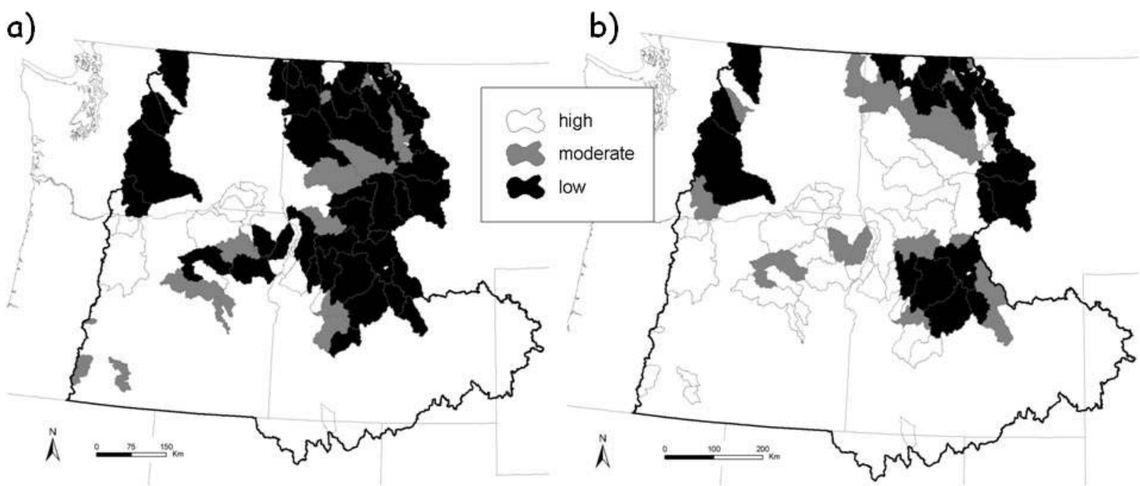

Figure 24. Climate vulnerability of bull trout within USFWS core areas across the Interior Columbia River Basin for the historic (panel a) and future climate scenarios (panel b). Vulnerability categories follow definitions in Rieman et al. (2007) and are described in text.

3.2.4 Discussion

Results of this assessment highlight the considerable risks that climate change may pose to bull trout populations this century. Natal habitats in many core areas appear to be highly sensitive to climate change and vulnerability is predicted to increase substantially by mid-century if projected warming occurs. Moreover, the future scenario we considered is representative of a mid-range warming trajectory and appears to be less aggressive than the rate at which temperature increases and are actually occurring (Raupach et al. 2007), which could make our results overly optimistic.

Work to update and improve the resolution and accuracy of climate projections for bull trout has progressed in recent years (Isaak et al. 2010; Wenger et al. 2011b) and efforts are underway to expand these efforts across the northwest U.S. and most of the southern bull trout range (Isaak et al. 2011). These higher resolution analyses will no doubt alter the specific results within many core areas. For example, in the original Rieman et al. (2007) analysis one stream in the Blue Mountains was a large negative outlier, suggesting that bull trout were distributed to lower elevations than predicted from the model. Other streams deviated in the opposite direction, presumably due to local variability in habitat conditions that regulated bull trout distributions. More of this local variability will be accounted for in the next generation of bioclimatic assessments that are being developed but it is unlikely that these assessments will significantly alter the basic spatial pattern of risk described here across the ICRB. As such, this broad application still provides a reasonable foundation to consider the possibility of regional differences in the vulnerability of bull trout to climate change and all the concerns and ideas originally expressed in Rieman et al. (2007) remain relevant five years later.

Despite the above considerations, broad-scale bioclimatic models based on correlative relationships like the Rieman et al. (2007) model gloss over important details regarding how projected habitat changes will translate to biological effects that cause population distributions to contract. It seems reasonable to assume that the historical climatic factors that have regulated population distributions will remain important in the future but more detailed mechanistic studies and biological models are needed to better understand these historical linkages. Another significant shortcoming at present is a lack of long-term distributional monitoring records that could describe whether, or how fast, bull trout populations may be shifting in association with climate change during recent decades. Such shifts have now been documented for many other plant and animal taxa (Parmesan and Yohe 2003; Root et al. 2003). As these estimates are developed for bull trout populations, stronger linkages between bioclimatic model predictions and biological effects will be possible that facilitate climate risk assessments of increasing precision.

Acknowledgements
We would like to thank Dan Isaak, Dona Horan and Howard Schaller for leading the development of Chapter 3.2. We would also like to thank the U.S. Fish and Wildlife Service and all those who have contributed to bull trout recovery planning for providing a stimulus to conduct this work. The findings and conclusions in this chapter are those of the RMEG and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

3.2.5 References

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Appendix A; Table 23. Descriptive summaries of thermally suitable natal bull trout habitats within 83 U.S. Fish and Wildlife Service core areas across the interior Columbia River Basin for historic and future climate scenarios. See text for details regarding climate scenarios and definitions of climate sensitivity and vulnerability.

USFWS core area	Historical stream length (km)	Future stream length (km)	Climate sensitivity (% decrease)	Historic patches > 10000 ha	Historic patches >5000, < 10000 ha	Climate vulnerability	Future patches > 10000 ha	Future patches > 5000, < 10000 ha	Climate vulnerabilit y
Anderson Ranch Reservoir	318.9	136.9	-57.1	2	0	low	0	0	high
Arrowrock Reservoir	257.2	110.5	-57.0	0	2	moderate	0	0	high
Big Salmon Lake	80.2	60.8	-24.2	1	0	moderate	0	1	moderate
Bitterroot River	1130.7	595.1	-47.4	3	17	low	0	0	high
Blackfoot River	1118.9	482.4	-56.9	5	4	low	2	2	low
Bowman Lake	30.4	30.4	0.0	1	0	moderate	1	0	moderate
Bull Lake	108.0	78.7	-27.1	0	1	moderate	0	0	high
Clark Fork River (Section 1)	1813.2	704.8	-61.1	11	12	low	2	4	low
Clark Fork River (Section 2)	662.4	287.8	-56.5	0	3	moderate	0	0	high
Clearwater River & Lakes	201.3	78.1	-61.2	0	3	moderate	0	0	high
Coeur d'Alene Lake	691.6	128.7	-81.4	2	2	low	0	0	high
Cyclone Lake	10.1	10.1	0.0	0	0	high	0	0	high
Deadwood River	61.7	30.7	-50.1	0	1	moderate	0	0	high
Doctor Lake	10.1	10.1	0.0	0	0	high	0	0	high
Entiat River	261.0	199.8	-23.5	2	0	low	1	2	moderate
Flathead Lake	2293.7	1404.7	-38.8	12	6	low	8	12	low
Granite Creek	19.6	9.1	-53.3	0	0	high	0	0	high
Harrison Lake	10.1	0.0	-100.0	0	0	high	0	0	high
Holland Lake	5.3	2.8	-46.2	0	0	high	0	0	high
Hood River	77.8	31.9	-59.0	0	0	high	0	0	high
Hungry Horse Reservoir	1294.6	781.3	-39.7	6	5	low	4	5	low
Imnaha River	267.8	106.7	-60.2	2	0	low	0	2	moderate
Jarbidge River	82.1	17.5	-78.7	0	0	high	0	0	high
Klickitat River	412.9	234.1	-43.3	2	1	low	1	1	moderate
Kootenai River	1408.4	641.6	-54.4	4	18	low	1	6	low

USFWS core area	Historical stream length (km)	Future stream length (km)	Climate sensitivity (% decrease)	Historic patches > 10000 ha	Historic patches >5000, < 10000 ha	Climate vulnerability	Future patches > 10000 ha	Future patches > 5000, < 10000 ha	Climate vulnerability
Lake Creek	9.8	2.4	-75.9	0	0	high	0	0	high
Lake Koocanusa	719.0	422.4	-41.2	4	5	low	2	2	low
Lake Pend Oreille	2198.4	956.6	-56.5	5	20	low	0	3	moderate
Lemhi River	1093.8	646.4	-40.9	6	2	low	1	3	moderate
Lincoln Lake	3.1	3.1	0.0	0	0	high	0	0	high
Lindbergh Lake	41.6	27.3	-34.4	1	0	moderate	0	0	high
Little Lost River	575.4	308.4	-46.4	4	0	low	1	1	moderate
Little Minam River	22.6	11.4	-49.6	0	1	moderate	0	0	high
Little-Lower Salmon River	469.2	210.7	-55.1	0	6	low	0	0	high
Lochsa River	550.5	266.0	-51.7	5	3	low	0	0	high
Logging Lake	21.6	7.7	-64.6	1	0	moderate	0	0	high
Lookingglass / Wenaha	105.2	20.4	-80.6	0	0	high	0	0	high
Lower Deschutes River	317.0	77.3	-75.6	0	0	high	0	0	high
Lower Quartz Lake	3.2	3.2	0.0	0	1	moderate	0	1	moderate
Methow River	1414.8	1113.9	-21.3	5	6	low	8	9	low
Middle Fork John Day River	157.4	27.4	-82.6	0	0	high	0	0	high
Middle Fork Payette River	59.8	14.4	-75.9	0	0	high	0	0	high
Middle Fork Salmon River	1873.0	1167.4	-37.7	14	9	low	3	5	low
Middle Salmon R./Chamberlain	727.3	463.9	-36.2	3	7	low	0	3	moderate
Middle Salmon River-Panther	1167.8	780.4	-33.2	5	7	low	3	2	low
North Fork Clearwater River	578.2	148.8	-74.3	1	4	moderate	0	0	high
North Fork John Day River	687.4	170.4	-75.2	3	3	low	0	1	moderate
North Fork Malheur	130.7	41.7	-68.1	0	2	moderate	0	0	high
North Fork Payette River	290.9	160.9	-44.7	2	2	low	0	0	high
Odell Lake	47.1	21.5	-54.5	0	1	moderate	0	0	high

USFWS core area	Historical stream length (km)	Future stream length (km)	Climate sensitivity (% decrease)	Historic patches > 10000 ha	Historic patches >5000, < 10000 ha	Climate vulnerability	Future patches > 10000 ha	Future patches > 5000, < 10000 ha	Climate vulnerabilit y
Pahsimeroi River	652.8	396.0	-39.3	4	5	low	3	2	low
Pine/Indian/Wildhorse Creeks	97.9	45.0	-54.0	0	0	high	0	0	high
Powder River	311.5	147.1	-52.8	0	5	low	0	0	high
Priest Lakes	399.5	195.6	-51.0	3	7	low	0	0	high
Quartz Lakes	18.8	18.8	0.0	0	1	moderate	0	1	Moderate
South Fork Clearwater River	309.5	100.1	-67.7	0	3	moderate	0	0	high
Rock Creek	651.2	395.6	-39.3	2	1	low	5	2	low
Selway River	842.2	388.3	-53.9	1	6	low	0	0	high
Sheep Creek	10.7	7.2	-32.9	0	0	high	0	0	high
South Fork Salmon River	846.8	585.4	-30.9	3	6	low	2	1	low
Swan Lake	400.1	254.9	-36.3	1	3	moderate	0	0	high
Sycan River	212.7	78.7	-63.0	1	2	moderate	0	0	high
Touchet River	15.7	3.2	-79.4	0	0	high	0	0	high
Trout / Arrow Lakes	11.9	6.4	-46.1	0	0	high	0	0	high
Tucannon River	48.4	8.0	-83.4	0	0	high	0	0	high
Umatilla River	35.2	0.0	-100.0	0	0	high	0	0	high
Upper Grande Ronde	319.6	86.4	-73.0	1	2	moderate	0	0	high
Upper Kintla Lake	20.3	20.3	0.0	0	1	moderate	0	1	moderate
Upper Klamath Lake	141.9	43.4	-69.4	0	1	moderate	0	0	high
Upper John Day River	284.3	70.4	-75.3	0	1	moderate	0	0	high
Upper Malheur	136.3	40.6	-70.2	0	2	moderate	0	0	high
Upper Salmon River	1876.8	1226.6	-34.6	8	11	low	5	7	low
Upper South Fork Payette River	245.1	112.7	-54.0	1	3	moderate	0	1	moderate
Upper Sprague River	134.8	34.1	-74.7	1	0	moderate	0	0	high
Upper Stillwater Lake	99.2	57.1	-42.5	1	0	moderate	0	3	moderate
Upper Whitefish Lake	11.5	11.5	0.0	0	0	high	0	0	high

USFWS core area	Historical stream length (km)	Future stream length (km)	Climate sensitivity (% decrease)	Historic patches > 10000 ha	Historic patches >5000, < 10000 ha	Climate vulnerability	Future patches > 10000 ha	Future patches > 5000, < 10000 ha	Climate vulnerabilit y
Walla Walla River	18.3	0.0	-100.0	0	0	high	0	0	high
Wallowa / Minam	316.8	210.9	-33.4	2	3	low	0	1	moderate
Weiser River	129.0	52.0	-59.7	0	0	high	0	0	high
Wenatchee River	727.3	468.5	-35.6	5	5	low	0	11	low
West Fork Bitterroot River	216.2	120.0	-44.5	4	2	low	0	1	moderate
Whitefish Lake	80.5	49.0	-39.2	1	0	moderate	1	0	moderate
Yakima River	1943.3	982.4	-49.4	11	12	low	0	9	low